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WP5:

Application of an integrated vulnerability conceptual approach

Del. 5.3.4:

Development of the Integrated Approach on the Ethiopian, Istanbul and Corvara case studies

Reference code: ENSURE – Del. 5.3.4

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Short Description:

In this deliverable, we present the (partial or full) application of the ENSURE integrated framework developed within WP4 to assess vulnerability and resilience within three case studies which were not initially included in the DoW, namely the Ethiopian (droughts), the Istanbul (earthquakes) and the Corvara (landslides) cases.

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1 Executive Summary

This deliverable presents the application of the ENSURE integrated framework developed within WP4 to assess vulnerability and resilience within three case studies which were not initially included in the DoW of the project, but appeared to be interesting for testing the framework. The proposed case studies cover three different hazards: droughts in Ethiopia, earthquakes in Istanbul (Turkey) and landslides in Corvara (Italy).

In the ENSURE framework, a differentiation is made between physical vulnerability ("vulnerability to stress"), systemic vulnerability ("vulnerability to losses") and resilience ("mitigation capacities") and by recognizing the time and spatial scales of the natural phenomena, the framework is able to deal with the several stages of assessment aiming at mitigation and policy design.

For the particular topic of drought in Ethiopia, the different stages of the framework could not be applied, as collecting data for African developing countries is a difficult task. Here, the solution of collecting data by means of Earth Observation and Geo-Information was chosen, and consequently, only the first part of the framework (physical vulnerability or) could be processed. It was not possible to collect data for the systemic vulnerability assessment, let alone resiliency. As a result, the study was restricted to an empirical investigation on physical vulnerability in Ethiopia.

Regarding the Istanbul case, the macro-scale vulnerability and resilience of Istanbul to earthquakes are evaluated using the ENSURE framework, and systemic vulnerability, as well as vulnerability to Na-techs are discussed. The results show that indirect impacts of a probable earthquake are hard to estimate but are likely to give great impacts on urban area not only on physical structure but socio-economic structure as well. This study is a good example to demonstrate that in metropolitan cities, such as Istanbul, a macro perspective is necessary to evaluate both vulnerability and resilience, as well as systemic vulnerability and vulnerability to Na-techs. In Istanbul, for the last 10 years, most of the projects have been focused on reinforcement of buildings/structures and local/small scale regeneration projects. They are certainly notable improvements to mitigate risks; however, large cities have always complex and inter-related systems which are likely to affect each other in both direct and indirect way.

In the Corvara case study, the first three stages of the ENSURE methodology could be applied and the following conclusions were drawn:

- The 1st matrix of the framework (*"Resilience: Mitigation Capacity"*) is best suited for vulnerability assessment in order to implement hazard and risk plans (here against landslides), providing measures to verify the capability of a municipality to cope with natural hazardous phenomena, trying to prevent their negative effects on the natural and built environments. Good alert and civil protection systems may develop only if those plans exist. The main problems found are essentially the necessity to constantly update those plans and to cope with the deterioration of mitigation works and sometimes also of monitoring systems.
- The 2nd matrix (*"Physical Vulnerability: vulnerability to stress (hazard)"*), if a small area is considered, works properly since quantification of both impact energy and strength of structures and infrastructures can be reasonably done. That is not feasible for a wider area like a municipality and the Corvara case study showed how a more qualitative approach might give "more usable" (and more economically affordable) results.
- Regarding the 3rd matrix (*"Systemic vulnerability: vulnerability to losses"*) within the Corvara case study not much has been done by the Community to assess capacity to recover of structures, infrastructures and systems. Nevertheless, a more qualitative

"degree-of-functionality" assessment was suggested, certainly more applicable at the meso-scale. Moreover, stress is put on the need to have the best picture as possible of past events and damages (also taking advantage of experiences made in other areas) in order to forecast what degree of functionality can be expected also in the future. Qualitative results from the physical vulnerability assessment (matrix 2), have demonstrated to be useable to forecast semi-quantitative losses (direct and indirect) that may affect even the systemic economy, with all its relevant domino effects.

- The 4th matrix of the framework (*"Resilience: response capability in the long run"*) deals partly with something that has not been considered in Corvara (i.e., Civil Protection Plan), but whose goodness depends a lot on the existence of hazard and risk plans, which was identified in matrix 1. While the value of a Civil Protection Plan depends at first sight from the availability of devices and on the preparedness of people (at all levels), it surely depends also on the presence of well-done and updated hazard and risk plans. Therefore matrix 4 leads back to matrix 1 along the timeline axis, showing that "updating of knowledge" is the most important parameter to work on.

2 The Ethiopian case study

2.1 General presentation

In Ethiopia, drought is a frequently recurring phenomenon. It is the single most important climate related natural hazard impacting on the country from time to time. Historical drought events reveal that Ethiopia frequently faces drought and famine. In the past nine centuries there were about 30 major drought episodes. Of these drought episodes 13 of them are known to have covered the entire nation and they were reported as severe. From 1970 onwards, drought hit the country at least once in every ten years but during the last years the event is becoming even more frequent. It is now recurring every two or three years at different levels of intensity (Margaret, 2003). In recent years the spatial extent and frequency of droughts have both increased causing significant water shortages, economic losses and adverse social consequences.

Climatic conditions during drought years are characterized by either almost total failure of rainfall or a late or too early onset of inadequate rainfall during both the short and the main rainy seasons locally known as "Belg" and "Kiremit". A continuous dry spell or poor rainfall in successive years hinders ground-water recharge and imparts stress on ground-water resources leading to severe water deficit in many parts of the region during both the wet and the dry seasons.

The droughts of the last decades have produced a complex impact, which spans many sectors of the economy, especially the agriculture sector. Droughts of the year 1984-1985 took the lives of an estimated one million people, destroyed crops, contributed to the death of animals, and threatened the lives of millions of people with starvation. The drought caused the then biggest famine affecting an estimated 5.8 million people forcing them to be dependent on food hand-outs or food aid (Benson, 1998). As a result, a considerable part of the society proved vulnerable to famine that in turn caused a deep-seated destitution. The recent drought of 2002-2003 with affected 13.5 million people showed once more the magnitude and the proportion of the problem (Wagaw et al., 2005).

The chronology of Ethiopian drought history further indicates that most of the drought and food crisis events have been geographically concentrated in two broad zones of the country. The first consist of the central and northern highlands, stretching from northern Shewa through Wello and Tigray, and the second consists of low-lying agro-pastoral lands ranging from Wello in the north, through Hararghe and Bale to Sidamo and Gamo Gofa in the south (Ramakrishna and Assefa, 2002). They indicated the eastern and northern parts of the country as the most vulnerable.

Major parts of Northern Ethiopia experience year-round water deficit. Drought is frequent due to abnormally low and untimely rainfall. Even commencement of rainfall at the right time cannot guarantee a drought-free season since frequency, intensity; amount and duration of rainfall all play crucial roles in the occurrence of drought. Tigray region is dry for most of the year except during the rainy season, and exhibits a semi-arid climate. Recurrent droughts form the major threat to rural livelihoods and food security in the region. Almost every year, the study region experiences localized drought disasters causing crop failure and jeopardizing development activities. The region's agro-ecosystem is highly sensitive to rainfall fluctuations and even a slight change has a large impact on the socio-economic activities of the region. As a result, rural livelihoods and agricultural systems in the region are subject to continuous and widespread disequilibrium dynamics.

Despite the fact that drought forms the major uncertainty that farming households have to deal with, it has attracted little scientific attention and no attempts have been made to quantify the spatial and temporal characteristics of drought within the study region. Furthermore, recent studies reveal that climate change in Ethiopia could lead to extreme temperatures, extraordinary rainfall events, and more intense and prolonged droughts and floods (UNDP, 2008). Thus, expected changes in spatial and temporal patterns of precipitation can trigger new characteristics of drought in affected regions. Consequently, the need for a drought assessment and monitoring mechanism is crucial to minimize socio-economic losses. This can be achieved by developing drought indices that are capable of characterizing and timely assessing drought at different spatial and temporal scales.

This report attempts to provide a detailed analysis of seasonal drought dynamics in order to identify the spatial and temporal characteristics of drought over the last decade by employing standard drought index methods with meteorological and remote sensing data.

With respect to the Ensure framework we will restrict ourselves to physical vulnerability.

2.2 Drought hazard characterization

A variety of indices using meteorological data have been used to quantify droughts (Heim, 2002). However, the most widely used today is the Standard Precipitation Index (SPI) (McKee et al., 1993, 1995), which is now considered as the most reliable index for measuring the intensity, duration and spatial extent of drought (Guttman, 1998; Lloyd-Hughes and Saunders, 2002). This index enjoys several advantages over the others. Calculation of the SPI is easier than more complex indices such as the Palmer Drought Severity Index (PDSI) (Palmer, 1965), because the SPI requires only precipitation data, whereas the PDSI uses several parameters (Soulé, 1992). Moreover, the PDSI has some shortcomings in spatial and temporal comparability (Alley, 1984; Karl, 1986; Guttman, 1998). However, the SPI provides a comparison of the precipitation over a specified period with the precipitation totals of the same period for all the years available in the historical record. The SPI is comparable in both time and space, and it is not affected by geographical or topographical factors (Lana et al., 2002).

The SPI is a probability index that considers only precipitation. The probabilities are standardized so that an index of zero indicates the mean precipitation amount. The index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. The duration of every drought appearance is determined by negative index values. Accumulated totals of negative values of SPI could also be used as a measure of drought severity. The relative simplicity of the SPI is one strong advantage of the index (Logan et al., 2010). Moreover, it is spatially consistent in its interpretation and the magnitude of the departure from zero is a probabilistic measure of the severity of a wet or dry event that can be used for risk assessment (Guttman, 1999). The SPI can track drought on multiple time-scales, i.e. 1-, 3-, 6-, 9-, 12-, and 48-months, but the index is flexible with respect to the period chosen. The SPI requires different interpretations according to its time scale. Among users there is a general consensus about the fact that the SPI on shorter time scales (say 3 and 6 months) describes drought events affecting agricultural practices, while on the longer ones (12 and 24 months) it is more suitable for water resources management purposes (Raziei et al., 2009). SPI for 3 and 6 months time steps are used in this paper to study the characteristics of drought in short and medium range time scales.

Although it is a quite a recent index, the SPI was already used in Turkey (Komuscu, 1999; Touchan et al., 2005), Argentina (Seiler et al., 2002), Spain (Lana et al., 2002), Korea (Min et al., 2003), China (Wu et al., 2001) Europe (Lloyd-Hughes and Saunders, 2002), Italy (Bordi et al., 2001) and South Africa (Mathieu and Richard, 2003) for real time monitoring or retrospective analysis of droughts. It is also becoming an increasingly important tool for initiating drought response actions at state, regional and local level (Wilhite et al., 2000).

Therefore, SPI is used here to study the spatial and temporal characteristics of meteorological drought in the region of Tigray, which has a history of recurrent droughts.

2.2.1 Vegetation based drought analysis

Drought indicators like the SPI assimilate information on rainfall, but do not express much spatial detail. Furthermore, drought indices calculated at one location are only valid for a single location. Thus, a major drawback of climate based drought indicators is their lack of spatial detail as they are dependent on data collected at weather stations which sometimes are sparsely distributed affecting the reliability of the drought assessment indices (Brown et al., 2002). In contrast remote sensing or satellite imageries have proven to be effective tools that provide spatially continuous information regularly in timely manner with improved detail. The vegetation indices developed using band combination of satellite imagery has been used for monitoring drought over large areas since mid-1990s. A range of vegetation indexes based on remote sensing have been thus used to monitor greenness of vegetation (Bannari et al., 1995).

Satellite-derived drought indices typically use observations in multispectral bands, each of which provides different information about surface conditions. Because droughts are naturally associated with vegetation state and cover, vegetation indices are commonly used for this purpose (Tucker and Choudhury, 1987), utilizing data in the visible red (R), near infrared (NIR), and the shortwave infrared bands. The most commonly used vegetation index is the normalized difference vegetation index (NDVI) (Tucker, 1979) and is given by the equation:

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

where NIR is reflectance in the near-infrared wavelengths and RED is reflectance in the red wavelengths. The temporal variations in the NDVI reflect the vegetation's response to weather variability (Potters and Brooks, 1998). Consequently, this index has been widely used to monitor ecosystem dynamics, crop yield assessment/forecasting and to detect the spatial extent of drought episodes and their impact (Tucker and Choudhury, 1987; Marsh et al., 1992; Di et al., 1994; Kogan, 1995, 1997; Groten and Octare, 2002).

However, many studies report that the spatial and temporal variability of NDVI values is closely related to the contribution of geographical resources to the amount of vegetation. This contribution fluctuates considerably depending mainly on climate, soils, vegetation type and topography of an area (Di et al., 1994; Ichii et al., 2002; Li et al., 2002; Domenikiotis et al., 2004). Thus, in tropical rainforest areas, high NDVI values could result from the lush tropical forest vegetation, whereas, in deserts, low NDVI values are to be expected. Obviously, these differences are not due to the impact of the weather. For this reason the NDVI is not comparable in space, especially in non-homogeneous areas (Vicente-Serrano, 2007).

Furthermore, surface moisture and aerosol signals may limit the accuracy of the observed NDVI in arid or semi-arid regions (Funk and Brown, 2006). Soil formations in the most arid areas may also play an important role in intensifying the effects of drought on vegetation. Land degradation and specific soil erosion may in part also prevent the development of a high amount of vegetation cover (Guerrero et al., 1999). These vegetation indices, NDVI, are also mainly linked to vegetation biophysical factors and problems exist because of external factor effects, such as soil background variations (Huete et al., 1985; Huete, 1989).

Accordingly, Huete (1988) proposed a soil-adjustment factor to account for first-order soil background variations and obtained a soil-adjusted vegetation index (SAVI), which reduced the influence of the soil type below the vegetation. According to Huete (1988), SAVI is much better than NDVI for areas with low vegetation cover and can be used to characterize the arid zone vegetation. However, the SAVI is a method by which spectral indices requires local calibration so that soil substrate variations are effectively normalized and are not influencing the vegetation measure. Furthermore, since it is difficult to predict how soil effects are manifested within large pixel areas, which aggregate soils and vegetation of many different types, each of which requires in principle, separate calibration which makes the method not easy to apply for large areas. We believe, however, that the most appealing approach to apply in our case is to rely on NDVI as is difficult to have access to such calibration values for our study region, which covers 53,000 square kilometres.

Moreover, though natural vegetation has developed a great capacity for physiological adaptation and resistance to long droughts and soil moisture below the theoretical wilting points, precipitation is considered as the primary limiting factor for plant growth in semi-humid and semi-arid areas (Wang et al., 2003; Reynolds et al., 2004). But when NDVI is used for analysis of weather impact on vegetation, the non-weather effect must be separated. Accordingly we applied the VCI for study.

