The application of geodemographics to social vulnerability and volcanic hazard assessment

Iain Willis[1] Maurizio Gibin[1] Joana Barros[1] Richard Webber[2]

[1]*Department of Geography, Environment and Development Studies, Birkbeck College, Malet Street,* London, WC1E 7HX; tel: 020 7631 6473, fax: +44 (0) 20 7631 6498, email iwilli02@bbk.ac.uk, m.gibin@geography.bbk.ac.uk, j.barros@bbk.ac.uk

[2]*Department of Geography, Kings College London, Strand*, London, WC2R 2LS; tel: +44 (0)20 7836 5454 fax: +44 (0) 20 7631 6498, email richardwebber@blueyonder.co.uk

---

Abstract

The dynamic forces of urbanisation that characterised much of the 20th Century and still dominate population growth in developing countries have led to the increasing risk of natural hazards in cities around the world (Chester 2000, Pelling 2003). None of these physical dangers is more tangible than the threat volcanoes pose to the large populations living in close proximity. Vesuvius, a recognised decade volcano following the UN's International Decade for Natural Disaster Reduction (IDNDR) has an estimated 550,000 people that live in areas susceptible to Pyroclastic Density Currents (PDC) (Barberi 2008) and a further 4 million at risk from ash fallout around the sprawling suburbs of Naples. Though quiescent since 1944, the prospect of a large eruption of Vesuvius presents a greater geophysical threat to the Campania region of Italy than perhaps ever before.
With the Neopolitan region at risk from such an event, this paper proposes a new methodology for creating a Social Vulnerability Index (SoVi) using geodemographic classification systems. In this study, Experian's MOSAIC Italy database is combined with geophysical risk boundaries to assess the overall vulnerability of the population around Vesuvius.

1.0 Introduction

Vesuvius is located in the Campania region of Southern Italy. Volcanic eruptions are documented as far back as 18.3ka years B.P., with perhaps the most infamous event being in AD 79, when the Roman towns of Pompeii, Herculaneum, and Stabiae were all but destroyed by devastating Pyroclastic Density Currents (PDC) (Lirer et al 1982) as total column collapse occurred.

Historic and stratigraphic evidence suggest the eruption magnitudes at Vesuvius have been steadily decreasing with time, whereas the frequency of the eruptions has been increasing (Cioni 2008). Stratified deposits of PDC's and tephra fallout have detailed a range of eruptive behaviour for this volcano (Esposti Ongaro and Erbacci 2008). Eruptive patterns range from Strombolian and Sub-Plinian events to very large-scale Plinian eruptions.

Coupled with the geophysical risks of an eruption, substantial population growth in Italy over the last 100 years has made any significant eruption at Vesuvius a far more devastating proposition.

Naples grew by 38% from 1901 to 2001, and despite a slight fall in recent years (circa 4%), there are still some 963,000 people living in the central areas of the city (ISTAT 2001). With the economic development of Naples rapidly evolving in the last 30 years from a region of agriculture dependency to one focused around the service industry (Eurostat 2009), modern day Naples is a hive for 21st century tourism (CNR 2009). A big part of the attraction for visitors to this province of Campania is based on seeing the hazard that poses this very real threat to the region.

1.1 Evacuation

Current evacuation plans divide the area around the volcano into three zones that are designated for different levels of priority and risk; Yellow, Blue and Red zones delineate the evacuation regions and were designed by the Department of Civil Protection (DPC 1995). However, the evacuation plans have been criticised in recent years as lacking local understanding, support and confidence (Barberi 2008). In fact, current evacuation maps have not been updated since 1995.

The most hazardous region is classified as the Red zone, an area containing all the municipalities around the volcanic vent and home to some 550,000 residents. Added to the physical hazards of an eruption of Vesuvius, the Naples province has residual social problems that it faces day-to-day. Statistically, unemployment has fallen in Campania in recent years, but compared to Italian national averages, this region remains one of the most deprived areas of Italy (European Commission 2009). Therefore, the consequences of an eruption have socio-economic consequences that go far beyond just the immediate risks associated with volcanoes.

1.2 Social Vulnerability

Drawing from the literature on natural disaster risk (Quarantelli 1978, Hewitt 1983, Wisner 2004), certain demographic and socio-economic variables can be recognised as increasing a household's social vulnerability during a disaster.

The use of demographic data to assess social vulnerability came about during the late 1970's, early 1980's as a paradigm shift in the standard interpretation of natural disasters (Wisner 2004). The classical view had regarded 'natural disasters', such as earthquakes, volcanoes and hurricanes, as the sole consequence of natural processes. However, following the work of early pioneers in disaster management (Westgate and O´Keefe 1976), focus began to be placed on understanding how hazards became 'disasters'.

The fundamental link and inter-dependencies between social marginalisation, an individual's access to resources, and their capacity to financially recover from a disaster are all themes explored here. The idea of creating a Social Vulnerability Index (SoVi) was pioneered by Susan Cutter (2000) as social statistics were combined with natural hazard frequencies and spatial boundaries to create thematic risk maps for the US state of South Carolina.

Cutter devised a statistical and integrative approach to classify an area's risk, ranking US counties according to both their social vulnerability and frequency of natural hazards. This was largely undertaken using techniques such as Principal Component Analysis (PCA) and factor analysis.

Causative factors of social vulnerability can be assessed with census or survey data to quantify associated risks. Variables that are understood to affect an individual's vulnerability during or after a natural disaster include both demographic indicators (age, gender, and ethnicity) and socio-economic factors (income, house ownership).

For example, the elderly and the young are considered to be more difficult to move during disaster evacuation and have a higher propensity to adverse health conditions (McMaster 1998).
Ethnic minorities are noted to have a differential exposure to disasters (Pulido 2000) suggesting that they are less able to access the necessary resources available to them during a disaster. This includes a lack of political means and the social networks available to indigenous populations during disasters.
One of the most discriminating variables dividing communities is household wealth. Less affluent households are very much more likely to struggle in terms of their financial resilience and subsequent economic recovery following the onset of a disaster (Burton et al 1993).
Gender also plays an important role in vulnerability as women are often noted to be more exposed than men during natural disasters (Enarson and Marrow 1998). However, gender will not be taken into account in this study because the data used would not provide enough variance for inclusion in the SoVi.

Lastly, population density is considered a significant factor during evacuation procedures (Johnson and Zeigler 1986) as densely populated areas are more difficult to evacuate than more rural regions.

By taking the notion that location based social statistics can help understand a regions vulnerable populations during a disaster, this paper addresses the possibility that pre-defined consumer segmentation data can be used to show vulnerabilities of households and individuals at a census area scale.

This approach to DRR has not been undertaken before, but there are very real and significant benefits it could provide. It gives the Department of Civil Protection, Non-Governmental Organisations (NGO) and city planners' greater understanding of the spatial variance of vulnerable groups in areas such as Vesuvius. In doing so, it helps raise awareness of the social drivers behind population settlement and geophysical risk.

1.3 Geodemographics

With the growth of client segmentation and marketing analytics in recent decades, one of the key protagonists has been the emergence of neighbourhood classification systems. More commonly known as Geodemographics in the UK, this discipline classifies households into defined profile types based on a suite of social data. Among other sources, this includes census data, consumer lifestyle surveys, crime surveys, and the electoral register (e.g. UK). Now available at household level (Mosaic 2009), there is now a level of micro marketing in the UK that was not available 30 years ago.

Geodemographics had its origins in the UK public sector (Webber, 1977, 1985) but is perhaps more commonly associated with the commercial sector in recent years. Providing a level of client modelling particularly suited to both direct market penetration and customer retention, there are now several competing classifications systems available for the UK alone. Experian' MOSAIC classification system is among the market leaders in this field.

Experian has expanded into global markets, now including classification systems for Singapore, Australia, Japan, Italy and a MOSAIC global product. With Experian kindly loaning the use of MOSAIC Italy 2007 data for this study, we seek to assess the use of geodemographic data to both social vulnerability analysis and the creation of a SoVi in the event of a large Sub-Plinian eruption at Vesuvius.

There are 223 survey variables that come with the MOSAIC Italy dataset to describe each neighbourhood profile (or cluster). The neighbourhood classifications derived from these split the Italian population into one of 47 groups. Each of the 47 groups is then aggregated into one of 12 geodemographic categories (Experian 2009). MOSAIC Italy, like its UK counterpart, is compiled largely off the last census survey in the country (ISTAT 2001) as well as telemarketing data with each census output region containing approximately 60 households.

Drawing from the literature on DRR, each of the 223 variables is assessed according to its discriminatory ability to define a household's social vulnerability to evacuation, access to resource, financial recovery and physical risk of collapse. A range of social statistical methods has been used to analyse each of the variables. This includes gini-coefficients, Pearson's correlation coefficients and the index range in MOSAIC survey variables (Leventhal 1995). These factors are then weighted and combined with geophysical risk modelling of a Sub-Plinian eruption to formulate a SoVi for the area around Vesuvius. It should be noted that the weighting methodology used in this assessment has never been used before and is proposed as a means of appropriately weighting geodemographic variables in a vulnerability index.

1.4 Eruption Scenario

Volcanoes pose multi geophysical hazards to an environment and Vesuvius is no exception. Past eruptions of SV have included several of the following; **tephra (ashfall), pyroclastic flows/surges**

(superheated ash), lava inundation, lahars (mudflows), outputs of poisonous gases, pyroclastic bombs, generation of ocean tsunamis and volcanogenic earthquakes. Superficial deposits from previous volcanic eruptions can be found in the surrounding geological and geomorphological strata of the Neopolitan area (Esposti Ongaro 2008). In general, past behaviour of the volcano has been characterised by short periods of high explosivity and longer periods of lower intensity eruptions (Cioni 2008). This can be defined by the Magma Disacharge Rate (MDR) which has been steadily increasing for the last 3000 years. Higher MDR rates are more characteristic of frequent but lower magnitude eruptions. Though all volcanic events are quite unique in their exact size and nature, Vesuvius has exhibited styles and eruptons of magnitude similar to the following definitions;

- Plinian eruptions
- Sub-Plinian eruptions (further subdivided in Sub-Plinian I and Sub-Plinian II)
- Violent Strombolian eruptions
- Ash emission events

Reducing magmatic intensity

In terms of assessing the geophysical risk to loss of life that an eruption of Vesuvius threatens, the scope of this research did not take all Volcanic hazards into account. For example, lava inundation and volcanogenic earthquakes are a common phenomenon associated with a volcanic eruption and frequently result in casualties due to house fires, building collapse, and hillslope failure.

When categorising physical risk boundaries for the vulnerability model presented here, historical evidence suggests the most likely loss of life from Vesuvius would be due to PDC and Tephra fall (Cioni 2008). It should be recognised that in a more comprehensive study focused on geophysical risks of Vesuvius, seismic and topographical analysis of Digital Elevation Models (DEM) could have further delineated these hazards.

