

Assessing Social Vulnerability to Urban Flooding: The Case of Santa Cruz de Tenerife

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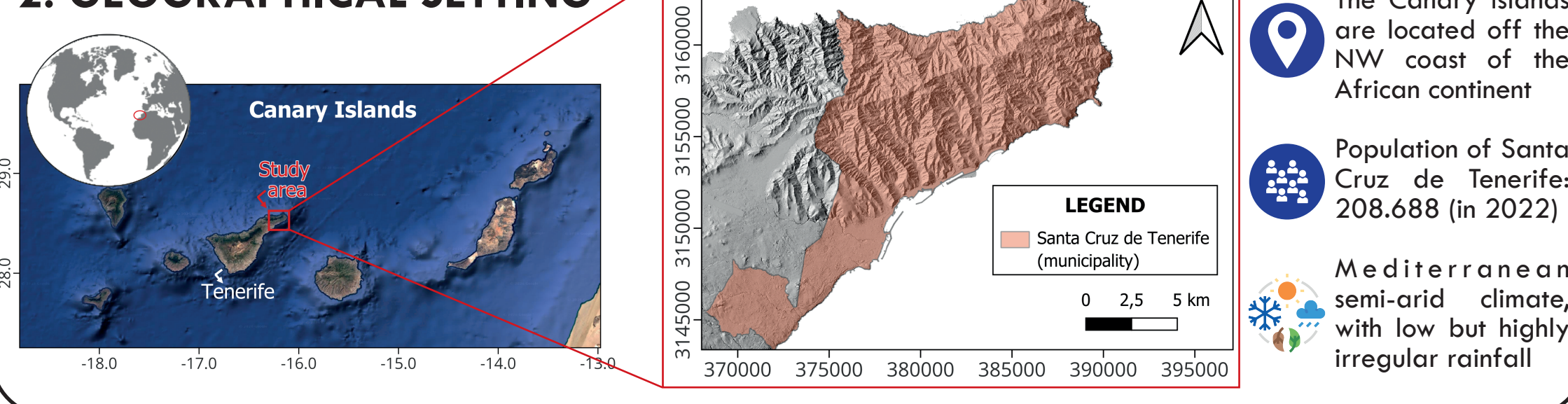
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1. INTRODUCTION

Floods are among the **most damaging natural hazards globally** and remain the leading cause of weather-related fatalities. Indeed, **climate change** has been associated with **increasing flood frequency** and severity in many regions (e.g., Tabari, 2020), which, together with the **complex sociodemographic structures** and **spatial inequalities**, strongly **shape the impacts** of extreme hydrometeorological events. In particular, **urban areas** have become **increasingly hazardous** due to rapid **population growth**, urbanisation and the resulting extensive soil sealing, typically coupled with **inadequate land-use planning**. This is the case of the **municipality of Santa Cruz de Tenerife** (Canary Islands), characterised by a Mediterranean semi-arid climate with low but highly irregular annual precipitation, often concentrated in short, intense rainfall events. When combined with steep, ravine-dominated orography, these short-duration episodes **may trigger flash flooding**, as evidenced by **past events** (2002 and 2010).

In risk analysis, hazard denotes a potentially damaging physical process, whereas **vulnerability refers to the social conditions that make people and places more or less susceptible to harm** (e.g., Navarro et al., 2020). In this sense, **social vulnerability** refers to the set of **demographic, socio-economic, and infrastructural** conditions that shape a population's ability to anticipate, withstand, cope with, and recover from the impacts of hazardous events (Cutter, 2003). It is therefore essential to **explain why**, under comparable physical forcing, **flood impacts are not evenly distributed across space** or **social groups**.

