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A census-based housing vulnerability index for typhoon hazards in the Philippines

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ABSTRACT

The Sendai Framework for Disaster Risk Reduction recognises housing as an important element of vulnerability, however, there remains limited understanding of how sub-national housing vulnerability varies spatially. This research sought to develop a municipal-level housing vulnerability index for typhoon hazards, applied at a national scale in the Philippines. We first selected 25 housing vulnerability indicators from the 2015 Philippines census, which were reduced into seven underlying dimensions of typhoon-related housing vulnerability using principal component analysis: housing density, housing quality, crowdedness, tenure security, extreme substandard housing, drinking water source, and structural integrity. These components were then aggregated to create a relative housing vulnerability index. We applied spatial clustering analysis to test for patterns, finding increasing housing vulnerability from north to south, with nuance in municipalities that defy these national trends. Our results offer a more granular view of housing vulnerability which may assist in unpacking how localised housing conditions contribute to disaster risk and assist researchers and government agencies in targeting disaster interventions.

1. Introduction

The Philippines is exposed to a wide range of natural hazards [5,44], which, when combined with political, social, and economic factors, render the country one of the most at risk to disasters. The uneven distribution of disaster damage and loss across the Philippines highlights the spatial variability in disaster risk, which cannot be explained by environmental conditions alone. In the Philippines, loss of life and damages caused by typhoons and their epiphenomena (flooding, storm surges and landslides) exceed all other hazards. Almost 20 typhoons enter the Philippines Area of Responsibility (PAR) each year [8,19], yet the contribution of vulnerability to the spatial variation in typhoon-related disaster risk is not well understood, particularly at lower administration levels. The Sendai Framework for Disaster Risk Reduction outlines several targets centred around improving understanding of disaster risk and reducing losses [88]. The Framework acknowledges access to housing as a sub-component of overall disaster vulnerability, with housing widely documented in literature as a contributory factor to the variability in disaster related losses [33,35,47,48,73]. However, the minimal amount of baseline data and paucity of studies mapping social vulnerability, and more specifically housing, at sub-provincial levels demonstrates a need for comparative research conducted at a municipal level to understand better how local changes in the social environment influence disaster risk [25,55,96]. Current policy and disaster risk reduction initiatives operating at the national, regional, or even provincial level are therefore potentially limited in their effectiveness.

This research aimed to examine municipal level housing vulnerability to typhoon hazards in the Philippines. We sought to answer the question: How does housing vulnerability vary at the municipal scale across the Philippines? In unpacking this question, we aim to address three primary objectives: (1) identify housing vulnerability indicators as a sub-set of social vulnerability from national census data; (2) identify dimensions of housing vulnerability and create a composite index; and (3) spatially map the composite index across municipalities in the Philippines and determine clustering patterns.

We first begin by reviewing existing disaster literature, focusing on how scholars have conceptualised and defined social vulnerability. This section also synthesises current approaches to measuring and mapping housing vulnerability at different scales whilst identifying gaps in the Philippines. Our approach then draws on principal component analysis to create a housing vulnerability index at the municipal level across the Philippines and uses cluster analysis to identify trends. Finally, we discuss the implications of a sub-provincial census-based housing vulnerability index in the Philippines and its potential role in supporting disaster risk reduction efforts.

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2. Background

The following section begins by unpacking the complexity of disaster risk and the ways in which this has been conceptualised overtime in disaster literature. It then defines vulnerability and how spatial variability in social vulnerability is evident across the Philippines. We then describe housing vulnerability more specifically and discuss how housing vulnerability is typically measured in existing literature.

2.1. The complexity of disaster risk

Historically, the importance of vulnerability in disasters has been overlooked [73]. Contemporary studies agree that disasters are complex and that disaster risk is a function of both hazard exposure *and* vulnerability [11,33,73]. Hazards occur globally; however, their impacts are not uniformly distributed [24,98]. When a hazard, particularly one extreme in scale and intensity, interacts with a vulnerable population, a disaster of greater magnitude is far more likely to ensue [11]. The critical factor in understanding the disproportionate impacts of disasters worldwide hinges on the appreciation of vulnerability and its effects [46].

The complexity of disasters is founded on the variable interaction between hazards and vulnerability. Hazard exposure and vulnerability vary immensely spatially, meaning that disaster risk is also variable in space. The poorest often suffer higher consequences from disasters, with poverty being one of the most critical factors determining vulnerability [22]. The detrimental effects of disasters fall disproportionately on those least equipped to respond to them [7,38]. Vulnerable groups are not only at risk because they are exposed to a hazard but as a result of marginality and unequal access to resources [15]. Groups lacking access to economic and social resources, independence, power, and those who live in low-quality housing are expected to be particularly vulnerable to disasters [10,50,51,59]. In addition to immediate impacts, communities impacted by typhoons and other hazards are often severely impacted in the long-term, resulting from damage to housing and infrastructure, contamination of clean water in flooded areas and destruction of livelihoods [74].

Nearly 90% of deaths caused by disasters over the past two decades have occurred in developing countries, with disasters reinforcing the cyclical nature of poverty [95]. A comparison of the 2012 Haiti earthquake and the 2010 Chile earthquake clearly illustrates how social vulnerability contributes to the disproportionality of fatalities [66]. The Chilean quake was 500 times stronger than that in Haiti, although more distant from population centres. However, there were 223,000 fatalities reported following the Haiti earthquake, with the death rate being roughly 35,000:1 when compared to losses sustained in Chile. The differential death rate is attributable primarily to an ineffective political system, expansive poverty, and weak infrastructure systems in Haiti. Further, an earthquake of similar magnitude occurring in New Zealand in the same year resulted in no deaths. While geographic regions of increased hazard exposure are often well researched, the spatial variability of vulnerability and uneven distribution across populations is less defined [92]. In the context of the Philippines, there have been limited attempts to map vulnerability at a sub-provincial level, leaving fundamental gaps in understanding why particular population groups face higher levels of disaster risk.

2.2. Defining and understanding vulnerability

Vulnerability is a complex web of the physical, socioeconomic, and political environment [1,11,73]. Despite the emergence of social vulnerability in literature in the 1970s [4,6,11,20,24], there remains a lack of a singular, standard definition [23]. Cutter [23] summarises 18 different vulnerability definitions, highlighting the complexity of vulnerability and the challenges associated with developing models to explain and quantify vulnerability and its uneven global distribution [11,34]. All 18 definitions identified by Cutter share the commonality that vulnerability refers to the characteristics or circumstances of a population (physical, political and socioeconomic) and how these circumstances affect one's ability to cope with hazards. A widely accepted definition of vulnerability in relation to disasters was termed by the United Nations Office for Disaster Reduction [87] and similarly focusses on these key concepts: “the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards”.

