POLITECNICO DI MILANO

Department of Civil Environmental and Territorial Engineering

Master's Degree in Civil Engineering for Risk Mitigation

SATELLITE IMAGERY AND GIS TO ASSESS URBAN EXPANSION FROM A RISK PERSPECTIVE

THE CASE OF NAPLES

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Abstract (English)

Cities all over the world are still rapidly expanding and, according to the Atlas of Urban Expansion, their recent-term urban expansion has been mostly unplanned, increasing land consumption and poorly served urban areas. This has consequences also on risk, with a link that is still not much studied. This study, therefore, focuses on this link, starting by the Atlas methodology to develop the maps and measures about urban expansion, to be then analysed in a risk perspective, particularly regarding the exposure growth and systemic vulnerability related to the urban expansion.

To do so, it has been chosen as study area the multi-risk city of Naples, with its hinterland and its volcanic threat. Starting by satellite imagery, ISTAT population data, roads shapefiles from Open Street Maps and Corine Land Cover maps (for land use), through imagery classification and data processing, this study has computed maps, measures and attributes, alike the Atlas of Urban Expansion, to describe Naples urban growth and the actual layout of its urban extent. These measures and attributes have been exploited to compare, then, the Volcanic Hazard Zones, and Naples urban extent included into, in a ranking procedure aimed at assessing the area that has suffered the most from exposure growth or systemic vulnerability, due to Naples urban expansion.

Naples has proven to have grown fast from 1972 up to 2019, with an urban extent that now is more than twelve times the 1972 extent, despite the slower increase of population in its territory. This development has created also areas less accessible and served. Moreover, it has not cared about volcanic risk, with Yellow Vesuvian Zone registering the highest exposure growth, as well as the highest systemic vulnerability. This evidence could guide future decision-makers towards more conscious choices that considerate both urban planning and risk mitigation.

Abstract (Italian)

Le città di tutto il mondo sono in rapida espansione. Secondo l'Atlas of Urban Expansion, la loro recente espansione urbana è stata per lo più non pianificata, aumentando il consumo di suolo e il numero di aree urbane scarsamente servite. Ciò ha conseguenze anche sul rischio, nonostante tale relazione non sia ancora molto studiata. Questo studio, pertanto, si concentra su questo collegamento, partendo dalla metodologia dell'Atlas per sviluppare le mappe e le misure relative all'espansione urbana, analizzate, poi, in una prospettiva di rischio, in particolare per quanto riguarda la crescita dell'esposizione e la vulnerabilità sistemica correlate all'espansione urbana.

È stata scelta, dunque, come area di studio il territorio della città multirischio di Napoli, considerando in particolare il rischio vulcanico. Lo studio ha iniziato dalle immagini satellitari, dai dati ISTAT sulla popolazione, dai dati vettoriali sulle strade da Open Street Maps e dalle mappe Corine Land Cover (per l'uso del suolo), per calcolare, attraverso la classificazione delle immagini e l'elaborazione dei dati, le mappe, le misure e gli attributi per l'espansione urbana di Napoli, nello stesso modo dell'Atlas. Tali misure e attributi sono stati sfruttati per confrontare, quindi, le zone di pericolosità vulcanica e l'estensione urbana di Napoli al loro interno, in una procedura di comparazione volta a valutare l'area che ha maggiormente risentito della crescita dell'esposizione o della vulnerabilità sistemica, dovute all'espansione urbana di Napoli.

Napoli ha dimostrato di essere cresciuta rapidamente dal 1972 al 2019, con un'estensione urbana che ora è più di dodici volte quella del 1972, nonostante il più lento aumento della popolazione nel suo territorio. Questo sviluppo ha creato anche aree meno accessibili o servite e non ha considerato il rischio vulcanico, con la zona gialla vesuviana che registra la più alta crescita di esposizione, nonché la più alta vulnerabilità sistemica. Questa evidenza potrebbe guidare scelte più consapevoli che tengano conto sia della pianificazione urbana che della mitigazione del rischio.

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Chapter 1
INTRODUCTION

Cities are rapidly expanding driven by urbanization and economic development. Worldwide, people, assets and infrastructures tend to concentrate more and more in the urban fabric. The huge urban growth of the last fifty years has proven, however, to be mostly unplanned (Angel, et al., 2016a; Angel, et al., 2016b; Gencer, 2013), thus producing many shortcomings for the settled population. Among these, risk is a rising concern for cities, as it is magnified by urban plans that do not consider it. For this reason, risk mitigation as well as resilience strategies should be integrated into the urban planning and this integration should start by consciousness and knowledge of the urban expansion and its effects on risk. The Atlas of Urban Expansion (Angel, et al., 2016a; Angel, et al., 2016b) has succeeded in mapping and measuring short-term urban expansion of the last years. The study of this thesis wants to test the Atlas results to be applied for an analysis about exposure growth and systemic vulnerability, in cities, related to urban growth, to create therefore that type of mentioned integrated tool. To do so, it will develop maps and measures alike the Atlas for the multi-risk city of Naples, to develop then a methodology to look at the rise of exposure and systemic vulnerability due to its urban expansion towards its volcanic hazard zones.

1.1 The last years of unplanned urban growth and their consequences on risk

People tend to live more and more in cities. Since 1950, when only 30% of the world's population resided in cities, the share has increased up to 55% by 2018 and United Nations expect it to increase to 68% by 2050 (United Nations Population Division, 2018). All over the World, more people move to urban areas with rates that become even higher for the less developed countries, in the high growth markets. Cities are growing, concentrating not only an increasing number of people but also assets and infrastructures, and a huge number of different dimensions as the economical or also political ones. This complex *system* affects the urban growth and the way the city is expanding, upwards and outwards; as it is true also the contrary: the way the urban fabric grows could affect all the parts of the city as a system. Therefore, it is interesting here to ask *how* this expansion has occurred and is still occurring now.

Many authors (Angel, et al., 2016a; Angel, et al., 2016b; Serre, et al., 2013 ; Gencer, 2013) have described a **rapid urban growth** that, in the last years, has outpaced urban planning, with an expansion faster than population increase. Particularly, the Atlas of Urban Expansion (Angel, et al., 2016a; Angel, et al., 2016b), has mapped and measured this urban expansion for a representative sample of the most populated cities in the World, and it has provided evidence of a decrease in urban densities, thus an increase in land consumption. Analysing also the quality, the layout, that urban expansion had drawn there, it has described also a rise of residential areas, many times poorly served by critical infrastructures (Angel, et al., 2016b). Therefore, it has been depicted an urbanization that is becoming highly *unsustainable* (Angel, et al., 2016a). Moreover, some authors have underlined (Gencer, 2013; Swiss Re, 2013) that this fast market-driven urban growth has carried out spontaneous settlements to proliferate around major cities- Gencer (2013) mentions Mediterranean areas in this sense- with low quality constructions, or land speculation. In less developed countries it has even driven informal settlements to sprawl around urban areas.

This unplanned urban growth carries **heavy costs**, as written by (Angel, et al., 2016a), that affect quite all dimensions of the urban systems. Cities become less inclusive, less efficient or accessible, not all people have access to relevant services: it is the peripheries, the expansion areas that suffer the most, usually inhabited by the urban poor. Nevertheless, the consequences are reflected also on the entire urban extent.

Among the different issues that a poorly planned urban development implies, **increasing of risk** is not to be forgotten. On the contrary, according to (Wamsler, et al., 2013) cities are becoming *hotspots for risk and disasters*. Indeed, human activities as well as the number of people or assets concentrated into cities, together with a poor land-planning, increase risk and the possible loss in case of a disaster. Loss that regards not only the local scale with the only territory hit by disaster but also the national scale, due, for example, to the growing relative economic or political importance of cities. Also Swiss Re (2013) has reflected on this difference between absolute and relative loss in case of urban disaster, with resulting evidence that in smaller countries, where big cities could concentrate many of national functions, it is more difficult to handle with urban loss due to a natural disaster.

It is important therefore for cities, to mitigate the risk. First, to reduce risk, it is important to understand the **different factors of risk**, on which to act. And, with a focus on urban development, it is important to know the effects that urban growth could cause specifically on these factors. Particularly, risk is provided by the combination of *hazard* (the adverse event causing loss), *exposure* (the property, people, plant or environment threatened by the event) and *vulnerability* (thus, how the exposed is vulnerable to that certain event), according to the Sendai framework (United Nations Office for Disaster Risk Reduction, 2015). The urban expansion could increase the value of these factors, resulting in a worsened risk and this is largely the result of poor or no planning: for example, exposure rises since the city expands towards hazard-prone zones, with high concentrations of people and assets at risk, or the hazard could be exacerbated by urban land and its peculiarities. Vulnerability too is affected by the rapid urban growth. Vulnerability has many dimensions as the physical one, regarding structures, that could be affected by the previously mentioned low quality construction, or the social one affected by segregation and a less inclusive city and, last but not least systemic vulnerability. This last, regards the city as a *system* looking at the interrelations of the different dimensions; a poorly planned urban area that suffers from a lack of services and critical infrastructures, or also that presents a low redundancy in terms of road network, is more vulnerable to an eventual disaster. And, from the Atlas of Urban Expansion (Angel, et al., 2016b), it has been assessed that many peripheries in the World suffer from a lower accessibility and redundancy due to the recent urban growth.

Therefore, as it is evident by what has been written before, in agreement with (Wamsler, 2004), it is possible to state that *urban development is in itself a cause of disasters, whilst disasters, in their turn, place development at risk*. Existing risk is *magnified* by urbanisation and the failure of adequate planning. However, as it is highlighted by (Wamsler, 2004), this link between urban planning and risk is still not much recognized or applied: both urban planners or risk experts still do not consider the effects that their choices could have on the other ones. There is thus a **gap** between the two subjects; the link is also weakly theorized, in all the aspects that it covers, as the social, environmental, demographic, economic and institutional ones.

Therefore, in a future where, as mentioned by (Bull-Kamanga, et al., 2003)**,** *the trend is for the risk to become urban*, there is a rising need to **integrate urban planning and risk mitigation strategies**. It is important for worldwide cities to manage their risks trying to reduce not only the impact of natural disaster, in a physical perspective, but also to learn how to cope with these risks, in a way to reduce the eventual time to respond as well as to recover from them. This could be possible only through the integration of risk mitigation strategies into urban planning. This type of perspective could allow to look at risk mitigation strategies in a different way, no more to act in order to reduce the potential damage, as it is usually done alone according to (Wamsler, et al., 2013), investing huge resources in physical measures, but to cope, to adapt to risk. Indeed, risk zero is impossible, particularly in complex systems as cities, thus, it is possible to insist more on awareness and preparedness of people and assets to respond and fast recover from a disaster. The concept that lies at the base of this mentioned

ability to cope with risk is *resilience*, a complex subject that is growing in importance. Resilience does not want to physically change the whole city but to plan and organize it in a way it could be more prepared to risk. It addresses the city as a system with its interrelations, insisting on redundancy of its objects, in a way the city could respond to emergency resisting to the disturbance.
Resilience starts by preparedness and **awareness** for all the stakeholders: everyone should be aware of the present risks and should know its role in case of emergency. Particularly, decision-makers need to plan for adaptation, once they know all the aspects that could affect risk or resilience. It is for this reason that there is the need for tools that integrate the urban planning perspective to the risk and resilience one, to make decision-makers more conscious about what is already present or the effects of their eventual decisions.
It is here that this study starts. It takes the methodology of the Atlas of Urban Expansion, that looked at urban expansion only from an urban planning perspective, to implement it with an analysis in a risk perspective about exposure growth and systemic vulnerability related to the urban development. In this, way, it could be possible to create and test an integrated tool that could have the advantage of measuring the urban expansion and then guiding towards more conscious choices about land-planning consequences on risk. However, aim and objectives will be furtherly explained in the following paragraph.

1.2 Aim and objectives

The aim of this study is to test the Atlas methodology to be integrated with a risk perspective in order to analyse the consequences of urban expansion on exposure growth and systemic vulnerability, for cities under risk. Particularly this study does not exploit the Atlas results regarding one of its sampled cities, but it develops its own maps and measures about the urban growth of Naples, that is of interest for its multi-risk peculiarity.

Specifically, to reach the aim, the objectives are the following:

1. To map and measure Naples urban expansion of the last fifty years, in a way to develop measures and attributes that are similar to those proposed in the Atlas.

2. To analyse those results from a risk perspective, considering the growth of exposure and systemic vulnerability aspects.

The first objective will be achieved starting by the Atlas methodology, particularly exploiting satellite imagery of different years representing the study area. Classification of these satellite images, a further GIS-based subclassification and the exploitation of population, roads and

land use data will allow to create maps and measures to describe urban expansion of Naples over the years as well as the urban layout it has created.
After that, the analysis mentioned at the second point will exploit a ranking procedure in a way to develop a tool that could guide urban planners or decision makers towards more conscious choices, that could act in a risk mitigation or resilience perspective.

1.3 The study case: the multi-risk city of Naples

This study focuses on the city of Naples, localized in Campania region, in the South of Italy. Particularly, the study area covers a wide territory of the region, it comprehends the whole Neapolitan province and the territories nearby in order to detect the whole urban expansion of the city. The choice of Naples and its metropolitan area is linked to its **unique case**: a complex urban area, hosting more than 3 million people, in a multiple source volcanic area, tightened as it is by quiescent Phlegraean Fields and Vesuvius volcanos. Moreover, it is interesting not only for what concerns risk but also due to its peculiar urban expansion of the last fifty years.

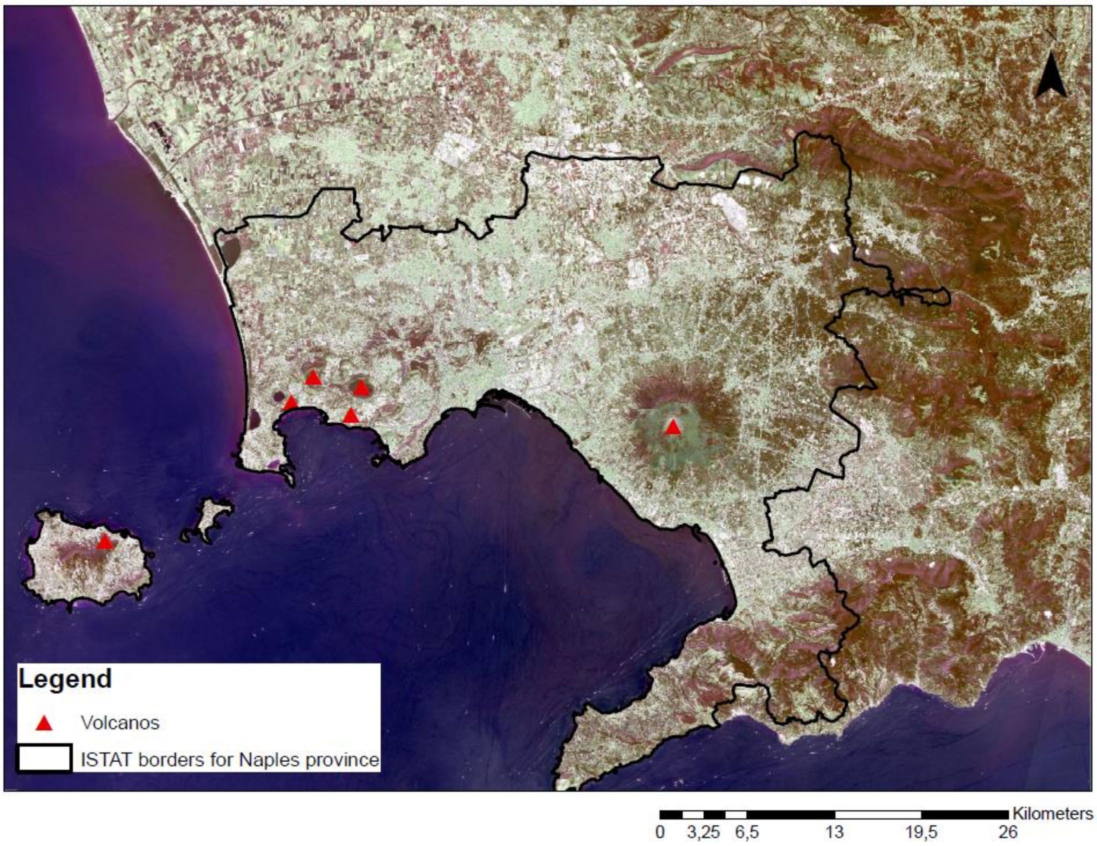


Figure 1.1 The study area and the presence of Vesuvius and Phlegraean Fields volcanos.

Starting to look at the risks the city is prone to, it has to be mentioned that volcanic risk, though being the most famous risk for this city's territory, it is not the only one: the area is exposed also to earthquakes, landslides and floods, due also to its geological characteristics. Nevertheless, this study will concentrate just on the **volcanic threat**, looking at both sources, **Vesuvius and Phlegraean Fields**, whose respective probable eruptions could affect a wide territory that comprises also Naples urban extent. Indeed, Vesuvius is just 10km away from the westside of Naples while the super-volcano of Phlegraean Fields is next to its east side, and their eventual eruptions, expected to be explosive could hit a great measure of the hinterland Neapolitan areas and also some of the quarters of the city itself. Both eruptions scenarios could cause disruptive pyroclastic flows to rapidly spread from the volcanos. As well as ash falling, that would depend on quantity by direction of winds and column height, being able to cause roofs collapses. For both volcanos, before and during the explosive eruption, earthquakes could occur, aggravating loss and emergency management. Moreover, it is needed here to be reminded that the complex characteristics of Phlegraean Fields super-volcano make it more difficult to assess the scenario of an eventual eruption, due to the low frequency of events as well as the difficulty in understanding the location of the starting of a potential eruption.
Both Vesuvius and Phlegraean Fields are constantly monitored and, for both, emergency plans by Italian Civil Protection have been determined, considering the different levels of volcanic threat in the zones and the different possible levels of warning, all the actions that have to be taken. Particularly, the people from areas that could be subjected to pyroclastic flows would be all evacuated before the occurring of eruption. Finally, as the situation stands now (March 2020) the warning level for Phlegraean Fields is of *yellow* type, meaning for a state of attention.

Urban planning in these lands could be fundamental in a way to be more prepared to manage and faster absorb the possible eruptions. However, in agreement with (Alberico, et al., 2011), Naples territory represents an important example of urban development that has not adequately considered risk. This is rather evident looking at houses built next to Vesuvius or in its expansion towards the area of Bagnoli, exposed to Phlegraean Fields volcanic risk. The last fifty years of Naples urban expansion are surely complex and cannot be adequately written here. However, it is interesting to notice a phenomenon that, according to Scaramella (2003) is slowly moving people outwards to Naples hinterland, instead than inwards to its historic centre, particularly, people are gradually leaving some decaying areas that are also in the historic centre. The author (Scaramella, 2003) describes also the illegal buildings that have sprawled around the city over the years, not as informal settlements but also as middle-class houses. All this making Naples recent urban development as a unique case for which it becomes interesting to map and measure, as for the Atlas, that urban expansion.
Therefore, Naples, as it has been described, represents an important case on which to test the tool that this study wants to provide: an instrument to study both from an urban planning and

a risk perspective the city urban growth and be of help for decision-makers. Indeed, Naples needs an urban planning that addresses volcanic risk while deciding for future urban development, being conscious of the consequences and the opportunities driven by this. Moreover, this awareness tool that the study wants to create could be useful also for the management of the emergency, providing evidence about systemic vulnerability of the different areas exposed to volcanic threat.

Chapter 2
THE ATLAS OF URBAN EXPANSION

The *Atlas of Urban Expansion* has been the fundamental starting point for this study to be. This chapter is meant to describe its project as well as its methodology, through the mention of its two volumes, their adopted procedures and results. Particularly, the Atlas has had the important result of having measured the recent urbanization phenomenon with its peculiarities. From an urban planning perspective, it has mapped and measured urban expansion and urban layout of a sample of 200 representative cities in the World, through the use also of descriptive attributes. Due to this study's first objective of mapping and measuring Naples urban expansion and actual layout, the Atlas has been the first guide and inspiration for this study. And, for this reason it is important here to describe it, also to make this study's methodology and procedures clearer after. However, due to the growing need of integrating urban planning and risk mitigation knowledge and strategies, the maps and measures, collected following its methodology, are not the end point: they will be analysed from a risk perspective, particularly from an exposure growth and systemic vulnerability perspective. In this way, the Atlas methodology and results will be tested for their exploitation in risk field.

2.1 The Atlas of Urban Expansion: purpose and structure

The *Atlas of Urban Expansion* (Angel, et al., 2016a; Angel, et al., 2016b) represents the first result of the ongoing multi-phase research program *Monitoring Global Urban Expansion*, run by the *NYU Urban Expansion Program* at the *Marron Institute of Urban Management* and the *Stern School of Business of New York University*, in partnership with *UN-Habitat* and the *Lincoln Institute of Land Policy*. The initiative gathers data and evidence on cities worldwide, particularly, information about growth and expansion, as well as quality of that expansion. The purpose of the Atlas is here to monitor the quantitative and qualitative aspects of global urban expansion producing maps and measures of recent and long-term expansion, in an easily accessible format. Its general intent could be summarized with its own words:

" *Soon we will need our best tools to craft people into the cities we, and the planet, need. The Atlas is one of those tools*." (Angel, et al., 2016a).

Thus, the Atlas recognizes itself as a tool, particularly meant for guiding decision-makers towards informed choices. It wants to provide them awareness coming from its monitoring of urban expansion and cities all over the world. Due to that, its methods, maps and measures must be open to the user, in order to become, the Atlas, an effective tool.

To come up with results about urban development over years, the Atlas starts its research by the following study questions:

- *Has expansion of cities slowed down?*
- *Is urban population density increasing or decreasing?*
- *Where are built the new areas?*
- *How were they built with respect to previously-built-up and considering the different periods?* (Angel, et al., 2016a).

The first three questions are answered in the first Volume (Angel, et al., 2016a), focused on the Areas and Densities of urban expansion over time, while the last question is faced in Volume II of the Atlas (Angel, et al., 2016b) that is interested on roads and urban layout. Last, a third phase of the research is still on going, called *The Land and Housing Survey in a Global Sample of Cities*, focused on surveys about land ownership patterns, land-use planning practices and prices of housing all over the world. All these volumes look at a sample of cities, they do not study all settlements on the Earth, but they focus only on 200 cities with more than 100.000 people (up to 2010). This sample of cities was determined in a way to represent a significant number of cities of the world, for example they are localized in both more or less developed countries with larger or smaller cities. Thus, it allows a comparison also among the different countries and cities. For these cities, the different volumes of the Atlas exploit data from 1984 to 2015, in addition, for 30 cities it has been studied also the long-term urban expansion, considering periods from 1800 up to 2015 (through the use of historical maps).

In the next paragraphs, the focus will be on first volumes, Volume I and Volume II and particularly on their methodology and types of results.

2.2 Volume I of the Atlas: Areas and Densities

The first volume of the Atlas of Urban Expansion is focused on mapping and measuring worldwide urban expansion. Particularly, its name *Areas and Densities* refers, with Areas, to

the mapping and measurement of urban expansion in terms of Built-up or Urban Extent growth over the years, while Densities is referred also to the comparison between this urban growth and resident population in these cities.
Methodology of this Volume I starts by **satellite imagery**. According to the Atlas, satellite technology might be used to guide the future growth of the world's cities (Angel, et al., 2016a) and it is for this reason that it starts all of its analyses by their choice and processing. Particularly, its choice goes to cloud-free medium-resolution Landsat-imagery, exploiting sensors from Landsat 5 to 8, for years between 1984 and 2015, for the sampled cities. The Atlas has exploited their spatial resolution of 30m as well as their different spectral bands, that could provide different types of information about the areas under study.
Satellite imagery from the different periods have been subjected to **land cover classification.** The first land cover classification, performed on these images, has differentiated among *Built-up*, *Open Space* and *Water* areas. The overall accuracy of its resultant land cover maps is of 87,1%± 0,4, with a Built-up user's accuracy of 83,6% and a Built-up provider's accuracy of 89,3%, according to (Potere, Schneider, Angel, & Civco, 2009), meaning that more Built-up land could be mislabelled as Built-up than missed.
Thus, pixels for Built-up have been counted, with the use of a Geographic Information System GIS, to **measure Built-up land** in the different years.
However, after this first classification, the authors of the Atlas of Urban Expansion (Angel, et al., 2016a) have exploited another finer type of classification, always exploiting GIS as a tool. They have differentiated Built-up and Open Space classes into the subclasses shown in Table 2.1. In this way, the Atlas has been able to characterize among the pixels related to urban areas and the pixels related to rural areas, out of the urban fabric, both when considering Built-up land or Open Space. It must be mentioned that the subdivision has been, for Built-up, in some way, arbitrary and based on experience, while, for Open Space also guided by theoretical concepts about ecology studies.
Land Cover sub-classes have allowed to define the *urban clusters*, constituted by *Urban*, *Suburban* and *Urbanized Open Space* pixels. And, from *urban clusters*, thanks to GIS buffering and based on geographical proximity, to assess, in the end, the **Urban Extents** of the sampled cities in all the periods under study. Particularly, the Urban Extent has been defined by the Atlas of Urban Expansion (Angel, et al., 2016a) as the biggest *urban cluster* with added other smaller urban clusters that are chosen following an *inclusion rule* that states that, if an urban cluster, buffered to increase its area of one quarter, intersects a buffer of another urban cluster, then, the two urban clusters have to be considered together.

Table 2.1 Subdivision of major Land Cover Classes into sub-classes, from the Atlas of Urban Expansion methodology (Angel, et al., 2016a).

<table>
<tr><th>Land Cover Class</th><th colspan="2">Sub-class of Land Cover</th><th>Description of sub-class</th></tr>
<tr><td rowspan="3">Built-up</td><td colspan="2">Urban</td><td>A Built-up pixel is Urban if more than 50% of pixels around is Built-up too.</td></tr>
<tr><td colspan="2">Suburban</td><td>A Built-up pixel is Suburban if between 25-50% of pixels around are Built-up too.</td></tr>
<tr><td colspan="2">Rural</td><td>A Built-up pixel is Rural if less than 25% of pixels around are built-up too.</td></tr>
<tr><td rowspan="3">Open space</td><td>Captured Open Space</td><td rowspan="2">Urbanized Open Space</td><td>An Open Space pixel is Captured if part of an area smaller than 200ha, surrounded by Built-up land.</td></tr>
<tr><td>Fringe Open Space</td><td>An Open Space pixel is Fringe if it corresponds to the nearest open space that surrounds a city, affected by the city itself. This ‘belt’ around a city is defined by Landscape ecology studies, as around 100m.</td></tr>
<tr><td colspan="2">Rural Open Space</td><td>It is the sum of the remaining pixels classified as Open Space and not in Captured or Fringe Open Space subclasses.</td></tr>
</table>

Again, exploiting GIS, measures have been performed and shown for the sample of cities, regarding urban extent areas and their subdivision in Urban, Suburban and Urbanized Open Space over the years. From maps and metrics about urban extent, the Atlas has drawn the different **expansion areas** that have been added to the city through time, areas that are the difference between the urban extents at different years. Finally, the Atlas has differentiated also each time the new Built-up areas included into the urban extent into *Infill*, *Extension*, *Leapfrog* and *Inclusion*. However, this subdivision is not explained here as it will not be of interest for this study to be.

As mentioned before, this first Volume does not focus only on the maps and measures of areas but also on **densities**. Indeed, the Atlas of Urban Expansion, from an urban planning perspective wants to compare the areas with the number of people that live there. Thus, first the Atlas has needed **demographic data**, for all the cities under study. Moreover, to make consistent comparison with the areas, it has needed the population data to be referred to *enumeration zones* (like census data) and to interpolate or extrapolate them to be also time consistent. In case the enumeration zones had not similar limits with the areas they would have to be compared to, their population number has been re-calculated on a proportionality basis regarding areas shares. Finally, the comparison has been performed with the use of *Density* indicator, subdivided into the two following attributes applied on each decade image,*i*:

2.1

$$\text{Built} - \text{up area density}_\text{i} = \frac{population_i}{built - up_i}$$

2.2

$$\text{Urban extent density}_\text{i} = \frac{population_i}{urban\ extent_i}$$

The first being always higher than the second, since the urban extent is always a wider area (that considers also Urbanized Open Space) than only the Built-up included in it.

However, urban expansion has not been described only by Density attributes. Indeed, the Atlas of Urban Expansion has proposed also the two following **attributes** that are computed from the measures of areas. The attributes are the followings, applied on each decade image *i*:

- *Fragmentation*. It measures the level to which the Built-up area into the urban extent is fragmented by the Urbanized Open Space. The more fragmented would be the Built-up area the smaller its Urban Extent Density, the greater the distance between locations in the city, but also the closer would be the Built-up area to the Open Space. It is described by two different factors:

2.3

$$Saturation_i = \frac{Built - up\ within\ the\ urban\ extent_i}{urban\ extent_i}$$

2.4

$$Openness\ index_i =$$
$$= Average\ share\ of\ Open\ Space\ pixels_i\ within\ the\ Walking\ Distance\ Circle\ of\ every\ Built\_up\ pixel_i$$

The first related to distance between locations, the second linked to the walkable proximity of Urbanized Open Space, thus related to quality of a city.

- *Compactness*. It describes the shape of a city. The Atlas has considered here that a circle could be the shape that could provide more accessibility to the urban fabric; thus, it has compared all the cities to the circular shape. This comparison between shapes have been performed with two attributes: *proximity index* and *cohesion index*, whose description could be furtherly read into (Angel, et al., 2016a).

Therefore, at the end, together with maps, the Volume I of the Atlas provides measures and attributes to describe areas and densities of the sampled cities. These results are fundamental to compare cities spatially and temporally. Particularly, they agree that the urban growth of the last years has occurred in an unplanned way, with cities expanding faster than their populations, with decreasing densities and lowering of public spaces. Results from this first Volume of the Atlas (Angel, et al., 2016a), show an urbanization "*becoming highly unsustainable*", with more land consumption, fast increasing year per year with cities growing outwards, and not only upwards.

2.3 Volume II of the Atlas: Blocks and Roads

According to the authors of the Atlas of Urban Expansion (Angel, et al., 2016a), when cities expand they need land to be converted and prepared for urban use. Expansion needs to be planned in advance to guarantee lands that are accessible and properly serviced. However, this has not been the case for many cities, particularly in less developed countries, where residential fabric has grown in an unplanned way, so that peripheries fail to be well connected and cities become less efficient, inclusive and sustainable. Moreover, after land has been occupied, it is difficult, after, to ensure place for services as road infrastructures. Therefore, the purpose of this second volume of the Atlas has been, this time, to **map and measure urban layouts**, focusing on roads and blocks, the urban fabric units separated by road network. The authors (Angel, et al., 2016b) compare the actual expansion areas of the different cities discussing about their accessibility, services and land use. They wanted therefore to ask about quality of urban areas.

To perform this study, authors (Angel, et al., 2016b) have digitized and analysed **random samples of 10ha locales** using high resolution Bing imagery, freely available worldwide. They have compared an unique expansion area (from the sum of all the expansion areas per city mapped in the first Volume (Angel, et al., 2016a)) to the pre-1990 urban extent, for all the cities of the sample. Several sampled locales per city, about a hundred, depending by the complexity of the city under study, have been selected randomly. Locales have been selected from both expansion area and pre-1990 urban extent.

For each locale, **manual digitization** has been exploited to identify, map and measure the physical characteristics of its urban fabric. These characteristics have been, then, generalized, averaged, for the whole pre-1990 urban extent or the expansion area, this for each city. The primary focus has been the orderliness of block and roads layout, the quality of infrastructures, the size of blocks and the density of roads intersections. Manual digitization has been performed first recognizing between *road* or *block space*. Block space is divided into *blocks,* that are areas continuously bounded by roads or rural open spaces, and, furtherly, into *plots*, parts of blocks that correspond to individual parcels of territory, with specific land uses. Plots have been exploited to assess the **shares of different land uses** in the whole urban fabric. Particularly the authors of the Atlas (Angel, et al., 2016b) have considered the following types of land use:

- *Open Space*
- *Non-Residential areas*
- *Residential Areas*
    - *Atomistic settlements*
    - *Informal Land Subdivisions*
    - *Formal Land Subdivisions*
    - *Housing Projects*
- *Road Space*

These land uses have been decided for their easily recognizable pattern and a focus has been made on residential areas and their orderliness, with types describing the stages in the evolution of the housing sector, from a state of weaker planning skills and traditions, less regimented property-right and regulatory regimes and low availability of capital (atomistic settlements) to a state of stronger planning and regulatory regimes and a broader availability of capital (housing projects). The characterization among the different residential areas, as well as the attributes computed from it, are furtherly described in (Angel, et al., 2016b).
Moreover, with respect to roads, the authors have zoomed on **arterial roads**, considered as the roads that could link the whole urban extent, being connected among themselves and also to the minor roads (not considering therefore motorways). These roads have been still digitized for the whole extent or just for single sampled locales, depending by the size of urban fabric under study. They have been found also with exploitation of open data as Java Open Street Map to be taken as guide. Arterial roads are *Wide* and *Narrow*, depending, respectively, if their width overpasses 18m or not.
Distinction through width measures does not concern only arterial roads but also all types of roads, in order to define, for each locale, the **measures and attributes**, that could describe the road network there. Measures and attributes that are generalized, then, to describe the whole pre 1990 urban extent and the expansion area after 1990 road networks. Roads have been subdivided for widths smaller than 4m, between 4-8m, 8-12 and more than 16m, widths that are easily measured thanks to the digitized sampled locales. This classification, together with arterial roads characterization, has led to the following attributes, that have been computed for both urban extent pre 1990 and expansion area:

- *Share of road class i on the total network of roads*. It is defined by equation 2.5. It allows to compare the different shares for different types of roads.

2.5

$$Share\ of\ road_{class\ i} = \frac{Linear\ lenght\ of\ all\ roads_{class\ i}}{Linear\ length\ of\ all\ roads\ in\ the\ area}\ [-]$$

- *Average Road Width*. The average roads widths per locales then averaged to represent the whole area (the pre-1990 urban extent or the expansion area).

- *Average Density of All Arterial roads*. It measures the quantity of arterial roads with respect to an area. Its intent is to understand how much an area is served just by arterial roads.

2.6

$$Average\ Density\ of\ all\ Arterial\ roads = \frac{Linear\ length\ of\ all\ Arterial\ roads\ in\ the\ area}{Considered\ area}\ [\frac{km}{km^2}]$$

- *Average Density of Wide Arterial roads*. It gives an insight of the measure of wide arterial roads (18m+) passing through an area (the pre-1990 urban extent or the expansion area).

2.7

$$Average\ Density\ of\ all\ Arterial\ roads = \frac{Linear\ length\ of\ Wide\ Arterial\ roads\ in\ the\ area}{Considered\ area}\ [\frac{km}{km^2}]$$

- *Share of urban extent within walking distance (625m) of all arterial roads*. It represents the walkability of the area towards all arterial roads, thus their accessibility from the inwards of the pre-1990 urban extent or expansion area:

2.8

$$Share\ of\ areas\ within\ walking\ distance\ to\ arterial\ road = \\ = \frac{total\ area\ within\ walking\ distance\ to\ arterial\ road}{total\ area}$$

- *Share of urban extent within walking distance (625m) of wide arterial roads*. It represents the walkability of the area towards wide arterial roads, thus their accessibility from the inwards of the pre-1990 urban extent or expansion area:

2.9

$$Share\ of\ areas\ within\ walking\ distance\ to\ wide\ arterial\ road = \\ = \frac{total\ area\ within\ walking\ distance\ to\ wide\ arterial\ road}{total\ area}$$

If these attributes describe road networks and accessibility, looking at the **block layout** the **attributes** considered are the followings:

- *Average size of blocks [ha]*. The blocks size matters: if blocks are too big, they become aggregates of built-up structures segregated inside, not much accessible.

- *Density of 3-ways intersections*. Related to orderliness and practicability of urban layouts and particularly accessibility and redundancy of roads, it is the average number of 3-ways intersections over an area. The computation for density of 3-ways intersections is summarized by the following equation:

2.10

$$Density\ of\ 3-ways\ intersections = \frac{number\ of 3-ways\ intersections\ in\ an\ area}{the\ area}\ [\frac{km}{km^2}]$$

- *Density of 4-ways intersections*. The same as above but regarding 4-ways intersection. The computation for density of 4-ways intersections is summarized by the following equation:

2.11

$$Density\ of\ 4-ways\ intersections = \frac{number\ of 4-ways\ intersections\ in\ an\ area}{the\ area}\ [\frac{km}{km^2}]$$

All these attributes mentioned allow to compare, for each sampled city, the urban layout, thus, on a first sight, the quality of pre-1990 urban extent and expansion area for each city, but also to compare the different sampled cities due to an adopted processing and data that have been similar for all the cities. The metrics that have been summarized here, coming by the Volume II of the Atlas (Angel, et al., 2016b), do not represent the whole list of measures provided by the project, but the ones that are of interest also for this study to be. The following chapter is meant therefore at describing furtherly the connection between the Atlas and this study.

2.4 From the Atlas to Naples urban expansion and its linked exposure growth and systemic vulnerability

The Atlas of Urban Expansion (Angel, et al., 2016a; Angel, et al., 2016b) depicts, with its results and its ongoing research programme, an unplanned and unsustainable urbanization that has occurred worldwide in recent years from 1984, in more or less developed countries. The Atlas has measured it, as well as it has analysed its quality, through the study of urban layout. In this way, it wants to be a tool that would guide future decision-makers to better manage urban expansion, thanks to the knowledge it could provide them.

The Atlas project is studying the numbers and peculiarities of this urban expansion phenomenon, but it does not focus on the **effects** of it. Its authors are conscious about the effects and costs that are driven by an unplanned urbanization, they describe the *heavy costs* that would be carried out by *allowing cities to expand simply through cumulative acts of their residents* (Angel, et al., 2016a). However, they do not analyse deeply the effects on the single cities, and they do not mention the effects on a risk perspective. Indeed, the *heavy costs* that they mention could affect a lot of fields and dimensions, social, economic, physical and among them **risk cannot be forgotten**. This study wants to analyse the effects of this urban expansion on risk, looking at its factors as exposure and vulnerability, particularly systemic vulnerability. Indeed, if urban planning needs to be integrated with risk knowledge and mitigation strategies, as stated by many authors (Wamsler, 2004; Wamsler, et al., 2013; Serre, et al., 2013), there is the need to analyse the effects that both could have had on each other. Therefore, the results of the Atlas of Urban Expansion could be analysed in this perspective, looking for the consequences that urban growth could have carried. And, particularly, since the Atlas results first describe urban growth in terms of measures of Built-up growth, urban extent expansion or population increase, it could be connected to the study of exposure growth, as well as the roads and blocks layout could be related to the analysis of the accessibility of the urban areas and redundancy of roads in a systemic vulnerability point of view. Thus, this study wants, in the end, to apply and test the Atlas measures and attributes for the analysis of exposure growth and systemic vulnerability related to an unplanned urban expansion.
Moreover, the Atlas of Urban Expansion has chosen its sample of cities, again on the base of its exclusive urban planning perspective, thus, its sample does not show all cities that could be of interest also from a risk point of view. It is for this reason that this study has decided to reproduce and start from the Atlas methodology to study a city that has not been included in its sample: the multi-risk city of Naples, that could be of interest looking at urban development and its effects on risk, particularly on volcanic risk, from Vesuvius and Phlegraean Fields. Therefore, here it starts the project of this study: a methodology will be developed starting by the experience of the Atlas, producing similar attributes and measures with respect to it for the city of Naples and its territory. And then, these results will be tested for their application in a risk perspective, for an analysis aimed at investigating and comparing the different zones exposed to volcanic risk about their exposure growth and systemic vulnerability linked to recent urban expansion.

Chapter 3

METHODOLOGY:

FROM MAPPING AND MEASURING URBAN EXPANSION, LIKE IN THE ATLAS, TO EXPOSURE GROWTH AND SYSTEMIC VULNERABILITY ANALYSIS

This chapter is meant to illustrate the methodology that has been followed. Particularly, it summarizes the different processes, the types of studies and analyses that have been prompted by this study's objectives and aim. Methodology is divided in two parts as the two main objectives of this study:

1. The first, aimed at mapping and measuring Urban Expansion, as well as the actual Urban Layout for Naples, similarly as it was done by the Atlas of Urban Expansion for its sample of cities (described in Chapter 2).
2. The second, aimed at exploiting these maps, measures and attributes, previously produced for the entire study area, for the analysis of the linked Exposure Growth and present Systemic Vulnerability (related to accessibility) in the Volcanic Hazard Zones present in the study area.

The first part of this methodology, *Mapping and Measuring Naples Urban Expansion*, is inspired by the experience of the Atlas of Urban Expansion (Angel, et al., 2016a; Angel, et al., 2016b), explained in Chapter 2. Then, the second one, *Analysing the urban expansion from an exposure growth and systemic vulnerability perspective,* starts by the evidence provided by the former, to get an Exposure-based analysis for the areas under volcanic hazard, focusing on the Exposure Growth and Systemic Vulnerability that are linked to Naples urban expansion and urban layout there. Indeed, Urban Expansion, particularly if not planned in a risk perspective, has consequences on risk, increasing it and making cities more and more as *hotspots for disaster and risk,* as suggested by C. Wamsler et al. (Wamsler, et al., 2013). And, exposure growth and a greater systemic vulnerability could be important factors determining this risk increase. Finally, this second part of methodology must be considered also as a purpose of analysis, to be tested, to exploit the Atlas results in terms of risk, to develop a more integrated knowledge that links planning to risk.

The whole methodology is summarized in Figure 3.1. This diagram is the starting point for the description of the two stages of methodology that will be presented in the next paragraphs.

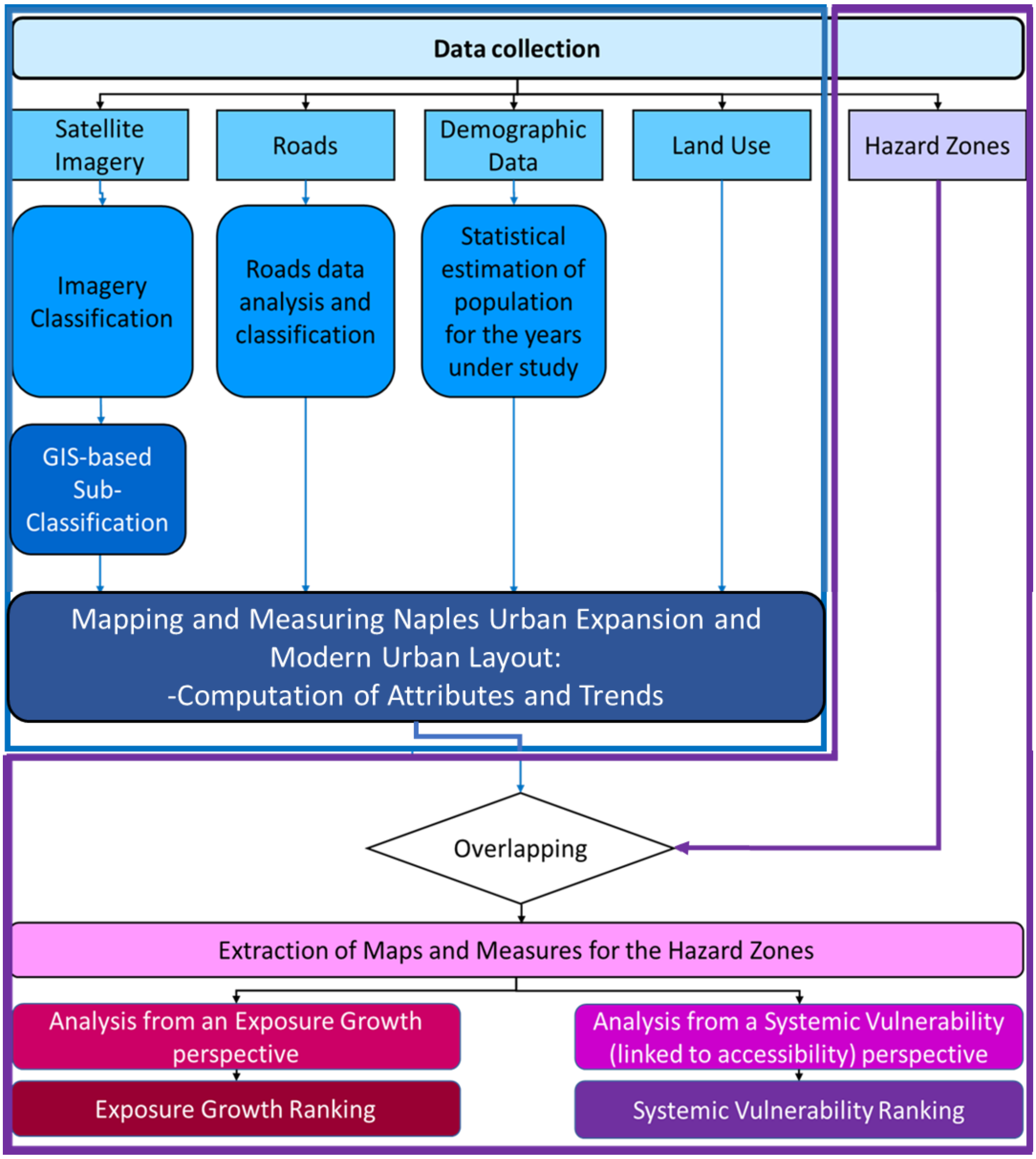


Figure 3.1 Methodology of the study represented in a block diagram.

3.1 Mapping and Measuring Naples Urban Expansion

This first stage of methodology aims at producing maps and measures for the case of Naples, as it was done by the Atlas of Urban Expansion for its sampled cities. The case of Naples urban extent and territory could be of great interest due to the volcanic risk it is subjected to, however, it was not considered into the Atlas sample of cities. As shown in Figure 3.1, the first point of the analysis is represented by data collection. Necessary data are satellite imagery, roads and demographic data, as well as land use. **Satellite imagery** is the real beginning of this study, as it was for the Atlas of Urban Expansion (Angel, et al., 2016a). It allows the study to be extensive and cover a large area over Naples, as well as to look at the different years from 1972 up to present days. Therefore, Remote Sensing theories and applications have been exploited to, first, choose among the whole free satellite imagery that is downloadable from the Web, choosing, also, the years to be considered for the study. Once the images and their spectral and spatial characteristics have been chosen, they have been cut to focus just on a chosen study area. In this way, satellite imagery was ready to be analysed with the use of software ENVI, a tool that allows to process and analyse geospatial imagery, focusing on Remote Sensing theories and practices. Particularly, as it was performed by the Atlas of Urban Expansion (Angel, et al., 2016a), the satellite images were subjected to **classification**, to derive a first characterization for the represented areas into Built-up, Open Space and Water. Here, this classification step has involved a choice among different types of classification algorithms, a choice that has been guided by testing for accuracy on first results. Once classification has been performed it has been possible to apply some improvements, by photointerpretation, in order to get a result that could be suitable for the purpose. The result of this first step has been Selective Land Cover Maps.

The produced classifications have been compared with the layers for Naples area from *Global Human Settlement* European project (European Commission, 2019), which provides the extension of the Built-up globally at different times, in order to verify if the GHS could be used for the purpose of this work.

Following the Atlas, another **sub-classification**, finer than the previous one, has been performed, this time with the use of ArcGIS. This sub-classification is referred to differentiate more deeply Built-up and Open Space. For the whole remaining methodology, after the first imagery classification, ArcGIS allowed to perform analyses, measures and computations for quite all steps of this methodology.

Sub-classification, as it has been described for the Atlas of Urban Expansion sampled cities at 2.2, has had also for this study the purpose of drawing Naples urban extent over the years, always exploiting ArcGIS tools (e.g. buffers) and theory-based classes grouping.

As seen for the Atlas of Urban Expansion (Angel, et al., 2016a), urban growth is not related just on the physical Built-up growth but it is provided also by population increase. Moreover, comparison between physical and social dimensions could be interesting for a better understanding of recent urbanization. Therefore, as it is represented in Figure 3.1, also **population data** have been exploited in this study, provided by Italian National Institute of Statistics, ISTAT. These data have needed statistical elaboration to be consistent for the years and the areas under study: differently from the Atlas of Urban Expansion, they have been averaged on a municipal basis, due to limits of the data and they have been interpolated and also extrapolated, for what concerns the first years under study, due to lack of more detailed data. Thanks to the municipal basis, population estimate for the different years could be georeferenced through ArcGIS, to allow for the comparison of demographics in different areas and times.

From classification, subclassification and population estimate for the different years and places, the **first measures and attributes** have been computed **to describe urban expansion**, as it was in the first volume of the Atlas of Urban Expansion (Angel, et al., 2016a), to be analysed and discussed for what concerns the area of study or just the urban extent of Naples.

Nevertheless, satellite imagery and population are not the only data necessary for this study. This methodology has got inspired also by the second volume of the Atlas of Urban Expansion (Angel, et al., 2016b), about Blocks and Roads of the urban fabric. It is for this reason that **roads data** as well as **land use** maps have been exploited, even though in a different process with respect to the Atlas. Indeed, differently from the procedures described in the previous chapter, roads and land use have not been manually drawn for single representative areas, to extract statistical attributes but, attributes for block layout have been found out from analysis and processing about data that are freely available on Web for Naples area of study: Open Street Maps roads and CLC Corine Land Cover layers. These data, that have been exploited, have been subjected to the analysis for their characteristics and for their reliability, particularly for what concerns Open Street Maps data. They have been both downloaded and added as different layers on ArcGIS and different processing and measures have been performed to compute the attributes that are described by the Atlas of Urban Expansion (Angel, et al., 2016b), summarized in 2.3. These different data as well as processing make the analysis different from the one of the Atlas, no more based on single locales from which to extract statistical representative measures for the whole urban extents, but an extensive analysis that covers the whole study area and computes its attributes upon its measures. However, there is still a common sense with the Atlas: roads are still classified, even though, here, based on the Open Street Map characterization and no more on the road width. For land use the methodology here instead changes the sense and adapts it more to the final purpose of this study, looking at the different land uses (with an intrinsic economic value) and not focusing

on the types of residential settlements described for the Atlas (just summarized from (Angel, et al., 2016b)into 2.3), also due to the CLC data that does not describe this detail of residential areas.
Finally for this first part, roads and land use have been compared with the area of study measures or with the different expansion areas of the actual urban extent to compute the **attributes that describe**, as for the Atlas, **the block layout and roads accessibility**. Comparison of the attributes for the different expansion areas can provide a first comparison among the quality for urban planning of the different areas. As it could be noted, differently from the Atlas, this study has chosen to analyse separately all the different expansion areas, coming by the first part of methodology, and not to unify them in a unique expansion area. In this way, all the areas could be compared among them.
This has been the process for deriving **maps** and measures about Naples urban expansion. As anticipated, it has followed for the most the Atlas methodology, however, it has also derived from it its own procedures and choices to overcome the limits and issues that it has encountered. The processing will be explained in Chapter 4.

3.2 Analysing the urban expansion from an exposure growth and systemic vulnerability perspective

Looking again at Figure 3.1, it is possible to focus on the second part of methodology, the one that links the previous results regarding urban expansion and actual urban layout to the relative exposure growth and systemic vulnerability in the volcanic hazard zones. As mentioned, this proposed part of methodology aims at deriving knowledge about the link between urban planning and these risk factors, looking at the effects of urban growth in the volcanic areas of Naples territory, from an exposure growth and systemic vulnerability perspective. Better knowledge about exposure and vulnerability would be a great tool for future urban planning and for decision makers.
The methodology here is based on a focus on the volcanic hazard zones, defined by the Emergency Plans (Italian Civil Protection, 2018) in case of Vesuvius or Phlegraean Fields eruption. This focus is allowed through the **overlapping** of the zones on the maps processed in the previous steps. Zones are Yellow and Red, where Red is referred to mandatory evacuation in the alarm phase, before the volcanic event, due to probable spreading of pyroclastic flows there during eruption, while Yellow is referred to the probable huge fall of ashes during the event. The processing has been all performed exploiting ArcGIS software. Thus, the study here focuses on these zones, looking at their whole territory, described with the land cover maps, the urban extents, roads, population and land use georeferenced data that were cut to be consistent with their limits. But it consisted also in specific analyses of just

the Naples urban fabric included into these zones, therefore a comparison also among the actual urban expansion areas that are part of them.

The link between urban growth and **exposure growth** is first theoretical, it needs the understanding of exposure term: according to authors (Corbane, et al., 2017) exposure represents *the people and the assets at risk of potential loss or that may suffer damage to hazard impact*. Therefore, with urban growth in the hazard zones, it is also exposure to grow, in many dimensions as the physical (e.g. building stock), social (e.g. population) and economic one. The results of the first stage of methodology have provided evidence for the Built-up, urban extent and population growth; overlapping them with the hazard zones makes it possible to look at exposure growth over the years in the different volcanic areas. The analysis is based on the computation of the attributes and trends for the volcanic hazard zones, separately. The separate analysis allows then to compare the different trends for Built-up, population and urban extent growth over the years and to derive in the end a **ranking** scheme to come up finally with a ranking that compares the volcanic hazard zones from an exposure growth perspective.

The study of **systemic vulnerability** has followed a similar process, deciding the attributes and measures that, coming from the first part methodology results, could be linked to this risk factor. Again, to decide the attributes and measures to be considered and therefore to link the previous results to the study of systemic vulnerability (mostly relative to accessibility) it must be clear the complex meaning of the term systemic vulnerability and first the more general vulnerability term. Vulnerability, is, according to results of ENSURE project (ENSURE, 2011), *how prone is a system to be damaged in case of a given stress*. It is a measure of fragility and weakness. Systemic vulnerability is a factor of vulnerability as well as something more, a dimension related to emergencies, that looks at the interrelations among the different vulnerability dimensions. It gets important in an urban extent, taken as a system to be understood in all its interrelations and effects. For this study, systemic vulnerability is mostly focused on accessibility analysis, thanks to blocks and roads measures and attributes. Infrastructures as roads can be very important: in case of risk, it would be fundamental that all places would be accessible towards the inner or the outwards of the city. Particularly, they could be fundamental in the alarm phase evacuation of Red Zones or to manage emergency after the event and it is very important to assess the places that would experience more problems regarding it, thus the places more vulnerable about accessibility of their system.

The analysis of the accessibility-related systemic vulnerability has been more articulated with respect to exposure one; it has exploited different levels of detail, starting from the study of the whole hazard zones, zooming then to Naples urban extent comprised in their areas, and finally comparing each expansion area within each hazard zone. For all levels of detail, in the end it has been exploited a **ranking analysis** that has been useful to compare the different hazard zones looking at the whole of their territories or just at Naples urban extent included into, focusing also on the single expansion areas. The result coming out by these different levels of detail has been always represented with a map showing the ranking related to their whole systemic vulnerability or their urban extent systemic vulnerability. All these levels of detail allow to provide a more reliable assessment of systemic vulnerability as well as the possibility to underline the smaller areas that could be more systemic vulnerable to risk, in an accessibility perspective.