The principal boundaries for the geophysical index of this study comprised of Tephra loading (isopach) maps and a PDC map based on 3D column collapse modelling by Eposti Ongaro (2008).

Also included in this analysis was the use of an evacuation map based on Civil Protection measures for the areas around the volcano. This was also the basis for the geodemographic population analysed around the Mt Vesuvius summit: a concentric area 50km in radius.

Eruption magnitude

After considering several historic eruptions, it was determined the most appropriate scenario to assume in terms of a risk hypothesis and evacuation was a large Sub-Plinian (II) eruption (VEI 3-4). There were several reasons for choosing an eruption of this magnitude.

Firstly, civil protection measures in the Napoli province are based upon the supposition of a Sub-Plinian eruption. Therefore, it seemed prudent to keep all scenario parameters consistent with this size.

Secondly, given the past activity of the volcano, such as the Pollena eruption of AD 472 or the AD 1631 eruption (Andronico 2002), a large Sub-Plinian (II) event, with a Volcanic Explosivity Index (VEI) of between 3-4 is widely regarded as a very probable eruption magnitude in the future (Cioni 2008).

Of course, eruption scenarios are a moot point as volcanoes are highly unpredictable in terms of eruptive behaviour and temporal patterns. Nonetheless, Vesuvius' eruption history provides good evidence to support such a scenario.

2.0 Creating the vulnerability indices

In order to calculate the overall vulnerability of the census regions around Vesuvius, it was necessary to pursue two separate areas of analysis; namely, assessment of the social vulnerability of each census region and then separately calculate the spatial extent of the geophysical hazards.

Once these risk factors were accumulated, they were then combined using a Geographical Information System (GIS) to provide an overall SoVi.

In creating the SoVi for census regions, a new methodology was prepared. By classifying MOSAIC index variables according to their gini-coefficient, a bespoke level of weighting was assigned to each vulnerability factor.

2.1 MOSAIC variables

Along with the MOSAIC Italy (2007) database, a series of 223 data variables describe each of the 12 demographic categories and 47 types. This data consists of detailed statistics on the demographic, socio-economic, and housing profile of each cluster.

For the purposes of this study however, not all these variables were needed in assessing a household's social vulnerability.
The initial variables in the SoVi were selected from reference to the literature on factors that have been identified to further an individual/household's vulnerability during a natural disaster.

Social Vulnerability factors	**MOSAIC Italy Variables**
Individual/Household access to resources during a disaster	Accessability to local facilities, Phone connection, Ethnicity, Rurality
Demographic/Ethnic vulnerability during evacuation	Gender, Ethnicity, Age, Daily movements
Financial capacity to recover	Socio-economic variables (income, rented property, loan, credit card)

Table 1: Social vulnerability variables

Category of social vulnerability, Mt Vesuvius area	**MOSAIC Italy Variables**
House/Flat is vulnerable to collapse (pyroclastic flow / tephra)	Building age, Building type, High rise flats

Table 2: Physical vulnerability variables

2.2 Measurements of discrimination

The degree to which geodemographic classifications can discriminate between clusters of a population is their key purpose as this enables the analyst to make informed decisions and assumptions about neighbourhoods. For example, if one geodemographic classification has only 2 groups, and another 500, providing there are sufficient survey variables to describe a population, it can be assumed that the 500 clusters will more accurately discern a neighbourhood cluster than having just 2 (Leventhal 1995). This was an important consideration in using the MOSAIC Italy data 2007 as it is divided the population into both 12 categories and 47 types.

Likewise, of the variables chosen for the SoVi, some were more discriminating than others in their ability to define a cluster. In assessing these variables it was therefore necessary to run statistical tests that allowed for a comparative study. This involved making calculations on the index variation range, Pearson correlation coefficients, Lorenz curves, and Gini-coefficients of each MOSAIC variable.

2.3 Variation in Indices

The index range of a variable is a good measure of the spread of data among a population. It gives an indication of how varied survey variables are between clusters. This was used to gain an understanding of how well defined cluster neighbourhoods were in both the 12 and 47 cluster groups. The larger the index variation, the more discriminating a variable is.

Index Range = $_{Max}$ Index Value$_x$ – $_{Min}$ Index Value$_x$

Index range (Leventhal 1995)

As the equation above demonstrates, where $_x$ is the chosen variable, the range is measured by deducting the maximum index value from the minimum index value. *Figure 1* shows the comparison of all 223 variables for both 12 and 47 cluster profiles.

The separation in the two lines show that there is greater variation in the 47 MOSAIC types than there is in the 12 categories.

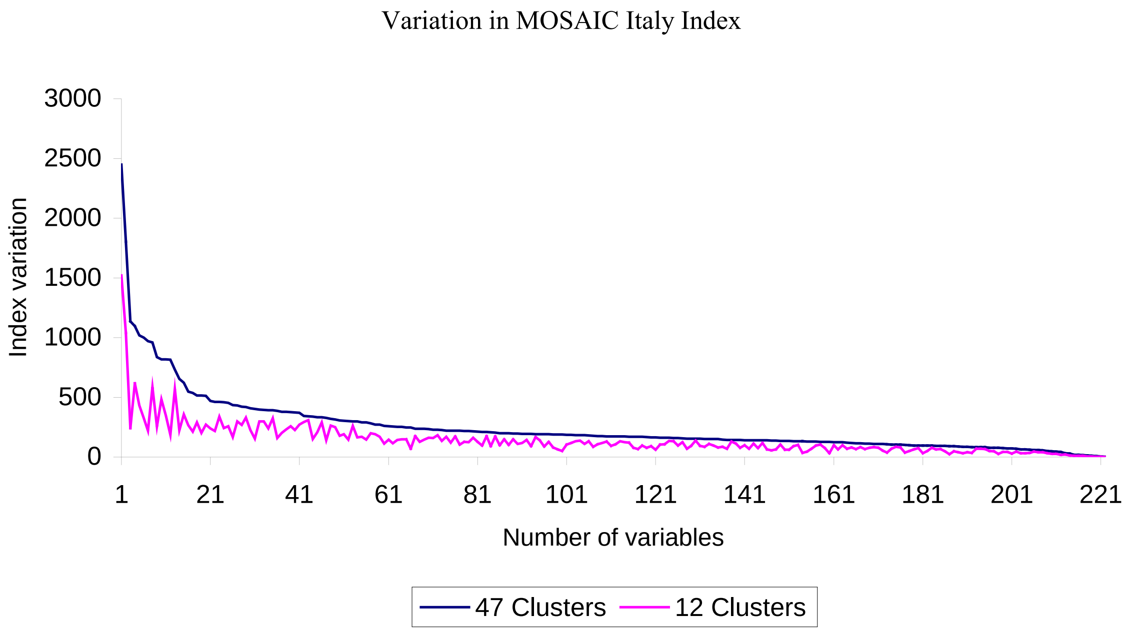


Figure 1: Index Variation, Mosaic Italy 2007

2.4 Lorenz curves and Gini coefficients

Lorenz curves are a cumulative distribution function more commonly associated with macroeconomics. Developed by Max O. Lorenz in 1905 they were originally designed to show inequality and wealth distribution among populations (Gastwirth 1972). They can also provide a graphical representation of geodemographic discrimination as they highlight how variable data is skewed amongst a cumulative population.

With application to MOSAIC Italy data, discriminatory differences can be brought out by analysing population distribution using Lorenz curves for each variable.

Figure 2 shows the data skew within the distribution of residents over 65 years old within the 50km analysis zone population. Essentially, this graph informs that some MOSAIC categories have higher proportions of over 65 residents than other MOSAIC clusters.

The area between the hypothesised 'line of equality' and the 'actual' cumulative distribution observed is known as the Gini Coefficient. This area provides a quantitative measurement of this discrimination within a population. This figure can be calculated from either direct measurement off a Lorenz curve or from tabular calculation.

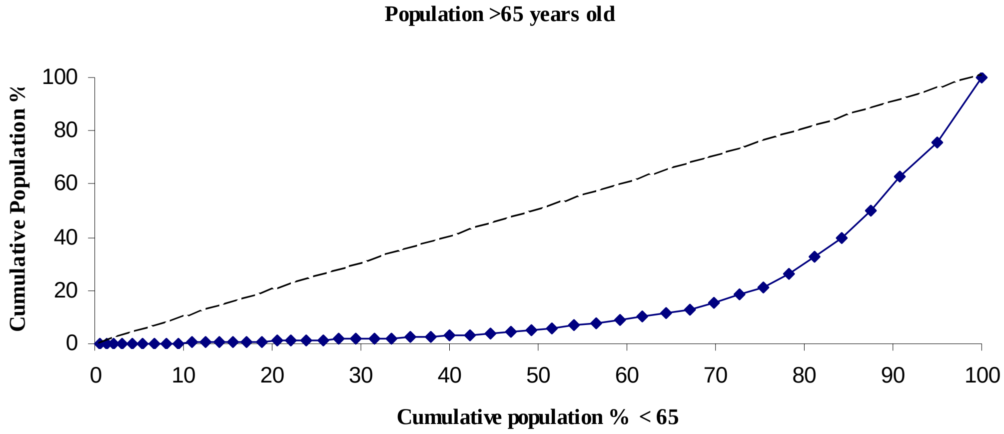


Figure 2: Lorenz curve, Population >65 years old (Mosaic Italy 2007)

Gini coefficients were calculated for each of the 24 variables. These values can only range from 0-1 and are independent of whether the final value is positive/negative. If the coefficient is closer to 0 than 1, the more evenly distributed the variable. If the figure is closer to 1, there is a more unequal distribution of a variable.

The results indicated (*Table 3*) that the most unequal distributions of data included the following variables; *Divorce, Buildings with 3-10 flats* and *Houses without water/toilet*.
This shows there are neighbourhoods where these factors are far more prevalent than others.

Variables	Gini Coefficient (47)	Variable weighting
Divorced	-0.208	0.208
Age <5	-0.029	0.029
Age >65	-0.066	0.066
Daily movement (inside Comune)	-0.109	0.109
Buildings with 3-10 flats	-0.108	0.108
Buildings with more than 10 flats	-0.336	0.336
Population Density	-0.163	0.163
Illiterate	0.096	0.096
Unemployed workforce	0.001	0.001
Retired	-0.051	0.051
Rented house	-0.096	0.096
Loan (2006)	-0.058	0.058
% Without reinforced concrete	0.029	0.029
Buildings Built before 1919	-0.013	0.013
Buildings Built between 1919-1945	-0.032	0.032
Buildings with >4 floors	-0.305	0.305
Multiple flat appartments	-0.108	0.108
Foreigners from Africa	-0.028	0.028
Foreigners from Asia	-0.276	0.276
Origin Pakistan	-0.118	0.118
Origin Black African	-0.072	0.072
Origin Bangladesh	-0.131	0.131
Origin Black Caribbean	0.056	0.056
House without water or toilet	0.346	0.346

Table 3: Gini-coefficient and variable weighting

2.5 Correlations (Evacuation, Financial recovery, Access to resources)

The last statistical test involved correlating all variables with each other to ascertain their inter-dependencies and reduce data redundancy within a risk category. This was undertaken using the SPSS statistical software package by comparing the covariance of two variables divided by the product of their standard deviations. This calculation is known as the Pearson's product-moment coefficient.