One of the most widely accepted conceptualisations of vulnerability, Blaikie et al. [11]. describe a progression of underlying root causes that lead to dynamic pressures and unsafe conditions [15,18,60]. Many disaster risk factors such as occupation, level of wealth, and type/quality of housing are unsafe conditions and represent conditions of the social environment generated by root causes. This conceptualisation helps to explain the spatial variability of social and housing vulnerability as different populations express the effects of root causes differently [15]. In the context of the Philippines, root causes for vulnerable populations stem from centuries of economic and political restructuring associated with Spanish colonial rule (1565–1898), American imperialism (1900–1946) and various corrupt and authoritarian governments, the most notable of which was the 20-year rule of Ferdinand Marcos between 1965 and 1986 [13,78]. The “criminal regime” of Marcos left the nation polarised as the rich “lived in ostentatious splendour” whilst majority of Filipinos suffered below the poverty line ([13], p. 1; [78], p. 15). Dynamic pressures that emerge from these root causes include rapid urbanisation and livelihood restructuring [11].

Planning and administration in the Philippines has led to rapid population growth in urban areas as low- and middle-income groups migrate to regions which offer greater livelihood opportunities [69]. The population of metropolitan Manila has increased thirty-fold since 1903, resulting in a scarcity of affordable land and housing [6]. In urban areas of the Philippines, land inaccessibility has led to the growth of informal settlements, known as “Barong-Barong” ([69], p. 4). Housing in informal settlements is characterised by unsafe construction materials and limited access to amenities such as electricity and clean water. Due to lack of land availability, houses are often situated in vacant areas designated as hazardous by the government due to their close proximity to coastlines, riverbanks and creeks, heightening vulnerability to typhoon exposure [69,89]. ‘Unsafe conditions’, including living in hazardous locations or unsafe housing, have been linked to increased disaster risk as well as higher rates of morbidity and mortality [6,84,89]. An increased understanding of housing vulnerability is thus vital to understand how broader social vulnerability emerges in the Philippines.

2.3. Housing vulnerability in the Philippines

Over the period spanning 1980–2013, over 30,000 people in the Philippines alone have perished as a result of typhoons with an estimated 5 million people affected in some capacity each year [96]. The importance of safe housing emerged as early as 1948 in the Universal Declaration of Human Rights and has remained relevant, as even today safe housing is not available to all [81,84]. Following Super Typhoon Haiyan, which made landfall in the Philippines in 2013, more than 1.1 million homes were damaged or destroyed, leaving over 4 million people displaced. Coastal areas which fell directly in the path of the storm reported that more than 90% of infrastructure was destroyed. Studies by Kure et al. [48] and Mas et al. [53] following Haiyan found that houses in coastal villages mainly consisted of lightweight (wood/timber) pile dwellings were either completely destroyed by the storm surge or by ships which had moved during the storm surge. Masonry, reinforced block, or reinforced concrete homes that were more common in village centres, such as in central Tacloban, sustained comparatively minor structural damage.

Access to safe housing is also important for the Sendai Framework for Disaster Risk Reduction and has been identified as a contributing factor to vulnerability and hence disaster risk [41,77,88]. Existing social vulnerability indices use variables pertaining to housing to better understand the spatial complexities of vulnerability and disaster risk [17,61,68]. Poverty is a common indicator used to assess social vulnerability across a wide variety of contexts [28,31,56,77] and is often measured through variables including but not limited to; income, gender, race, social dependence, and housing quality [28,77]. It is well recognised that "poor people are more likely to live in poorly built housing, which can be a major disadvantage when disasters occur" ([61,77], p. 4). Moreover, studies have focussed on housing in the context of adaptive capacity, suggesting that those living in unsafe housing are not only more vulnerable as their homes suffer disproportionate damage during a hazard, but that the high degree of damage and often low socioeconomic status of occupants renders them ill equipped to recover – creating cyclic unsafe housing after each disaster [61]. In the context of typhoons, housing has been found to be a significant indicator of vulnerability [17,61,68,77], yet little has been done in the Philippines to assess and map the contribution of housing to typhoon vulnerability at low administrative levels on a national scale. Further, there is limited research focussing on developing and mapping a social vulnerability index derived from proxies for housing vulnerability at low administrative levels across the Philippines, and in particular, looking specifically at the vulnerability of municipalities to typhoons. By measuring and spatially understanding the significance of housing vulnerability across the Philippines, strategies to reduce vulnerability can be prioritised to communities most in need – with the aim of ultimately reducing typhoon related losses [77].

2.4. Spatial variability of housing vulnerability in the Philippines

Spatial variability in social and housing vulnerability across the Philippines is widely recognised; however, studies into this variability are limited, especially at subnational levels [96]. The scale at which vulnerability analysis is conducted is an important factor as it dictates the level of variability that will be captured. Statistical relationships between underlying indicators often vary significantly across analysis scales, meaning that the same index at different scales can yield distinctive patterns of vulnerability [9,83]. Whilst analysis at a national level is effective in informing national disaster policy, subnational analysis scales can help to identify how more localised conditions affect disaster vulnerability, and hence contribute to more targeted risk reduction initiatives. Mendoza et al. [56] conducted a climate change vulnerability study at a commune and household level across three provinces in three Southeast Asian countries, comparing the vulnerability of selected regions. Similarly, Toda et al. [85] mapped the vulnerability of four local government units (LGUs) in the Philippines to climate-related disasters. Usamah et al. [89] also used a localised approach to study the social and housing vulnerability and resilience of two rural barangays (villages) situated in highly hazard exposed regions of the Philippines. Whilst these studies were conducted at a subnational scale, they were limited to a small selection of regions, limiting their usefulness to national disaster risk reduction initiatives. There have also been efforts to create and measure social vulnerability indices applied within single municipalities [43,63,64,67], which are again limited by a lack of comparative analysis between municipalities [72]. In contrast, studies have focused broadly on national and subnational policy [3]; however, there has been a minimal attempt to bridge these units of scale. As a result, there is a need to examine lower administration levels but do so on a national scale. This study seeks to address this gap by investigating housing vulnerability at a municipal level across the Philippines.