Rankings have been exploited since they could be a great tool to guide decision-makers into an urban planning more integrated with risk mitigation strategies. It is important to highlight here that not all measures and trends from the first part of methodology are exploited in the ranking analyses for the two factors, however, all of them have been important to better understand first the context of analysis and then to look at urban growth and the urban fabric actual layout from different points of view. An example could be also the zoom that has been performed about land use in the volcanic hazard zones, that has allowed a temporal and spatial analysis for the different land uses.

Chapter 4

APPLICATION TO THE CASE STUDY:

FROM SATELLITE IMAGERY AND GIS TO NAPLES URBAN EXPANSION FROM A RISK PERSPECTIVE

This chapter describes the different steps that have been taken to apply the methodology of this study. Thus, it corresponds to the application of the previous chapter. It is for this reason that still it will be divided into the two parts that constitute the methodology, in a way to focus on the different aspects and techniques that have been involved by the chosen objectives. For this reason, the initial steps linked to the mapping and measuring Naples urban expansion alike the Atlas of Urban Expansion (Angel, et al., 2016a; Angel, et al., 2016b), will constitute the first part of this application, while the analysis of the maps and attributes, obtained by the first part, to look at the exposure growth or vulnerability (particularly systemic vulnerability, linked to the accessibility) of the city with respect to volcanic risk, will be described in the second part of the chapter. There, it will be provided a focus about the steps from the proposed ranking analysis.

Therefore, the first part of methodology will be devoted to the classification of satellite images and the procedures to obtain the different measures and attributes suggested by the Atlas, while the second one will focus on the proposed application of those data for the field of risk, particularly for the analysis of exposure growth over time and for accessibility in the different expansion areas.

4.1 Mapping and measuring the urban expansion

The Atlas of Urban Expansion has the merit to have mapped and measured a phenomenon such as the last forty years of general unplanned growth of cities in the World. Authors before had described it (Gencer, 2013) but there was still the need to have a measure of it to know it better and help decision makers to choose in future with more consciousness. However, as already mentioned, the Atlas of Urban Expansion does not provide maps and measures for Naples. That is the reason why the first steps of this study, which will be later explained in detail, take inspiration by the Atlas to develop similar measures, maps and attributes for this city, being subjected to volcanic risk, from Vesuvius but also from Phlegraean Fields. This first part of methodology, therefore, starts from the very beginning with choices of satellite imagery and classification to be performed on, to follow with all procedures performed on GIS that were fundamental for a more detailed classification of the area and then to achieve the attributes suggested by the Atlas.

4.1.1 Choice of satellite imagery

Every study needs data to be collected as a starting point. Here, as for the Atlas of Urban Expansion, the first fundamental data to look for is *Satellite imagery*. Particularly, satellite imagery about the area of study of Naples, at different times in the last fifty years. There is a huge amount of free imagery on the Web and the choice of the most suitable images can be challenging as well as the choice of the provider. This is the reason why the analyst needs some criteria to guide the choice, based on theoretical concepts as well as on the purpose of using the images.
Satellite images are possible thanks to **Remote Sensing** discipline. According to theory (Lillesand, et al., 2015), *Remote Sensing is the science and art of obtaining information about an object, area or phenomenon through analysis of data acquired by a device that it is not in contact with the object, area or phenomenon under investigation*. That means it is a wide discipline that includes different types of means (sensors) that collect data remotely, to analyse them and to obtain information. Thus, according to (Lillesand, et al., 2015), satellites are just one of these possible sensors, they are *electromagnetic energy* sensors, that operate by *spaceborne* platforms. They acquire data of the surface of Earth exploiting different ways of different features of emitting and reflecting electromagnetic energy. These sensors are differentiated by (Lillesand, et al., 2015) in *active* or *passive*. They are called *passive* when they *receive* the energy reflected or emitted by Earth features, while they are *active*, as for radars, if they illuminate objects with their own source of energy waiting for reflected signal to come back. There are a lot of different spaceborne sensors so that, when searching for Satellite images, about an area of interest, the analyst needs to choose among them, following some criteria. First, as it may have been understood before, he needs to know **radiations principles** that are at the base of this science. That is because they are fundamental to understand *how* data have been collected by a sensor and to discriminate among the different sensors. Indeed, radiation principles are the theory that lies behind *data acquisition* from all

types of sensing systems, determining also their characteristics. Here, some of these principles, the most relevant for a basic understanding of the discipline, are mentioned:

1. Every object, that has temperature T higher than absolute zero, emits energy M, proportionally to its temperature T.

4.1

$$M = \sigma T^4 \ (Stefan\ Boltzmann\ law, \sigma = constant\ )$$

2. This energy radiates following *wave theory*, that obeys the following equation:

4.2

$$c = \nu\lambda$$

Where c is a constant ($3^* \ 10^8$ m/s), ν is the frequency and λ is the wavelength. Thus, frequency or wavelength (inversely proportional) characterize the wave.

3. Wavelenght λ can be related to the energy radiated. According to (Lillesand, et al., 2015), inverse proportion between them can be obtained remembering the particle theory for radiations rewritten in this shape:

4.3

$$Q = \frac{hc}{\lambda}$$

With
$Q = energy\ of\ quantum, J$
$h = \ Plank's\ constant, 6{,}626 * \ 10^{-34}, Js$
$c = 3 * \ 10^8 \frac{m}{s} and\ \lambda = wavelength, \mu m.$

4. Following with reasonings, *Wien's displacement law,* starting from spectral distribution of the total radiant exitance M, previously mentioned by Stefan Boltzmann, states the following:

4.4

$$\lambda_m = \frac{A}{T}$$

Where:
$\lambda_m = wavelength\ of\ maximum\ spectral\ radiant\ exitance,$ μm
$A = 2898\ \mu m$
$T = temperature, K$

Summarizing: the hotter is an object, the higher is its maximum spectral radiant exitance, M, (according to Stefan Boltzmann) but the less will be its maximum wavelength related to that M (according to *Wien's displacement law*). Thus, the sun, the first principal source of electromagnetic radiation, emits with small wavelengths, differently from the Earth features, with T≈300K, that emit only with long wavelengths, longer than 3μm (Lillesand, et al., 2015). In Remote Sensing it is common to categorize waves by their **wavelength** location (spectral band) within the *electromagnetic spectrum,* represented in Figure 4.1 (Lillesand, et al., 2015).

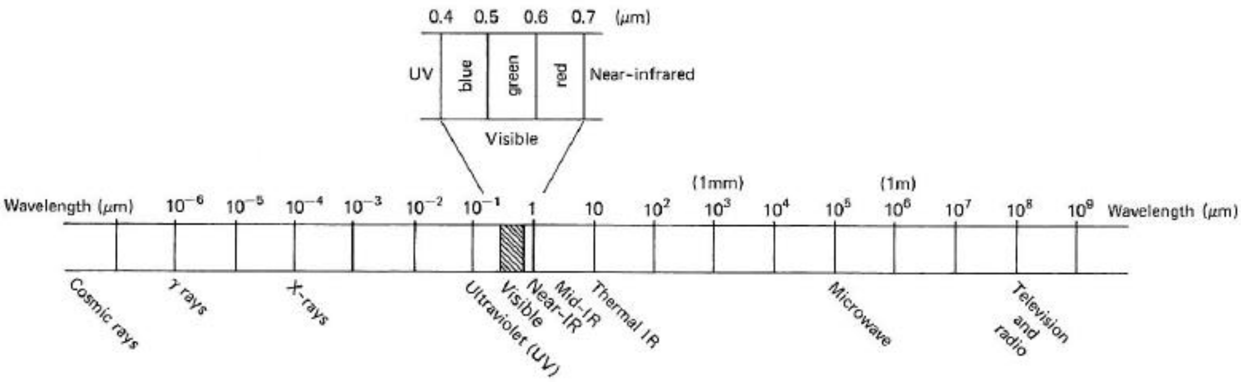


Figure 4.1 Electromagnetic spectrum. Retrieved from (Lillesand, et al., 2015).

All sensors can be sensitive to different values of wavelengths. Human eyes are sensitive to wavelengths from approximately 0,4 to 0,7 μm. Thus, reasoning about the principles explained above, what they can observe is just virtue of *reflected* solar energy, they cannot look at *emitted* energy from Earth objects. On the other hand, electromagnetic sensing systems are designed to detect a wider spectrum of wavelengths, so that, there are sensors capable of detecting also emitted radiations from Earth features, for example in the Thermal Infrared (IR) wavelengths. Here lies one of the first criterium to look at, when choosing among different satellite sensors as providers for data. *Some satellites can be sensitive to some types of wavelengths that others cannot detect.* The choice would be related to the purpose of the study and the information that the analyst wants to be stored in the image.

But still, to know which wavelengths are the most suitable to the study's purpose, an important concept needs to be explained: the **spectral signature**. Coming back to the concept of radiation, an object can be hit by energy emitted by a source: a part of this energy will be absorbed, another transmitted and the last part reflected. According to Lillesand et al. (2015), the *spectral reflectance* is the ratio between this energy reflected and the first incident one. This spectral reflectance depends by wavelengths investigated in the sense that an object hit by incident energy can reflect more or less part of it depending by the wavelength looked at (Lillesand, et al., 2015). The curve that represents this behaviour for that particular object is the spectral reflectance curve, or that mentioned *spectral signature*. Looking at features as vegetation, soil, water, sand, snow it is possible to distinguish them thanks to their different *average* spectral signatures (Lillesand, et al., 2015). Figure 4.2 shows some spectral reflectance curves for different features. From the figure it can be observed that there are wavelengths for which features have a similar reflectance and others for which they can be easily recognized. It is for this reason that a certain range of wavelengths (band) could be more significative than another one if the purpose is to differentiate for example between vegetation and water (in this case, IR wavelengths, that would be more significative than blue band). That is the reason, finally, why choice of satellite sensors, from which to get satellite imagery, needs to consider the wavelengths to which the sensor is sensitive to and the values that would be more significative for the purpose.

However, it should not be forgotten *variability*: as mentioned before, these curves represent an average behaviour for groups of objects that can change significantly due to spatial or temporal effects. Taking grass for exemplum, depending by season, climate conditions and geographical location its spectral signature changes, as it could be represented just by the different curves for dry or green grass in Figure 4.2. Moreover, it should be considered also that a sensor does not receive and detect the pure reflected radiation, but atmosphere, geometrical influences, shadows have changed it.

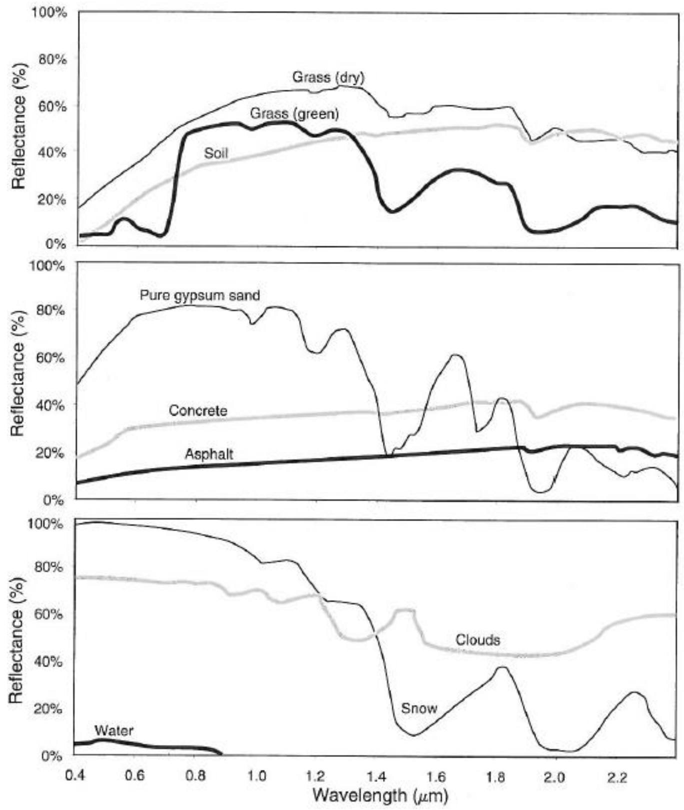


Figure 4.2 Spectral signature of different features. Retrieved from (Lillesand, et al., 2015).

In the end, considering therefore which would be the most significant wavelengths to search for, when choosing satellite imagery for this study, it is important to remember first how they

will be analysed: the first step, after having images, will be to classify them to derive the Selective Land Cover maps of Naples at different times, for the last fifty years. To classify is to identify the different Earth features represented in a scene by means of pixels categorization, particularly, on a spectral basis (it will be better addressed at 4.1.2). Here the first features to be recognized are *Built-up*, *Open Space* and *Water* lands. These classes are very wide. Sure, for Open Space Near and Mid IR bands will be useful, in the way to better distinguish its vegetation. Visible bands are also good, for example for built-up but also for water, as it reflects only in these wavelengths. There is no need for thermal-IR here as well as longer wavelengths as micro-waves, that would be detected only by active sensing systems. Here, therefore, only *passive* sensing systems will be exploited.
However, wavelengths detected are not the only criterium to look at when choosing satellite images. This study calls for a **temporal analysis** of the area, thus an important condition to be met is that images should be acquired at different times from the seventies up to present days. All satellites have a 'life', they are launched in a date and then, after some years, they can stop their functions. Thus, when looking for an image of a certain period it is important to remember which satellite sensor could be working at that time. *The choice is here to take a satellite image about every decade, from 1972* (the year of the launch of the first Landsat) *up to 2019*. Other conditions to be met, explained in the end, in addition to shortage of images from years seventies and eighties, have determined the fact that the interval of decade is less respected for those years.

Important aspects, still not mentioned here, are related to **spatial and radiometric resolutions**. While the number of wavelengths that a sensor could detect is related to spectral resolution of a sensor, spatial and radiometric resolutions are linked to the digital nature of satellite images. Digital satellites images are constituted by *pixels*, discrete picture elements, each with a value, a Digital integer Number DN, that corresponds to the average radiance measured in each pixel for a certain range of wavelengths (Lillesand, et al., 2015). Thus, each pixel represents a small unit of the area acquired in the image and the value DN stored in that pixel is linked to the average brightness in a band that the sensor measures coming by that unit of area. For each pixel there will be a DN stored in it, one for each detected band (images are called multispectral when more bands are detected). Digital number DN can go from 0 (black) to 2^n-1 (white) with n=number of bits to store information; usually it is 8 bits. Number of bits to store information is related to *radiometric resolution* of a sensor. The more the bits the more the detail. But also, due to the averaging of radiance measured for each pixel, size of pixels is of great importance, it decides the *spatial resolution* of a sensor. If a satellite has a spatial resolution of 30m it can happen that in a detected area 30m x 30m there are more features: these ones will be 'mixed' in the corresponding pixel with troubles when having to recognize spatial details (Lillesand, et al., 2015). Therefore, every application needs to ask itself the level of detail it needs stored in the satellite images it will use. Different providers and different sensors give different spatial and radiometric resolutions. For this study, having to derive a first land cover classification from satellite images, following also the exemplum of the Atlas of Urban Expansion (Angel, et al., 2016a), *it was decided for spatial resolutions between about 60m and 10m*. This choice agrees with the USGS land cover land use classification system for remotely sensed data (Anderson, et al., 1976). An insight on their general rules (Anderson, et al., 1976) is given in Table 4.1. Their classification levels are related to the level of detail that the analyst wants its land cover land use map to describe, from I, the most generalized level, for users who desire data on a nationwide, interstate, or state-wide basis, up to Level IV for municipal purposes. Each level of detail needs an appropriate spatial resolution of the image to be classified. Here, the study needs a low to moderate resolution satellite data, having to classify at the beginning just Built-up, Open Space and Water lands.

Table 4.1 Representative formats for image interpretation at different levels of detail. Adapted from (Anderson, et al., 1976).

Land Use/Land Cover Classification Level	Representative Format for Image Interpretation
I	Low to moderate resolution satellite data (e.g. Landsat MSS data)
II	Small-scale aerial photographs; moderate resolution satellite data (e.g. Landsat TM data)
III	Medium-scale aerial photographs; moderate or high-resolution satellite data (e.g. IKONOS data)
IV	Large-scale aerial photographs; high resolution satellite data (e.g. Quick Bird data)

Spectral, spatial, temporal and radiometric resolutions are fundamental aspects to choose the sensors that would provide the satellite images. It is also not to be forgotten that their imagery needs to be free. Two different providers were exploited: **Landsat** and **Sentinel**.
Landsat is a U.S. Program that provides free Earth imagery since 1972. It is part of the USGS *National Land Imaging* (NLI) *Program*, with the aim of continuously providing space-based images of the Earth's land surface. Through the years it has developed three generations of satellites looking at the Earth: from Landsat 1-3 (working between 1972 and 1983), passing through Landsat 4-5 (1982-2010) up to the modern Landsat 7 (sent in 1999, it is now partly operational) and 8 (from 2013, partly operational). Through the different generations the spatial, spectral and radiometric resolutions have improved more and more:

- Spatial resolution: from 80-60m (Landsat 1-3), passing through 30m/120m (120m for the thermal band, Landsat 4-5), up to 15m/30m/100m (15m for panchromatic band, 100m for thermal bands, 30m for all other bands, Landsat 8)
- Spectral resolution: from 3-4 bands, up to 11 bands (Landsat 8)
- Radiometric resolution: from 6 bits up to 12 bits (Landsat 8).

Sentinel, differently from Landsat, is a European mission recently born. It is part of *Copernicus Programme*, coordinated and managed by the European Commission, looking at our planet and its environment for the ultimate benefit of all European citizens. The Sentinel Programme aims at providing vast amounts of global data from satellites. The information services provided are freely and openly accessible to its users. First Sentinel satellites are Sentinel-1A launched in 2014, Sentinel-2A launched in June 2015 and its twin Sentinel-2B in March 2017. While Sentinel-1A uses SAR Synthetic Aperture RADAR and here will not be exploited as sensor, the two Sentinel-2, on the contrary, aim at providing high-resolution optical imagery. Their sensors have 10m/20m/60m spatial resolution, 13 bands as spectral resolution and finally 16 bits of radiometric resolution. Vegetation, soil and coastal areas are among their monitoring objectives.
Finally, Table 4.2. shows the sensors chosen, as well as their chosen spectral bands with their spatial resolution.

Table 4.2 Satellite sensors considered for the choice of images. Data courtesy of U.S. Geological Survey and Copernicus.

Sensor	Satellite	Chosen spectral bands	λ [µm]	Band Applications	Spatial resolution of the sensed band [m]	
Multispectral Scanner (MSS)	Landsat 1 (1972-1978)	1- Green	0,5-0,6	Sediment-laden water, delineates areas of shallow water	80	Resampled by provider into 60m ground pixel
		2-Red	0,6-0,7	Cultural features	80	
		3- NIR	0,7-0,8	Vegetation boundary between land and water, and landforms	80	
		4 - NIR	0,8-1,10	Penetrates atmospheric haze best, emphasizes vegetation, boundary between land and water, and landforms	80	
Thematic Mapper (TM)	Landsat 5 (1984-2011)	1- Blue	0,45-0,52	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation	30	
		2-Green	0,52-0,6	Emphasizes peak vegetation, which is useful for assessing plant vigour	30	
		3-Red	0,63-0,69	Discriminates vegetation slopes	30	
		4- NIR	0,76-0,90	Emphasizes biomass content and shorelines	30	

		5- SWIR 1	1,55-1,75	Discriminates moisture content of soil and vegetation; penetrates thin clouds	30
		7- SWIR 2	2,08-2,35	Hydrothermally altered rocks associated with mineral deposits	30
Multispectral Instrument (MSI)	Sentinel 2B (since 2015)	2-Blue	0,46-0,53	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation	10
		3- Green	0,54 - 0,58	Emphasizes peak vegetation, which is useful for assessing plant vigour	10
		4-Red	0,65 - 0,68	Discriminates vegetation slopes, cultural features	10
		8- NIR	0,78 - 0,89	Emphasizes biomass content and shorelines	10
		8a-Vegetation Red Edge	0,85 - 0,87	snow/ice/cloud detection, or vegetation moisture stress assessment	20
		11- SWIR	1,56 - 1,66	Discriminates moisture content of soil and vegetation	20
		12-SWIR	2,09 - 2,28	Hydrothermally altered rocks associated with mineral deposits	20

So far, this chapter has focused on the principal aspects when choosing for sensors but there are still a lot of other crucial aspects to be considered when choosing for satellite imagery. It is for this reason that the image selection criteria needed to be studied carefully and in a comprehensive way before performing any analysis. The other criteria considered here are schematized below:

1. Images are preferable with 0% of cloudiness to not loose data in some of their areas depicted.

2. Radiance values, thus DNs of pixels, can change due to sun elevation or Earth-Sun distance. Sun elevation changes through seasons as it is shown in Figure 4.3 adapted by Lillesand et al. (2015), thus the radiance that will be sensed by satellite will be higher in Summer than for example in Winter, according to the authors (Lillesand, et al., 2015). Earth-sun distance works in a similar way. Thus, since the following analyses want to exploit and numerically compare data from different satellite

imagery of different times, it is better to have satellite images acquired in the same period of the year.

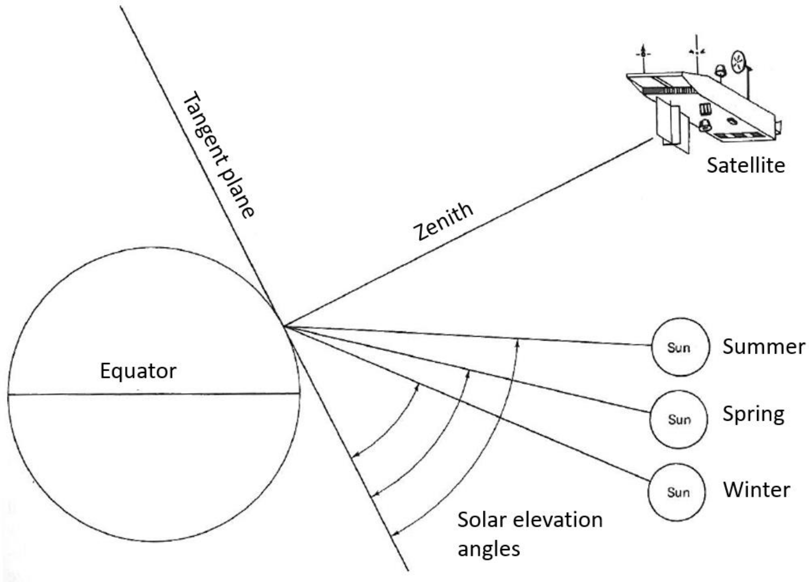


Figure 4.3 Different solar elevation angles in different seasons. Retrieved from (Lillesand, et al., 2015).

3. It is better a high sun elevation to reduce shadows in the images.

4. It should be remembered the concept of variability explained above for spectral signature of objects. An image in a season shows different colour tones and patterns than in another one and sometimes also the same period could bring to different information to be collected, depending by the weather and meteorological conditions occurred at the time of caption and before. These can be huge differences when looking at for example the Open Space class: vegetation, particularly in crops, change through seasons and climate conditions and a field that in summer can be much green, highly reflecting in IR band, in winter, on the contrary can become a barren field. Thus, in a season as summer, vegetation could reflect more in the IR band yielding to a clearer different spectral information between the Open Space class with respect to the built-up lands. It has been demonstrated by (Saadat, et al., 2011) that the best period for land cover and land use mapping in a vegetated area is late summer. However, their studies were developed in Iran, it would depend also by local knowledge also about human interventions on vegetation through the year (like periods of irrigation, grazing...).

Therefore, in the end images were chosen when acquired in summer, trying to get dates of caption the nearest as possible. Sun elevation was chosen when at 60-62° given that higher values are very difficult to be found due to the design of today sensors. In Table 4.3 are finally presented the images that have been chosen as first data for this study.

Table 4.3 The chosen satellite images.

Satellite images	Date of caption	Sensor	Grid cell size [m]	Radiometric resolution [bit]	Spectral Bands	Sun elevation [°]	Cloud cover land	Origin
S2B-20190811	11/08/2019	Sentinel 2B	10	16	7	60,0	0%	Image courtesy of Copernicus
LT05-20080731	31/07/2008	Landsat 5 TM	30	8	6	59,1	0%	Image courtesy of the U.S. Geological Survey
LT05-19980602	02/06/1998	Landsat 5 TM	30	8	6	62,2	0%	Image courtesy of the U.S. Geological Survey
LTO5-19840627	27/06/1984	Landsat 5 TM	30	8	6	60,6	1%	Image courtesy of the U.S. Geological Survey
LM01-19720809	09/08/1972	Landsat 1 MSS	60	8	4	55,2	1%	Image courtesy of the U.S. Geological Survey

4.1.1.1 Delimitation of the area of study

The chosen satellite images, represent the area of Naples in a wider context, depending by the image spatial resolution (Landsat 1 image represents a large portion of Middle-South Italy, while the Sentinel image represents a smaller area, limited to Campania region). The first step was to cut the satellite images in the way to focus their area on Naples. The 2016 ISTAT borders of the city were useful to understand where to cut the area: Naples province needs to be entirely comprised in the area of study (all but Capri, that, for some years data, had been acquired in separate different satellite images than the ones that had detected the rest of the Province; it was considered not important for the aim of this study, thus not included in the area of interest). To define the size of the area, it has been important to check to include in it also the hazard zones for Phlegraean Fields, as well as for Vesuvius (that will be treated after). Finally, it was decided to consider also the area north of Naples representing Caserta city, since very near to the regional capital, to look at possible interactions in the whole urban extent. When cutting the area of study, a rectangular shape should be maintained. In Figure 4.4 the cut satellite images, that correspond to the first data of this study, are reported.

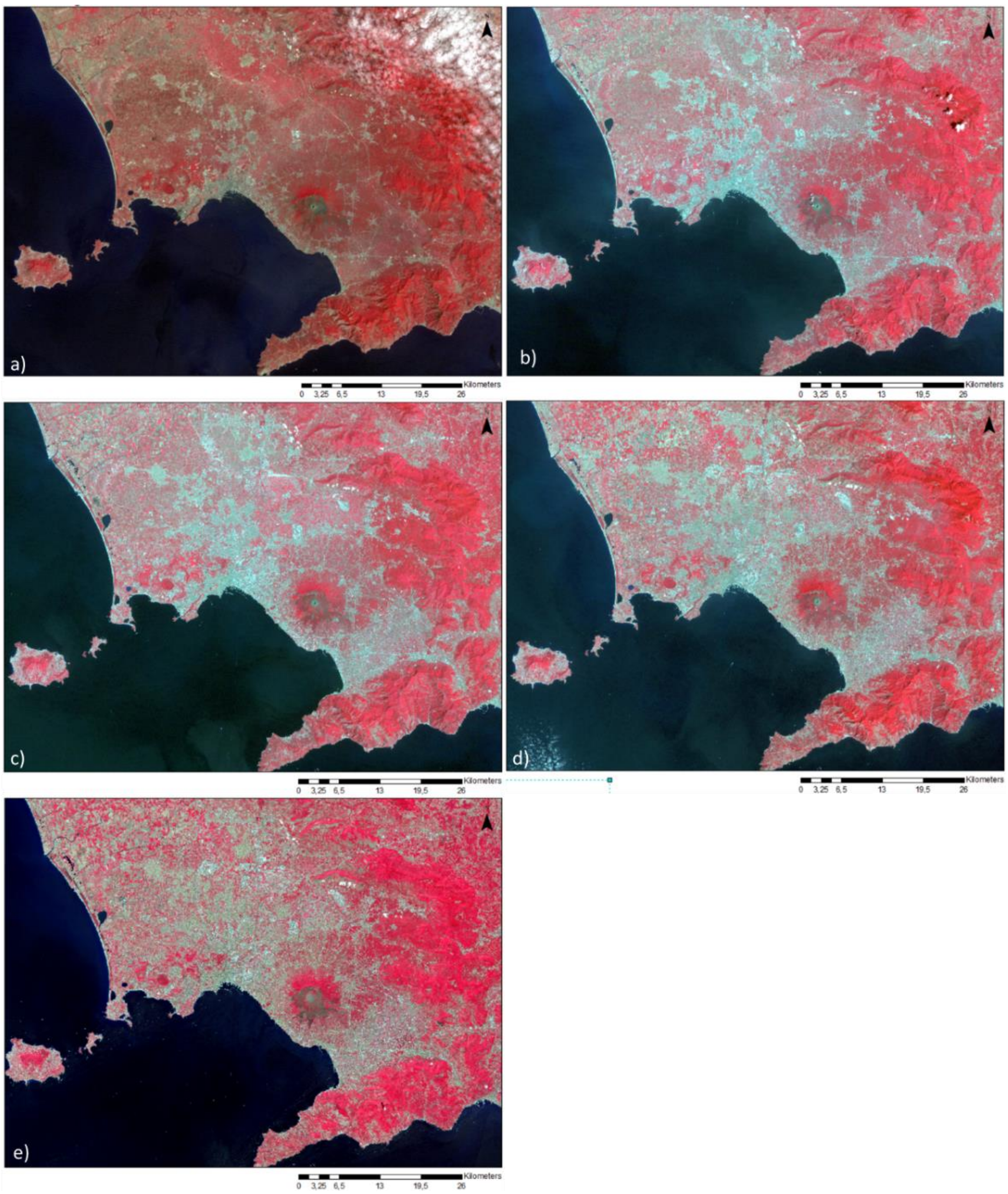


Figure 4.4 Satellite imagery cut on the area of study: a) represents year 1972, b) 1984, c)1998, d) 2008 and e) 2019. They are represented here with their false colour composite (to be more comparable to 1972 image that has no blue band).

4.1.2 Classification of satellite images to develop Selective Land Cover Maps

Once that satellite imagery has been collected, it is possible to start *data analysis*. The aim is to start from the images to provide information about the Earth surface features that are represented there. As for the Atlas of Urban Expansion (Angel, et al., 2016a), this study started the analysis with image classification to derive for each of them a first land cover map where pixels of the satellite images are classified into three different classes: B*uilt-up*, *Open Space* and *Water*. To clarify, a land cover map is a spatial representation and categorization of different types (classes) of physical coverages of the Earth's surface. A classification is the set of procedures to identify these different features in a scene, categorizing pixels as one or another land cover class (Lillesand, et al., 2015). Categorization is applied focusing on spectral, spatial or temporal patterns, according to Lillesand et al. (2015), and the intent is to make it automatically, in the way that results could be repeatable by different interpreters. This last is an important criterium defined by USGS Classification System (Anderson, et al., 1976). It is also for this reason that *computer assisted techniques* can be useful and often visual interpretation only is not enough. Remote Sensing has been described as '*a tool best applied in concert with others*' (Lillesand, et al., 2015). Computer assisted techniques can help also the analyst recognizing spectral patterns remedying human limits in evaluating this kind of characteristics, as it is written by Lillesand et al. (2015). This study used as first tool the software application ENVI, that allows to process and analyse geospatial imagery.

With the aid of ENVI, classification was performed, based on spectral patterns recognition. It meant to perform a numerical categorization of pixels upon their digital numbers DNs. Computer assisted techniques have been useful here in the way they can take advantage of numerical format of information stored in pixels to help categorizing them, according to their spectral patterns. However, it did not mean that the analyst gave a small contribute on classification and it did not mean the result could be 'perfect', 100% sure. Classification can be really time consuming and a matter of experience. Lots of trials need to be tested before to find out the best method that would suit the purpose. And still, error has to be accepted inside. However, the aim of the analysis is to provide the best classification that the data could permit, following also the criteria for land cover classification defined by (Anderson, et al., 1976). Particularly, it was important that results of different times could be comparable among themselves, as well as the overall accuracy of the results being higher than 85%.

There are different methods for classifications based on spectral pattern recognition. Some of these methods were considered to decide which one to use to classify all satellite images. The different tests were always performed on the same satellite image (the one of 2019) for a matter of consistence.

First, it was a matter of choice between *unsupervised* and *supervised classification*. Indeed, the *Atlas of Urban Expansion* (Angel, et al., 2016a) does not describe its choice of a 'human-assisted' algorithm.

4.1.2.1 Unsupervised classification

The unsupervised classification starts as *computer-based* (Lillesand, et al., 2015): different types of algorithms directly examine all pixels and aggregate them into spectral classes in function of their DNs. These spectral groupings are called spectral clusters (Lillesand, et al., 2015). Particularly, the analyst decides the number of spectral clusters the image has to be split in (or he decides a range of numbers of classes) and the algorithms, on a statistical basis, assign each pixel to a spectral class. Thus, the most similar pixels, in spectral information terms, will be assigned to the same cluster while when different will join different groups. It is important to recognize still that these spectral classes are different from information classes (e.g. built-up land or water): after classification operated by the computer, they still lack an identity, they are just aggregated in spectral clusters, defined upon similar DNs. Therefore, it is only after, when the image analyst compares these spectral classes with reference data, that spectral groups are assigned to information classes. The assignment of an identity to every spectral cluster, thus, is up to the image analyst, that can help himself with ground reference data.

There are a lot of different algorithms for the unsupervised classification. Here, the intent is to explore only the ones that were used to classify the 2019 satellite image. Their description is adapted from Lillesand et al., 2015. **K-means** is one of the most well-known ones. It receives from the image analyst the number of spectral groups to be searched for, then with an iterative procedure it identifies each time the centres of a spectral clusters assigning pixels to the closest ones in terms of mean vectors. Once that all pixels are assigned to a spectral cluster it recomputes centres for each cluster and reassigns pixels. The iterative procedures continue until results do not significantly change anymore from one classification to the next. The a priori setting of the number of clusters is the main limitation of the K-means algorithm (Raykov, et al., 2016). The final classification can strongly depend on its choice. In addition, the K-means is not particularly recommended in cases where the clusters do not show convex distribution or have very different sizes (Raykov, et al., 2016). However, besides having low computational cost, K-means can provide good results in many practical situations, it is for this reason it is commonly used. The **ISODATA classifier**, Iterative Self-Organizing Data Analysis Techniques A^2, is similar to K-means with the difference that number of spectral groups is not a-priori defined but can change through iterations, by merging, splitting or deleting spectral classes when maximum or minimum distance, decided before, between mean points of clusters are no more respected, or when a spectral cluster undergoes a number threshold of pixels part of it.

K-means and ISODATA classifiers are implemented in ENVI software, which is dedicated to satellite image processing. For K-means, input parameters, given to the algorithm, were the followings, it was chosen 30 as number of clusters (number decided after trials looking at best results, big enough to group different spectral clusters but not too much to confuse their limits). For ISODATA classifier, on the other hand, the chosen range for number of clusters went from 15 to 30.

In ArcGIS software, moreover, there is the possibility to use the **Iso Cluster Unsupervised Classification** tool. This one is based on the Iso Cluster and Maximum Likelihood Classification algorithms. The first mentioned algorithm uses a modified iterative optimization clustering procedure, also known as the migrating means technique, while the maximum likelihood classification will be better explained when talking about supervised classification. Also this algorithm needs an a-priori defined number of classes to group cells. Here it was chosen 50, again after different attempts.

It should be remembered again that the results provided by all these algorithms were no more than spectral clusters. They had to be labelled and classified (within information classes) by the analyst and often, more than one cluster belonged to the same information class. The assignation of information class was performed without ground reference data, but only thanks to visual interpretation of satellite images. It was possible also thanks to the very small number of information classes searched. However, difficulties were encountered particularly when some spectral clusters contained more different information classes among Built-up, Open Space and Water lands.

4.1.2.2 Supervised classification

The supervised classification has a different process with respect to the unsupervised one: according to theory (Lillesand, et al., 2015), it does not start by algorithms and machine computations; it starts with the analyst visual interpretation and experience. In this first step, called *training stage*, the image analyst specifies to computer algorithm the numerical descriptors of classes he wants the scene to be categorized in. There is, then, a second phase, the classification stage, when a computer algorithm classifies all pixels from the given descriptors.

Prior to training stage, as well as during it, due to the visual interpretation needed, according to theory (Lillesand, et al., 2015), it is important to **enhance the image,** as well as to decide how multispectral images are better to be displayed to help the analyst looking at patterns. Here, images were represented in their false colour composites (where red image component represents NIR band, green component represents red band and blue component represents green band). In this way, it was possible to look at differences in vegetation and crops as well as to understand better the differences with water and built-up lands. Moreover, image enhancement could provide a more effective display of the image. *Contrast manipulation* was exploited in ArcGIS, increasing the contrast among different DNs values. Particularly, it was performed contrast stretching, expanding the range of DNs recorded by the sensing system (represented by a histogram, a distribution of frequencies of DN values recorded in a band over an image) over the widest range as possible for the radiometric resolution of the image (for 8 bits values range from 0 to 255). The true range of DNs values was expanded with computations like the *histogram-equalized stretch* that was exploited due to its sensitiveness to frequency of DNs, with more display values assigned to the most frequently occurring values in the histogram.

Having data displayed in a clearer way, training stage could start. **Training stage** requires a big effort in terms of time and experience by the image analyst. Indeed, Lillesand et al. (2015) write that the training effort required is both *an art and a science*, it requires a close interaction between analyst and data as well as reference data and knowledge of the studied area. The objective of this stage is to assemble a set of statistics that describes the spectral response pattern for each class to be mapped. The image analyst needs to collect training areas, pixels that can describe the different classes in the most *representative* and *complete* way (Lillesand, et al., 2015). It means that for each *spectral class* constituting an *information class* there must be a pixel that represents that spectral class. Thus, a minimum of n+1 training areas need to be set for each information class to be researched for, with n equal to the number of spectral bands in the image (Lillesand, et al., 2015). However, there are information classes, e.g. this study's Open Space class, that are made of several different spectral classes. In this case, it becomes also a matter of statistics and the more pixels in training set the better the statistical representation of the information class. Nevertheless, too many pixels could create repetitions that can change the statistics of training set. For this reason, training areas are a matter of experience as well as the result of an iterative procedure with trials and refinements. For this study, trials meant different quantities of training areas as well as different sizes for drawing them to be tried. It meant different combinations of training areas based on the different spectral patterns recognized in the image. And, it meant also to try to split training areas for Built-up, Open Space and Water classes in training areas for more subclasses with less statistical variance inside. It is for this reason that this stage was really time consuming.

Each trial needs to be 'tested' for quality of its training set and then refined. It is the way to try to converge to the best training set for the image to be classified. As it is written by Lillesand et al. (2015), *training set refinement* is fundamental to improve, iteration by iteration, the representativity and completeness of training areas. Measures of quality for the new training set are needed each time to know if it is converging to the best one. First, it is important to look at histograms for each category and spectral band. According to theory (Lillesand, et al., 2015), histograms need to show a quite normal distribution. In case distribution is bimodal it means there could be more sub-classes in that category under study. So that, in the next iteration the image analyst can try to split that information class. This was the case, for this study, for Open Space training set: it was decided it to be split in Vegetation and Bare Soil training areas. Indeed, looking at its histograms in NIR and Red Bands (in Figure 4.5, point a), for the 2019 satellite image), it was possible to recognize a quite bimodal distribution. Splitting the training set in two parts, referring to two new different sub-classes, allowed for histograms more resembling a normal distribution (Figure 4.5, points b, c).

However, it has to be admitted also that still in Red Band for both new subclasses there is a small second peak in the histograms. Refinement could proceed in that sense, however here this error is accepted. These subclasses, Vegetation and Bare Soil, could be mixed again into Open Space class after classification stage.

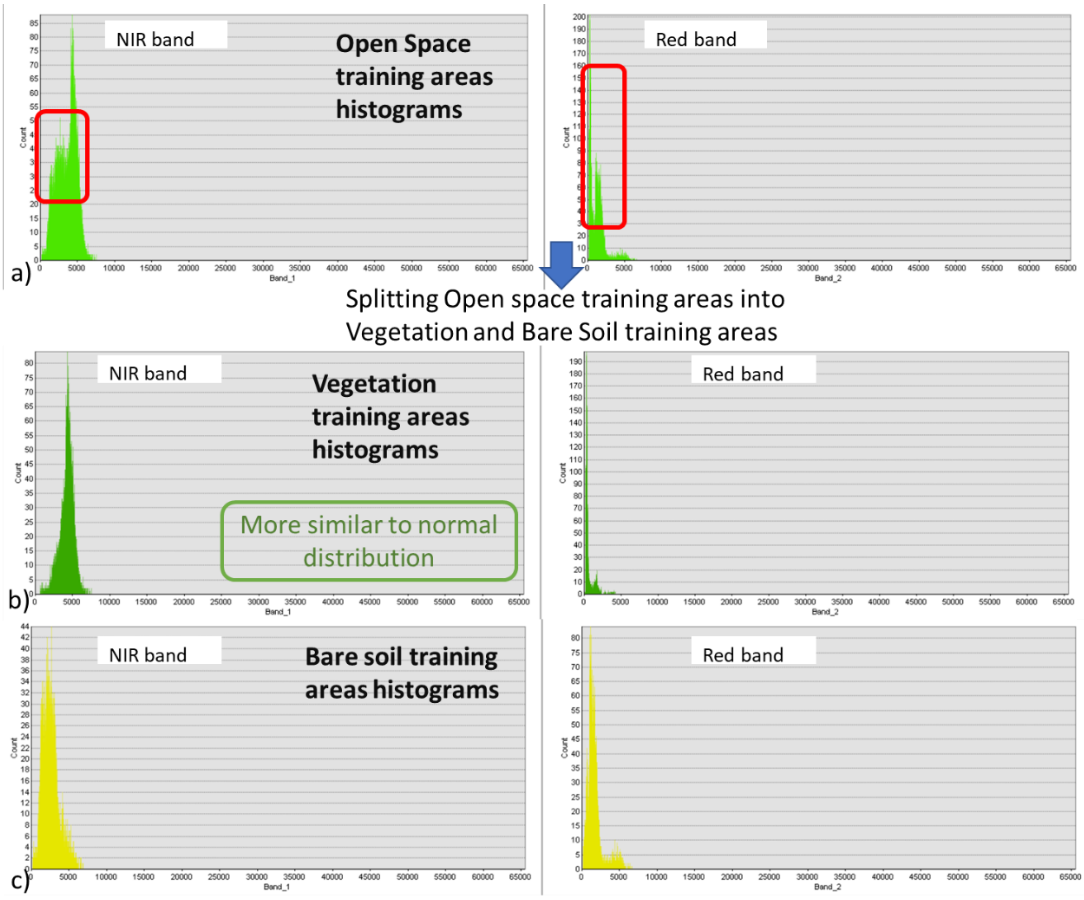


Figure 4.5 Histograms for NIR and Red bands for training sets of Open space class, point a), and then for its subclasses Vegetation, b), and Bare soil, point c).

Moreover, theory (Lillesand, et al., 2015) mentions *spectral separability* as a possible measure of statistical separation of the different information classes described by the training set. It can be computed numerically with different methods, as Divergence, Transformed Divergence, or Jeffries-Matusita distance. Each can be more or less meaningful, depending by training sets. All these methods look at distances among category means as well as statistical distributions of data points for each training set (Thomas, et al., 1987). ENVI software provides the possibility to compute separability with Transformed Divergence and Jeffries-Matusita distance. Transformed Divergence is a covariance weighted distance between category means, the larger it is, the greater will be the 'statistical distance' between two training patterns and the higher the probability of correct classification of the two classes. Jeffries-Matusita distance is like Transformed Divergence, a saturating function. Both Transformed Divergence and

Jeffries-Matusita distance tend to exaggerate results for small class separations and under-emphasize results for the greater separation (Thomas, et al., 1987). From separability measure, it was possible to see that in this study's 2019 satellite image separability between Built-up and Bare Soil training sets was not so clear, despite the different trials. Different refinements were tried and, in the end, it was accepted a separability of 1,34 according to Jeffries-Matusita distance. Table 4.4 shows final spectral separability for the last refinement of training sets for 2019 image.

Table 4.4 Spectral separability of training areas for 2019 image, according to Jeffries-Matusita distance (JMD) and Transformed Divergence (TD).

Spectral separability	Bare soil		Built-up		Open Space		Water	
	JMD	TD	JMD	TD	JMD	TD	JMD	TD
Bare soil			1,34	1,64	1,67	1,93	1,99	2,00
Built-up	1,34	1,64			1,95	2,00	2,00	2,00
Open Space	1,67	1,93	1,95	2,00			2,00	2,00
Water	1,99	2,00	2,00	2,00	2,00	2,00		

In the end, the training set for year 2019 was finally assessed, giving start to the **classification stage**. The classification stage is up to a computer algorithm. It takes the '*clouds of points'* (Lillesand, et al., 2015) representing multidimensional descriptions or spectral response patterns provided by training set and it performs the classification for each 'unknown' pixel in the output. There are several algorithms to compute classification. Among all of them it was chosen to use the *Gaussian Maximum Likelihood classifier*. This algorithm is not simple as it could be, according to Lillesand et al. (2015), the *Minimum-Distance-to-Means classifier*, or the *Parallelepiped classifier*, but, differently from these ones, it evaluates both variance and covariance of spectral patterns for each category to be classified. Indeed, it is statistically based and, as it is written in theory (Lillesand, et al., 2015), it starts by an assumption: the clouds of points, forming each category spectral response, follow a gaussian distribution. The algorithm computes statistical probability for each pixel value being a member of a certain information class. Thus, it creates probability density functions for each spectral category with whom each pixel is assigned to the most *likely* class. According to Lillesand et al. (2015), it is a great tool, but it requires many computations for each pixel, making it less computationally effective than other algorithms.

The Gaussian Maximum Likelihood classifier was performed on the ENVI software. ENVI took as inputs the satellite image with all its spectral bands, that were decided in chapter 4.1.1, and training sets defined on ArcGIS, later transported to ENVI as shapefiles. Training sets are defined on ENVI as ROIs, format conversion was necessary, before giving them to the classifier algorithm. After Maximum Likelihood concluded its computations, a new digital output, with all pixels categorized, was provided. The classification was then exported again to ArcGIS, but in a vector format, that is a limit for ENVI.

4.1.2.3 Accuracy assessment and choice for the classification method to be applied to all satellite images

Once that unsupervised and supervised classifications were applied to 2019 satellite image, it was time to test their accuracy, to decide the best result, thus the best method to be applied to all satellite images. Moreover, accuracy assessment is always necessary: '*a classification is not complete until its accuracy is assessed'* (Congalton, et al., 1999). Indeed, the error inside them needs to be numerically estimated, to have a measure of their quality. Here, accuracy assessment was used as a test for the different classification methodologies.

Quantitative accuracy assessment is of certain importance, providing a measure of map errors through comparison between sample points (test areas) on map and corresponding ground reference data. The error matrix, also called *confusion matrix*, stores these comparisons category-by-category. This matrix is built taking for column values the ground truth data while for rows the classification results. In this way, all diagonal elements in the matrix will refer to pixels correctly classified, while elements that are outside will correspond to errors, particularly the omission or commission errors. *Omission errors* are given by non-diagonal column elements in the matrix, they are useful to measure the share of pixels that were missed in an information class, thus, the pixels that should have been classified as a certain class but they were classified differently. Omission errors are related to the *Producer's Accuracy*, a measure of accuracy for each column category that has been correctly classified (a diagonal element for each column) divided for the total number of pixels of that certain class in ground-truth data. There are also the *commission errors*, computed for each row of the matrix, so for each classified category. Commission errors are related, differently, to the number of pixels that were wrongly put in an information class. From number of correctly classified pixels for a certain class divided by the total number of pixels classified for that class, it is computed the value for *User's accuracy*, always for each category. Omission and commission errors can provide important measures and findings about a classification. Moreover, it is possible to compute also the *overall accuracy* of a classification product: it is the sum of all diagonal elements divided by the total number of sampled pixels. Finally, *Kappa accuracy* is a measure of difference between actual agreement, between reference data and the classifier, and chance agreement between reference data and random classifier. It is another measure of accuracy of a classification map but, differently from the overall accuracy, it includes in its computations also the non-diagonal elements that correspond to errors. Obviously, the validity of accuracy assessment is based also on the samplings it uses. First, test areas need to be great in number to be statistically representative, better if more than 50 for each category to be tested, according to theory (Lillesand, et al., 2015). Second, only pixels, whose ground truth identity is sure, should be chosen. The choice is often to define test areas randomly, but it needs to be remarked that in this way the error matrix would tend to under sample small but potentially important areas.

Accuracy assessment was performed exploiting different tools from ArcGIS. Test set was created as *random validation points*, a group of points that keep in their attribute the value of both ground truth and classification results. Ground truth values were assigned to each point of the subset by means of visual interpretation of the satellite image. The number of points, first, was chosen to be just 100 that was consistent with the purpose of this first decisional stage.

From the results coming out by the different confusion matrices for the different results, it was possible to have a first insight on the most suitable way to perform classification for each satellite image. From Iso Cluster Unsupervised Classification, performed in ArcGIS, the overall accuracy turned up to be around 89% while the Kappa index showed a value of 81%. The ISODATA Unsupervised Classification showed better results with 91% overall accuracy and 84% as value for Kappa index. However, the best result coming from Unsupervised Classification algorithms was the one of K-means that gave at a first insight with 100 validation points 96% overall accuracy and 93% as Kappa index. After that, it was chosen to redo the validation of K-means results with 300 validation points, a number that can be statistically more reliable than 100, and its overall accuracy was recalculated as 94% with a Kappa accuracy of 89%. The accuracy was calculated also for the Maximum Likelihood Supervised Classification. First, as for the Unsupervised results, only 100 validation points were set, and the confusion matrix showed 95% overall accuracy and a Kappa index of 91%. Then, due to the good results, comparable with the K-means ones, a more precise validation stage was performed with 300 points. Now, the Maximum Likelihood Supervised Classification proved to be better than the K-means Unsupervised one with 95,6% overall accuracy and 92,2% Kappa Index. These numbers from the validation stage are clearly shown in Table 4.5. The second accuracy assessment was performed only for K-means and Maximum Likelihood classifications because Iso Cluster and ISODATA had proven already, with the test set of 100 points, they had a far lower accuracy with respect to the others.

Table 4.5 Results from the accuracy assessment for the different classifications applied on the 2019 satellite image. Two steps are shown: the first with 100 validation points and the second only for K-means and Maximum Likelihood classification products with 300 points for test set.

Validation results:		**overall accuracy**	**Kappa index**		**overall accuracy**	**Kappa index**
Iso Cluster Unsupervised Classification	**100** validation points	89%	81%	**300** validation points	/	/
K-means Unsupervised Classification		**96%**	**93%**		94%	89%
ISODATA Unsupervised Classification		91%	84%		/	/
Maximum Likelihood Supervised Classification		**95%**	**91%**		**96%**	**92%**

Therefore, in the end, it can be assumed that K-means Unsupervised Classification and Maximum Likelihood Supervised Classification show to be more accurate for this study. To finally decide which method to apply to all images a finer validation was produced with 300 points where ground truth was compared with classification results. Maximum Likelihood proved to be the best algorithm for this case study with this type of classification in *Water*, *Built-up* and O*pen Space* classes. Thus, it was chosen to analyse all satellite images over the years with the **Maximum Likelihood Supervised Classification**. And for year 2019, only the product of this classification was considered afterwards.

Therefore, then, all remaining satellite images for years 2008, 1998, 1984 and 1972 were classified, following the same steps that are described for the supervised classification. Particular attention had to be devoted to the training sets which have been redefined for each image. Every time training set for Built-up and Open Space needed to be consistent with data of that time and thus had to change. Size of training areas needed particularly to change from the smallest for classifying year 2019, with small spatial resolution, up to a larger size for the 60m spatial resolution of year 1972. Spectral separability proved to be a good tool in the way to get nearer to best solutions. Therefore, in the end, it was necessary to accomplish with error and perform, after, some improvements. Indeed, it was possible to intervene on the result after the classification and some errors that were clearly recognizable by the analyst were corrected by photo interpretation. That happened for example for a few pixels on the top of Vesuvius mistakenly taken as Built-up. These corrections were applied to all images, being careful to be consistent among the different analysed images, gaining in visual understanding of the map.

4.1.2.4 After classification: greenhouses, data conversions and spatial resolutions

Facing results of the first land cover maps of the different years, some issues were encountered. There were a lot of areas that were classified as Built-up being greenhouses. These greenhouses, in Naples area, were, and still are mostly, of the tube type, probably self-made, built with just tubes and plastic (an exemplum is provided in Figure 4.6). Thus, they can be quite seasonal.

Figure 4.6 An exemplum of a typical tube greenhouse in Neapolitan territory.

The question was if those greenhouses could be considered as Built-up land or not. For this study, Built-up land is artificial land mostly related to buildings, residential, industrial or commercial activities. The seasonality characteristic of greenhouses could not be consistent with Built-up category: what would be a greenhouse in Summer, could be a simple crop, classified as Open Space, in Winter. Moreover, according to the technical Province map for the built-up of 1998 (1998), provided by the WebGIS of Naples Province, greenhouses, are not to be drawn as Built-up. Indeed, even though they were recognized in the satellite image of 1998, they were not drawn as Built-up in that map. The decision was to follow the same choice of the Province, looking at greenhouses as Open Space, like crops. The issue was how to correct the land cover maps: it was tried to go back to supervised classification adding a training set to search for the greenhouses, as another sub-class of Open Space, but it proved to confuse the algorithm that did not distinguish industrial buildings from greenhouses, mixing, in the end, Built-up and Open Space. It was tried also a separate supervised classification to recognize the only greenhouses features, but still it did not work. Due to their wide spectral characteristics, they are difficult to be recognized separately, particularly for the satellite images of less spectral resolution. The choice was therefore to intervene on land cover maps after classification. Visual interpretation is up to the analyst's experience, it is not automatic. Here, the analyst needed to search in the satellite images, of the different years, a huge number of greenhouses and then manually correct the related features, on land cover maps, in a way to classify them as Open Space. It introduced error as well as it decreased the repeatability of the results. However, it was necessary for a correct representation of the area, as well as for statistics to be derived about urban growth.

Greenhouses' correction was performed with vector data. This was helpful for that stage, but it was related to another issue, the conversion of data from ENVI to ArcGIS. After classification, performed on ENVI, the new land cover maps were moved to ArcGIS. ArcGIS allows to work with spatial data in the form of raster or vector data. The landcover maps on ENVI were in an extension (.class) not compatible with ArcGIS. The only option was, therefore, to convert data in a format readable, and usable as classification, for ArcGIS and, the only way provided by ENVI, was to transform classifications in vector data. Vector data means here that the land cover map was split into polygons with borders given by arcs and nodes, based on point coordinates, linked among themselves, with the presence also of topological relationships recorded among the different features of the image. Here lies the first problem of that conversion: borders. Differently with respect to vectors, a raster layer, based on pixels, has 'blurred' borders, according to Lillesand et al. (2015). Therefore, the conversion from raster to vector introduces error in the borders of the different features, as it is described also by (Congalton, 1997). Moreover, land cover maps need to be retransformed, once in ArcGIS, into raster, to maintain them consistent with their meaning. Indeed, according to theory (Lillesand, et al., 2015), raster data represent spatially distributed phenomena by means of 'averaging' them with respect to the grid size, to the extension that a cell can represent, differently from vectors. Thus, it was exploited the command *Polygon to Raster* on ArcGIS, being careful this conversion would have been the least distorted. Despite distortions, classification products were still comparable among themselves, being subjected to the same procedures for conversion.