The maximum amount of vegetation is developed in years with optimal weather conditions, because such conditions stimulate efficient use of ecosystem resources. Conversely, minimum vegetation amount develops in years with extremely unfavourable weather, which suppresses vegetation growth directly and through a reduction in the rate of ecosystem resources use (Domenikiotis et al., 2004). Therefore, the absolute maximum and minimum of NDVI, calculated over several years, contains the extreme weather events. The resulting maximum and minimum values can be used as criteria for quantifying the potential of geographical areas (Kogan, 1995, 1997). This is expressed by the VCI that is given by the equation:

$$VCI = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right) * 100 \qquad (2)$$

where NDVI, NDVImin, and NDVImax are the smoothed 10-day NDVI, its absolute multi-year minimum and its multi-year maximum NDVI respectively for each pixel. The VCI, given by Kogan (1995), has been used to estimate the weather impact on vegetation. The method is useful to separate the short-term weather signal in the NDVI data from the long-term ecological signal and in this sense it is a better indicator of water stress condition than NDVI (Kogan and Sullivan, 1993; Maselli et al., 1993; Kogan, 1997). The VCI provides accurate drought information not only for well defined, prolonged, widespread, and intensive droughts, but also for very localized, short-term, and well-defined droughts (Kogan, 1995). The VCI varies from 0 to 100 corresponding to changes in the vegetation condition from extremely unfavourable to optimal condition (Kogan, 1995; Kogan et al., 2003). Based on

Kogan's (1995) VCI classification threshold, VCI values of 35% or less is considered to be as an indicator of drought condition. VCI values around 50% are considered as a fair vegetation condition, while VCI values between 50 and 100% are judged optimal or above normal conditions. The VCI algorithm was developed and tested in several areas of the world with different environmental and economic resources (Kogan, 1990, 1995).

2.2.2 Analysis of the Tigray region

2.2.2.1 Drought evaluation using the SPI

SPI series were computed for 25 weather stations of Tigray region from January 1979 to December 2009 at a temporal scale of 3- and 6-month to study the characteristics of drought at short and medium ranges. These scales are useful for monitoring various drought types (Edwards and McKee, 1997). The 3- and 6 months SPI is used to describe the drought events affecting agricultural practices and characterize seasonal droughts due to rainfall deficit during the main rainy season. The SPI program developed by the National Drought Mitigation Centre, University of Nebraska- Lincoln, was used to generate time series of drought indices (SPI) for each station in our study region and for each month of the year at 3- and 6-month time scales. The 3-month SPI calculated for September uses the precipitation total for July, August and September while the 6-month SPI calculated for September uses the precipitation total for April to September. Since drought is a regional phenomenon, the SPI values of the meteorological stations have been spatially interpolated using inverse-distance moving average interpolation technique in the software package ILWIS to create drought severity maps for the region at multiple time scales of the year. An inverse distance moving average technique was employed as it is better suited for interpolation of rainfall distribution over heterogeneous topographical terrain. SPI classification threshold values proposed by McKee et al., (1995) and explained by Edwards and McKee (1997) were used in order to map the spatial extent of meteorological drought intensities corresponding to the SPI value (Table 1).

Table 1: Drought classification by standardized precipitation index (SPI) value

1.	*SPI values*	2.	*Drought category*
3.	-2.00 and less	4.	Extreme drought
5.	-1.50 to -1.99	6.	Severe drought
7.	-1.00 to -1.49	8.	Moderate drought
9.	0 to -0.99	10.	Near normal or mild drought
11.	Above 0	12.	No drought

2.2.2.2 Drought evaluation using the VCI

A ten-day composite NDVI for each month of the indicated period was produced for the study region. The decadal composite NDVI data set was then divided into groups for analysis i.e. the main rain season or monsoon months (June, July, August and September) and the dry season (March, April and May). The monsoon months was only used for the analysis as this study was focused on drought due to water stress during the rainy season. All negative values have been reclassified to 0 in all data set so that scaled NDVI data contain only positive values, which are required for further analysis.

After the production of average monsoon NDVI (June – September), absolute NDVI minimum and maximum maps for each monsoon season were generated for the period 1998-2009. After the production of these images VCI composite images were produced for each year monsoon season using equation 8. Accordingly 396 decadal images were processed in order to produce the multi-temporal drought maps and determine the relationships between average monthly precipitation and vegetation indices at a station level. Kogan's (1995) VCI classification threshold values were then applied in order to prepare the annual vegetative drought maps. Pearson correlation analysis was performed to correlate VCI values with precipitation data. In order to investigate the time lag between the occurrence of the precipitation and VCI response, correlation between VCI data and various precipitation schemes including the current month and the current month plus last two preceding months were examined.

2.3 Socio-economic settings of the case study

2.3.1 Study area

Tigray is one of the national regional states of Ethiopia located in the North Eastern part of the country, covering a total area of 53,000 square kilometers. Geographically, it lies between latitudes 12015'N and 14057'N and longitudes 36027'E and 39059'E. The state is structured into 6 administrative zones and 34 districts. Intervening mountain ranges rise locally to 3000 m above sea level. These high elevations result in a more temperate climate than would normally be associated with the latitude (Virgo and Munro, 1978).

Climatically, the region belongs to the sub-tropical region where monsoon weather prevails throughout the year. Three distinct seasons can be recognized from a climatic point of view: the dry winter season from October to February; the pre-monsoon hot season from March to May; and the rainy monsoon season which lasts from June to September (locally called kiremt), during which 80 percent of the crops are cultivated. Rainfall is distributed very unevenly in the study region. The data from the Ethiopian National Meteorological Services Agency (ENMSA) reveals that the climate of the study region is characterized by large spatial variations which range from about 1000-1300 mm over some pockets areas in the Southwest to about less than 260 mm over the Northeast lowlands (Figure 1). The mean annual rainfall of the region is estimated to be 560 mm while the mean annual monsoon rainfall is 473 mm, 84% of the annual rainfall. The coefficient of variation (CV) of annual rainfall is found to be 38 percent, which is high compared to the national figure of 8 percent.

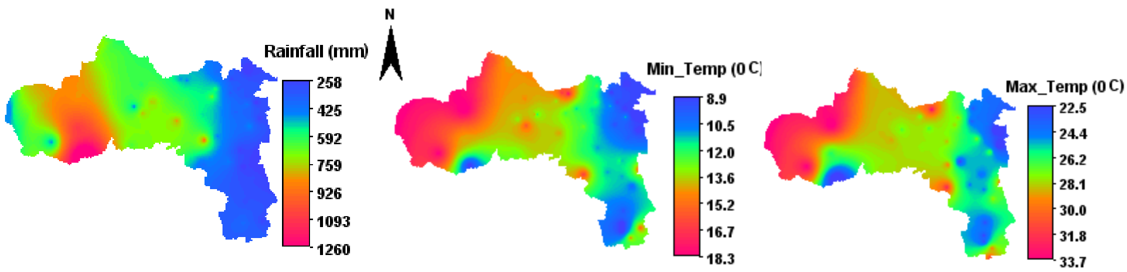


Figure 1: Climate distribution of monsoon rainfall, annual minimum and maximum temperatures in the Tigray region for the year 2008.

The southern and eastern zones of the region receive much lower rainfall than other parts of the region (Figure 1). The distribution of monsoon rainfall over the region is characterized by large spatial variation. The inter-annual variability of the monthly average minimum and maximum temperature based on the data from Ethiopian National Meteorological Services (ENMSA) for the period of 1979-2009 shows that the minimum temperature is highest in May - June and reaches its lowest value in December - January, while the maximum temperature over the region is highest in May and reaches its lowest in August (Figure 2). Mean temperature distribution over the region varies from about 13.4 0C over the highlands of the Southwest and East to about 28 0C over Western lowlands in 2008.

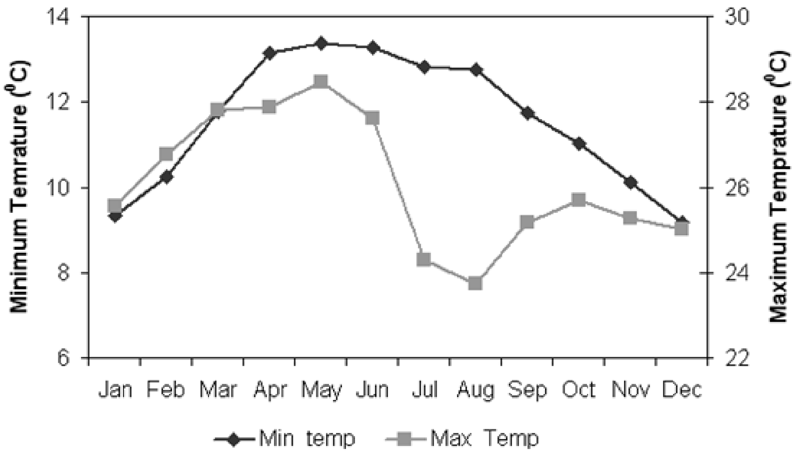


Figure 2: Inter-annual variability of the average monthly minimum and maximum temperatures in Tigray for the period 1979-2009.

2.3.2 Data used for analysis

Historical records of monthly precipitation data for the time period 1954- 2009 were acquired from the Ethiopian National Meteorological Services Agency for a total of 46 meteorological stations within Tigray (Figure 3). However, the period of records for these stations varies and some have missing records. Thus, the period of study has been chosen as long as possible depending on the availability of recorded data for 25 stations in the region, being 1979-2009.

Besides the above mentioned data, geo-referenced SPOT vegetation 10-day composite Normalized Difference Vegetation (NDVI) images (S10 product) were acquired from vgt4africa of the DevCoCast project website (http://www.vgt4africa.org), for the period of April 1998-December 2009. In this report, drought is studied using 11 years SPOT NDVI data at 1kmx1km resolution data, which covers the African continent. The NDVI product acquired is a 10-day synthesis. The satellite data on SPOT vegetation are applied for several procedures in order to ensure the quality of the NDVI product. The product can be used for crop and agricultural monitoring; early warning of failing growing seasons; and as an indicator and alert function for drought events. The multi-temporal NDVI data was selected due to its provision of opportunities to recognize vegetation changes at a longer time span.

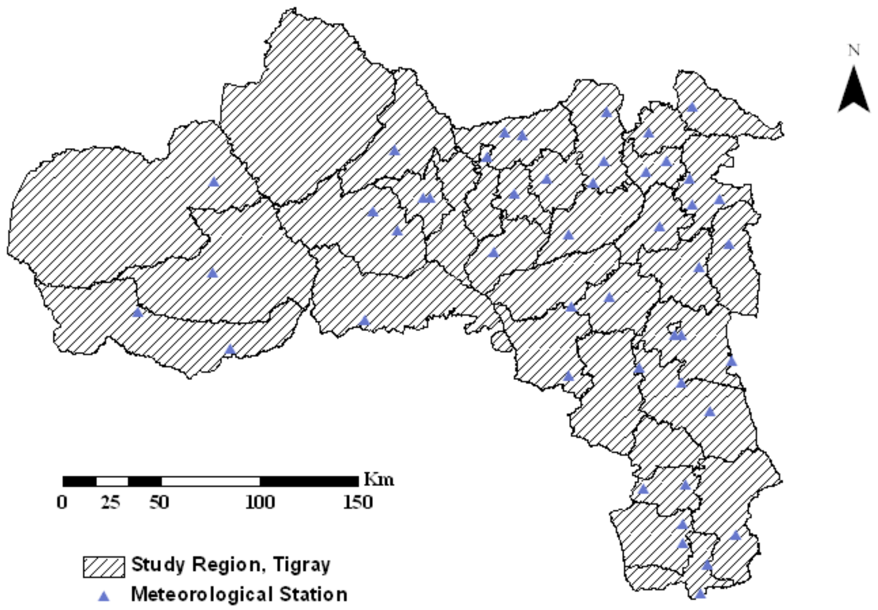


Figure 3: Location of rain-gauge stations in Tigray.

2.4 Application of the Ensure framework for Physical Vulnerability

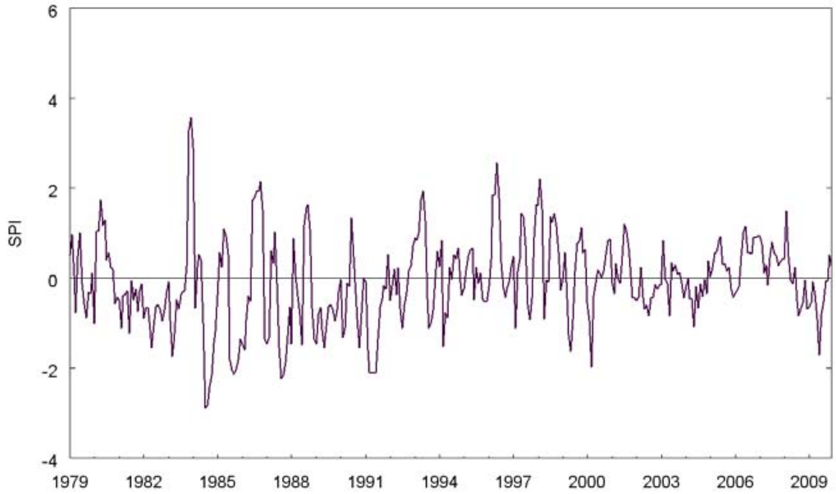
2.4.1 SPI based drought identification

2.4.1.1 Temporal drought pattern

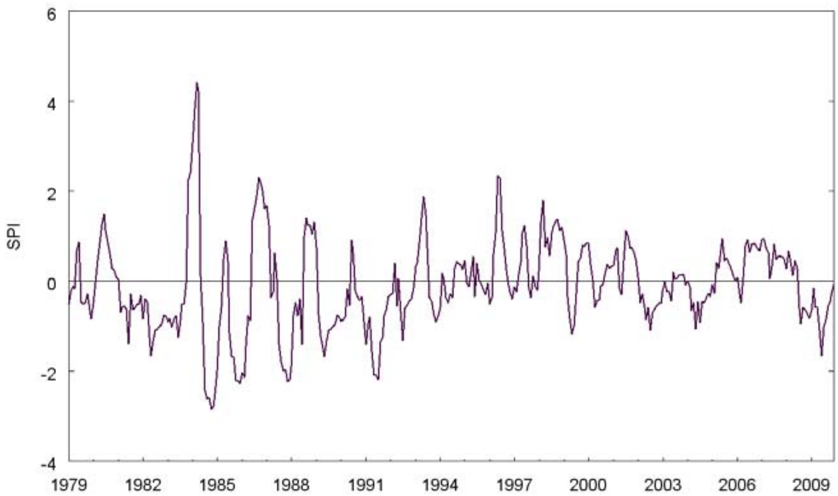
Meteorological drought indicates the deficiency of rainfall compared to normal rainfall in a given region. The temporal and spatial characteristics of drought in Tigray region was identified from SPI time series of multiple-time steps. In our study, SPI for 3- and 6-month time steps are computed to examine the characteristics of drought in short and medium time periods. The 3-month SPI provides a seasonal estimation of precipitation and the 6-month SPI indicates medium term trends in precipitation patterns (Lia et al., 2004). The 3-month SPI is thus used to describe the monsoon drought for the crop growing season, while the 6-month SPI is used to characterize seasonal droughts that occur due to rainfall deficit in monsoon months.

Appearance of drought is happening every time when SPI is negative and its intensity comes to -1.0 or lower. Drought stops when SPI is positive. The duration of every drought appearance is determined by negative index values. Accumulated totals of negative values of SPI could also be used as a measure of drought severity. The regional SPI time series for all the stations selected were calculated at 3 and 6-month time steps. A representative example of the evolution of the SPI for Mekelle station between 1979 and 2009 with a time scale of 3 and 6 months is shown in Figure 4. According to the criteria of McKee et al. (1995), severe and extreme droughts correspond to the categories of $-1.99 < SPI \leq -1.5$ and $SPI \leq -2.0$ respectively. Consequently, several drought episodes were detected from the temporal evolution of the SPI, the most severe or extreme droughts occurred in 1984, 1985, 1986, 1987 and 1991 (Figure 4).