2. GEOGRAPHICAL SETTING



3. METHODOLOGY

1. DATA SOURCE

- Demographic and socioeconomic data** (INE, ISTAT)
- Housing and Buildings** (INE, Cadastre)
- GIS data** (Land use, green areas, OSM)
- Educational facilities** (Preschool, primary and secondary schools)
- Healthcare facilities** (Healthcare centers, hospitals)
- Flood hazard** (Martín-Raya et al., 2024)

2. TWO SPATIAL SCALES

A) CENSUS TRACTS

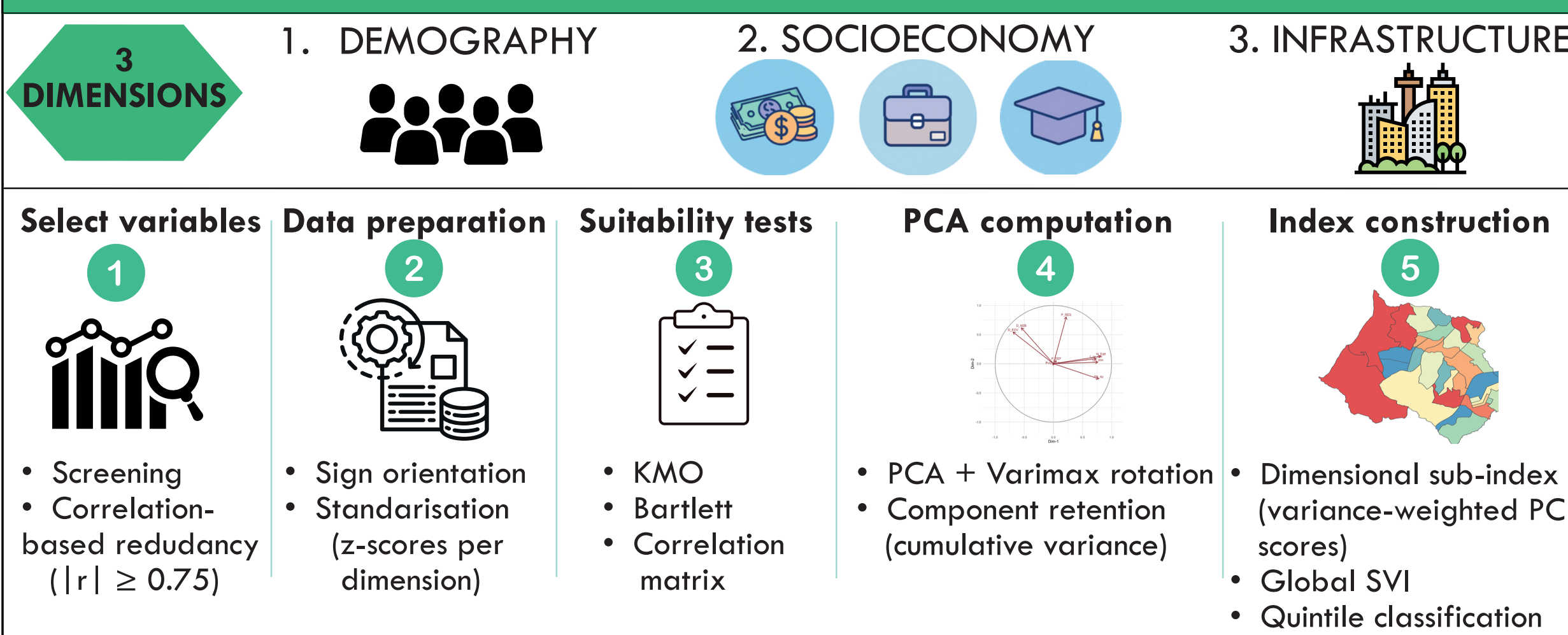
- The smallest official statistical unit of the Spanish National Statistics Institute (INE) for the Population and Housing Census
- n = 164 census tracts (2022) in Santa Cruz de Tenerife municipality
- Richest layer of socio-demographic and socio-economic data

B) REGULAR GRID (250 X 250 m)