Correlation coefficients vary between -1 and 1. The closer a value is to 1 or -1, the greater the linear correlation between the variables.

Variables	% Separated	% Widowed	% Divorced	% Age <5	% Age >65	% Daily movement (inside Comune)	% Buildings with 3-10 flats	% Buildings with more than 10 flats	People per Household	Household Density	Population Density
% Separated		0.260	**0.967**	-0.170	0.180	0.559	0.418	0.616	-0.670	0.579	0.466
% Widowed	0.260		0.375	-0.669	**0.970**	-0.360	-0.070	0.040	-0.752	0.200	0.100
% Divorced	**0.967**	0.375		-0.280	0.318	0.526	0.367	0.585	-0.753	0.568	0.435
% Age <5	-0.170	-0.669	-0.280		-0.682	0.210	0.230	-0.130	0.485	-0.130	-0.060
% Age >65	0.180	**0.970**	0.318	-0.682		-0.346	-0.140	0.010	-0.745	0.160	0.050
% Daily movement (inside Comune)	0.559	-0.360	0.526	0.210	-0.346		0.407	0.715	-0.030	0.601	0.593
% Buildings with 3-10 flats	0.418	-0.070	0.367	0.230	-0.140	0.407		0.130	-0.130	0.210	0.230
% Buildings with more than 10 flats	0.616	0.040	0.585	-0.130	0.010	0.715	0.130		-0.220	**0.847**	0.844
People per Household	-0.670	-0.752	-0.753	0.485	-0.745	-0.030	-0.130	-0.220		-0.356	-0.190
Household Density	0.579	0.200	0.568	-0.130	0.160	0.601	0.210	**0.847**	-0.356		**0.978**
Population Density	0.466	0.100	0.435	-0.060	0.050	0.593	0.230	0.844	-0.190	**0.978**	

Table 4: Evacuation variable R^2 correlations

Table 4 shows the correlations between variables that would increase a household's vulnerability during disaster evacuation. Several of these initial variables were taken out of the SoVi because their correlation was too great. This would have resulted in data redundancy and effectively duplication within the SoVi.

The variables with particularly high correlation are highlighted in *Table 4* in bold. These included the following:

Population density - Household density (0.978)
Divorced – Separated (0.967)
Over 65 - Widowed (0.970)
Household density – Buildings with more than 10 flats (0.847)

Decisions had to be made regarding which of the variables to remove from the index. It was therefore necessary to compare each variable to see their relative inter-dependencies and correlations in a vulnerability subset.

This resulted in the *Household density, Separated,* and *Widowed* variables being removed from the index. There was no requirement to have both *Separated* and *Divorced* variables as this was effectively data duplication with both variables showing very similar geodemographic alignment. Likewise, *Household density* was not considered necessary when there was already a *Population density* variable.

2.6 Re-classify variables
Table 5 shows the revised evacuation variables after this analysis.

Variables	% Divorced	% Age <5	% Age >65	% Daily movement (inside Comune)	% Buildings with 3-10 flats	% Buildings with more than 10 flats	Population Density
% Divorced		-0.280	0.318	0.526	0.367	0.585	0.435
% Age <5	-0.280		-0.682	0.210	0.230	-0.130	-0.060
% Age >65	0.318	-0.682		-0.346	-0.140	0.010	0.050
% Daily movement (inside Comune)	0.526	0.210	-0.346		0.407	0.715	0.593
% Buildings with 3-10 flats	0.367	0.230	-0.140	0.407		0.130	0.230
% Buildings with more than 10 flats	0.585	-0.130	0.010	0.715	0.130		0.844
Population Density	0.435	-0.060	0.050	0.593	0.230	0.844	

Table 5: Revised Evacuation variable R^2 correlations

2.7 Geophysical risk
In considering the spatial extent of the two main geophysical hazards it was necessary to use numerical modelling simulations to predict these boundary extents.

Tephra Fall
Ash fall from a Volcano can be devastating in terms of both loss of life as well as the destruction of rich agricultural areas and transportation networks. Although indirect consequences of tephra fall include flash floods of mud (lahars) and the potential plume hazard they cause to airplane routes, it is ash loading on houses that is regarded in this study as the greatest threat to households around Vesuvius.

Using Tephra 2 (Bonadonna et al 2005), a numerical modelling package that simulates the accumulation of sedimentation across a spatial area, isopach maps were created to quantify this distribution. *Tephra 2*, an advection-diffusion model (Bonadonna et al 2005) takes into account the grain size-dependent diffusion of ash fall in a stratified atmosphere as the volcanic plume rises and deposits erupted material. The user must define all input parameters such as particle sizes, eruption size, wind characteristics and a geographical output grid. Isopach maps can then be created based on the output text file of this model.

Input parameters used for this model were based on a large Sub-Plinian eruption hypothesised by (Macedonio et al 2000) for a likely eruption of Vesuvius.

Input parameter	Quantity
Plume height (m)	27000
Eruption mass (Kg)	9×10^{12}
Maximum grain size (phi units)	-5
Minimum grain size (phi units)	5
Median grain size (phi units)	1
Standard grain size (phi units)	1.5
Vent Elevation (m)	1281
Eddy constant (m2/s)	0.04
Diffusion coefficient (m2/s)	20
Fall time threshold (s)	288
Lithic density (Kg/m^2)	2500
Pumice density (Kg/m^2)	1000
Column steps	100
Plume ratio (of total plume height)	0.2

Table 6: Input parameters, Tephra 2 (based on Macedonio)

One of the crucial parameters that any tephra model must be completely transparent about is the subjective choice of wind direction. This input essentially dictates the spatial orientation of the heaviest ash loading around the volcanic vent but can also be the most unpredictable. Due to most locations having a varied wind field, the choice of picking one direction for modelling can be understood to be a predicted estimate rather than any guarantee.

Therefore, studying the wind field breakdown of the Vesuvius area for a given year, the choice of prevailing wind on the day of the eruption was estimated to be North North East (322°). Over the course of a year, 18.6% of the prevailing wind emanated from this direction (Bonadonna 2005).

Once initial results were output, it was then necessary to establish those areas that were most at risk of building collapse. Based on work by (Pareschi 1999), a threshold of 300-400 kg/m^2 was assumed to represent the demarcation of those areas at highest risk of building collapse.

Pyroclastic flow

Pyroclastic flows are one of the most deadly forces of nature and perhaps the most characteristic of large volcanic eruptions. The Pompeii eruption of AD75 is still the most infamous pyroclastic event in history as thousands of Neopolitans died from asphyxiation and subsequent burial. This was the result of superheated gravity flows of hot ash that swept down to coastal towns through systematic column collapse of Vesuvius. Unlike lava inundation, pyroclastic flows can travel at over 100km/hr and may reach distal towns in a matter of minutes.

The area designated as being at the highest risk from PDC in this study was based on a transient 3D flow model by Eposti Ongaro (2008). This takes into account the topography of the land around Vesuvius to simulate total column collapse during a Sub-Plinian eruption. Propagation maps of the PDC's 800 seconds after column collapse were the basis for the pyroclastic flow boundary used in this analysis.

Evacuation

The evacuation regions for the Georisk Index were based on the official Civil Protection plans for the area around Vesuvius (DPC 2005). This included the Blue, Red and Yellow zones that corresponded to a given level of risk. Red is deemed the highest risk area and evacuation from this region is of priority in the event of an imminent eruption. The Blue zone is the next highest risk area and the Yellow zone the area of likely tephra fall around the volcano.

2.8 A new method for calculating Social Vulnerability Indices

It is believed this method has not been used previously and would be an authentic contribution. In this model, there are essentially 3 levels of vulnerability assigned to each census output region around Vesuvius.

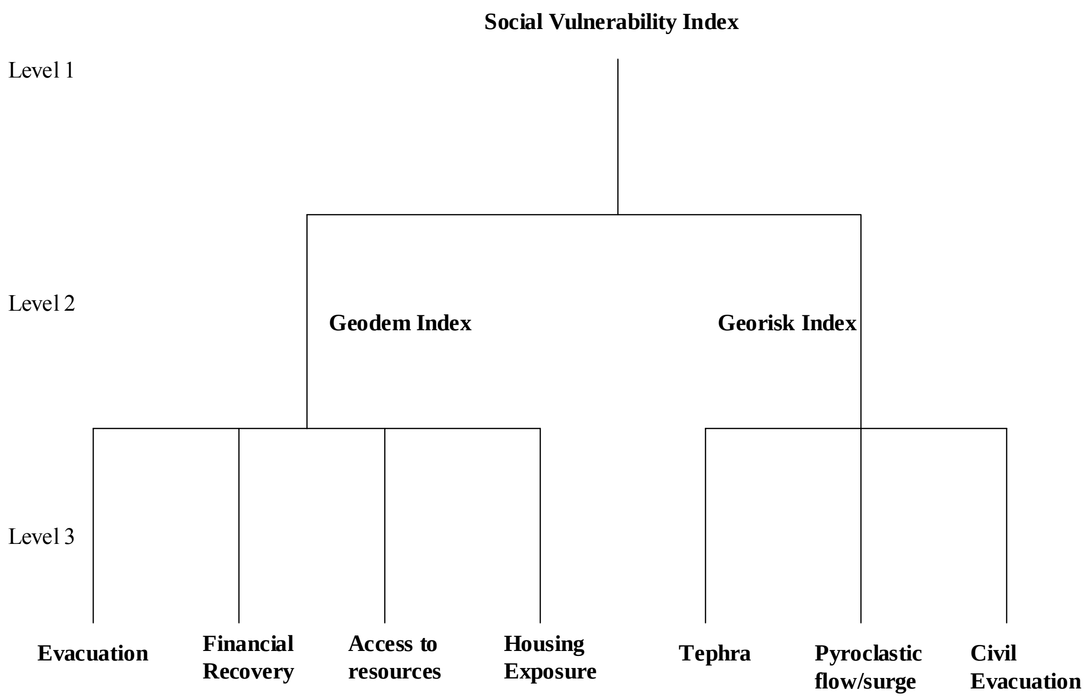


Figure 3: SoVi hierarchy

Level 3: These are the individual social vulnerability scores for each household for the following social and physical risks; *Evacuation, Financial recovery, Access to resources, Building exposure, Tephra fallout, Pyroclastic surges and Civil Evacuation (according to the 1995 DCP plans).*

Level 2: These index scores are created as a composite of the respective social and physical risk scores.