Finally, it has to be remembered that, from the satellite imagery, there was a difference in spatial resolution among the images. The 2019 image had the smallest spatial resolution, with 10m for Red, Blue, Green and NIR bands and 20m for the remaining other chosen bands. Also, the 1972 image had a cell size of 60 m, different from the other Landsat imagery of 30m cell size. It was decided to transform 2019 land cover map into a raster with 30m spatial resolution, in the way the image was more comparable with the others, without losing too much accuracy. While, the land cover map of year 1972 was considered with its 60m cell size (it would be wrong to give to it a better spatial resolution than it has). This last will be less comparable with respect to the other images from other years but it was chosen to be maintained for the importance of information stored by it. Moreover, it was seen that this discontinuity was not so large when compared to the other land cover maps.

4.1.2.5 After classification: handling with errors

Due to the manual corrections explained before as well as the classification procedures, it was necessary to handle with the errors that, for example, visual interpretation could have caused. Particularly, it was important to make all first results, coming by classification and post classification, consistent and comparable. To start this elaboration, it was necessary to start comparing land cover maps from the different years, particularly Built-up land. Comparison was made first by overlapping the different Built-up lands represented in each image from the most recent 2019 image to the oldest 1972 image. In this way, it was possible to see the growth of the city through the years. This image will be exploited later to derive measures for urban expansion. However, now the type of comparison chosen was of another type. It was chosen to overlap the Built-up lands in an inverse order with 2019 up to the others. Proposal for errors correction started here by a hypothesis, that was confirmed after by readings: what is Built-up in a year cannot be detected, years later, by satellite sensor in a way that it could be classified in that time as Open Space. What is Built-up ten years ago it is difficult it could be classified as Open Space in the image of today. Hypothesis is that Built-up should not disappear completely from a year to the others after, and even though there could be demolitions, still, terrain would keep track of it. Moreover, looking at the 'inverse overlapping' described above, it was possible to see, with the satellite images as reference, that, most of the times, pixels, that were classified in a year as Built-up and the decade after as Open Space, were pixels wrongly classified in the first previous image. An example could be a pixel, classified in 1998 land cover map as Built-up, while in 2008 as Open Space, that, compared with 1998 satellite image, is seen to be still a greenhouse or another type of Open Space.

Before correcting land cover maps, this hypothesis needed to be confirmed particularly for the area of study. It was searched a confirm that if there were demolitions, these ones could have been in small number and could have left sign of the previous building. This type of research was addressed to the issue of illegal buildings, for which demolitions could have been consistent, thus not negligible. Illegal buildings needed to be considered here, as recent studies (Legambiente, 2018) have declared that, still in 2018, in Campania region, 50,6 buildings over 100, are illegal buildings. And it is known that these buildings have not been constructed only in the last years, on the contrary, there was a boom for construction of illegal buildings already in the seventies (Berdini, 2010), with first laws as well as building amnesties from the eighties. Thus, if demolitions would have been carried out, their number could have been huge, and the hypothesis to correct land cover maps errors not consistent. However, as the report of Legambiente and ISTAT (Legambiente, 2018) states, from the last building amnesty of 2004 up to 2018, from 16.596 known decrees of demolition only the 3% demolitions have been applied (just 496 buildings for the whole Campania region) and only the 2% (310 buildings) were acquired by municipality. And still, it has to be mentioned, it is difficult also that an illegal

building receives a decree for demolition due to legal quibbles. Moreover, it could be considered that illegal buildings built before year 2004, with 1985 and 1994 building amnesties, had not been subjected to more demolitions than the ones operated in these recent times. The number of demolitions, thus, is irrelevant, particularly for the wide area of study and the spatial resolution of 30m-60m.
It was possible to apply the hypothesis and thus the correction. Correction was applied in an automatic way, intersecting the different Built-up lands calculated for the different years. In this way, the intersection between a year land cover map and the ten years after other land cover map, is the considered Built-up land for the previous decade. The methodology to apply this intersection, on ArcGIS, among raster data, was the following:

1. It was considered land cover maps from one year, *landcover(i)*, and the decade before, *landcover(i-1)*;
2. In these land cover maps Built-up had value of 1 while Open Space 2 and Water 3;
3. With *Raster Calculator*, it was applied a logic proposition to find out the pixels that were classified as Built-up (thus, value 1) for both the land cover maps. The logic proposition was the following:

   (*"landcover(i)" ==1) & ("landcover(i-1)" ==1) =Built-up(i-1)*

   The result, *Built-up(i-1)*, was a raster with 1 for the corrected Built-up land of i-1 year and 0 for Open Space and Water;
4. *Built-up(i-1)* was reclassified in *RBuilt-up(i-1)* with 0 for Built-up land and 1 for Open Space and Water lands
5. With Raster Calculator it was performed the following computation:

   *"Built-up(i-1)" + "RBuilt-up(i-1)" * "landcover(i-1)" = "selective(i-1)"*

   Where *selective(i-1)* is the final first Selective Land Cover map of the year i-1, called Selective to be differentiated with the next classification that will be explained in chapter 2.1.3. This new land cover map has still 1 for Built-up land, 2 for Open Space, 3 for Water.

This process needs to be made in order, first for 2008 and 2019, then 1998 and 2008 and so on until 1972, in a way to compare the year i-1 with the year i previously corrected. In this way the only year that is not corrected remains 2019 year, but it is to remember that this year had a better spectral, radiometric and spatial resolution than the others from the satellite image. Thus, it could be accepted to be as it is, also because the objective is to make maps comparable and consistent among the years.

Image classification, as well as post classification corrections are concluded, it is now possible to integrate these data in ArcGIS, overlap land cover maps and derive statistics about categories in the scene.

4.1.3 A GIS-based subclassification for urban extent definition

With the end of classification and its issues, it is time to analyse, synthetize and integrate its results in ArcGIS. According to Lillesand et al. (2015), a GIS (Geographical Information System) can allow to manage data in a more comprehensive and complete way, allowing for monitoring Earth's features. The previous step ended with the so called Selective Land Cover Maps, in raster format, in which three classes were categorized: *Built-up* (value 1), *Open Space* (value 2) and *Water* (value 3).These maps could allow to generally measure the growth of built-up land over years in the area of study. However, thanks to GIS it was possible to derive other important measures more relevant to the city's expansion itself and its quality. It was possible to apply different computations in order to manipulate data coming by the first classification, in a way to develop newer land cover classes, with more detail. The procedures followed, and here explained, were inspired by the Atlas of Urban Expansion (Angel, et al., 2016a) that provided the guidelines and theory behind the finer subclassification here applied (see 2.2 and Table 2.1). Therefore, Subclassification was necessary to develop, in the end, the different urban extents of Naples city, at the different times, as the Atlas did for its 200 studied cities.
The finer classification started with **Built-up** class. Each Built-up pixel was reclassified into the following categories: *Urban*, S*uburban* and R*ural*, depending by the share of Built-up in its neighbourhood of 1km^2, considered as the Walking Distance Circle. The definitions for each subclass are the same of the Atlas and are to be found at Table 2.1.
Also **Open space** was sub-classified, as the Atlas, into U*rbanized* and R*ural* Open Space. The first being affected by the presence of a city, and the other, far from it. Moreover, Urbanized Open Space could be of type *Captured* or F*ringe*, again following the names and definitions given by the Atlas (Angel, et al., 2016a), explained at Table 2.1.
The procedures to get these subclasses started with Built-up categorization to finish with Open Space subdivision. All computations were performed in raster format. Built-up subdivision needed a tool to compute the spatial statistics of the circular neighbourhood around each pixel: *Focal statistics* was exploited, considering a circle of 20 cells radius (or 10 for the 1972 image, due to its pixel size of 60m, instead of 30m), around each pixel. It is a tool on ArcGIS that allows to calculate for a cell the average value of the pixels around. However, to be useful, it needed a reclassified land cover map in input with just value 1 for Built-up and 0 for the remaining classes, in a way that if it detected an average value higher than 0,5 it would have meant that more than 50% pixels around were Built-up, thus the studied pixel would have been classified after as Urban Built-up. The same for the other classes with average values to be between 0,25 and 0,5 for Suburban and less than 0,25 for Rural Built-up. This strategy gave some errors near seaside, with the more coastal pixels classified as Suburban or Rural, even though being more part of the urban fabric. The error was solved increasing of a class the pixels

closer than 600m to the seaside. In the end, with the use also of a *Raster Calculator*, it was computed for each Selective Land Cover map the correspondent *Built-up map*, with the following values: 0 for Water, 1 for Urban Built-up, 2 for Suburban Built-up, 3 for Rural Built-up and 4 for Open Space.

At this point, also Open Space could be subclassified. It needed Built-up subclassification to be performed before, because it was necessary to know first where was the urban fabric that could affect it. Indeed, the Atlas of Urban Expansion (Angel, et al., 2016a), as well as this study, considered that only the Suburban and Urban Built-up lands could have a significant effect on the Open Space around, to such an extent to consider it as Urbanized Open Space. The first subclassification regarded the Captured Open Space, selected for having a continuous area less than 200 ha, added to the previous representation, where it took value of 5, thanks to a raster calculator. Finally, performing Euclidean Distance, Open Space pixels closer than 120m to Suburban and Urban Built-up (the Atlas of Urban Expansion used 100m but here it was preferred 120m to be more consistent with raster cell sizes of 30m and 60m of the different land cover maps) were classified as Fringe Open space with value 6, and again added with a Raster Calculator to get the *Final map* for each year. In the end the Open Space pixels that were not modified in the two previous steps remained with value 4 and were called as Rural Open Space. These final maps are, finally, the finer land cover maps, storing information for six classes with the following values:

- 0 for Water,
- 1 for Urban Built-up,
- 2 for Suburban Built-up,
- 3 for Rural Built-up,
- 4 for Rural Open Space,
- 5 for Captured Open Space,
- 6 for Fringe Open Space.

ArcGIS allows to count the number of pixels for every class. In this way, it is possible to derive statistics and attributes for the different years, also limited to certain areas included in the land cover maps (as the volcanic hazard zones). In this way it was possible to look on the development of Naples over years through different aspects, that will be explored in the Result chapter. However, as already mentioned, this subclassification had also another reason to be performed: considering only the Urban and Suburban Built-up areas and the Captured and Fringe Open Space it was derived the **urban extent** for the city of the different decades. Again, to draw Naples urban extent of the different years, it was followed the example of the Atlas of Urban Expansion (Angel, et al., 2016a), summarized at 2.2. The buffered urban clusters that intersected the biggest urban cluster of Naples city were considered as part of its urban extent, while the ones that remained out, were called as ex-urban areas. This procedure was applied for all the years studied. The urban extent was meant to detect the extension of Naples over the years, without looking at municipal borders but only on the contiguous spatial distribution of its urban fabric in the territory. It allowed also to detect the trends in the growth of the city and the directions of its expansion.

4.1.4 Measuring urban expansion

What is of primary importance in this study is to be able to compare data from different years. It is for this reason that, besides comparing the different results in map format, the power of this study was also to compare *measures* related to urban expansion. Among these measures, **attributes** needed to be computed. They follow the Atlas definitions (see paragraph 2.2), adapted for this study as in the following:

- *Density*. As for the Atlas, it is divided into *Built-up area density* and *Urban extent density*. These measures are applied, both to Naples urban extent, while just the Built-up area density to the whole study area. Their values depend by population estimate.

- *Fragmentation*. Its measures of *Saturation* and *Openness index* are applied to Naples urban extent.

However, attributes are not the only possible measures of urban expansion. Measures for just Built-up area were considered (just counting pixels of Built-up in an area over time) as well as analysis was performed on the different types of Built-up over time in an area. The Atlas of Urban Expansion (Angel, et al., 2016a) was focused particularly on the urban extent, here for this study, it was useful to exploit also the measures of Built-up and its subclasses also out of the urban extent, for the whole study area or, later, in correspondence of the volcanic hazard zones. All these attributes and measures allowed for a temporal analysis of the development of the area. However, fragmentation attributes was revised also for a spatial analysis, to look at fragmentation in the different parts of the actual urban extent.
An important aspect that should be further examined here regards **population data**. At this stage the study needed new further open data to be integrated with results coming by satellite imagery analysis. Thus, they needed to be consistent with those results and that regarded particularly the time population data were referred to. Population data were provided by Italian National Institute of Statistics, ISTAT, particularly by its demographic databases (ISTAT, 2019) mostly open to the users through the Web. This ISTAT Web Platform (ISTAT, 2019) provides, at the date this study it is written, population data for the different enumeration zones for years 1991, 2001 and 2011. The Enumeration zones are the statistical-

administrative units in which Italy was divided for the census of those years, 1991, 2001 and 2011; each census enumeration zone collecting different data for its zone and population. Exemplum for 2011 year can be seen below in Figure 4.7. The site provides these spatially based data only for those years, different from the years of land cover maps 1972, 1984, 1998, 2008 and 2019. Thus, it was necessary to statistically intervene on ISTAT data from 1991, 2001, 2011 to derive demographic data consistent with land cover maps years. For years between 1991 and 2011, thus 1998 and 2008, it was easy. The Enumeration Zones, provided by ISTAT, were downloaded and cut for the area of study, then, demographic data were extracted for all census units. Census units changed through the years, thus, to compare and interpolate their data, it was decided not to consider them but the municipalities they constituted, that were more constant through time. Thus, demographic data for every Enumeration Zone of each municipality, within the study area, were summed together to get total population for years 1991, 2001 and 2011 of all municipalities. Moreover, in this way, data to be managed decreased. Then, for each municipality it was estimated the rate of increase (or decrease) of population between these years, and thus the trends. The trends were quite all continuous through these years. Thus, 1998 and 2008 populations were extracted by means of linear interpolation between 1991, 2001 and 2011 ISTAT population data.

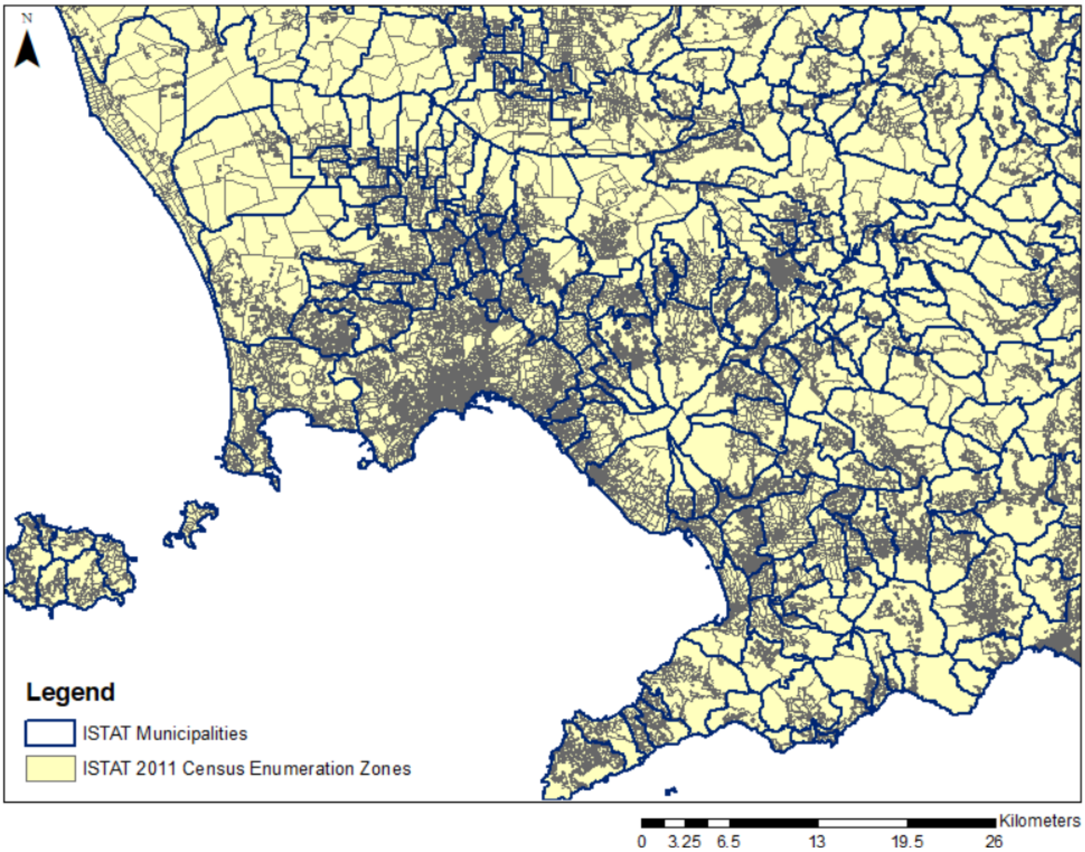


Figure 4.7 Enumeration zones and municipalities administrative limits. Exemplum for 2011 year. Data by ISTAT.

Coming to 2019, on the other hand, ISTAT provided a different type of data: it was possible to download data directly referred to the 1st of January 2019 divided for municipalities. Indeed, from 2018 census data have been permanently collected each year thanks to statistical means and administrative data. These data were municipally based. Finally, the remaining total population data to be assessed were the ones of years 1972 and 1984. For these years it was no longer possible to exploit linear regression from years 1991, 2001 and 2011, since they were out of the interval. Moreover, for these years, it was more difficult to find data on ISTAT to be municipally based. The ISTAT Databases provided provincially based census data for years 1972 and 1984 as a census statistical reconstruction for those years. It was tried to use these data as a basis to find municipal estimated quantities for total population. The link to municipalities was estimated with the use of provincial estimates also for the known years. Thus, for the given ISTAT municipal data for 1991, 2001 and 2011 it was assessed the share of population of the municipalities in the study area and the Province estimated value from ISTAT. To clarify, the computation followed these steps:

1. Download for provincially based estimated population data for 1972 and 1984.
2. Download for provincially based population data for 1991, 2001 and 2011.
3. Take 1991, 2001, 2011 municipal based population and divide each municipality population by the population of the whole Province, to get the shares for each municipality within a Province population.
4. Control if shares are constant through 1991, 2001 and 2011 data.
5. If constant multiply Provinces estimated values for population of 1972 and 1984 for the shares to find probable values of population in municipalities of 1972 and 1984.

Certainly, in this way, data for 1972 and 1984 (particularly 1972) are less reliable than the other data. And it is also to be mentioned that quite all data, being here statistically based, are not reliable as real numbers but only as trends compared to the others. It will be considered when analysing results. Finally, having all data projected in the years of this study land cover maps, it was possible to join these data with a map representing all municipal borders, provided again by ISTAT. Thus, population data could be used spatially cutting always the areas of interest. When a municipality intersected an area under analysis, as it could be the urban extent or a risk zone (or together), without being completely within that area, its population was considered proportionally to the area of municipality included, as it is suggested by the Atlas of Urban Expansion (Angel, et al., 2016a). Still this was a simplification, but it could hold when these municipalities not completely included were in little number and had little population.

In case of more significant values for population in a cut municipality, it was considered the shares from Enumeration Zones for years 1991, 2001 and 2011, to get a more precise estimate of the amount of population in that area.

4.1.5 Measuring urban layouts: roads and blocks

Until this point, all the study had for intent to map and estimate urban expansion, developing maps, measures and attributes. However, following now the second volume of Atlas of Urban Expansion (Angel, et al., 2016b), summarized at 2.3, the analysis was not finished: once that the different urban extents had been determined for the different decades, it was now turn to investigate the quality of the present urban extent, studying its different parts, added to itself through the years, the *expansion areas*. Thus, further procedures were derived to analyse the actual urban layout of the city, measuring with attributes, its quality as accessibility. These attributes are related to *roads* that have the important role of drawing and linking an urban extent. Thus, data for roads were needed in order to be overlapped, with the use of ArcGIS, to the expansion areas investigated.
Roads data were needed for the present time: while the first part of this methodology, related to the Atlas experience (Angel, et al., 2016a; Angel, et al., 2016b), was interested to the development of the city through time, thus it was based on a temporal description and measurement of the urban growth, this second part, had for intent to study the *present* times, from a spatial point of view; thus differentiating measures of quality of urban layout through the new different parts of the actual urban extent, to study whether some of its locations could have a better quality than others. The hypothesis of the Atlas of Urban Expansion (Angel, et al., 2016b) is that once a land is occupied by the urban fabric, it is difficult, if not impossible, to ensure proper services or accessibility that have not been planned before with the expansion, e.g. it could be really difficult to put an arterial road in a land already occupied by houses. Thus, this study, while giving an insight on the modern layout of the different parts of the city, it could allow also to measure the quality of urban planning that could have brought to expansion.
Therefore, updated data for roads were needed. They were provided by *Open Street Map* and freely downloaded with the server *Geofabrik*. To clarify, Open Street Map is a collaborative project with the aim to create free editable map of the whole World. Its data are daily updated by a community that is mostly volunteer. Geofabrik server was needed in order to download these crowdsourced roads data in the format of vector. Roads data used in this study are dated 10th March 2019. They are described according to the different Open Street Map definitions and guidelines about roads data, particularly they are classified into different typologies of roads, from paths to motorways. Some of them are given also other data as the names of the

streets and the maximum travel speed, or, if they are one-way, bridge or tunnel ways. However, data are not complete for all roads, except data for classes.

At the beginning of the analysis it was useful to identify all these classes of roads that would have been useful to derive attributes for quality of urban layout. It was fundamental to understand the differences among these classes and to select the types that would have been interesting for the objective. Particularly, here, it was important to remember the final objective for this part of the study: the attributes derived by this part of methodology will be needed then to analyse accessibility, thus systemic vulnerability of the different parts of the urban extent of Naples, related to volcanic risk. Classes of roads define approximately their width, the means of transport on it and the number of users at time it could support. Thus, their type is strongly related to accessibility, of much importance in case of evacuation. Therefore, selection and use of these roads data, particularly their classes, needed to be guided by the purpose of a systemic vulnerability study to be performed after. It is for this reason that some types of ways, like paths, steps, cycleways, bridleways and living streets, were decided not to be considered in this study, as not significant for accessibility. As well as *track roads* not considered in this study, being difficult to be travelled as mostly unpaved or narrow and since their function is more related to access to crops, farms or generally countryside, not to leave the city towards safer places.

Classes for roads were not exploited only for the selection of useful road data, they were used also to group these data. The Atlas of Urban Expansion (Angel, et al., 2016b) distinguishes among different types of roads, focusing its categorization on the drawn width of some sampled roads. Here the procedure followed this general intent of subdivision, but it preferred focusing on classes, indeed, attributes assigned to all the roads data in the layer, knowing that classes and width could be somehow also related among themselves. Furthermore, different classes proved to be still easily grouped. Roads classes were grouped for similar functions, as well as layouts and maximum travel speeds. Therefore, roads were divided into the following data:

- *Motorways*. It is the group for Open Street Map roads classes defined as motorways and motorways links. It represents parts of A1, A3, A30, A56 and their motorway links. Motorways were differently classified due to their restricted access and their two or more running divided lanes with emergency hard shoulder. Their travel speed can arrive up to 130km/h. Motorway links connect motorways to other roads and their maximum travel speed decreases to 40km/h. They tend to be short ways, thus, despite the huge difference with motorways, they were grouped together due to their similar function; however, width differences will be considered after for parameter computations. A1, A3 and A30 are managed by *Autostrade per l'Italia* S.p.A. while

A56 by *Tangenziale di Napoli* S.p.A. These societies are concession agencies whose actions and decisions are supervised at the end by the state government.

- *Trunks*. It is the set of data for roads defined by Open Street Map as *Trunks* and *Trunks Links*. Trunks in Italy correspond to *roads for high travel speed*, maximum 90 km/h, with in ramps and off ramps (Trunks Links) and without crossings or roundabouts. They tend to be mostly roads of national importance, the SS roads, they are the most important connector roads with no restricted access.

- *Primary roads*. They have the role to link together the biggest cities. They are constituted by the classes defined as Primary roads and Primary Links. They represent parts of different SS, SR and SP (state, region or province roads) of some importance for the city and the state. They can have two or more lines (usually in the area of study just two) and no central barrier. Travel speed is up to maximum 70 km/h (but generally also 50km/h).

- *Collector roads*. This set of roads groups together Open Street Map *Secondary* and *Tertiary roads*, counting also their links. Secondary roads have usually the function of linking primary roads or trunks. Tertiary ones, on the other hand, are less important, connecting local centres of the city or small settlements. Usually secondary roads have provincial or regional significance, while tertiary ones are usually provincial or communal roads. Both types contribute to create a denser network in a city. Their maximum speed is about 50km/h. They are similar for their layouts, speeds and width; moreover, they both have the function to link together different parts of the urban extent or its neighbourhood. It is for this reason that secondary and tertiary road, with their links, were considered similar and grouped together as Collector roads.

- *Local Roads*. They are constituted by the following Open Street Map classes: Unclassified, Residential and Service roads. The *Unclassified roads* are quite streets, less important than tertiary roads even though they still have the role of connectors for small settlements at local scale. A common example for them would be a countryside paved road, more used for access than for traffic. These roads tend to be narrower than tertiary ones, as well as slower driving. Moreover, they tend to be similar to residential streets, streets used for traffic within a settlement, used to access a residential area. Both are usually made of just one lane, meaning that a few cars can pass in the same time, not necessarily in one way. Maximum travel speed in a city is about 50 km/h, however these roads are mostly travelled with a speed of 30km/h. Finally, *Service roads* are meant to access buildings, service stations, beaches, parking, industrial estate, business park, etc. In that, they are similar in function to the residential roads. Indeed, while the unclassified roads still play a role of connectors, the other two types are more meant for accessing and they will be considered for just some of the attributes to be computed. Therefore, these classes of roads tend to have a small width and a slow travel speed. They were taken having similar width, a similar travel speed as well as layout. They tend to be similar among themselves, even though their function is different: while unclassified still plays the role of a link among places, the other two play more a function of access.

- *Pedestrian Roads*. Pedestrian roads correspond to the type of roads that are primarily meant for pedestrians, like streets of historic centres. For accessibility in normal conditions they do not have to be considered because of their restrict access and very slow speed. However, in emergency cases they can be more used to allow the accessibility also of the most historical parts of the city. Thus, these roads will be considered for some attributes, always remembering their peculiarities. This choice is supported also by the layer of roads provided by the Geoportal of Campania region that, drawing the principal road network of the region, it reports also some roads in Naples, considered by the Open Street Map layer as pedestrian.

Figure 4.8 shows the road network for the zoom on Naples city, grouped as described above.

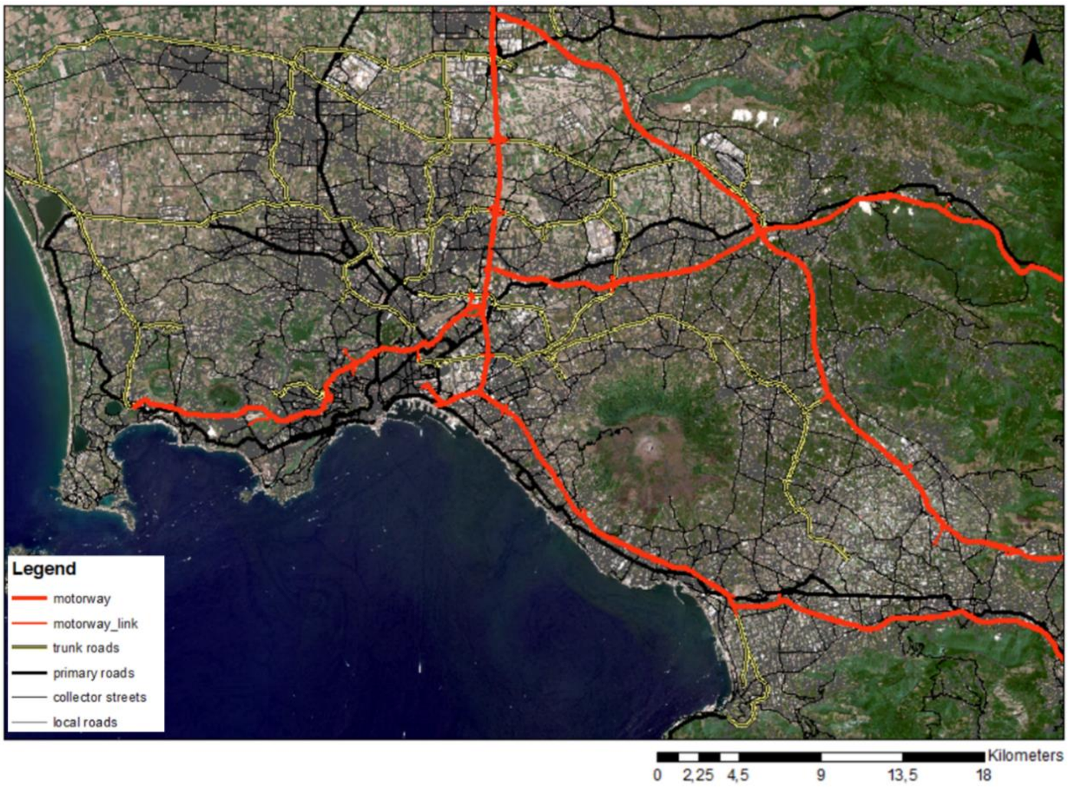


Figure 4.8 Grouping of roads data, adapted from Open Street Maps roads data.

Moreover, road network has been differentiated also into *arterial* or not arterial roads (as for the Atlas). Arterial roads have been divided into *Narrow* and *Wide* arterial roads (see definitions at 2.3). These roads define the 'fast accessibility' of an urban extent and the measure of how it is well connected. Here it was still considered the layer of Open Street Map roads and it was decided that arterial roads were all the roads with a significant importance for traffic, for linking locations, thus, they are motorways, trunks, primary roads and collector streets. Motorways were chosen to be part of arterial roads, despite the different choice that was taken by the Atlas of Urban Expansion: indeed, according to them (Angel, et al., 2016b), motorways should not be considered as arterial roads due to their restrict access, however, since they are included in both the Emergency plans for volcanic eruption of Vesuvius and Phlegraean Fields, they were considered too important to be neglect as arterial roads for this study. Finally, it was considered that Motorways and Trunks are wide arterial roads.
As anticipated above, the Campanian geoportal was exploited to download data for urban roads by another source, this time more reliable than Open Street Map Roads. Indeed, being crowdsourced, data from Open Street Map could have sometimes lower reliability, thus, it becomes important to compare them with other more reliable data. By comparison, Open Street Map roads proved to be consistent with the principal roads shown by data provided by the region. It should be underlined, however, that with "principal" it is meant that residential, service or the other small roads are not included into the regional layer, differently by Open Street Map data. It is also for this reason that the data provided by the region were not preferred upon the Open Street Map ones. Moreover, they proved not to store attributes for their roads like the classes nominated before. Usually, 'official' data should be always preferred upon the others, but not in this case, for which it was chosen completeness as important requirement for data, particularly about the classes, discriminant of the different roads.
The layer of roads and their groupings, in the end, were needed to compute different attributes to describe the accessibility and 'quality' of the different expansion areas. The attributes are adapted by the ones defined by the Atlas of Urban Expansion (Angel, et al., 2016b), see 2.3.
Coming finally to attributes, they are meant to describe accessibility and quality of urban layout in the different expansion areas of today urban extent. The concept for expansion areas has been defined by the Atlas (Angel, et al., 2016a) and at paragraph 2.2 it has been summarized. Practically, the expansion area referred to a year i would be the difference between the urban extent of year i minus the urban extent of year i-1:

$$Expansion\ area_i = urban\_extent_i - urban\_extent_{i-1} \tag{4.5}$$

All expansion areas needed to be considered separately to derive the different attributes for *measuring urban layouts*. Each expansion area had its roads selected by overlapping with it.

The attributes, derived by the Atlas (see definitions and formulae at 2.3), have been adapted to the case study and the different data. Particularly:

- *Share of road class i on the total network of roads*. It has allowed to compare the different shares for local, collector, primary roads and trunks or motorways.

- *Average Road Width*. It has considered all the roads in an expansion area to derive their average width. It consists in a weighted average, where weight is given by total lengths for each class of road. Each class of road has been given a representative width, thanks to different measures on map, on visual interpretation and some guidelines that hold for Italian road construction. Motorways were assigned a 24m width, trunks 16m, primary roads 10m, collector roads 7,5m and 5 meters for all the remaining local roads. There was an exception for the subclasses motorway-links and trunks-links that were not assigned here the same width as their respective class (thus, 24m and 16m) but were given value of 5m, in a way not to overestimate the total average width, also because they had a very different value for width with respect to the roads they link. Due to variability of width of road, this value should be considered as just indicative to understand the most predominant widths in an area and useful to compare then different areas.

- *Average density of all arterial roads*. It measures the quantity of arterial roads with respect to an area. Arterial roads, fast linking different part of an urban extent could give an estimate of how much an area is accessible from the others of the urban extent.

- *Average density of wide arterial roads*. It gives an insight of the measure of wide arterial roads passing through an area. Wide arterial roads, thus motorways and trunks, are linked to the high-speed connections of an area towards more distant locations.

It has been added by this study also the following attribute:

- *Average Density of all roads*. It gives a measure of how much an expansion area is served by roads. Thus, it is calculated in this way:

$$Average\ Density\ of\ roads = \frac{Linear\ length\ of\ all\ roads\ in\ the\ area}{Considered\ area}\ [\frac{km}{km^2}] \tag{4.6}$$

These attributes describe the road network, looking at accessibility of an area through its connections to the outside or the inside zones. However, as already mentioned by the Atlas of Urban Expansion, roads draw also the urban layout of a city, splitting it into *blocks*. The blocks size matters: if it is too big it becomes an aggregate of built-up structures segregated inside, not much accessible. Thus, also the Atlas *Average size of blocks* was computed, thanks to ArcGIS potentialities in splitting the expansion areas by the road network overlapped to them. Here, services roads as well as pedestrian ones were not considered when splitting the urban areas since they would have created too small areas, depicting a well accessibility that could have been overestimated. Also motorways were not considered due to their restrict access by motorway links that do not split the urban layout: considering them would mean to consider the urban fabric split any time a motorway could pass over a zone without cutting and really intersecting it. Moreover, related to blocks, orderliness of urban layouts and particularly accessibility and redundancy of roads, it was estimated the average number of intersections on an area, thus the *Density of intersections*, particularly, the *Density of 4-ways intersections*. Formulae for these densities of intersections can be found in the Atlas (Angel, et al., 2016b) and therefore are summarized at paragraph 2.3. The computation for the number of intersections (generally all intersections or just the 4-ways ones) proved to be difficult, related to the intersecting and editing of the roads vector data. Roads needed to be intersected among themselves but to do so, it was necessary first to unsplit their lines not to overestimate points of intersections, then, after intersecting, to remove the duplicated points that were created in the process. All these procedures were performed automatically by ArcGIS geoprocessing tools and, therefore, also the count for the number of intersections was done automatically, this time with a *spatial join* between the layer of intersection points and the re-split layer of roads, a method that gives back for each point of intersection, the number of roads coming to it, in order to identify intersections of 3 or 4-ways (or more) and count them separately.

Finally, following the Atlas of Urban Expansion (Angel, et al., 2016b) methodology, also the measures for *Share of areas within walking distance to arterial roads (or wide arterial roads)* have been computed. It was considered the Walking Distance of 600m to look how much urban extent would be in a walkable distance towards arterial or wide arterial roads. Thus, all arterial roads were buffered with that distance to look whether some places were out of the walkable distance and therefore would have been less accessible.

In the end, these attributes described above were the attributes chosen and adapted by the Atlas of Urban Expansion methodology to describe Naples roads network, urban and blocks layout, as well as its accessibility related to them. The second volume of the Atlas (Angel, et al., 2016b) described also a procedure to estimate land use shares in the urban extent, always to look at quality of it. This study developed its own methodology about it that is described in the next chapter.

4.1.6 Measuring urban layouts: land use

The first paragraphs of this of this chapter got land cover maps for all the years of study (1972, 1984, 1998, 2008 and 2019). However, it could be interesting to have also a land use map describing those years. It would represent human activity or economic function of lands, collecting information about different uses of pieces of lands. Thus, it can be, together with land cover map, a great tool for conscious land planning and management, since both show different characteristics of a land, one in a more physical way, the other from economical and law perspective. Together they can provide a more complete view on the studied territory.

The Atlas of Urban Expansion (Angel, et al., 2016b) does not provide a land use map for the different years. It considers, as for roads, some representative areas of the urban extent to derive measures of the shares of the different land uses in the urban extent. Here, it was chosen to proceed with another method: it was downloaded the freely available CLC Corine Land Cover Map for the area of study, to be analysed and measured over time. The CLC Corine Land Cover Map is a European programme, born to monitor land cover and land use characteristics over time (Copernicus Programme, 2020). It was initiated in 1985 (reference year 1990) with updates produced in 2000, 2006, 2012 and 2018. It consists of an inventory of land cover in 44 classes, mostly produced by visual interpretation of high-resolution satellite imagery, provided by the participating countries (today 39, among them Italy). Even though its principal intent is to map land cover of its involved nations, particularly with the aim to monitor and defend natural environment, some of its classes, can be representative also of land use of the different areas. It is for this reason that CLC was exploited in this study. Obviously, the level of detail could not be very high. The spatial resolution of CLC is about 100m and its Minimum Mapping Unit (MMU) is 25 ha, meaning that it filters its representation in order to show classes whose pixels are clustered in areas larger than 25 ha (Copernicus Programme, 2020).

For this study it was needed Corine Land Cover Map for years comparable to the ones exploited for land cover mapping and measuring, thus 1972, 1984, 1998, 2008 and 2019. Corine Land Cover Map provides land cover land use map for years 1990, 2000, 2006, 2012 and 2018. Therefore, it is clear that for year 1972 it would not be any comparable land use, while for the others it was assessed to compare this study results with CLC maps respectively considering for 1984 results CLC-1990, for 1998 results CLC-2000 , for 2008 CLC-2006 and for 2019 CLC-2018. CLC layers for these chosen years are shown in Figure 4.9. To clarify, comparing maps referred to different years would introduce error, however, this error could be accepted also because of the poor spatial scale for which small changes between near years could be neglected.

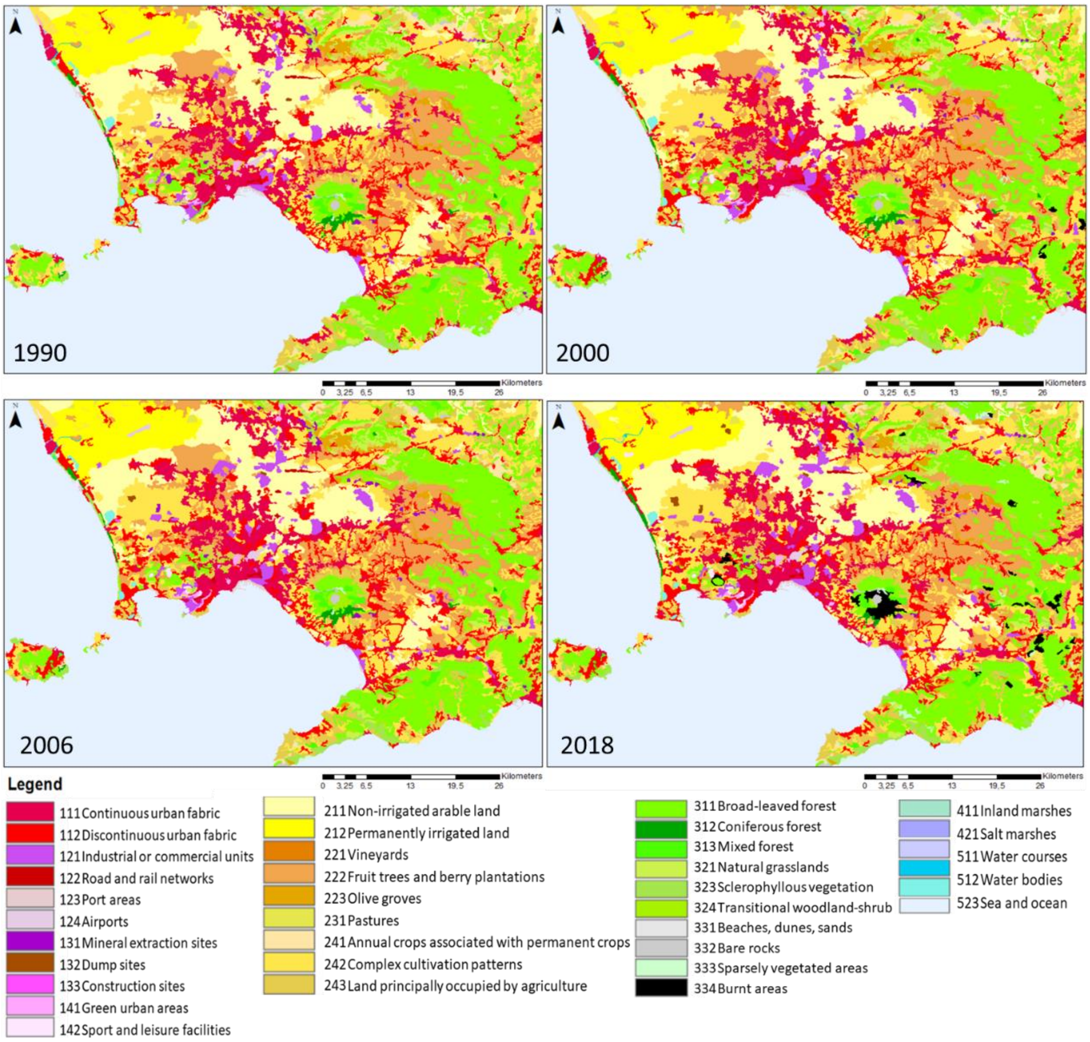


Figure 4.9 CLC Corine Land Cover Maps for the area of study.

To follow the Atlas of Urban Expansion intent (Angel, et al., 2016b), it would have been needed just the most updated CLC map to be compared with the different expansion areas of 2019 urban extent, in order to derive attributes for the shares of different land uses in different areas of the present urban extent. These attributes were computed by this study; however, it was decided to exploit the possibility of CLC to look at past to derive also a temporal analysis of land use changes over time compared to the expansion of the urban extent. This analysis was not derived for all urban extent of Naples, but it was performed already on a different perspective looking at Yellow Vesuvian Risk Zone, as it will be better explained after.
Indeed, all the maps, measures and attributes found out until this point, thus land cover, land use maps and measures, as well as urban layouts calculated, will be applied for the second part of methodology, as starting point to derive analyses that would be useful for knowing better the related exposure growth and today vulnerability of the areas subjected to volcanic risk.

4.2 Analysing the urban expansion from exposure growth and systemic vulnerability perspective

All the results from the first part of methodology were finalized to be the data at the base to develop an analysis of urban expansion from an exposure growth and systemic vulnerability point of view. The Atlas of Urban Expansion approach (Angel, et al., 2016b; Angel, et al., 2016a) would have stopped here with the mapping and quantification of the urban growth of the last decades. However, it is recognized (Gencer, 2013; Wamsler, 2004) that poor land planning can exacerbate the effects of a natural disaster affecting an urban fabric, it can affect risk, particularly impacting on its factors as exposure and vulnerability. It is for this reason that this study wants here to exploit maps measures and attributes to develop a proposal for a methodology that would link the measures for the urban growth and layout to the study of exposure growth and systemic vulnerability. The following paragraphs will explain better the steps that have been followed to study and develop this link for the area of study, focusing on the volcanic hazard zones that it is subjected to.

4.2.1 The focus of the analysis: the volcanic hazard zones

Prior to the following analysis, the area of study needed to be redefined, in order to focus only on the areas that are subjected to volcanic risk, from Vesuvius or Phlegraean Fields. It meant to overlap, to the maps previously created, the hazard zones, defined by the Emergency Plans (Italian Civil Protection, 2018; Italian Civil Protection, 2018) that have been written for the case of Vesuvius or Phlegraean Fields eruption. Both Emergency Plans have determined their Red and Yellow Zones to distinguish the different procedures to be taken at the different alert levels that could precede a possible eruption. Particularly, the main difference between Red and Yellow Zones is that in case of alarm, the last alert level that could anticipate an eruption, the Red Zone resident population has to leave the zone within 72 hours, since preventive evacuation would be the only safeguard measure for them, against expected pyroclastic flows or (for Vesuvian Red Zone 2) collapses of buildings roofs due to the accumulation of pyroclastic deposits. On the other hand, Yellow Zones have been defined based on studies and simulations of the probable distribution to the ground of volcanic ash, considering historical wind statistics. These areas would not have the obligation to evacuate before eruption, but, therefore, they need management of emergency to be planned. Figure 4.10 shows Vesuvius or Phlegraean Fields hazard zones. It is possible to see that Vesuvian Red Zone overlays some parts of Vesuvian Yellow Zone, in correspondence of Naples and Nola municipalities. It is because the borders of Vesuvian Red Zone were drawn following the only probability of being subjected to pyroclastic flows (Red Zone 1) or to collapses due to big amount of ashes (Red Zone 2), while the Yellow Zone borders were drawn, on the other hand, grouping and following the administrative limits of all municipalities interested by the probability curve of being subjected to a fall of 300kg/m2 of ashes. Obviously, in case of alarm Red Risk Zone predispositions would have priority on Yellow ones.

For the next analysis it was given no difference to Vesuvian Red Zones 1 and 2. The overlapping with the hazard zones allowed to apply the maps, measures and attributes defined by the Atlas approach, particularly to those hazard zones to derive a methodology that would focus on exposure growth and systemic vulnerability related to accessibility.

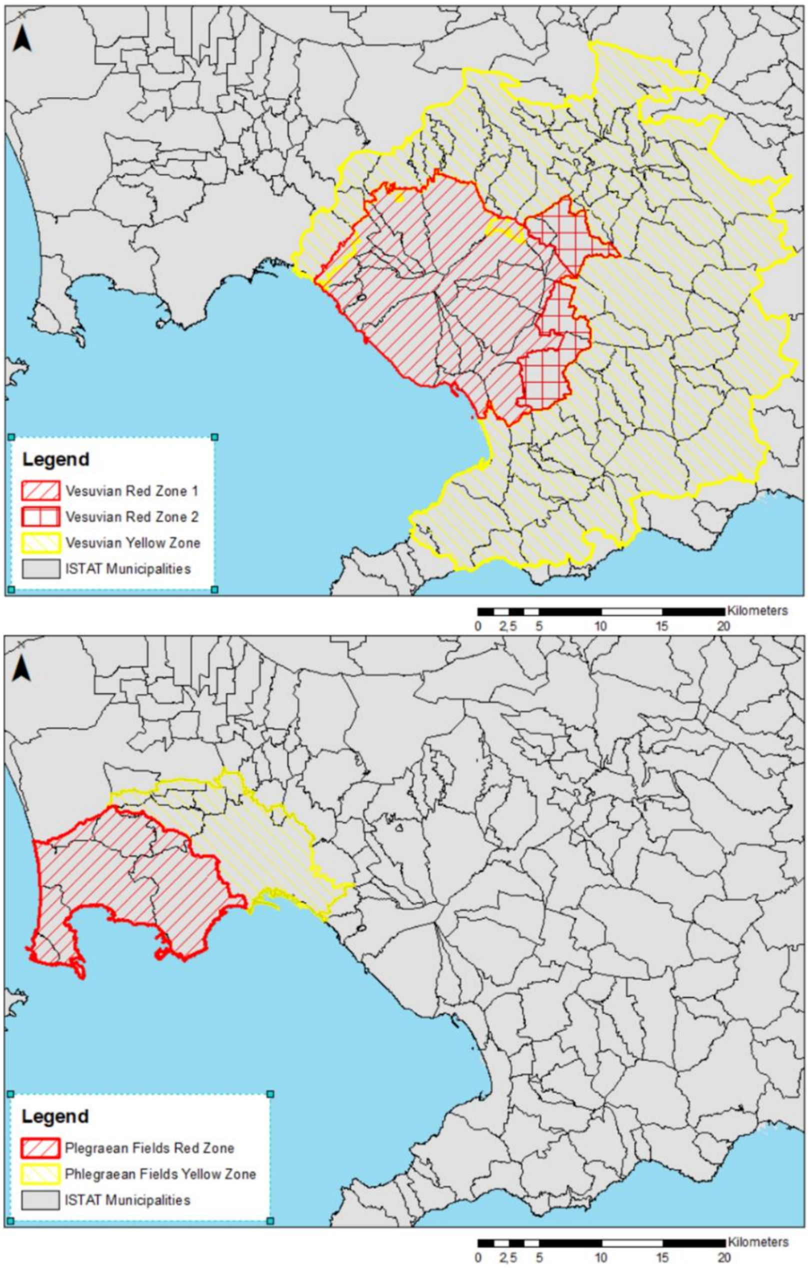


Figure 4.10 Red and Yellow Zones from the Emergency plans of Vesuvius and Phlegraean Fields.

4.2.2 Urban expansion and exposure growth ranking

Maps and measures describing urban expansion were the starting point to analyse the exposure growth in the Red and Yellow Hazard Zones. The approach of the Atlas, that had been applied before measuring the urban growth in the whole study area, was now exploited for the hazard zones to measure the urban growth there. The urban growth in these areas is linked to exposure growth: the increasing of number of people as well as the number of built-up means the exposure to grow. Exposure, together with hazard and vulnerability is an important factor that determines risk, and acting on it could affect the risk, positively or not. The same mandatory evacuation from Red Risk Zones, to be done before the volcanic eruption, is an exemplum of risk management that decides to decrease the risk decreasing the exposure, forcing people to leave the zones at risk. However, due to multidimensionality of exposure, it is still not to be forgotten the physical exposure, the built-up that would be exposed to, for example, the pyroclastic flows, that would have a value also in economic terms. And if the built-up has increased in the years for example in the Red Zones, it means that the exposure has increased too, at least the physical one, and that impacts negatively on risk.

Hazard zones for both Vesuvius or Phlegraean Fields Emergency plans cover large areas with a lot of people and built-up that could be exposed to a volcanic event. Thus, it is important to know the numbers and values of exposure to be able to better manage the emergency and risk. Therefore, knowing better is very important to be conscious of the effects that a poor land planning could provide. Moreover, as it could be perceived by the above exemplum, exposure is dynamic, according also to (Corbane, et al., 2017). It changes over time and space; thus, a conscious land planning could affect the exposure of future, investing on policies that could decrease it. Spatial analysis of exposure would be also important focusing interventions where they are most needed.

In this way, the land cover maps that have been derived in the first part of this work, following the Atlas approach, are useful to provide information about exposure in the different years. Indeed, according to the authors of chapter 2.2 of the book '*Science for Disaster Risk Management*' (Corbane, et al., 2017), land cover maps, as well as land use maps, like the CLC Corine Land Cover Map, can be a great tool to study exposure. However, the power of the Atlas procedure is to provide land cover maps and measures of urban growth through time, and not to study just the present situation or the different years separately. The power that its results bring with themselves is related to the possibility of comparison through quantities of built-up or urban extent or population inside, thus the analysis of the urban growth. Therefore, coming to the exposure analysis, the application of maps and measures will be finalized not to analyse the present days exposure, but to focus on the changes over time of exposure, thus its growth. Particularly, to be useful for policy makers and stakeholders, it was decided to derive a ranking procedure that could have considered the different aspects of growing exposure in the different hazard zones, to define, in the end, the levels to which each zone had been subjected to, and so which zone could have experienced the poorest urban planning, the least sensitive to exposure issue.

Coming to the previous measures and maps, thus, considering the different hazard zones, it was easy to derive the quantities for built-up in the different years for the different hazard zones. Their measures were plotted on a temporal basis to look at the rate of built-up growing in the years. Ranking was assigned: the fastest growth of built-up was given the highest value (here 4), while the slowest growth the smallest (thus 1). Built-up was then analysed for its shares among Urban, Suburban and Rural Built-up, to have a better overview on the development that had happened in all zones at risk, thus its quality, even though this second analysis was not meant for ranking, since it was not linked to the level of exposure.

Exposure always rises within an urban extent: cities tend to have denser urban fabric and more features also of economic value that could be more exposed to risk, all authors (Corbane, et al., 2017; Wamsler, 2004; Gencer, 2013) agree on that. Therefore, another parameter, to be derived for the ranking, was the level to which each zone had experienced the most urban extent expansion, from the city of Naples, with the highest rates. Again, it was given a rank from 4 (the zone with the highest increase of Naples urban extent within its area) to 1 (the zone that had experienced the least Naples urban expansion). These were considered the parameters linked to physical exposure growing. However, it was possible to analyse the exposure related to the resident population. In the previous parts of methodology, ISTAT data were exploited to estimate the amount of population over time. Again, plotting the population trends over time in the different zones, it was possible to look and rank the social exposure differently increasing in the zones. Attributes as density of population with respect to built-up area were plotted too, not to assess another rank but to have again an overview on the quality of urban development that had happened in the zones at risk, to analyse, particularly, the link between rise of population and rise of built-up.

In the end, these ranks, coming by physical and demographic exposure growth, were summed together to derive the final ranking that would assess the level of total exposure growth over time for each zone. In Figure 4.11 it is possible to look at this summarized ranking procedure. Finally, the results of the ranking were represented on a map with values from Very Good to Very Bad Exposure Growth. For the worst situation, it was decided to analyse also the history of land uses within its area, to look at changes over time of it. To perform this analysis, the different CLC Corine Cover Maps were exploited considering all studied zone or just the urban extents at different times. Land use could give a better overview of the features exposed to risk at the different times, looking at their trends and having also an idea of how economical values at risk are increasing.

Built-up growth	Ranking
Vesuvian Red Zone (1)	1≤x1≤4
Vesuvian Yellow Zone (2)	1≤x2≤4
Phlegraean Fields Red Zone (3)	1≤x3≤4
Phlegraean Fields Yellow Zone (4)	1≤x4≤4

Urban expansion	Ranking
Vesuvian Red Zone (1)	1≤y1≤4
Vesuvian Yellow Zone (2)	1≤y2≤4
Phlegraean Fields Red Zone (3)	1≤y3≤4
Phlegraean Fields Yellow Zone (4)	1≤y4≤4

Demographic Exposure growth/decrease ranking	Ranking
Vesuvian Red Zone (1)	1≤z1≤4
Vesuvian Yellow Zone (2)	1≤z2≤4
Phlegraean Fields Red Zone (3)	1≤z3≤4
Phlegraean Fields Yellow Zone (4)	1≤z4≤4

Exposure growth	Scores	Ranking
Vesuvian Red Zone (1)	x1+y1+z1	1≤E1≤4
Vesuvian Yellow Zone (2)	x2+y2+z2	1≤E2≤4
Phlegraean Fields Red Zone (3)	x3+y3+z3	1≤E3≤4
Phlegraean Fields Yellow Zone (4)	x4+y4+z4	1≤E4≤4

Map Representation:
from Ei=4 as Very Bad
to Ei=1 as Very Good

Figure 4.11 Exposure growth ranking procedure.