2.5. Measurement of vulnerability

As vulnerability is increasingly being used as a means of explaining the spatial variability in the impacts of natural hazards, the need to develop a quantitative measurement of social vulnerability has simultaneously emerged [91]. Social vulnerability is a latent variable, meaning that it is inherent to a region but not directly observable, and therefore, only possible to measure indirectly through statistical methods [79]. Thus, social vulnerability is commonly assessed using a series of indicators that highlight a community's susceptibility to a particular hazard [2]. The Social Vulnerability Index (SoVI) is an additive model which was among the first attempts to quantify vulnerability based on a set of selected indicators [24]. SoVI was initially constructed as a numeric index quantifying the vulnerability of the United States to general environmental hazards but was criticised for its limited applicability to other geographic contexts [14,79]. This model was quickly adapted within academic literature and applied in a broad range of geographic contexts, inspiring the study of other similar yet context-specific, quantitative indicators of social vulnerability [70]. The resultant vulnerability indices typically utilise demographic data related specifically to the local social, economic and political environment, and build algorithms that analyse the effect of these factors on the spatial distribution of disaster-related losses [83]. The final index is a culmination of a multistage process, from indicator selection, choice of analysis scale, data collection and transformation, scaling, weighting and aggregation. Disaster literature is relatively consistent on the baseline indicators of vulnerability that are applicable across multiple contexts [24,25], including access to resources, access to political power and representation, social capital, beliefs and customs, building stock and age, frail and physically limited individuals, and the quality and density of infrastructure. In aggregating multiple indicators such as these, vulnerability indices seek to distil the complexity of an entire system into a single metric.

It can be argued that housing vulnerability, much like social vulnerability, cannot be directly measured and proxies must be used [77]. Attempts to measure housing vulnerability have focussed on four categories of proxies: (1) *Structural characteristics* such as building material of walls and roof; (2) *Housing-type characteristics* such as size, number of bedrooms, number of storeys, type of house and tenure; (3) *Provision of amenities* such as indoor toilet, indoor kitchen, appliances, access to electricity and hygienic water supply; (4) *Socioeconomic indicators* such as household income, age of head of household, social network, human capital (assessed by educational attainment and participation in the labour force), and crowding [30,35,37,57,71,86,97]. However, there remains no consistent method of measuring housing vulnerability since many of the proxies used are subjective and their relevance varies with location and hazard type [97]. For example, provision of amenities such as appliances may be a useful proxy for housing vulnerability in higher income countries, however other determinants including structural characteristics may be more useful in low-income nations [97]. Furthermore, wall and roof material have been found to be good proxies for assessing housing vulnerability to typhoons, however they are less relevant when assessing vulnerability to other hazards, such as floods [17,76]. In the case of floods, the number of storeys is a much better proxy of housing vulnerability as occupants can escape to higher floors [41,48]. With the projected increase in frequency and intensity of many hazards such as typhoons due to climate change, a need arises to further understand the contribution of housing vulnerability to disaster risk in the Philippines [19]. This research is loosely guided by Cutter et al.'s [24] methodology that has been extensively adapted throughout disaster literature but focuses specifically on indicators of housing vulnerability to typhoon hazards in order to develop an even more nuanced housing vulnerability index, as a sub-component of overall social vulnerability.

3. Methods

We sought to develop a national housing vulnerability index in the Philippines. The following section describes our data collection and analysis to expand our understanding of the distribution of housing vulnerability across the Philippines. We first provide an overview of how we selected indicators and sourced data. Next, we use Principal Component Analysis (PCA) to identify underlying dimensions of housing vulnerability, combing these to create a composite index. Finally, we map these dimensions and use cluster analysis to identify regions of high and low housing vulnerability. This study draws on 2015 data to align with the baseline period used by the Sendai Framework for Disaster Risk Reduction. Our approach focuses on typhoons as these are the most frequent hazard facing the Philippines in terms of coverage and historical losses.

We took a data-driven approach to measure relative housing vulnerability. We approach our analysis in this way for two reasons. First, understanding vulnerability at a national level requires immense data that are primarily captured by existing censuses. While others have raised critiques of data-driven approaches [82], the standardisation in how census data is collected and regular interval of the collection offers the ability to sustainably source data over time. Second, we are interested in measuring *relative*, not absolute, vulnerability of housing. This aim does constrain the possible use, such as for damage models, but offers a simple way to prioritise resources and to conduct exploratory analysis of differences in disaster risk and impact. It also affords the same methodology to be applied to new censuses for the index to be updated. In constructing our housing vulnerability index, it is also important to note that we conceptualise housing not only as a static physical asset but also for its role in social infrastructure.

3.1. Indicator selection and data collection

Vulnerability indicator data was sourced from the Philippine Statistics Authority (PSA), which conducts a census of population and housing every 5 years. This study draws upon the 2015 housing and population census, which is currently the most recent published dataset available. Ten vulnerability concepts of housing characteristics were selected to represent both the social and physical aspects of housing. The social dimension of housing has been further dissected into the socioeconomic status and tenure of a household, whilst physical aspects of housing have been described through structural characteristics of the housing unit and access to amenities. A total of 25 indicators made up the analysis. These indicators are summarised in Table 1.

3.1.1. Socioeconomic status

To represent socioeconomic status, poverty incidence and crowdedness (measured through ratio of household population to occupied housing units) were considered. Low socioeconomic status suggests reduced adaptative capacity to respond and recover from typhoon hazards [67]. Poverty incidence has a positive relationship with vulnerability due to infrastructure deficiencies for those with lower economic status and inhibited ability to potentially make repairs [31]. Increased crowdedness within the home also suggests higher vulnerability, particularly when considering that higher incidences of poverty often correspond to crowdedness [65]. We include these occupant characteristics as they capture how populations interact with housing stock. Percentage of urban population and housing type can also represent socioeconomic status through the lens of urbanisation and population density. Highly urbanised populations tend to have more extensive social networks which increase adaptive capacity following typhoons [58].

3.1.2. Tenure

Ownership of house units and the lot of residence was used to understand tenure conditions. Ownership tenure has a negative relationship with vulnerability, whilst rental tenure has a positive relationship. Lack of tenure security can deincentivise individuals from using robust materials and construction methods, increasing the vulnerability of housing to typhoon hazards [58].

