Social vulnerability and coastal hazards: Acknowledging floating population needs in Barcelona, Spain

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Abstract: Increasing occurrences of flash flooding poses significant social and economic threats to Barcelona. Approximately 65% of the population reside along the coast. Many rely on beach assets to attract 35 million annual visitors that buttress the city's 7.1 billion EUR tourist sector. Both residents and tourists are vulnerable to late-summer and early-autumnal flash floods of intense rainfall events that that exceed the capacity of urban drainage systems designed for 55% less loading. Government efforts do not account for non-resident population needs by focusing primarily on residents' safety following floods. Regular flash floods in Barcelona indicates an urgent need to develop a water sensitive strategy that comprehensively accounts for point source pollution in this vulnerable coastal region, as well as for its socioeconomic profile. While Social Vulnerability Indices have been developed for climate change-related disasters over the past fifteen years, these indices are designed for use at a national scale and overlook the needs of seasonal residents (*e.g.* short-term residents and tourists) in social profiling. This research broadens the scope of social vulnerability indices to factor in temporary resident needs in disaster planning at a regional scale. The social vulnerability index can help government planners include floating population groups in post-disaster management efforts.

Keywords: Social vulnerability index; SVI; resilience; seasonal population; disaster risk reduction.

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1. *Introduction*

Coastal metropolises are sensitive to hazards due to their having high concentrations of people and economic activities within their geographic boundaries (Guillard-Gonçalves et al., 2015). Previous climate change research has indicated that densely populated coastal areas are vulnerable to disasters such as flash floods (Velasco et al., 2018). Consequently, preparing for and minimizing vulnerability to hazards such as urban flooding is of interest to coastal cities. Social vulnerability (SV) is a population's inability to cope with adverse impacts of natural and/or man-made disasters. It encompasses characteristics that influence human susceptibility to disasters and their ability to respond, as well as context-specific social and environmental factors (such as urbanization and economic activities) (Cutter et al., 2003).

This case study focuses on the second most populous region in Spain (Barcelona). Approximately 65% of its population reside along the coast (idescat, 2018). Increasing occurrences of flash flooding pose significant socioeconomic threats to the province and its residents, as many rely on beach assets to attract 35 million annual visitors that buttress Barcelona's 7.1 billion EUR tourist sector (WTTC, 2017). Both residents and tourists are vulnerable to late-summer and early-autumnal flash floods of intense rainfall events that exceed the capacity of drainage systems designed for 55% less loading (Santos and Martos, 2009).