The analysis shows that four extreme drought events occurred around the Mekelle station in the case of SPI-3 whereas in the case of SPI-6, five extreme drought events were evident during the recorded period. All these episodes were prolonged in time with critical and extreme situations. Two extreme drought events (1984 and 1985) lasted for 3-6 months with critical and extreme situation. Especially, the annual precipitation of the year 1984 is the smallest for the 30 years of analysis. The drought occurring in 1984 is the most severe drought ever experienced in Tigray region in general. The annual minimum 3-month SPI for this drought event occurred in July 1984 (SPI = −2.89), whereas the annual minimum 6-month SPI observed in October 1984 (SPI = −2.84). Successive moderate drought episodes were also recorded during the period 1992 to 2009 at the two short and medium term time scales.



(a)



(b)

Figure 4: Values of SPI for Mekelle station 3-month (a) & 6-month(b) time steps.

Severe drought events occurred in 1982, 1983, 1985, 1987, 1988, 1989, 1991, 1999, 2000 and 2009. Severe droughts are much more prolonged drought events than the drought event of 1984. The period 1985-1989 except for the year 1986 was characterized by rainfall shortages during the rainy season. The minimum 3-month SPI was observed in October 1987 (SPI = −1.88) and a minimum 6-month SPI was observed in September 1987 (SPI = −1.99). This prolonged drought event caused exploding water demands and subsequent impacts in Mekelle area and Tigray region in general. The annual minimum SPI values for the 3-month and 6-month time scale most frequently occur during July and October. The temporal analyses of 3-month and 6-month SPI values show that Tigray region was predominantly characterized by frequent moderate droughts.

2.4.1.2 Spatial characteristics of drought

Although the estimation of drought severity at a certain point gives useful information for water management, it is important to assess the drought over a specified region. The regional drought analysis is useful for determining the spatial distribution and characteristics of drought, and evaluating the most affected areas for a specific drought event. In this study, the spatial analysis was performed using the SPI values estimated for 3- and 6-month time scales. Using the developed SPI database and the abilities of ILWIS software package, one can visualize the distribution of SPI values across the area of interest for the various time scales. As an example, Figure 5 and Figure 6 show the variation of SPI across Tigray for the period 2000-2009 for time scales of 3- and 6-month respectively.

The spatial analysis of moderate drought occurrences indicates that they tend to occur in the eastern and south zones of Tigray at a 3-month time step, while the northwest and western parts are characterized with the lowest frequencies at the same time step (Figure 5). In other words, the majority of the historical droughts that occurred in the eastern and southern zones of the study region were of moderate severity in short-time steps. At a 3-month time step, moderate droughts occurred more frequently and covered nearly two-thirds of the study region during the worst drought of 2002. As the time step increases to 6-month, severity of drought increased in some pocket areas.

Severe to extreme drought occurred during 2000-2009 in discrete pockets in two seasons. During 2002, 2004, and 2009 monsoon, most parts of the region suffered drought conditions. In the years 2000, 2001, 2003, 2006 and 2007 years, the monsoon period was mostly drought-free. Severe drought was observed in the year 2002, when the eastern and southern zones of the regions were affected by severe to extreme drought. During 2002, the monsoon was poor and as a result the whole region suffered drought conditions. During 1999–2009, just within a span of 10 years, monsoon-drought appeared throughout the Tigray region five times.

In 2002, 62% of the study area was affected by drought, among which, 3% was affected by severe droughts and 24% was by moderate monsoon drought. In 2004, 2005, 2008 and 2009, the whole study area was affected by drought. About 67% of the area in 2004 and 63% of the area in 2009 was affected by mild drought.

The spatial extent of the 6-month SPI shows that in 2002, almost 64% of the study area was affected by drought, with almost 29% of the area affected by moderate drought for the 6-month time scale (Figure 6). In 2004, about 65% of the area was affected by drought, with almost half of the region affected by mild drought. The spatial extent of both 3- and 6-month SPI's show that in most of the drought years the eastern and southern zones had an SPI less than -1.0. Drought is persistent for more than four seasons particularly in the southern and eastern zones of the region over the last five years. The spatial distributions of drought for a 3-month and 6-month time step are shown in Figure 5 and Figure 6 respectively.

The SPI maps indicate that meteorological drought in the study region appears continuously in the monsoon seasons. The analysis of drought at the 3-month and 6-month time-steps further indicates that southern and eastern zones of Tigray are most vulnerable to droughts. Besides, certain pockets particularly in the northwest zone of the region have also suffered from water stress. From the two time scales it can also be concluded that droughts in Tigray are of a more seasonal than a long-lasting character. Based on the SPI, the southern and eastern zones of the region can be delineated as a drought prone zone.

However, Tigray is one of the Ethiopian regions where meteorological stations are generally inadequate and the networks are not well-developed. Weather stations are sparsely located from each other and hence the spatial resolution of rainfall data derived from these weather station data has been approximately 100-150 square kilometre. Besides, continuous rainfall records are scarce or difficult to obtain in a timely fashion for all weather stations as infrastructural networks are very low. Consequently, SPI assimilated information on rainfall does not express much spatial detail and could have drawbacks in identifying localized drought at a regional level, which in turn hinders the possible prediction, monitoring and mitigation effects of drought disaster.

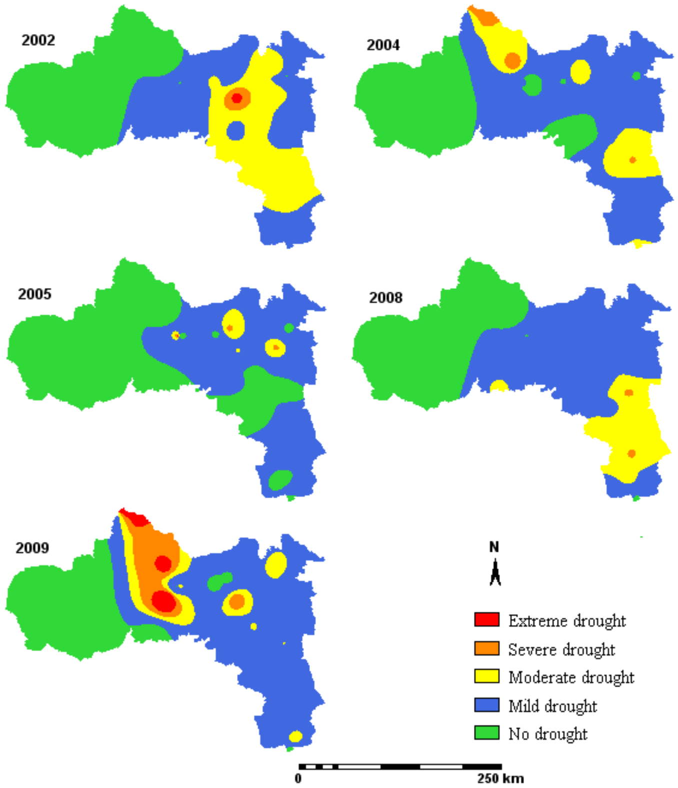


Figure 5: Spatial distribution of 3-month SPI computed for the month of September for five drought years.

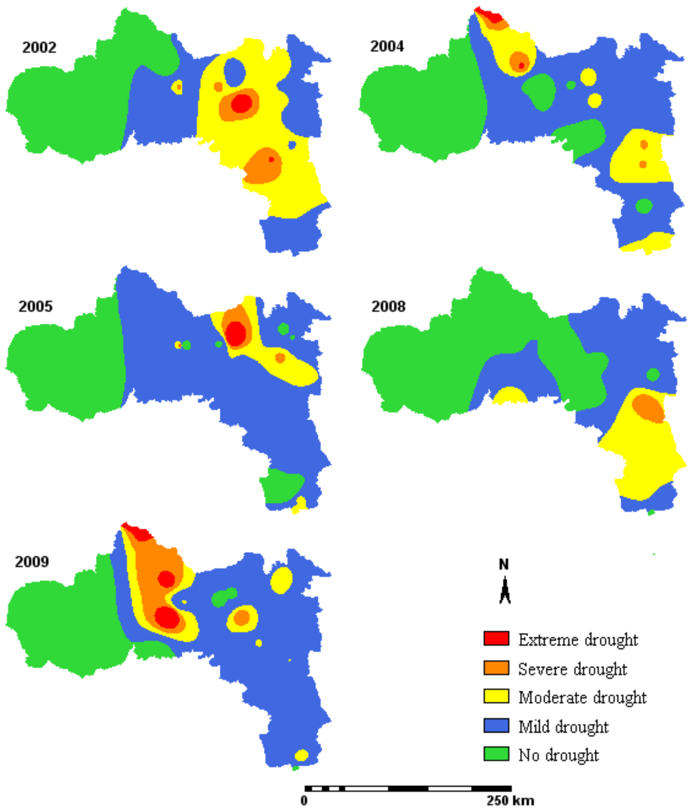


Figure 6: Spatial distribution of 6-month SPI computed for the month of September for five drought years.

2.4.2 Vegetation based drought identification

2.4.2.1 Mean vegetation and rainfall patterns

The average rainfall for the monsoon season gives an overview of the general distribution of rainfall as the main crops are cultivated during June – September in the whole part of the region. Figure 7 provides a visual comparison of average monsoon rainfall and NDVI for the period 1998-2009. During the monsoon season, the southern and eastern zones of the study region receive low rainfall as compared to the other zones of the region. The figure shows an increasing rainfall pattern from southern zone to western region. The spatial pattern of NDVI for the growing season of the period 1998-2009 corresponds well with the monsoon rainfall pattern with the most pronounced vegetation signal for the northwest and western zones of the Tigray region. The above normal greening of this region obviously is associated with high rainfall during the months of June – September in the area. We performed a correlation analysis on average monsoon rainfall and NDVI/VCI for the period. The average monsoon precipitation and NDVI/VCI pattern for the whole study region for the period 1998-2009, reveal that there is a positive correlation between monsoon NDVI/VCI and rainfall. The high similarity in spatial pattern of both NDVI and rainfall illustrates the impact of rainfall on vegetation condition.

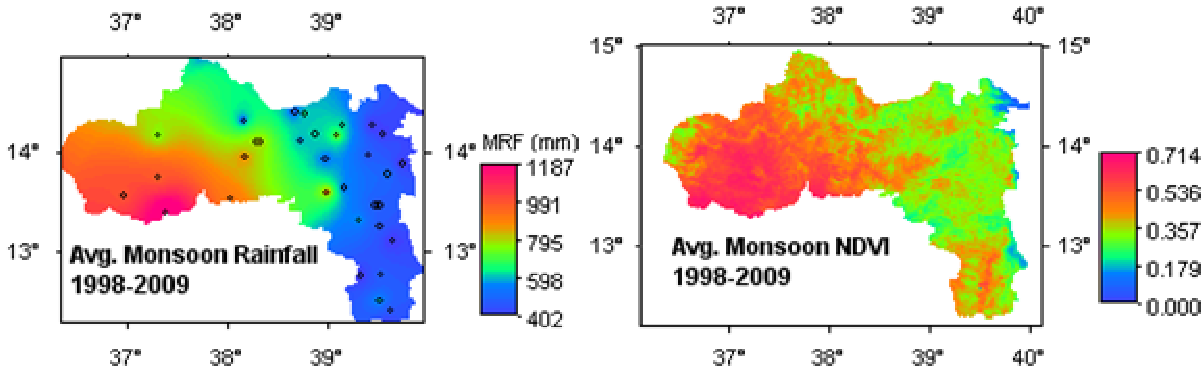


Figure 7: Multi-year average monsoon rainfall (MRF) and the multi-year average monsoon NDVI for the period 1998-2009.

2.4.2.2 Spatial extent of Vegetative drought

The annual cycle of vegetation in Tigray region is basically unimodal similar to the rainfall regime. As discussed before, a monsoon drought was analysed using time series VCI. Based on Kogan's VCI threshold of 35% or less as extreme drought condition, VCI time series data was used to determine the drought. At a VCI of around 50%, fair or normal vegetation conditions exist. When VCI values are close to 100%, the brightness vegetation for the monsoon/September is equal to the long-term Maximum for the pixel. Low VCI values indicate drought period in that year. A consistently low VCI value over several consecutive time intervals indicates drought development. Accordingly, VCI indicates that the study area was affected by drought condition in the monsoon year 2002, 2004, 2005, 2008 and 2009 (Figure 8). During the monsoon of 2002, the vegetation experienced stress and loss of vegetation health. The region experienced an exceptionally continuous drought spell from the monsoon of 2002 until 2009 particularly in the southern and eastern zones of the region due to poor rainfall in the last consecutive monsoon seasons (Figure 8). The worst situation was encountered during the year 2004, 2008 and 2009 monsoon when 20.1%, 18.1% and 17.4% of the region suffered drought condition respectively; having VCI values less than 35%. In the years 1999-2001, most of the study area except for some pocket areas had VCI values higher than 35 and thus there were normal conditions. Agricultural practices, in particular in times of sowing and harvesting have significant bearing in shaping the NDVI patterns. Agriculture was severely affected during the year 2004, since crops could not be sown due to failure of rainfall commencement particularly in the southern part of the region.

Furthermore, a high intensity of drought condition occurred in 2004, 2005 and 2008 due to failure of rainfall during the last crop growing period, mostly around September as is illustrated in Figure 9, which indicates the VCI of September 2000-2009 and where the severity of drought in 2004, 2005 and 2008 appeared relatively higher.

Our result of vegetative drought analysis illustrates that the spatial and temporal analysis of drought using vegetation condition index were found useful in characterizing spatial patterns and temporal aspects, and in evaluating drought proneness across the spatial units. Multi-temporal VCI maps are useful in assessing the severity of droughts at spatial details, implying the utility of the Vegetation condition index in semi-arid and arid regions.

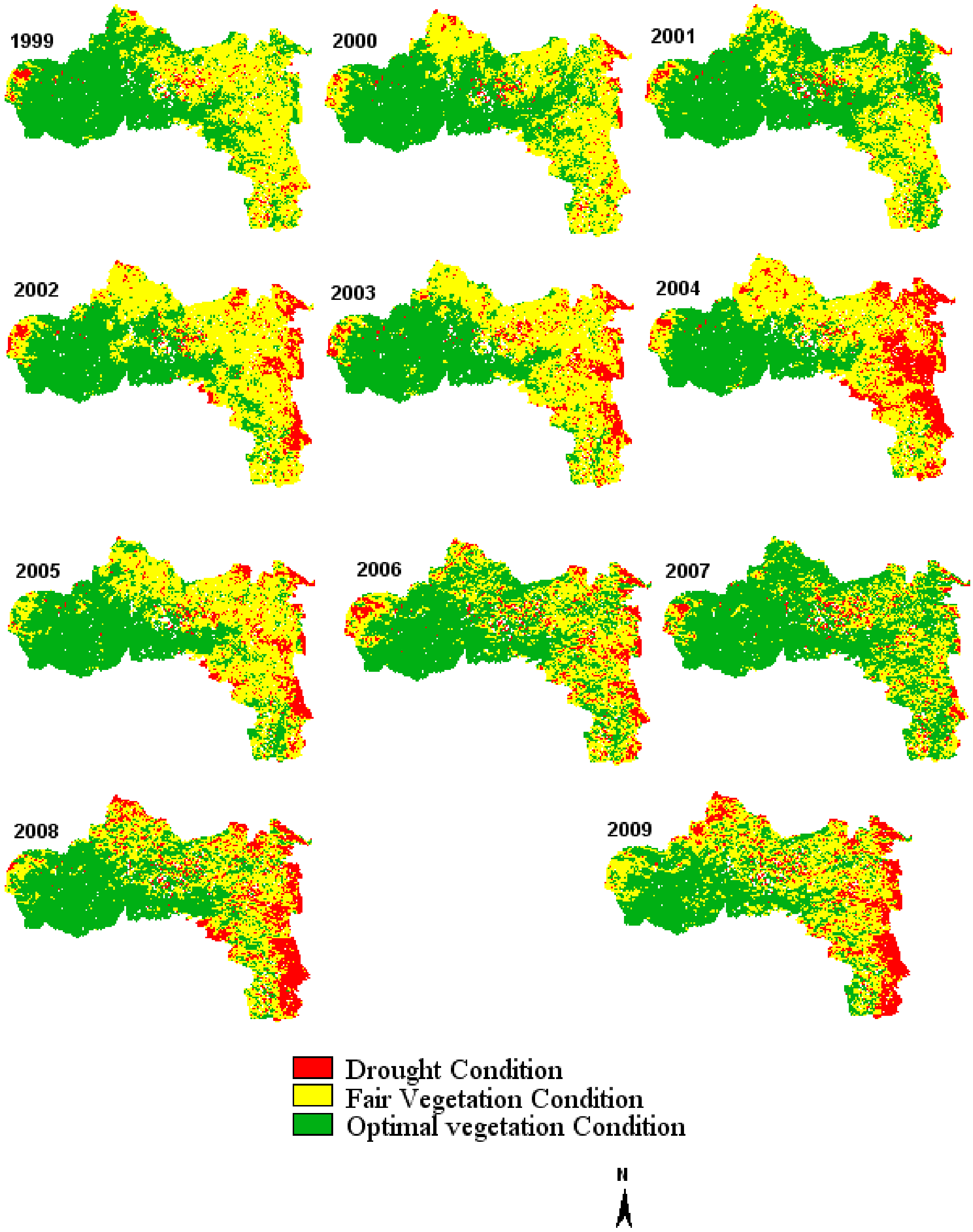


Figure 8: Drought frequent region using VCI for monsoon season, 1999-2009.