Level 1: The overall SoVi is calculated as an index from all physical and social variables in level 1.

To factor in a level of weighting in this methodology, Gini-coefficients were used for each MOSAIC variable. The main reason for this was to factor in the level of discriminatory weighting. Therefore, those variables with Gini coefficients closer to 0 were given less weighting in the overall vulnerability score.

The following four equations describe how the index scores were calculated as a metric for each variable ($_x$). These were then combined for all social factors to create the *Geodem Index*.

1. Weighted variable $_{x}$ = ([1]Gini-coefficient $_{x}$)* (MOSAIC Index Value $_{x}$)
2. $\sum$ (Weighted variable $_{xn}$) = Vulnerability score $_{x\ (\text{Area of social vulnerability})}$
3. Total Social Vulnerability$_x$ =$\sum$ (Vulnerability scores$_x$) ($_{\text{Evacuation, Financial recovery, Access to resources, Building exposure}}$)
4. Geodem Index = Total Social Vulnerability$_x$ / Total Social Vulnerability $_{\text{MeanAverage}}$ * 100

In order to calculate the overall SoVi, it was necessary to first calculate risk ranks for areas subject to Tephra, Pyroclastic surges and the Civil Evacuation around the volcano. For simplicity with regards to the index model, a numeric risk number between 0-3 was assigned for each Census area and for each hazard (3=high risk, 0=Very low/no risk). These values were then multiplied by a factor of 10 and accumulated to provide a *Georisk Index*.

The final SoVi score was deduced from all social and physical scores as an index.

Social Vulnerability Index$_x$ =$\sum$ (Social & Physical vulnerability scores$_x$) ($_{\text{Evacuation, Financial recovery, Access to resources, Building exposure, Tephra, Pyroclastic surge, Civil Evacuation areas}}$)

3.0 Results

Social Vulnerability maps

Access to resources:
The displacement of vulnerability for a community to access resources during a disaster shows a strong relationship to rurality. *Figure 4 a)* highlights this spatial relationship as the higher vulnerability scores show the areas most at risk. These census areas are geographically focused on the periphery of the analysis region in largely rural census areas. Conversely, the urban areas, found around the city of Naples are (displayed here in dark green), show a lower level risk. This variation suggests urban areas have higher levels of those factors likely to increase a household's access to resource during the onset of a natural disaster.

In terms of the most vulnerable MOSAIC groups for inadequate access to resources, the profiles over-represented in this category came from the *Large Farmhouses* MOSAIC category. Types 47 and 46 were among the highest ranking areas for this category, which correspond to *Very remote self employed farmers* and *Large farms in very low density areas*.

The lowest social risk categories were largely formed from the *Wealthy Elite* group. The census regions assigned to this group are located in the highly urban areas, normally in city centre apartments and the prosperous suburbs around Naples.

Evacuation:
In perfect contrast to an individual's access to resources, the risk of evacuation to communities is found to be highest in urban areas and the least in distant rural regions.

As seen in *Figure 4 b),* the highest ranking areas to disaster evacuation are found principally in and around the city of Naples as well as other minor conurbations scattered around the Mt Vesuvius area. This included the towns of Caserta, Avelino, Atripalda, Mercato San Severino, Salerno, and Benevento.

The MOSAIC profile of these high risk areas to evacuation are inextricably linked to the defining variables of evacuation, as defined earlier in the study. i.e. demographic age, household composition and population density. Therefore, older people living in city centre apartments are defined as the most vulnerable neighbourhood group with regards to the stresses of evacuation. The MOSAIC Italy classifications *Eldery Households* and *Urban Apartments* are the main categories, with types 8, 7, 13 and 12 among the highest ranking within this group.
The lowest scoring classifications for evacuation risk were *Large Farmhouses* and *Rural low income*.

Financial Recovery:
The defining characteristic of those areas worst affected in financial terms from an eruption would be those profiles of particularly low income. The spatial distribution of less affluent areas around the Volcano has a mixed pattern. These areas of higher risk are found in both urban town centres as well as rural isolation. In fact, the only common denominator is low income, as other characteristics such as age and ethnicity are not really taken into account.

The MOSAIC Italy profiles over exposed to risk of financial recovery are *Low status apartments* and *Rural low income.* This explains the mixed geographic distribution of financial risk in *Figure 4 c)* as these categories have an inverse spatial pattern with regards to urban proximity.

Geodem Index:
The combination of the previously mentioned social risks during an eruption (Access to resource, Evacuation, Financial Recovery and Household risk to Tephra/Volcano) creates a polarised pattern of social vulnerability across the Neopolitan area.

Pockets of highly populated urban areas are deemed equally as vulnerable as low-income rural regions. This pattern is reflecting the spatial conflict of the various geodemographic profiles making up each risk category. For example, though a lack of resource is defined as a rural characteristic, in the Geodem Index, urban areas exposed to problems during evacuation are given equal weighting. Add to this the mixed distribution of financial recovery and the overall geographical pattern is polarised, with both highly urban and highly rural areas being those deemed equally at risk.

However, as noted in the MOSAIC Italy profile of the overall Geodem Index, the commonalities of the worst hit areas are age and wealth. Elderly households that are financially less secure are the main areas of risk in the Geodem Index. This is reflected in the MOSAIC sub groups of both *Eldery Households* and *Urban apartments* that constitute highest-ranking areas.

Georisk Index:
Figures 5 a) - e) show the physical risk maps for civil evacuation priority areas, pyroclastic flow inundation and Volcanic ash fall loading. Using GIS overlays of each of these maps, *Figure 5 e)* is the culmination of these boundaries assigned to census areas and given an overall physical risk weighting.

The highest risk areas defined from this analysis were directly southeast of the Volcano. In the event of a Sub-Plinian eruption, with tephra fall largely to the East of the cone and pyroclastic flow south of Vesuvius, this region would be hit by a combination of these geophysical hazards.

The areas within the analysis region that would likely to be least impacted by these hazards are predominantly found directly North of the Volcano; a region that is topographically less susceptible to column collapse and tephra fall.

SoVi:
Having combined the physical risks associated with the onset of a volcanic eruption, the civil evacuation of regions and the social vulnerability of households, an overall vulnerability classification (SoVi) was assigned to each Census region. In *Figure 6 a),* the physical risks of an eruption (tephra, pyroclastic flow) largely dominate the overall vulnerability weighting to the analysis region. This can

be seen by the geographical patterns of high index scores (140-200) immediately to the South of the volcano and following the estimated ash fall dispersal directly to the East of the Mt Vesuvius summit.

Looking more closely at the high risk areas on the flanks of Vesuvius the social vulnerability factors start to become more apparent. Within a 5-mile radius of the Volcano we see the areas most at risk from Vesuvius. These consist of highly populated coastal towns along this stretch of the Campania region, including Torre del Greco, Percolator, San Giorgio a Cremano and Portici. Not only are these town exposed to substantial volcanogenic hazards, but they are extremely vulnerable to the social consequences of a volcanic eruption. They largely consist of communities with elderly, low-income households in areas of high population density.

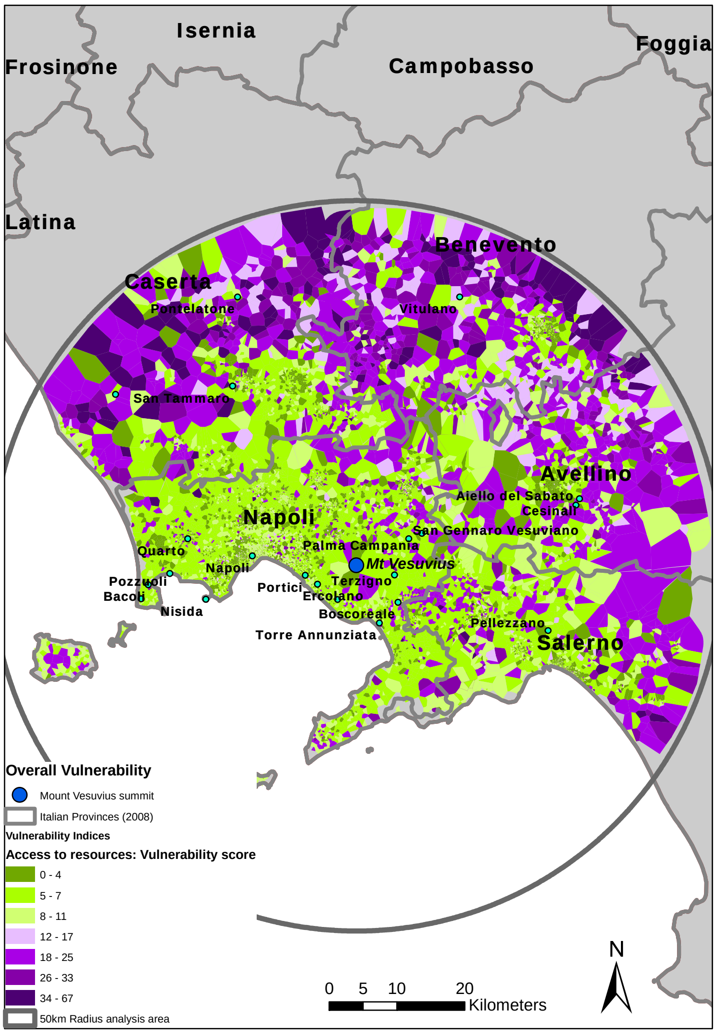


Figure 4 a)