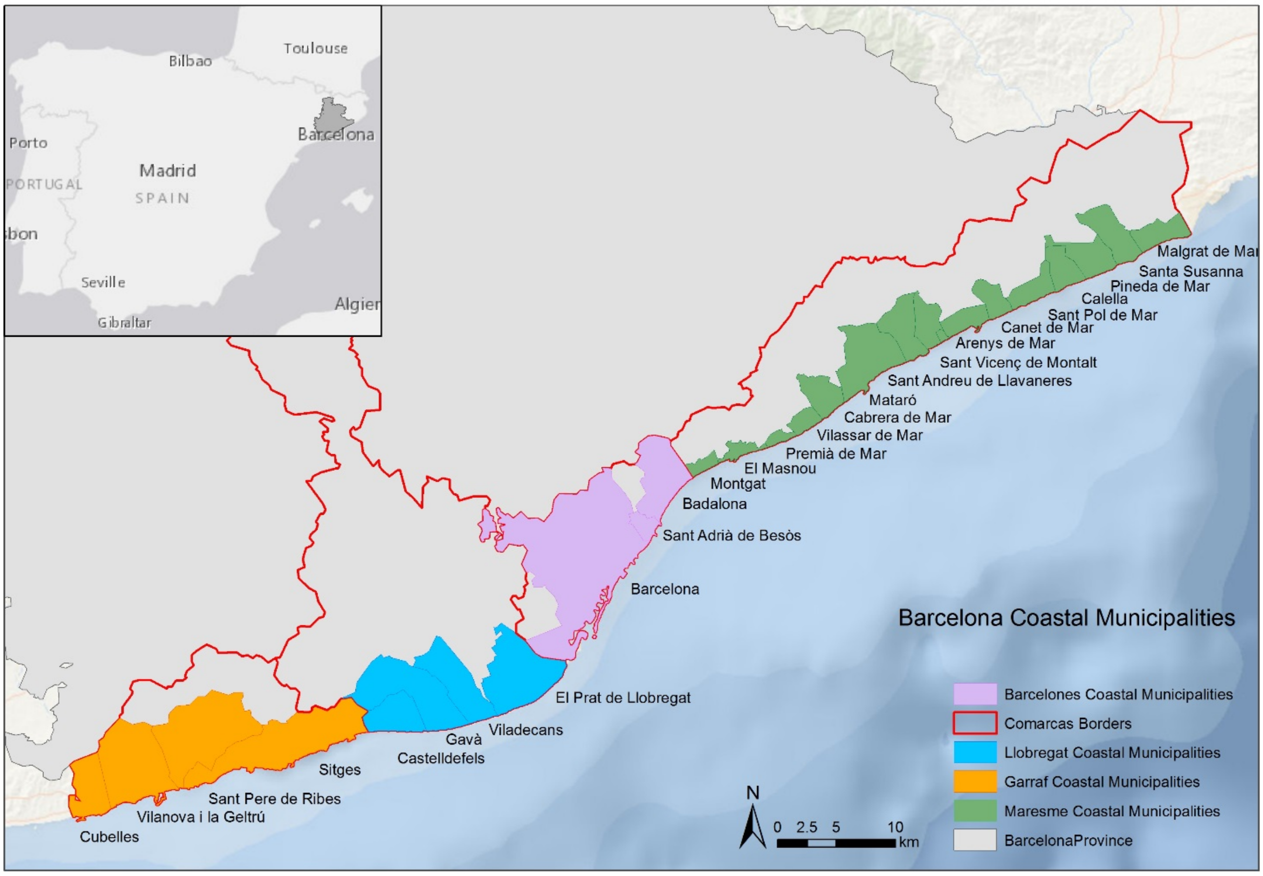
This research follows in the tradition of SV exposure and resilience studies undertaken by Cutter, *et al.* (2003). As per previous research, we analyze available socioeconomic and demographic data to construct a Social Vulnerability Index (SVI) for Barcelona's coastal hazards to link the attributes that make people vulnerable to the support structures and facilities that can help them resist and recover (Gomes, 2018). We, however, diverge from Cutter, *et al.* (2003) in that we use municipal-level data instead of country-level data to develop an index that takes into account Barcelona's short-term residential and tourist population as vulnerable groups, as this floating population (*població estacional*) has thus far been overlooked in previous SVIs. Tourists especially are important to account for because Barcelona's tourist numbers increased by over 25% between 2008-2015 (Barcelona City Council, 2015).

The study's aim is to inform the development of floating population variables. Developing means to assess this SV can facilitate our understanding of factors that make non-residents and places susceptible to disasters over time and in different places. It additionally can offer guidance to government officials responsible for prioritizing resources in emergency events (CDC, 2018) – especially in areas that are heavily reliant on tourism.

2. *Study Area & methodology*

The study area covers coastal municipalities of Barcelona Province (41N, 2.1E UTM coordinates). The coastline is approximately 160 kilometres in length and is relatively narrow with a high elevation. It comprises of 103 beaches distributed along four coastal administrative units (*comarcas*: Maresme, Barcelonès, Llobregat and Garraf) (Figure 1). According to idescat (2018), 5.5 million people reside in these coastal *comarcas*.

Figure 1. (a) Study area map



(b) Created in Arc GIS 10.5.1 (1)

We examined both residential and floating populations' SV to coastal hazards in 25 municipalities located within these four *comarcas*. (We excluded a further 3 municipalities with <5,000 inhabitants due to their having unreliable data.) Data is limited to the 25 municipalities due to the study's coastal hazards objective. In this study, we applied the US Federal Emergency Management Agency's SV tool using R scripts to prepare and analyze data (FEMAdata, 2016; R Development Core Team, 2008).