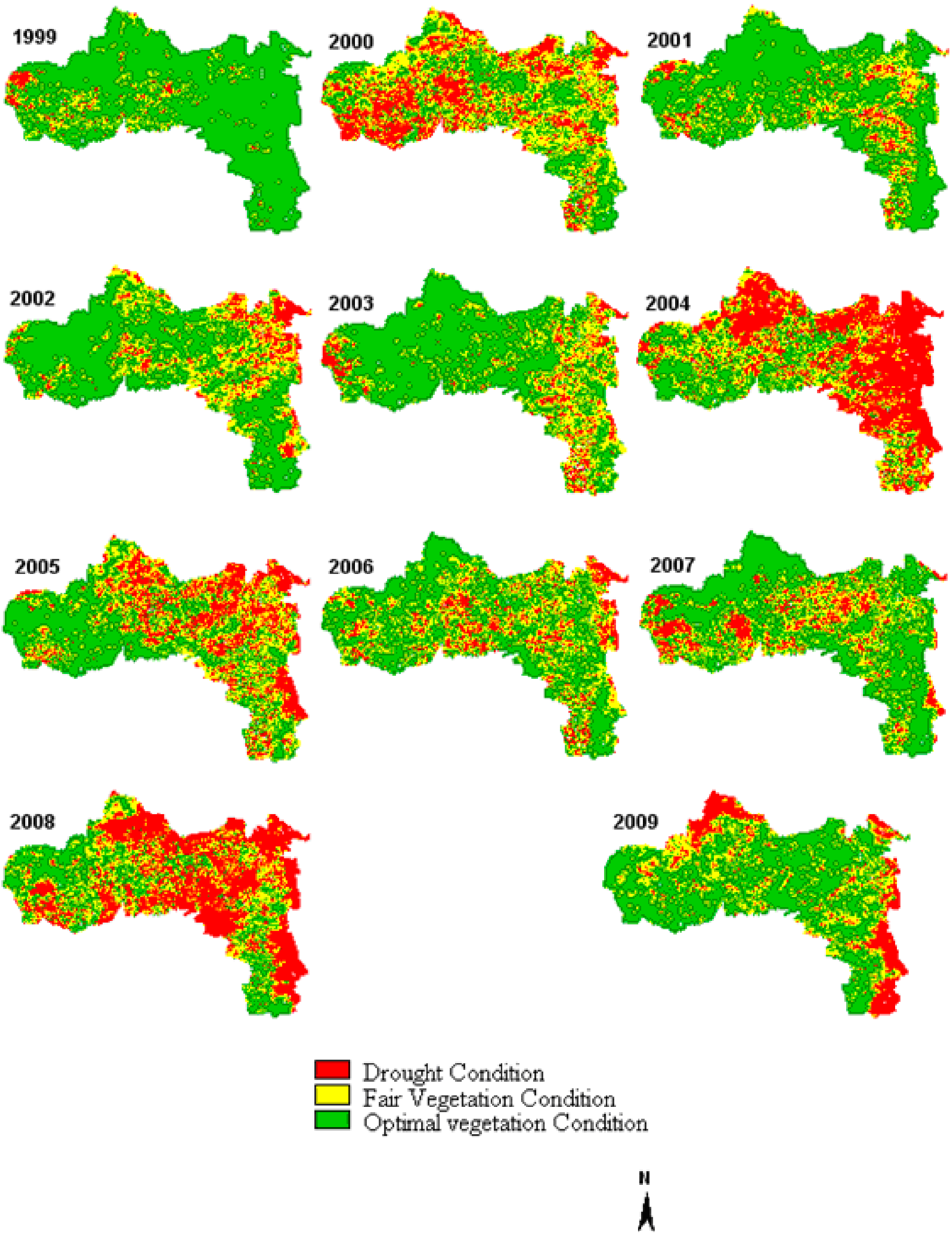


Figure 9: Drought frequent region using VCI for the month of September, 1999-2009.

2.5 Concluding Remarks for the Ethiopian case study

In the ENSURE framework, a differentiation is made between physical vulnerability, systemic vulnerability and resilience. In moving from vulnerability to stress, via vulnerability to losses, towards resiliency, the framework presents a logical structure to investigate the issue at hand. The methodological improvement that is proposed in the framework certainly is a step forward compared to standard literature on resiliency. By splitting up into several stages and by recognizing the time and spatial scales of the phenomena, empirical research is directed towards several stages of policy design that has to deal with hazards.

For the particular topic of drought, in our case drought in Ethiopia, the three stages of the framework can be applied; however, we faced enormous problems in collecting data for African developing countries. That is the reason why we moved to collecting data by means of Earth Observation and Geo-Information. We processed 396 decadal images in order to produce the multi-temporal VCI drought maps. The results of the SPI and VCI analysis revealed that the Eastern and Southern zones of the study region suffered a recurrent cycle of drought over the last decade. Results further show that there is a time lag between the period of the peak VCI and precipitation values obtained from the meteorological stations across the study area. Consequently, we were able to process the first part of the ENSURE framework (vulnerability to stress).

We encountered however huge problems in collecting data for the two other stages of the ENSURE framework. The sheer extent of drought in the Eastern part of Africa, and the enormous consequences at this particular moment in time, made it impossible to collect data for the phase of vulnerability to losses, let alone resiliency. As a result we restricted ourselves to an empirical investigation on vulnerability to stress in Ethiopia. In a possible follow-up project, additional data will highlight the strengths of the whole ENSURE framework.

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3 The Istanbul case study

3.1 General presentation

During its long history, Istanbul had faced several natural hazards which turned to great disasters that the city had to be rebuilt many times. In one hand, the need of reconstruction of the entire city due to massive collapses might be evaluated as because of its vulnerability, on the other hand the capability of Istanbul to recover and to reach to its former power in the territory might be evaluated as its resilience.

According to the historical records, Istanbul had received great damages because of earthquakes, fires and floods respectively. The most devastating earthquakes occurred in 1509, 1766 and 1894 and they caused massive destructions in masonry buildings. In the reconstruction processes after each big earthquake, the Sultans of the period encouraged wooden constructions to prevent future losses due to earthquakes. However, Istanbul was facing with another threat called urban fires. As in that period many of domestic functions such as heating, cooking and lighting were provided with fire, even a small ignition could expand very quickly due to wooden structures. Consequently, in more than hundreds big urban fires, thousands of buildings were totally burned. Regarding to floods, on the high precipitation seasons they had caused inundations in several parts of the old Istanbul. Floods have been common hazards in this territory because of the undulated topography of the city where there are many rivers and large water basins. In these events, the city received damages not only because of flood but also the debris carried by water.

Besides earthquakes and floods that Istanbul is facing with, the changing urban pattern of the city provokes additional risks. Firstly, as exposure, Istanbul has reached to a population of more than 12 million. Moreover, Istanbul undertakes several leading roles in cultural, financial, commercial, tourism and service functions. Istanbul's contribution to tax revenues reaches 44,7%, its contribution to the budget is 37,2% and its share in GDP exceeds 20%. On the other hand, the problem of un-planned housing development laying back to 1950s makes physical structure of Istanbul vulnerable. There are two critical facets of this development where the first one is that this un-planned development mostly settled on sensitive natural areas causing natural degradation and the second one is that site conditions and low building quality of structures are likely increasing damageability of buildings. Furthermore, concerns on location and maintenance level of hazardous industrial facilities are increasing especially after many na-tech events occurred in last decades.

Considering the window of opportunity, Kocaeli Earthquake in 1999 has been the milestone in the disaster history of Turkey. Many lessons were learnt not only by governments but also by people. Local and central governments accomplished several researches and projects to find out the way to decrease the vulnerability of the city. However, considering that Istanbul has gained its current structure mostly in the last 60 years, 10 years since 1999 earthquakes is not enough for Istanbul to fix all of its deficits.

The following section aims to provide an overall macroscopic evaluation of Istanbul not only by the means of scale but by the time sequence which enables to better comprehend the big picture underlying deficits and strengths of the city against earthquakes and its induced hazards. First, resilience and mitigation capacities of Istanbul will be discussed according to time sequence. The first period is dedicated to mitigation process until the Kocaeli Earthquake in 1999 and the following period is set on the last decade where mitigation activities have gained a great acceleration to make Istanbul and the other earthquake prone cities to be ready for large scale hazards. The second chapter focuses on the physical vulnerability and damageability of the city. Hereby the main focus has been done not only for the overall structural vulnerability but also likelihood of Na-techs. Finally, systemic vulnerability of the city will be discussed.

3.2 Application of the Ensure framework

3.2.1 Resilience: Mitigation Capacities

Mitigation capacities against earthquake can be considered as organizational adjustments to achieve an efficient system to cope with the threat, as well as robustness of built environment which are expected to improve resilience of a given area. Hereby, mitigation capacities focuses on long term historical process from micro to macro scales which would reflect on settlement patterns and which would point out root causes of vulnerability and resilience.

Looking back to the historical development of building codes and disaster mitigation regulations in Turkey, we can observe that each catastrophic event had created a shift in improvement of legal system. For instance, after the earthquake occurred in 1509, Sultan Beyazid II had enforced the new development of civil architectural buildings (mostly residential units) with wooden structure that might be able to resist seismic tremors (Genc and Mazak, 2000). Tracing back to the early period of the Turkish Republic, new adjustments had been set, however, the lack of implementation tools and the lack of qualified technical personnel who would control the practice of building codes in the field (especially in newly metropolitan areas) led the governmental attempts for healthy development un-sufficient. Within the 1950s, the mass migration flow from the rural parts of the country through relatively developed cities had arisen the need of land production for residential purposes. New comers of the city had tended to solve their sheltering problem by their own with building their own houses on the "empty" areas which were public properties indeed. On the other hand, governmental bodies had overlooked this un-planned development because of some political and sociological reasons. Furthermore, in a certain while, these vulnerable shelters and zones gained legal status with amnestation laws.

In 1999, when a big earthquake with the magnitude 7,4 hit Kocaeli area, the damage that Istanbul received created a big concern among people and as well as government. Because, due to media, this was the first time that academicians became visible and they had the opportunity to share their knowledge with public. They were saying that 1999 earthquakes occurred in both Kocaeli and Duzce had been expected and no precaution had been taken neither by central nor local governments. In this earthquake, in Istanbul, Avcilar (in south-west) and Tuzla (in south-east) were the most affected districts with collapsed buildings. In Istanbul 1-2% of the buildings were damaged, 454 people were killed and 3600 people were injured (Erdik et al., 2000). Following to the earthquakes, in 2000, firstly new disaster organizations were settled at both local and central governmental level and then TCIP (Insurance against Natural Hazards) was founded. In 2002, two comprehensive studies have been released: one was by Istanbul Greater Municipality and Japan International Cooperation Agency, and the other one was Bogazici University. The both studies include earthquake scenarios, vulnerability level of Istanbul and risky areas. In 2003, Istanbul Greater Municipality, within the contribution of academic staff of 4 pioneering universities of Turkey (Istanbul Technical University, Bogazici University, Middle East Technical University and Yildiz Technical University) developed "Earthquake Master Plan" for Istanbul. Following negotiations between the Earthquakes and Megacities Initiative and Istanbul Metropolitan Municipality in 2004, the Municipality decided to have the Earthquake Master Plan for Istanbul (IEMP) evaluated by an International Team of Experts. The experts emphasized the importance of IEMP for the reduction of risk in Istanbul and considered the Zeytinburnu Pilot Project as the laboratory of this plan. The Zeytinburnu Pilot Project Framework is in response to the IMM and JICA report and the IEMP. The project is the first phase of the implementation of the IEMP. In 2005, the agreement of ISMEP Project was signed between

Republic of Turkey and International Bank of Construction and Development. Istanbul Project Coordination Unit (IPCU) has been established within Istanbul Governorship, Special Provincial Administration to implement the Project. The recent accomplishments of the ISMEP Project can be cited as reinforcement of more than 200 schools, 7 health centers and 3 dormitories; establishment of Disaster Management Center under the coordination of the Istanbul Governorship and disaster awareness campaigns and training activities for decision makers, technical staff and community representatives. In 2005, Istanbul Metropolitan Planning and Design Office was established to prepare a comprehensive development plan for Istanbul targeting the year 2023. Within the objectives, the Master Plan of Istanbul aims to improve the city with economic structure based on science and technology, to increase touristic activities in both historical and environmental values and to make Istanbul a competitive world city. Regarding natural threats that Istanbul faces to, the main notices are on enforcement of building codes and microzonation plans which will be basic input on smaller scaled plans. Hazardous industrial facilities, on the other hand, are planned to be decentralized from the inner city. Furthermore, urban regeneration projects which are being developed parallel to the Master Plan are very important tools to mitigate urban risks in un-planned areas of the city.

Once considering vulnerability, it is worthy to note that vulnerability is a product of a long term process which means cities cannot become vulnerable over night and consequently it is better to figure out resilience as a long term target to achieve. For instance, in Turkey, building amnesty laws in the last period of the 20th century has targeted un-planned developed zones in major cities (i.e. Istanbul). In this period, both central and local governments were unable to fulfill residential need of large number of immigrants from the rural parts of the country to big cities. Therefore, at the fringe of settlements, a new type of development gave a start without respecting to any regulation, without taking building codes into account, without receiving engineering support and expanded mostly near to natural resources and on hazardous areas. Un-planned areas within illegal houses are mostly situated on risky zones such as water basins, alluvial soil and filled land. These areas were used to be remained empty before this development. Because of their location near to city center, they had been favorable for new comers who suffered to find shelter in the city (Figure 10). Earthquakes occurred in 1999 in Kocaeli and Duzce have been evidences on the vulnerability of settlements which had been grown in un-controlled way. Consequently, especially in Istanbul, urban regeneration projects have been initiated in order to make city more resilient.