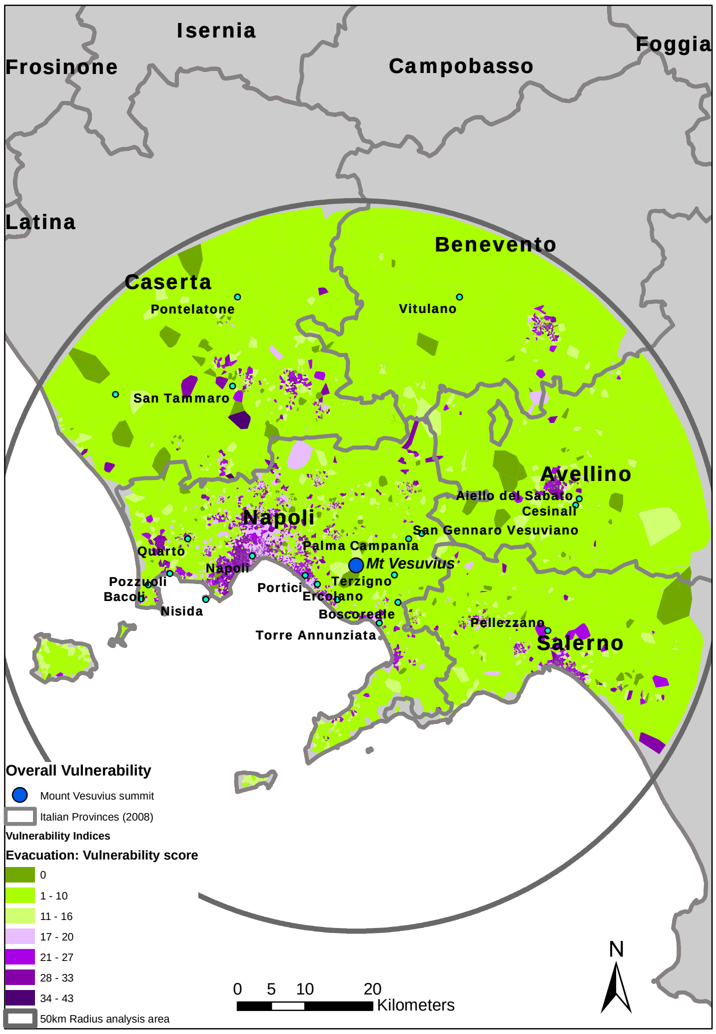


Figure 4 b)

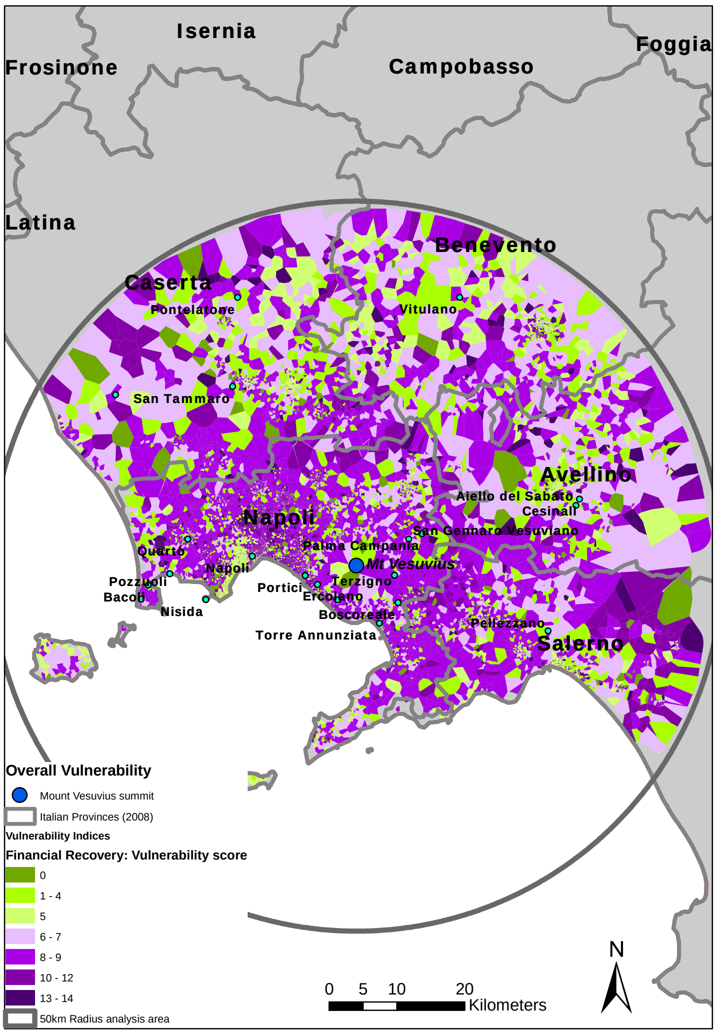


Figure 4 c)

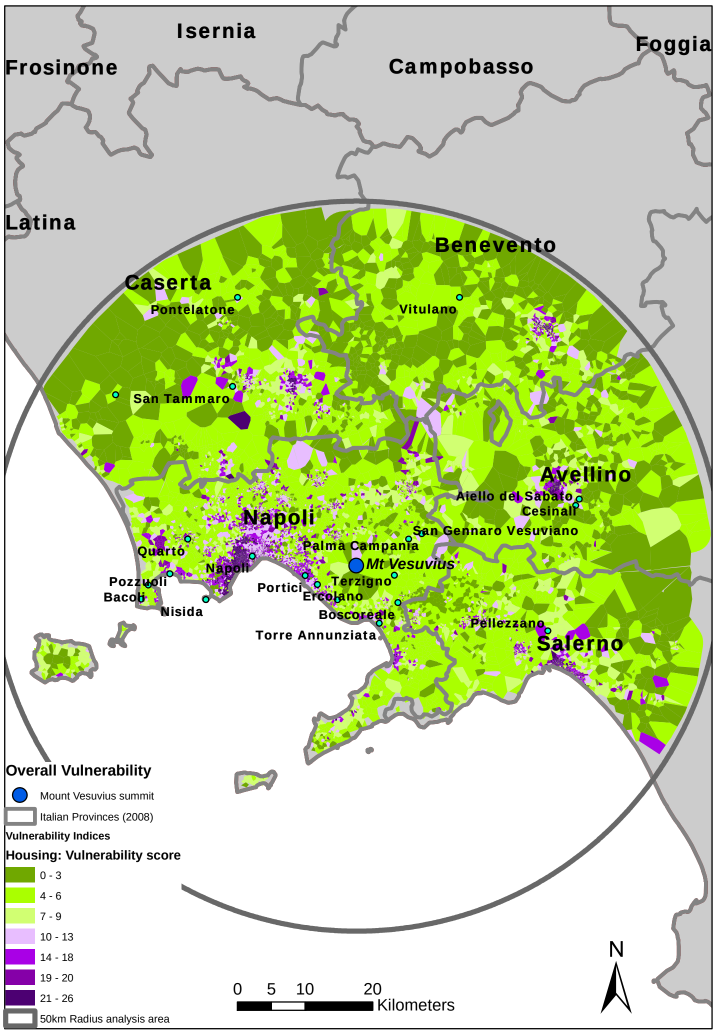


Figure 4 d)

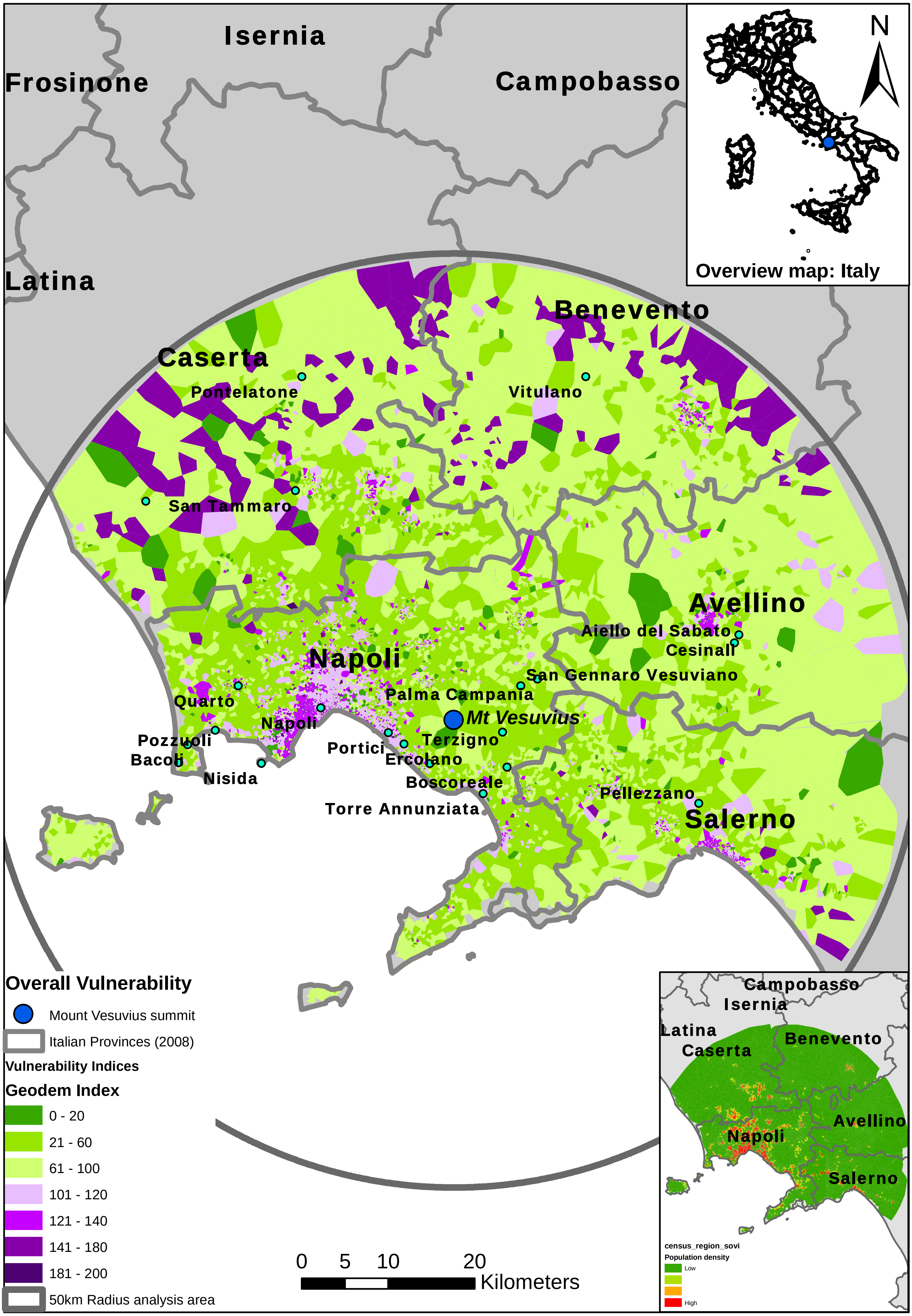

Isernia
Frosinone
Campobasso
Latina
Caserta
Benevento
Pontelatone
Vitulano
San Tammaro
Avellino
Aiello del Sabato
Cesinali
Napoli
San Gennaro Vesuviano
Palma Campania
Quarto
Mt Vesuvius
Napoli
Pozzuoli
Bacoli
Portici
Terzigno
Ercolano
Nisida
Boscoreale
Pellezzano
Torre Annunziata
Salerno
N
Overview map: Italy
Overall Vulnerability
Mount Vesuvius summit
Italian Provinces (2008)
Vulnerability Indices
Geodem Index
0 - 20
21 - 60
61 - 100
101 - 120
121 - 140
141 - 180
181 - 200
50km Radius analysis area
0 5 10 20
Kilometers
Campobasso
Isernia
Latina
Caserta
Benevento
Avellino
Napoli
Salerno
census_region_sovi
Population density
Low
High