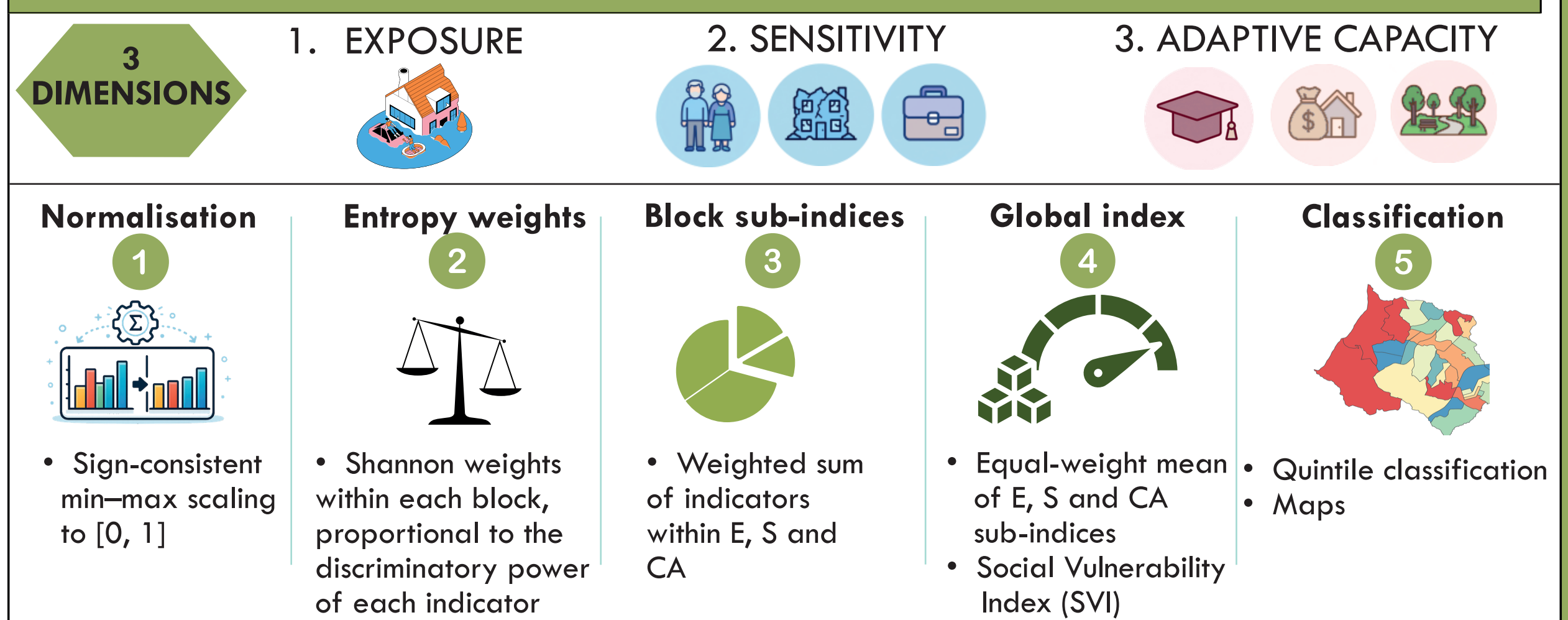
- A regular grid splits the territory into equal square cells. Here we use the ISTAT 250 m x 250 m reference grid (Canary Islands, 2022).
- n = 477 grid cells in Santa Cruz de Tenerife municipality.
- Homogeneous grid cells enable finer, comparable spatial detail, but limited socioeconomic data.

4. TWO METHODOLOGIES

4A. METHODOLOGY 1: PRINCIPAL COMPONENT ANALYSIS (PCA)



4B. METHODOLOGY 2: SHANNON ENTROPY



4. RESULTS AND DISCUSSION

Overall, the results suggest that social vulnerability is not spatially concentrated in a single sector of the municipality, but rather distributed across different areas. To facilitate the presentation and discussion of the results, the municipality of Santa Cruz de Tenerife can be divided into three broad sectors: the south-western, central urban core, and north-eastern sectors.