The rapid urban expansion of the city has caused a great pressure on natural sources as well. The city of Istanbul shows linear development on the directions East-West. The northern part of the city is covered by forest areas (47.7% of the total area). The main underground water reservoirs are wider in the European part. Sensitive and critical areas hereby, are crucial natural zones which can be either easily affected from disruption and/or under the threat of urban development. Once natural features of the city overlays with the built up area, we can easily notice that some parts of underground water reservoirs are covered by urban land. These areas are at the same time most problematic areas in heavy precipitation as well. Regarding to earthquakes, these areas are more susceptible to collateral hazards considering leakage of hazardous materials to the soil and then to underground water (Figure 11).

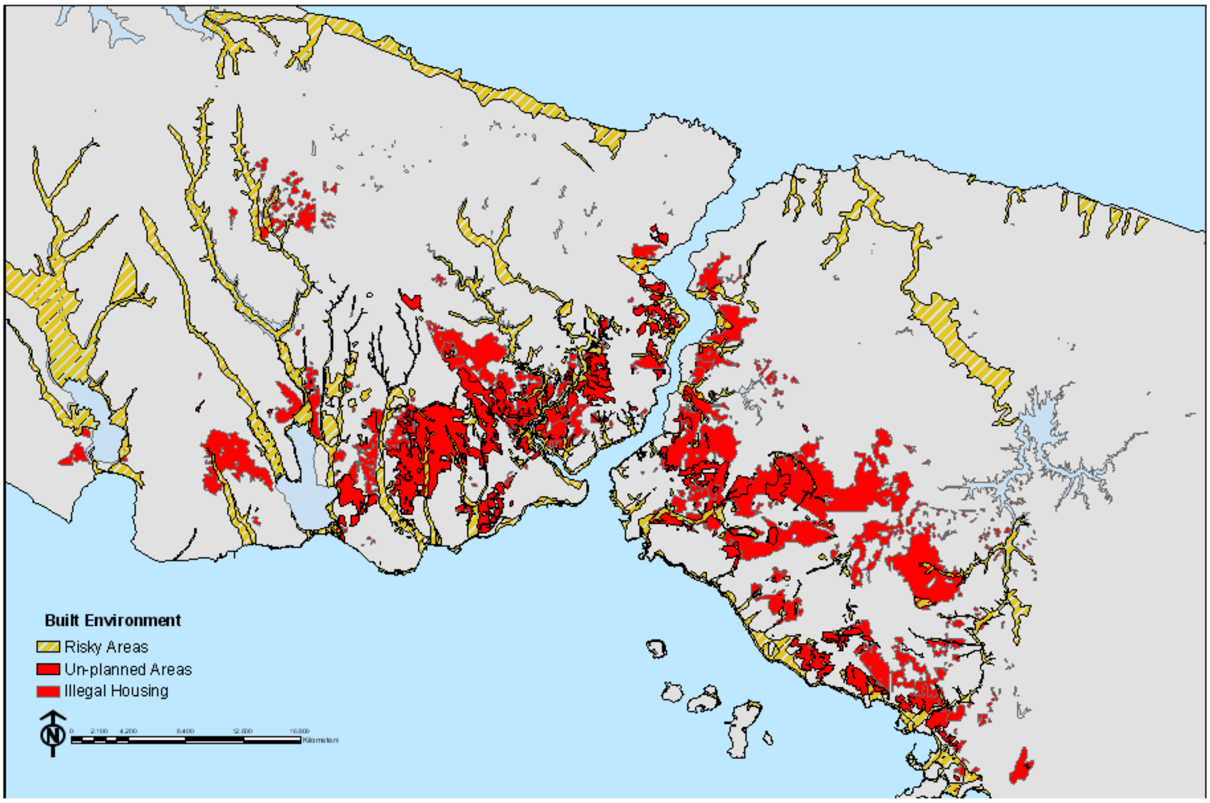

Figure 10: Overlay of risky areas and un-planned areas in Istanbul (data provided from Istanbul Master Plan Reports, 2009).

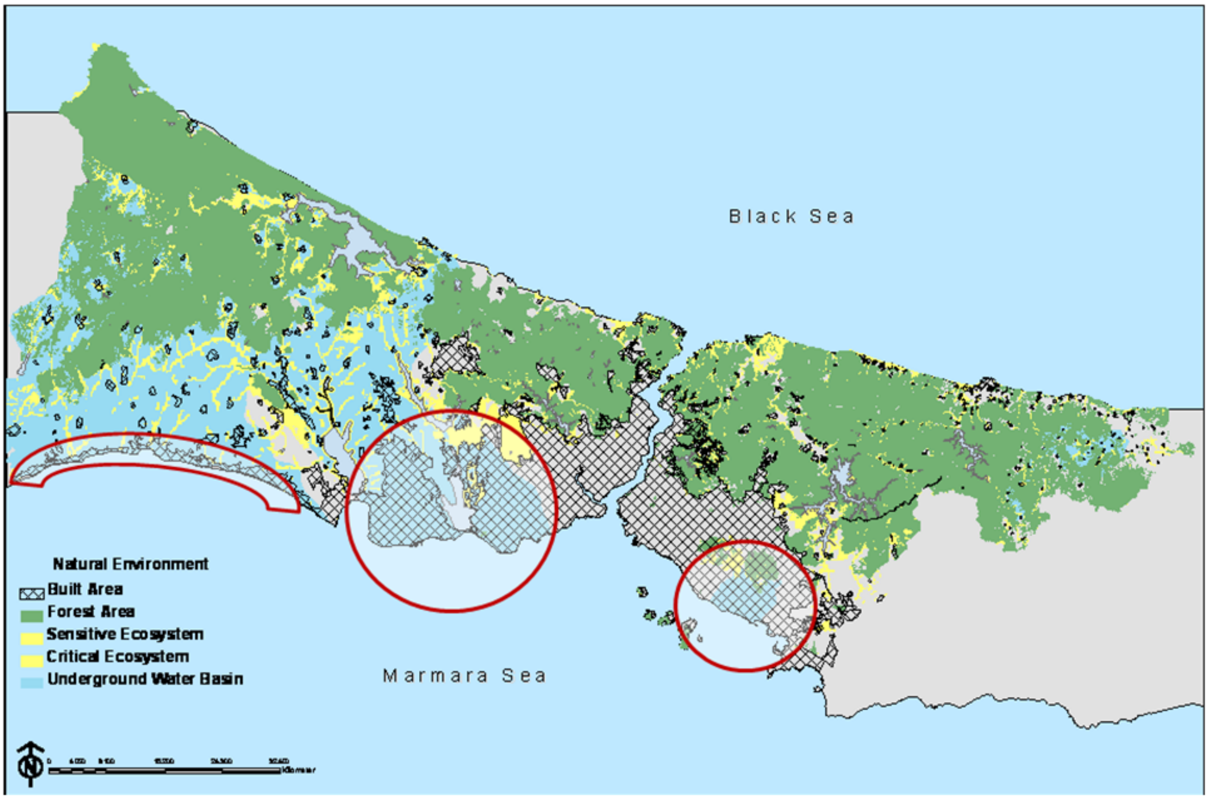

Figure 11: Natural environment and built up area (data provided from Istanbul Master Plan Reports, 2009).

Socio-economic aspect of Istanbul unfolds vulnerability and resilience at the same time. Regarding urban exposure of the city, the elements at risks reveal as major element inherently having vulnerable. But on the other hand, social and economic capital that city has is the main element to make the city resilient. Istanbul is the primate city in Turkey with its population more than 10 million and its great contribution to the national budget. Furthermore, as Istanbul is specialized at the tertiary sector, it is the economic heartland of the country as well. Within this perspective, Istanbul seems to have a better mitigation capacity, however, once considering the economic losses due to the Kocaeli Earthquake on the national economy, we may assume that even Istanbul is able to recover itself in the case of any crises; there can be some negative impacts on national economy such as less contribution to the budget. Theoretically, if we consider "the stronger is resilient", we ignore probable losses which may affect not only Istanbul but also the entire country. If we just focus on probable losses and their indirect impacts, so this time we underestimate the recovering capacity of the metropolitan city. This dilemma makes difficult to assess macro level vulnerability and resilience of large cities.

3.2.2 Physical Vulnerability / Physical Damageability

In the physical vulnerability assessment the aspects of natural environment, built environment, infrastructures and production sites and social system that can affect the seismic damageability of each one of these systems are considered. At the micro scale, the assessment of the physical vulnerability depends on the evaluation of the each component of the systems.

Physical vulnerability of the built environment at this scale is mostly related to the features of the individual buildings. The material, age and maintenance of buildings are primary indicators to evaluate vulnerability. In some cases, construction or development process of built environment goes ahead as the most important parameter. For instance, as mentioned on the previous part of this chapter, unplanned (illegal) development in major cities of Turkey is one of the biggest problems in disaster mitigation. It is possible to evaluate the development process into three main groups: legal, legalized and illegal. Legal buildings are constructed respecting land use plans and building codes. Legalized buildings are which had been built in illegal way in the past but then due to amnesty laws they gained legal status. Illegal building, on the other hand, are those which are built without permissions or have some of the permissions (such as to have building permit but no occupancy permit). The second and the third group building are evaluated as most vulnerable buildings in the city wide. The areas developed in unplanned way cover approximately 41% of the inner city of Istanbul. Besides engineering deficits in these buildings, high building density in the urban pattern without green areas, lack of many urban facilities and incompatible land uses (non-permitted manufacturing and housing near to each other and/or in the same building) increase urban risks not only related with natural hazards but also common accidents.

Numerous research and earthquake scenarios developed for Istanbul have given probable losses in buildings, human life and basic infrastructural facilities. However, collateral hazards and Na-techs are not well studied topics yet. Considering industrial development process in Istanbul it is worthy to note that with the urbanization process, manufacturing industries have been decentralized from the city center through the fringes. In the last decades of 20^{th} century, within the establishment of organized industrial areas (OIA), industrial activities have been located in more compact form. Kucukcekmece district is some of these locations where there are dense industrial facilities (Figure 12). Furthermore, the nuclear research center sets near to Kucukcekmece Lake.

Referring to na-techs events occurred in the Kocaeli Earthquake, two different data have been overlaid with the location of these industrial facilities. The first one is the probable water pipe damages in this area. The second one is the critical and sensitive ecosystems including underground water. Once considering probable fires caused by structural failures in industrial facilities, the consequences of Kocaeli Earthquake gives a realistic perspective to Na-tech accidents which may occur in Istanbul. The special extinguishing substances remained insufficient and water shortage caused by broken pipes made difficult fire extinguishing.

Another point which is crucial regarding to natural environment is that the location of these industrial facilities. For instance, the Kucukcekmece Lake is a lagoon having a very sensitive eco-system. In the northern part of this area, other sensitive eco-systems related to potable water reservoirs. On the other hand, underground water occupies a very large area under some of these facilities. Hereby, the probable problem may be the contamination of natural resources by the leakage of chemical substances into soil through water as experienced in the Kocaeli Earthquake in 1999.

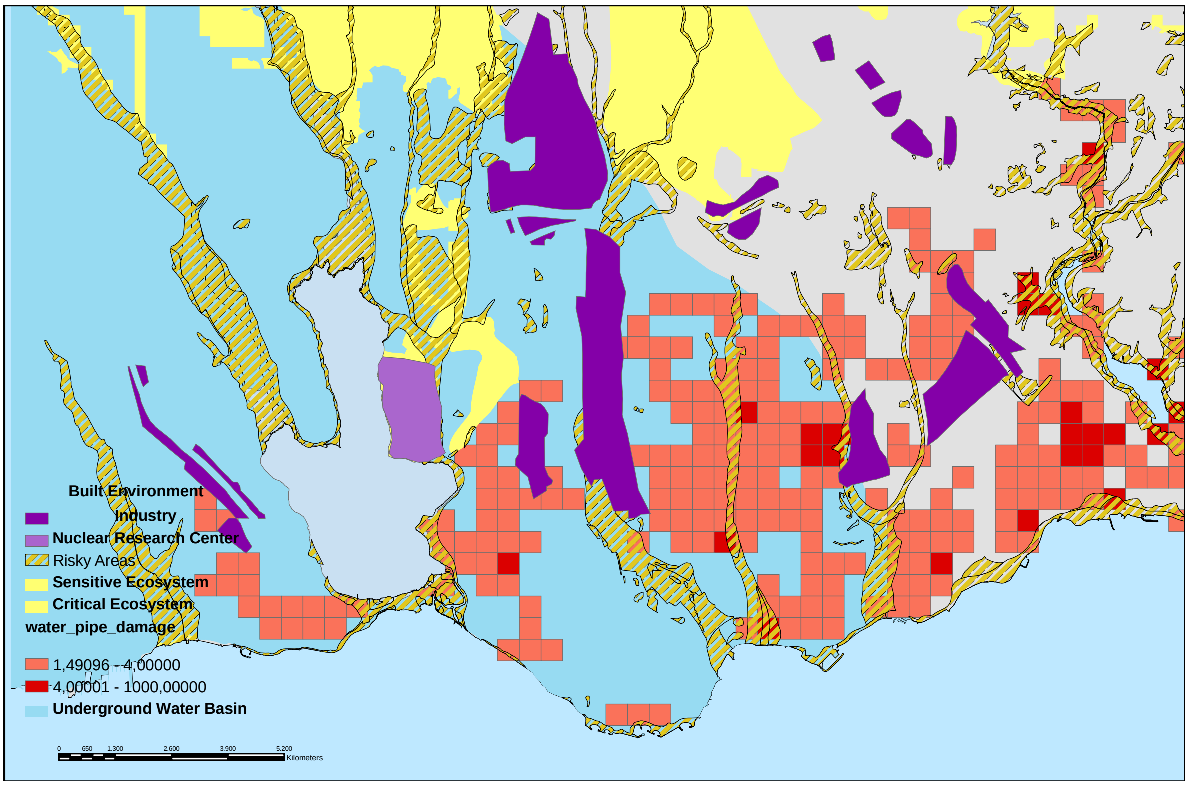

Figure 12: Industrial areas in Istanbul and vulnerability to Na-techs (data provided from JICA & IMM, 2002).

3.2.3 Vulnerability to Losses

Systemic vulnerability is one of the less studied types of vulnerability in Istanbul. However, as it refers "susceptibility to losses", it is crucial to assess the urban system at this framework. Hereby, the health facilities are considered regarding to systemic vulnerability due to earthquake hazard. In Istanbul, some greatest health services are focused on populated areas, but on land where soil conditions are not favorable considering earthquake. Another problem arises due to high building density around these facilities which might cause systemic problems.

In the case of hospitals, the question is "even if these facilities do not receive damage, will they be able to give necessary services or not?". Water system is another crucial item in health services respecting to sanitary reasons. Despite all hospitals have their own reserves to provide water in the case of shortage, once considering that disaster response and recovery time may last longer, it can be assumed that the reserves may be over in a certain period. In this case, basic and/or complicated operations may not be performed by physicians. Electric system is able to affect several systems in the urban areas. The black outs may cause interruptions of functioning health equipments as well as water pumping system. Once more generators, as reserves, may substitute for a while, but again after a certain period they need to be charged (Figure 13).