2.1 Data collection and preparation

Table 1 summarizes the variables used for analysis. The first 28 variables are based on SVI research from Cutter et al. (2003) and Guillard-Goncalves et al. (2014) and Martin et al.'s (2017) adaptations for European contexts. Variables development accounted for European contexts – such as foreign nationals living in Spain, as Guillard-Goncalves et al. (2014) noted that ethnicity components are not included in the Cutter framework. The latter 5 floating population variables are drawn from Barcelona's latest municipal (2011) census (idescat, 2018). Barcelona's statistics institution (idescat) includes in its floating population those who have a primary or secondary municipal residence; tourists who stay overnight at tourism establishments; and students or workers who travel between municipalities but do not stay overnight. Idescat (2016) bases floating population figures on censuses and tourism, labor, education and lifestyle statistics. We grouped the 33 variables in 11 categories to reflect socioeconomic attributes or support structures: housing and installations, age, race and ethnicity, education, family structure, urban, socioeconomic status, medical services, special needs population, population growth, and floating population.

Table 1. Variables names and descriptions

Code Name	Description
Housing and services	
PriWatSup	Proportion of dwellings with private water supply/Total dwellings
NoWatSup	Proportion of dwellings with no water Supply/Total dwellings
NoHeat	Proportion of dwellings with no heating/Total dwellings
NoPhone	Proportion of dwellings with no telephone line/Total dwellings
NoBath	Proportion of dwellings with no toilet, bathroom or shower inside the apartment/Total dwellings
NoCool	Proportion of dwellings with no cooling/Total dwellings
Age	
Elderly	Population 65 and older/ Population 15–64 years
Young	Population under 15 / Population 15–64 year
Race and ethnicity	
Spanish	Proportion of population with Spanish Nationality/Total Resident Population
Foreign	Proportion of population with Foreign Nationality/Total Resident Population
Education	
Element	Proportion of people elementary school graduates/Total number of graduates
Univer	Proportion of population who completed College/Total number of graduations
Familial structure	
MothersAlone	Proportion of mothers alone with child/total number of families
ParentsAlone	Proportion of parents alone with child/total number of families
HouseholdSize	Average number of people per household
Urban	
Density	Number of people/area (in km^2)
Socioeconomic status	
GDP	Income per capita (thousands of Euros)
RatUnemLabor	Ratio of unemployed population and labor force
Act.Rate	Rate of activity
Agri	Proportion of population employed in agriculture/Active population
Tou	Proportion of population employed in tourism/Active population
Renters	Proportion of rented or sub-rented conventional dwellings/Total Dwellings
Medical services	
Phar	Number of pharmacies for 1000 inhabitants (in 2002)
HosBeds	Number of hospital beds for 1000 inhabitants (in 2002)
Special needs population	
Disabled	Proportion of disabled persons (auditory, visual, motor or mental)
DisabledDep	Proportion of persons that are disabled and are under 4 or above 65 years old
Disabl60	Proportion of persons with a disability degree above 60%
Population growth	
NetMigra	Net Migration (annual average) (rate per 1.000 inhabitants). 2001-2011
Floating population	
BedHotCamp	Number of beds in hotels & camping
NonResPop	Non-resident population
TouEst	Estimated number of tourists results for the period 2002-2015
RatPopVicandRes	Floating estimates for the period 2002-2015/ resident population
nonres_Res	Non Resident Population_Tourist/Resident Population

To prepare data, we applied a multi-collinearity (Kendall's rank correlation) test to reduce data amplitude because all variables do not have normal distributions. We discarded the Disabl60 variable from the dataset because the Kendall s-b value was below the accepted correlation rate of ±0.7.

2.2 PCA with varimax rotation

This is performed to select key principal components (PCs), which facilitates data interpretation. We (1) applied a varimax rotation procedure using the Kaiser Criterion; and (2) normalized the variables with Z-scores. For variables with an eigenvalue higher than one, we excluded those with correlation coefficients <0.4 as they likely do not contribute to SV. We examined the remaining variables by assigning a positive or negative contribution to vulnerability, and considered how socially vulnerable each municipality in the dataset is to coastal hazards.