Figure 4 e)

Figure 5 a)

Figure 5 b)

Figure 5 c)

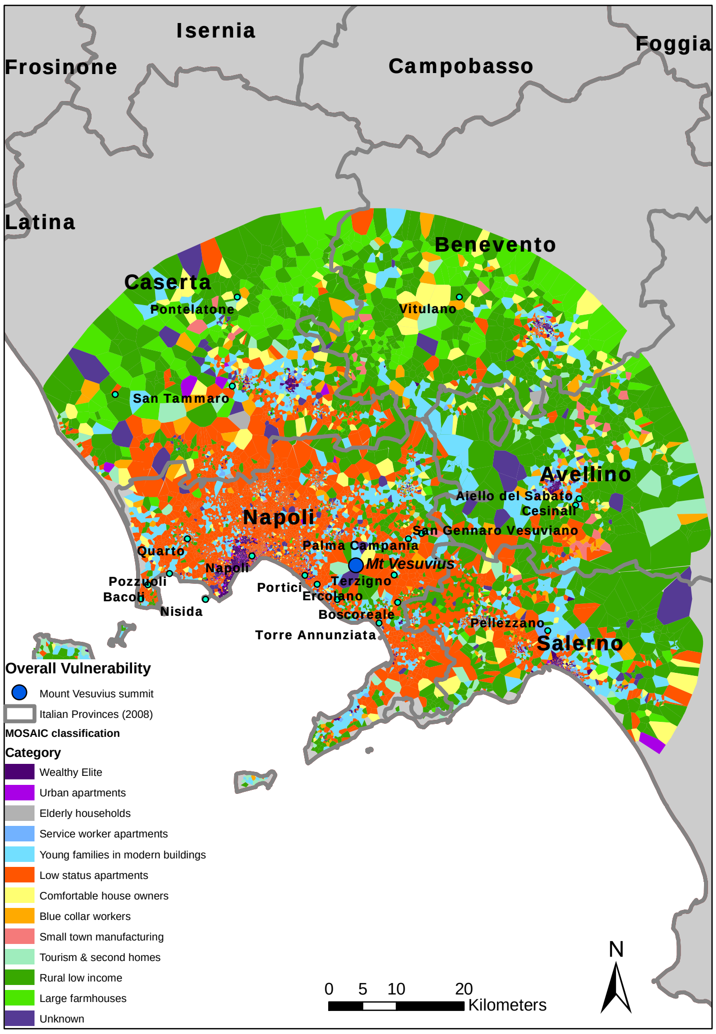


Figure 5 d)

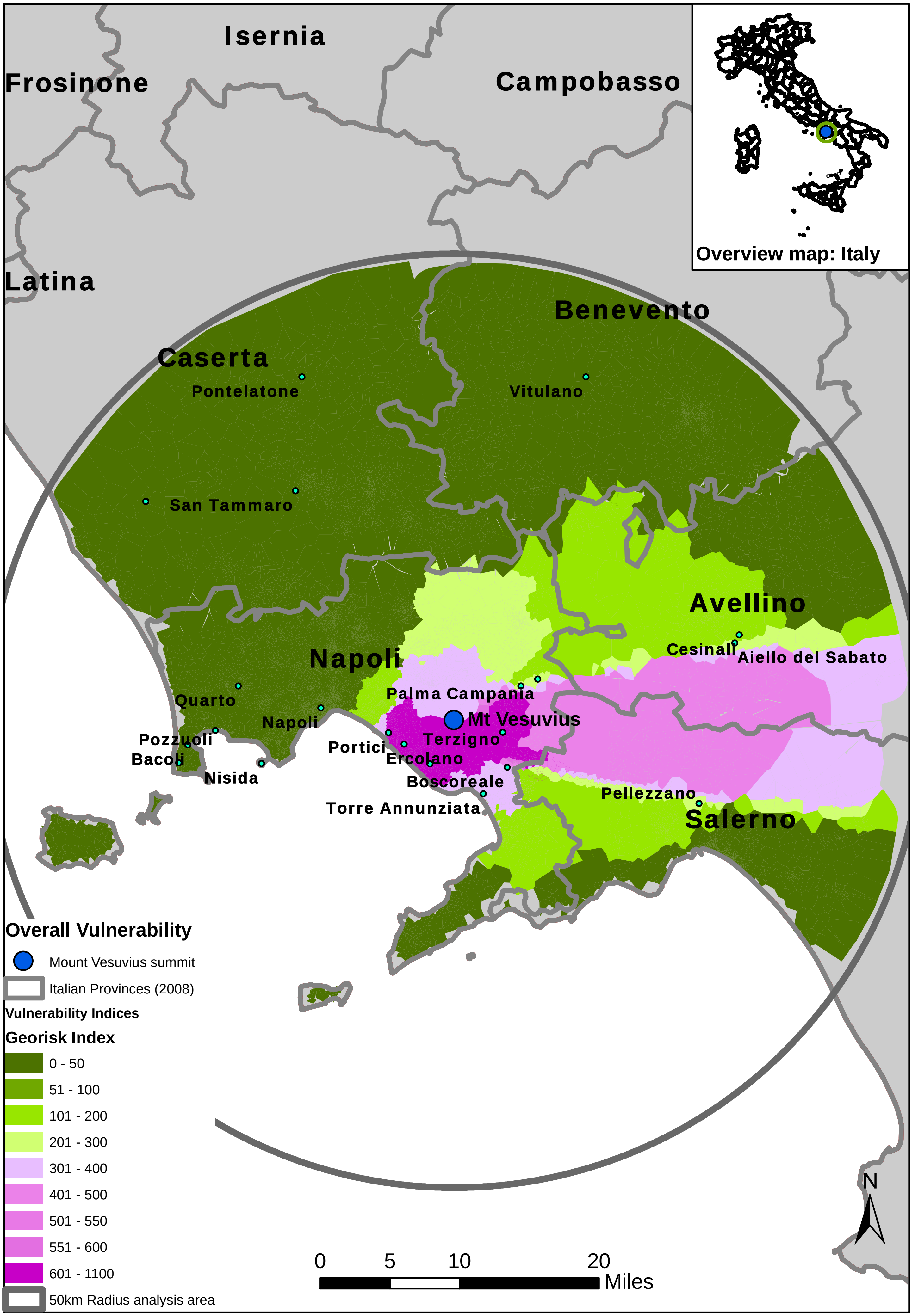

Isernia
Frosinone
Campobasso
Latina
Benevento
Caserta
Pontelatone
Vitulano
San Tammaro
Avellino
Napoli
Cesinali
Aiello del Sabato
Palma Campania
Quarto
Napoli
Mt Vesuvius
Pozzuoli
Terzigno
Portici
Bacoli
Ercolano
Nisida
Boscoreale
Pellezzano
Torre Annunziata
Salerno
Overview map: Italy
Overall Vulnerability
Mount Vesuvius summit
Italian Provinces (2008)
Vulnerability Indices
Georisk Index
0 - 50
51 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 550
551 - 600
601 - 1100
50km Radius analysis area
0
5
10
20
Miles
N

Figure 5 e)

