*Vulnerability* can be defined as the potential for loss (Cutter et al. 2003). Taking that definition, the wider region around the Etna is a region of a very high vulnerability with a high population, one of the largest cities of Italy, and a lot of industry and infrastructure. The aim of the vulnerability analysis is to take a closer look into the region and analyze which areas have the greatest potential for loss and damage and thus may require special protection.

To assess the vulnerability, the general procedure is to define dimensions, define indicators and find data for each of the dimensions and finally weight the different parameters to get a final vulnerability map (Aceves-Quesada et al. 2007, D'Ercole 1996, El Morjani et al. 2007, Stieltjes & Mirgon 1998, Torrieri et al. 2002). Biass et al. (2012) define vulnerability in five dimensions: 1) social vulnerability, 2) economic vulnerability, 3) environmental vulnerability, 4) physical vulnerability and 5) territorial vulnerability. In **Table X**, different aspects of the dimensions are listed.

|  |  |
| --- | --- |
| Dimensions | Aspects |
| Social vulnerability | Population, education level, demographic situation |
| Economic vulnerability | Industry, occupation |
| Environmental vulnerability | nature reserves, vegetation, forests, ozone holes, |
| Physical vulnerability | Infrastructure, buildings, houses |
| Territorial vulnerability | Infrastructure with key importance to public interest, roads, power lines |

The different dimensions very much vary in the complexity to research on. Most times, a scale to measure does not exist and often, also appropriate data is either not available open source or can only be gathered knowing the region very well or by making surveys. This would go far beyond the scope of this analysis. Nonetheless, we found open source data to evaluate each of the dimensions.  
Every dimension is evaluated on a scale from one (not vulnerable) to five (highly vulnerable) to enable a better comparison between the different data sources. Later on, they are all weighted and summed up to a final vulnerability map with a raster of 20 x 20 m. The whole vulnerability analysis is implemented in a Python script using GRASS GIS which offers many different powerful tools and with Python a way to also create longer scripts while still maintaining a good overview.

The social vulnerability can be estimated using the population, better the population density. Data for the population density is available from ISTAT (Istituto Nazionale di Statistica) and contains the governmental data from Census 2011, e.g. the population density sorted by postal codes. The population density can easily be reclassified using **Table X** to get the vulnerability ranking. Afterwards, the map is converted to the raster format.

|  |  |
| --- | --- |
| Population Density Range [people/km²] | Vulnerability Rating |
| 0 | 1 |
| 1 to 50 | 2 |
| 51 to 500 | 3 |
| 501 to 1000 | 4 |
| 1001 and more | 5 |

The economic vulnerability can hardly be measured or scaled using any open source data. Nonetheless, the landuse classification of OpenStreetMap (OSM) gives an indication for which purpose land is used and thus also where industry is located and which areas are used for agriculture. To assess the vulnerability of an area, the OSM landuse tags are classified with the vulnerability rating (see also **Table X**). “Unused” areas like grass or meadows are rated with the lowest rating followed by parks and recreation grounds—areas, that are more a matter of comfort than necessary for life. The next higher ranking are farms and vineyards that are economical relevant, but rather for individuals. Industry and military areas are important for a much larger group of people and thus rated higher. The highest ranking of five is reserved for all areas where people live.

|  |  |
| --- | --- |
| OSM Landuse Tags | Vulnerability Rating |
| Allotments, grass, heath, meadow, nature\_reserve, scrub | 1 |
| Cemetery, forest, orchard, park, quarry, recreation\_ground | 2 |
| Farm, vineyard | 3 |
| Commercial, industrial, military | 4 |
| Residential, retail | 5 |

The environmental vulnerability can also be assessed using the OSM landuse classification. The problem at this point is that most eruptions of Mt. Etna are rather effusive than explosive. Thus, in this project, only the lava flows are considered. A large area around the vents of Mt. Etna is declared a nature reserve, but the paradox is that this cannot be considered a vulnerable area since it is in fact a result of an earlier eruption, so a “loss” would only be a “renewal” of the reserve. Because of that, the environmental vulnerability can only be assessed in a very restricted way integrated in the landuse classification of the economical vulnerability.

The physical vulnerability is again easier to assess using data from OSM, e.g. the building density for an area. The number of buildings within each raster field is counted and reclassified using the classification of **Table X**.

|  |  |
| --- | --- |
| Building Density [buildings/raster unit] | Vulnerability Rating |
| 0 | 1 |
| 1 to 20 | 2 |
| 21 to 50 | 3 |
| 51 to 70 | 4 |
| 71 and more | 5 |

Lastly, the territorial vulnerability is especially important for the time short after a hazard, i.e. how efficiently a region might get evacuated. Therefore, OSM again delivers good data about the streets including their type. Since different sizes of roads also have a different importance e.g. in case of an evacuation of the region or for supply purposes, this needs to be also considered in the analysis. Therefore, the types of roads are classified into five classes using **Table X**. Afterwards, roads are converted into so called “roadpoints”, i.e. every few meters of the road, a point is set. Since the distance varies depending on the classification of the road, afterwards, the roadpoints can be counted, their density can be measured and thus the vulnerability of a raster field can be determined using **Table X**.

|  |  |  |
| --- | --- | --- |
| OSM Road Classifications | Rating | Distance Between Roadpoints [m] |
| Cycleway, footway, path, pedestrian, service, steps, track, track\_grade1, track\_grade2, track\_grade3, track\_grade4, track\_grade5, unclassified, unknown | 0 (not considered) | - |
| Living\_street, residential | 1 | 80 |
| Tertiary | 2 | 65 |
| Secondary, secondary\_link | 3 | 50 |
| Primary | 4 | 24 |
| Motorway, motorway\_link, trunk, trunk\_link | 5 | 15 |

All classifications shown in the tables are based on relative numbers, i.e. the scale is chosen so there is a reasonable amount of areas within the class of highest vulnerability and so are chosen the values for the other classes. This needed to be done since there is no objective measurement of vulnerability and a lot more data, e.g. the size and stability of houses or the demography of the population would be needed to make more precise assessments.

To get the final vulnerability map, the different dimensions of vulnerability need to be weighted. Many sources decide to use an equal weighting in absence of objective criteria (Biass et al. 2012, Cutter et al. 2000). In our case we decided to weight the different criteria using the weighting showed in **Table X** for following reasons: The country of Italy, Sicily belongs to, is an industrial country and though having high debts still has a strong economy being able to support people in need. Thus, the most vulnerable aspect is the life of the people itself and “no risk can exist unless there is a human population to be affected” (Chester et al. 2002). Despite that, the population density is weighted very low because it only tells us values for a comparable large region. The building density tells us a lot more about where people actually live.

|  |  |
| --- | --- |
| Dimensions | Weighting |
| Social vulnerability (population density) | 20% |
| Economic (environmental) vulnerability (landuse) | 20% |
| Physical vulnerability (building density) | 35% |
| Territorial vulnerability (roadpoint density) | 25% |

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