- At the census-tract scale (Fig. 1 and 2), the highest levels of social vulnerability are concentrated in the north-eastern sector, followed by the south-western sector and the central urban area, which generally shows comparatively lower levels. The prominence of the north-eastern sector is explained by the repeated co-occurrence of high infrastructure and socio-economic burdens, with demographic pressure reinforcing this pattern in some tracts of the sector.
- Moreover, this spatial pattern appears to be associated with limited access to healthcare services, denser urban areas, and, in several tracts, relatively high levels of flood-hazard exposure (e.g., the La Alegría, María Jiménez, Valleseco and San Andrés neighbourhoods).

- Similar spatial patterns emerge when the analysis is repeated using the entropy-based index (Fig. 3 and 4). Despite differences in dimensional structure, weighting and tract-level ordering, both approaches highlight the north-eastern and south-western sectors as the main areas of concern, while much of the central urban core tends to remain comparatively less vulnerable.
- The entropy-based approach tends to accentuate the south-eastern pattern more clearly. The central area and urban core, by contrast, is more heterogeneous and method-sensitive, showing local hotspots such as La Salud, Somosierra, Barrio Nuevo and Duggi. However, these are more fragmented than the broader peripheral clusters, and their relative prominence shifts more noticeably between PCA and entropy.

PCA SUB-INDICES (D, S, I) AND GLOBAL SVI AT CENSUS-TRACT SCALE

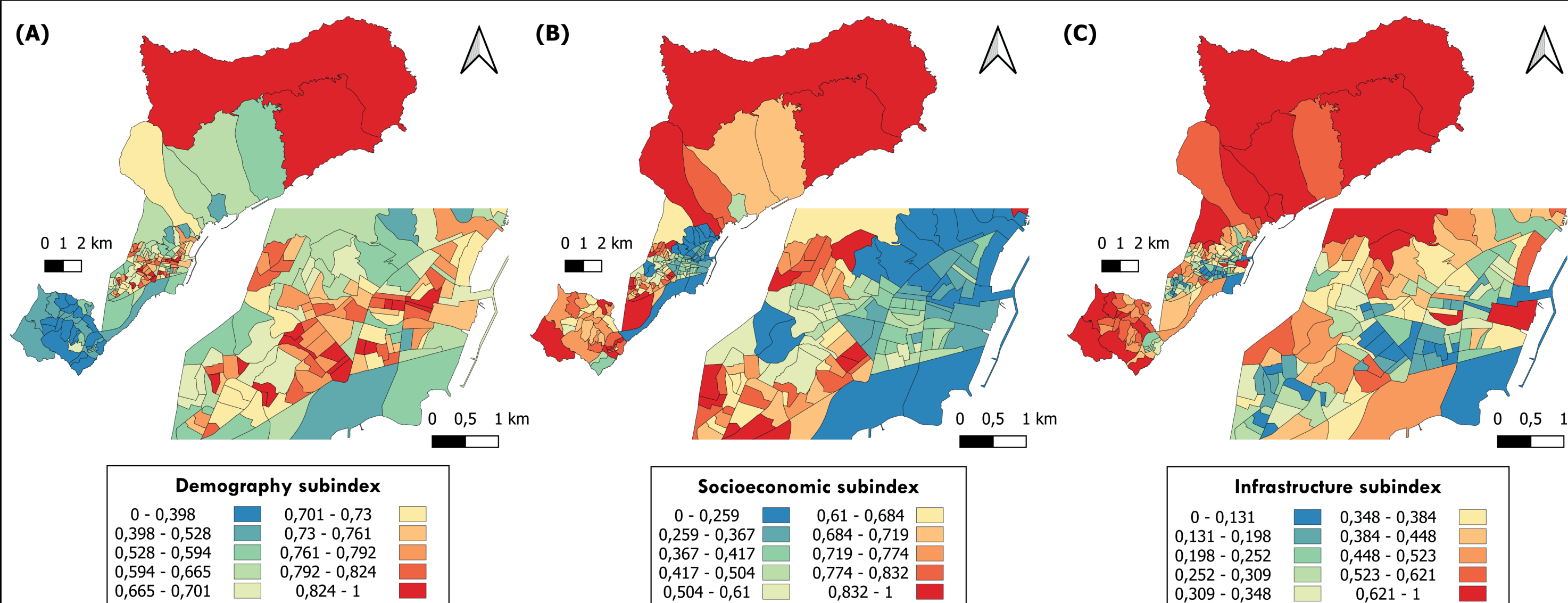


Figure 1. Spatial distribution of PCA sub-indices (Demography, A; Socio-economy, B; and Infrastructure, C) by census tract. Values scaled 0–1 (higher = greater vulnerability)