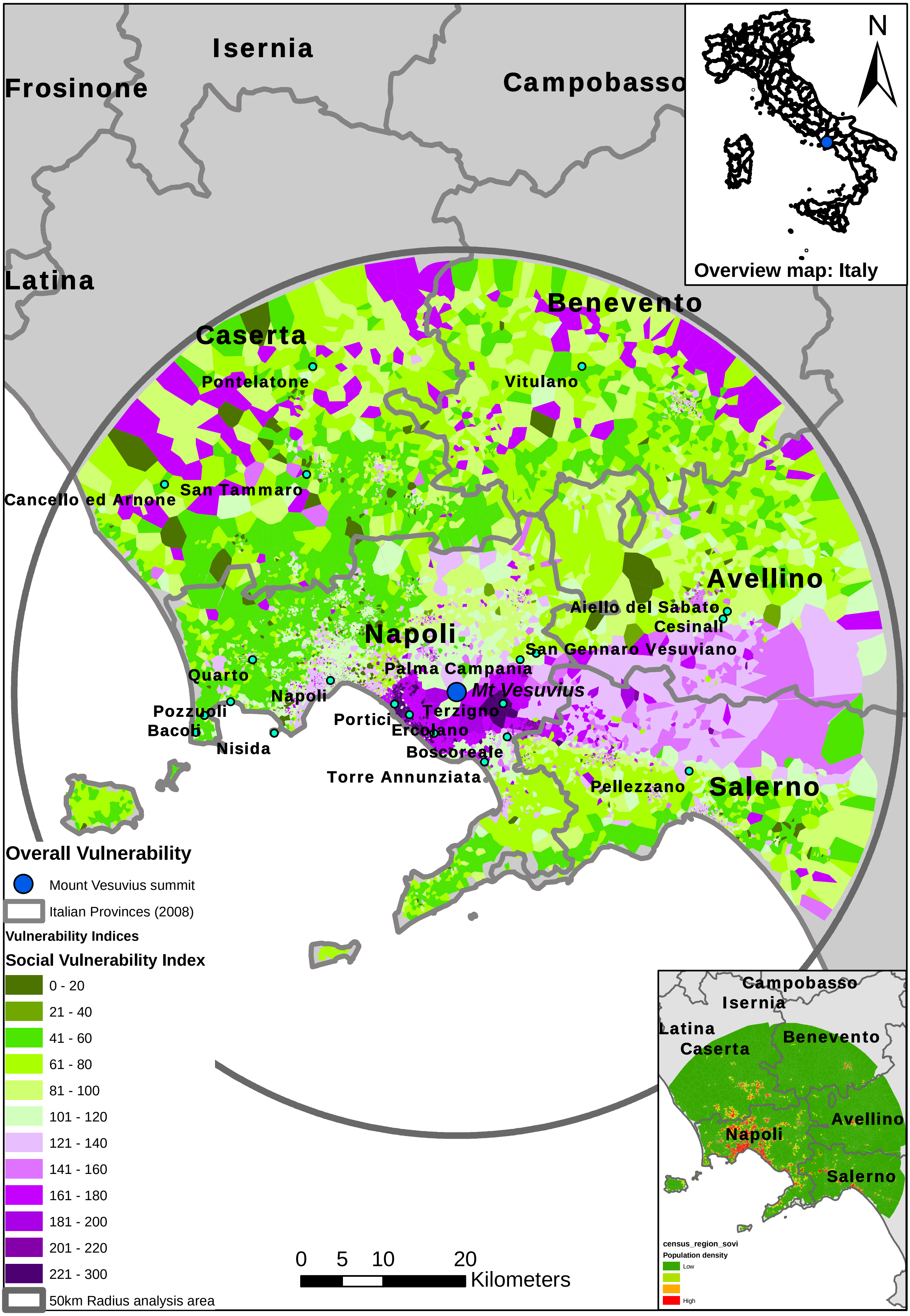
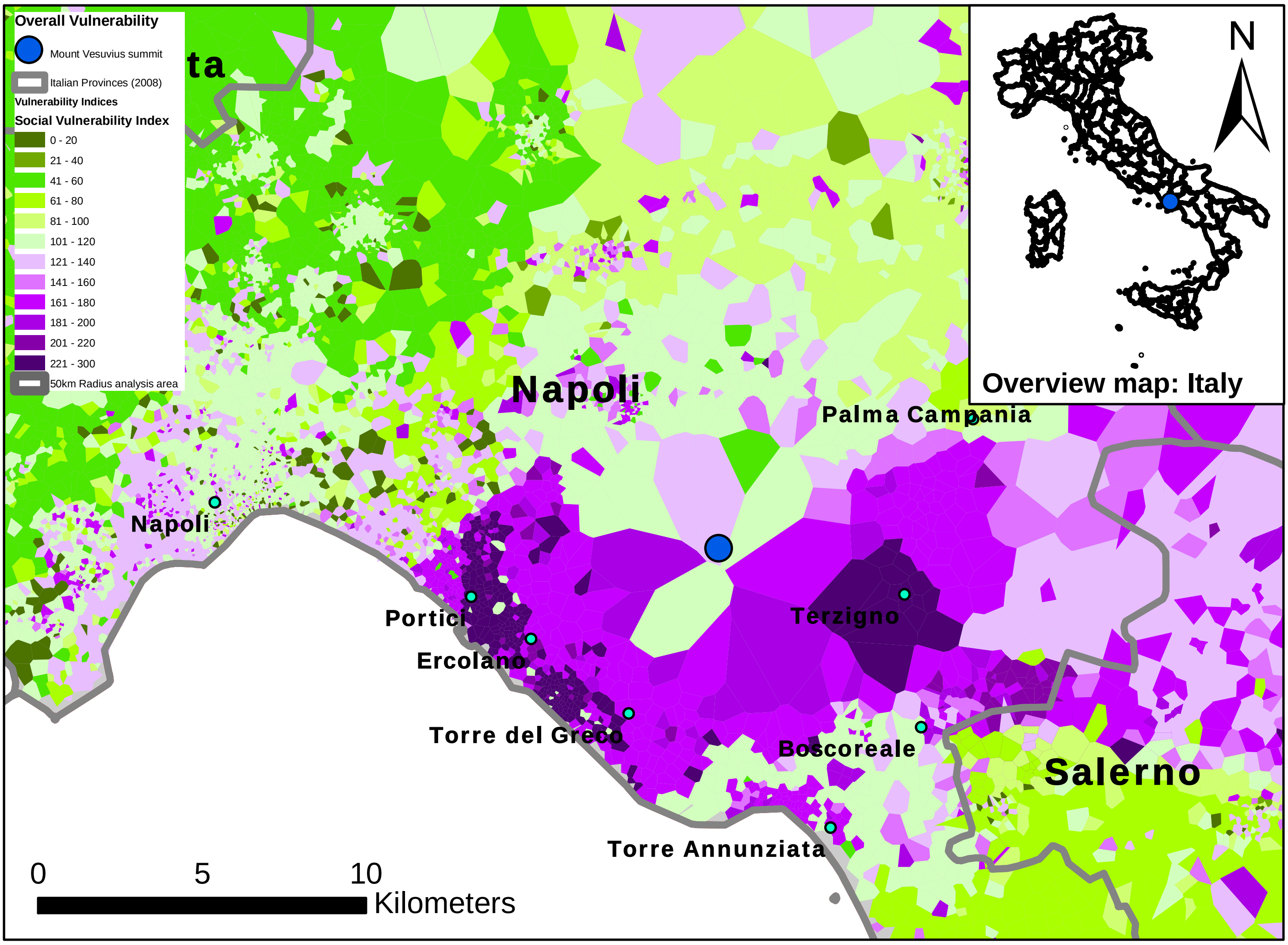

Isernia
Frosinone
Campobasso
Latina
Benevento
Caserta
Pontelatone
Vitulano
Cancello ed Arnone
San Tammaro
Avellino
Aiello del Sabato
Cesinali
Napoli
San Gennaro Vesuviano
Palma Campania
Quarto
Mt Vesuvius
Napoli
Terzigno
Pozzuoli
Portici
Bacoli
Ercolano
Nisida
Boscoreale
Torre Annunziata
Pellezzano
Salerno
Overview map: Italy
N
Overall Vulnerability
Mount Vesuvius summit
Italian Provinces (2008)
Vulnerability Indices
Social Vulnerability Index
0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181 - 200
201 - 220
221 - 300
50km Radius analysis area
0 5 10 20
Kilometers
Campobasso
Isernia
Latina
Caserta
Benevento
Avellino
Napoli
Salerno
census_region_sovi
Population density
Low
High

Figure 6 a)



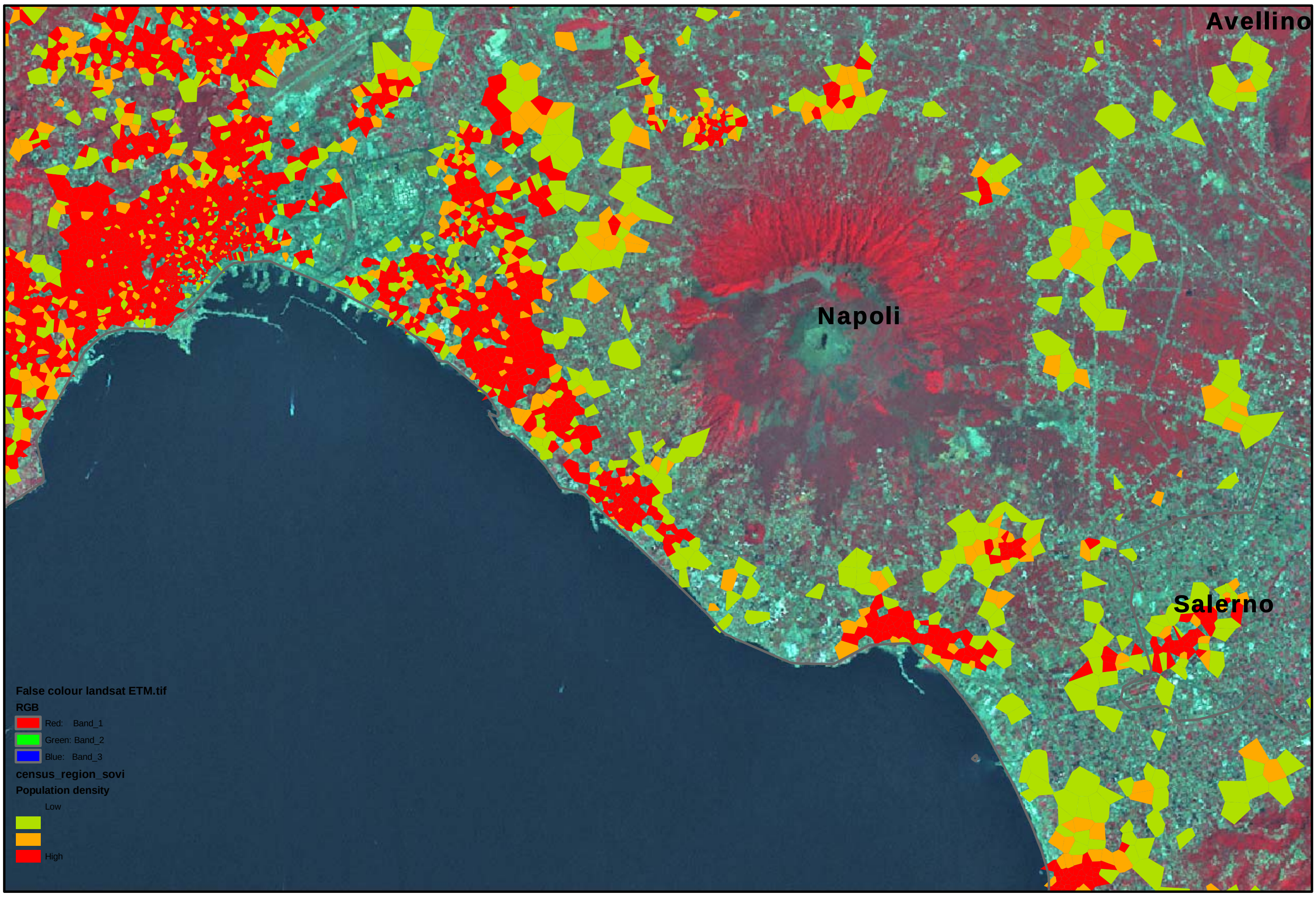


Figure 6 b) *above* c) *below*

Summary and Future considerations

From 1901 to 2001, the city of Naples urban area grew from 621,000 people to over 1 million (ISTAT 2009). With a volcano of Vesuvius' potential in the midst of this region, there is no doubt that an eruption of Sub-Plinian magnitude would be catastrophic to the region.

Coastal areas in the Napoli province are some of the most densely populated in Europe. They are also the areas identified from this research as those impacted the hardest from an eruption, both socio-economically and in geophysical terms. The consequences would be far reaching and varied with particularly vulnerable neighbourhoods identified from this study. This could include significant loss of life, agricultural land, housing stock and serious economic hardships. There is also the risk of post eruption adverse consequences to households such as increased stress, financial deficit, depression and the possibility of increased anti-social behaviour such as looting.

Given these scenarios, it is believed this work holds value in contributing towards both understanding how social vulnerability is spatially orientated as well as proposing a transferable methodology that can be applied for other hazards.

Although commercial geodemographics are fundamentally created for a different purpose, they are constructed from Census data and social survey data that has inherent uses in DRR. The vulnerabilities of certain social groups in a society can be measured using MOSAIC data and value can be gained in understanding these patterns in towns and cities.

One of fundamental issues raised in this study regards the inter dependencies of variables to measure social vulnerability. For example, a MOSAIC variable assumed to increase social vulnerability in one SoVi category may also act to negate the risk in another SoVi category.

For example, ethnic minority areas are considered to be more predisposed to risk during a natural disaster (Cutter 2000) due to a lack of politcal access and communication practicalities during a disaster. However, in terms of social statistics, these same areas often form the wealthiest urban clusters in the MOSAIC Italy dataset. This highlights a level of complexity and ambiguity in the data that further study should be mindful to acknowledge.