4.2.3 From the urban layout measures to systemic vulnerability ranking

The paragraph 4.1.5 was devoted to describe and measure the urban layout of the actual urban extent of the city of Naples. Particularly, roads data were exploited. The measures that had been derived by that procedure could be useful here to analyse vulnerability, particularly systemic vulnerability, linked to accessibility. For vulnerability and systemic vulnerability definitions see 3.2. Vulnerability is dynamic and multidimensional, and, in an urban extent, its systemic dimension becomes very important, being linked to the spatial, temporal and functional interrelations among the different weaknesses of a city. During emergency, systemic vulnerability could be a very important concern, particularly for today cities where many services, many dimensions are connected and influencing each other.

Infrastructures as roads can be very important: in case of risk, it would be fundamental that all places would be accessible towards the inner or the outwards of the city. Also for this study, knowing that the emergency plans for Vesuvius or Phlegraean Fields eruptions intend to evacuate all the people resident in Red Zones, accessibility becomes fundamental, and it is very important to assess the places that would experience more problems regarding it, thus would be more vulnerable about accessibility of their system. Also for the Yellow Zones, to manage the emergency, accessibility would be crucial, in order to be able to face huge fall of ashes, threatening buildings as well as same roads and water pipelines.

Considering thus the measures and attributes provided by the previous analysis of block and roads layout, it becomes clear that these measures could be applied in order to analyse accessibility within the volcanic hazard zones. The analysis of the accessibility-related systemic vulnerability exploited different levels of detail, starting from the study of the whole hazard zones, coming then to the analysis of the urban expansions of Naples, applied then to understand the urban extent systemic vulnerability in each hazard zone, and finally the separate analysis of each expansion area within each hazard zone. The result coming out by these different levels of detail was always a map with the representation of a ranking for the different hazard zones related to their whole systemic vulnerability or their urban extent systemic vulnerability. They allowed to provide a more reliable assessment of systemic vulnerability as well as the possibility to underline the smaller areas that could be more systemic vulnerable to risk, in an accessibility perspective.

Therefore, attributes as Density of Roads, Average Road Width, Average Density of Arterial Roads and Average Density of Wide Arterial Roads, described in paragraph 4.1.5, were derived for the different areas under study (the whole hazard zones or the urban expansion areas) and they were ranked assigning the best value of 1 to the biggest values of attributes increasing accessibility, while 4 for the worst, with lowest densities for roads in the areas and for their widths.

However, the ranking exploited also the attributes that described the urban layout, as Density of Intersections, Block Sizes (only for the urban expansion accessibility analysis) and Share of areas within Walking Distance to Arterial or Wide Arterial Roads. Particularly, density of intersections, and moreover, density of 4-ways intersections was a fundamental factor, describing the redundancy of roads in the areas: it would allow to reach a place from different roads, better connecting the different urban fabrics. Block Size also was important since it can describe the level of segregation of a neighbourhood to the outside: the larger the block, the more the segregation. Finally, the Shares for Roads within Walking Distance to the different arterial roads were still considered of interest measuring how much places could be fast reachable from arterial roads; thus, it gives again a measure of accessibility, particularly here, fast accessibility to the outwards. For the first level of detail all these attributes were ranked, and it was derived, by summing the rankings, the first thematic map for systemic vulnerability related to accessibility of hazard zones.

For the other levels of detail that focused on the urban extent and its expansion areas, on the other hand, it was possible to exploit also Saturation Attribute, that is related to the consumption of soil of the different urban expansions and to the accessibility in the sense that the less the saturation the more time to reach a place due to its larger distance.

In the end, again all the factors rankings were summed together to compare the systemic vulnerability of the different hazard zones urban extents.

Finally, data for roads provided also information whether roads would pass over a bridge, characteristic that would be not negligible in case of earthquakes before the eruption. Indeed, bridges could undergo higher damage, under seismic action before and during volcanic eruption. For these issues it becomes much important to assess as soon as possible their safe condition during emergency. It was decided thus to explore the presence of bridges over the areas, measuring their densities to better understand if their presence could affect more or less accessibility.

Chapter 5
RESULTS FOR ASSESSING NAPLES URBAN EXPANSION FROM A RISK PERSPECTIVE

The different steps, described in Chapter 4, have led to results and further analyses that will be discussed in this section. The study has applied the whole methodology to the case of Naples city, starting by satellite imagery to derive, in the end, a procedure to analyse its exposure growth and systemic vulnerability. All this work would not be useful without description, as well as interpretation, of its results. This chapter will have this role and, to do so, it will follow the structure of the methodology. Thus, it will be constituted by two subsections, again the first part related to the maps and measures of the urban expansion, while the second explaining the results of the analysis for exposure growth and systemic vulnerability.

5.1 Maps and measures of the urban expansion

Maps and measures of urban expansion are the results of the adaptation of the Atlas of Urban Expansion approach to this study purpose. These results must be considered as the objectives to pursuit the final aim, the starting point, the data for the following analysis of exposure growth and systemic vulnerability. Therefore, the interpretation of the final results is first based on the understanding of the maps and measures produced by the first steps of methodology. In the following sections they are summarized and discussed, for their peculiar characteristics, looking also at their reliability.

5.1.1 Selective Land cover maps from supervised classification of satellite imagery

This section aims at presenting the classification results and summarizing some of their characteristics. The first step of classification has resulted in the **Selective Land Cover maps** representing *Water*, *Open Space* and *Built-up* land. These classes, described in a raster format, are differentiated with different numerical values that have been at the base of the subsequent computations for the finer classification described in 4.1.3. They are wide classes of features, that proved to provide some issues to the machine to univocally recognize their spectral patterns. Moreover, the classification steps, particularly the ones related to the training stage proved to be really time consuming and they could be affected by **subjectivity**. Particularly, the analyst experience affects the results: when defining and refining the training areas, thanks to experience, an operator could recognize more easily, and in a smaller time, the different spectral patterns to identify a class of features, that would be more recognizable, then, for the classification algorithm. It is also true that, also with experience, a classification is not error free. The **accuracy** assessment for the first classified images provided an average total accuracy of 95% and an average Kappa Accuracy of 92% for all the images of the different years. The results from the assessment were very similar among the images and that proved their comparability. Producer's Accuracy was always higher than the User's Accuracy for the Built-up class, the class of interest for this study, that meant there is higher commission error than omission error for this class: more pixels were wrongly classified as Built-up when they were not.

Here, a further discussion could be made on results of classification: due to the digital nature of these satellite images, it should be remembered also that classification is really affected by **spatial resolution** of satellite imagery. It decides the scale of the results, thus the level of detail of each map. Still, it should be remembered, that land cover map coming from year 1972, is discontinuous due to its cell size (thus, its level of detail) different to the other land cover maps of 30m cell size. The Atlas of Urban Expansion (Angel, et al., 2016a) does not consider images from the seventies, maybe also for this issue, that makes them less comparable to the other years. However, the results from classification, confirmed the importance of 1972 image to be considered, due to the huge changes in the urban fabric with respect to 1984, already testified by the writings of Berdini (Berdini, 2010). It is possible to perceive this difference looking at the Selective Land Cover Maps resulted at the end of this supervised classification (Figure 5.2). Even the first Selective Land Cover Maps results of classification showed that from 1972 to 1984 built-up has really grown. Regarding cell size, it should be remembered that also the 2019 Sentinel image had a different spatial resolution with respect to the other

Landsat images. However, differently from 1972 result of classification, it was resampled to be comparable to the other land cover maps (thus to 30m cell size).

After the classification process, there was the need to perform some **corrections** based on visual interpretation. The correction for greenhouses proved to be really time consuming and introducing still more subjectivity to the results. However, it was necessary, when no good results were provided by automated procedures for greenhouses detection. In the end, the adopted intersection method (see section page 62) proved to be very useful in conforming all images among themselves. Furtherly analysing that choice, results, some of them shown in Figure 5.1, could demonstrate the correctness of the first hypothesis: looking at the differences between two land cover maps related to the same year, one before and one after the intersection, it is possible to see that most of the areas that were reclassified in Open Space, were areas of greenhouses or crops, wrongly classified before into Built-up. Just rarely some houses were missed.

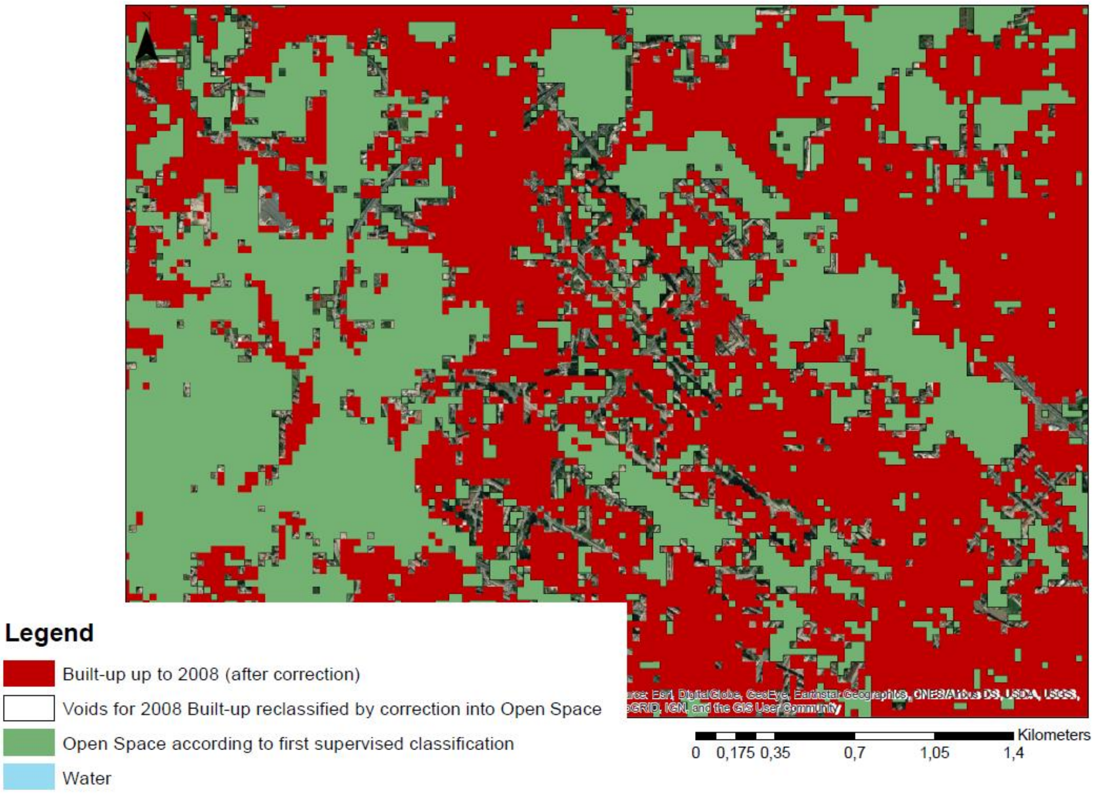


Figure 5.1 Comparison for 2008 Selective Built-up before and after correction.

Now that all substages results to compute the Selective Land Cover maps of Naples over the last decade have been discussed, it is important to describe these maps, showing them in Figure 5.2. Particularly, it is important to observe the **comparison** among the land cover maps related to the different periods, through their overlapping from the most actual 2019, under, up to the oldest 1972 on the top in Figure 5.3. However, comparison is not based only on maps but also on **measures**, comparing the measures of urban fabric over the years (see Table 5.1).

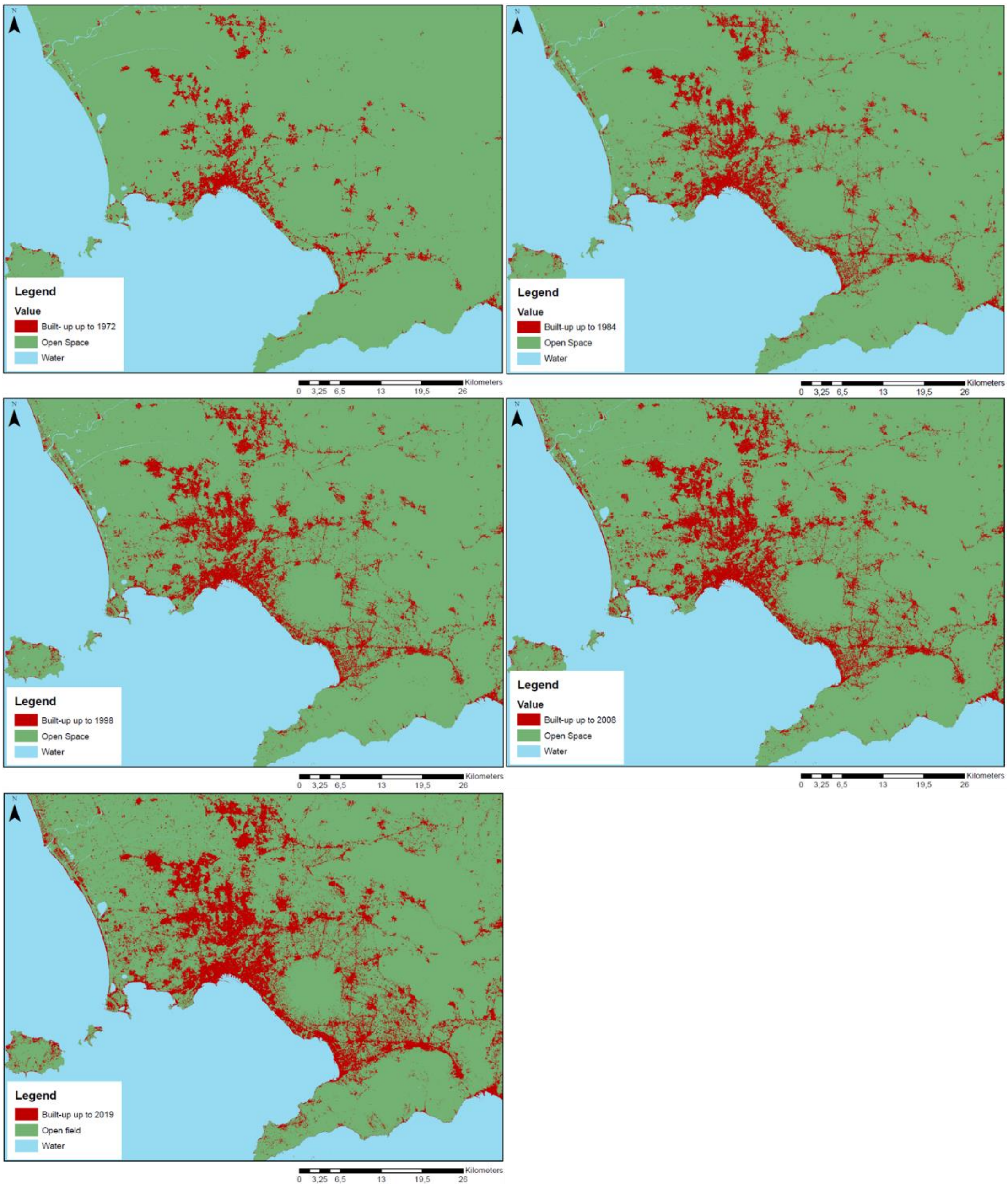


Figure 5.2 The Selective Land Cover Maps for years 1972 (the first on left) to 2019 (the final one).

Looking at the different Land Cover maps and comparing their numbers for Built-up Land, the periods from 1972 to 1984 and from 2008 up to 2019 have shown the largest Built-up growth. It should still not be forgotten that land cover maps of 1972 and 2019, particularly the first one, are discontinuous with respect to the others, coming by different sources for satellite imagery of different cell size and different spectral information detected. Therefore, data remain significant, but it should be considered that maybe their measure could be overestimated.

Table 5.1 Total study area measures over time.

		1972	1984	1998	2008	2019
Total study area	**Built-up [km^2]**	**144,66**	**260,12**	**318,91**	**377,58**	**513,84**
	Open field [km^2]	2814,65	2699,65	2638,87	2582,94	2448,83
	Water surfaces [km^2]	1881,43	1882,79	1882,15	1880,18	1878,08
	density (built-up/ (built-up+ open field))	**4,89%**	**8,79%**	**10,78%**	**12,75%**	**17,34%**
	Rise of built-up		**+79,81%**	**+22,60%**	**+18,40%**	**+36,09%**

From results and measures it could be seen that between 1984 and 1998 it is signalled the smallest urban growth. Moreover, looking at maps, it is more evident also the trend of urban growth: Naples city has grown over the years, confined by Vesuvius and Phlegraean Fields, it has grown up to north, north-west. It could be perceived also by maps that Built-up has spread out in the very last years: while up to 1972 Built-up was more limited to the city of Naples, then it has grown to the outwards with a new urban fabric less concentrated and more discontinuous.

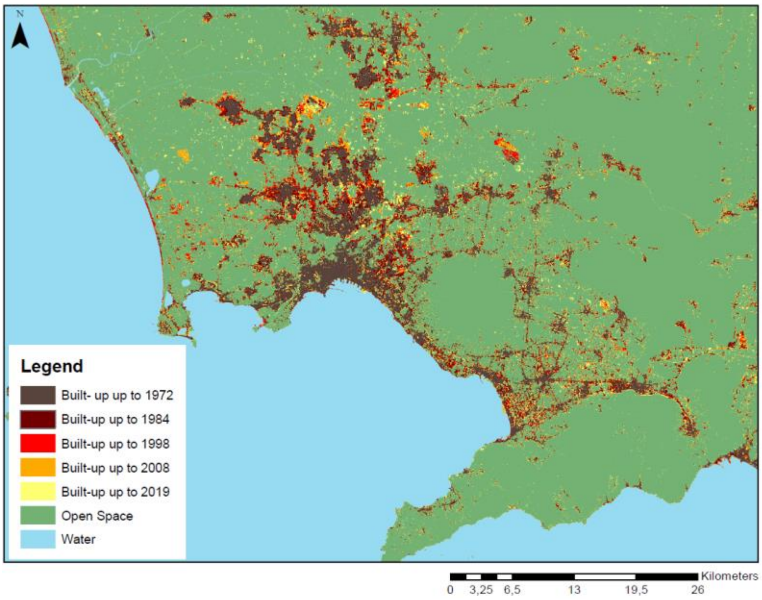


Figure 5.3 Overlapping of the different land cover maps Built-up lands, from the oldest, at the top, to the newest, behind.

The map shown here at Figure 5.3, corresponds to the first final result of this study, it will be part of the tool presented in Chapter 6, to describe to the stakeholders Naples urban expansion.

5.1.2 A Comparison between Selective Land Cover Maps with GHSL

So far, Selective Land Cover Maps have been analysed and technically discussed together with the methodology exploited. However, it is interesting now to compare these results with the land cover maps of the study area that can be freely available on Web. Indeed, there are different exempla of land cover maps that could have been exploited, instead of classifying the satellite images to derive this study's maps. First, there could have been the Corine Land Cover Land Use map that could have been applied to the case of Naples area. But, its first results are dated 1990 and its spatial resolution is, as already mentioned in 4.1.6, just 100m with a minimum spatial unit even larger, 25 ha. Therefore, Corine LCM would have provided a lower detail for the results. Moreover, time factor is at the base for this study and depicting the urban growth just from 1990 would have been less significant.

Here, it has come the comparison with **GHS Layer**. From all the projects aimed in classifying land covers of the whole world, GHSL is the most similar to the results of this study, with a spatial resolution of 30m, exploiting Landsat and Sentinel imagery from 1975 up to present days. The *Global Human Settlement* GHS (European Commission, 2019) is a European project aimed at providing free and open data about development of world human settlements and population through the years from 1975 up to present days. It wants to explore and assess the human presence on planet in a complete and cost-effective way and let any user to freely download these results for any place on Earth. It is supported by the *Joint Research Centre* (JRC) and the *DG for Regional Development* (DG REGIO) of the *European Commission*, together with the international partnership of *GEO Human Planet Initiative*, where *GEO* stands for *Group on Earth Observations*. It stands at the base for the Atlas of Human Planet. The GHS Layers (GHSL) purpose to help decision-makers to act and prioritize efforts in an informed way makes it very similar to this study's Selective Land Cover maps. Moreover, it starts too by a heterogeneous amount of data, like fine-scale satellite image data streams, census data and volunteering geographic information sources with the important difference that its data cover the whole World and they are automatically processed. It extracts analytics and knowledge about urban development, globally, in a consistent way, at these different periods: up to 1975, from 1975 to 1990, from 1990 to 2000 and then from 2000 up to 2015.

However, GHSL brings an important difference with respect to this study's methodology: **it automatically processes data**, particularly satellite images, in a totally reproducible way. Its method is based on a combination of data-driven and knowledge-driven reasoning by implementing supervised and unsupervised data classification processes. The supervised classification is done independently at the scene level, for all processed scenes, using the same global training set while the unsupervised classification chains are implemented with the same criteria and the same parameters to the whole data set (Pesaresi, et al., 2016). No manual intervention is performed during the processing. Therefore, GHSL exploits the same typology of data as this study, but its methodology is deeply different: while this study has performed supervised classification with parameters and training set designed for the specific area of study of Naples, GHSL has developed a procedure that classifies all places in the World in the same way, with same parameters and same training areas.

Therefore, GHS classifications, with the assessment of built-up over last 50 years, were downloaded in a raster format for the area of this study and compared with the Selective land cover maps. **Comparison was performed in both qualitative and quantitative ways** through the overlapping of classifications and the measures of Built-up lands for both GHSL and Selective land cover maps. The GHS Layers are presented here in Figure 5.4 overlapped as it has been done for this study Selective land cover maps (presented in Figure 5.3) from the oldest at the top to the most actual at the bottom. For a first comparison, looking at Figure 5.4 and Figure 5.3, it is clear, at first sight, that Built-up Land is much more present in GHSL than this study results. Moreover, the GHSL represents a human settlement mostly dated up to 1975, with less differences in the years after. Particularly, Built-up land from 1975 up to 1990 is quite insignificant, totally different by this study's results. Urban growth after 1975 has occurred more in suburban and rural areas.

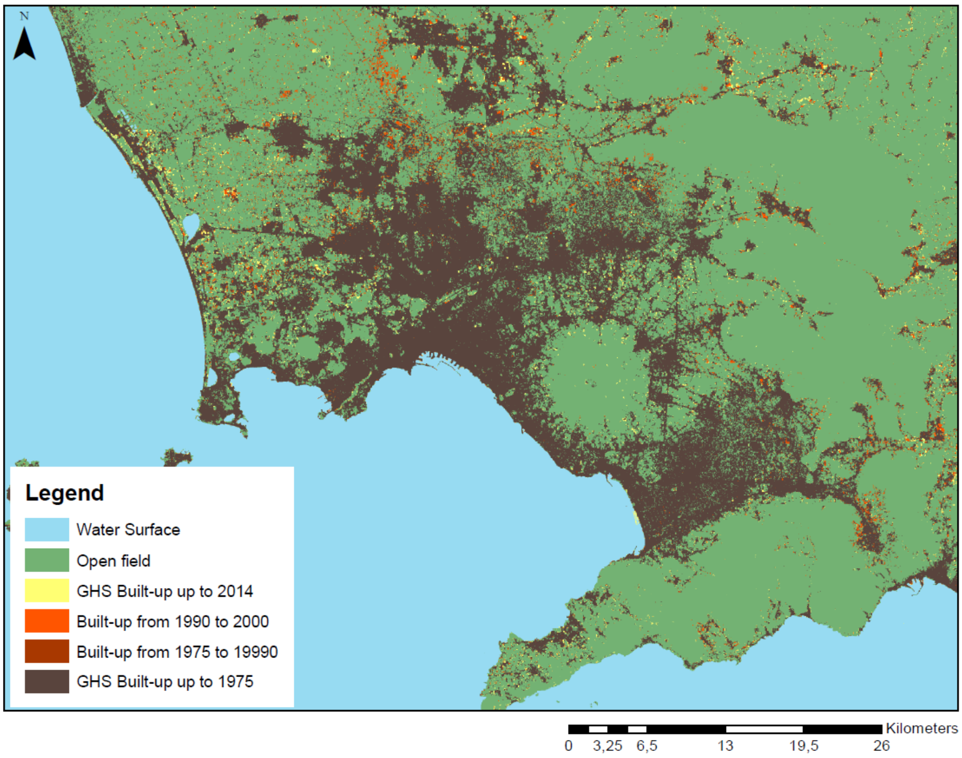


Figure 5.4 GHS Layers for Built-up in the different periods from 1975 up to 2014.

To better compare results, measures are necessary, thus pixels for each Built-up land related to the different periods have been counted and results are presented in

Table 5.2. The small increase of Built-up detected by GHSL between 1975 and 1990 is evident, while the largest rise of Built-up would be from year 1990 up to 2000 (+7,74% for the whole study area), but still changes are small and the biggest part of Built-up would be dated before 1975 (it would account as 88% of the whole study area Built-up land).

Table 5.2 GHSL Built-up land in numbers, for the total study area or for the Province of Naples.

			1975	1990	2000	2014
GHSL results	Total study area	**Built-up [km2]**	**831,12**	**831,18**	**895,52**	**947,38**
		Open field [km2]	2144,93	2144,87	2080,54	2028,67
		Water surfaces [km2]	1868,92	1868,92	1868,92	1868,92
		density (built-up/ (built-up+ open field)	**27,93%**	**27,93%**	**30,09%**	**31,83%**
		Rise of built-up		**+0,01%**	**+7,74%**	**+5,79%**

The years GHSL refer to are different with respect to the ones considered by this study: if GHS classifies the Landsat imagery of 1975, 1990, 2000 and 2014 this study has images for 1972, 1984, 1998, 2008 and 2019. Thus, comparison among different years results would not be fully correct due to changes over time of the overall settlement in the area. It is for this reason that only results of years that are closer have been compared. Therefore, comparison has focused on 1975/1972, 2000/1998 and 2014/2019.

Starting the comparison from 1975/1972 (GHSL/this study's Selective land cover map), this couple of results show the most remarkable difference, even in qualitative terms: the Built-up area depicted by GHSL is extended for more than 6 times the Built-up area resulted by this study's classification, it is even larger than this study's classified Built-up area of 2019. The GHSL 1975 Built-up area is about 831,12 km^2, covering about 28% of the territory of the study area (not considering water surfaces). This study 1972 Selective Land Cover map, differently, shows a Built-up land that covers an area of just 144,7 km^2 with a density, Built-up over total area (without considering water surfaces), of about 5% (see Table 5.1). Therefore, results show very different trends, and it is possible to understand it just looking at the two maps in Figure 5.5. This huge difference seems to be explained by GHSL accuracy assessment (Pesaresi, et al., 2016) that states: "*The most critical point seems to be the processing of the 1975 MSS data. Visual analysis by experts evidenced some cases of instability and low signal-noise ratio in the response of the classifier using this data input. The phenomenon is geographical-related: it is linked to the specific contrast between the reflectance of the materials of the urban fabric and of the background*". Therefore, it could be considered that also for Naples 1975 image the

GHSL classifier has found some problems and instability that has provided a wrong result, that would explain also the insignificant growth detected for the years after.

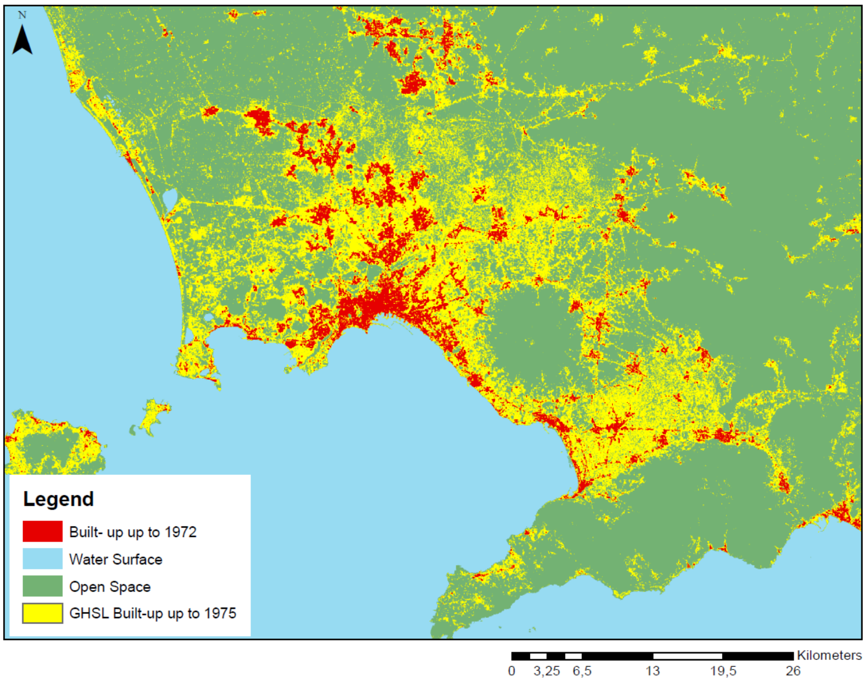


Figure 5.5 Comparison through the overlapping of 1972 Selective Land Cover Map and 1975 GHSL Built-up.

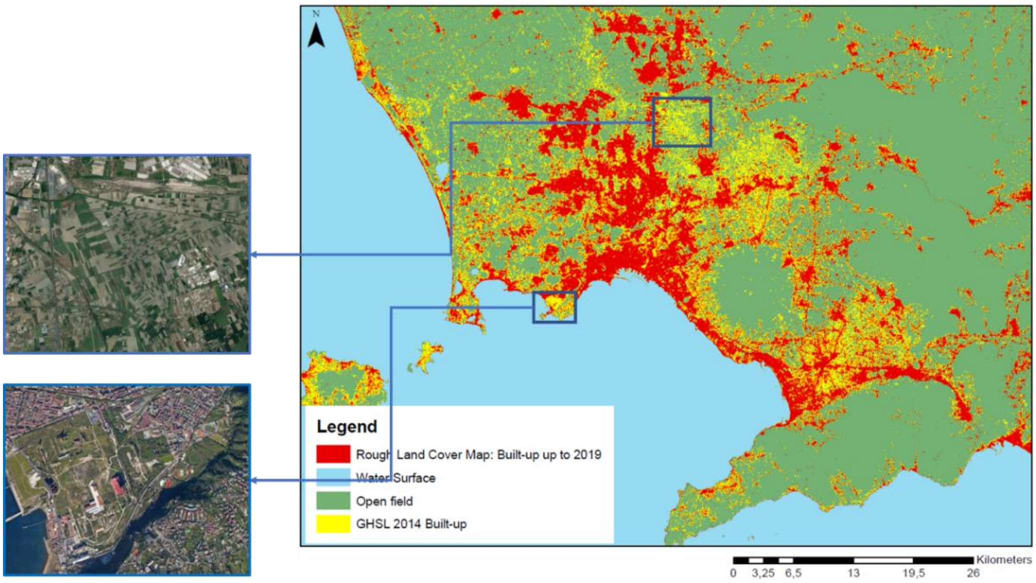


Figure 5.6 Comparison for 2019 Built-up, from this study's classification, and 2014 GHSL Built-up, with evidence of areas wrongly classified by GHSL as Built-up being crops (from 2019 Google Earth imagery).

Qualitative comparison between 1998 and 2000, as well as years 2014 and 2019 has provided similar evidence: GHSL has always detected a larger amount of Built-up with respect to the

Selective Land Cover maps, however, most of the times it has been proved its classification was less accurate: looking at high resolution Google Earth imagery, a lot of pixels, identified by GHSL as Built-up, demonstrated to be crops wrongly identified by its automatic processing. An exemplum is shown in Figure 5.6.
However, the results coming by this study classification and GHSL are not totally different: looking at their trends (see Figure 5.7), it is possible to see that, without considering the first phase from 1975 to 1990, trends for urban growth tend to be more similar in the following years. They still detect a similar urban development, particularly for years from 1990 up to 2008. It must be considered that still the different considered years affect the comparison of the trends, that could be even more similar.

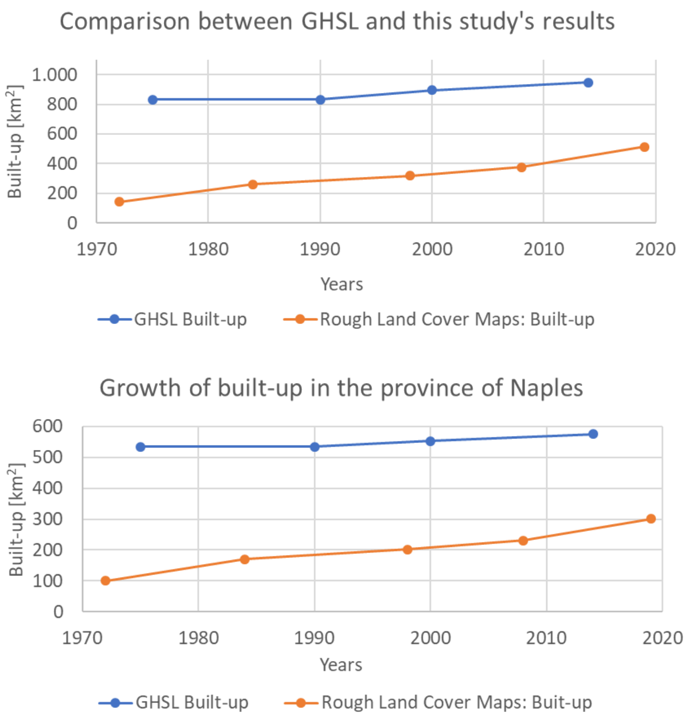


Figure 5.7 Trends for Built-up growth: GHSL and Selective Land Cover Maps.

In the end, summarizing, this paragraph has compared the results for Naples area from GHSL and this study. It has been assessed a significant difference among these results, even with some general agreement for the trends. From this, it has been justified the choice of this study to perform its own classification in a way to be more consistent with the only area of Naples. The two results indeed come from different perspectives: the GHSL classifies satellite images from quite all World, while this study has been set up for Naples, building its training areas for the only purpose of classifying this area.

5.1.3 Urban extent and attributes for urban expansion

After the first classification, the procedures described at 4.1.3, have applied a finer classification. Its results were fundamental to draw the urban extents of the city through the decades and to derive, after, the different attributes of urban growth. All these results are here described and analysed.

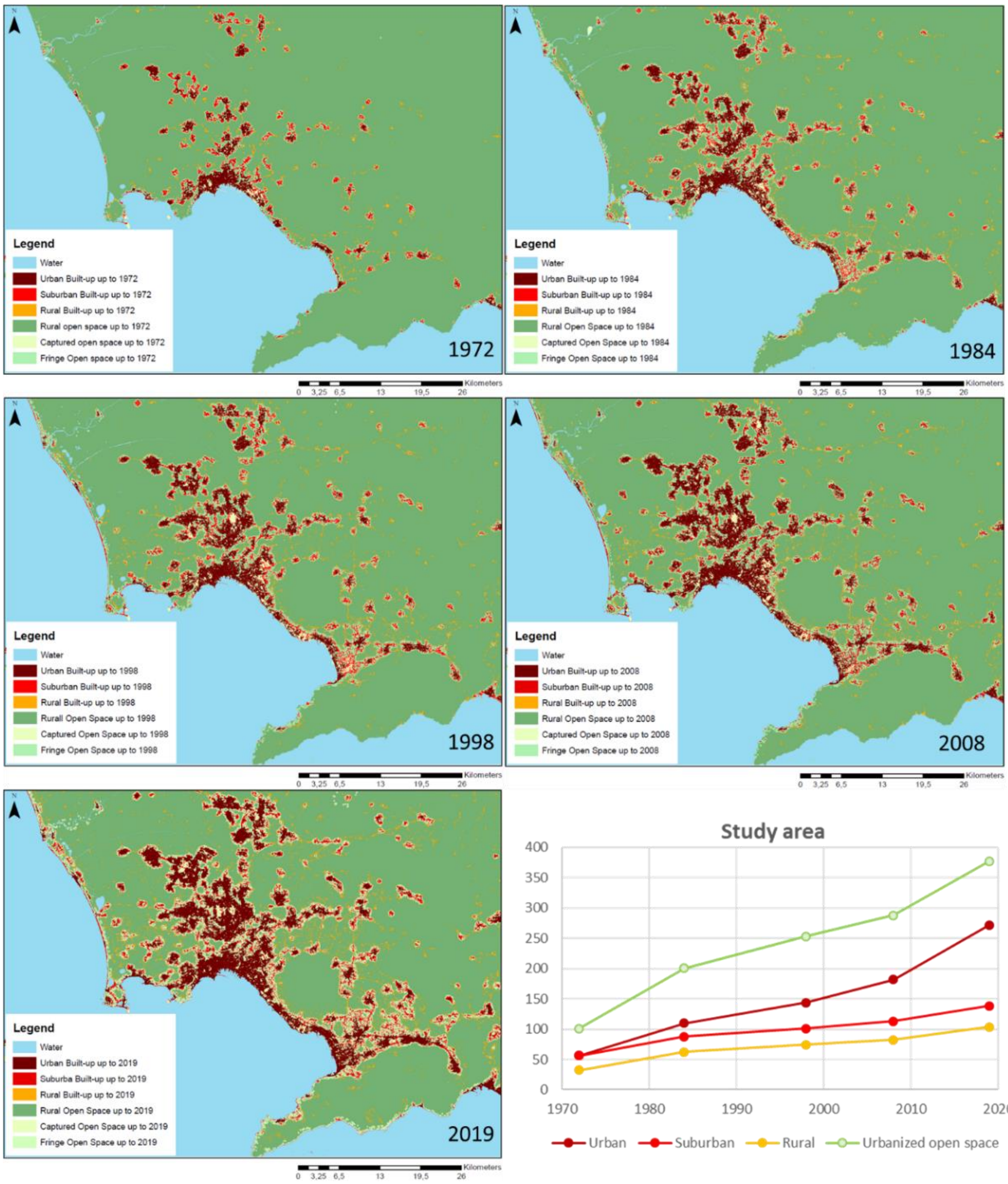


Figure 5.8 Finer Land Cover Maps and the urban development trends for the study area.

Figure 5.8 represents the **Finer Land Cover Maps** realized by this study, as well as the urban development trends they describe for the entire study area. These maps and trends still confirm and characterize the urban growth that has occurred over the years in the study area. Particularly, while with Selective Land Cover Maps it has been assessed just a general increase of Built-up land, now, with this finer categorization it has been possible to see where and how the Built-up has increased. **Urban**, **Suburban** and **Rural** subclasses of Built-up land have proved to be useful in characterizing the spatial relationships between Built-up areas, that can be referred to the concept of city and urban fabric. Urban Built-up describes the urban fabric itself, where Built-up gets denser while coming to the centre of a city. Suburban is more related to the usual peripheries of cities, where Built-up density gets lower and Rural, finally, is referred to all the buildings that can be found outside the urban fabric, less grouped together, more surrounded by Open Space (crops, forests…). Therefore, from this characterization of Built-up, trends can clarify the context that the urban growth has preferred and has created. Particularly, they show the **most of Built-up growth has been related to urban contexts**, more than Suburban and Rural. Suburban measures too need to be analysed. As it is possible to see in the trends, Suburban land has been a smaller part of the Built-up growth: while Urban Built-up has grown fast, Suburban and Rural have been slower, so that their portions, constituting with Urban the whole Built-up, have decreased becoming the 27% and 20%, respectively for Suburban and Rural, of the whole Built-up, from the initial 39% and 22%.(Table 5.3) That is already a good result, even though it should be noted from trends and rates of increase (Table 5.3) that still Suburban has grown, particularly in the years between 1972 and 1984, and in the last years from 2008 to 2019 when its rates and trends of growing have doubled. That confirms the spreading out phenomenon that was observable from the 1984 and 2019 satellite images with respect to the other ones.

It must be discussed also that with the increasing of Built-up land over the years, looking at just spatial relationships, it is possible that Built-up would be more easily classified as Urban. Therefore, Suburban is right to be lower than Urban, but its measure is still to be monitored and in periods like this last one, when it starts to rise again, urban planning should firmly address this evidence. Finally, it should be discussed also that Urban, Suburban and Rural subclassification depends also on the shape of the cities: the more a city is similar to a circle the less would be its perimeter, and, therefore, the less the opportunity for the GIS procedure to account areas as Suburban or even Rural. A regular shape sometimes is indicative also of a good urban expansion, where places into can be better connected among themselves: Naples, constrained between the two volcanos could not develop a regular shape, thus the parts that are classified as Suburban could have suffered an over estimation, due to its shape. However, looking at maps, the spreading out, not always in a well-connected way, of the urban fabric is evident and not related only to the presence of volcanic threat, therefore, Suburban measure (as well as Rural) still provides a reliable measure of quality of urban expansion.

Table 5.3 Measures for urban expansion.

	Classes	up to 1972	up to 1984	up to 1998	up to 2008	up to 2019
Study area	**Urban [km^2]**	56,19	110,00	143,42	182,10	271,74
	Rise of Urban		+96%	+30%	+27%	+49%
	Share for Urban in the whole built-up	39%	42%	45%	48%	53%
	Suburban [km^2]	56,40	87,86	101,28	113,04	138,25
	Rise of Suburban		+56%	+15%	+12%	+22%
	Share for Suburban in the whole built-up	39%	34%	32%	30%	27%
	Rural [km^2]	32,06	62,26	74,22	82,44	103,85
	Rise of Rural		+94%	+19%	+11%	+26%
	Share for Rural in the whole built-up	22%	24%	23%	22%	20%
	Urbanized open space [km^2]	101,02	200,54	253,49	287,67	377,08
	Rural open space [km^2]	2713,63	2499,10	2385,38	2295,27	2071,76

Furthermore, the subclassification applied on the Selective Land Cover Maps has involved also the Open Space, from which it identified the **Urbanized Open Space**, made up of the Fringe and Captured Open Space. This subclassification has allowed to distinguish and to measure the part of Open Space that is affected, or it is part of the urban fabric. The Fringe Open Space and its growth are still related to the perimeter of the Built-up clusters and therefore to its shape, so that the irregular shape of growing Naples has affected too the rising of Urbanized Open Space. Urbanized Open Space could describe urban parks (the captured Open Space) as well as simply the Open Space that could contour a city (thus, the Fringe), these measures still provide parameters to assess the quality of the urban fabric as well as how it affects the natural environment outside, of interest for the urban planning.

The **urban extent of Naples** has changed through time, incorporating more and more urban clusters in its surrounding; Figure 5.9 describes this growth overlapping the different Naples urban extents from its oldest on the top to the newest at the bottom: in this way it is possible to look at the different expansion areas that have created the actual layout of its urban extent. This map, as the previous one in Figure 5.3, will be exploited as part of the final tool to be provided to the stakeholders, explained at Chapter 6, in a way to illustrate the urban growth of the city.

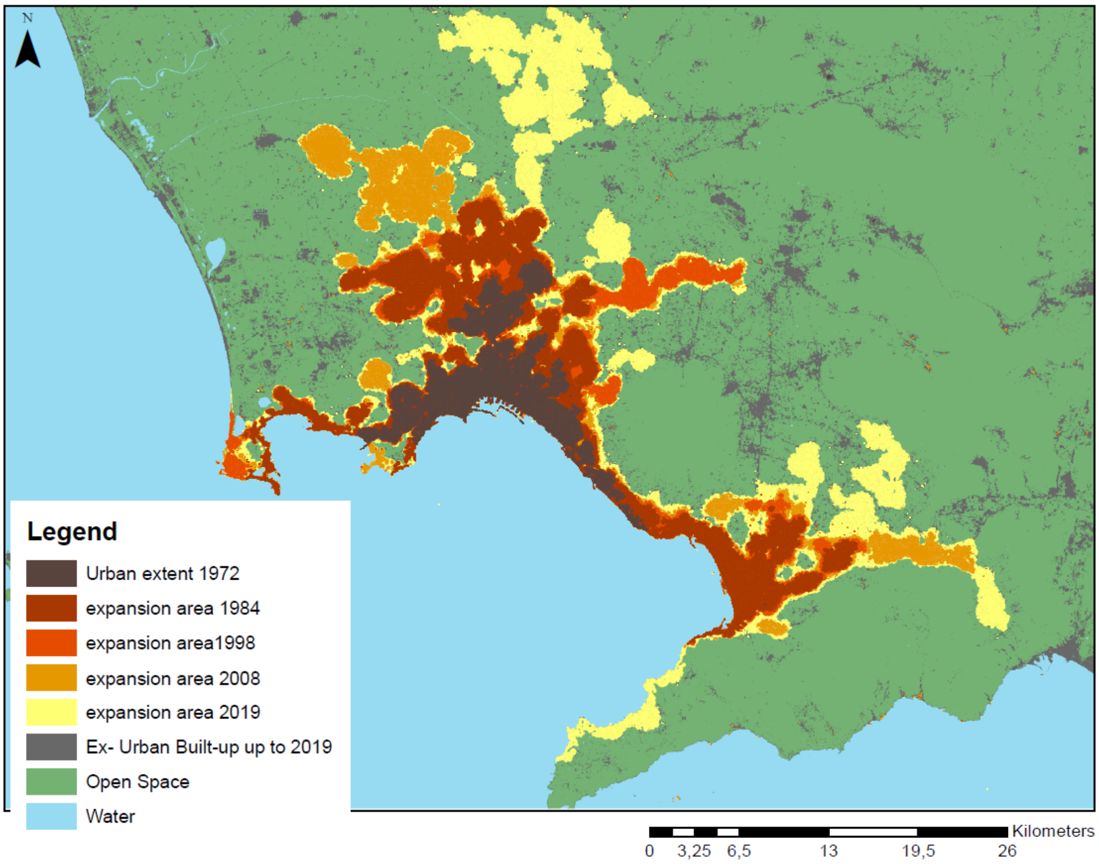


Figure 5.9 The Urban extent of Naples, and its expansion areas that have constituted its present shape.

It should be remembered here that the urban extent for each period includes the Urban and Suburban Built-up as well as the Urbanized Open Space. From Table 5.4 and Figure 5.10 it is possible to look at measures as well as trends for the urban extent of Naples through time. Particularly, it stands out the urban expansion between 1972 and 1984: Naples urban extent has more than doubled its previous size, extending its urban fabric up to North and spreading it towards the coast. Moreover, also the last years have experienced a huge urban expansion that has included also the city of Caserta. The urban extent of Naples has reached an extension (585,69 km^2) that corresponds to more than seven times the original urban extent up to year 1972.

In this expansion, it is interesting to look again on how it has occurred: thus, to consider the different classes that constitute the urban extent, measuring their trends and shares through the years (represented in Figure 5.10). Particularly, it is still recognizable the trend for Urban Built-up that is the Built-up subclass that rises the most, even though, the peripheries, in the most recent years, from 1998, have shown an increase that is little faster than trends for the whole study area. Moreover, it is of interest again the period from 1972 up to 1984: in these years Suburban raised very fast and it is possible to see that also Fringe Open Space increased becoming more extended than the same Urban Built-up. As mentioned before, the Fringe Open Space is the Open Space the most related to the limits of the urban fabric. Its increase at that levels in those years could highlight the irregular shape of 1984 urban extent. And Figure 5.9 can confirm this assumption with large territories, for the expansion area of 1984, surrounded by the urban extent and not included in it, filled only in the years after. Finally looking at shares, therefore at the portions that Urban, Suburban and Urbanized Open Spaces have constituted for the total urban extents, in the different years, the shares are quite similar with the ones that have been estimated for the whole study areas: considering Built—up land, Suburban has accounted always for about the 30% of the whole Built-up (without considering here the Rural class that is not included in the urban extent).

Table 5.4 Measures for the urban extent of Naples at the different periods.

Urban Extent	Classes	up to 1972	up to 1984	up to 1998	up to 2008	up to 2019
	Urban [km^2]	32,42	76,74	101,87	148,04	243,44
	Rise of Urban		+137%	+33%	+45%	+64%
	Share for Urban in the whole built-up	70%	65%	69%	72%	74%
	Suburban [km^2]	14,02	41,51	46,19	58,35	83,65
	Rise of Suburban		+196%	+11%	+26%	+43%
	Share for Suburban in the whole built-up	30%	35%	31%	28%	26%
	Captured open space [km^2]	8,70	25,51	35,55	38,14	38,29
	Fringe open field [km^2]	22,67	80,56	92,68	128,21	220,32
	Total Urban extent [km^2]	77,82	224,32	276,30	372,73	585,69

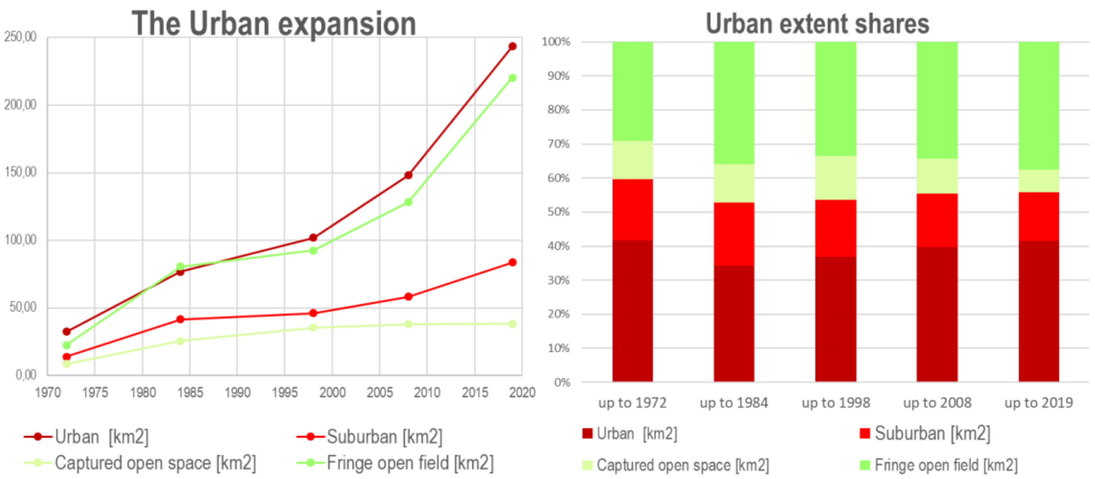


Figure 5.10 Trends and Shares for urban extents of Naples through the last fifty years.

Attributes have been exploited to better describe the urban expansion: these measures have been applied to the whole study area or the urban extent and its expansions. The analysis of the evidence they provide can bring more consciousness about the area and the city in their urban development. The attributes that have been computed by the Finer Land Cover Maps or the urban extents are related to density and fragmentation. **Density** is of two types, the $Built - up\ area\ density$ or the $Urban\ extent\ density$, both related to the measure of population. Population numbers in Table 5.5 needs further discussion. Due to its peculiarities described in 4.1.4, it is not to be considered as a precise number but just as an estimate that, consistent with the scale of study, can be useful in computing attributes to compare also the different years among themselves. Here an issue must be discussed about the urban extent density, related to population. Having estimated a municipally based population data has meant great difficulties when it came to assess population for the different historical urban extents of Naples. Indeed, they do not follow the municipal limits, and this applies for the whole of their extents: assessing their population has meant to statistically derive it for the part of each municipality territory included into the urban extent. The error therefore becomes significant and the attribute for density of the urban extent less reliable with respect to the Built-up one.

Table 5.5 Population, extents and attributes for the whole study area or Naples urban extents.

	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019
Built up of the whole study area [ha]	14465,88	26011,62	31891,32	37757,79	51383,97
Population study area	3843209	4225861	4361926	4434448	4685376
Density of population in the built-up of the study area [pop/ha]	266	162	137	117	91
Urban extent [ha]	7781,76	22431,60	27629,91	37273,32	58569,21
Built up in the urban extent [ha]	4644,36	11825,01	14806,44	20638,35	32708,97
Saturation	60%	53%	54%	55%	56%
Openness	55%	55%	53%	51%	48%
Population in the urban extent	1172321	2200374	2356041	2827076	3723290
Density of population in the urban extent [pop/ha]	151	98	85	76	64
Density of population in the built-up of urban extent [pop/ha]	252	186	159	137	114

The attributes presented in this table will be a fundamental evidence provided in the final integrated tool at Chapter 6. As it could be seen by the table, the most relevant result regards density of population that has decreased through the years both in the urban extent as in the Built-up land. It means that the same piece of land is inhabited by less people than before. Built-up land has increased more than the number of people. It is interesting also to compare the densities for population in the Built-up land of the whole study area or of the urban extents: population density has got higher for the urban extent than for the whole study area Built-up, as it could be predictable, however, in a first period, up to 1972, it has been an opposite situation, with more people in a Built-up hectare in rural land than in the urban extent.

Finally, analysing attributes for **saturation and openness**, this study demonstrates again that consumption of soil has increased very much in the seventies up to 1984 to then decrease very little and slowly in the decades after (still being more than the one relative to 1972). However, this last could be a good sign that, after 1984, urban planning has been given more importance or, at least, there has been a little more consciousness with respect to the decade before. But still, looking at Openness attribute, it is evident that if urban planning has been taken, green areas have not been considered much as part of it as a liveable urban extent, with green areas reachable by walk, from every point of the urban extent, decreasing over the years. All these analyses and measures need to be remembered that are just results from mathematical procedures based on spatial relationships, therefore they could provide just an overview on the urban expansion of Naples, but they could not represent the detailed context as it could be done by local knowledge of the area. However, so far, the methodology applied has proven to be consistent and significant with the study area.

5.1.4 Roads, blocks and attributes for Naples urban layout

The results from this study does not focus their point of view just on the development that has occurred, but they look particularly on its consequences, first regarding the present urban layout that it has drawn over the years. Roads analysis has been at the base of these results provided by the methodology described at paragraph 4.1.5. Still, it should be remarked here that the results and discussion, that are presented here, are more focused on the description of the present spatial layout of the urban extent of Naples, even though it is to remember that it is the result of the urban development that has occurred in the past.

First, the procedures for roads, blocks and attributes for the urban layout have been applied overall 2019 Naples urban extent. The attributes are useful not only to describe the city and the quality of its urban development through its actual layout but also, they will be fundamental for the second part of this study results. Their values, related to the 2019 actual layout of the urban extent of Naples, divided in its expansion areas, are summarized in Table 5.6.

Table 5.6

Table 5.6 Roads and block attributes for 2019 Naples Urban Extent.