2.3 SVI calculation & GIS visualization

We mapped equally weighted SVI scores in ArcGIS 5.1 using standard deviation classifications of very high to very low vulnerability classes (Figure 2). To note, as per previous SVI frameworks, a positive sign indicates increased vulnerability and a negative sign indicates a diminishing effect (Table 2). We used an absolute value symbol when the variables within the category conflict in contribution. If a component's variables tend to increase SV but have a negative loading (or vice-versa), the component's cardinality is adjusted by multiplying by -1. A SVI is calculated by summing the component values for each municipality (Equation 1).

$$\text{SVI Score} = PC_1 + PC_2 + PC_3 + PC_4 + |PC_5| - PC_6 + PC_7 - PC_8 + PC_9 + PC_{10} \quad (1)$$

3. *Results*

Twenty variables remained after processing, which were clustered according to ten PCs with 87.3% variance. However, we found that three variable combinations (PC3: NoHeat and Disabled; PC7: NoBath and NoCool; PC9: NoWatSup and Agri) have limited relevance to SV in coastal hazard events, and hence excluded these PCs. The variance for the remaining PCs is 66.7% (Table 2).

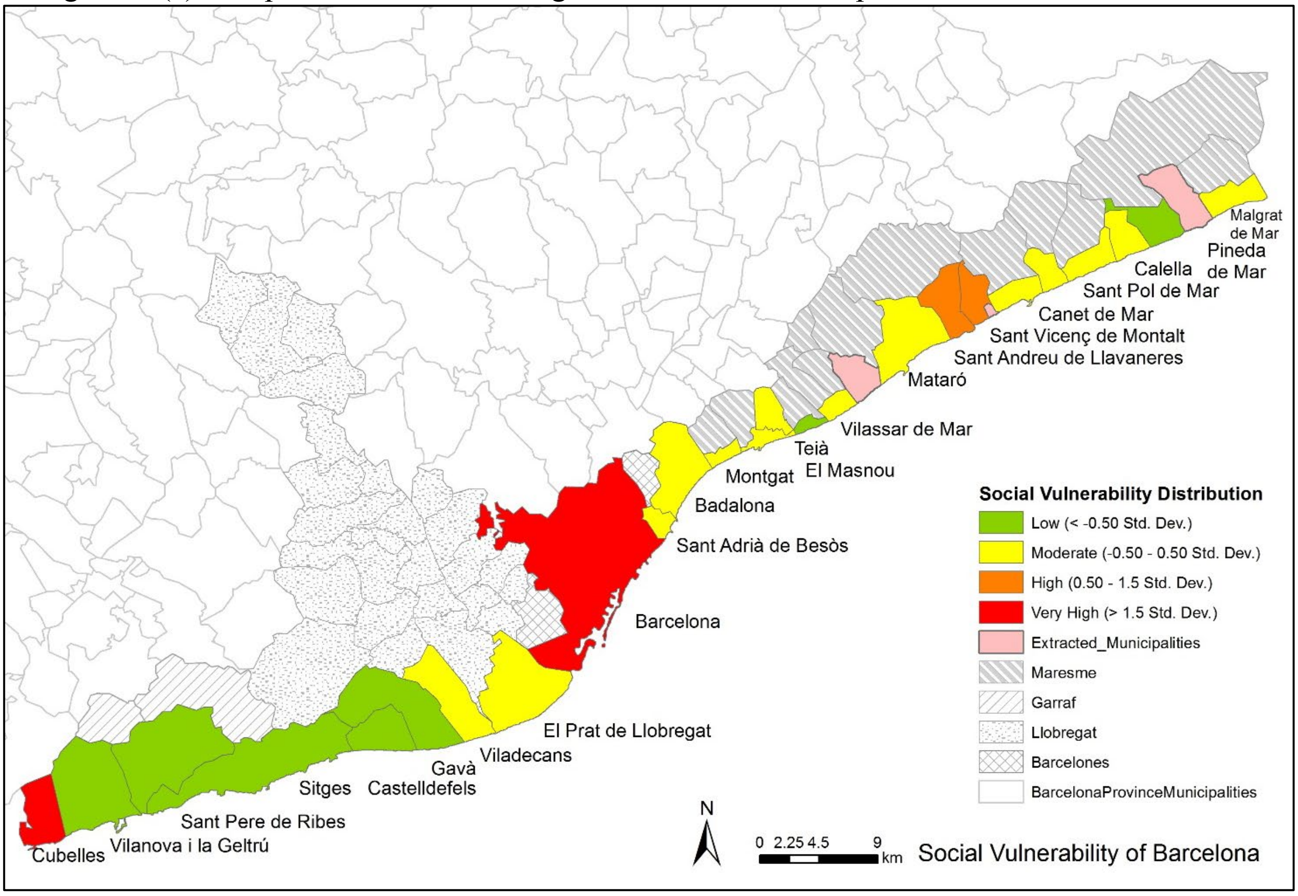
Table 2. SV components, attributed signs and correlation