The use of geodemographics should always be treated with caution to fully understand the limitations and caveats of these classification systems. Misinformation can be even more harmful than a lack of knowledge about an area's social vulnerability. For example, the MOSAIC Italy 2007 data used for this work is nearly 3 years old. Data accuracy has therefore degraded in the years following its original release. Most of the demographic clusters defined in this dataset will have changed in age and socio-economic construction.

Likewise, the data associated with MOSAIC Italy was largely derived from a telemarketing sample, which is unlikely to be wholly representative of the Italian population. Geodemographics are subject to the problems of using aggregated data (such as the Modifiable Areal Unit Problem), whereby the characteristics of a census region will not always reflect the attributed of an individual or household accurately.

Nonetheless, this work does offer a practical and micro-level understanding to social risk that could be widely used. Civil protection agencies and NGO's could use this lower level of granularity for disaster mitigation and management. Community outreach and hazard awareness could be targeted more carefully to those demographic profiles worst affected. Local authority planning and development projects could use these maps to mitigate the spatial variance of risk around a hazardous region. With current Civil Protection plans for Vesuvius considered by 60% of residents in the Red Zone to be inadequate (Barberi 2008), this work could help contribute to a reassessment of evacuation measures.

Using commercial Geodemographics for social vulnerability also provides a level of scalability for other natural or anthropogenic hazards. For example, the methodology used here is not exclusive in its application. It could be used to similar effect studying earthquakes or applied to a country experiencing severe food shortages. Social vulnerability variables such as gender, age, and ethnicity are universal important to food entitlement as they are to natural disasters.

A paradox about volcanoes is the fact that they provide nutrient-rich soils highly sought after for farming and cultivation whilst also being one of nature's deadliest phenomena. It is no coincidence that 9% of the world's population is estimated to live within 100km of historically active volcanoes (Small et al 2001). The high altitude slopes and fertile soils have for centuries provided a rich agricultural base for human population. However, it's an unfortunate irony that many areas of the world where volcanoes are most prevalent are also the areas least adept to mitigate their hazards (Macdonald 1972).

With regard to the population living around Vesuvius, future considerations worth exploring further could be the economic and cultural drivers that have led people to live in this region historically. It has also been acknowledged in recent years that Naples has had a falling population since 2000 (circa 4%, Eurostat 2010).

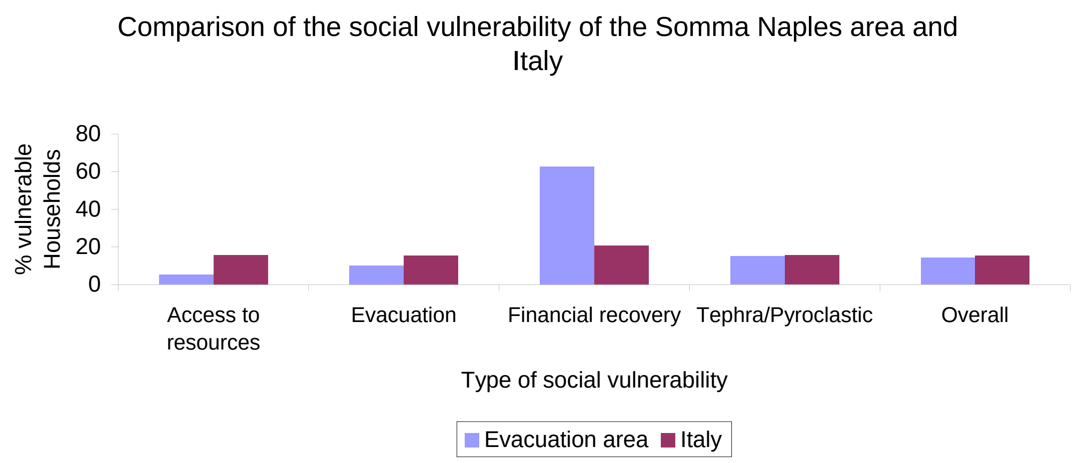


Figure 7: Comparison of social risks to national averages

Other factors worth considering are whether house prices or social marginalisation have been catalysts for previous urbanisation to the Napoli province.

Figure 7 provides a comparison of the geodemographic populations of both the 50km analysis zone and the Italian national average. It shows that the evacuation zone is nearly three times more vulnerable in terms of financial recovery, but overall social vulnerability is very nearly equal to the national average. This suggests that in terms of overall social vulnerability, the area around Vesuvius is no more disadvantaged in terms of social vulnerability than the nation as a whole.

Though geodemographics cannot provide a panacea solution to the complexity of DRR, it certainly holds value in providing a micro-scale level of assessment to volcanic hazard preparedness, mitigation and hopefully reduction.

Acknowledgements

This work has been carried out with the support of Birkbeck, University of London. Many thanks to Experian for their loan of the MOSAIC Italy 2007 data, without which, this study would not have been possible.

References

Andronico, D., Cioni, R., 2002. Contrasting styles of Mount Vesuvius activity in the period between the Avellino and Pompeii Plinian eruptions, and some implications for assessment of future hazards. Bull. Volcanol. 64, 372–391.

Barberi, F., Davis, M.S., Isaia, R., Nave, R., Ricci, T. (2008). "Volcanic risk perception in the Vesuvius population." Journal of Volcanology and Geothermal Research 172: 244–258.

Burton, I., Kates, R.W. and White, G.F. 1992: The environment as hazard. New York: Oxford University Press

Bonadonna, C., Connor, C.B., Houghton, B.F., Connor, L., Byrne, M., Laing, A., & Hincks, T. Probabilistic modeling of tephra dispersion: hazard assessment of a multi-phase eruption at Tarawera, New Zealand. Journal of Geophysical Research, 110, 2005.

Brown, P.J.B., Hirschfield, A.F.G., Batey, P.W.J. "Adding Value to Census Data: Public Sector Applications of the Super Profiles Geodemographic Typology" Journal of Cities and Regions GIS Special, 2000 - car.busmgt.ulst.ac.uk

Chester, D.K., Degg, M., Duncan, A.M., Guest, J. E., (2001) "The increasing exposure of cities to the effects of volcanic eruptions: a global survey." Global Environmental Change Part B: Environmental Hazards Volume 2, Issue 3, September 2000, Pages 89-103 - Elsevier

Chester, D.K., 1993. Volcanoes and Society. Eduard Arnold, London. 351 pp.

Cioni, R., Bertagnini ,A., Santacroce, R., Andronico, D. (2008). "Explosive activity and eruption scenarios at Somma-Vesuvius (Italy): Towards a new classification scheme." Journal of Volcanology and Geothermal Research 178: 331–346.

Cutter, S. L., J. T. Mitchell, et al. (2000). "Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina." Annals of American Geographers 90(4): 713-737.

Deaton, Angus (1997). Analysis of Household Surveys. Baltimore MD: Johns Hopkins University Press.

DPC, 1995. Pianificazione Nazionale d'Emergenza dell'Area Vesuviana. Dipartimento della Protezione Civile, Roma.

Enarson, E., and Morrow, B. 1998 The Gendered Terrain of Disaster. Praeget: New York.

Esposti Ongaro, T., Neri, A., Menconi, G., de'Michieli Vitturi, M., Marianelli, .P, Cavazzoni, C., and G. Erbacci, Baxter, P.J. (2008). "Transient 3D numerical simulations of column collapse and pyroclastic density current scenarios at Vesuvius." Journal of Volcanology and Geothermal Research 178: 378–396.

Eurostat, European Commission, 2009. Available: http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ (Accessed 15 November 2009)

Experian Mosaic (2009) Index. Available at: http://strategies.experian.co.uk/. (Accessed 15 November 2009)

Gastwirth, Joseph L. (1972). "The Estimation of the Lorenz Curve and Gini Index". The Review of Economics and Statistics 54: 306–316

Hewitt, K. (1983). "Interpretations of calamity from the viewpoint of human ecology." Winchester M.A.

ISTAT. (2001). Istituto Nazionale di Statistica. Available: http://www.istat.it/english/. Last accessed 09/06/2009.

Johnson, J., and Zeigler, D. 1986. Evacuation Planning for Technical Hazards: An Emerging Imperative. Cities 3: 148-156.

Leventhal B (1995). "Evaluation of geodemographic classifications." Journal of targeting, measurement and analysis for marketing. 1995; Volume 4: 173-183.

Lirer, L., Vitelli, L., 1998. Volcanic risk assessment and mapping in the Vesuvian area using GIS. Nat. Hazards 17, 1–15.

Macdonald, G.A., 1972. "Role of science and technology in reducing the impact of volcanic eruptions". In: The Role of Science and Technology in Reducing the Impact of Natural Disasters on Mankind. United Nations, New York, pp. 26–32.

Macedonio, G., Costa, A., Folch, A. "Ash fallout scenarios at Vesuvius: Numerical simulations and implications for hazard assessment." Journal of Volcanology and Geothermal Research 178 (2008) 366–377

McMaster, R.B. and Johnson, J.H., jr, 1887: Assessing community vulnerability to hazardous materials with a geographic information asystem. In Chrisman, N.R., editor, Autocarto 8 Proceedings, Falls Church, VA: American Society for Photogrammetry and American Congress on Surveying and Mapping, 471-80.

National Research Council, http://www.cnr.it/sitocnr/Englishversion/Englishversion.html, 2009

Pareschi, M.T., Cavarra, L., Favalli, M., Giannini, F., and Meriggi, A. (2000) "GIS and Volcanic Risk Management". Journal of Natural Hazards. 2000. Volume 21: 361-379

Pelling, M. (2003). Natural Disasters and Development in a Globalizing World: In a Globalizing World, Routledge, London.

Pulido, L. 2000. "Rethinking Environmental Racism: White Privilege and Urban Development in Southern California." Annals of the Association of American Geographers 90:12–40.

Quarantelli, E.L (1978). " Disasters : theory and research". London ; Beverly Hills,

Small, C., Naumann, T. 2001. "The global distribution of human population and recent volcanism." Environmental Hazards 3 (2001) 93-109

Webber, R.J. (1977): An introduction to the National Classification of Wards and Parishes, Planning Research Applications Group Technical Paper 23, London, Centre for Environmental Studies

Webber, R.J. (1985): “The use of census-derived classifications in the marketing of consumer products in the United Kingdom” Journal of Economic & Social Measurement 13, 113-124.

Webber, R.J. (1989): “Using multiple data sources to build an area classification system: operational problems encountered by MOSAIC” Journal of the Market Research Society 31, 103-9.

Westgate, K.N. and O'Keefe, P. (1976) 'Some definitions of disaster', Occasional Paper 4, Disaster Research Unit, University of Bradford, Bradford.

Wisner, B. (2004). At risk : natural hazards, people's vulnerability, and disasters. London ; New York, Routledge.