ENTROPY SUB-INDICES (E, S, AC) AND GLOBAL SVI AT REGULAR GRID SCALE

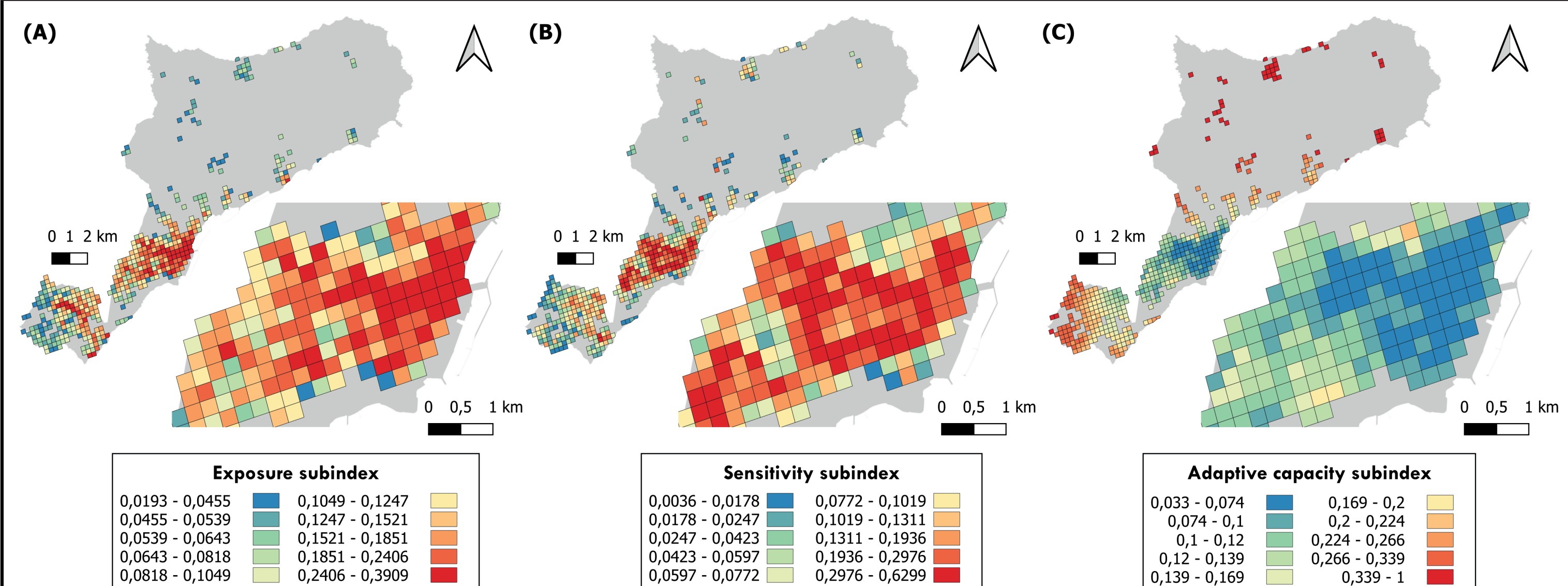
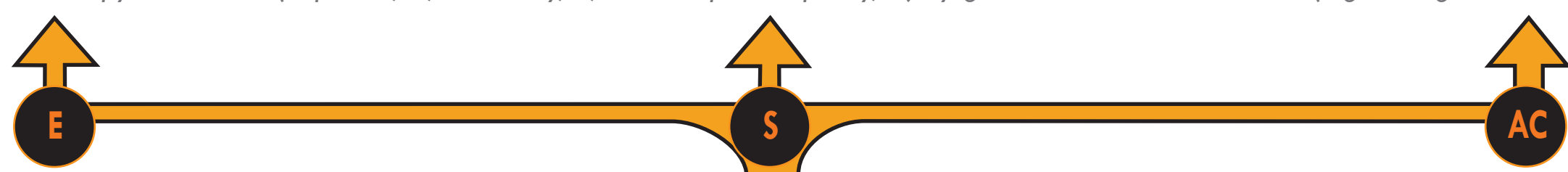
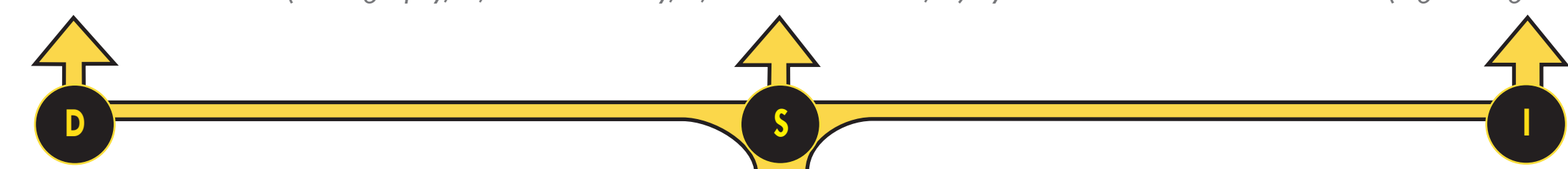