Roads	Attributes	Areas of 2019 Naples Urban Extent				
		Urban Extent pre 1972	**Expansion area 1972-1884**	**Expansion area 1884-1998**	**Expansion area 1998-2008**	**Expansion area 2008-2019**
	Share of local roads [km/km]	73%	76%	74%	80%	67%
	Share of collector roads [km/km]	14%	15%	14%	12%	20%
	Share of primary roads [km/km]	5%	3%	4%	2%	3%
	Share of trunk roads [km/km]	1%	2%	4%	2%	4%
	Share of motorways [km/km]	3%	3%	3%	2%	5%
	Average density of all roads [km/km^2]	18,36	13,10	10,22	12,61	15,03
	Average road width [m]	5,89	5,91	6,05	5,78	6,50
	Average density of all arterial roads [km/km^2]	4,29	3,09	2,61	2,40	4,80
	Average density of wide arterial roads [km/km^2]	0,77	0,69	0,76	0,55	1,32
Block layout	Average block size [ha]	1,87	2,23	1,32	1,76	2,78
	Density of intersections [n/km2]	87,44	77,52	42,78	67,18	39,16
	Density of 3-ways intersections [n/km^2]	62,06	65,07	36,39	56,80	33,25
	Density of 4-way intersections [n/km^2]	19,76	12,37	6,39	10,35	5,91
	Share of intersections that are 4-way	22,60%	12,19%	14,94%	15,41%	15,09%
	Share of areas within walking distance to arterial roads [km^2/km^2]	98%	95%	89,10%	92%	89,12%
	Share of areas within walking distance to wide arterial roads [km^2/km^2]	21%	23%	18,87%	18,93%	16%

Looking first at roads attributes, the meaning for the attributes is quite clear: this study has described the quantities, the shares and quality for road network in the different expansion areas. Regarding the **shares** for the different classes of roads it is possible to see that the most of roads are, for all the areas, the local ones, however, in the expansion areas related to the periods from 1972 up to 2008 their part is even larger with respect to all the other types of roads, while in the last years expansion area their share has decreased, with advantage of arterial roads, particularly the collector ones. For the fastest roads, as primary roads, trunks and motorways, the shares do not change much over the urban extent, they always are small (maximum the 5%) with respect to the other types of roads. It could be noted that, in the expansion area related to the years from 2008 to 2019, the sum for primary, trunks and motorways is higher (for example it doubles the same sum for the 1998-2008 area). This increase makes also the average road width attribute larger for the 2008-2019 expansion area, as well as the average densities for arterial roads. However, looking at the **average densities** for roads, the values describe a spatial decrease of roads, when going from the urban extent dating back to 1972 to the most recent 2019 expansion area. Still 2008-2019 expansion area shows an improvement but still lower than the value for density of the first urban extent of 1972. The average density for all roads is an important attribute that provides a measure of how much an area could be served by roads, and thus how much it could be accessible by the outwards but also by the inwards. Regarding the **road width**, the worst result is given by the expansion area of 1998-2008, that could be related still to an urban fabric that remains more comparable to the ex-urban territory in terms of accessibility. However, differently from the attributes described before, the average road width increases, even if slowly, in the expansion areas from 1972 to 1998. This trend could seem it disagrees with the other trends for shares and densities, in reality it is related to the fact that width has been calculated splitting the classes for motorways and trunks by their links that were given a 5m width differently from their 24m and 16m widths: it means that, looking at the similar shares for example of motorways in the urban extent dated 1972 and the others after, the motorways links are more present in the first area, decreasing its average road width. This result needs a further discussion: for motorways particularly, with a restricted access, the motorway links could be more indicative for the accessibility of the area from the outwards than the presence of the motorway itself that is inaccessible without them. The value for road width should be more studied, also because, as mentioned in methodology, the measure for road widths per typologies are just a simplification of a really more variable road network, where the same road could have different widths depending by the places it passes through. Indeed, it has been already warned to consider the average road width only as a tool for comparison among the different expansion areas and not a real absolute attribute. The width of roads could be a measure for their importance, the accessibility they can provide, as well as the measure for urban planning lying behind and ensuring infrastructures for the urban expansion.

Particularly, road width could be linked to the travel speed. Therefore, even considering the issues related to this attribute, road width has been considered still, with a reminder for a further study.

Describing then the block layout of the recent urban extent, the first attribute, the **average size** for a block, is related to the density of roads: the more the density (if regular) the smaller the size of a block. However, it depends by the regularity of the roads, therefore this parameter, can tell something more with respect to the density. For example, it underlines the irregularity of road network in the expansion area of 1972-1984, with a peak for its average block size, and then it shows also another peak for the last expansion area of these last years. The average block size could be important as it could measure the accessibility of the small pieces of an urban extent: the smaller the block the higher the possibility to reach the different locations inside it. Therefore, the irregularity for the road network in the expansion areas from 1972 to 1984 and from 2008 to 2019 make these areas less accessible and more difficult to be travelled into. Furthermore, also **density of intersections** could be a great parameter for accessibility: being related to the redundancy of roads, it measures the possibility of reaching a place from different roads, that could be of interest in case of emergency. From these results, the focus goes to the 4-ways intersections as well as to the total amount of intersections in an area (the density for intersections):it could be seen that density of intersections decreases coming to the last expansion area of the urban extent and so it is for the 4-ways intersections that become more rare. Finally, the last measures present in table, are linked to the areas that could be found in a walkable distance (about 600m) from the arterial or wide arterial roads. Thus, how much each block could be fast connected to the others. These measures do not underline a trend but they show a big difference between arterial or wide arterial roads presence in the urban layout: while quite whole urban extent could reach easily arterial roads (particularly, more secondary and primary ones) when selecting just the wide trunks and motorways, the reachable areas decrease fast. It still demonstrates that the city is much more served by slower roads than faster ones.

It is to be remembered here, that all this analysis has no an absolute value, particularly for an urban planning point of view: all the procedure that have bring to it are consistent in the way they were born to compare their own results among themselves, also the comparison with the Atlas of Urban Expansion values for the other World cities, could be possible only on a generalized and not detailed perspective, due to their different choices. This could be a limit for these results, when looked only from an urban planning point of view. However, the attributes and the analysis of the urban expansion and the blocks layout in this study have had the only purpose of creating the base for the analysis on an exposure growth and vulnerability perspectives, to compare the different times or the different areas, and derive, if the methodology demonstrates it to be possible, a ranking thus a prioritization in land planning against risk.

5.1.3.1 The actual urban layout: Land use

CLC maps for years 1990, 2000, 2008 and 2018 have been exploited to look at another important evidence for the study of consequences of Naples urban development. From the study of CLC map for year 2018, overlapped to the different Naples expansion areas the differences among the land uses in the areas have been analysed. Here, this knowledge could be important to provide a general view on the land use of the Naples urban context, to be able, then, to understand more its land uses related just to a chosen hazard zone. In
Figure 5.11, it is shown the overlapping of the different expansion areas upon the 2018 CLC Map.

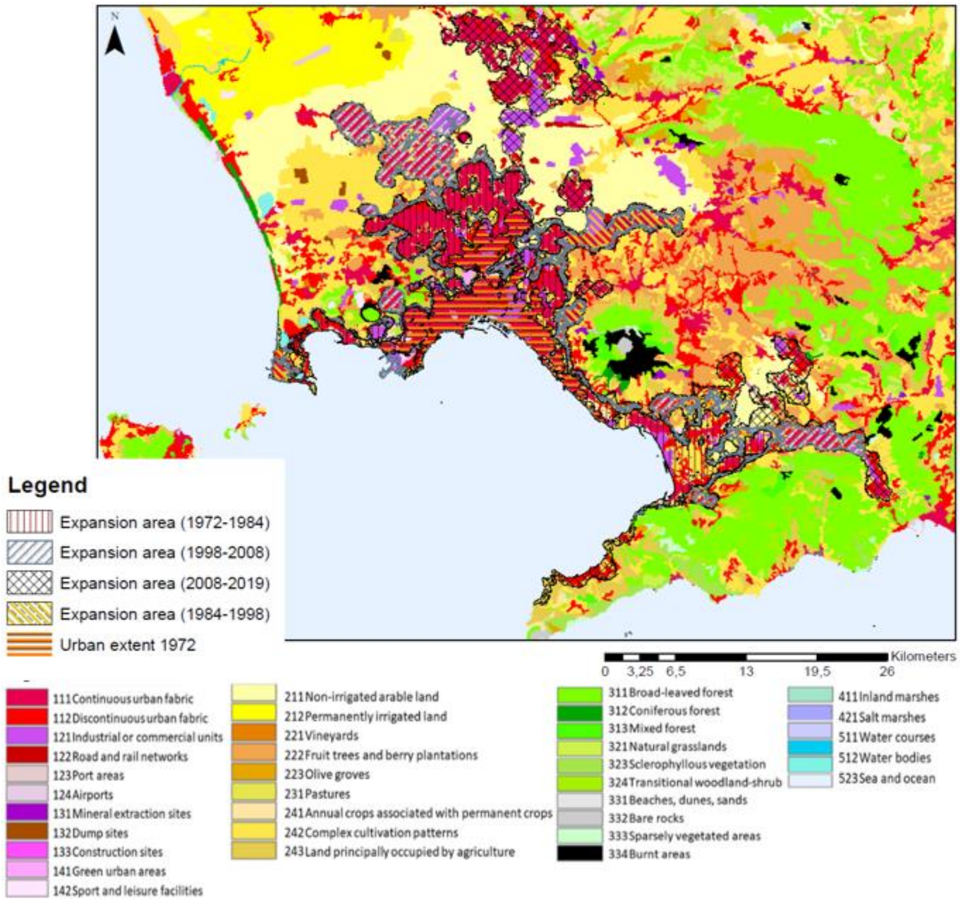


Figure 5.11 Overlapping of expansion areas on 2018 CLC map.

This overlapping has made possible the extraction of shares for the land uses in the different expansion areas of the present urban extent of Naples, shares that are shown into the graph of Figure 5.12.

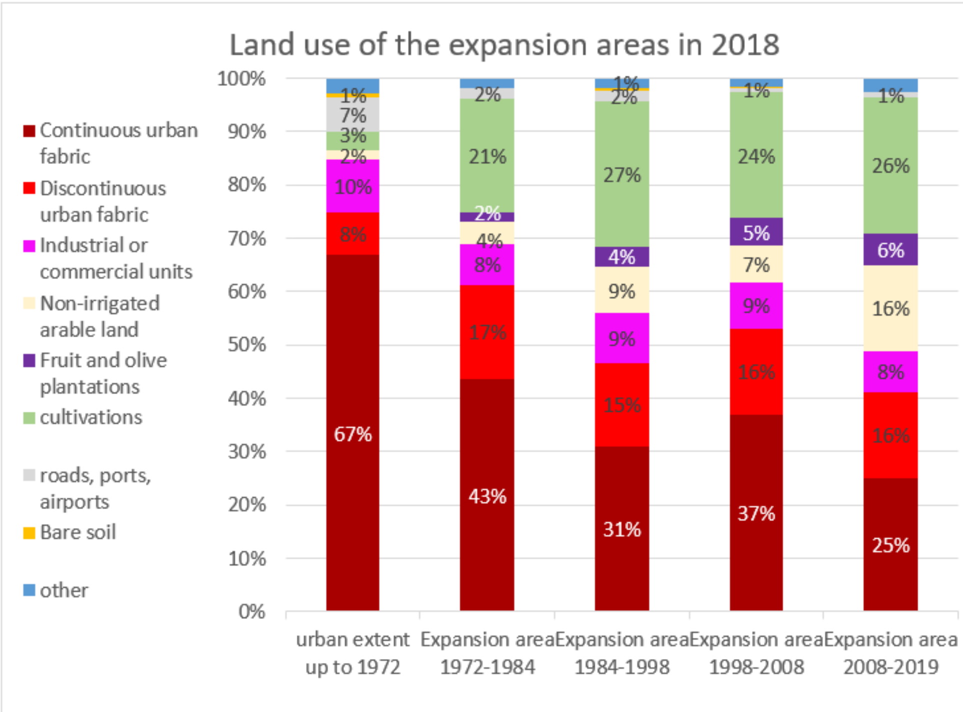


Figure 5.12 Shares for land uses in the different expansion areas of Naples present urban extent.

As it could be noticed, it is remarkable the difference among the shares for the continuous urban fabric included in the different expansion areas: The CLC map underlines an urban fabric that, moving outwards to the most recent expansion areas, becomes more discontinuous and less important. The general concept of Built-up decreases with advantage of cultivated land and non-irrigated arable land. These shares allow also to a comparison with saturation first results about the whole Naples urban extent: it could be seen that CLC and the saturation attribute, shown by this study at Table 5.5, are similar, both see a more saturated urban extent in the historical area of pre-1972, saturation that tends to decrease moving to the outwards, even though the differences are slighter for the results of this study. The differences could be related mostly to the different 100m spatial resolution of CLC map and its minimum mapping unit of 25 ha that could overestimate the Built-up land and the differences among the expansion areas. But still the trends describe the same decrease of Built-up coming to the peripheries of Naples urban extent. Moreover, from CLC, it is possible to look also at industrial or commercial units or the different cultivations that could be performed in the areas. As it is shown, factories and commercial units are quite similar in number in the expansion areas even though they remain lower than their number (10%) in the historical urban extent of 1972. It means that production and commercial activities seem quite uniformly distributed on the urban extent (even if a little more in the inwards, as expected when comparing the centre of a city and its peripheries). However, it should be needed more detail not only on a spatial

resolution point of view but also on the differences among factories, commercial units, etc. CLC map detects also leisure facilities and green urban areas but their small numbers, for some expansion areas they are estimated as quite zero, make them not significant and a detailed classification of services not possible. Obviously, land use detail is difficult to be detected by satellite imagery, as also CLC does, and a further study with other types of reliable data would be needed. CLC can assess the most prevalent land use for an area larger than 25ha and this use is quite general, particularly, when it comes to human activities not related to agriculture. Indeed, for agriculture, always for a matter of Remote sensed first data, there is much more characterization that could be exploited for land use analysis: for Naples case study, it is recognizable a big increase for green areas as cultivated land, fruit and oil plantations and non-irrigated arable land, coming to the limits of its urban extent. This characterization could also allow to estimate broadly their economic value, that could be of interest when assessing the 'value' being exposed to threats. However, for the study of land uses of an urban extent, the lack of more detailed information about land uses more related to the industrial and services activities is predominant so that agriculture characterization loses importance.
In the end, summarizing, the evidence from this land use study of the Naples urban extent is still that saturation decreases getting further from the centre, as already assessed by this study saturation attribute, industrial and commercial units tend to be similarly spread in the urban extent, however the analysis would need more detailed data. In the second part of Results, the same analysis will be performed only on the chosen hazard zone, together with a temporal analysis of CLC data.

5.2 The consequences of urban expansion for exposure growth and systemic vulnerability

So far, urban expansion of Naples has been studied, looking at the whole study area or focusing on its urban extent. These results, measures and maps, are now to be analysed in their link with exposure growth and systemic vulnerability. Particularly, here, it will be discussed also the proposed methodology of this link, in a way to see its effectiveness to develop an integrated tool that mixes urban planning and risk perspective.

This second section of Results is aimed, therefore, to provide and discuss the outcomes of the second section of methodology, focused on the volcanic hazard zones, that are part of this study area. Rankings and maps will be presented as the final results, comparing the different hazard zones and the urban extent included into. Particularly, rankings would have for purpose to guide future decision-makers to a more conscious urban planning that would prioritize and adopt measures in mitigating volcanic risk by acting on its factors as exposure and vulnerability.

5.2.1 The urban expansion consequences on exposure growth in the volcanic hazard zones

The results that regard exposure growth are presented in this paragraph. To be computed, first, it was necessary to overlap the volcanic hazard zones to the Built-up land development depicted by the Selective Land Cover maps for Built-up, as well as to the urban expansion map. The overlapping is shown in Figure 5.13, as well as in the Appendix. From the overlapping it could be seen that these zones have been subjected to Built-up growth as well as urban expansion. Overlapping the hazard zones has meant to extract the measures for this development limited to just these areas.

The measures for Built-up and urban expansion are related to the exposure, therefore they are at the base for this analysis. **Built-up land** numbers in the volcanic hazard zones are presented into Table 5.7, and the graphs linked to, in Figure 5.14. For this first analysis, the whole Built-up of the volcanic hazard zones has been compared. Particularly, in the first graph, that is shown in Figure 5.14, it is compared the growth of Built-up in the last years, in these zones: it is possible to see that the Yellow Vesuvian hazard zone has experienced the biggest increase trend of Built-up (for example in the first studied period between 1972 and 1984 Built-up has more than doubled its previous land there), with a difference with the other zones increasing over time. The others, on the other hand, still show an increasing trend for Built-up, that is, however, less fast: the Yellow Phlegraean Fields zone shows the least Built-up growth, the red risk zones show a similar trend, but between them the highest growth comes still by the Vesuvian red zone. As it is possible to see in the graph, the highest rates of Built-up increase have been registered for the first and last periods under study, particularly, for the period between 1972 and 1984.

Nevertheless, it could be commented here that, the measure for the fast increase of Built-up in the Yellow Hazard Zone, could be due only for the size of this area, larger with respect to the others (like twice the Red Vesuvian Zone or more for the Phlegraean Fields Zones). However, the use of trends to compare the Built-up growth allows to untie the measures of growth from the sizes of the areas. Moreover, this method of comparison has made possible to compare the results for the different areas all together, to derive an overall ranking for Built-up growth, assigning a score from 1 to 4, with 1 representing the minimum exposure growth and 4 the maximum (thus, the Yellow Vesuvian Zone). The ranking is shown in Table 5.8. It will be exploited in the end to find out the final ranking for the exposure growth.

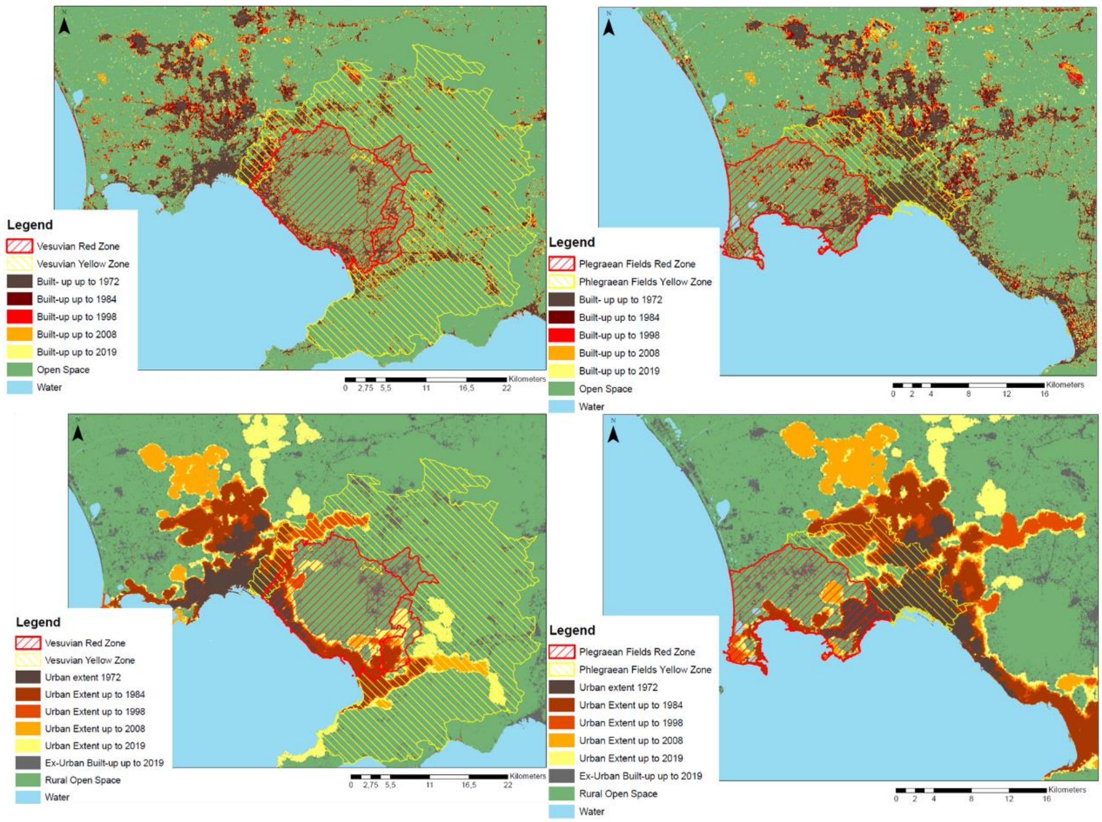


Figure 5.13 Overlapping of hazard zones on Built-up development or Urban Expansion.

Table 5.7 Measures for Built-up in the whole volcanic hazard zones.

Classes for the whole hazard zones	Vesuvian Hazard Zones									
	Vesuvian red zone					Vesuvian yellow zone				
	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019
Urban [Km²]	6,7	15,0	19,0	24,3	40,6	7,3	18,8	26,4	34,8	58,0
Suburban [Km²]	9,3	15,6	17,6	19,2	22,4	11,0	21,1	25,4	28,2	36,6
Rural [Km²]	7,0	12,0	13,1	13,2	13,3	9,5	18,0	20,5	22,5	26,7
Built-up [Km²]	23,1	42,6	49,7	56,7	76,2	27,9	57,9	72,3	85,4	121,3
Urbanized Open Space [Km²]	16,3	35,8	43,1	48,8	59,9	18,4	56,7	56,7	65,2	91,9

Classes for the whole hazard zones	Phlegraean Fields Hazard Zones									
	Phlegraean Fields red zone					Phlegraean Fields yellow zone				
	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019
Urban [Km²]	6,8	9,9	11,2	13,6	20,5	19,9	28,6	34,2	38,5	45,7
Suburban [Km²]	5,2	7,4	8,4	9,1	10,5	7,2	9,2	7,8	6,8	6,6
Rural [Km²]	2,2	4,3	5,4	6,0	6,8	2,1	2,3	2,5	2,8	2,5
Built-up [Km²]	14,2	21,5	25,0	28,7	37,8	29,3	40,1	44,5	48,0	54,7
Urbanized Open Space [Km²]	12,3	21,6	23,7	25,9	31,3	15,5	25,1	25,3	24,6	25,4

In Figure 5.14, the four graphs that describe the urban growth want to provide another point of view regarding the increase of Built-up: thanks to the subclassification of Built-up it is possible to look at its growth in its different parts, Urban, Suburban and Rural. In this way, it could be possible to have a first insight on the quality of development, as it has been done for the whole study area outcomes. This analysis has no value in terms of exposure because it does not add information about the quantities of the physical exposure. However, it is interesting to look and describe better the development of the areas. The Phlegraean Fields Yellow Zone, for example, shows a good outcome for the urban development: as it could be seen in the graph, the Urban Built-up has grown up with a trend similar to the total Built-up growth, with Suburban and Rural Built-up decreasing over the years. It means that in this area the urban fabric is less fragmented, and it seems to have grown in a more planned way. The others, that have experienced more similar trends, show to have increased the Urban Built-up, more than the other classes, particularly, only in the last period, while the Urban curve remains low before, meaning that Built-up growth has been constituted by all classes. Particularly, Yellow vesuvian risk zone presents the worst trends: Rural and Suburban have grown together with Urban class and represent an important part of Built-up land.

Comparing these results with the outcomes from the whole study area in paragraph 5.1.3, in the first decades under study, the Urban Built-up curve for the whole study area differentiates more with respect to the ones for Suburban and Rural, it stays higher, while for Vesuvian hazard zones the curve remains more attached to Suburban and Rural. It underlines again the poor urban planning that the Vesuvian region has experienced.

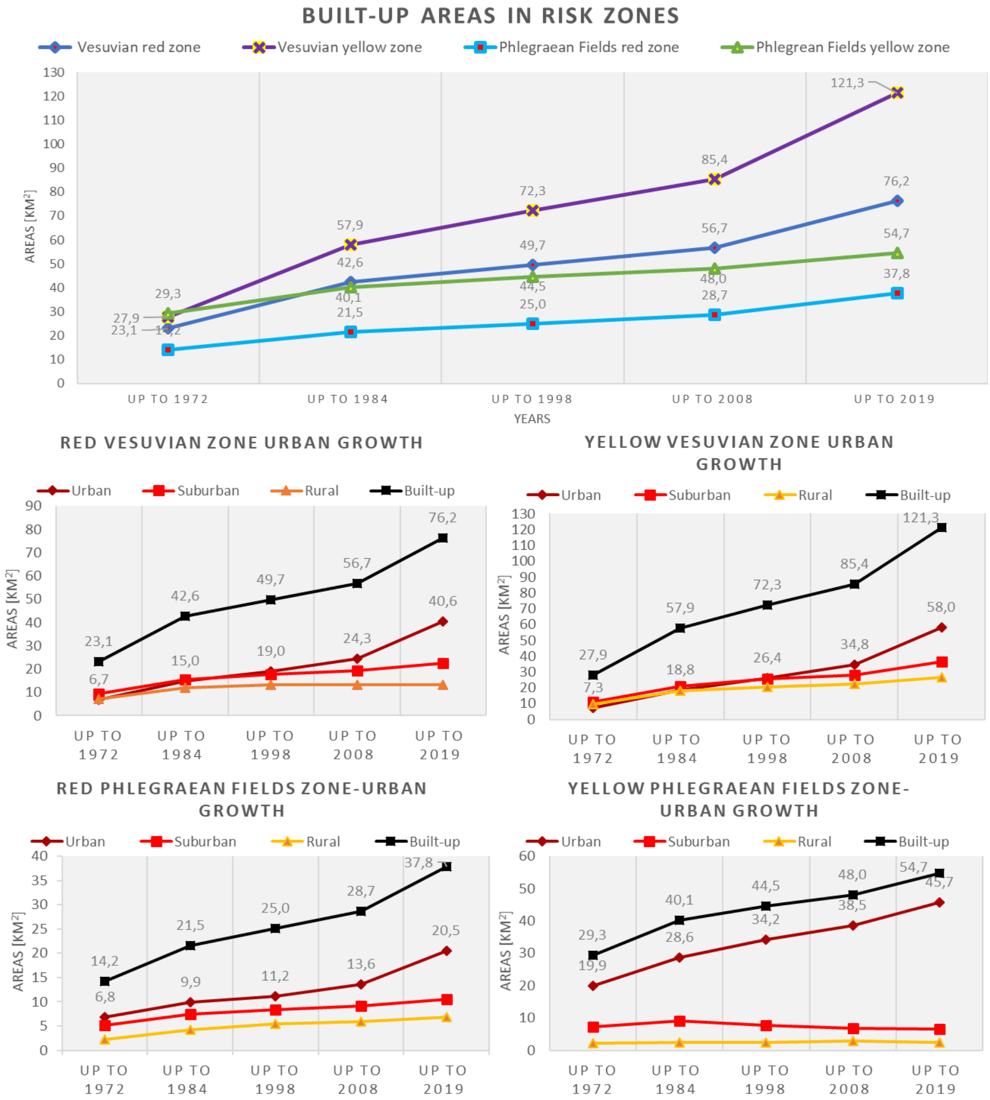


Figure 5.14 Graphs for Built-up development and urban expansion in the hazard zones.

Table 5.8 Ranking for Built-up growth in the volcanic hazard zones.

Ranking trends for Built-up growth	Vesuvian risk zones										Phlegraean Fields risk zones									
	Vesuvian red zone					Vesuvian yellow zone					Phlegraean Fields red zone					Phlegraean Fields yellow zone				
	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019
Built-up	23,1	42,6	49,7	56,7	76,2	27,9	57,9	72,3	85,4	121	14,2	21,5	25,0	28,7	37,8	29,3	40,1	44,5	48,0	54,7
trend		85%	17%	14%	34%		107%	25%	18%	42%		51%	16%	14%	32%		37%	11%	8%	14%
scores		15	7	4	11		16	9	8	13		14	6	5	10		12	2	1	3
sum scores for Built-up growth	37,0					46,0					35,0					18,0				
Ranking for built-up growth	**3**					**4**					**2**					**1**				

Coming to the **urban extent** measures, extracted for the volcanic hazard zones, in Figure 5.15, it is possible to compare the trends for urban expansion in the hazard zones. The trends describe the growth of Naples urban fabric towards the hazard zones. This analysis leads to another ranking that will be exploited, in the end, to find out the hazard zone that has experienced the biggest exposure growth. Indeed, the urban fabric has a different exposed value, also in economic terms, with respect to the simple physical Built-up exposure, thus, it needs to be considered separately. Through this analysis, it is possible to know where the city of Naples has expanded itself more and how much, relatively to the hazard zones.

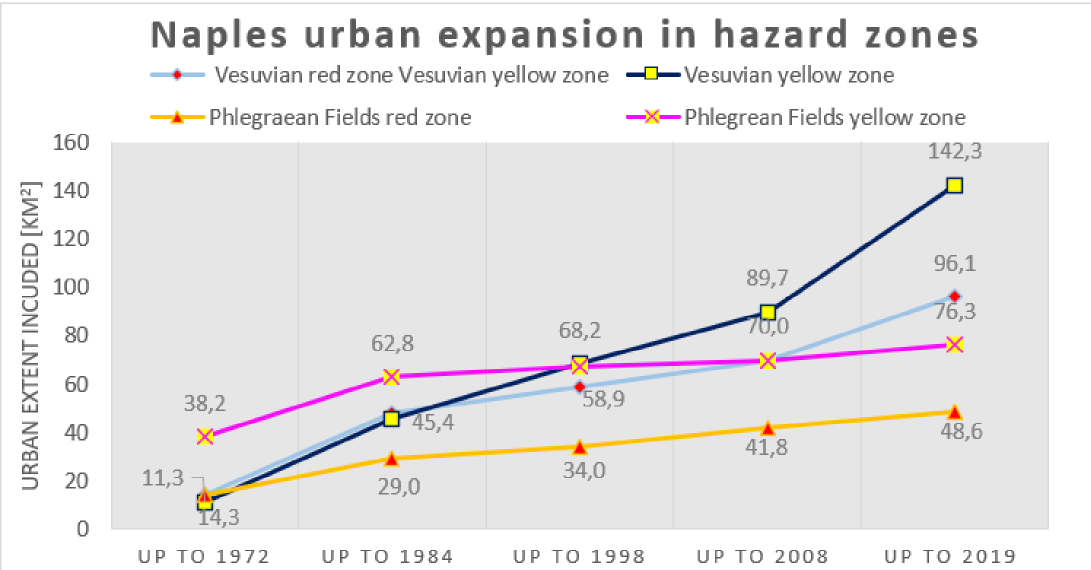


Figure 5.15 Naples Urban Expansion in the volcanic hazard zones.

It is evident that still the worst case is represented by Yellow Vesuvian zone: Naples urban fabric has expanded itself more and more over the years in this area, disregarding the volcanic risk, and its exposure has grown more and more with it. Behind it (represented by a score of 4), the Red Vesuvian Zone reports another worrying increase of urban extent over the years, followed by Red and Yellow Phlegraean Fields zones (value 1 for the lowest increase, estimated for the Yellow Phlegraean Fields zone). Numbers are shown in Table 5.9. Looking at them and at the ranking scores, it is possible to delineate the urban expansion directions that have been followed the most for what regards the hazard zones. The principal expansion direction has been to the North-East and East, while the Phlegraean Fields, therefore, the North-West and West have registered a lower expansion.

Table 5.9 Trends and ranking for urban expansion in the hazard zones.

Ranking for Urban Expansion in the Hazard Zones	Vesuvian risk zones										Phlegraean Fields risk zones									
	Vesuvian red zone					Vesuvian yellow zone					Phlegraean Fields red zone					Phlegrean Fields yellow zone				
	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019
Naples Urban extent [km^2]	14,1	48,2	58,9	70,0	96,1	11,3	45,4	68,2	89,7	142,3	14,3	29,0	34,0	41,8	48,6	38,2	62,8	67,2	69,8	76,3
trend		243%	22%	19%	37%		301%	50%	31%	59%		103%	17%	23%	16%		65%	7%	4%	9%
scores		15	7	6	10		16	11	9	12		14	5	8	4		13	2	1	3
sum scores for Built-up growth	38,0					48,0					31,0					19,0				
Ranking for built-up growth	**3**					**4**					**2**					**1**				

So far, Built-up land and urban extent have been analysed to derive the scores that will be summed to provide a ranking for exposure growth in the volcanic hazard zones. Built-up land, as well as the urban expansion are related more to the physical exposure and to the economic value of it, however, looking at exposure, **population** cannot be missed. Particularly, the data for population, municipally-based, have been extracted for the whole hazard zones in a way to detect their growth in these areas, so to compare and rank again these areas from an human exposure point of view, with a score that will be summed with the two previously defined. As already mentioned, the numbers for population could not be applied to the urban extent limits in the hazard zones, but they could be considered reliable for the hazard zones limits, being them similar to the municipal ones. The outcomes with the results in terms of population trends, are presented in Figure 5.16.

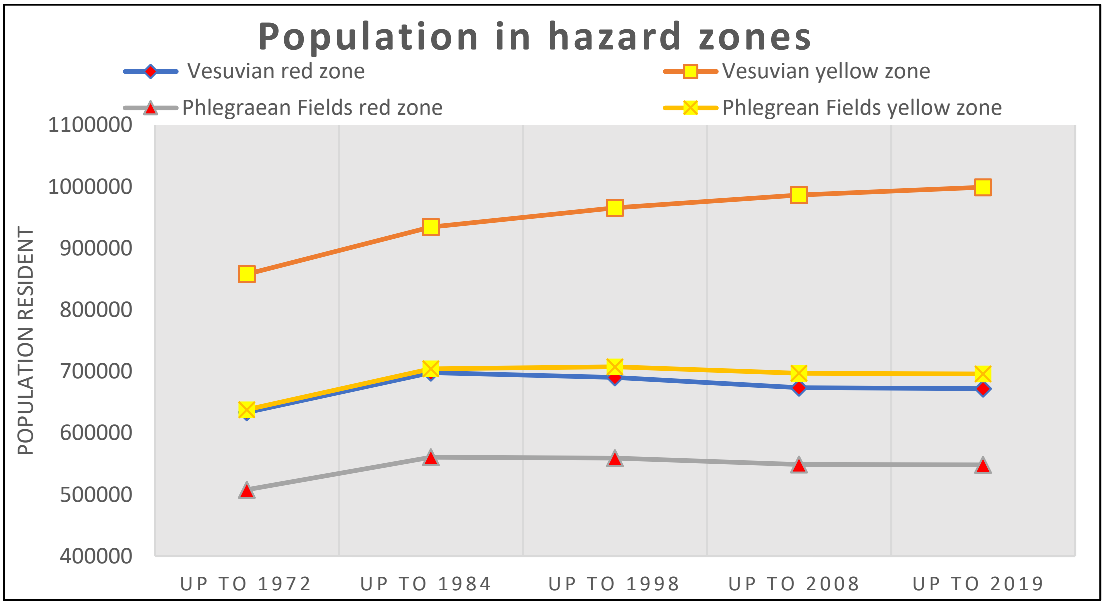


Figure 5.16 Population in the Hazard Zones over the years.

Results for the years after 1984 are significant: they detect a slow decrease, instead of population growth, for all the zones but the Yellow Vesuvian hazard zone. This zone is the only one that still registers an increase of resident population. The other areas show a similar trend, with Yellow Phlegraean Fields zone that has decreased the least towards the Red Phlegraean Fields area and the Red Vesuvian one where the population has decreased the most in the last years. However, looking at the changes over time also the first period, from 1972 to 1984, cannot be disregarded, therefore, all trends have been analysed as it has already done for Built-up and Urban expansion and the results with the final rankings that confirm the previous analysis, are shown in Table 5.10.

Table 5.10 Trends and scores for population growth or decrease over the years in the different hazard zones.

Ranking for Population increase/decrease in the hazard zones	Vesuvian risk zones										Phlegraean Fields risk zones									
	Vesuvian red zone					Vesuvian yellow zone					Phlegraean Fields red zone					Phlegrean Fields yellow zone				
	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019
Trends		10%	-1%	-2%	0%		9%	3%	2%	1%		10%	0%	-2%	0%		10%	0%	-1%	0%
scores		14	4	1	5		13	12	11	10		16	6	2	8		15	9	3	7
sum scores for Built-up growth	24,0					46,0					32,0					34,0				
Ranking for built-up growth	1					4					2					3				

Moreover, analysing the data for population trends in the hazard zones, it becomes interesting to compare them with the Built-up growth that has been registered by this study in those areas. Population was considered by the Atlas of Urban Expansion (Angel, et al., 2016a) for computing the attribute of population density that here could be interesting, even if sorted not for the urban extent, as it has been for the Atlas, but for the whole hazard zones. The trends for population density in Vesuvian and Phlegraean Fields hazard zones are shown in There it could be seen an important issue that is related to a lack of urban planning and an extensive soil exploitation: Built-up growth is no more related to the growth of population. The density decreases fast while Built-up increases and population not. And this happens also for the yellow Vesuvian area where population is still increasing: also there density is decreasing and less people tend to live in the same Built-up area as before in 1972. This result is in line with the World trends that have been described by the Atlas of Urban Expansion (Angel, et al., 2016a). Nevertheless, this last analysis has not for purpose the computation of another ranking and exposure factor, because as for Urban, Suburban and Rural discussion, it is not adding information of the measure of the exposed.

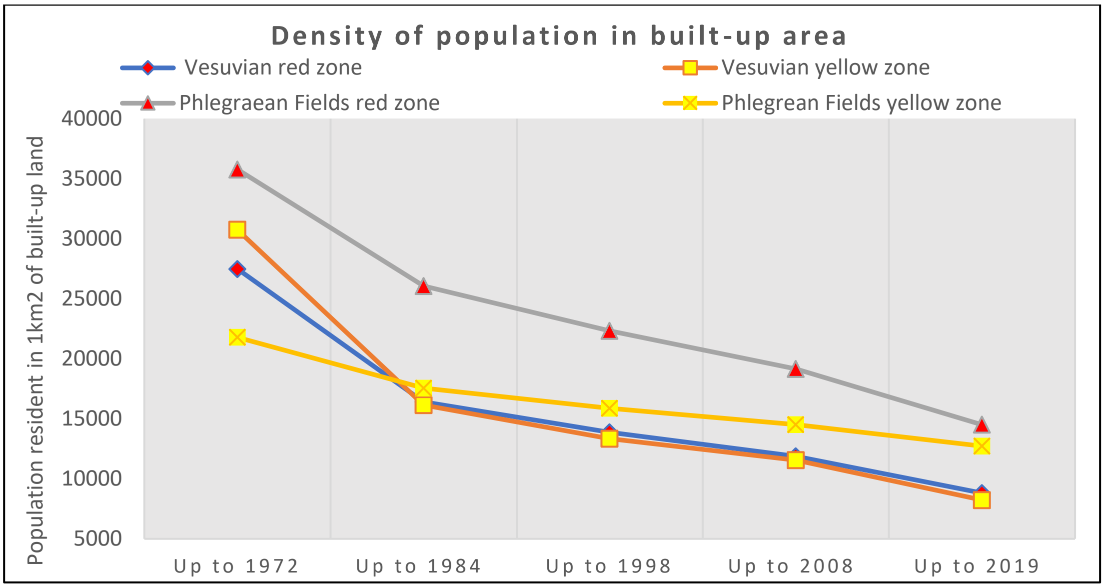


Figure 5.17 Trends for density of population in the Built-up land over years in the hazard zones.

Finally, the rankings for Built-up growth, urban expansion and population trends have been summed to derive an overall ranking for the exposure growth in the different hazard zones. The rankings are represented in the map for exposure growth shown in Figure 5.18. As possible to be forecasted, the worst area that has experienced the biggest exposure growth is the Vesuvian Yellow zone, followed by the Red Vesuvian, the Red Phlegraean Fields and finally the Yellow Phlegraean Fields hazard zone. As underlined by the previous analyses the Yellow Vesuvian zone has shown, for all the factors studied here, summed for the exposure growth analysis, the worst evidence, always with trends that are also very different with the ones of the other zones. It means that in this area urban planning has been really poor and not much conscious of its effects on exposure, it has disregarded the volcanic risk, increasing itself the risk acting on its exposure. However, it is to remember that this exposure growth comparison among the hazard zones is looking only at the evidence provided by this study about Built-up, population and Urban extent, therefore, it is linked only on the consequences of the urban growth and it is not valid in absolute terms. Its purpose would be to guide the future urban planning and decision makers but its ranking about exposure growth through the years could not be considered complete. Nevertheless, it still has drawn a worrying negligence for Built-up increase and urban expansion towards the hazard zones that seem not to consider the consequences that have been analysed through this section of results. Its last figure, representing the ranking, will be the fundamental result presented in Chapter 6, for exposure growth, in a way to guide and prioritize monitoring and planning.

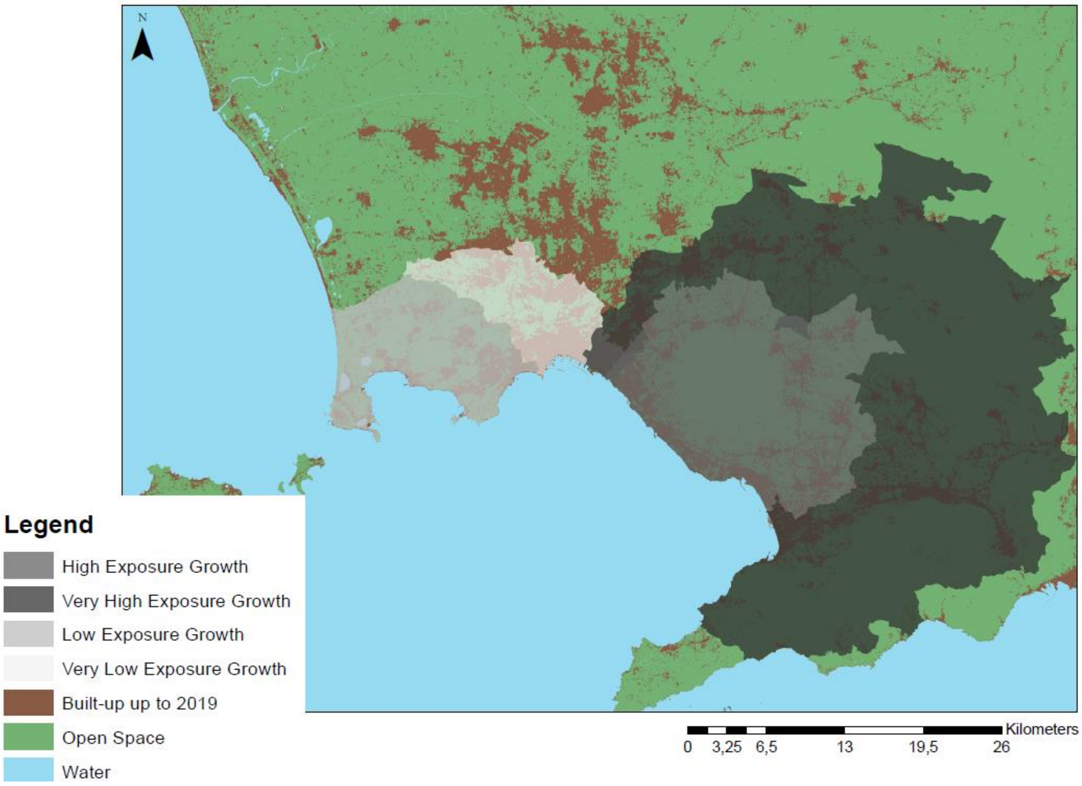


Figure 5.18 Comparison for Exposure growth in the volcanic hazard zones.

5.2.2 Systemic vulnerability in the hazard zones

After exposure growth to be studied from the outcomes for urban expansion, it is the turn for the analysis of urban layout consequences on risk, particularly on accessibility and, therefore, on systemic vulnerability. As for the analysis of exposure growth, the first point has been constituted again by the overlapping of volcanic hazard zones upon roads data and Naples expansion areas.

It should be remembered that here, the results are no more compared on a temporal basis but on a spatial basis, being referred only at the present times. For this reason, results here are organized in three spatial levels of detail:

1. Systemic vulnerability for the whole hazard zones
2. Systemic vulnerability for the whole urban extent
3. Systemic vulnerability for the expansion areas of the urban extent included in the hazard zones.

Each level of detail has determined a comparison among the hazard zones.

5.2.2.1 Systemic vulnerability for the whole hazard zones

In Figure 5.19 it is shown the overlapping of volcanic hazard zones on the roads of the study area. From this overlapping, it has been possible to extract the data that are needed for the systemic vulnerability analysis of the areas. These results are shown in Table 5.11. Particularly, the table presents also the scores that have been assigned to each measure that has been accounted for the systemic vulnerability comparison and ranking. The attributes are the same that have been already discussed in paragraph 5.1.4, however, it is missed the block size that would not be significant, here, due to the focus not on the urban extent but on the whole hazard zones. All these scores, being summed, have provided the first general ranking for systemic vulnerability of the hazard zones that looks at Yellow Vesuvian zone as the area with the highest systemic vulnerability (4) followed by Red Vesuvian zone (3) and then the Red (2) and Yellow (1) Phlegraean zones.

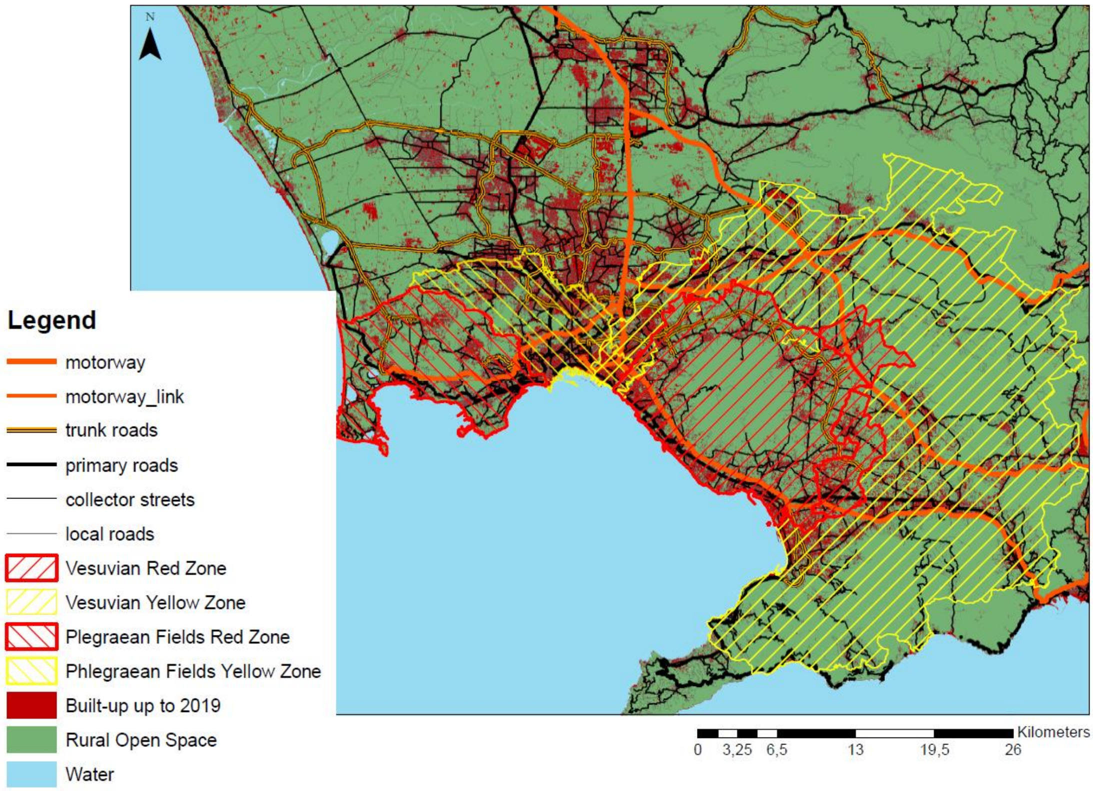


Figure 5.19 Overlapping of volcanic hazard zones on roads.

Table 5.11 Attributes and scores for the hazard zones systemic vulnerability factors.

	Attributes	Phlegraean Fields risk zones		Vesuvian risk zones	
		Phlegraean Red zone	Phlegraean Yellow zone	Vesuvian Red zone	Vesuvian Yellow zone
Roads	Average density of all roads [km/km^2]	9,2	13,7	6,0	4,6
	Score	2	1	3	4
	Average road width in urban extent [m]	5,9	6,0	6,0	6,3
	Score	4	3	2	1
	Average density of all arterial roads [km/km^2]	2,1	3,5	1,4	1,3
	Score	2	1	3	4
	Average density of wide arterial roads [km/km^2]	0,4	0,7	0,4	0,3
	Score	2	1	3	4
Block layout	Density of intersections [n/km^2]	27,8	68,3	20,8	15,1
	Score	2	1	3	4
	Share of intersections that are 4-way	0,2	0,3	0,2	0,2
	Score	2	1	4	3
	Share of areas within walking distance to arterial roads	0,8	0,9	0,7	0,6
	Score	2	1	3	4
	Share of areas within walking distance to wide arterial roads	0,3	0,4	0,3	0,2
	Score	2	1	3	4
Sum of the scores		18	10	24	28
Systemic Vulnerability Ranking		**2**	**1**	**3**	**4**

As it is possible to see from the table, the Yellow Vesuvian zone has the lowest density for roads and arterial roads, even though, looking as its average width, it is the highest , probably due to the motorways that are present in the zone. The high presence of motorways is not always a measure for the fast accessibility of the area or the outwards, it would depend by the presence of motorway links, that represent the only way motorways could be accessed. Looking at the extracted data for roads, indeed, motorway links registered for the area are less with respect to the other zones. This one could be an issue for this methodology proposed: grouping classes of roads, it simplifies the analysis and it makes it more readable and understandable, but detail can be loosened with the understanding of its consequences. Coming to redundancy of roads, the low values for intersection densities and share for 4-ways intersections still underline an area where roads network has not been planned consciously. Finally, the area has not much places that are in a short distance to arterial roads: this could mean a larger time to leave the area.

The red Vesuvian zone shows soon after the Yellow Vesuvian one, for its systemic vulnerability. It is shown form the table also that is the worst in terms of redundancy due to 4-ways intersections, that are the smallest in number, with respect to the other zones. Finally, Phlegraean Fields hazard zones underline as an issue only the very low average width of roads, that could mean a lack of fast roads to exit them.

Regarding seismic activity that could occur before the Vesuvian or Phlegraean Fields eruption, it has been interesting to look at bridges present in the hazard zones. The overlapping is shown in Figure 5.20. Particularly, extracting lengths for each area it could be seen that the area with the biggest presence of bridges is still the Yellow Vesuvian hazard zone, that from map, appears to be located in the area that is the most urbanized of the hazard zone.

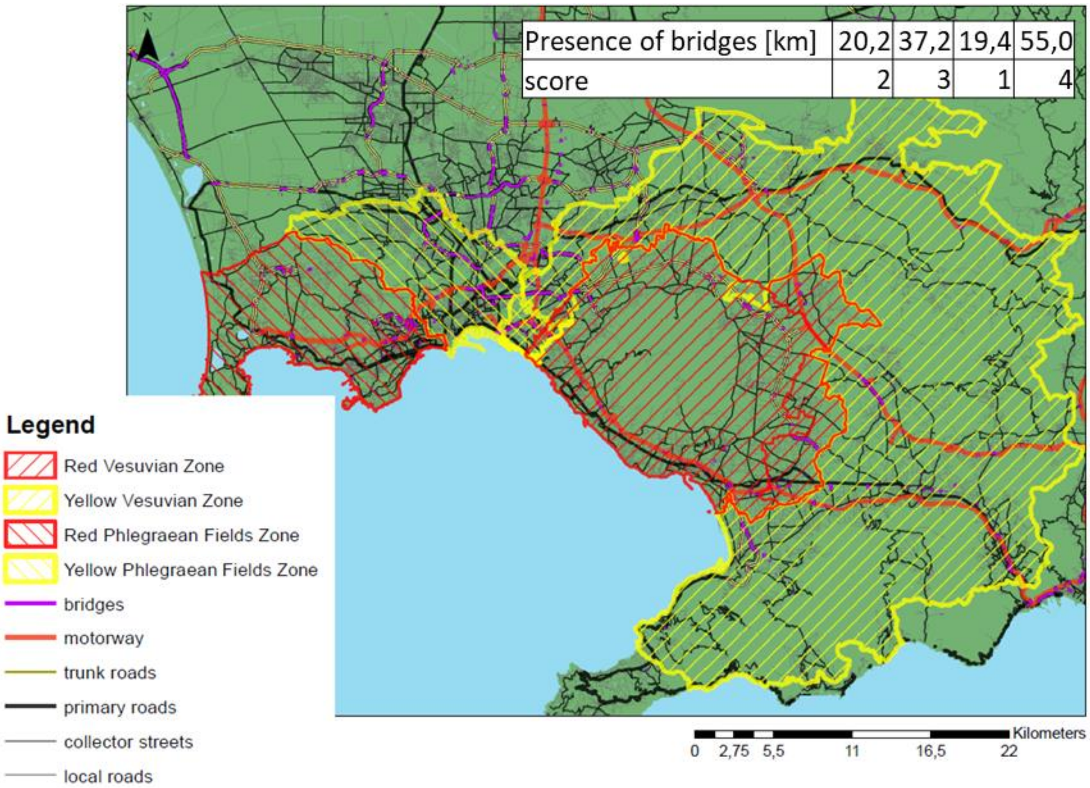


Figure 5.20 Bridges presence in the hazard zones.

In the end, it could be provided the map for Systemic Vulnerability of the whole hazard zones, represented into Figure 5.21. This map could summarize all the results shown so far for the whole hazard areas and it could be a great tool in prioritizing the planning of infrastructures, indeed it will be shown in the final tool presented to the stakeholders. However, the detail when looking at the whole areas, with also their not occupied territories, is low, this vulnerability analysis is looking on the whole hazard zones, but not all parts of them are interesting, the final result and ranking represents an average that comes also by the consideration of places like the top of Vesuvius, where systemic vulnerability assumes a very low importance. Therefore, this map must be compared with other analyses with an increased level of detail, that regard the urban extent exposed to volcanic risk. That is the reason for the following systemic vulnerability studies.

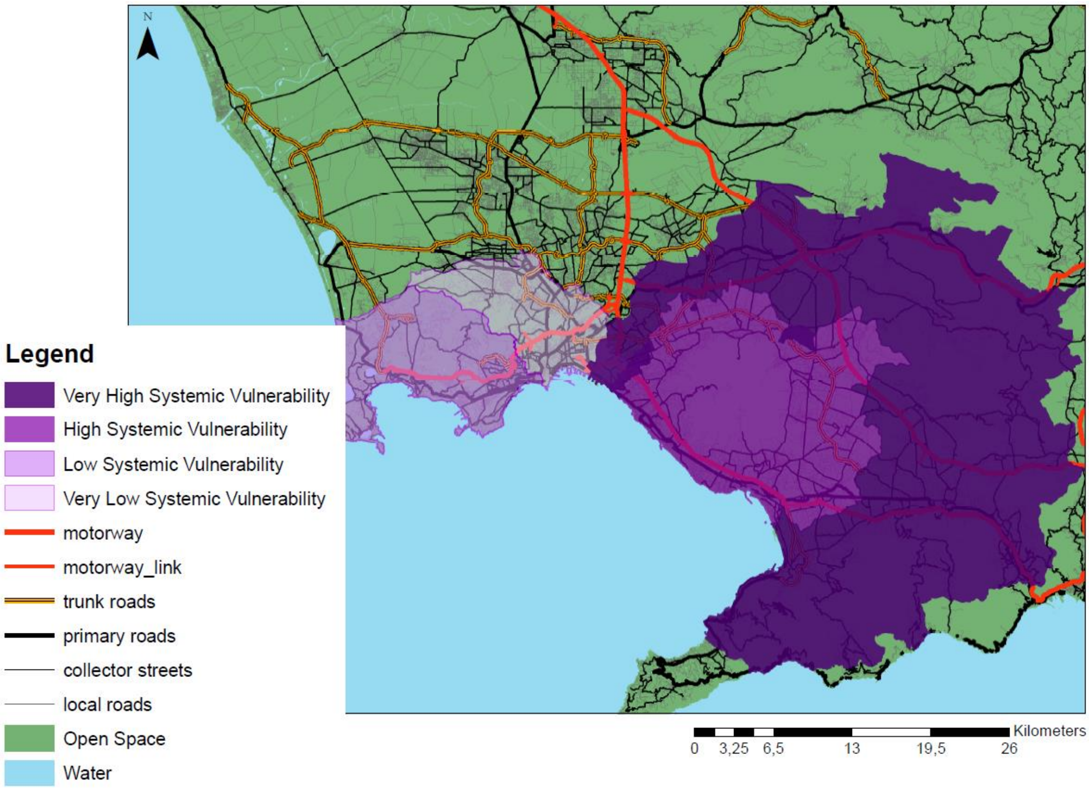


Figure 5.21 Systemic Vulnerability Ranking for the whole hazard zones.