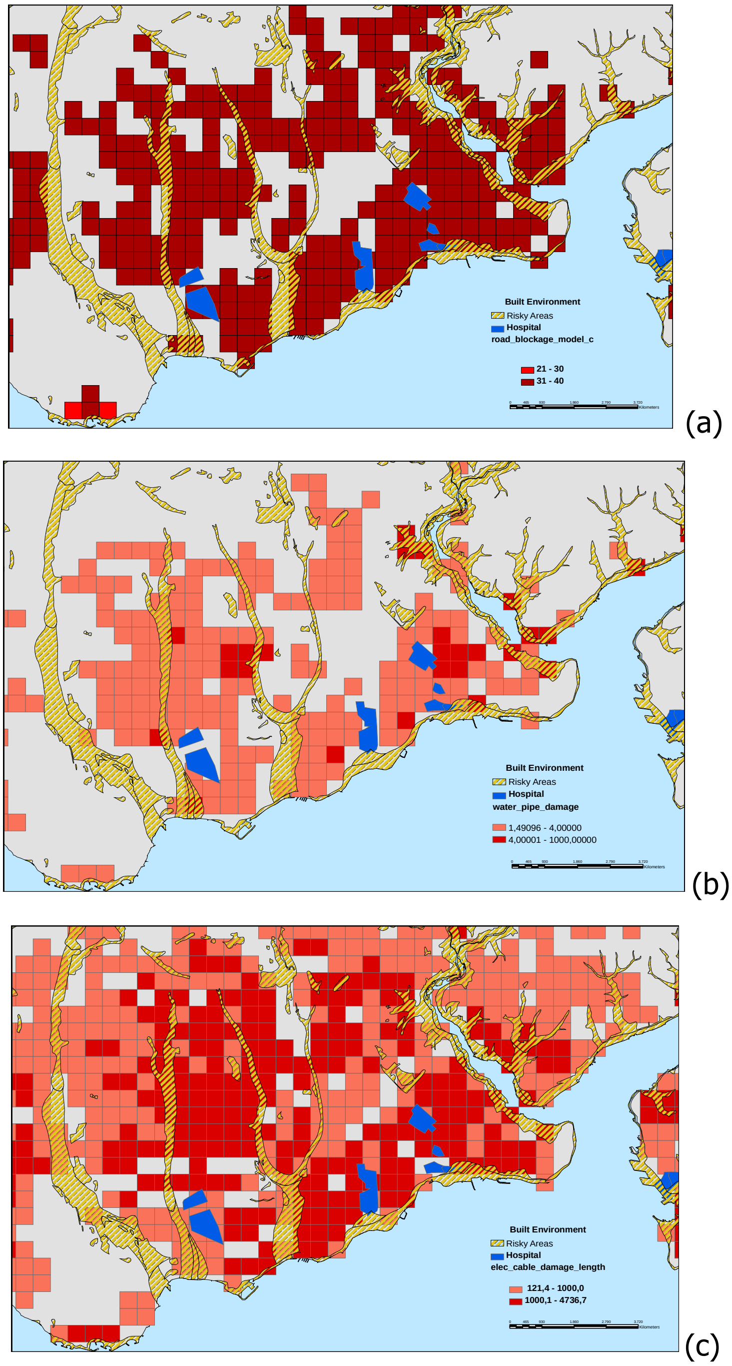

Figure 13: Major hospitals in Istanbul and their vulnerability to losses: (a) Road Blockage; (b) Water pipe damages level; (c) Electric network damages (data provided from JICA & IMM, 2002).

Systemic vulnerability due to losses at the other systems is described in the case of health services in Istanbul. In the case of a disaster, either one of them may occur or all three of them. The specific area taken for this assessment has several failures once considering earthquake threat. The area is prone to fault and the soil conditions are not favorable. On the other hand, urban tissue of this area has been formed by very high density of buildings and narrow streets. To increase resilience in health services in Istanbul, major hospitals should be relocated through relatively safe areas with different mode of transportation in order to increase accessibility. In this case, health services may be affected less due to systemic failures in the city wide.

3.3 Concluding Remarks for the Istanbul case study

Both vulnerability and resilience are not static concepts; on the contrary, they are very dynamic, transferable, changeable and sensitive to interactions with other items. For instance, a single form of vulnerability may differ according to time span and/or spatial scale. On the other hand, there is no single vulnerability identification of any characteristics.

Referring to the definitions and approaches given, the macro-scale vulnerability and resilience of Istanbul has been evaluated. Then, systemic vulnerability and vulnerability to Na-techs have been discussed as well. The results show that indirect impacts of a probable earthquake are hard to estimate but are likely to give great impacts on urban area not only on physical structure but socio-economic structure as well. Considering systemic vulnerability, health facilities are considered as an example for critical facilities. In recent mitigation projects, critical facilities are evaluated as a single element to take into consideration and therefore reinforcement is seen as the best solution to eliminate vulnerability. However, as mentioned several times to define systemic vulnerability, the functionality of a service depends on the services it gets. In this case, accessibility to health facilities and water/electric supply play crucial role to use them efficiently during the crises.

To sum up then, in metropolitan cities, such as Istanbul, a macro perspective is necessary to evaluate both vulnerability and resilience, as well as systemic vulnerability and vulnerability to Na-techs. In Istanbul, for the last 10 years, most of the projects have been focused on reinforcement of buildings/structures and local/small scale regeneration projects. They are certainly notable improvements to mitigate risks; however, large cities have always complex and inter-related systems which are likely to affect each other in both direct and indirect way.

3.4 References

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4 The Corvara case study

4.1 Work aim

This work, starting from the results of a landslide-risk plan undertaken for the Municipality of Corvara in Badia (Autonomous Province of Bolzano, NE Italian Alps) in 2006, is an attempt to verify the applicability of the vulnerability-analysis methodology proposed during the Ensure Project meeting held in Milan on 17-18 June 2010. The scale at which the study has been made is the meso-scale, comprising the whole municipal territory. A micro-scale (local) assessment has been performed for only one landslide body, namely the closest one to the village of Corvara in Badia within the framework of a previous contract.

4.2 General presentation

4.2.1 The studied area

The studied area is the Municipality of Corvara, which is located in the Upper Badia Valley - Alta Badia - (Figure 14). This is a mountainous area, characterized by a high flow of tourists both in winter and in summer. From the geomorphological viewpoint, it is characterized by very high relief energy and lithotypes which can be susceptible of various types of slope movements, making Corvara a real laboratory for landslide studies and suitable for a risk study, as it is possible to correlate vulnerability elements with hazard elements. With reference to the proposed methodology, both meso-scale and the micro-scale approaches were used; the former was applied to the whole study area, where a semi-quantitative assessment was made, while the latter was used for the specific case of the Corvara landslide.

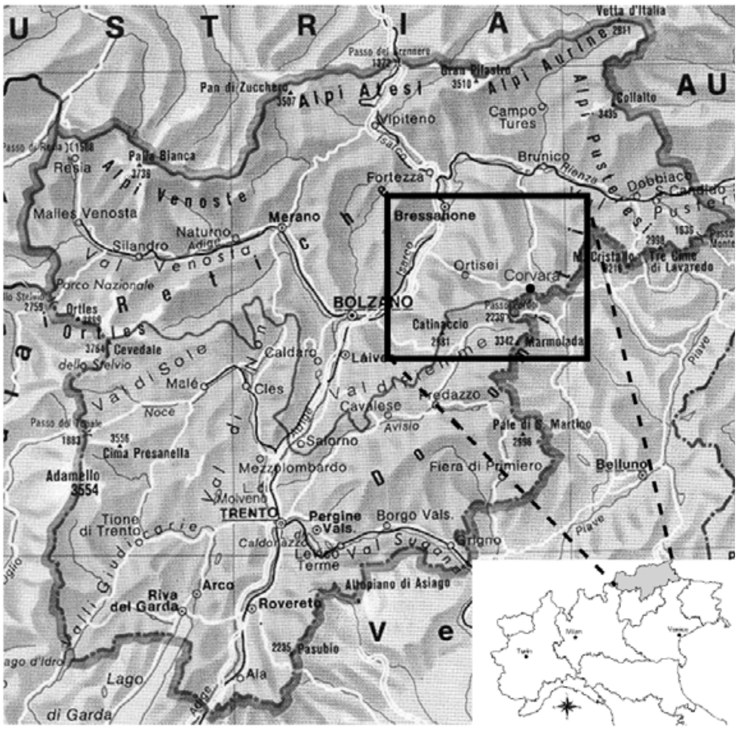

Figure 14: Geographical context of the Corvara study area (after Cavallin, 2009).

4.2.2 Meso-scale assessment: the Corvara in Badia Risk Plan

The Risk Plan was prepared in 2006 by the University of Modena and Reggio Emilia in collaboration with the Autonomous Province of Bolzano, the Municipality of Corvara and the National Research Council of Padova. The aim of the Risk Plan was to provide an outline of the possible socio-economic consequences of landslides, floods and snow avalanches in the municipality area, with reference to the elements exposed to risk and their vulnerability (following the vulnerability assessment scheme by the Autonomous Province of Bolzano), damage detectable on the ground on man-made structures, mitigation actions, in the last few decades on the side. This was a pilot study to assess hazard and risk, taking into account the peculiarities of the phenomena. The study provided detailed information on the specific risk for each phenomenon and the total risk for landslides, floods and snow avalanches altogether; in some cases the vulnerability of elements at risk was also evaluated. The total risk assessment was supplemented by indications of safeguards to eliminate or, at least, to reduce the specific risk. With the drafting of the Plan, a procedure, for the whole Province, was defined, which however, may require, from time to time, the adaptation to specific local conditions.

Within the Risk Plan, elements at risk have been classified and grouped according to their types, as follows, according to the vulnerability assessment scheme by the Autonomous Province of Bolzano which gives a vulnerability class to each element according to its typology, function and people involved etc.:

1. Settlements and recreational areas:

- Residential areas;
- Productive areas;
- Collective areas;
- Areas for tourism facilities;
- Other settlements;
- Public parks;
- Private gardens;
- Camping;
- Golf course.

2. Transport infrastructures and networks:

- Roads and lifts;
- Highways;
- Planned roads;
- Other roads;
- Bridges;
- Parking;
- Lifts;
- Ski lifts.

3. Network infrastructures and primary infrastructures

- Water storage;
- Water pressure pipes;
- Power lines;
- Phone lines;
- Water captures;
- Water tanks;
- Power station;
- Electrical cabins.

The map of the elements at risk considered allowed focusing the study in significant portions of the territory, involved by natural phenomena, which may interfere with the same elements at risk.

4.2.3 Economic evaluation Landslide Risk at the municipality level: systemic vulnerability

An attempt to evaluate the economic effects that the occurrence of one or more landslides could generate at the municipality level was undertaken, considering the time of occurrence of these landslides in relation to the main seasonal tourist periods.

The economic evaluation was focused on a particular area affected by different landslide types which may interfere mainly with roads and buildings. Especially the road represents a potentially high risk element for the systemic vulnerability of the municipality, just because the study area is reachable by only a few roads and the interruption of one of those could generate valuable monetary losses. The processed and analysed data refer to 2003 (Figure 15, Figure 16 and Figure 17). The evaluation was supported by economic analyses and surveys undertaken in the area in 2002. It might be interesting to update the data taking into account also the current economic crisis, but the data already available is enough for checking the suitability of this area to be studied according to the ENSURE methodology.

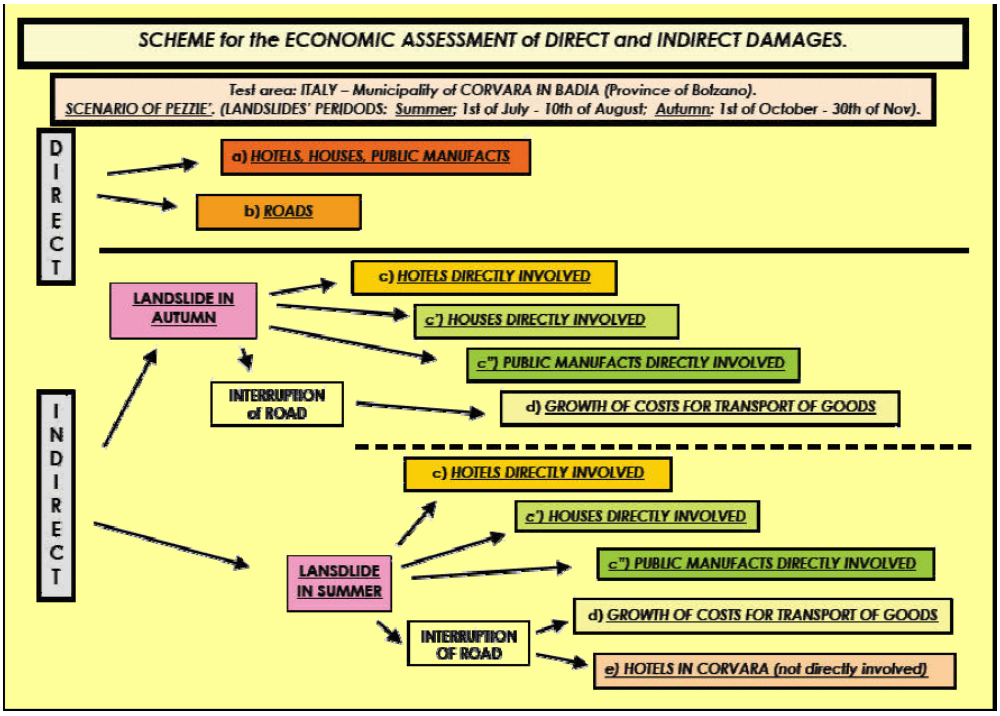

Figure 15: Methodological scheme for the economic assessment (Giacomelli, 2003 – ALARM).

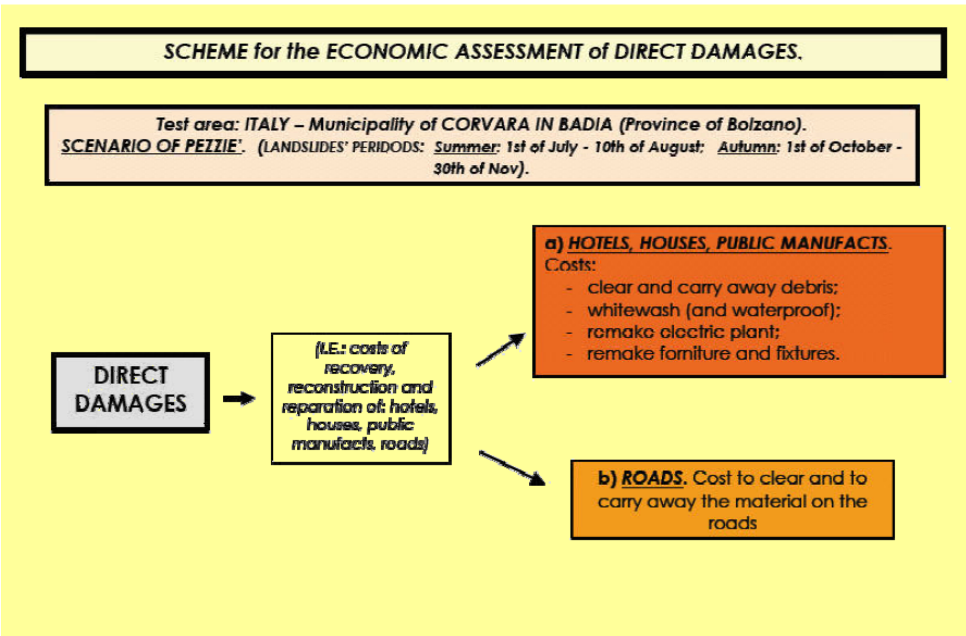

Figure 16: Assessment of the direct damages (Giacomelli,2003 – ALARM).