3.1.3. Structural characteristics of the housing unit

Structural characteristics of housing materials were considered in the outer wall and roof material indicators. Whilst it has been recognised that ‘how’ a house is constructed is often just as important as the construction materials used in the context of typhoon hazards [29,62], availability of baseline data is limited to construction materials. We therefore generalise that households with outer walls constructed from concrete, brick, or stone and roofs comprising galvanised iron/aluminium represent strong forms of construction that are more resilient to typhoon hazards. Unsafe construction materials used in both wall and roof construction (such as wood, bamboo, cogon, nipa, trapal and makeshift materials) have a positive relationship with vulnerability as they are assumed to be generally less resilient to typhoon hazards.

Table 1
Selected housing vulnerability indicators.

Vulnerability concept	Indicators	Sources
Poverty	Poverty Incidence (%)	Mendoza et al. [56]; Fatemi et al. [31]; De Silva and Kawasaki [28]
Urban Population	Percentage of Urban Population (%)	Lawal and Arokoyu [49]
Crowdedness of Household	Ratio of Household Population to Occupied Housing Units	Fatemi et al. [31]; Martins et al. [52]; Chen et al. [16]; Rabby et al. [68]
Tenure	% Owns house and lot of residence; % Owns house and rents lot of residence; % Owns house with rent-free lot with consent of land owner; % Rents house and lot of residence	Toda et al. [85]; Hofflinger [40]; Morin et al. [58]; Ignacio [42]
Type of Housing Unit	% Single House; % Multi-Unit; % Duplex	Morenikeji et al. [57]; Rowan and Kwiatkowski [75]
Outer Wall Material	% Concrete/brick/stone; % Wood; % Bamboo; % Half Concrete/Brick/Stone & Half Wood; % Trapal; % Makeshift materials	Bolin and Stanford [12]; Godschalk et al. [36]; White and Haas [93]; Nguyen et al. [61]; Morin et al. [58]; Ignacio [42]
Roof Material	% Galvanised Iron/Aluminium; % Bamboo; % Half Tile & Half Galvanised Iron/Aluminium; % Trapal	
Household Lighting	% Electricity; % Kerosene	Yust et al. [97]; Rabby et al. [68]; Hofflinger [40]; Mavhura et al. [54]; Lawal and Arokoyu [49]; Morenikeji et al. [57]
Drinking Water Source	% Improved Source[a]; % Other Improved Source[b]; % Unimproved Source[c]	Mavhura et al. [54]; Lawal and Arokoyu [49]; Hahn et al. [39]; Morenikeji et al. [57]; Prasetyo et al. [67]

[a] Defined as sourcing drinking water from an Own Faucet or a Bottled Source.
[b] Defined as sourcing drinking water from a Shared Faucet, Peddler or Protected Spring.
[c] Defined as sourcing drinking water from a Shallow Well, Dug Well, Shared Well, Own Well, Unprotected Spring or Lake/River/Rain.

3.1.4. Access to amenities

Household lighting and drinking water source were chosen to explain access to essential amenities. Homes using electricity for lighting as opposed to kerosene are assumed to be less vulnerable to typhoons as they have better access to necessary services that enhance adaptive capacity following hazards [97]. Indicators chosen to represent drinking water source were aggregated into three categories to align with definitions provided by The Joint Monitoring Programme for Water Supply and Sanitation (JMP); improved sources (own faucet and bottled), other improved sources (shared faucet, peddler or protected spring), and unimproved sources (such as wells, unprotected springs, lakes, river and rain) [45]. Unimproved water sources are susceptible to contamination and therefore contribute to increased vulnerability as sources are unsafe, particularly following typhoon events [27]. It was assumed that all types of wells (own well, shared well, dug well, shallow well) were susceptible to contamination and therefore classified as unimproved as there was no information to suggest that certain types of wells were isolated from contaminants and others were not. Other improved water sources also indicate increased vulnerability, however to a lesser extent when compared to unimproved water sources as they are isolated from contamination [45].

3.2. Principal component analysis

We used Principal Component Analysis (PCA), a dimensionality-reduction method, to assess and capture underlying components in the selected housing census data. PCA has been widely used in social vulnerability studies to identify latent variables, by statistically analysing input variables and removing unrelated, redundant and multicollinear variables [42,100,101]. Each census vulnerability indicator was first normalised, allowing comparability across municipalities. We confirmed that PCA was suitable by inspection of the correlation between all variables, assessing this on the basis of one or more correlations between variables above 0.3. The overall Kaiser-Meyer-Olkin (KMO) measure for all variables was 0.525 with 20 of the 25 individual KMO measures greater than 0.7, four above 0.6, and one above 0.45 – a minimum considered acceptable limit. Bartlett's test of sphericity was statistically significant ($p < 0.0005$), suggesting factorisation was feasible. We used varimax rotation and extracted components with eigenvalues above one – commonly referred to as the Kaiser criterion. Variable loadings that were greater than 0.45 or less than −0.45 in the retained components were kept, identifying only those that had the strongest relationships. The relationship of each factor (+/−) to housing vulnerability was theoretically assessed through manual inspection.

3.3. Spatial mapping and pattern identification

We then mapped the dimensions and their aggregated composite index. We classified municipalities by standard deviation (SD) into very low vulnerability (<−1.5 SD), low vulnerability (−1.5 to −0.5 SD), moderate vulnerability (−0.5 to 0.5 SD), high vulnerability (0.5–1.5 SD), and very high vulnerability (>1.5 SD). Municipal boundaries were obtained from the United Nations Office for Coordination of Humanitarian Affairs (UNOCHA), which hosts spatial files derived from the Philippines Statistic Authority (PSA) and National Mapping and Resource Information Authority (NAMRIA). In the Philippines, the Land Management Bureau under the Department of Environment and Natural Resources (DENR) is formally responsible for official administrative boundaries; however, available official administrative boundaries are not presently publicly available. The boundaries used in this research are derived from the Philippine Geographic Standard Code (PSGC) generated in April 2016 that correspond with the 2015 population census. While this data is comprehensive, UNOCHA, PSA, and NAMRIA note that the boundaries should be considered indicative, not official. These maps allow for visual identification of vulnerable municipalities to aid in future disaster risk planning and mitigation.

To identify spatial patterns in housing vulnerability, we used cluster and outlier analysis on aggregated components. This analysis creates an index using Anselin Local Moran's I, which measures autocorrelation among neighbouring municipalities. Further, we also used Global Moran's I to test for spatial autocorrelation on a national level across the Philippines. We used the ArcGIS Spatial Statistics package, which tests at the 0.05 significance level.