PC	Variance (%)	Vulnerability categories	Sign	Variables	Correlation
1	26.2	Floating population	+	BedHotCamp	0.439
				NonResPop	0.449
				TouEst	0.428
2	12.6	Housing services & population growth	+	PriWatSup	0.559
				NoPhone	-0.411
				NetMigra	-0.403
4	9.3	Education & socioecon. status	+	Element	-0.468
				RatUnemLabor	-0.486
5	5.9	Race & ethnicity	| |	Spanish	-0.521
				Foreign	0.472
6	5.4	Medical services	-	Phar	-0.463

8	4.1	Socioeconomic status	-	GDP	-0.567
10	3.2	Age & Familial structure	+	Young	-0.547
				MothersAlone	0.413

After identifying relevant PCs, we mapped the municipalities' SV according to standard deviation distributions of very high (>1.5) to high (1.5 to 0.5), moderate (0.5 to -0.5) or low (<-0.5). Taking into account the SVI score, the most vulnerable municipalities are Barcelona City and Cubelles, while Vilanova i la Geltru, Sitges, Castelldefels, Gava, Teia, Vilassar de Mar, Mataro, Canet de Mar and Pineda de Mar are the least vulnerable (Fig. 2).

Figure 2. (a) SV spatial distribution categories in coastal municipalities of Barcelona Province.



(b) Created in Arc GIS 10.5.1 (1)

Both education and socioeconomic status contribute to SV in Barcelona City and Cubelles. Barcelona City seemed to also very vulnerable due to its floating population, whereas wealth was the second contributory factor that affected Cubelles' classification. The nine least vulnerable municipalities did not have any very high PC scores. They additionally each have at least three moderate PC scores, with an overall average score of moderate. Housing services and population growth (PC2) contribute to SV in four of the nine municipalities, whereas sufficient medical services (PC6), wealth (PC8) and/or age/familial structure (PC10) seemed to lower vulnerability.

In terms of the primary contributory factor, the SVI scores indicate that floating populations (PC1) has the highest variance, which suggests that this cluster contributes most amongst the 25 coastal municipalities. Barcelona City is most vulnerable, though it is also a high contributor in four other municipalities (Badolona, Arenys de Mar, Calella and Pineda de Mar). Floating populations are a low contributor in eight municipalities (Cubelles, Sant Pere de Ribes, Viladecans, Teia, Mataro, Sand Andreu de Llavaneres, Sant Vicenc de Montalt and Sant Pol de Mar).

4. *Conclusion*

This study evaluated the SV of coastal municipalities in Barcelona Province against hazards such as flash floods. We applied the SVI framework to assess which are the most socially vulnerable populations in 25 coastal municipalities. We found that floating populations are the most vulnerable to coastal hazards. This is important to highlight to decision-makers responsible for government disaster risk reduction programs, as this suggests that emergency services should also account for short-term residential and tourist population needs in areas where tourism is a significant economic sector. Using SVI maps can additionally inform how finances and services can be spatially distributed according to risks.

This study joins a body of research that indicates that the SVI framework can inform disaster risk reduction decision-making and prioritization. The findings are also important because the SVI framework presently does not account for non-residential populations in its analysis. This paper thus serves as an opportunity to inform the development of a critical but overlooked variable for contexts that experience high rates of short-term residential and/or tourist populations.

Due to time and resource limitations, we limited the dataset to 25 Barcelona municipalities. We plan to expand this analysis across coastal municipalities in Catalonia to build a more statistically robust index for this region. And while determining and mapping SV factors have the potential to improve disaster response processes, its wider adoption is dependent on there being reliable government data and public institutions having basic statistical analysis knowledge in order to integrate and map statistical and spatial data.

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Conflict of Interest

The authors declare no conflict of interest.