5.2.2.2 Systemic vulnerability for the whole urban extent

This systemic vulnerability analysis starts by the results for the expansion areas that have already been shown into paragraph 5.1.4. It considers also the saturation attribute for urban expansion that has been found for the different expansion areas in paragraph 5.1.3. Saturation is a parameter of quality of the urban extent, related to how much buildings are sparse in urban extent and related to consumption of soil. It is related to accessibility in the way, the more distant the more time to reach different places. It gets sense only to describe the urban extent, for this reason it has not been considered in the previous analysis.

Table 5.12 Scores for Naples urban extent roads and blocks attributes.

	Attributes	Areas of the urban extent				
		urban extent pre 1972	**Expansion area 1972-1884**	**Expansion area 1884-1998**	**Expansion area 1998-2008**	**Expansion area 2008-2019**
Roads	Average density of all roads [km/km^2]	18,36	13,10	10,22	12,61	15,03
	Score	1	3	5	4	2
	Average road width in urban extent [m]	5,887	5,913	6,053	5,78	6,502
	Score	4	3	2	5	1
	Average density of all arterial [km/km^2]	4,290	3,087	2,606	2,40	4,799
	Score	2	3	4	5	1
	Average density of wide arterial roads [km/km^2]	0,769	0,687	0,761	0,55	1,317
	Score	2	4	3	5	1
Block layout	Average block size [ha]	1,87	2,23	1,32	1,76	2,78
	Score	3	2	5	4	1
	Density of intersections [n/km^2]	87,44	77,52	42,78	67,18	39,16
	Score	1	2	4	3	5
	Share of intersections that are 4-way	22,60%	12,19%	14,94%	15,41%	15,09%
	Score	1	5	4	2	3
	Share of areas within walking distance to arterial roads [km2/km^2]	98%	95%	89,10%	92%	89,12%
	Score	1	2	5	3	4
	Share of areas within walking distance to wide arterial roads [km2/km^2]	21%	23%	18,87%	18,93%	16%
	Score	2	1	4	3	5
Saturation		60%	53%	54%	55%	56%
Score		1	3	5	2	4
Sum of scores		18	30	40	37	25
Systemic Vulnerability ranking		**1**	**3**	**5**	**4**	**2**

This time, the first outcome is the expansion area, considering the whole urban extent of Naples, that has the highest systemic vulnerability. It is the expansion area related to the years between 1984 and 1998, followed by the expansion area of the period after. This ranking allows to compare the different expansion areas from a point of view of accessibility and redundancy of roads and its outcome could be a great tool also just in an urban planning point of view, to see the areas that most need an infrastructural plan. However, for this study the interest goes to the hazard zones and the consequences of urban layout on systemic vulnerability there. Therefore, it has been overlapped again the volcanic hazard zones upon the map for the ranking of expansion areas systemic vulnerability(Figure 5.22) to derive a general ranking for hazard zones related to the urban extent included into (the overlapping is presented in the Appendix). The scores for the overall urban extent expansion areas have been averaged for the hazard zones: each expansion area score has been multiplied by its share area into the considered hazard zone and then summed to derive the final score and ranking for the hazard zones. The ranking numbers are presented in Table 5.13 while the final result is summarized into Figure 5.23, that will be furtherly presented in Chapter 6.

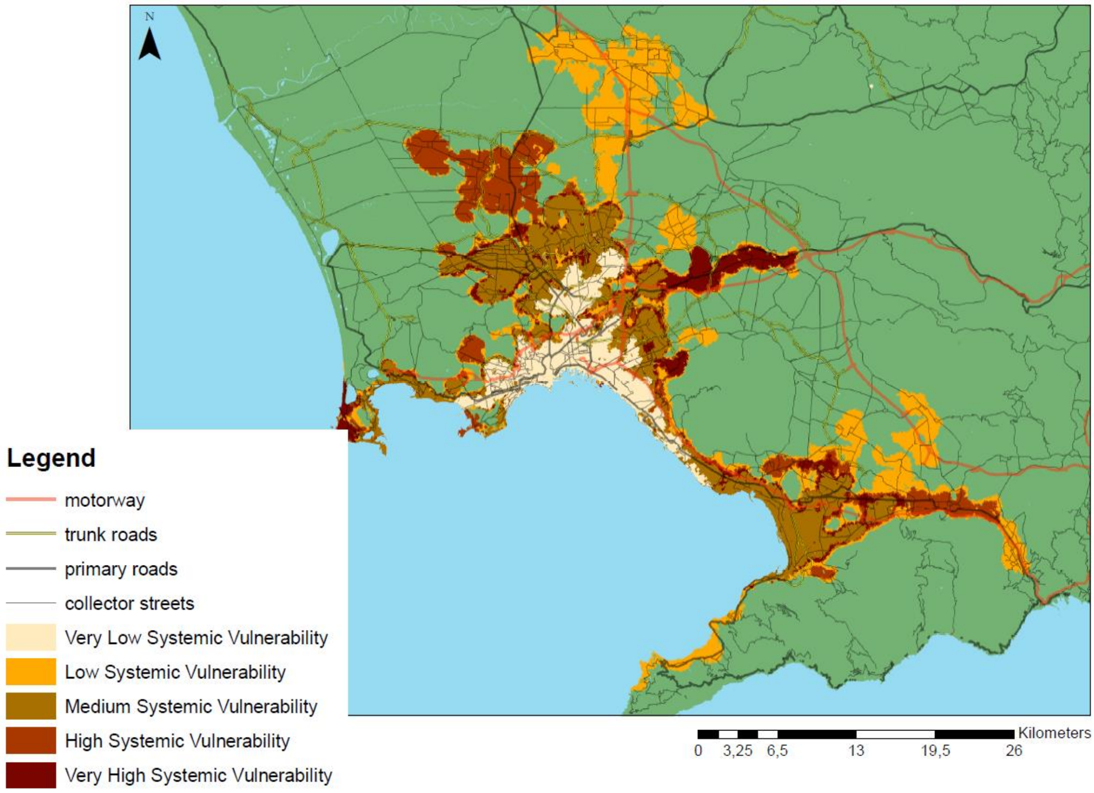


Figure 5.22 Ranking for expansion areas systemic vulnerability.

Table 5.13 Averaging the scores for the single expansion areas, calculated upon the whole urban extent, on the base of their shares into the urban extent contained in the volcanic hazard zones.

	Vesuvian hazard zones										Phlegraean Fields hazard zones									
	Vesuvian red zone					Vesuvian yellow zone					Phlegraean Fields red zone					Phlegrean Fields yellow zone				
Urban Expansion	pre 1972	1972-1984	1984-1998	1998-2008	2008-2019	pre 1972	1972-1984	1984-1998	1998-2008	2008-2019	pre 1972	1972-1984	1984-1998	1998-2008	2008-2019	pre 1972	1972-1984	1984-1998	1998-2008	2008-2019
Area of Urban Expansion contained in the hazard zone [km^2]	14,1	34,2	10,6	11,1	26,1	11,3	34,1	22,9	21,4	52,6	14,3	14,7	5	7,8	6,8	38,2	24,7	4,4	2,6	6,5
shares of urban expansions into Naples urban extent of the hazard zones	15%	36%	11%	12%	27%	8%	24%	16%	15%	37%	29%	30%	10%	16%	14%	50%	32%	6%	3%	8%
Score for each urban expansion (from previous ranking)	1	3	5	4	2	1	3	5	4	2	1	3	5	4	2	1	3	5	4	2
General score	2,8					2,94					2,61					2,04				
Ranking	3					4					2					1				

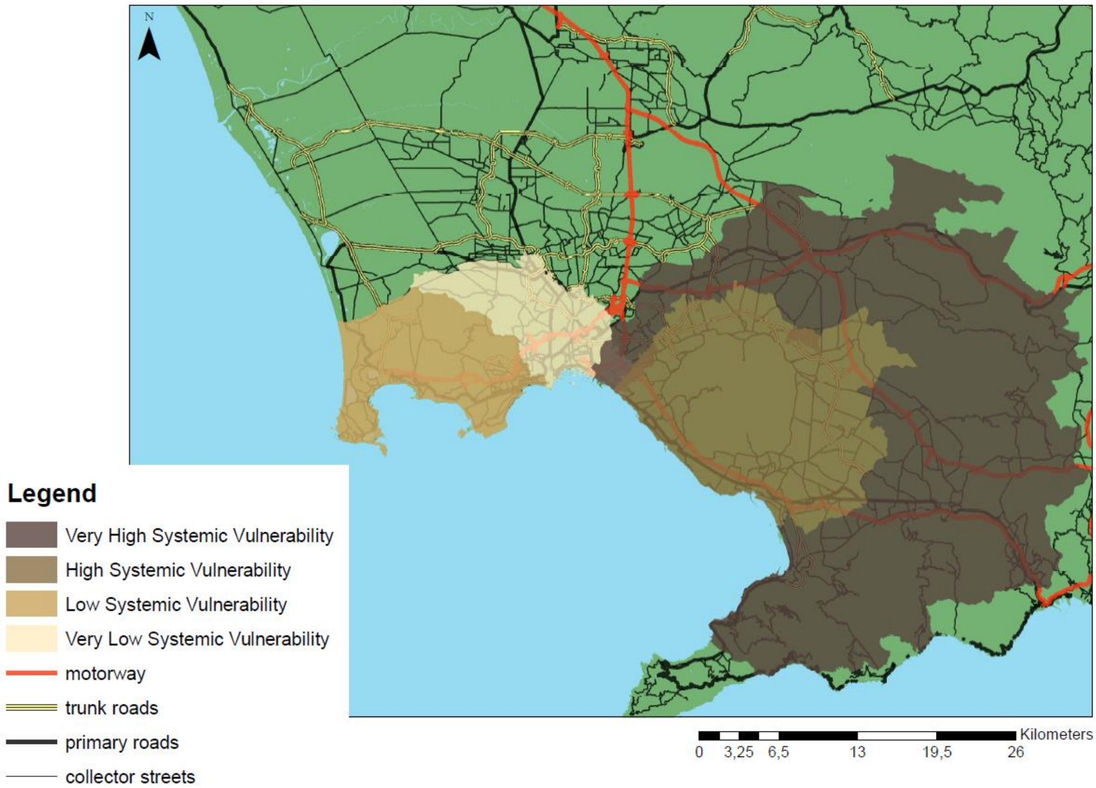


Figure 5.23 Systemic Vulnerability of hazard zones linked to their urban extent.

As it is shown by this last map, the hazard zones systemic vulnerability ranking agrees with the lower detail study of systemic vulnerability for the whole hazard zones. It means also that the information stored by this map is even stronger: the Yellow Vesuvian hazard zone needs an infrastructural amelioration, more than the other hazard zones, and not only from a general point of view but also for its part the most important for its level of exposure, its urban extent.

5.2.2.3 Systemic vulnerability for the expansion areas of the urban extent included in the hazard zones

Thus, it is now the turn of the most detailed level of analysis. The point here is no more to rank the different hazard zones but to rank the different expansion areas in each hazard zone to find out the most worrying systemic vulnerabilities for some locations of Naples urban extent. The same analysis, as before for the urban extent, has been applied to all the expansion areas that constitute the urban extent included into the hazard zones, differentiating them. It represents a detailed spatial analysis that will not be included here as table due to its huge dimensions. However, the outcomes could be very interesting and are shown in Figure 5.24.

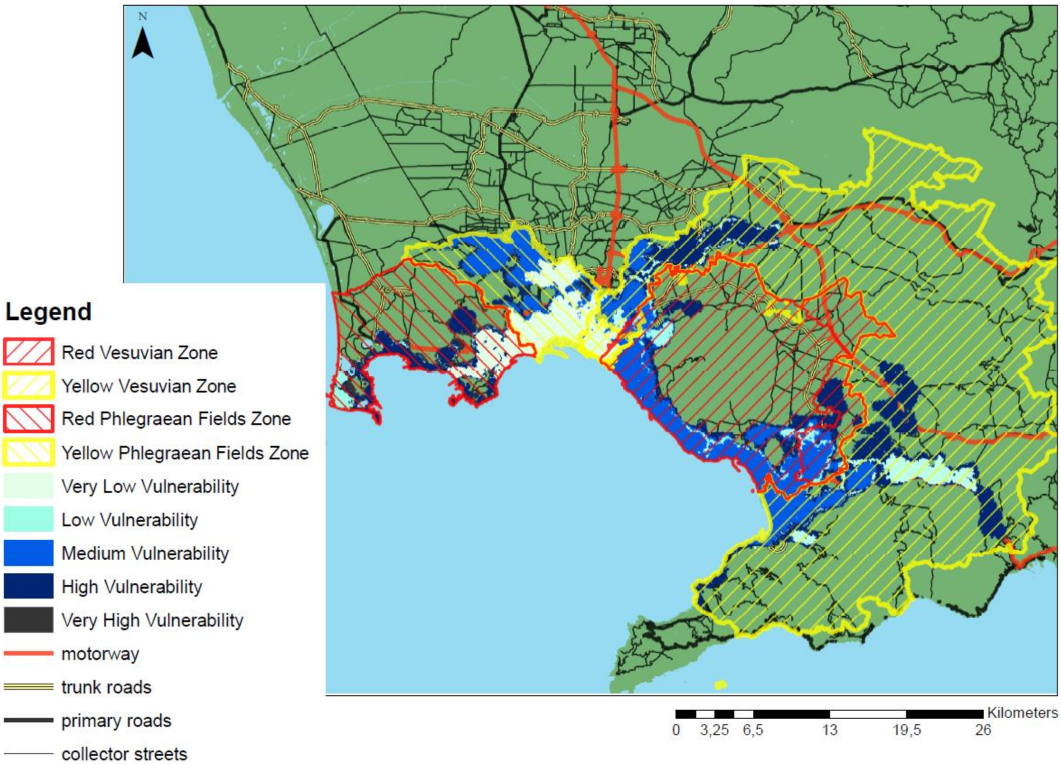


Figure 5.24 Systemic vulnerability for the expansion areas in the different hazard zones.

As it could be seen there it has been chosen to group the scores in five classes of ranking, in a way to make a more understandable map. Still, it is possible to see that the worst situation, with score 5 for systemic vulnerability is registered for just two small areas, both in Phlegraean Fields, into the expansion areas related to 2008-2019 period in the Red zone and the ones of 1998-2008 in the Yellow hazard zone. These zones are really small, they represent the peripheries of the most recent Naples urban extent. However, they are interesting as they add a focus on smaller areas that could need an improvement in terms of infrastructures. With this level of detail it could be seen also that the areas of expansion are not uniform in their

characteristics: also the first urban extent up to 1972 shows that in the Red Vesuvian hazard zone it becomes from a very low systemic vulnerability to a medium one. It means that this type of detailed analysis could be fundamental to understand the real situation of the hazard zones. Nevertheless, summing all the scores from these areas and comparing them to their sizes in the hazard zones, the result still does not change with respect to the previous systemic vulnerability analyses: the yellow Vesuvian zone remains the area with the highest systemic vulnerability, also due to its huge areas of High vulnerability, followed but the Red Vesuvian, the Red Phlegraean Fields zone and the Yellow one.
This map represents the end of systemic vulnerability analysis that has been able to provide important results of the accessibility and related systemic vulnerability of the hazard zones at different scales. This last map could guide decisions as well as inform the people involved in the emergency management about the areas that could suffer the most from a bad systemic vulnerability.

5.2.3 Land use analysis for the hazard zones

The results for this analysis are referred to just one hazard zone, the one that has shown the most worrying results for the exposure growth and systemic vulnerability: the Vesuvian Yellow Hazard Zone. The results refer first to a temporal point of view, then spatially look at differences in expansion areas in the hazard zones.
From a **temporal perspective**, looking at the whole Vesuvian hazard zone, this study has not remarked significant changes in the shares for land use. They are shown below, in Table 5.11. They have just underlined a prevalent use of the area that has always been forest followed by fruit and oil plantations; a land that is principally occupied by agriculture, with just some small industrial increase (from 3% up to 5% share, taking advantage on Urban and Suburban transformations into it). The artificial land in total has increased but very slowly.

Table 5.14 Vesuvian Yellow hazard zone in numbers for land use (artificial land).

Land uses	**Vesuvian yellow zone**			
	Up to 1990	**Up to 2000**	**Up to 2006**	**Up to 2018**
Continuous urban fabric [km^2]	48,59	56,4	52,04	55,12
Discontinuous urban fabric [km^2]	61,86	66,7	71,47	66,49
Industrial or commercial units [km^2]	13,96	16,88	20,32	22,86
Road and rail networks and associated land [km^2]	0,16	0,16	1,18	2,52
Port areas [km^2]	1,14	1,14	1,15	1,14
Artificial land [km^2]	**127,04**	**142,44**	**148,1**	**149,52**

Looking at the temporal evolution of the Naples urban expansion towards Yellow Vesuvian hazard zone, has meant moreover to overlap the CLC maps for years 1990, 2000, 2006 and 2018 to the urban extents of 1984, 1998, 2008 and 2019. An exemplum is represented in Figure 5.25 where CLC 1990 map is overlapped by the urban extent of 1984 as well as by the Vesuvian hazard zones. The results are shown with trends, in Figure 5.26, comparing land uses changes within the urban extent growing. There the graph shows the most significant land uses there. They could show that together with the obvious urban land growth also the cultivated land has started to be more and more included into the urban extent. It comes to the discontinuous urban fabric, that has already been mentioned for the whole Naples urban extent, showing also for the Vesuvian Yellow Hazard Zone an unplanned development of the last years.

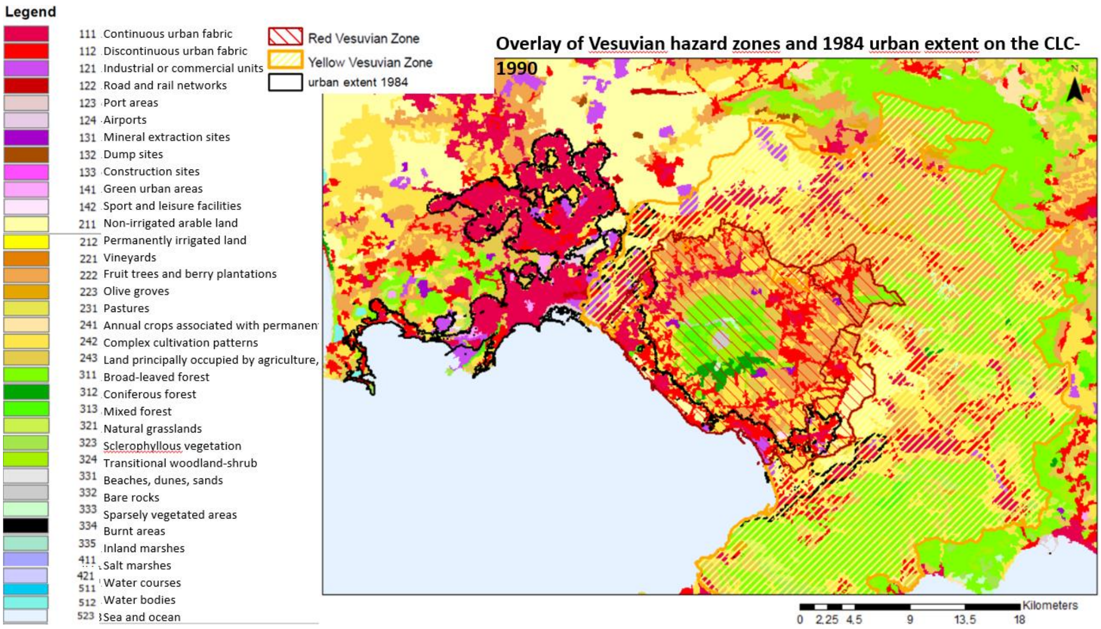


Figure 5.25 Overlapping of CLC and urban extents. Temporal analysis.

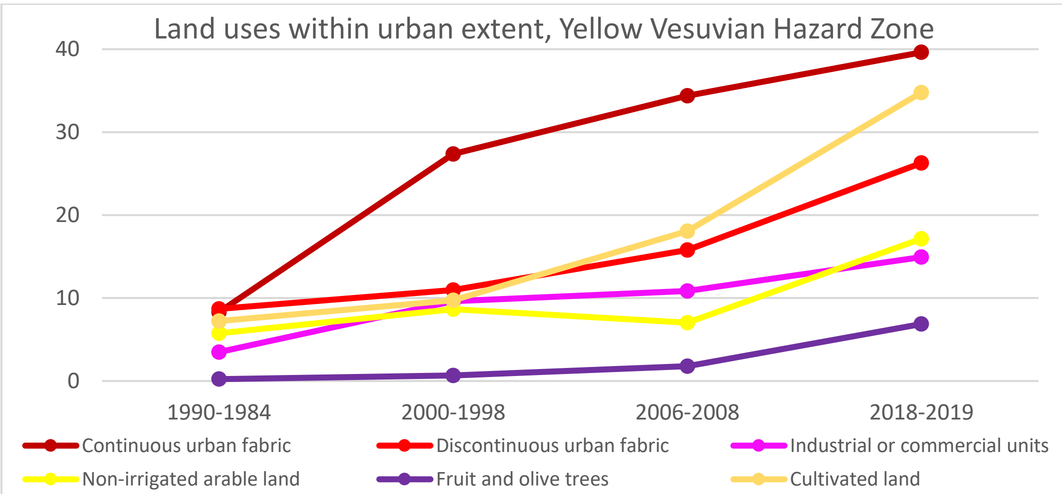


Figure 5.26 Land uses with urban extent.

Finally, looking at the spatial analysis: the 2018 land use for the urban extent in 2019 has shown the following shares for the different expansion areas. Particularly, in the 2019 expansion area there are less built-up in continuous urban fabric and more in discontinuous. And there is more non irrigated arable land and cultivated land that still agree with the temporal analysis: these last years of urban expansion have included an urban fabric that is more fragmented, with a not much clear predominant land use. It could be seen also that the oldest expansion areas contain much more industrial and commercial units than the further ones, highlighting a probable lack of services.

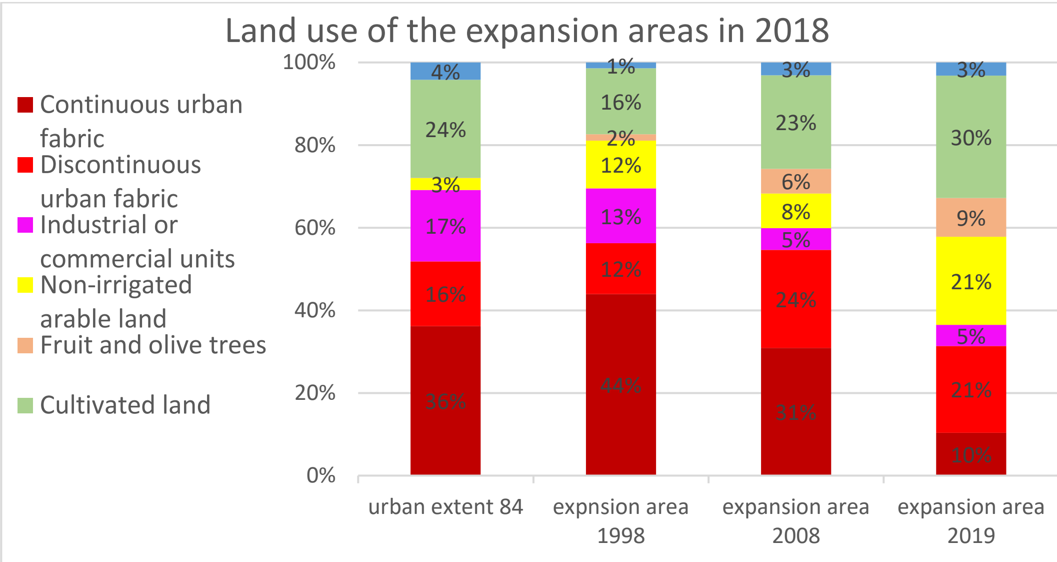


Figure 5.27 Land use for expansion areas in 2018

Therefore, the whole analysis on CLC with zoom on the Yellow Vesuvian Zone has provided evidence mostly about the predominant land uses. The temporal changes are not much significant, even though they still show, for the urban extent, an increase in the fragmentation of land uses, as it was perceived spatially looking at the whole Naples urban extent. The spatial CLC analysis for the urban extent contained into the Vesuvian Yellow Zone again shows evidence of this fragmentation that is again also spatial, following the expansion of the city. CLC level of detail does not allow for further reflections. Further study would be needed about.

Chapter 6
NAPLES URBAN EXPANSION FROM A RISK PERSPECTIVE

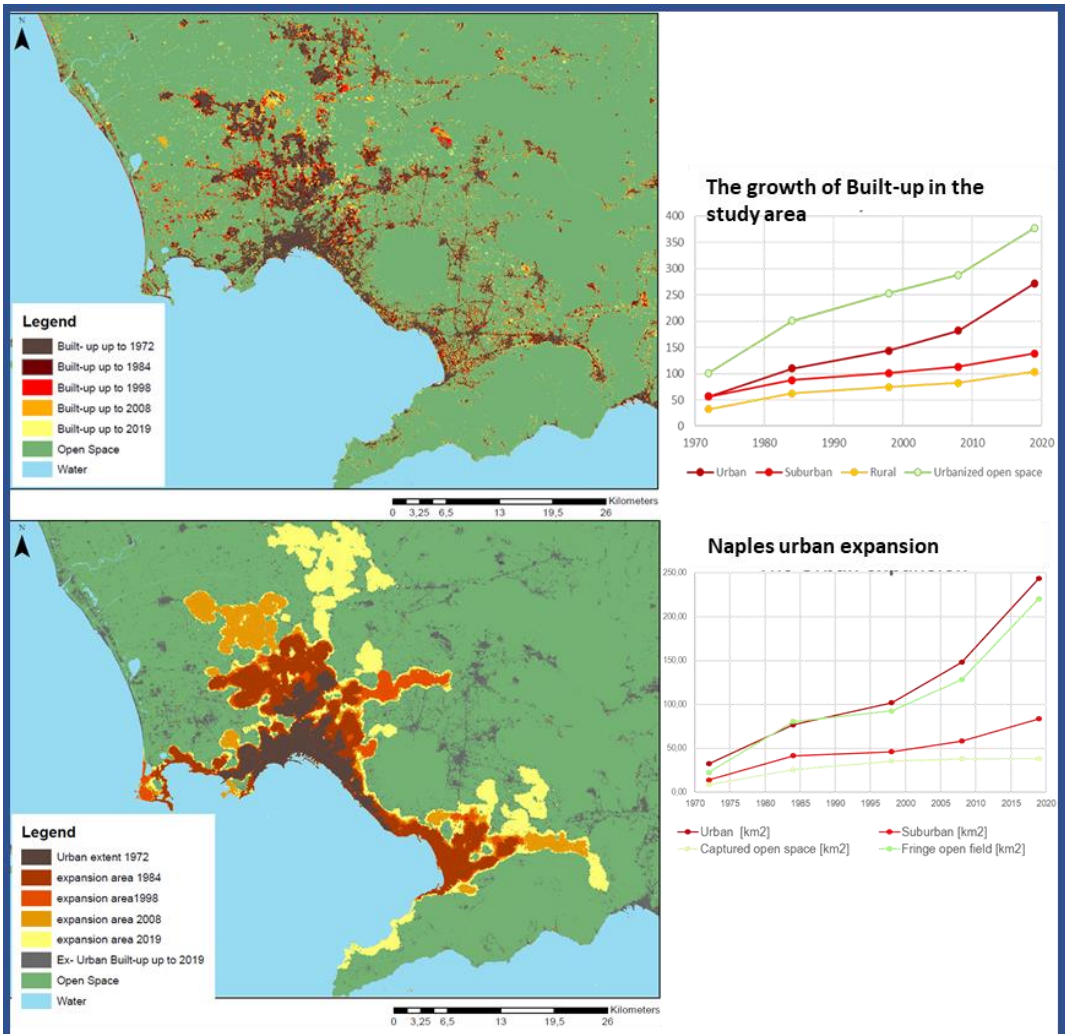
This chapter aims to present the evidence that, finally, this study has derived about Naples urban expansion looking from a risk perspective. Particularly, this chapter aims to be the final tool that every decision-maker and stakeholder should consider while planning for the city development. It wants to raise awareness about Naples urban expansion and its consequences on the volcanic hazard zones, analysing the exposure growth that it has caused a well as the systemic vulnerability that it has carried out there. The evidence that has been produced, presented and discussed here with the use of the most significant maps and measures, should guide a more conscious urban planning and future choices. Therefore, this chapter represents the final results of an integrated perspective regarding urban planning and risk measures that should be followed in future by actions that consider the same perspective, for a more resilient Naples urban extent and territory.

6.1 The last decades of Naples urban expansion

Naples urban development has been surely a complex phenomenon, as suggested by Scaramella (2003) as each city is somehow unique with its own history. However, through the maps and measures that this study has provided it is possible to have an important insight on the development process that the city and its hinterland have been subjected to. Particularly, looking at the extensive process of expansion, the city of Naples, as well as its hinterland tend to confirm the worldwide trends that the Atlas (Angel, et al., 2016a) already had depicted. Indeed, first, if it could have been asked whether urban expansion is still occurring in its area, for Naples, the answer is yes, moreover this expansion has proven to be significant and poorly planned. It has been an expansion, first in terms of construction of new areas, new Built-up lands, that has an impact on the urban expansion of the city of Naples, in a way that tends to follow the unplanned spread out of buildings. A comparison of the expansion of the built-up area and the whole footprint of Naples is represented in the two maps displayed in Figure 6.1. That figure summarizes the results about Naples urban expansion from a point of view of Built-up, urban extent and population growth, with the referred attributes. It is the first evidence that this study provides to the stakeholders, providing knowledge about the urbanization and the growth of urbanization in the area.

The two maps represented in the image show, the first one, the spread of Built-up over time from 1972 up to 2019, while the second one the urban expansion of Naples. Both overlaying the layers of the different years, with the same colours, from the oldest (1972, dark brown) to the most recent one (2019, yellow). In this way, it is possible to perceive the differences among the years and particularly, for the case of Naples urban expansion, the expansion areas that the city has created through time. Focusing on the first map, it is possible to see a fragmented growth of Built-up Land over the years, it could be perceived a disorderly spread out, particularly for example for what regards the last decade from 2008 to 2019. The map shows a huge increase of Built-up that the measures in the table below, always in Figure 6.1, demonstrate: the first 1972 Built-up Land (144,66 km^2) has been more than triplicated, with an area in 2019 of 513,84 km^2.

And from the map it can be seen that, if before 1972 clusters of Built-up were more confined to the city of Naples, later they have spread out more to its hinterland, agreeing also with the tendency described by Scaramella (2013) of an 'inverse urbanization' that has enlarged a discontinuous urban fabric out of Naples, creating a larger and larger urban fabric, as the second map represents. The first map, therefore, presents Built-up lands that, with the years, have become less concentrated, more discontinuous, affecting the whole study area of Naples and its territory. From the colours it could be also perceived what the numbers demonstrate again then, the Built-up growth has not been constant for the increase rate: there have been years, particularly, the decade from 1972 to 1984 and the decade from 2008 to 2019 that have experienced a larger growth (the rate of increase has been for example from 1972 to 1984 of +80%, see the table at Figure 6.1, *Rise of Built-up*). On the other hand, from 1984 to 1998, it is signalled the smallest Built-up growth. It is detected therefore a discontinuous trend in the Built-up growth that could have been guided by people, historical or market needs. Nevertheless, the number of people increase in the area shows that the dependency of Built-up growth from people needs has been quite low, with Built-up land increasing more than population. This argument will be better addressed later on.



	Measures and attributes for urban expansion	Up to 1972	Up to 1984	Up to 1998	Up to 2008	Up to 2019
Study area	Built up [km^2]	145	260	319	378	514
	Urban [km^2]	56,19	110,00	143,42	182,10	271,74
	Suburban [km^2]	56,40	87,86	101,28	113,04	138,25
	Rural [km^2]	32,06	62,26	74,22	82,44	103,85
	Rise of built-up		+80%	+23%	+18%	+36%
	Population	3,84*10^6	4,23*10^6	4,36*10^6	4,43*10^6	4,69*10^6
	Density of population in the built-up of the study area [pop/ha]	266	162	137	117	91
Urban extent	Total Urban extent [km^2]	77,82	224,32	276,30	372,73	585,69
	Built up in the urban extent [km^2]	46,44	118,25	148,06	206,38	327,09
	Urban [km^2]	32,42	76,74	101,87	148,04	243,44
	Suburban [km^2]	14,02	41,51	46,19	58,35	83,65
	Captured open space [km^2]	8,70	25,51	35,55	38,14	38,29
	Fringe open field [km^2]	22,67	80,56	92,68	128,21	220,32
	Saturation	60%	53%	54%	55%	56%
	Openess	55%	55%	53%	51%	48%
	Population in the urban extent	1,17*10^6	2,20*10^6	2,36*10^6	2,83*10^6	3,72*10^6
	Density of population in the urban extent [pop/ha]	151	98	85	76	64
	Density of population in the built-up of urban extent [pop/ha]	252	186	159	137	114

Figure 6.1 The overall results for Naples urban expansion.

Finally, the first map shows also a trend for Built-up expansion that, limited by the presence of Vesuvius and the Phlegraean Fields, have covered more areas towards North and North-West, but also at East, along the coast. The area of Vesuvius is quite clearly visible in the Eastern side of the city of Naples, showing that Built-up growth has affected also its area, as well as the area of Phlegraean Fields at the Western side of the city.
The map in Figure 6.1, shows how the Built-up has grown in the whole area. The Urban Built-up subclass has been growing more than the other subclasses Suburban and Rural. If the growth of Urban Built-up could be quite predictable due to the urban development of the area and the construction of buildings more related to urban sites, Suburban land and Rural lands have increased as well, in lower rates but still significant, configuring a whole urban fabric that has many peripheries, (the Suburban Built-up) that are fragmented and scattered. The presence of Suburban, even though less relevant with respect to the whole Built-up from 37% to 29%, due to the more rapid growth of urban land, still shows a quite significant part of artificial land that is fragmented and poorly planned. In particular, from the trends shown in the first graph of Figure 6.1, the years from 1972 to 1984 and the more recent ones from 2008 to 2019 are signalled for faster growth, describing the very significant growth that has occurred in these years to be less planned, more fragmented than the other years. The significant trend for these last years, particularly, claims for more monitoring and planning. Finally, the unplanned spread out of Built-up that has taken place between 1972 and 1984 is also noticeable from the growth of Rural land in this period that has increased also its share in the overall Built-up in 1984.
Looking at the second map at Figure 6.1, it can be seen how the growth of the Built-up has spread contributing to the expansion of Naples urban extent, towards its hinterland. Indeed, as long as the Built-up has increased and spread in all possible directions, the limits between urban areas have become blurred and the Naples urban extent has incorporated more and more urban areas in its surrounding, without a comprehensive planning. Looking at Naples urban expansion, thus, it is possible to spatially understand the enlarging of its urban fabric in the area.
The urban expansion of Naples, shown by the map, constitute a significant phenomenon, even more than the Built-up growth, considering the areas involved (see also metrics in the table below in the Figure 6.1). The urban extent has rapidly increased in these years, with preferred direction to North, towards Caserta, included in the urban extent at the date of 2019, and North-West, or to East, towards Salerno, following the principal transport networks that link these provinces. In this way, Naples urban extent has increased its area of about more than 7 times (see measures for Urban Extent at the table at Figure 6.1) creating with time a huge conurbation, reaching an extension of about 585,69 km^2. Again, looking at the second map and the respective measures for the urban extent of Naples it is possible to notice that still the years between 1972 and 1984 and 2008-2019 have been the ones experiencing the most of

urban expansion, highlighting a similar trend with respect to the Built-up growth of these periods. Particularly, it is still the period from 1972 to 1984 that shows the highest increment that almost triplicates the original 1972 urban extent, and it is possible to perceive it with the large presence of light brown colour (related to 1984 urban extent) that describes Naples urban extent expanding towards North, towards Afragola and Giuliano in Campania, spreading also towards the coast, at East, including Castellamare di Stabia, and at the Westside including Pozzuoli. These last areas are interesting because they already describe an urban expansion that since those years, and also afterwards, up to nowadays, has impacted also the areas that are most directly threatened by volcanic risk, making the city closer to the volcanos. The following paragraph about exposure growth indeed starts just by this evidence as well as the one from Built-up growth there.

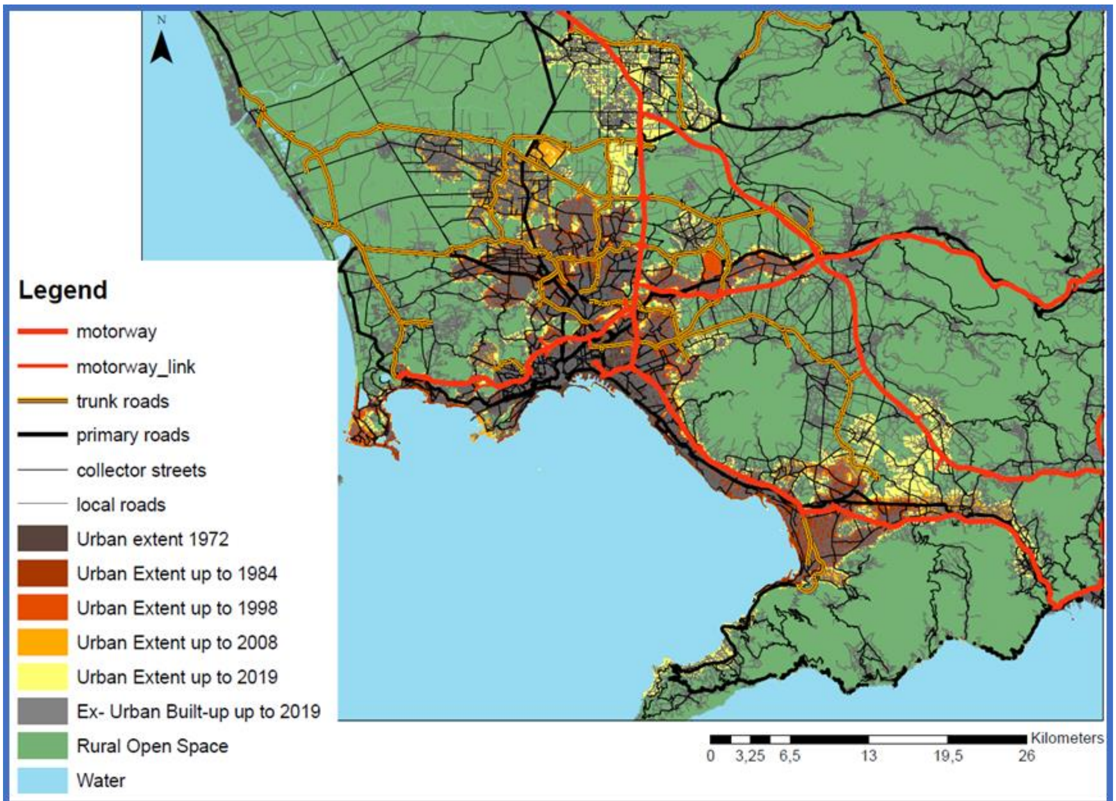
Moreover, the trends that are represented in the second map (Figure 6.1), as well as the measures reported below for the urban extent, show how this urban extent has grown over the years, thus how it has been distributed among the Urban, Suburban, Fringe and Captured Open Space subclasses. These trends and measures describe an urban extent that, as predictable, has grown particularly with the Urban Built-up, however, they depict also a growth for Suburban Land, that, even if still lower than the Urban Built-up (as it was for the Built-up of the whole study area), has shown a faster increase than the Suburban for the whole study area. The most of Suburban land, thus the fragmented and discontinuous peripheries are limited indeed to the Naples urban extent. The trends are interesting also because they show a larger growth of Suburban areas in the years from 1972 to 1984 and from 2008 to 2019 again underlining for these years a very poorly planned development that has affected also the same Naples urban extent.

Naples urban expansion, therefore, has occurred mostly in an unplanned way, for some years more than the others, as is confirmed also by the shape of its different urban extents represented in the second map in Figure 6.1. Indeed, as also the Fringe Open Space measure, related to the perimeter of the urban extent, suggests that the shape of the urban extent has developed irregularly, limited by the presence of Vesuvius or Phlegraean Fields, but also showing a lack of a comprehensive planning: Naples shows an expansion that has not been planned for what regards the areas involved, with a perimeter that increases without any rational layout. An further example is represented also by the expansion area related at the year 1998: it can be seen that the city has extended from 1984 to 1998 its urban fabric towards Marigliano that then has remained an isolated area due to the expansion that has moved to other locations. And Marigliano is not the only case, the jagged perimeter increases the possibility of having peripheries that are confined with respect to the city, not well connected to a city therefore less inclusive, that tends to segregate more its suburban areas. Particularly, the irregular shape is significant also for the 1984 urban extent whose area included also rural territories that have been filled only later, with the expansion at the year 1998 or at the year 2019.

Moreover, the urban expansion of Naples can be also described by attributes such as density, fragmentation and openness, that are reported again in the table in Figure 6.1. In particular, density is of great importance: getting back to what was mentioned before regarding Built-up growth, it demonstrates that the growth of Built-up as well as the urban expansion are no more only driven by people needs. Indeed, the densities of people for unit area of Built-up land (for the whole study area or just for the urban extent) or of the whole urban extent are significantly decreasing. From 1972 up to 2019 the same area could be inhabited by half of the people living there before. It is in line with the trends that have been documented by the Atlas for its global sample of cities (Angel, et al., 2016a): while Built-up or urban land still tends to increase fast, the number of people grows slower, with the trends for population and urban growth becoming independent variables, with an increasing consumption of soil. Therefore, Naples too has shown an unsustainable urban expansion that seems to lack an overall urban planning.

Finally, the saturation attribute, shown in Figure 6.1, presents an interesting result about Naples urban expansion: in 1984 saturation has become larger with respect to its value in 1972 and then it has started to slow down. This measure agrees and reinforces the evidence about 1984 urban extent being particularly fragmented after a large unplanned urban development, but it shows a slow improvement, after 1984, occurring maybe with the land filling of the years after. It could be a good sign that there is a little more consciousness for the exploitation of land, with respect to the decades before. There could be a little more concern on building more compactly in the urban extent, even if still with low care for the number of people that could really need it and without offering enough green areas as part of a more liveable urban extent, as signalled by Openness attribute (see the measures in the same table. Indeed, the numbers for Openness describe green areas to be less reachable over the years. It still underlines the lack of a general studied urban plan that could have considered all the aspects, the services that must be matched with the development of new neighbourhoods.

Regarding these services, the second figure of this chapter, Figure 6.2 , describes now the actual layout of Naples urban extent. The attributes and measures of the table there allow to describe and compare the orderliness as well as accessibility and redundancy of Naples roads, separately for each expansion area. The measures are explained and discussed below, with the help provided by the visualisation of the map represented in the figure. The map, particularly, represents Naples urban extent, with its expansion areas overlapped by the road network. It shows from a first sight the layout defined by roads passing through the urban extent and it confirms some of the measures reported in the table below.



	Attributes	Areas of 2019 Naples Urban Extent				
		Urban Extent pre 1972	Expansion area 1972-1884	Expansion area 1884-1998	Expansion area 1998-2008	Expansion area 2008-2019
Roads	Share of local roads [km/km]	73%	76%	74%	80%	67%
	Share of collector roads [km/km]	14%	15%	14%	12%	20%
	Share of primary roads [km/km]	5%	3%	4%	2%	3%
	Share of trunk roads [km/km]	1%	2%	4%	2%	4%
	Share of motorways [km/km]	3%	3%	3%	2%	5%
	Average density of all roads [km/km2]	18,36	13,10	10,22	12,61	15,03
	Average road width [m]	5,89	5,91	6,05	5,78	6,50
	Average density of all arterial roads [km/km2]	4,29	3,09	2,61	2,40	4,80
	Average density of wide arterial roads [km/km2]	0,77	0,69	0,76	0,55	1,32
Block layout	Average block size [ha]	1,87	2,23	1,32	1,76	2,78
	Density of intersections [n/km2]	87,44	77,52	42,78	67,18	39,16
	Density of 4-way intersections [n/km2]	19,76	12,37	6,39	10,35	5,91
	Share of intersections that are 4-way	22,60%	12,19%	14,94%	15,41%	15,09%
	Share of areas within walking distance to arterial roads [km2/km2]	98%	95%	89,10%	92%	89,12%
	Share of areas within walking distance to wide arterial roads [km2/km2]	21%	23%	18,87%	18,93%	16%

Figure 6.2 The overall results for Naples urban layout, blocks and roads.

It is quite evident that Naples is a city where the local and slow roads are still the ones more present with respect to faster roads. The average road width remains small, throughout the whole urban extent, meaning again for a road network that is slow, and with a low capability. It is difficult to reach the different locations in a short time. This road network describes an urban expansion that has gained territory over the rural areas, not planning for it, not adding what could have been suitable, as faster roads, for an urban extent of that measures. And, this is confirmed particularly, by the road network that spatially changes throughout the urban extent, worsening from the centre to the outskirts. Comparing 2008-2019 expansion area with the centre of pre 1972: it is evident that roads in 2008-2019 expansion area are rarer, more disperse, they cover more irregularly the area. From the centre to the outwards, thus, it becomes higher the probability of travelling in areas less and less accessible and more confined, with a worse urban layout, reflecting the unplanned urban expansion that has occurred in the previous years. As measures confirm indeed (see the table in the image), the expansion areas, compared with 1972 urban extent, present roads that become infrequent, with less intersections, and an irregular layout with block sizes that can become very large, as in the case for 1972-1984 expansion area or also for the 2008-2019 one. Particularly, the expansion area related to 2008-2019 period, the one that covers also Caserta city, seems to provide a small exception to the general worsening of urban layout, showing a larger Average Width as well as higher shares for fast roads, as it is possible to look in the table in Figure 6.2; however, as already shown by the map in the same figure, the small density of roads as well as its large average block size makes it to reflect about its interior accessibility, underlining again the lack of a comprehensive urban planning that could have covered all the aspects of accessibility. Even the percentage of the expansion area that can reach easily these fast roads (See *Share of areas within walking distance to Arterial Roads* in the table) is lower with respect to the other expansion areas, meaning that even if there could be a major presence of fast roads these are still not much accessible. Therefore, still also the 2008-2019 expansion area remains segregated.

Block size, that first represents the orderliness of the urban layout, moreover, is not a problem only for the 2008-2019 expansion area, despite giving there the worst value, it is an issue also for the 1972-1984 expansion area, highlighting again that the expansion that has occurred in 1972-1984 as well as from 2008 up to nowadays, has been weakly planned, due also to its rapidity, carrying out many issues among which also this low accessibility that the areas still presents today. Block size, in case of emergency, could be fundamental to access the single places and a huge block means that in the areas from 1972-1984 and 2008-2019, it would be needed a longer time to reach the places.

Finally, focusing on present intersections, the urban extent lacks redundant roads especially in the expansion areas, with respect to the pre-1972 urban extent. And the evidence gets worse when noticing that not only going from the centre to the new peripheries the number of intersections decreases and, in addition, the share for the only 4-ways intersection is smaller than the one of the center. The shares are quite similar among the expansion areas, of about

14% but as always it is the 1972-1984 expansion area that shows the worst value with 12%. Therefore, urban expansion has shown, particularly for that period, that redundancy of roads has been neglected, resulting in more traffic, and the impossibility to reach a place from different locations and paths, that, in case of emergency would imply places to be separated by the rest of the urban extent.

Furthermore, if the reader now asks himself if the irregular layout and the weak planning of the urban expansion have affected also the land uses of the city, the answer is again yes. Indeed, as the graph at Figure 5.12 shows, moving spatially from the inwards to the outwards, land uses become more fragmented with the urban fabric more and more discontinuous, separated by cultivated land and non-irrigated arable land.

All the outlines, at the end have shown an urban expansion that not only has occurred fast, and independently from the population increment, but also has created a complex layout that presents areas that are poorly accessible, lacking services and relying on not redundant roads in case of an emergency. Therefore, as it has been proven, this rapid growth has already carried out heavy costs in terms of accessibility, orderliness and discontinuity of urban fabric and land uses, however, it is interesting here to show its consequences in a risk perspective, summarizing the evidence that this tool has provided about exposure growth and systemic vulnerability driven by Naples urban development. Awareness is the first step to plan for adaptation to risk.

6.2 Exposure Growth in the volcanic hazard zones

Naples urban expansion has affected also the volcanic hazard zones. It was first perceived in the previous paragraph that Built-up growth as well as Naples expansion itself have affected also these zones, highlighting an overall lack of consciousness about the exposure growth that has been caused in this way. Therefore, here, this section will describe the effects of the urban development on the exposure in the hazard zones, comparing them, through the map and trends at Figure 6.3. Particularly, the map shown there is the final result that compares the different volcanic zones and shows with the darker colours the ones that have been affected by a larger exposure growth due to the urban development.

It could be seen that Vesuvian Yellow Zone is the area that has experienced the highest exposure growth rate in the last decades, followed by Vesuvian Red Zone. Their exposure growth has been due to the increase of Built-up, urban extent and population there, with the highest rates of growth with respect to the other zones for the same period. These rates can be appreciated while looking at the graphs present in Figure 6.3 together with the map that summarizes their evidence.

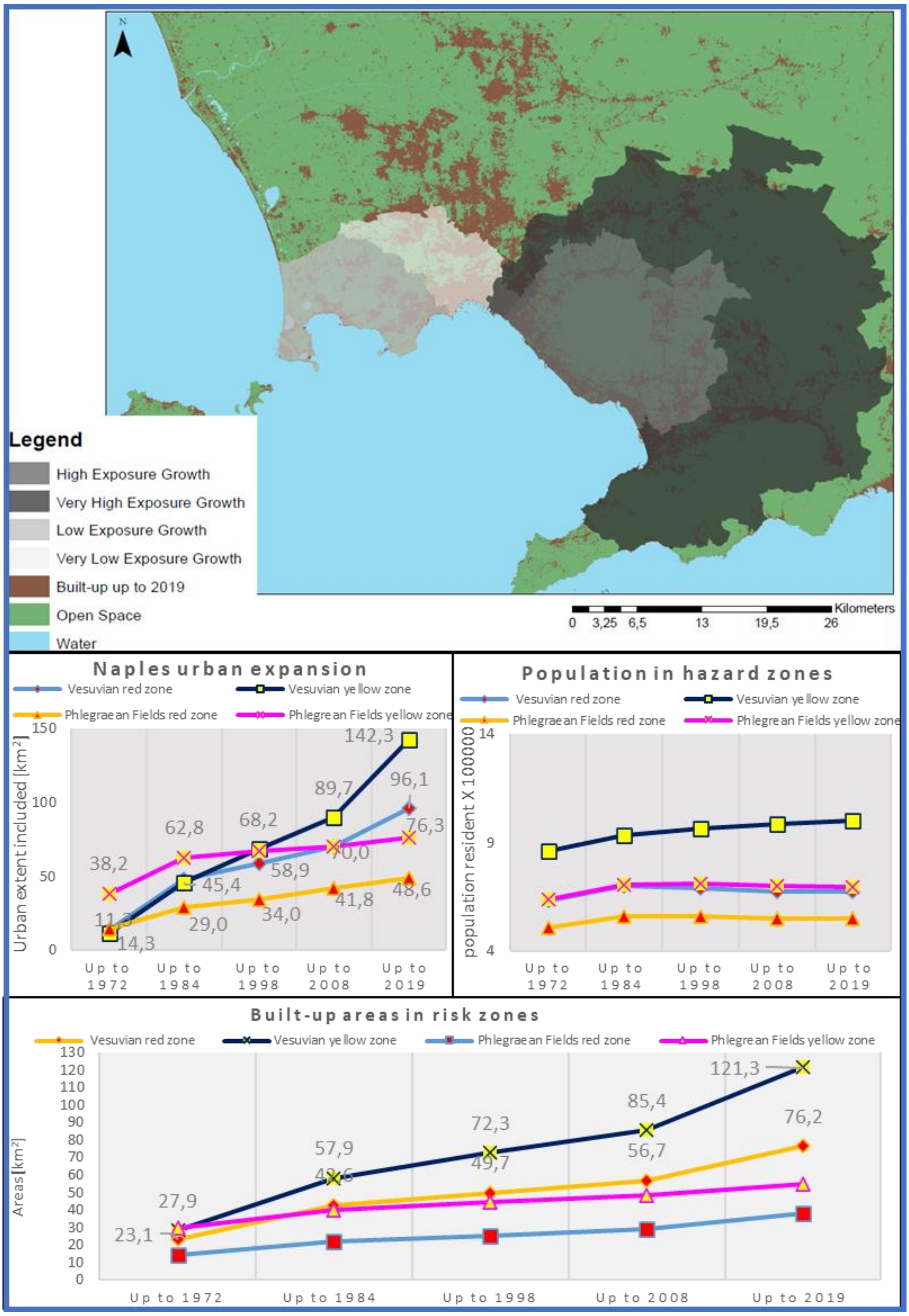


Figure 6.3 Exposure growth of volcanic zones: a comparison regarding Built-up growth, urban expansion and population trends, summarized in the map for the exposure growth ranking.

Particularly, in Vesuvian Yellow zone, people has kept growing in these years, differently from the other zones that have experienced a decrease over time (see the graph for population). Also, the urban extent has expanded with a high trend towards this area, as it can be seen by the graph regarding urban expansion in volcanic hazard zones. It has reached an area that is more than twelve times the original extent. Moreover, all the graphs agree that the area has been particularly subjected also to the large (as well as weakly planned) urban development of years 1972-1984 and 2008-2019, experiencing a huge exposure growth from them. The map highlights, thus, this area, that is most suffering from the lack of an integrated approach combining urban planning and risk reduction. The Vesuvian Yellow zone covers a wide territory and the recent urban expansion has developed also there, without considering the potential consequences. Therefore, for the future, the zone would need more monitoring as well as a plan and rules to discourage further urban expansion there.
Nevertheless, as previously mentioned, it is not only Vesuvian Yellow hazard zone to have been subjected to a high exposure growth, also Vesuvian Red Zone, as it is drawn by the map, follows a similar trend. However, here the seemingly lack of consciousness about volcanic risk could cause even worse issues. In a scenario where pyroclastic flows would cause a great quantity of structures to be rapidly destroyed, any increase of exposure means a significant greater loss. There is, as it could be seen in the map at Figure 6.3, a continuous Built-up land next to the coast, in the Vesuvian Red Zone, that exposes a great value to the volcanic risk, and, it was noticed from the previous maps about Naples urban expansion, it has been occupied more and more by this city urban extent. However, good news is that population in the area is decreasing, lowering the human exposure to risk. It could mean that people have started developing more awareness about the risk in the area. However, planning should continue to insist in this sense, to raise awareness for all the people involved, from the inhabitants of these zones to the stakeholders involved.