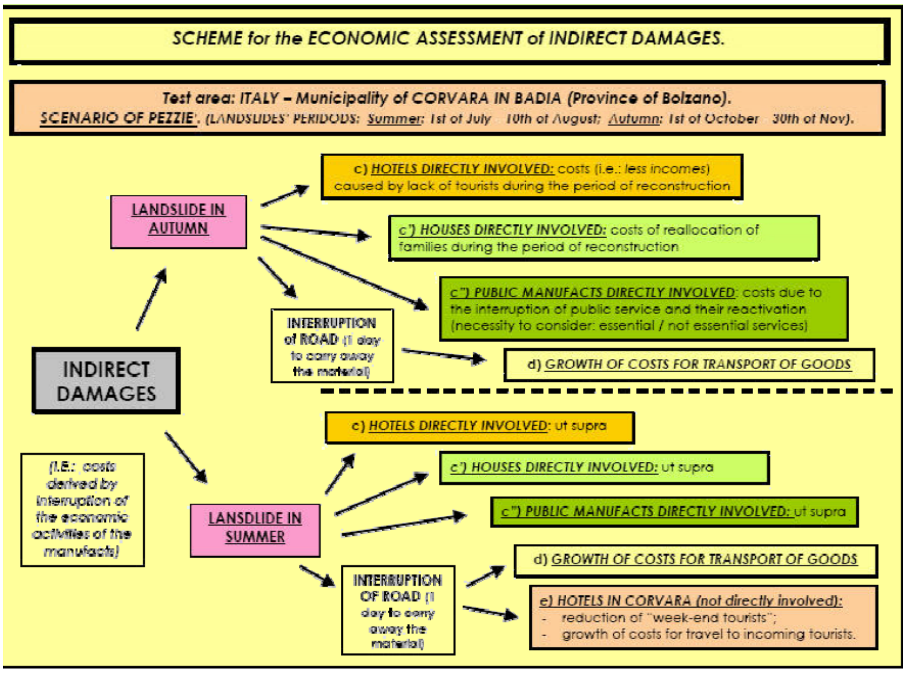

Figure 17: Assessment of the indirect damages (Giacomelli,2003 – ALARM).

4.2.4 *Risk scenarios leading to economic effects*

A general evaluation on the potential landslide damage in each scenario takes into consideration:

- High – low return period of landslides (structural and geomorphological conditions of reactivation);
- Magnitude of landslides;
- The morphology of the area which can strongly condition the possibility to rebuild damaged goods (i.e. to build a new road or find a temporary solution);
- High landslide occurrence probability in July–August and less in October–November. Possibility to have repercussions on the tourist season.

The typologies of economic damages that can be generated from the physical effects are two different types:

The *direct damages* are costs to recovery or reconstruction of the involved elements (buildings and infrastructures) these physical effects of disruption and they are only referred to direct exposed and involved elements that could be damaged or destroyed by the natural physical phenomenon: they directly derived from these physical effects of disruption and they are only referred to direct exposed and involved elements.

The *indirect damages* are costs derived from the interruption of the economic activity of the involved and/or non-involved elements. In fact, in case of infrastructures are damaged, some indirectly involved elements can suffer some damages for instance, tied to the interruption of the economic flows tourism, energy, etc.) from/to the damaged area.

This kind of damages is normally extended to a wider area than the direct involved one, far from the place of occurrence of phenomenon.

It is important to underline that the indirect damages depend upon the type of the involved human elements and from their importance and role in economy. The indirect damages could modify the social and economic directly and indirectly involved realities. These damages, because of their complexity and their relationship with the social and economic structure on the territory, may be long-lasting and generate high economic losses.

4.2.4.1 Micro-scale assessment

An example of a specific study, which focused particularly on the hazard assessment, regarded the active landslide body that directly affects the village of Corvara in Badia, namely the Corvara landslide (Figure 18). This specific assessment has been the object of a contract between the Autonomous Province of Bolzano, the Municipality of Corvara in Badia, the University of Modena and Reggio Emilia and the National Research Council of Padova.

The micro-scale assessment of hazard was possible since the causes of the landslide, the type of movement, the thickness of the mass involved and the velocities are very well known by a dense network of investigations and monitorings.

Figure 18: Corvara landslide (after Corsini, 2005).

4.2.4.2 Vulnerability assessment

Although the data available for the Corvara landslide were quantitative, thus suitable for a quantitative risk assessment, the physical vulnerability of the elements at risk could not be assessed, due to the lack of expert knowledge. Therefore, qualitative vulnerability levels (again according to the vulnerability assessment scheme by the Autonomous Province of Bolzano stated beforehand) have been used, without leading to a final risk assessment. Vulnerability classes range mainly from middle to high. Exceptions are forest roads, with a low class of vulnerability. Essentially, as well as some isolated buildings with high class of vulnerability, the SS 244 is the item with middle class of vulnerability, which is characterized by a high structural weakness and economic importance.

4.2.4.3 Hazard scenarios for the Corvara landslide

Qualitative analysis of the geomorphological evolution of the slopes, and data obtained from monitoring campaigns has allowed us to draw the following evolution scenarios:

- In the crown zone, retrogressions may occur in the main slope with consequent acceleration of underlying flow movement.
- In the transport area, as a result of increased volumes transferred from upstream, it is considered a possible increase of volume in motion, linked to an acceleration of the movements themselves; in addition, an advanced front of the landslide to the Rutorto stream could lead to dam the stream itself and possibly to the rapid overflow from the reservoir.
- In the accumulation area, the overload due to flows from upstream could lead to a general acceleration and collapses on the flanks of the landslide body, also aided by the erosion of the streams.

Rutorto stream evolution scenario

Simulation of the damming of the Rutorto river by a possible reactivation of the Corvara landslide was performed on two scenario-areas (Figure 19):

- in the area of the confluence of the landslide in the Rutorto valley (near the golf course, scenario 1);
- downstream of Costes da L'Ega house (scenario 2).

The damming scenarios were obtained applying barrier thresholds with the same height of the landslide body (quite conservative); regarding the upstream extent of the dam reservoirs, it resulted as quite limited in the second scenario but more worrying in the first one, where the reservoir would reach the municipal stable, the golf course offices and the Planac Hotel further upstream.

Calculations based on the volume of the reservoirs and the value of the average flow of Rutorto river in two critical seasons (spring and summer – fall) allowed to estimate the time to fill up the reservoirs before the consequent overflow:

Scenario n. 1:

Spring: time to fill up = **9 days**

Summer – fall: time to fill up = **29 days**

Scenario n. 2:

Spring: time to fill up = **4 days**

Summer – fall: time to fill up = **13 days**

The obtained data allow to assess that, in ordinary flow rate, it's possible to assume that there's always enough time to evacuate people and property or to artificially cut the barrier.

In case of floods with return periods of 100 or 200 years, not considered in the research, the filling time will be definitely shorter.

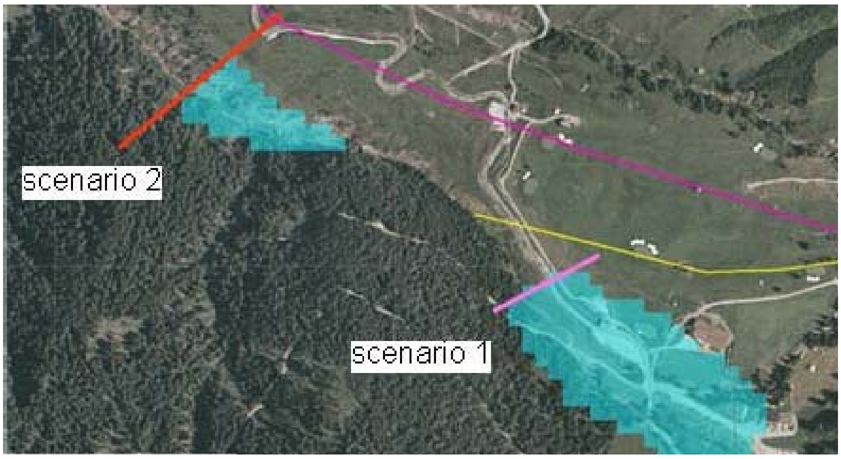

Figure 19: Results of 2 DEM-based river damming scenarios possibly caused by recrudescence of activity in the middle portion of the Corvara landslide body.

4.3 Application of the Ensure framework to the Corvara case study

4.3.1 Mitigation capacity

As stated in the Guidelines for ENSURE WP4 - point 4, the first matrix of the framework (Table 2) tries to define criteria for identifying parameters of resilience and vulnerability which develop **before the impact**, basically considering the capacity of a society (here a local community) to embed **prevention** into ordinary planning and ordinary actions. The systems involved are: the natural and the built-in ones; the agents involved are the single inhabitants and the local administrators, plus a series of "external" players which are represented by a portion of the scientific community and by provincial and regional administrations.

Therefore the principal keywords for this matrix are:

- **Landslides**, since they represent - as shown beforehand - the almost ubiquitous natural phenomenon able to produce risky situations in the area;
- **Prevention**, the keyword highlighted by the Guidelines;
- **Knowledge** as it is the starting point if prevention has to have a positive effect, the latter implying a positive effect also on mitigation.

Table 2: Resilience: mitigation capacities (ENSURE Matrix 1)

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Scoring = weight (in {1,2,3}) x value (in {1,2,3})
Natural environment	*Natural Hazards*	knowledge and mapping of landslides	landslide inventory map; state of activity of landslides; quantitative or qualitative assessment of landslide magnitude; landslide hazard maps	scale of detail: 1:10.000; 1: 5.000	municipality area studied: 2,5 Km2 (meso - scale); local scale: just the Corvara landslide	**3x3=9**
		availability of adequate knowledge	hazard maps	updating frequency	depending on the necessity to have an updated urban plan: for example in our case study the updating was done for the 2004 municipal	**3x3=9**

					structural plan (MSP) - matricial evaluation	
			landslide inventory maps	updating frequency	as soon as new landslides develop - by direct field surveys,	**3x3=9**
			quantitative or qualitative assessment of landslide magnitude	updating frequency	field work observations; frequency of output from instrumental monitoring data (just for the Corvara landslide)	**3x3=9**
			activity of landslides	updating frequency	on he basis of regular field surveys (seasonal: after snow melt, after heavy rainfalls etc.)	**3x3=9**
		monitoring of hazards	goodness of monitoring system (just for the Corvara and the Passo Gardena landslide - local scale)	Type, quality, density and lifetime of monitoring devices, maintenance and evolution of technology	inclinometers; TDR - cables; piezometers; GPS network; differential interferometry (SAR, J-ERS data) - constant monitoring of functionality	**3x3=9**
		mitigation measures	existence and quality of structural defenses	type and state of maintenance, efficiency of mitigation measures relation to landslides	expert judgment	**3x3=9**
Built environment	*Exposure and vulnerability of built environment*	exposure and vulnerability considered and acted upon in plans	Vulnerability assessment of exposed built stock	type of assessment and updating frequency	for the entire Corvara case study the qualitative classifications of the autonomous Province of Bolzano had to be used - obliged direction	**1x3= 3**
			Risk maps and scenarios, including enchained events	for risk maps: updating frequency of hazard and vulnerability maps; for risks scenario, including enchained events: assessment of the analysis procedure quality (pros & cons)	for risk maps: refer to G7; for vulnerability assessment refer to G13	**3 x 2= 6**
			Vulnerability and exposure assessment is considered in territorial plans	mode of inclusion	substantially	**1 x 3 = 3**
	Rules and tools for risk mitigation	Do rules for mitigation exist? What is their expected efficacy/quality?	Traditional building practice based on hazard knowledge	capacity to re-produce traditional techniques correctly	judgment about the capacity to conform to the "code of practice"	**1 x 3 = 3**
			Maintenance of building stock	degree	qualitative judgment by expert knowledge	**1 x 3 = 3**
			Land use plans embedding risk mitigation and vulnerability reduction	degree of embedding	comprehensive	**1 x 3 = 3**
Critical infrastructures and tourist	*Critical infrastructures*	vulnerability assessment of critical infrastructures	Vulnerability assessment of exposed critical infrastructures	type of assessment and updating frequency	for the entire Corvara case study the qualitative classifications of the autonomous Province of Bolzano had to be used - **obliged direction**	**1 x 3 = 3**
	Tourist facilities	vulnerability assessment of	Vulnerability assessment of	type of assessment and updating frequency	for the entire Corvara case study the qualitative	**1 x 3 = 3**

		tourist facilities	exposed critical infrastructures		classifications of the autonomous Province of Bolzano had to be used - **obliged direction**	
Social system (agents)	*People/individuals*	Parameters are addressed to evaluate the capacity of individuals living in prone hazard areas of coping with hazardous events, which largely depends on the perception and awareness of risk conditions before the event occurs.	Risk perception/ awareness	degree	not investigated	**3 x 1 = 3**
			Early warning systems	information addressing all components of community(ies)	not existent	**3 x 1 = 3**
			Individual preparedness	availability of useful manual devices	not investigated	**3 x1 = 3**
			Known evacuation procedures	training	not investigated	**3 x1 = 3**
	Community and Instituions	Parameters are addressed to evaluate the involvement of a community into decision-making processes related to risk prevention and mitigation, the capacity of Institutions of improving risk awareness through information and education campaigns and the level of cooperation among different institutions in charge of risk prevention/ mitigation.	Participation in development and prevention/mitigation strategies	degree	not investigated	**3 x 1 = 3**
			Education programs & media campaigns	frequency and quality	not investigated	**3 x 1 = 3**
			Coordination and cooperation among institutions in charge of risk prevention/ mitigation	degree	high: between the municipality, the autonomous Province of Bolzano, the University of Modena and Reggio Emilia and National resource Council of Padova	**3 x 2 = 6**
	Economic stakeholders	Parameters are addressed to evaluate the economic capacity to mitigate of the various stakeholders; the access to financial resources for mitigation	GDP; GVA (Gross added value, measure of productivity and size of economy)	level	qualitative assessment	**3 x1 = 3**
			extent of marginalized groups	dimension of poverty/marginalization	qualitative assessment	**3 x = 3**

The natural environment can be mostly identified as the source of hazard (landslides), therefore as the active subject towards which prevention measures have to be taken; it secondarily represents also natural assets, such as elements with a high geological or geomorphological aesthetic and/or scientific significance, or particularly valuable natural habitats for flora and fauna. In this sense, natural environment plays both an active and passive role towards itself.

In Corvara we basically concentrated on the direct effect landslides may have on the built-in environment, avoiding to analyze those on the environmental assets themselves. This is due to the high density of vulnerable elements present in the area, linked to its internationally known tourist vocation. The key parameters identified were thus the landslide distribution in space and time and the space distribution of the built-in environment.

4.3.1.1 Parameters

Bearing in mind the word "*prevention*", the most important tool a local community as Corvara can use to takle hazards is a hazard map which identifies the occurrence in space and time of all different types of landslides. This is the key parameter characterising the capability of a community to embed prevention in ordinary planning. The hazard plan is a semi-static picture of hazard which depends on the availability of data on past landslide phenomena (moving mass, movement type, movement velocity, frequency of occurrence) and on the experience of geoscientists. It strongly depends on the continuous updating of scientific knowledge and of new data about future reactivation or new activation of landslides.

Another parameter is the presence, distribution and state of maintenance of mitigation works and of monitoring devices. It should strictly derive from the hazard plan, although experience demonstrates that mitigation and monitoring are considered only after the occurrence of a certain phenomenon. Their efficiency strongly depends on maintenance frequency, on the evolution of technology and, above all, on the evolution of natural phenomena.

Vulnerable elements (within the built-in environment) are another key parameter whose assessment has been made, for Corvara, in a qualitative way, without taking into account measurable impact pressures, nor resilience of structures, but only classes depending just on frequency of usage, importance for the society and so on.