4. Results

Seven components were extracted that together explained 74% of the variance, exibiting excellent representation. The variable loadings for each component are shown in Table 2. The first component (PC1) was considered as *housing density* and explained 28% of the variance. It was characterised by higher percentages of urban population, occupied multi-unit and duplex residences, and households renting both house and lot, as well as lower percentages of occupied single standing homes. Higher percentages of homes with access to an improved water source for drinking (bottled or own faucet) also contributed to PC1, but to a lesser extent than the aforementioned variables. As a result, PC1 was deemed to have a negative relationship with housing vulnerability. The second component (PC2) was considered as *housing quality*, and explained 11% of the variance. It comprised of homes with a higher percentage of robust roof and wall material (galvanised iron and concrete/brick/stone respectively), higher rates of electricity usage for lighting, and lower percentages of unsafe construction materials (bamboo) and kerosene usage. PC2 thus had a negative relationship with housing vulnerability. The third component (PC3), defined as *crowdedness*, explained 9% of the variance. PC3 was characterised by higher ratios of household population to occupied housing units, as well as higher incidences of poverty, and more widespread use of wood as an outer wall material. PC3 therefore had a positive relationship with housing vulnerability. Component four (PC4) was conceptualised as *tenure security*, and also explained 9% of the total variance. PC4 comprised higher percentages of home ownership but rental lot tenure, and lower percentages of owning both house and lot. PC4 therefore had an assumed positive relationship to housing vulnerability, as higher incidences of PC4 corresponds to less secure tenure. Components five through seven (PC5, PC6, PC7), each explained between 4% and 7% of the total variance. PC5 was considered as *extreme substandard housing* and included houses constructed with makeshift and/or trapal (tarpaulin) wall material and trapal roof. PC6 was conceptualised as *drinking water source*, measured by lower percentages of unimproved drinking water sources and higher percentages of other improved water sources. PC7 was considered as *structural integrity*, capturing houses constructed of half concrete and half wood walls and half galvanised iron and half tile roofs. PC5 and PC7 had positive relationships to vulnerability as houses of extreme substardard materials or poorer structural integrity are more vulnerable to typhoons. PC6 had an assumed negative relationship to vulnerability, as having access to an uncontaminated water

Table 2
Housing vulnerability index components.

Component	Directionality	Variance explained (%)	Variable name (Loading)
(1) Housing Density	−	28	Percent Multi-Unit Residences (0.895); Percent Single Home Residences (−0.879); Percent Households Renting House and Lot (0.862); Percent Duplex Residences (0.751); Percent Urban Population (0.729); Percent Improved Drinking Water Source (0.475)
(2) Housing Quality	−	11	Percent Galvanised Iron/Aluminium Roof (0.841); Percent Bamboo Roof (−0.818); Percent using Kerosene for Lighting (−0.726); Percent using Electricity for Lighting (0.682); Percent Bamboo Wall (−0.673); Percent Concrete/Brick/Stone Wall (0.597)
(3) Crowdedness	+	9	Ratio of Houshold Population to Occupied Housing Units (0.817);Percent Wood Wall (0.783); Poverty (0.606)
(4) Tenure Security	+	9	Percent Own House & Lot of Residence (−0.834); Percent Own House, Rent-Free Lot with consent of owner (0.739); Percent Own House & Rent Lot of Residence (0.711)
(5) Extreme Substandard Housing	+	6	Percent Trapal Wall (0.851); Percent Trapal Roof (0.845); Percent Makeshift Material Wall (0.744)
(6) Drinking Water Source	−	6	Percent Unimproved Drinking Water Source (−0.802); Percent Other Improved Drinking Water Source (0.744)
(7) Structural Integrity	+	4	Percent Half Galvanised Iron & Half Tile Roof (0.787); Percent Half Concrete/Brick/Stone & Half Wood Wall (0.776)

source improves adaptive capacity following hazards. As a result, our housing vulnerability index (HVI) was reflected by

$$HVI = -PC1 - PC2 + PC3 + PC4 + PC5 - PC6 + PC7 \quad (1)$$

The dimension maps in Fig. 1 spatially depict the seven principal components: housing density, housing quality, crowdedness, tenure security, extreme substandard housing, drinking water source, and structural integrity. There are similar trends nationally in components including crowdedness, tenure security, and drinking water source. There exists generally increased crowdedness and less secure tenure in the Autonomous Region of Muslim Mindanao (ARMM), Region X and Region XIII in Mindanao to the south of the country, with coastal municipalities in these regions and pockets within Region VIII experiencing a greater degree of crowdedness and less secure tenure. Similarly, there is less secure tenure in Region VI and VII and in Region IV-A in southern Luzon, again with coastal municipalities showing enhanced insecurity. The inverse applies for drinking water source, with municipalities in Region X and Region VIII, for example, having greater access to protected sources of water. There is also a pocket in the Cordillera Administrative Region (CAR) in northern Luzon where municipalities have greater utilisation of protected drinking water sources. Extreme substandard housing shows a smaller variation across the country, however coastal pockets in Region VIII and Region XI in the south and Region IV-A in the north show heightened deviation from the norm. Housing quality is generally higher in the north of the Philippines, particularly on the island of Luzon. However, the majority of municipalities here are 0.5 SD - 1.5 SD from the mean, indicating that there are only a select few municipalities with the highest level of housing quality (>1.5 SD). Low housing quality is concentrated to Mimaropa (formerly Region IV-B) and Region XII, with some municipalities in Region VI and VII and Region V also showing the poorest level of housing quality. There are pockets with houses of poor structural integrity dispersed across the Philippines, however there appears to be a higher proportion of homes with poor structural integrity also in Region V in southern Luzon. Contrastingly, housing density is highly concentrated in the National Capital Region (NCR) to the north of the country.

The housing vulnerability index map in Fig. 2 shows a general trend of increasing housing vulnerability to typhoon hazards from south to north, with municipalities in the southern region and eastern/western coastlines having the highest vulnerability. This was confirmed by a Global Moran's I of 0.374 ($P < 0.001$), suggesting significant clustering. The mean housing vulnerability score was 0.000 with a standard deviation of 2.645. The maximum score was 13.375, with a minimum score of −7.472. We found 6.132% of municipalities had very low vulnerability, 23.437% low vulnerability, 44.262% moderate vulnerability, 19.126% high vulnerability, and 7.043% very high vulnerability.