Finally, as it could be seen on the map, the Phlegraean Fields have suffered from less exposure growth: indeed, Naples expansion towards those areas has been minor, concentrated in Pozzuoli. However, exposure growth has still occurred (indeed, the map shows a low or a very low exposure growth but never a zero or a decrease of exposure): even though people have decreased in the two areas, still the Built-up or the urban extent there has grown even though to a smaller extent with respect to the Vesuvian zones. Therefore, the map synthetizes this evidence of the overall trends being slower, more controlled. It should be noted also that most of the Yellow Phlegraean Fields zone is covered by Naples Built-up as well as its urban extent as shown into Figure 6.1 , this area still remains with the lowest rate of exposure growth, because after the first urban expansion occurred from 1972 to 1984, the urban expansion and Built-up growth there have been very slow and population has decreased. However, it does not mean that the zone has a low overall exposure that would need to be well managed during the emergency.

6.3 Systemic vulnerability in the volcanic hazard zones

The urban layout that has been described for Naples extent, with focus on its irregularity and its poorly accessible and redundant roads network, raises concerns regarding the systemic vulnerability of the volcanic hazard zones, albeit with different degrees of severity. Still the region that has proven to be the worst, even in terms of the actual systemic vulnerability, is the Vesuvian Yellow Zone. The overall results are shown in Figure 6.4. There, analysing all maps it is clear that the Vesuvian Yellow area provides the worst results in terms of accessibility and redundancy.

Particularly, the first map on the right in Figure 6.4 shows with dark purple the zone with the worst result regarding the presence of roads, their orderliness and their redundancy on the whole volcanic hazard zones, while the map on the right, with dark brown indicates the worst area looking just at the urban extent included into. Finally, the most interesting one, the map at the bottom shows the finest level of detail: from this map the single areas that suffer most from lack of proper access ways can be easily identified. This third map, even agreeing with the general ranking presented by the other two, (see ranking analysis at 5.2.2), shows that also the areas that are considered with a lower systemic vulnerability, as the Phlegraean Fields, can present some places that are more vulnerable than others to volcanic risk. Particularly, it is the case for the expansion areas of 2008-2019 at Pianura or the expansion areas of 1998-2008 at the peripheries of Scampia.

Looking at the first map at Figure 6.4, therefore focusing on the overall hazard zones territories, the Vesuvian Yellow Zone presents a rarefied road network (see also measures at 5.2.2), with the lowest density of roads, and the largest distances to reach the main arterial roads. In case of emergency, just before an eruption, it would mean more time to evacuate the areas that would need it. It is important that the stakeholders as well as the Emergency planning consider it, and, in future, it would be important to invest more on the accessibility of the area. However, what is still more worrying is what is represented in the brown-coloured map at its right: in the Vesuvian Yellow Zone, it is also Naples urban extent that suffers from the highest systemic vulnerability, due to the large unplanning that distinguishes the expansion area of 1998-2008, that is largely present in the zone. Therefore, not only the Vesuvian Yellow area presents a territory that is scarcely connected to the inwards and outwards, with respect to the other volcanic zones, but also Naples urban extent that is present into its limits shows to be the worst part of Naples urban extent included in a volcanic hazard zone.

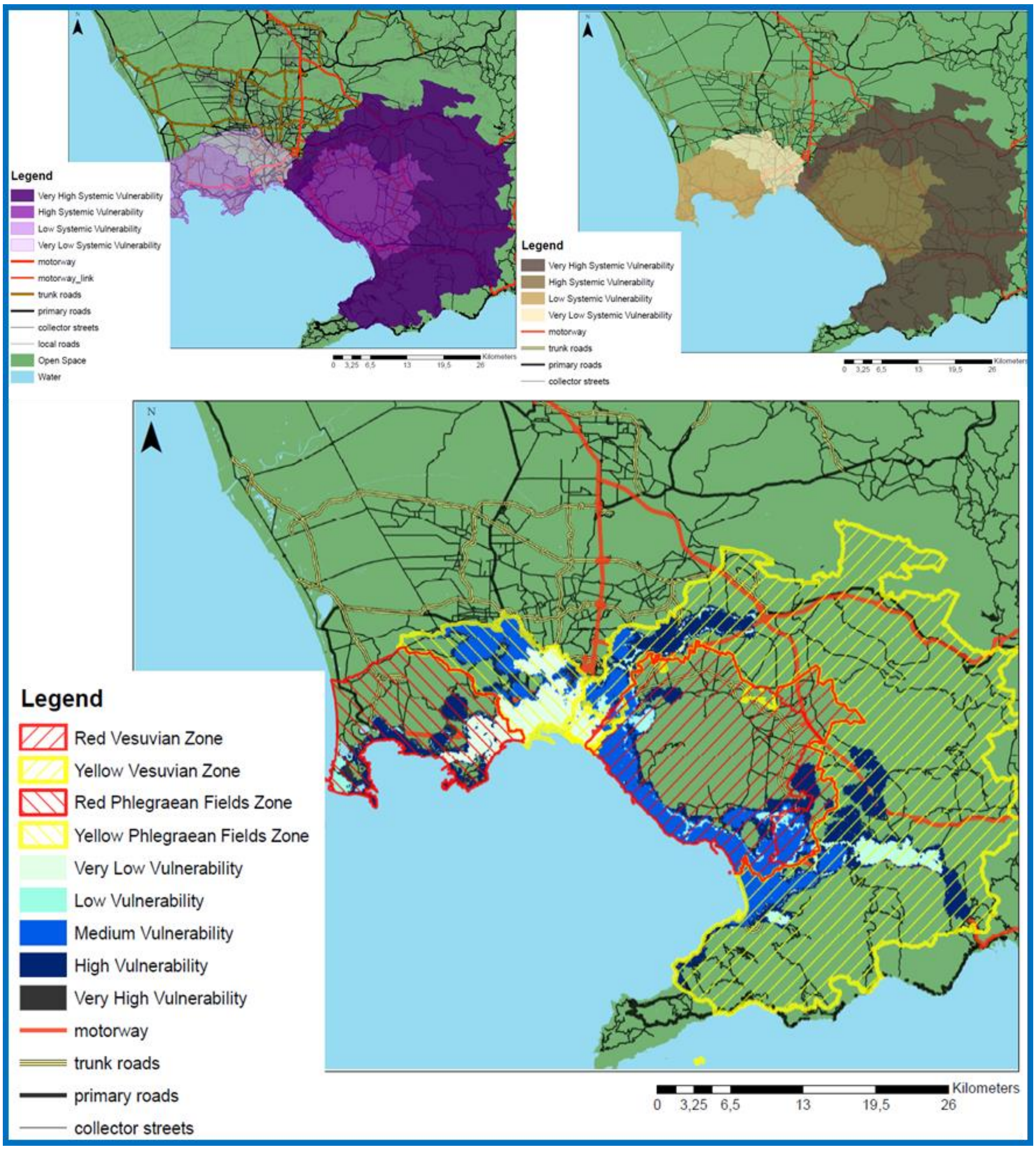


Figure 6.4 Systemic vulnerability from different levels of detail. The first map on the left refers to the overall zones systemic vulnerability, the second, on the right, on the systemic vulnerability of the urban extent comprised into, while the last at the bottom shows the systemic vulnerability for each expansion area.

Looking at the map at the bottom at Figure 6.4, it is also possible to distinguish the expansion areas that, in the Yellow Vesuvian Zone, would need the largest effort in order to make the urban fabric there less systemically vulnerable and also more resilient to a probable scenario of a huge fall of ashes. The areas of Nola and Marigliano at the North of Vesuvius, or also the Naples expansion area of 2008-2009 at Castel San Giorgio are the ones that show a high systemic vulnerability. These areas require urban planning and intervention to improve accessibility and networks redundancy, even though quite all the urban extent included into the Vesuvian Yellow zone shows a worrying medium level of systemic vulnerability. Vesuvian

Yellow Zone has proven also to be the one that has the largest quantity of bridges (see Figure 5.20), that means, in case of earthquakes before and during the event the collapses of bridges could worsen a road network already systemically vulnerable.
Finally, the land use analysis for Vesuvian Yellow area (see 5.2.3), while still showing an area that is mostly cultivated or forestated, represents the expansion areas of 2008-2019 that are very fragmented, worsening the overall vulnerability of the zone.
However, not only the Vesuvian Yellow Zone shows a very high systemic vulnerability: the Vesuvian Red Zone too, looking at all maps, provides similar evidence. Indeed, particularly, for what concerns redundancy, it shows to have the lowest number of 4-ways intersections with respect to all the other areas (see measures at Table 5.11), as well as a low roads density. Particularly in the alarm phase it could become a great issue because it would mean traffic to be spread in the area, particularly the areas underlined as high systemic vulnerable as Poggiomarino territory (see again the map at the bottom of Figure 6.4). And, in case of earthquakes before the eruption these places that lack redundancy could suffer from the collapse of some roads causing the segregation of urban blocks.
Finally, Phlegraean Fields hazard zones, are still the territories with lower systemic vulnerability, however, peripheral zones such as Pianura and Scampia display very high systemic vulnerability levels. Similar high level can be found in Pozzuoli, very near to the volcanic threat. These urban expansions are small; however, they should not be forgotten in case of emergency and from a management and planning point of view. Particularly, if it is to be chosen how to intervene, these areas have shown a general lack of large roads, that could mean a lack of fast roads to exit them.

Chapter 7
CONCLUSIONS

This last chapter wants to provide a summary of the outcomes that this study has provided, in terms of the evidence collected about Naples urban expansion, exposure growth and systemic vulnerability.
This study has started by the example of the Atlas of Urban Expansion. It has processed satellite imagery (provided by Landsat and Sentinel 2B) from 1972 to 2019 and it has integrated it with population, roads and land use data, in a GIS environment. The results, maps, measures and attributes about Naples urban expansion have been later analysed in a risk perspective, through a comparison of the volcanic hazard zones from exposure and systemic vulnerability points of view.

7.1 The results about Naples urban expansion

This paragraph is meant to summarize the results that this study has provided about Naples urban expansion. Particularly, it addresses the first objective of mapping and measuring Naples urban growth alike the Atlas has done for its sampled cities. The outcomes are the followings:

- Built-up has fast grown in the whole Neapolitan study area. From 1972 to 2019 it has more than triplicated its initial extent. It has shown a particular huge increase of Built-up, for the whole study area, between years 1972-1984 and 2008-2019. The maps show North and North-West as the preferred directions for growth.

- The most of this Built-up growth for the whole study area has been related to Urban subclass, even though Suburban and Rural Built-up are still growing. However, from

1972 to 1984 and from 2008 to 2019 Suburban and Rural trends have been higher describing an urban sprawl and a lack of planning.

- Regarding the only Naples urban expansion, its urban extent has doubled between 1972 and 1984 and now in 2019 the actual Naples urban extent is more than seven times the extent dated 1972. Looking at just the urban extent, Suburban Built-up has registered from 1972 to 2019 a larger growth than the whole study area for those years; particularly, as for the whole study area Suburban land has increased more from 1972 to 1984, with 35% share of Suburban Built-up with respect to the whole urban extent Built-up land in 1984 (in 1972 it was 30%). After 1984 the shares for Suburban Built-up have slowly decreased to 26%, showing an increase for Urban Built-up in a more continuous urban fabric. Even saturation attribute testimonies that, after a decrease between 1972 and 1984, it has turned to increase for the Naples urban extent. It could be a good sign of a process of filling out of the empty spaces among the urban fabric.

- Density for population in the whole study area Built-up, as well as in the urban extent has decreased with the years, with less people living in the same spaces and a greater land consumption.

- Roads are mostly of the local type, for the whole actual urban extent: it means that the city still prefers slow and local collectors. Only in the expansion area of years 2008-2019 it has been detected a larger presence of arterial roads. However, going from 1972 urban extent to the most recent urban expansions, roads density decreases as well as the number of intersections, thus the accessibility and redundancy of roads could be lower, highlighting a rapid urban growth that has not considered much the importance of roads network. The larger blocks sizes detected for the expansion areas of 1972-1984 and 2008-2019 still underline an irregular urban layout there and a weaker planning.

- Corine Land Cover maps show a land fabric that becomes more discontinuous coming to the outwards, with more cultivated and arable land comprised in the urban extent.

From all these results it is evident that the city is still growing and rapidly. The years that have provided the greater growth for Built-up or for the urban extent have been the ones from 1972 to 1984 or the most recent from 2008 to 2019. Moreover, that growth has also been poorly planned as it is confirmed by saturation and by the shares for Suburban land in the urban extents. The decrease in densities for population is also an important outcome that confirms the Atlas of Urban Expansion thesis about the cities that are unsustainably growing faster than their inhabitants. Finally, roads and land uses have been useful to look at the urban layout of the different expansion areas, to underline an overall decrease in accessibility and redundancy of roads, as well as fragmentation among the urban fabric land uses, that still makes it possible to perceive a poorly planned urban growth.

7.2 Exposure growth and systemic vulnerability rankings for the hazard zones

This paragraph aims at showing the outcomes with respect to urban expansion and exposure growth or systemic vulnerability. The conclusions here are referred to the volcanic hazard zones:

- The Yellow Vesuvian area has been the zone with the highest exposure growth. Particularly, its Built-up land has increased more than four times, with still the highest rates of growth between 1972 and 1984 or between 2008 and 2019. Moreover, Built-up has grown more fragmented with higher rates for Suburban and Rural Built-up. Differently from the Phlegraean Fields hazard zones where the growth of Built-up has been much more related to the only Urban Built-up land. The Vesuvian Yellow area has experienced, among the hazard zones, the biggest urban expansion: Naples urban extent has gained land in the zone growing of about 12,6 times there. Finally, the Yellow Vesuvian area has been the only zone, compared to the others, whose population has increased and not decreased after 1984; however, population density has decreased, highlighting an increasing land consumption also in this area.

- Vesuvian Yellow hazard zone is the worst also regarding systemic vulnerability. It has the lowest accessibility for what regards roads densities and proximity to arterial roads, but it has also the lowest density for intersections, thus the lowest redundancy. Looking at redundancy of roads also the Red Vesuvian Zone presents a bad result for density of 4-ways intersections, the lowest among all the areas values.

- The most detailed analysis for systemic vulnerability has detected the single expansion areas, from the hazard zones, that are the most systemically vulnerable to risk. It has noted that there are small areas of Phlegraean Fields hazard zones that could suffer much regarding their accessibility and lack of redundancy. They could be seen into Figure 5.24, related to the peripheries of Pianura and Scampia.

- Finally, for the worst area, the Yellow Vesuvian Zone, it has been calculated that the predominant land use is forest, followed by agricultural activities. There is a little evidence of a small increase for the industrial and commercial share from 3% to 5% with the most of these units localized in the oldest expansion areas.

Therefore, the area that has provided the worst results, with a planning that has not much considered the volcanic risk, has been the Vesuvian Yellow Zone, that presents also a discontinuous urban fabric poorly connected. The ranking methodology that has been adopted has proven to be able to provide a useful tool to guide future development choices towards a more important monitoring of the urbanization process in this area, as well as the improvement of infrastructures. Exposure growth ranking permits to compare the different zones on the base of the increase of their population, including Built-up and urban extent, in a way to see clearly where the risk has been more disregarded, highlighting the need for more control in those areas. On the other hand, systemic vulnerability analysis has shown the areas that show the worst accessibility and redundancy of roads, allowing to focus on these areas, in future, to improve their infrastructures. Moreover, the different levels of detail have allowed to test the results as well as to show the singular cases through the most detailed level: for example, it is important to pay attention to the areas (e.g. the peripheries of Pianura and Scampia) in the Phlegraean Fields hazard zones that have shown a very high systemic vulnerability.
This methodology seems to provide good potentialities, even with the limits that will be described after.

7.3 Limits and future perspectives

The study has provided interesting evidence about Naples urban expansion and about the methodology proposed to integrate urban planning and risk perspectives, nevertheless it should be noted that it has also experimented some limits and issues that could be addressed. First, it must be pointed out that the whole study starts with satellite images classification and all results are influenced by it. Despite the accuracy that has proven to be sufficiently good, a significant issue is provided by *subjectivity*. Indeed, to perform supervised classification, drawing the training areas before, or performing the corrections after, the analyst has introduced its subjectivity and its experience. This subjectivity makes the results less reproducible. Finally, the different spatial resolution of 1972 and 2019 could have caused a less reliable comparison with the images for the other years. The different results seem always to agree, in a way that it seems that this difference into spatial resolution has not much affected the outcomes. However, further study would be needed, to see if, for 2019, the exploitation of

Landsat 8, with resolution of 30m instead of 10m as Sentinel 2B could have provided different results for what concerns this year. Differently, this test cannot be performed on 1972 image due to the lack of satellite sensors in that period, providing free imagery with better spatial resolution.

Moreover, writing about the influence of data and their first processing to the following outcomes, it could not be forgotten the issue about population data. As it has already been explained at 5.1.3, the processing of ISTAT data, particularly extrapolation for the years before 1984 could have caused a decrease in reliability as well as the municipal reference could have provided estimates for population that stray from the real numbers. Therefore, the numbers are just to be considered relatively to the ones from the other years for the same city, they can provide a comparison among themselves, but they could not be compared to other population measures, like the Atlas ones.

A further study could be addressed also on an integration of land use data into the ranking procedure, for example from an exposure point of view (looking at the economic value), however, it is also to be admitted that the use of CLC maps with their low spatial resolution could provide just an insight of the real exposed values that should be integrated with more data.

Finally, this study has covered a large area thanks to the use of satellite imagery and GIS tools, however, it has not integrated its evidence with the local knowledge that could have allowed to test the results as well as to provide more points of view to the analysis of them. The methodology itself could have been aided by the local knowledge. It is true also that the scale of the study could not go too much into local detail, it had also to operate some simplifications (as the road grouping). However, in future, it could be interesting to deepen the knowledge provided by the study, to focus on the different themes that it has dealt with, and participation by inhabitants could be a really useful tool to go in deep. It would be important to first compare these study results with stakeholders' knowledge and then to focus on the themes that could be of interest for them. Indeed, active participation from stakeholders and inhabitants has been indicated by many authors (Serre, et al., 2013 ; Gencer, 2013) as a key for cities resilience.

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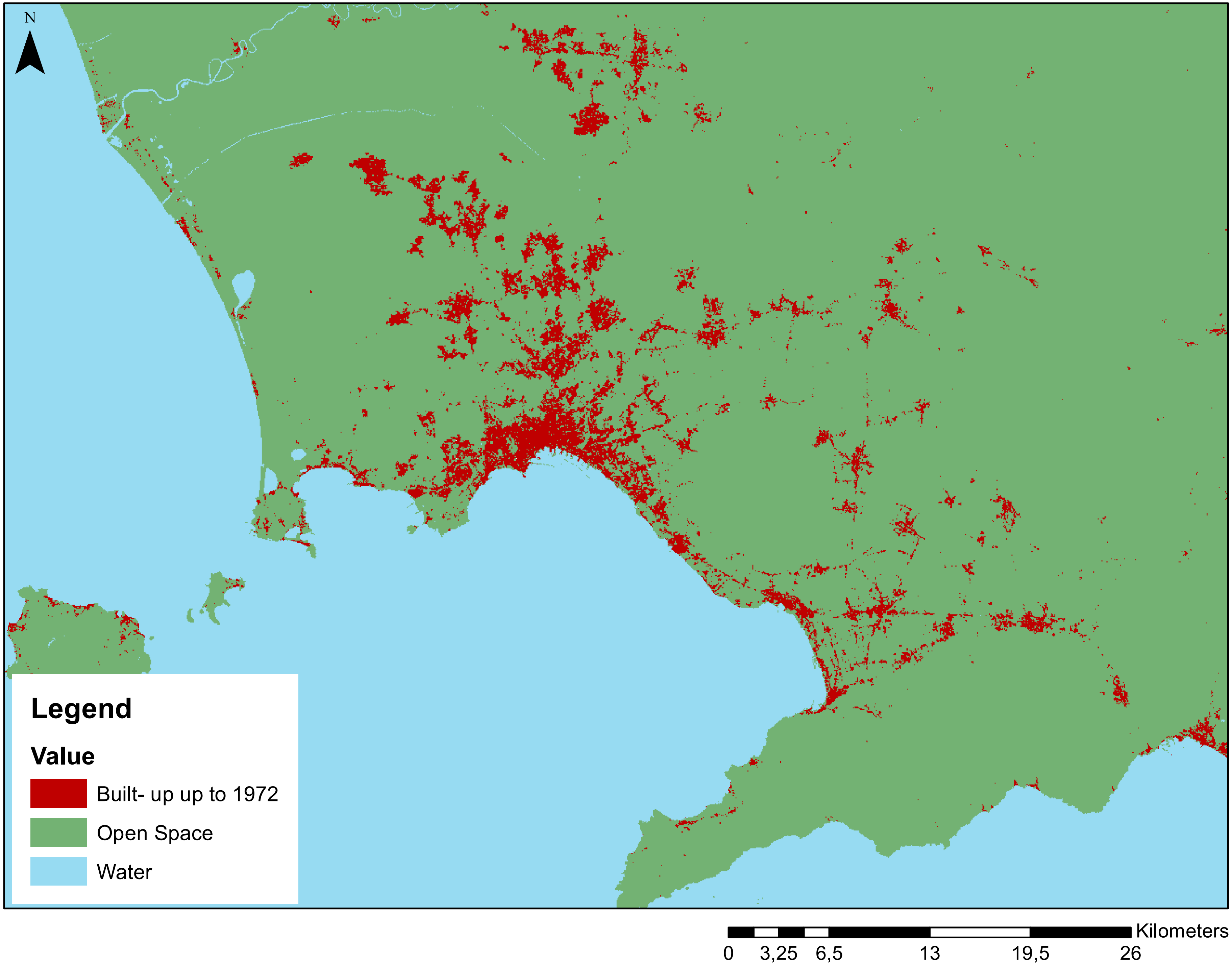
APPENDIX

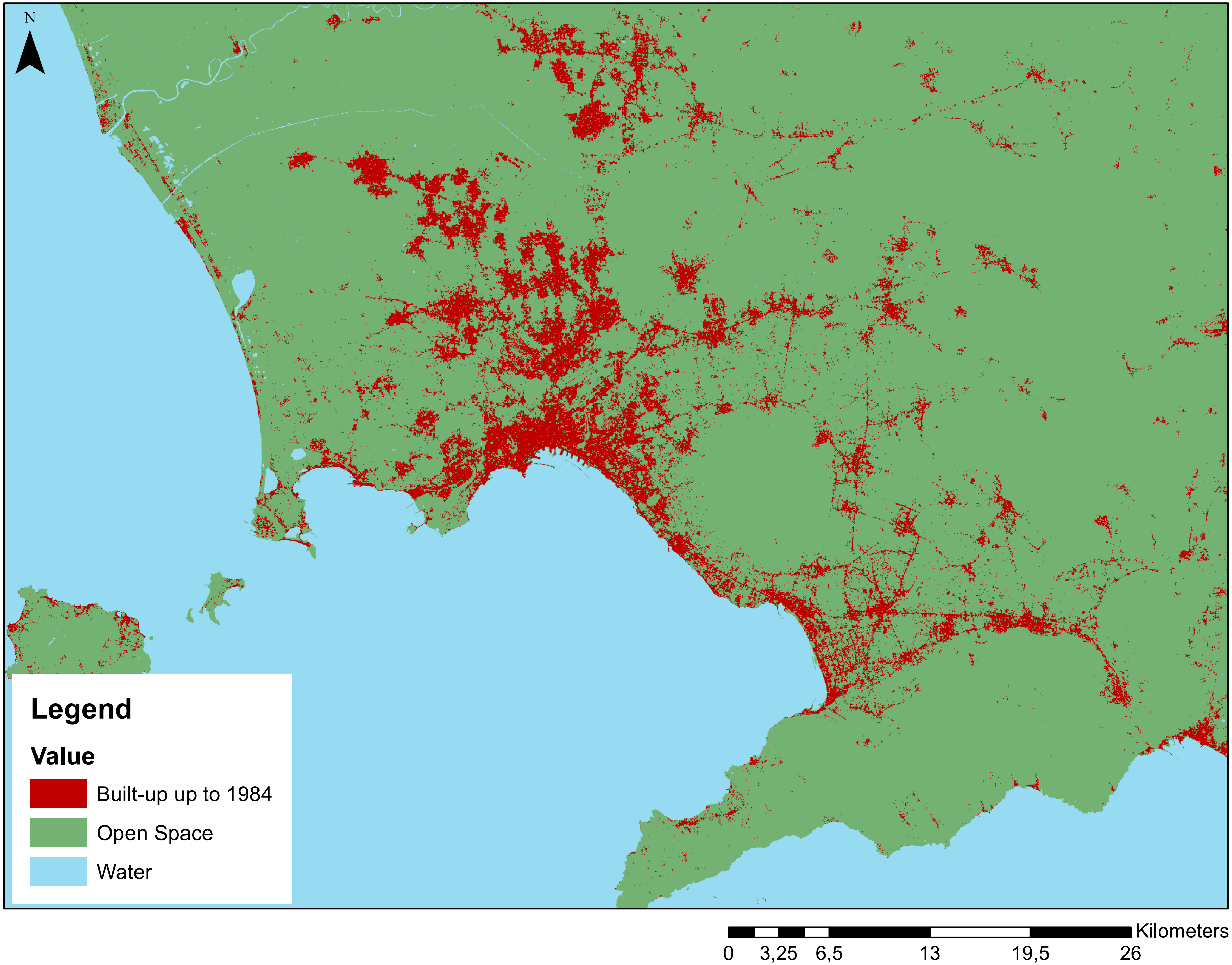
A.1 Maps for Naples urban expansion

The followings pages are aimed to collect and show in a more properly way the maps that are represented in this study, the ones that are significant for having guided it through the analyses and the ones that correspond to the final results. Following the maps, it is possible to follow again the storyline of this work.