Figure 3. Spatial distribution of entropy sub-indices (Exposure, A; Sensitivity, B; and Adaptive capacity, C) by grid cells. Values scaled 0–1 (higher = greater vulnerability)



SOCIAL VULNERABILITY INDEX (SVI)

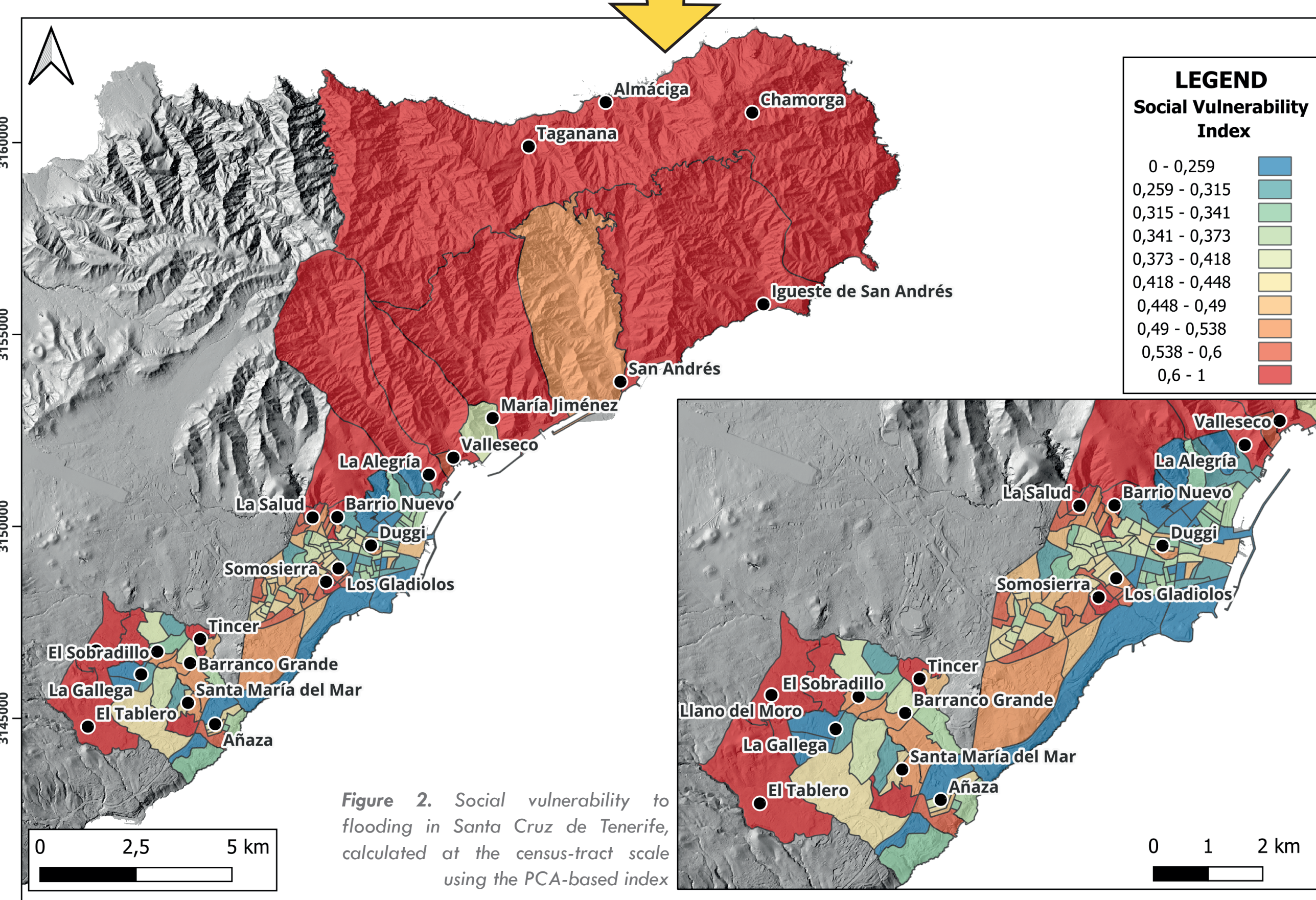


Figure 2. Social vulnerability to flooding in Santa Cruz de Tenerife, calculated at the census-tract scale using the PCA-based index