We were interested in not only national spatial patterns but also outliers within hotspots and coldspots. Cluster analysis is shown in Fig. 3. High-high clusters indicate areas of high housing vulnerability, while low-low clusters show the inverse – areas of low housing vulnerability. High-low outliers show municipalities that exhibit significantly higher vulnerability in low vulnerability pockets. Low-high outliers reflect municipalities of lower than expected vulnerability in high vulnerability regions. As can be seen, municipalities located in the CAR, Region V, and Mimaropa (formerly Region IV-B) have concentrations of municipalities with high vulnerability in otherwise lower vulnerability regions. These outliers reaffirm the importance of conducting analysis at the municipal level, as these municipalities are possibly overlooked in DRR initiatives based on their proximity within surrounding low vulnerability clusters Regions VII, VIII, and XI are outliers with lower vulnerability than their surrounding areas. Furthermore, an understanding of the spatial variability in housing vulnerability at the municipal level, including identification of these outliers, is necessary to identify the ‘root causes’ of this vulnerability.

5. Discussion

Whilst mapping of housing vulnerability at municipal levels has been undertaken in existing literature, most of these studies adopt a case study approach, with selected focus municipalities, preventing comparison of vulnerability at a national level. The mapping of the generated vulnerability index provides an opportunity to interrogate more closely the spatial relationships in housing across the Philippines.

As we have shown, there is an overall trend with lower housing vulnerability in northern municipalities and higher vulnerability in southern municipalities. This is no doubt influenced by historical hazard exposure, as Luzon – the Philippine's northern collection of provinces and municipalities – sees the brunt of typhoon paths. As a result, housing typologies are adapted to the higher frequency of typhoons. Houses in the northern municipalities of the Philippines tend to be constructed using more robust materials or construction methods. For example, Batanes province comprises the northernmost cluster of islands in the Philippine archipelago and is exposed to approximately 8 of the 20 destructive typhoons that affect the Philippines each year. As a result of consistent exposure to strong winds and destructive typhoons, the indigenous Ivatan people use building techniques tailored to the extreme conditions [90]. Traditional homes are commonly constructed using thick stone walls and layered cogon (grass) roofing. Other techniques such as the small and narrow size of doors and windows as well as the use of thick wooden shutters and bars protects homes from destructive winds.

Without our clustering analysis, one might assume that housing vulnerability is linearly related to exposure. However, by examining localised patterns, we can see this does not always hold true. These instances of high and low housing vulnerability that defy larger spatial patterns merit closer attention to their policies and programs. In the case of those with lower than expected vulnerability, there are likely lessons to be shared. Safer building materials and typhoon resistant construction methods are often unattainable for many living in poverty. Poverty is also cyclical when poorly constructed homes are repeatedly destroyed by typhoons. Affected individuals in Tacloban that were surveyed following Typhoon Haiyan indicated that ‘recovery’ simply meant building ‘back to pre-disaster conditions’ [80]. Within weeks, researchers observed that many of the destroyed homes had been reconstructed using the same methods and materials as before the disaster [53]. As the effects of hazards can further exasperate poverty, it reinforces the need for targeted disaster risk reduction reponse in vulnerable regions. Insecurity of tenure, as is more common in low income communities and informal settlements, also acts as a major disincentive for households to invest in quality materials and construction [58].

As others have raised [32], restraint is needed however to avoid stigmatising high vulnerability municipalities. Housing does not exist in a vacuum, and like other dimensions of social vulnerability, lower standards are often the result of inequalities and injustices. Our approach does, however, offer insights into where additional housing resources may be allocated. Whilst our HVI as a predictive tool for vulnerability requires further validation through further analysis of typhoon-related housing damage, it is ultimately successful in providing a *relative* understanding of housing vulnerability at a lower administrative level than seen in other similar studies. The study provides a granular spatial analysis that has the potential to be utilised and developed further in future studies that seek to examine housing vulnerability on the ground. Whilst this study effectively highlights the complexity of vulnerability and its underlying components, we believe that it can be further complemented through qualitative and community-based methods that have the potential to add further nuance through subsequent context-specific investigations. It is expected that the outcomes of this study will be reinforced through community-based methods, which have been applied widely to risk communication and perception [94]. Kelman [46] suggests that an important component of disaster prevention is understanding how people think and behave, which can be further understood through these methods. Ultimately, we believe that