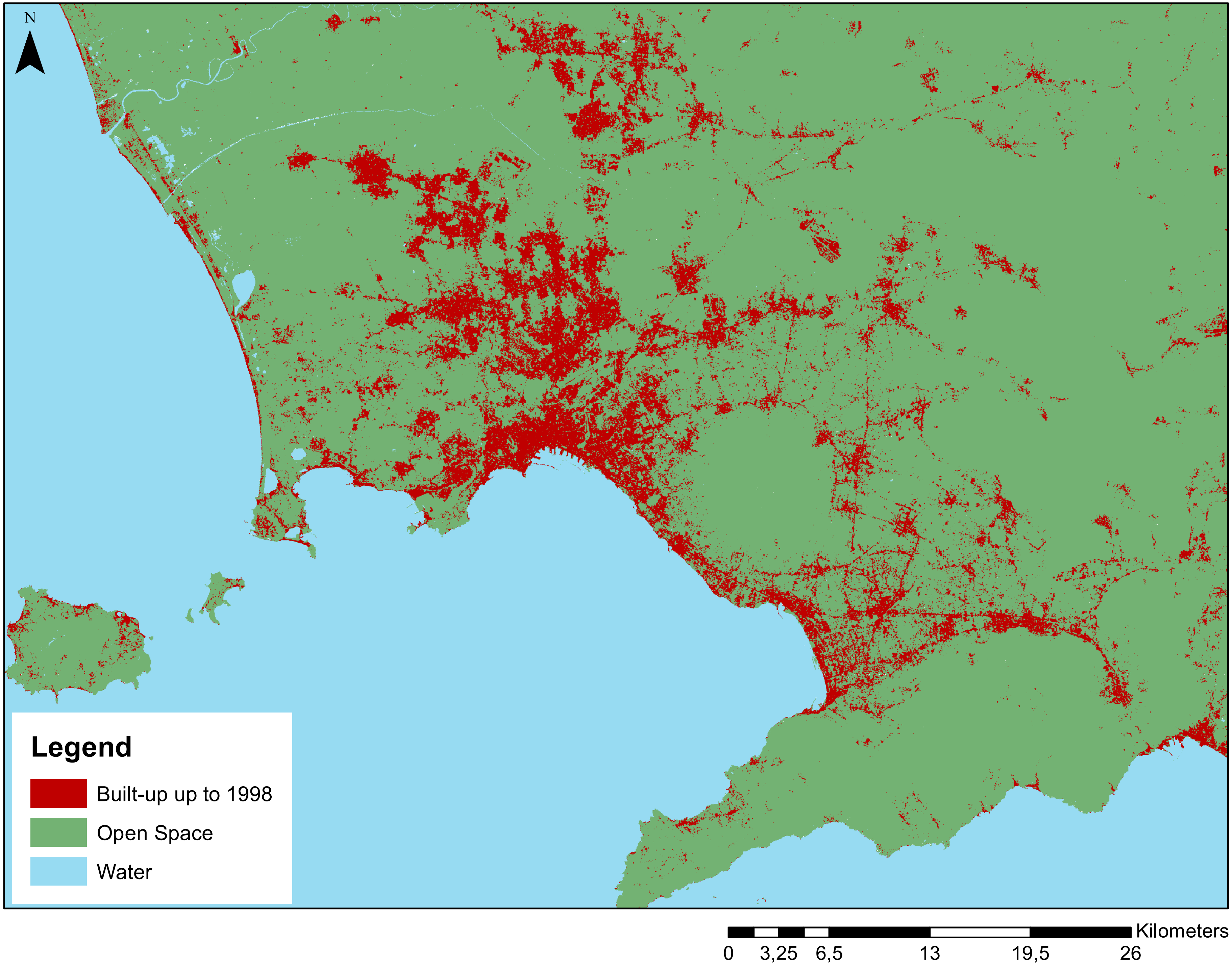
1972 Selective Land Cover Map



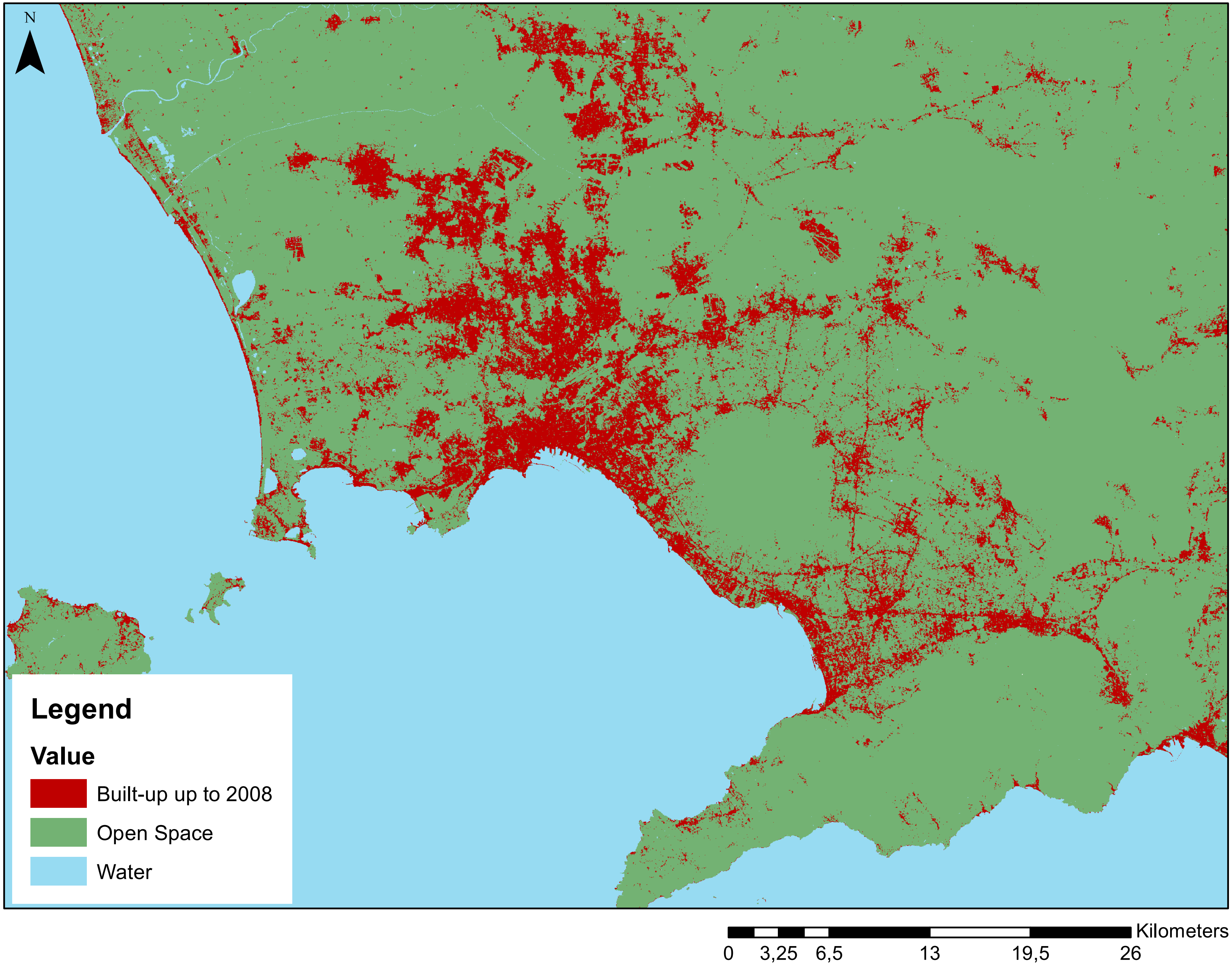
1984 Selective Land Cover Map



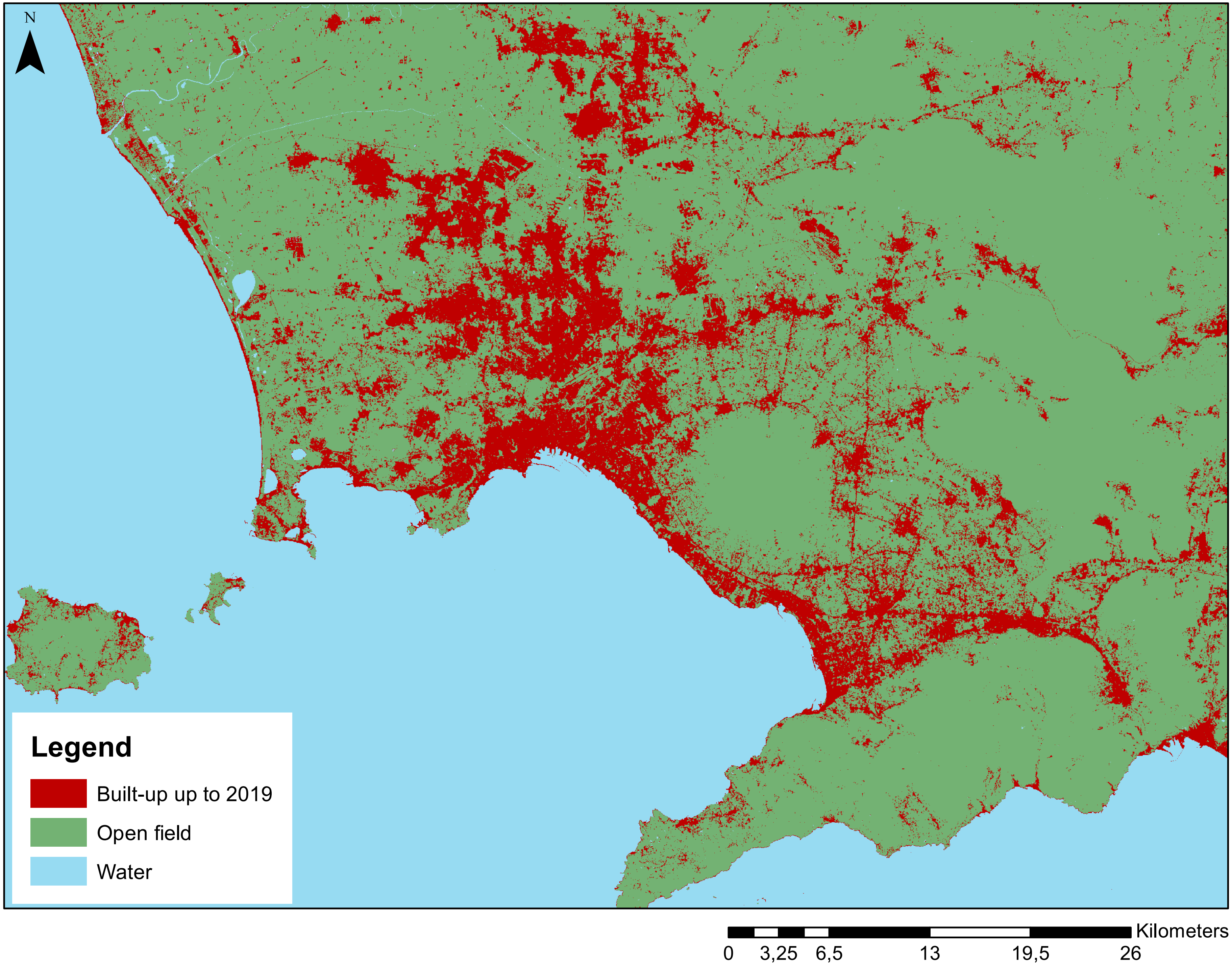
1998 Selective Land Cover Map



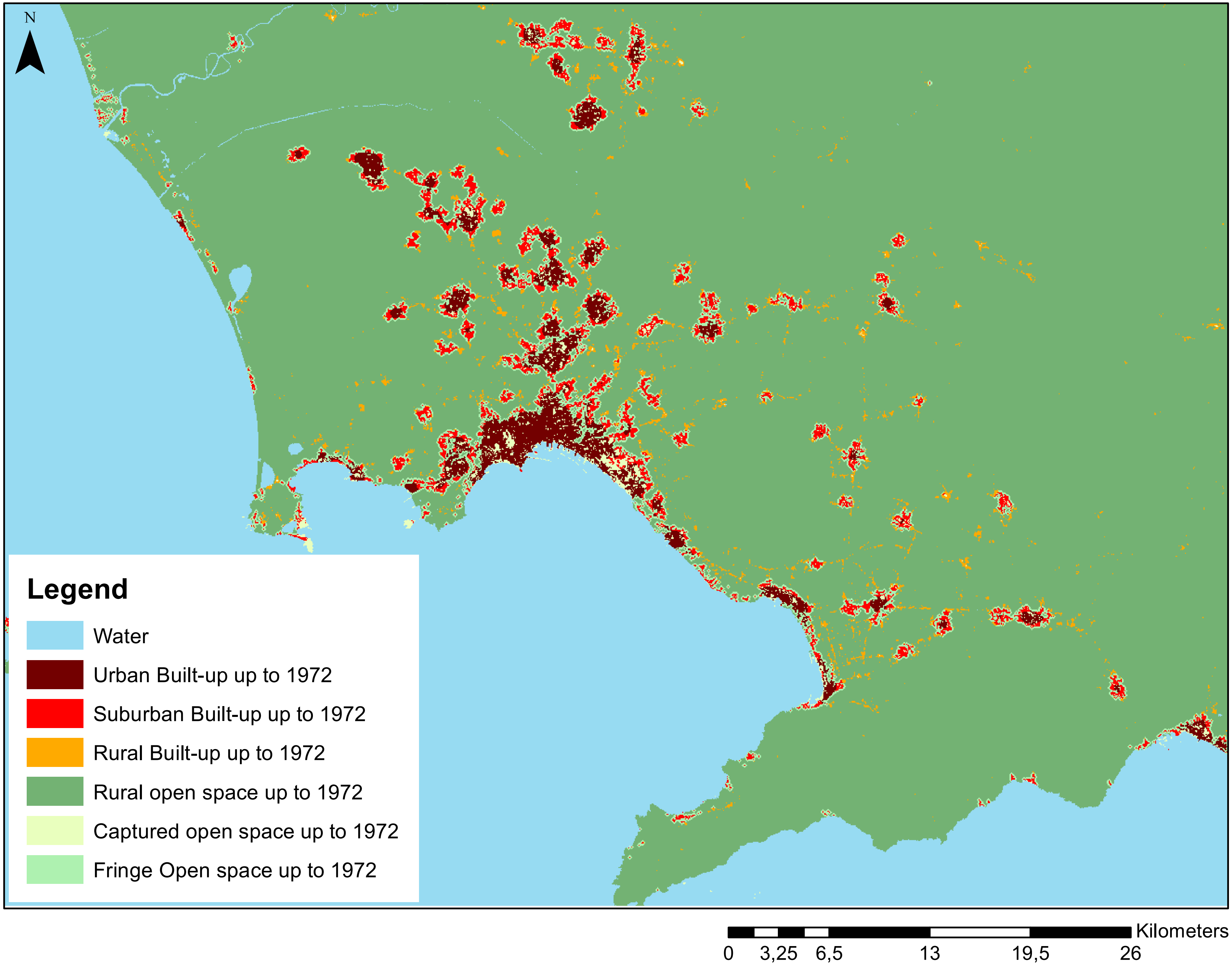
2008 Selective Land Cover Map



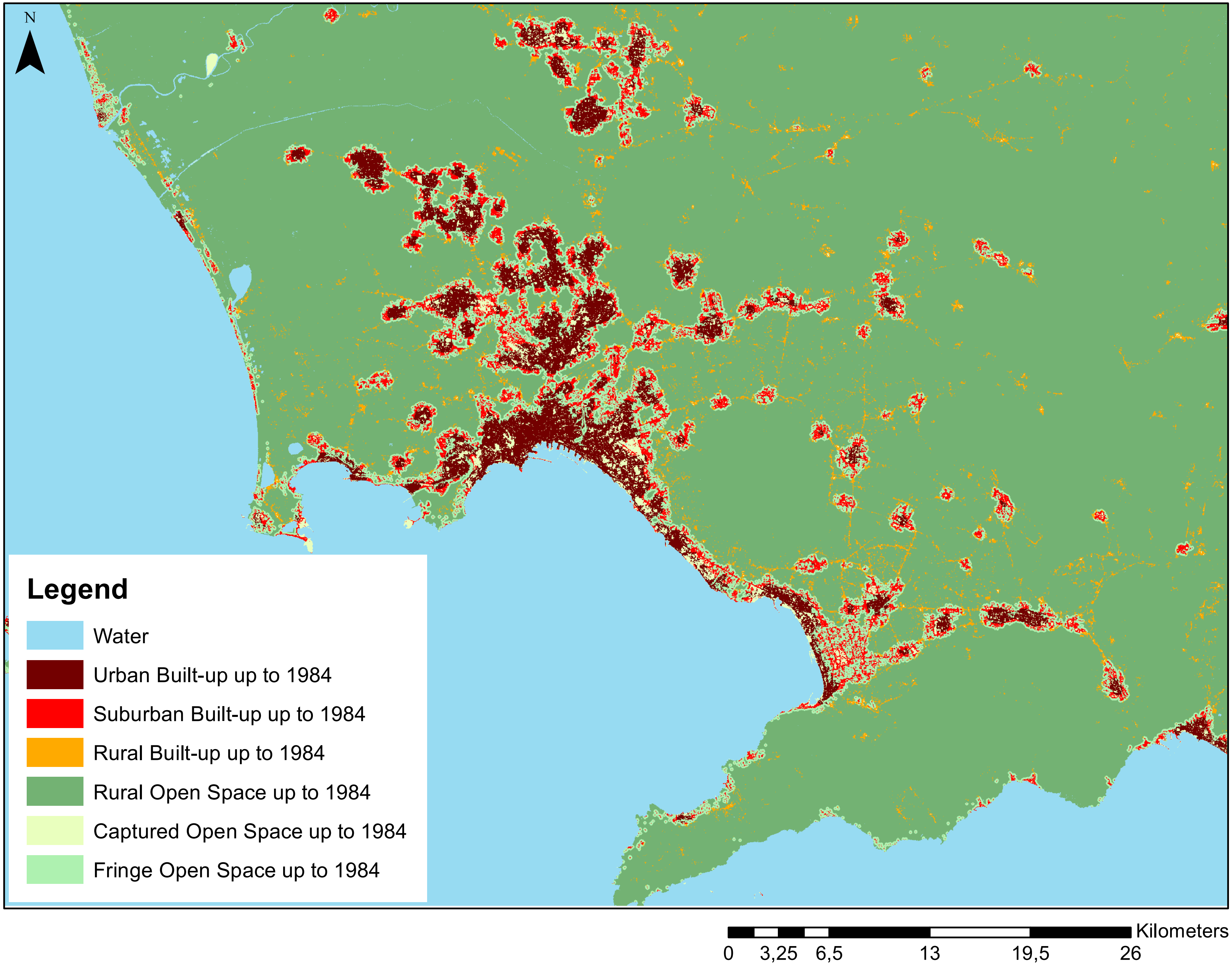
2019 Selective Land Cover Map



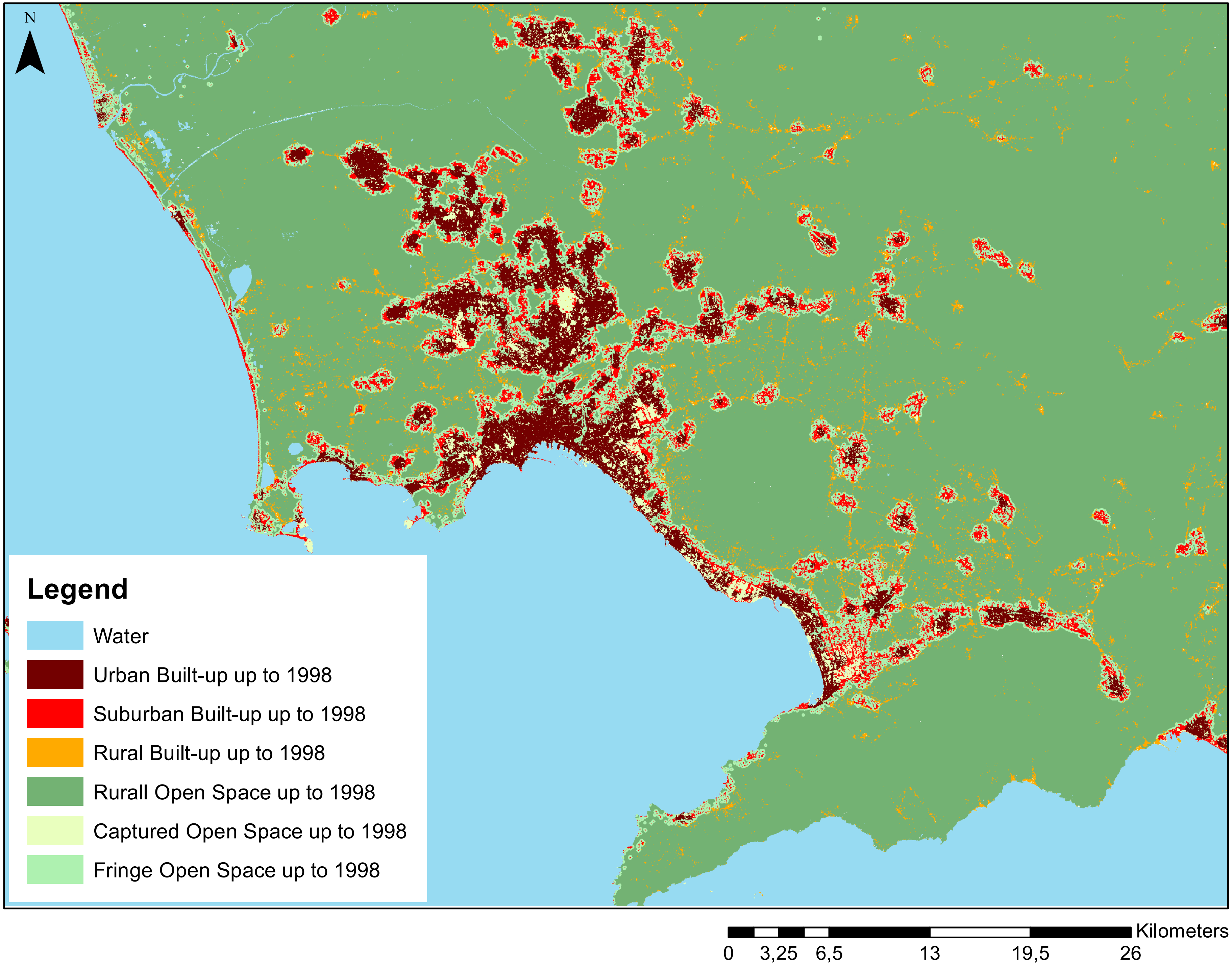
Finer Land Cover Map: 1972



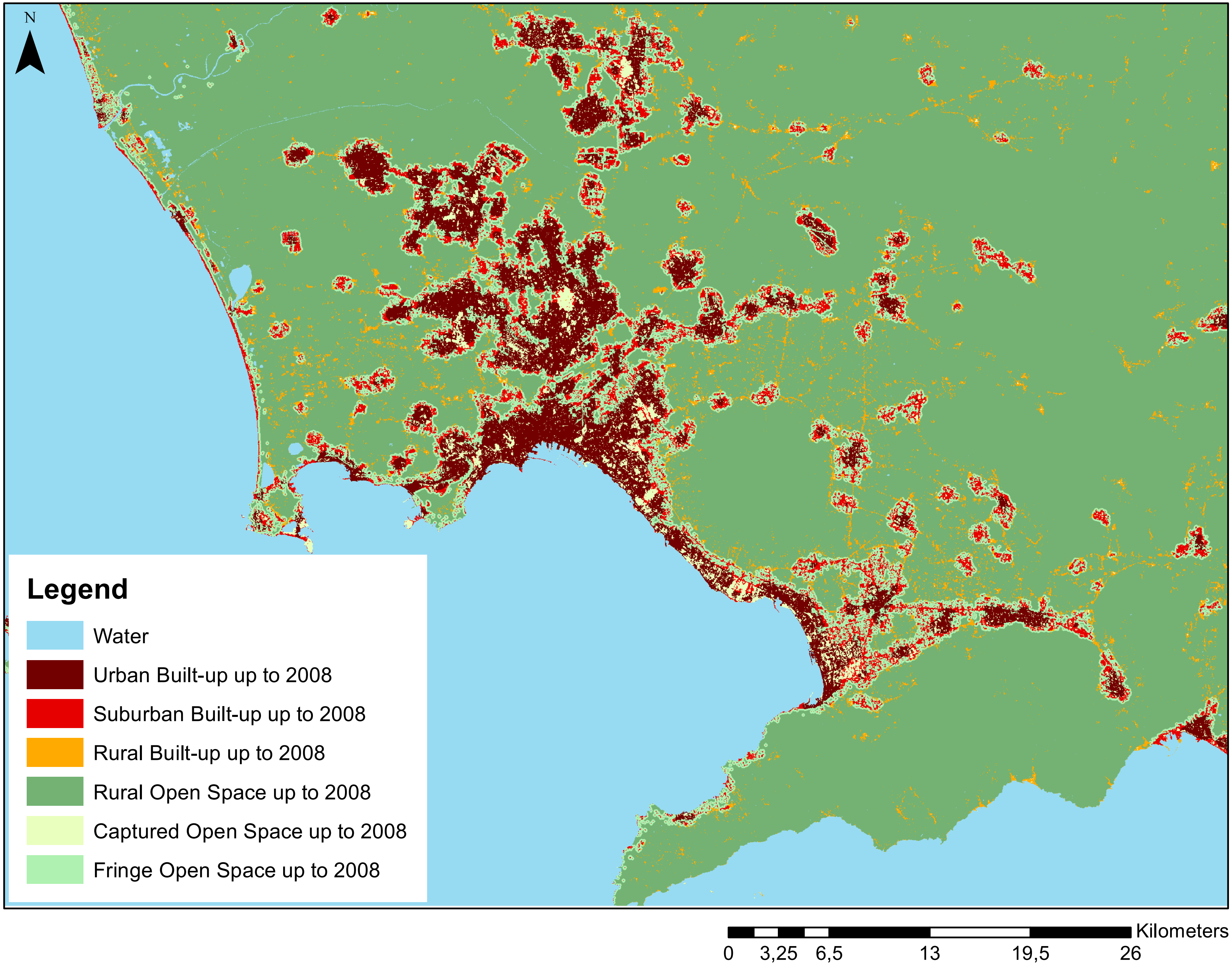
Finer Land Cover Map: 1984



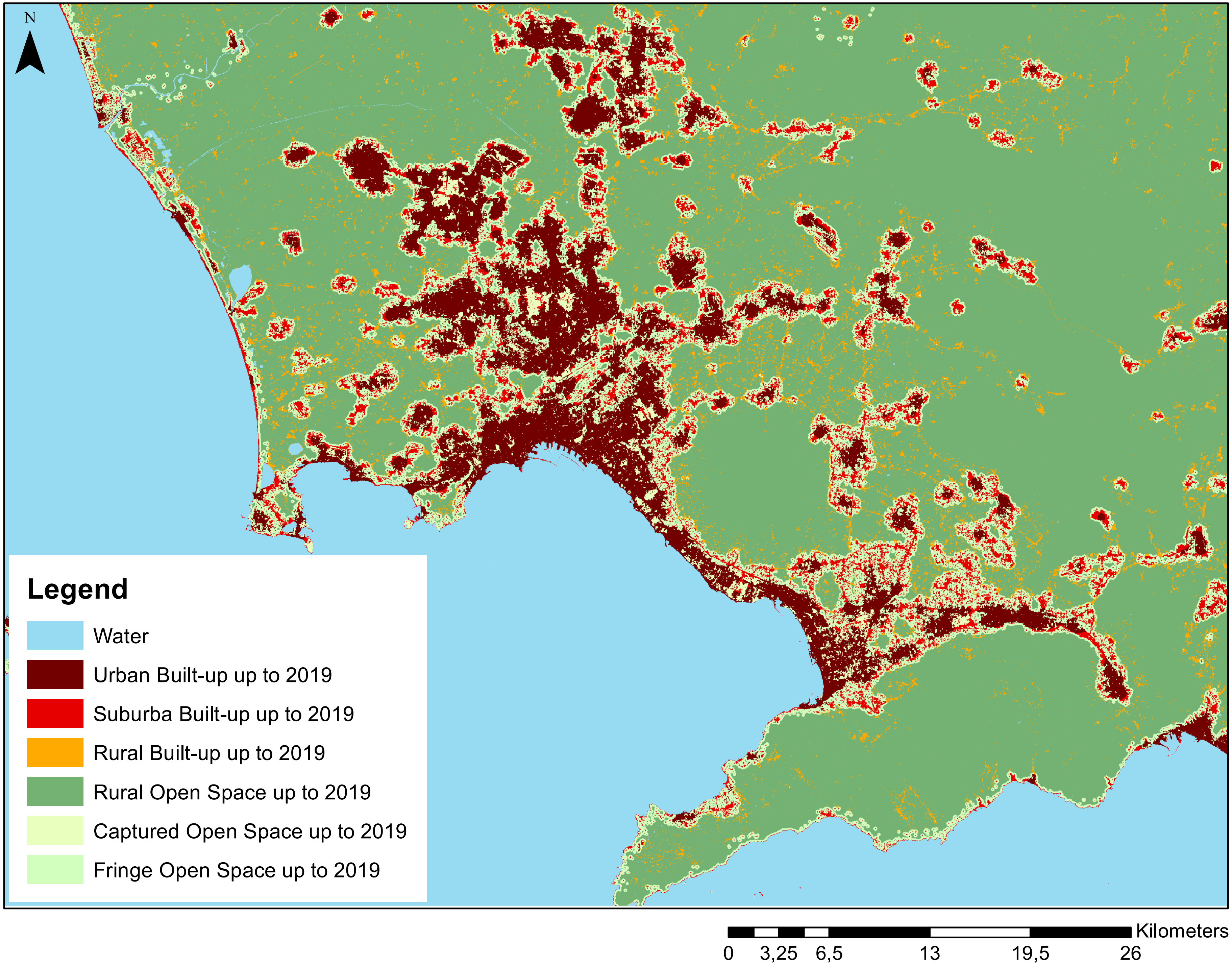
Finer Land Cover Map: 1998



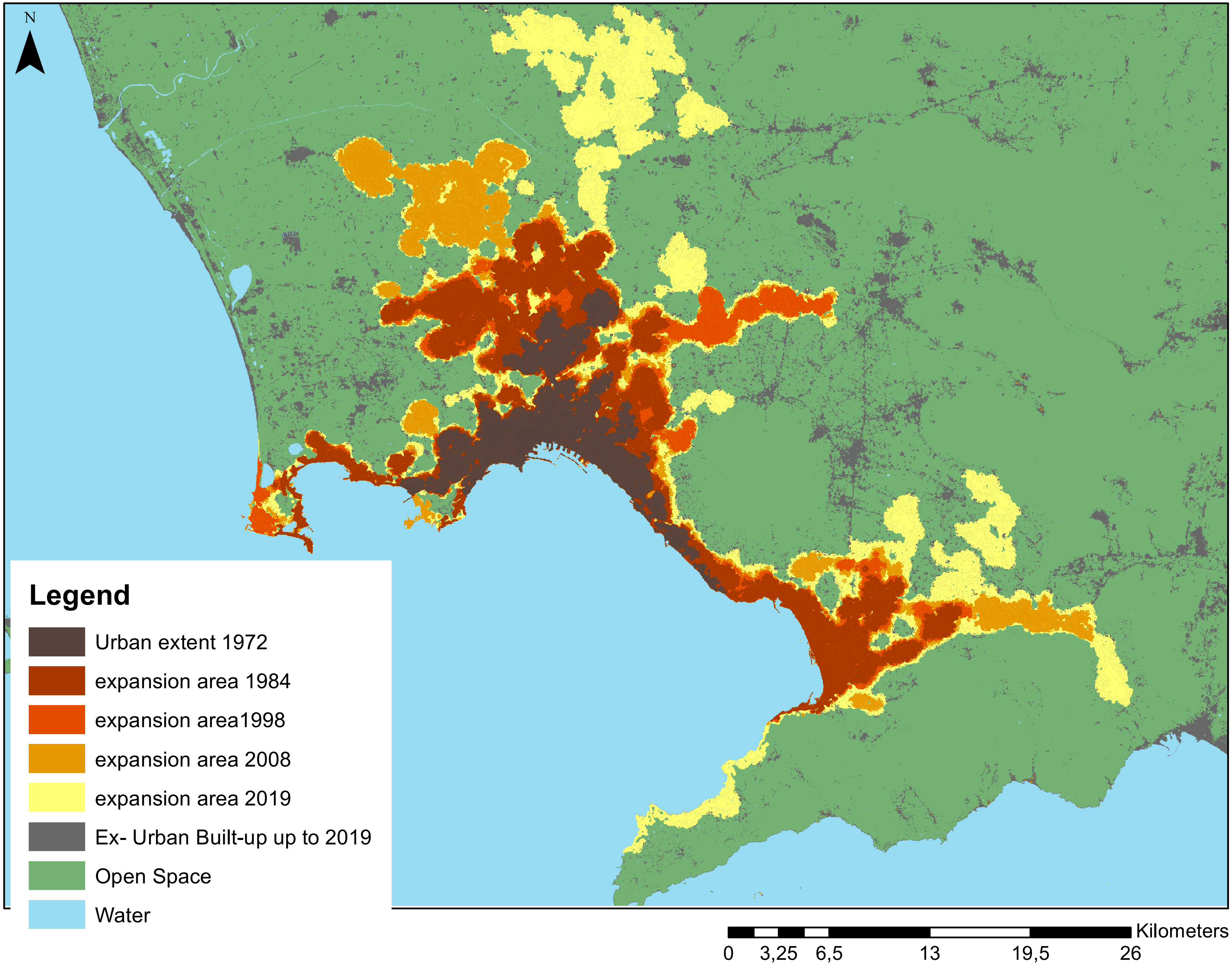
Finer Land Cover Map: 2008



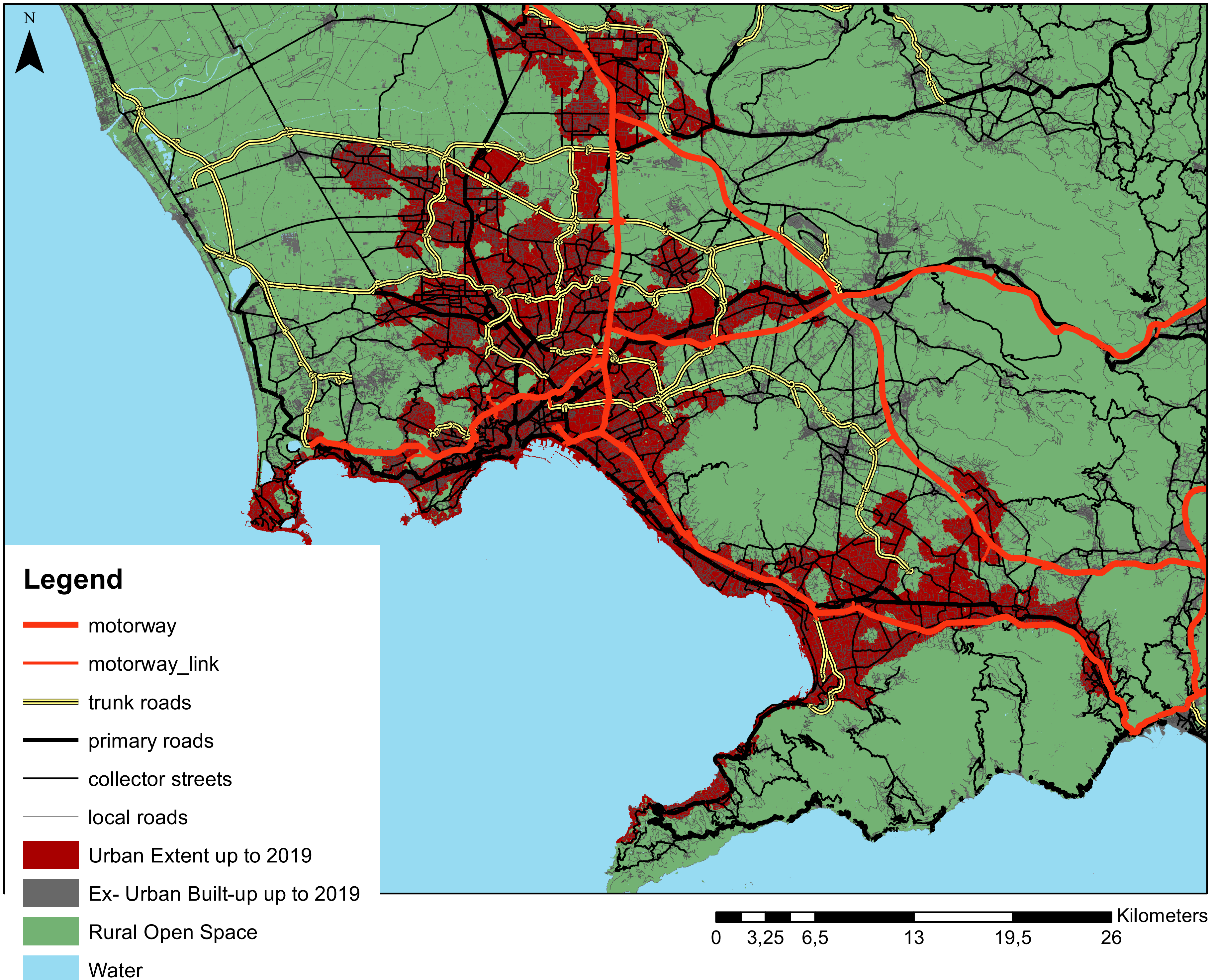
Finer Land Cover Map: 2019



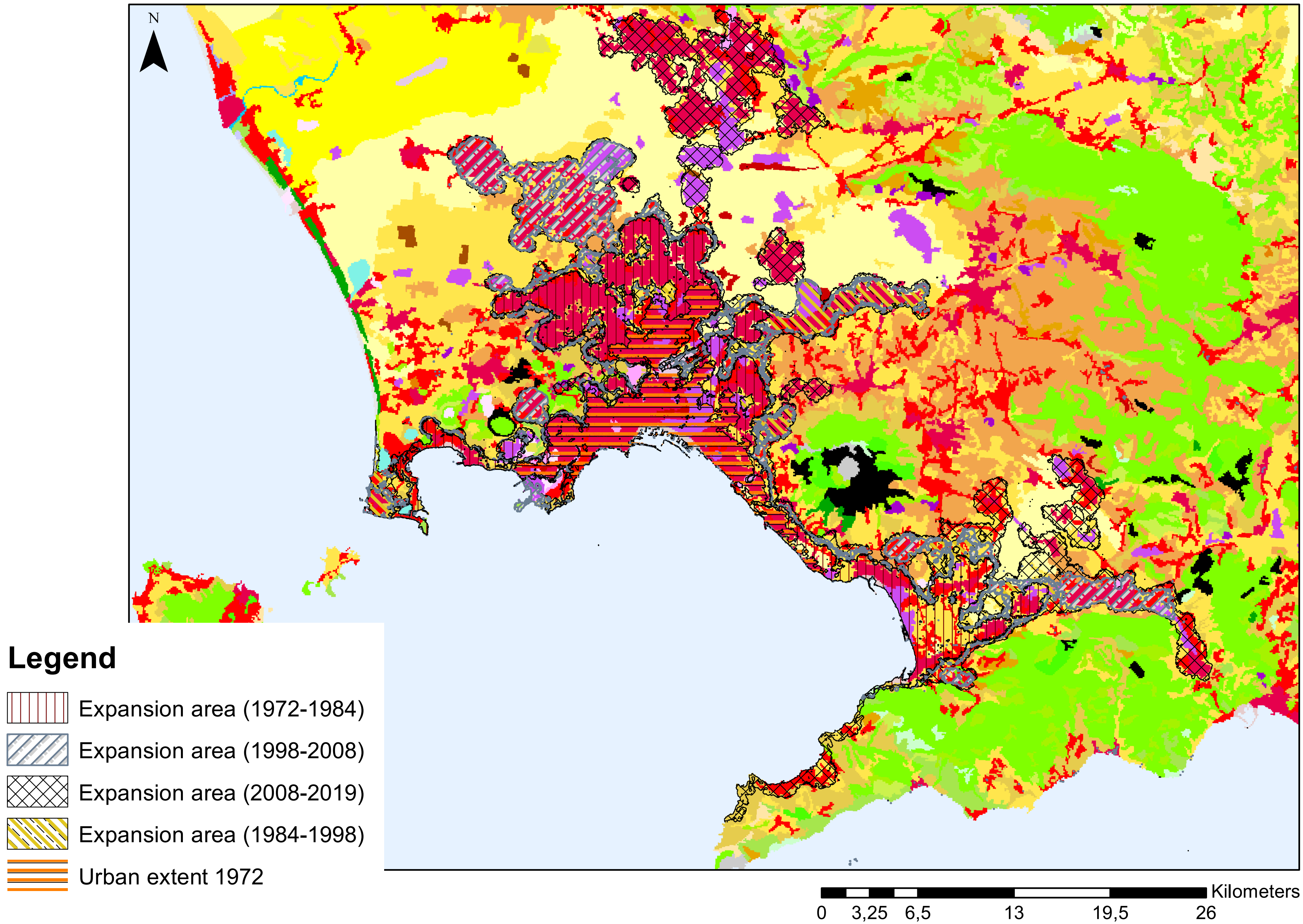
Naples urban extent and its expansion areas



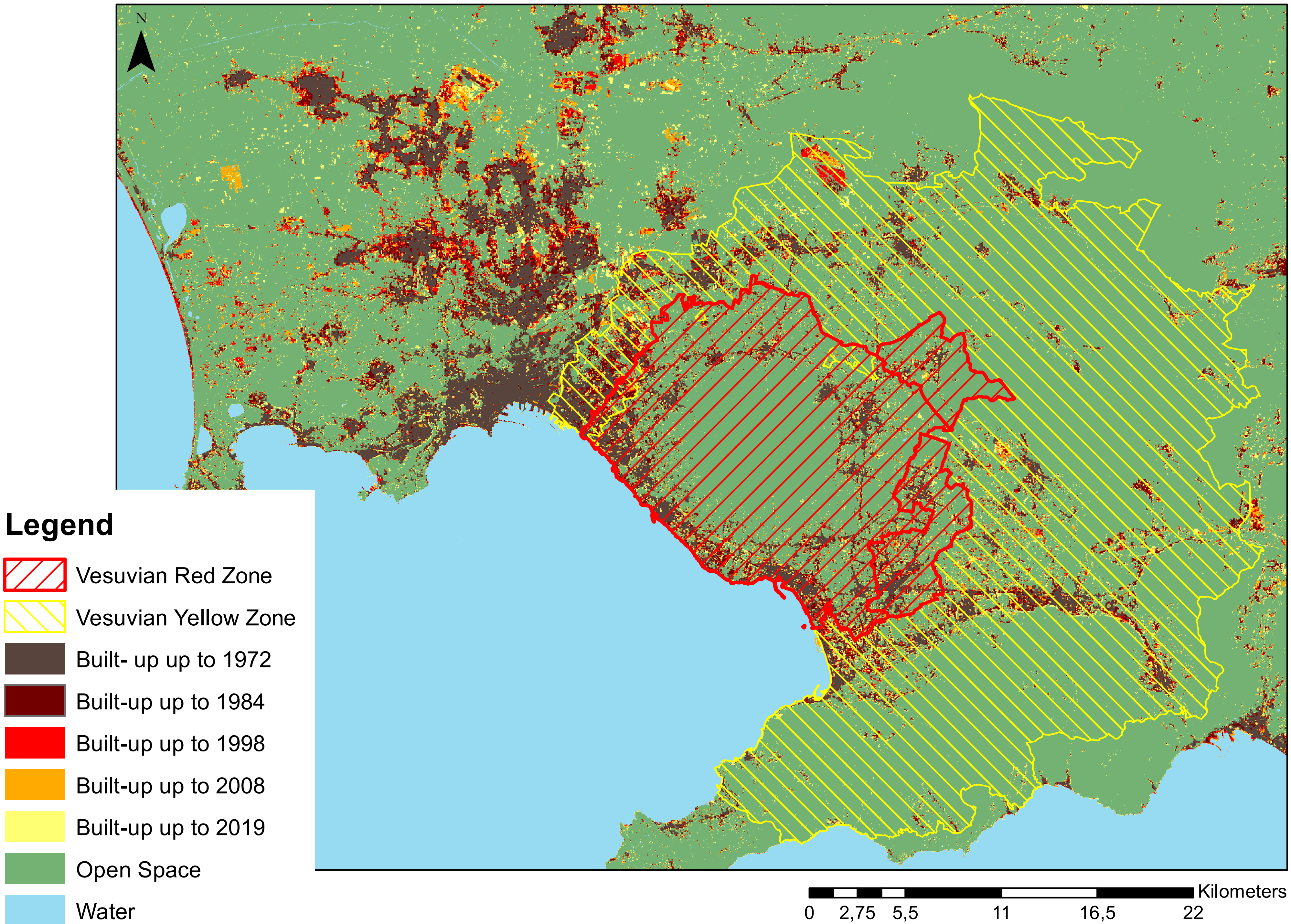
Overlapping of roads and 2019 Naples Urban Extent



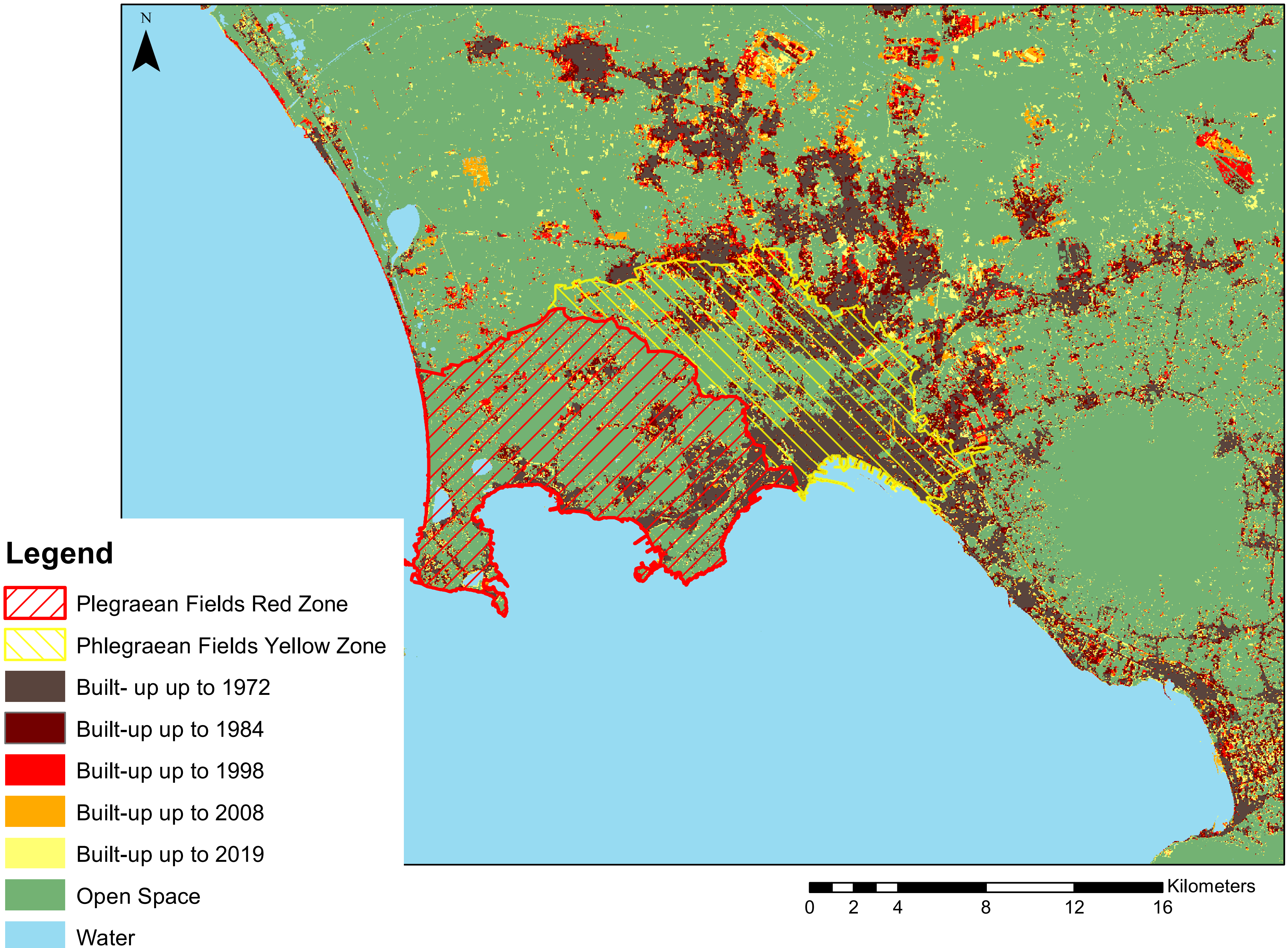
Overlapping the expansion areas of the 2019 Naples Urban Extent on the 2018 CLC



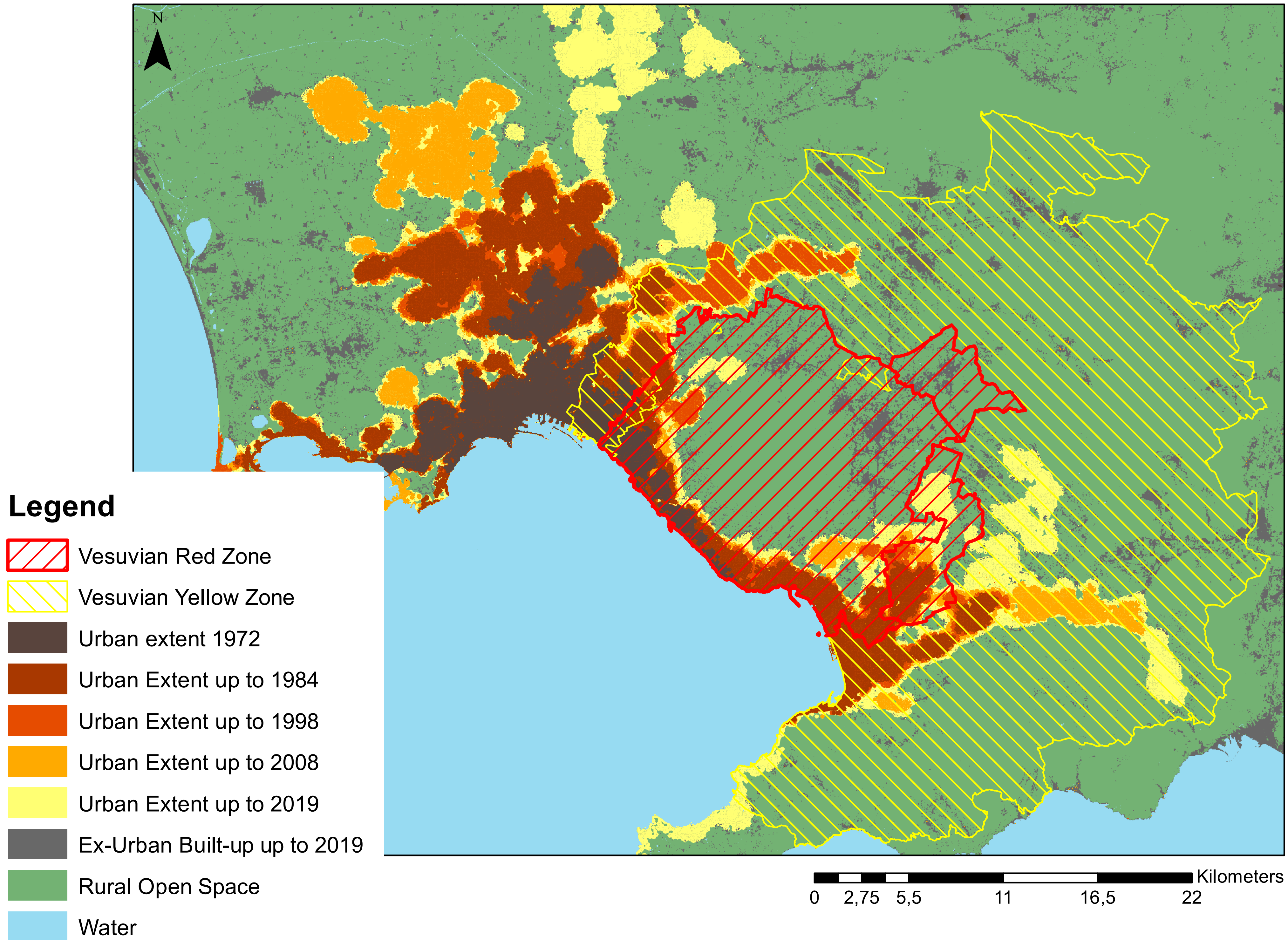
Overlapping of the hazard Vesuvian Zones on the Built-up development.

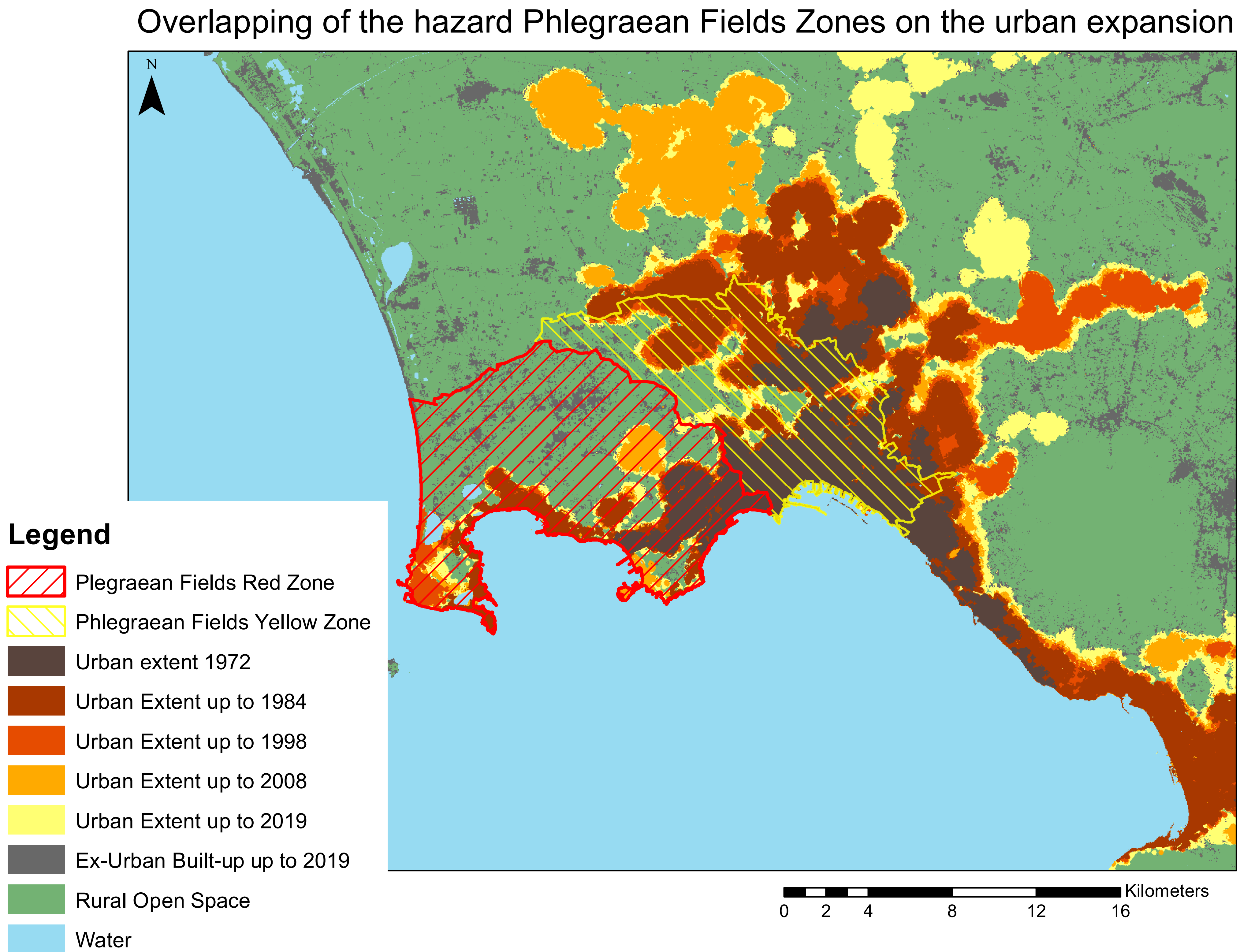


Overlapping of the hazard Phlegraean Fields Zones on the Built-up development.

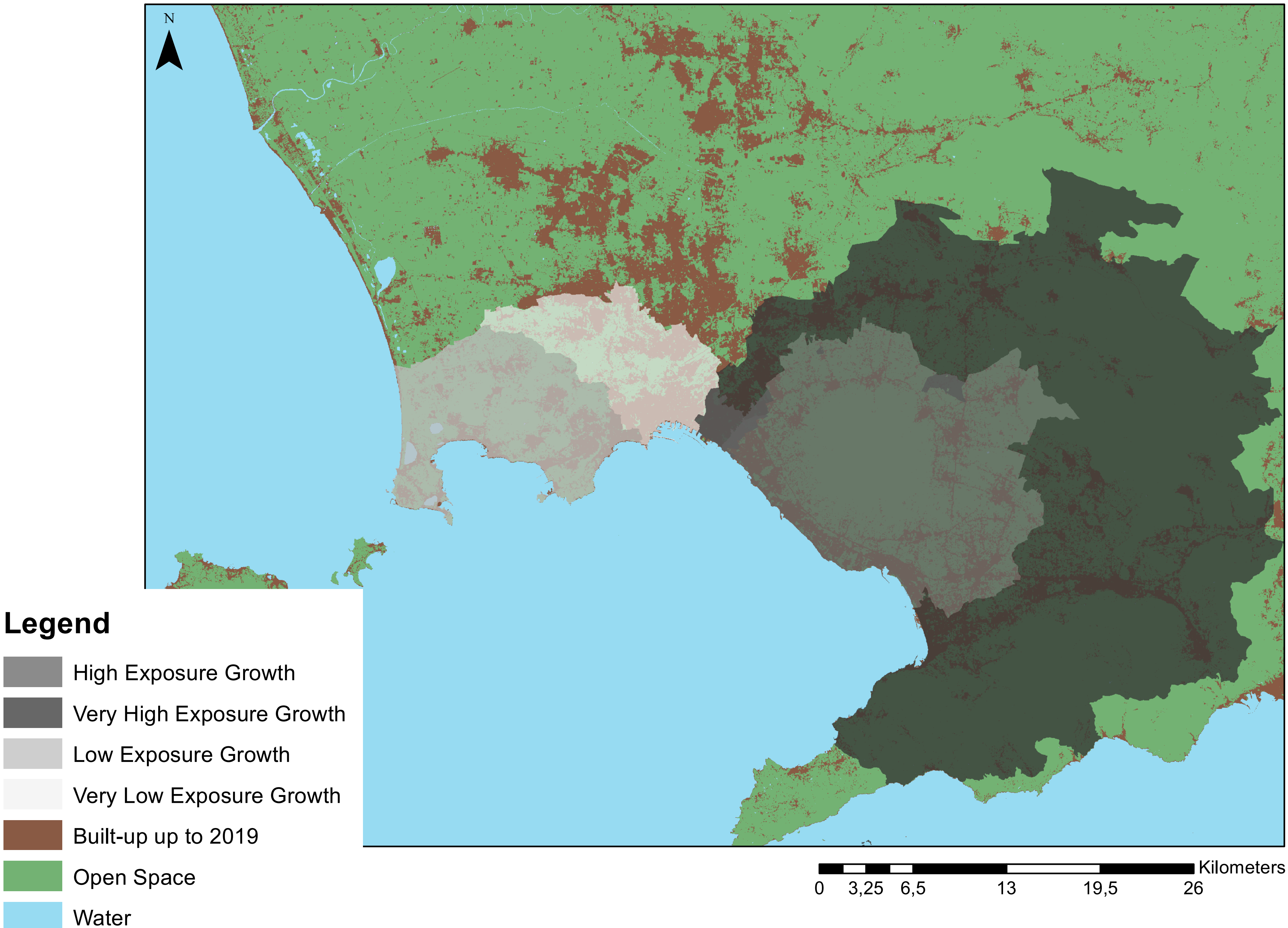


Overlapping of the hazard Vesuvian Zones on the urban expansion

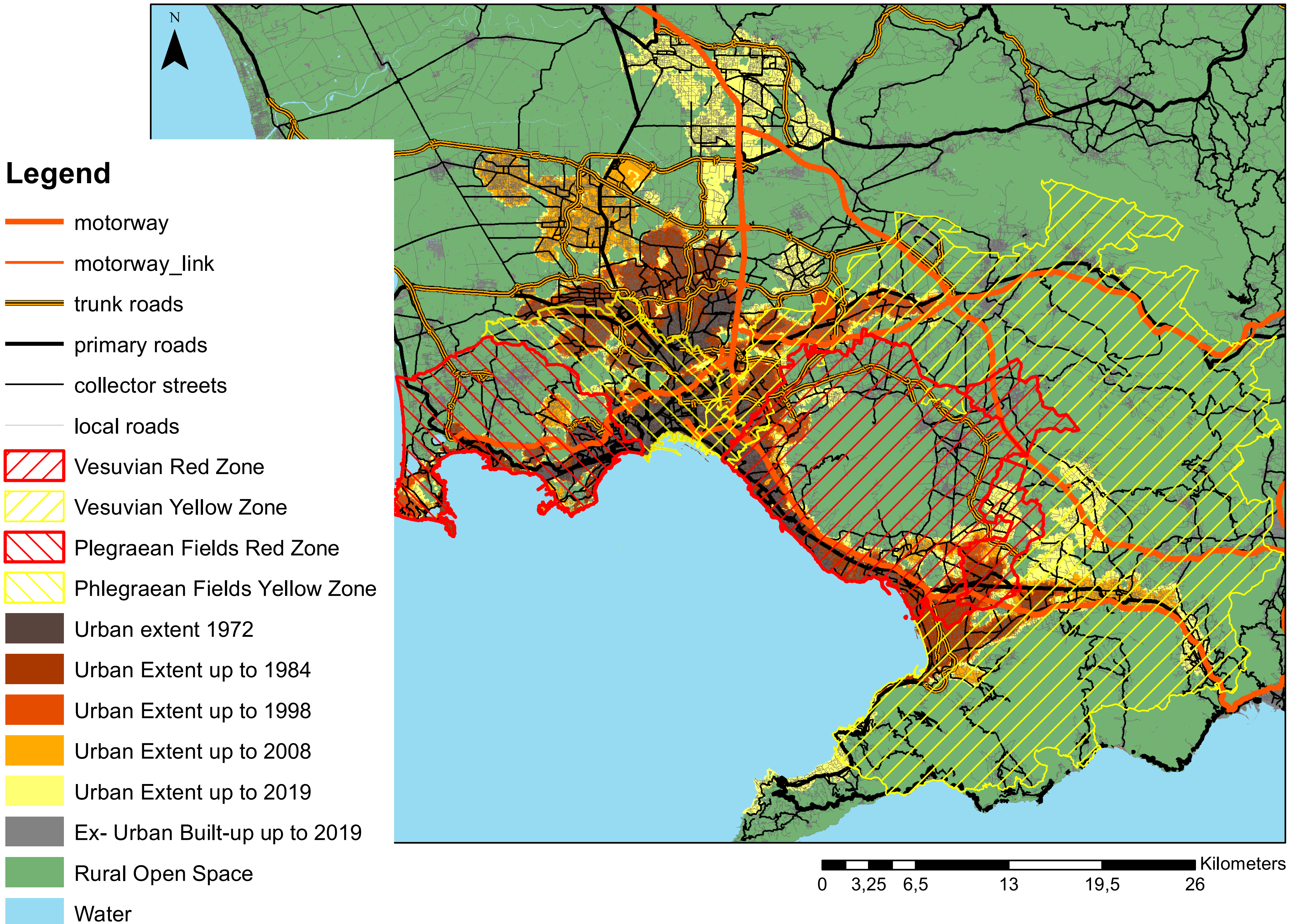



Overlapping of the hazard Phlegraean Fields Zones on the urban expansion
N
Legend
Plegraean Fields Red Zone
Phlegraean Fields Yellow Zone
Urban extent 1972
Urban Extent up to 1984
Urban Extent up to 1998
Urban Extent up to 2008
Urban Extent up to 2019
Ex-Urban Built-up up to 2019
Rural Open Space
Water
Kilometers
0
2
4
8
12
16

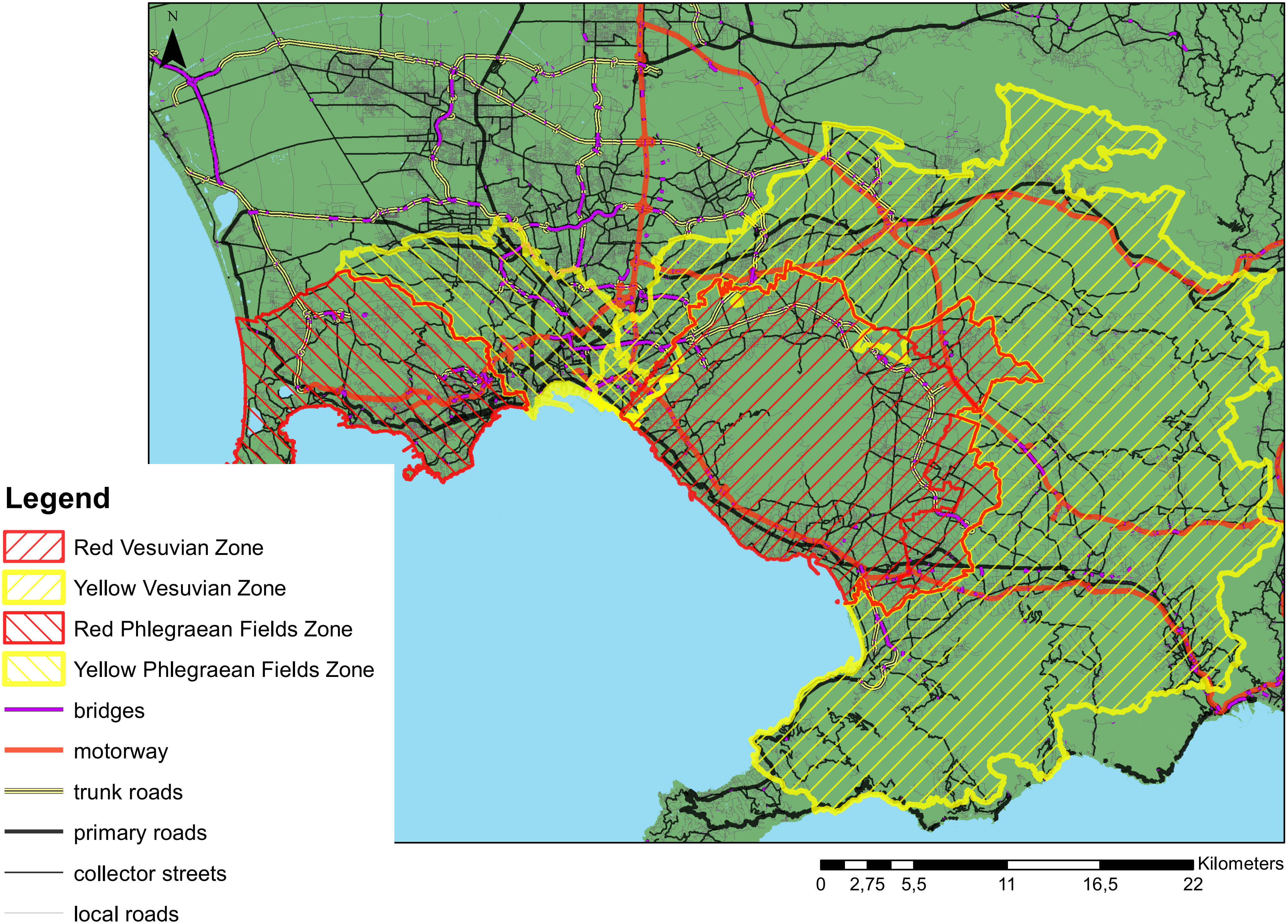
Exposure growth in the volcanic hazard zones



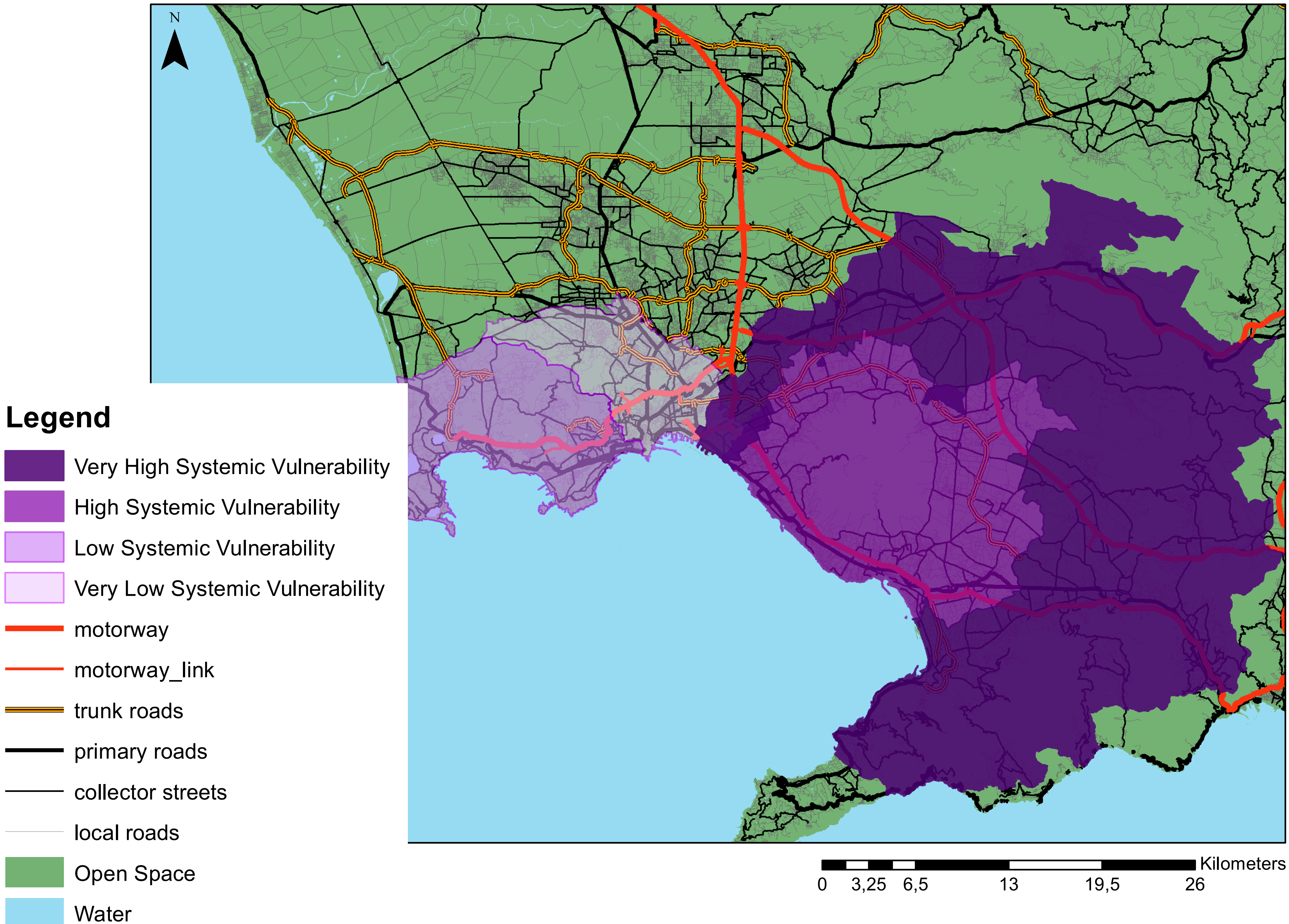
Overlapping of roads and Volcanic Hazard Zones on the Naples expansion areas



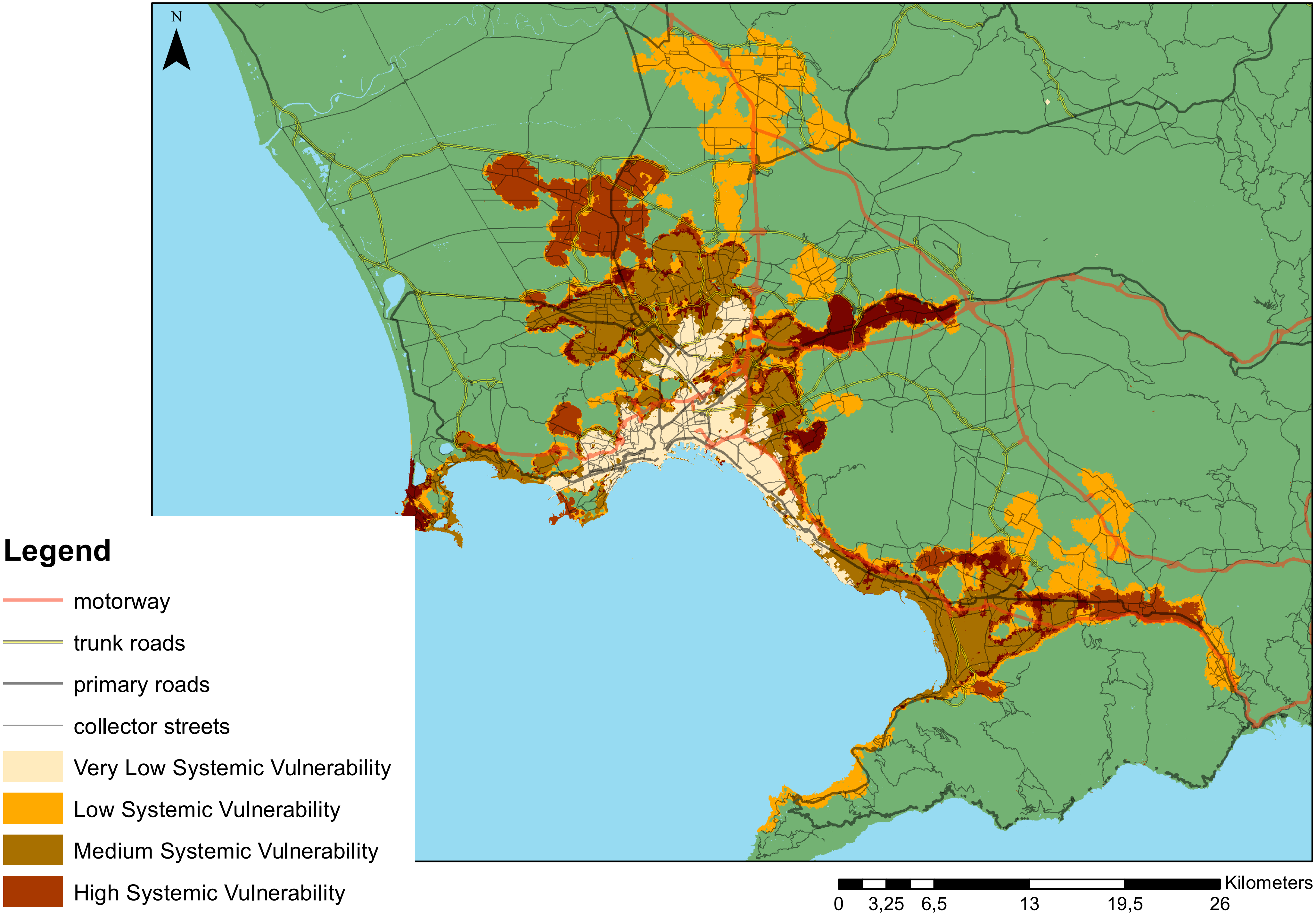
Bridges in the Volcanic Hazard Zones



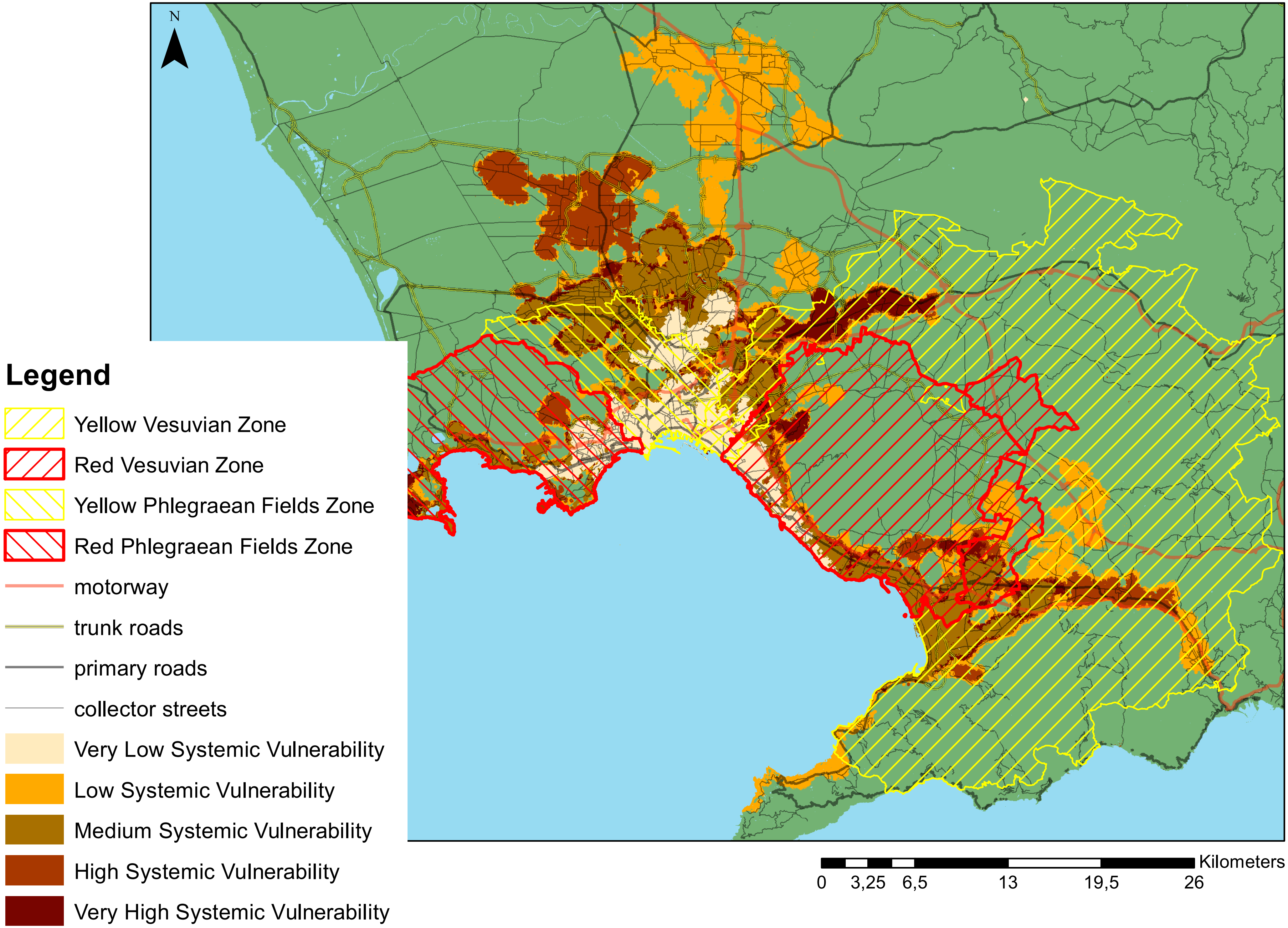
Systemic vulnerability due to the accessibility of the whole Volcanic Hazard Zones



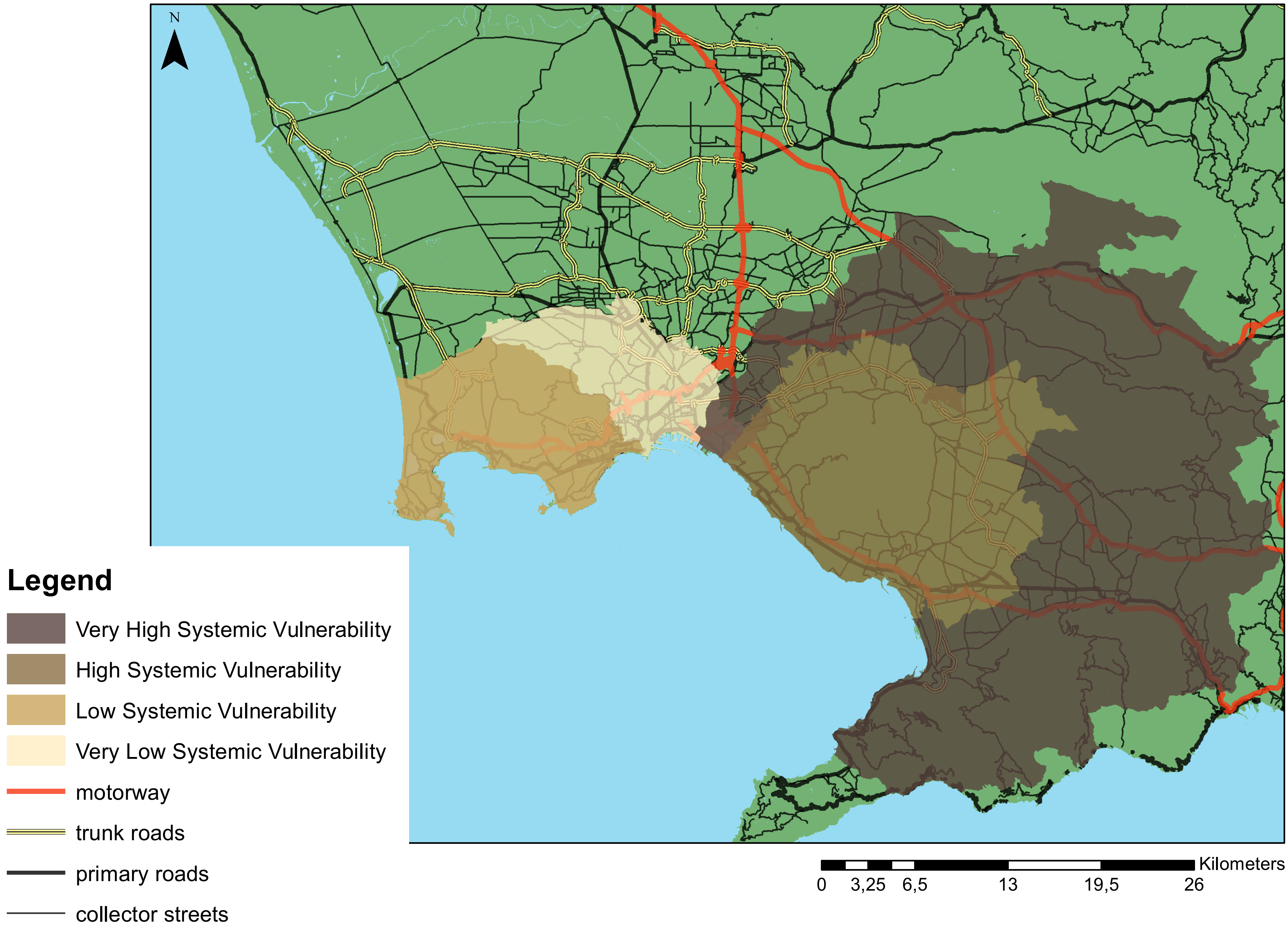
Systemic vulnerability related to the accessibility of Naples Expansion Areas



Overlapping of the Volcanic Hazard Zones on the ranking for Expansion areas
Systemic vulnerability related to the accessibility



Systemic Vulnerability for the Urban Extent included in the Volcanic Hazard Zones



Systemic Vulnerability in the Urban Extent exposed to volcanic risk: a detailed analysis