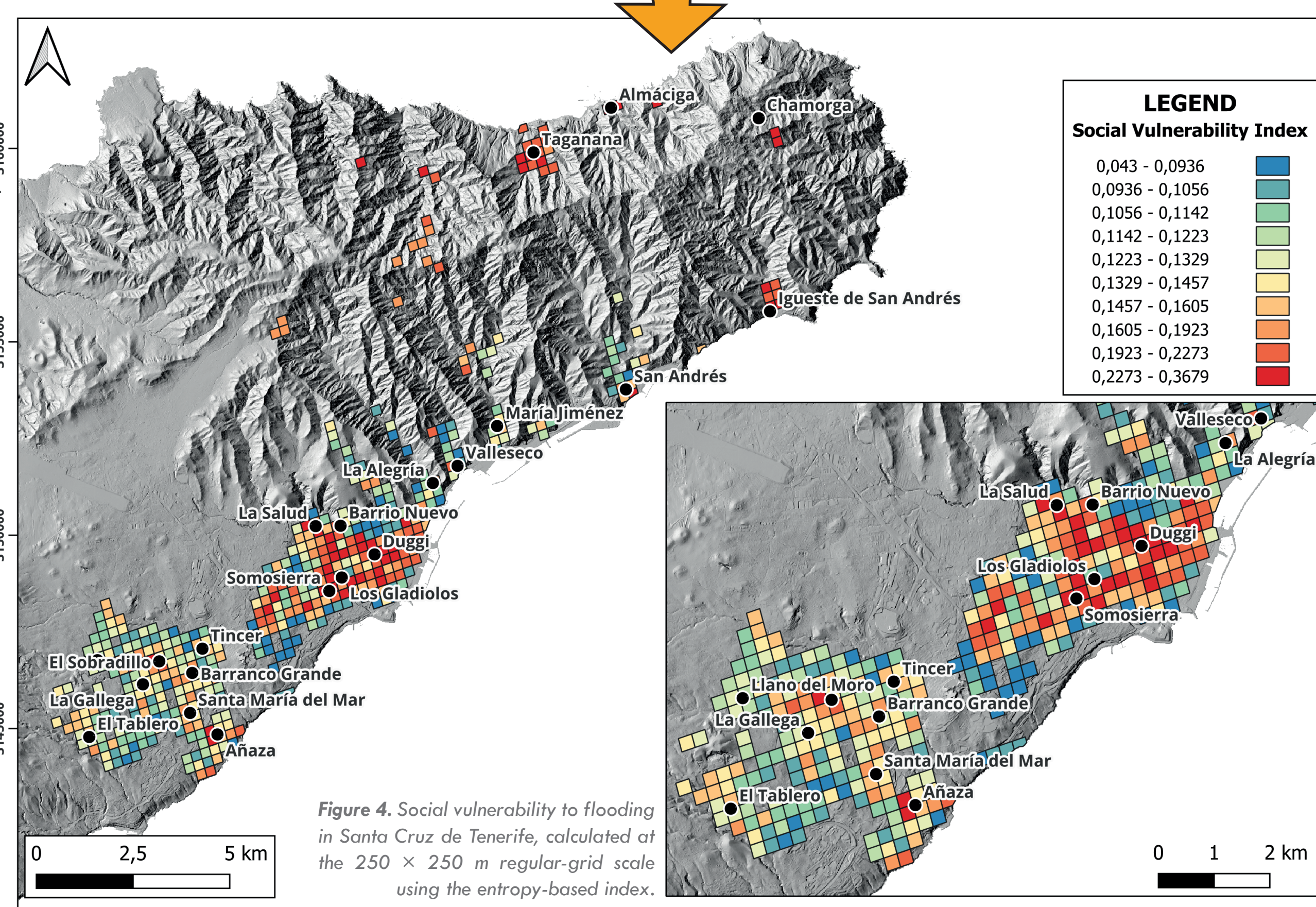


Figure 4. Social vulnerability to flooding in Santa Cruz de Tenerife, calculated at the 250 x 250 m regular-grid scale using the entropy-based index

- The south-eastern sector also contains a clear concentration of highly vulnerable tracts, particularly around El Sobradillo, El Tablero, Llano del Moro, Barranco Grande, Añaza, Santa María del Mar and parts of Tincer and La Gallega, which are linked to the combination of socio-economic disadvantage and infrastructure-related constraints, with flood hazard further reinforcing high scores in several sections.

- At the grid-cell scale (Fig. 1B), the entropy-based results broadly confirm the tract-level geography while revealing finer pockets of vulnerability that are partly smoothed within larger census units. High values are also found in the north-eastern fringe, including Taganana, Iguete de San Andrés, Almáciga and Chamorga, and in parts of the south-eastern sector (e.g., Añaza and El Sobradillo), as well as in selected inner-city areas such as Los Gladiolos, La Salud, Duggi and La Salle.

5. CONCLUSIONS

- Social vulnerability to flooding in Santa Cruz de Tenerife is **spatially unequal** and concentrated in neighbourhoods such as **El Sobradillo, Tincer, El Tablero and Santa María del Mar** in the southern sector, **La Salud, Barrio Nuevo, Somosierra and Duggi** in the central urban area and across the whole Anaga massif (northeast sector), particularly **Iguete de San Andrés, La Alegría and María Jiménez**.
- PCA and entropy **converge only partially**, with a moderate rank correlation (Spearman's $\rho \approx 0.45$). This is enough to indicate that **both approaches are capturing a similar broad geography of vulnerability**, but not enough to treat them as interchangeable. That mismatch is not surprising, given that the two methods organise variables and indicators into **different dimensions and derive weights in different ways**. By contrast, the regular grid provides a more even spatial support and brings out **local hotspots** that large census tracts can smooth over. Even so, **census tracts remain the stronger basis** for interpretation because they contain much richer socio-economic information, whereas the grid is limited by the lack of microdata and by the fact that many intensive variables cannot be redistributed reliably to that scale.

ACKNOWLEDGMENTS

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