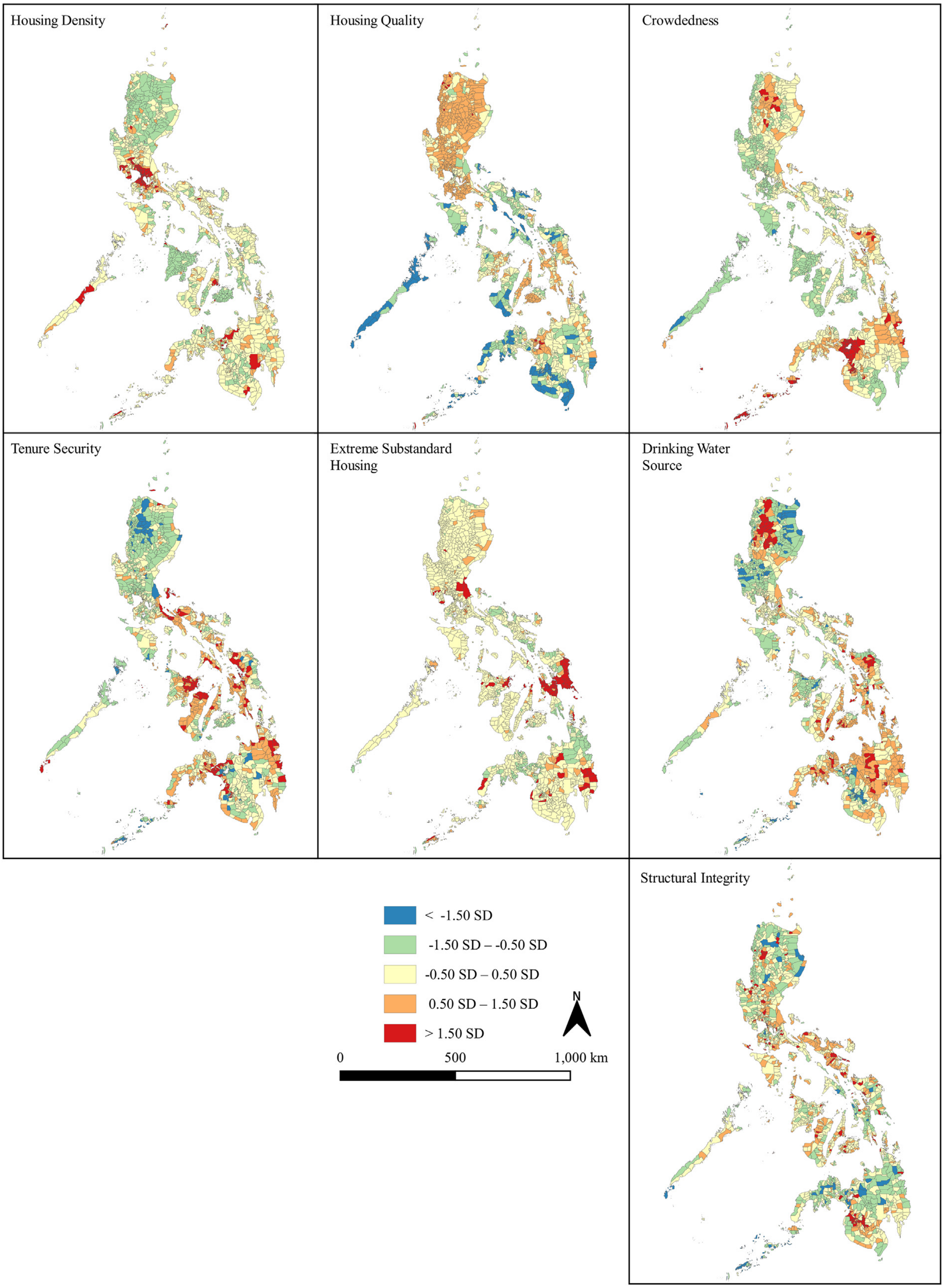

Fig. 1. Individual principal component maps.

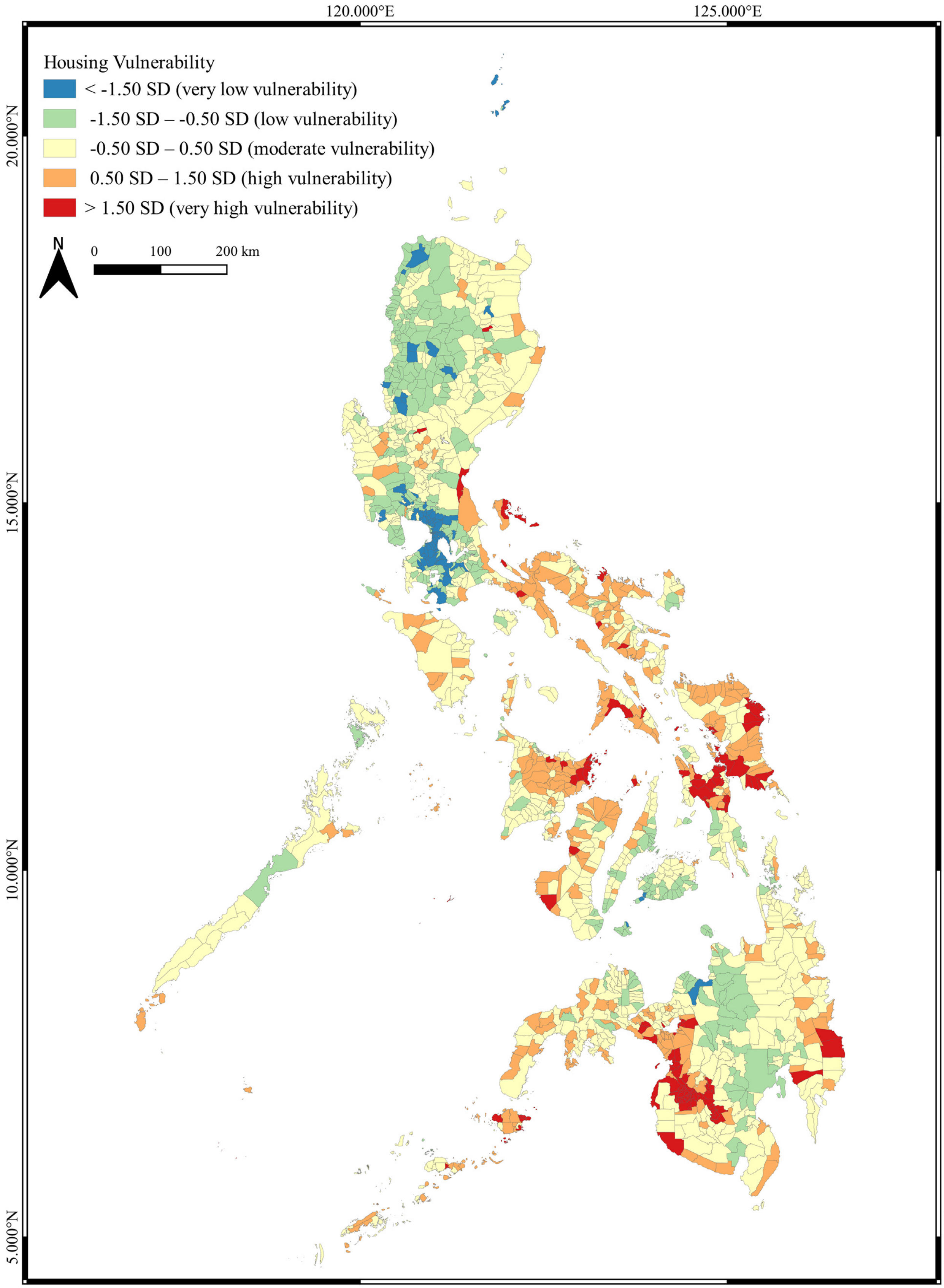

Fig. 2. Housing vulnerability index map of the Philippines.

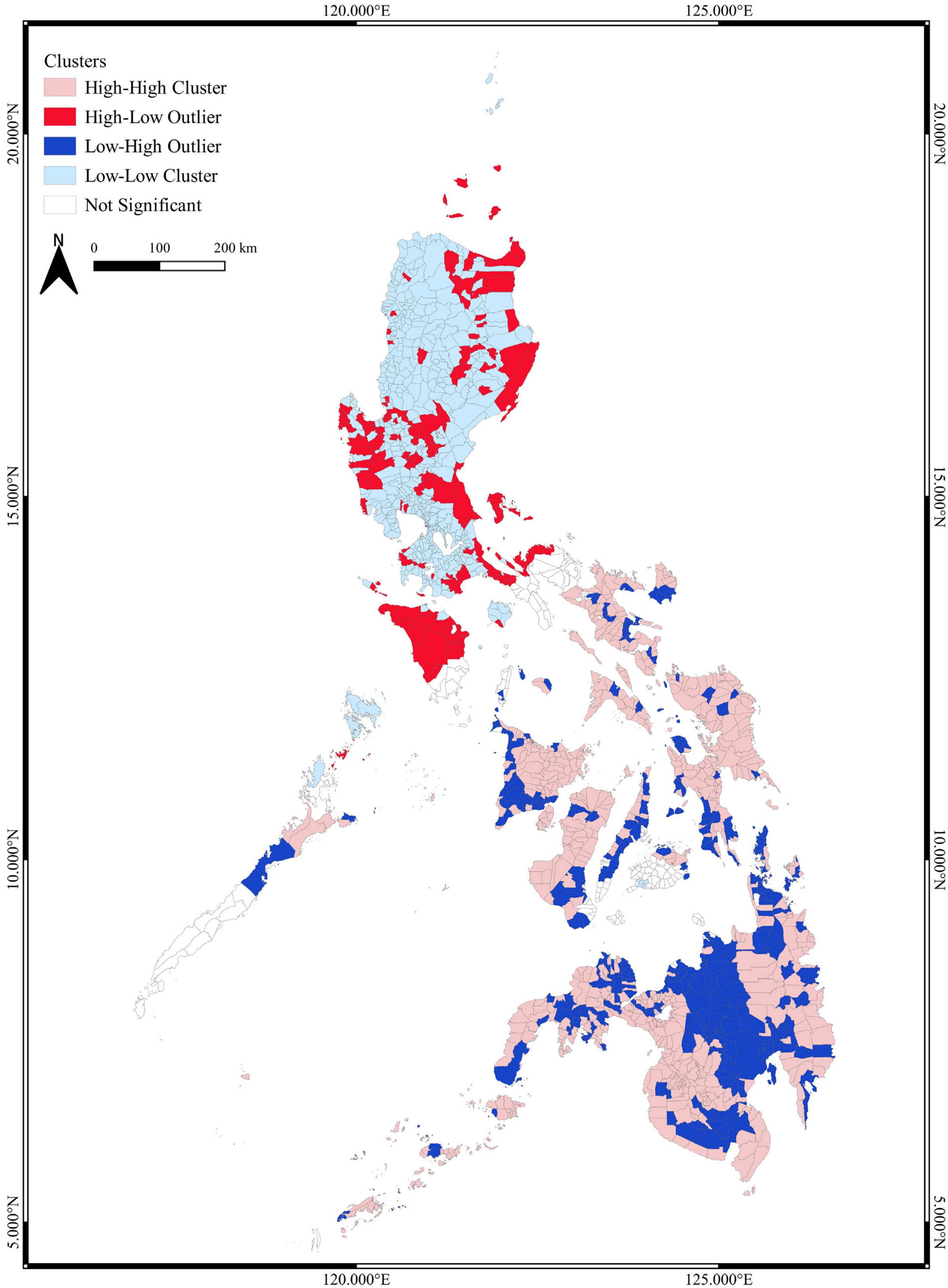

Fig. 3. Spatial clustering of housing vulnerability.

this research and its future developments can be used to inform the allocation of resources in disaster risk planning and reduction.

5.1. Limitations and future work

Vulnerability indices are not without debate [79], and we acknowledge several limitations. This study was limited by the availability of data related to the relevant vulnerability indicators, as determined by the applicable fields of existing census questionnaires. A criticism of Cutter et al.'s [24] SoVI, and other vulnerability indices, is their lack of specificity to a particular hazard. It is often argued that some underlying indicators, especially those related to housing, represent a higher level of vulnerability in one hazard context but a lower level of vulnerability in another. For example, houses with more stories allow individuals to reach safety in a flood context, yet pose a more significant risk of collapse and damage to individuals in the context of an earthquake. To avoid similar issues, we have developed our index with typhoon hazards in mind. However, this also limits the application of the index. As we have raised earlier, we do believe that there is potential for the index to be applied to a broader range of hazards given that many of the indicators are fundamental characteristics of housing vulnerability.

Data used in the study was taken from 2015 census data; however, since vulnerability is dynamic, with expected temporal variability [26], this data may not be the most accurate representation of the municipality's vulnerability over time. Instead, new methods should look at ways to capture longitudinal changes outside of census years. Ideally, future studies would draw data from multiple years of census data to derive a more accurate temporal cross-section of results. Future research may look to using an Analytic Hierarchy Process (AHP), or other methods, which consider the level of importance of each component based on a review of available literature and expertise in the field. Finally, we recognise that the vulnerability index proposed lacks empirical validation and future research should seek to compare housing vulnerability scores of individual municipalities with actual observed damages and losses across a wider range of typhoon events.

6. Conclusion

In this research, we take a data-driven approach to propose a housing vulnerability index for the Philippines for typhoon hazards. Using Principal Component Analysis (PCA), we identified seven dimensions of housing vulnerability: housing density, housing quality, crowdedness, tenure security, extreme substandard housing, drinking water source, and structural integrity. We then used Moran's I to examine local and global spatial clustering, finding north to south patterns and identified outlier municipalities. To our knowledge, this is the first such attempt to create a national index for housing vulnerability at the municipal level in the Philippines.

This research contributes an understanding of how housing vulnerability in the Philippines varies at a sub-national level. Unlike previous studies, the housing vulnerability index (HVI) provides an opportunity to directly compare municipalities spatially and understand overarching trends across the Philippines. The identified dimensions of housing vulnerability can be used as an explanatory tool to understand what aspects of housing vulnerability differ between regions and provide an insightful tool for future disaster risk reduction (DRR) research and implementation.

We believe our housing vulnerability index can be a planning tool, as other indices have shown in the past [55]. For government agencies, donors, and those working in housing practice, this research offers a tool to prioritise investments in housing for disaster risk reduction. It may also provide a way for municipalities to benchmark their housing vulnerability. For researchers, the housing vulnerability index may assist in identifying cases of high and low vulnerability, and can be used as a basis for more in-depth case study research. The housing vulnerability index developed offers a means to better understand spatial patterns and drivers of vulnerability, risk, and disasters.

Declaration of Competing Interest

None.

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