4.3.1.2 Problems encountered

What we found during the Corvara experience with the Risk-plan, whose basic starting point is the hazard assessment, is that the hazard picture cannot be quantitatively assessed at the municipality level. This is mainly because it won't be meaningful: a quantitative hazard assessment implies a huge amount of monetary effort which can be saved if downscaled to lower planning levels. The only quantitative hazard assessment in Corvara has been undertaken on only one landslide body, namely the one closest to the main village: that micro-scale hazard assessment absorbed a huge amount of monetary effort, giving a hazard picture that nevertheless will always be incomplete and with unknowns.

Mitigation works and monitoring systems are hardly well maintained, if not when probable high-risk situations may occur. Mitigation and monitoring are usually done by different subjects (public ones), often not sharing common knowledge. Therefore, a clear picture of those two important parameters is missing, leading to an ineffective mitigation system able to prevent risky situations, reducing the level of risk.

4.3.1.3 Possible implementations

Feasible implementations can only be the continuous updating of knowledge on landslide hazard in a semi-quantitative way and of vulnerability assessment in a more quantitative way.

Vulnerability and resilience of structures and infrastructures should be made in a more quantitative way, considering their structural strength towards proximal phenomena, introducing a cross-validation assessment between structural engineering and geomorphology.

As regards the **agents**, we took into account three categories which could play an active role in pre-impact mitigation:

1. Single residents, owners of hotels & huts, ski resorts etc., whose "exposure" to risk (**parameter**) can be modelled by the level of their insurances, probably linked to the frequency of occurrence of natural hazards and to the state of the local economy (**key**

criteria); the exposure to risk has not been done for Corvara, but it would certainly be feasible through the implementation of experts in economics;

2. Public local administration, Province: the **parameters** considered for this category are: education and communication programmes, public financing, setup monitoring system and mitigation programmes that **depend** on cultural evolution of inhabitants and political attention of public administrators; this could be measured by analysing the flow of public acts signed by the local and provincial Administrations regarding those specific issues; verifying the number of public meetings attended; analysing written or web publications made to inform citizens, evaluating, through written questionnaires, the knowledge of people about hazards and risks in their territory.

4.3.2 Physical vulnerability

By the experience gained in Corvara, we think that a physical vulnerability assessment cannot be undertaken at a municipality scale (we think that the word "meso" better identifies a study scale such as that of Corvara). This is because a physical assessment implies a very specific quantification of impact pressures (it can hardly be assessed for all phenomena) and of structural strength related to those specific impact pressures. Can impact pressures be forecasted? Only if we assume that the landslides of the past occur with the same magnitude also in the future. A physical vulnerability assessment can be done for single phenomena, such as the case of the Corvara landslide, although in the study previously undertaken no such an assessment was done.

During the development of the scheme about physical vulnerability, the systems taken into account are (Table 3):

1. The natural environment, composed by geomorphological and geological assets. Their physical vulnerability **depends** on their intersection with hazardous phenomena (therefore known when a hazard plan exists) and on their intrinsic strength, related to the magnitude of each single landslide. The unknowns are even more complex than for the interaction between the built environment and the natural hazards: the most difficult data to gather are, in fact, those related to geomechanical parameters, much more than those related to man-built elements. Implementations have to be considered only if natural elements at risk have an extraordinary importance regarding economy, scenery, history, culture, science and so on.
2. The built environment, divided into buildings and recreational areas whose functionality **depends** on the construction techniques and on the annual maintenance. The problem found about this category is the lack of detailed knowledge about building type, construction characteristics and resilience to possible natural hazards. Possible implementations could include detailed engineering research on structural damage analysis from existing bibliographic data or direct measurements, even if the latter are probably not feasible at a municipality scale.
3. Critical **infrastructures and facilities**, for which it is necessary to **take into consideration** the annual maintenance, the landslide effects and the assessment of the state of mitigations works. The problem found, about this category, is linked to the difficulty to get a constantly updated state of maintenance of networks, systems etc. It would be necessary an updated functional system for economical evaluation of cost – benefit effects, possibly implemented in a geographical database.
4. **Tourist facilities**, divided into hotels, huts, sports facilities and camping site with facilities. Those can be treated like in point 3, but it has been separated due to its high economic relevance for this area.

Table 3: Physical vulnerability: physical damageability (ENSURE Matrix 2)

	System	Aspect	Parameters	Criteria for assessment	Descriptors	types of landslides					Scoring
						slow movement		rapid movement			
						lateral spread	earth flow/slide	debris/ mud flows	rockslide	rock falls	
Natural environment	*Natural ecosystems*	Are natural ecosystems fragile to the potential effects of hazard(s)?	presence of vegetation and forests on sliding slopes	degree of intersection with natural hazards	not significant for Corvara	/	/	/	/	/	/
		Can natural systems interact with hazard(s)?	geomorphological and geological assets	surface/ volume of geomorphological/ geological assets destroyed or damaged by each natural hazard	% of surface/ volume	independent from the landslide type	indep. from the landslide type	indep. from the landslide type	indep. from the landslide type	indep. from the landslide type	/
		Are natural ecosystems vulnerable to mitigation measures taken particularly during the emergency phase?	presence of ecosystems that may be endangered by landslides	binary type	not significant for Corvara	/	/	/	/	/	/
Built environment	*Exposure and vulnerability of built environment*	What are the factors that make buildings, the urban fabric and public facilities vulnerable to the stress?	structure	material	reinforced concrete, masonry (different types), other	1	3	3	3	3	not investigated
				type of connection among parts	good/poor	3	3	3	3	3	not investigated
			foundation	depth and type	non-existent, deep, superficial	2	3	3	3	3	not investigated
			spans between resistant elements	distance in m.	> 3 mt; < 3 mt (for masonry mainly)	3	3	3	3	3	not investigated
			shape	openings	number and dimension of windows/ doors	1	2	3	1	1	not investigated
				direction of openings	permitting the flow to pass through	1	2	3	1	1	not investigated
			maintenance	building conditions	good	3	3	3	3	3	3
			position	with respect to each active lanslide body	parallel, perpendicular	3	3	3	3	3	3
				position with respect to the moving mass	on the movement mass/ below/ below at a distance/ lateral	3	3	3	3	3	3
			Vulnerability assessment of public facilities	as for buildings		3	3	3	3	3	3

			Vulnerability of the urban fabric	position with respect to the moving mass	right below the rockfalls, rockslides, mudflows/on the rockslide/ below earth flows/on the earthflow	3	3	3	3	3	3
				internal spatial organisation of the urban fabric	presence of runaway corridors for landslide runout; space between buildings that favour the energy dissipation of the phenomenon	1	2	3	3	3	3
Infrastructure and tourist facilities	*Critical infrastructures*	What are the factors that make critical infrastructures vulnerable (mainly lifelines)	hiking tracks Lifts: - chair lifts - cableways - ski lifts local roads; bridges, parkings Primary electrical substation; Power station Basins Production facility Water system Water pipe Power line Telephone line water storages	position with respect to the mass movement	across the moving mass/below/lateral	2	3	3	3	3	3
Social system (agents)	*People/ individuals*	What are the factors that may lead to injuries and fatalities?	Preparedness	prior training and exercises; information about what to do	yes/no; frequency of training:	1	2	3	3	3	not investigated
			Evacuation plan	binary and quality	yes/no; expert judgment	1	2	3	3	3	not investigated
			hour of occurrence of the phenomenon	late night, early morning, rush hours, meals time	expert judgment	1	2	3	3	3	not investigated
			Age; mobility impairment, other impairment	difficulties to comply with evacuation orders; difficulties in escaping	yes/no; number of people	1	2	3	3	3	not investigated
	Community and Institutions	What are the factors that may lead to large number of victims?	concentration in space and time	resident and present population in dangerous areas; during high/low tourist seasons	density	1	2	3	3	3	not investigated

The **agents** we took into account were: single residents, owners of hotels, huts, ski resorts, local public Administration, Province and scientific world. The key parameter is the knowledge about past damages occurred in the area and the will to learn from past experience, which depends on:

- The existence of a **database** that gathers the "historical memory" of people and community on all past landslide magnitudes and damages caused: this could be measured by the analysis of the amount and quality of data available at public offices and at privates'; it can also be measured by the quality of the hazard plan;
- The **political will** to invest resources on construction quality, mitigation actions, monitoring plans: it can be measured by analysing the flow of public acts signed by the local and provincial Administrations regarding those specific issues;
- The **historical trend of insurance levels** for buildings and other structures (infrastructures?), especially those linked to the tourist economy.

4.3.3 Systemic vulnerability

Vulnerability to losses is the meaning taken by "systemic vulnerability" in matrix 3 proposed in ENSURE framework (Table 4). In other words, we could say the **degree of functioning** of elements or systems affected by a certain hazard. This type of vulnerability has not been assessed during the Corvara study. Nevertheless, we intend to make some proposals in the light of our knowledge of the Corvara study site.

Table 4: Systemic vulnerability (ENSURE Matrix 3)

	System	Aspect	Parameters	Criteria for assessment	Descriptors	types of landslides		Scoring
						slow movement	rapid movement	
Natural environment	*Natural ecosystems*	Are natural ecosystems fragile to the potential secondary effects of hazard(s)?	presence of forests/vegetation on slid slopes	binary and extent	yes/no; types and % of coverage	3	1	3
		Are natural ecosystems vulnerable to mitigation measures taken particularly during the emergency phase?	presence of forests and ecosystems in the path where structural works have to be built	binary	yes/no; types and % of coverage	/	/	not significant for Corvara
Built environment	*Exposure and vulnerability of built environment*	What are the factors that make buildings, the urban fabric and public facilities vulnerable to losses?	Existence of public facilities: hospitals, fire brigades mechanics, emergency control rooms, reception areas,	yes/no; functional capacity of such facilities	assessment of functional potential of facilities	1	3	not investigated
			Range of service of public facilities	Importance of facilities in the potentially stricken areas	Local facilities/regional/national relevance	1	3	not investigated
	Critical infrastructures	What are the factors that make critical infrastructur	Degree of interdependence among lifelines	level of redundancy; binary	large redundancy; emergency devices exist/do not; autonomous capacity exist/does not	3	3	As in most mountain areas, there is limited redundancy to lifelines; in the

Infrastructures and tourist facilities		es stop functioning ?	Continuity plan for lifelines, individually and in a coordinated fashion	binary	yes/no; considers all potential threats/does not	3	3	Corvara area electrical power and water facilities are likely to be the most affected.
			Degree of dependence of critical public facilities from lifelines	binary	autonomous plants exist/do not; alternative resources available/not available	3	3	
			People and areas depending on lifelines in potentially affected zones	number/area dimension	number of customers who may be affected; geographic area	3	3	
			Availability of personnel and spare materials for quick repairs	binary	yes/no	3	3	
			Duration of outages	hours	few hours/> 24	3	3	
		How well accessibility to and within vulnerable areas is guaranteed?	accessibility from/to damaged areas	to strategic facilities	more than 1 access/1 access/0 access	3	3	As most mountain valley, there is no redundancy in access ways; furthermore the SS244 would be difficult to repair in short time, due to its physical vulnerability
				physical vulnerability of access ways	vulnerable/not vulnerable	3	3	
				condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt)	3	3	
			internal accessibility	in residential areas	more than 1 access/1 access/0 access	3	3	
				physical vulnerability of access ways	vulnerable/not vulnerable	3	3	
				condition and features of access ways	narrow/large (> or < 12 mt); inclination (> or < 3%), twisting and curves (yes/no), material (asphalt/not asphalt)	3	3	
			availability of personnel and means for quick reopening	binary; distance in hours to be covered by personnel and means	yes/no; x < = 2h/ x> 2h	3	3	
	tourist facilities	What are the factors that make tourist facilities vulnerable?	Degree of dependence of tourist facilities from lifelines	binary; degree of presence of autonomous devices	yes/no; %	3	3	Tracks and ski lanes are fundamental to the tourism economy of the area
			Accessibility to the plant and to markets	see internal and particularly external accessibility of the area		3	3	Heavy lorries cross the valley using the only existing road: SS 244

			Contingency plan for na-tech	binary	yes/no; considers all potential threats/does not	3	3	
			Business continuity plan	binary	yes/no	3	3	
Socio - Economic system (agents)	*People/individuals*	What are the factors that may lead to injuries and fatalities?	information on risk	degree	enough/sufficient/none	1	3	Risk plan publication and presentation to citizens (ex. via Webgis: showing interactive hazard and risk maps) Note: Analyses are supported by national and international scientific and non-scientific publications
			trust in authorities	binary	yes/no	1	3	not investigated for Corvara
	Community and Instituions	What are the factors that may hamper effective crisis management?	continuing monitoring (>weight if early warning possible)	binary	yes/no	1	3	not investigated for Corvara
			available equipments	binary	yes/no	1	3	not investigated for Corvara
			potable water storage; independent electric generators	binary	yes/no	1	3	not investigated for Corvara
			civil protection plan	binary	yes/no	1	3	not investigated for Corvara
			training and exercise	degree	frequent/not frequent; involving the population /not involving	1	3	not investigated for Corvara
			communication plan (multilingual)	binary	yes/no	1	3	not investigated for Corvara
	Whole economic system	What are the direct effects caused by the interruption of the road system to the local economy?	recovery of the road	degree	monetary value	3	3	3
			recovery of damaged tourist offer	degree	monetary value	3	3	3
		What are the indirect effects caused by the interruption of the road system to the local economy?	interruption of economic activities of the involved and/or non-involved elements	time, length	monetary value	3	3	3

Therefore, the **systems** taken into account are always the same as listed beforehand:

1. The **natural environment**, composed by geomorphological and geological assets. A degree of functioning is not the most suitable word to express what happens after a natural asset has been impacted by a certain natural hazard; we suggest to use the word "degree of integrity" which better shows how much of it has been left so that it can still be scientifically recognized as an asset. As for the case of point 1. in the previous matrix, the degree of integrity can be measured by the same well known and tested asset-evaluation procedures.
2. The **built environment**, divided into buildings and recreational areas whose functionality and ability to function **depend** on construction techniques and on annual maintenance. The problems found about this category are still the lack of detailed knowledge about building type, construction characteristics and resilience to specific types of natural hazards. Possible implementations could be the same as those mentioned beforehand. Moreover, it should be assessed whether damaged structures may or may not keep functioning without the need to be completely reconstructed. Given the great number of uncertainties the latter implementation will introduce, we think a more qualitative assessment should be adopted for this issue, searching similar damage situations already occurred in the study area or in other places. Something similar has been done for Corvara in some risky sites, forecasting the magnitude of the **key parameter** phenomenon and the degree of damage through expert knowledge (delphi method, or other decision support systems): in that way something could be hypothesized on the future degree of functioning, which is then a key criterion also to quantify monetary losses.
3. Critical **infrastructures and facilities**: again, for those it is necessary to **take into account** the annual maintenance, the landslide effects and the assessment of the state of mitigations works (as a function of the state of the hazardous phenomenon they are meant to mitigate: activity and supposed magnitude). As for structures, the degree of functionality after having been hit by an hazard is not an easy matter do solve. Again, a more qualitative assessment based on expert knowledge could be more effective at this scale. In Corvara, expert knowledge could figure out the degree of functioning of key access roads to the village. Therefore, it has been possible to estimate the amount of money to be spent to improve the road conditions and the monetary loss the local tourist business may suffer depending which tourist season the damage occurs in ("functionality of the economic system").
4. **Tourist facilities** are divided into: hotels, huts, sports facilities and camping site with facilities. Those can be treated like in points 2 and 3, but they have been separated due to their high economical relevance for this area.

The **agents** we took into account were: single residents, owners of hotels, huts, ski resorts, local public Administration, Province. Here again, the **key parameter** is the knowledge about past damages occurred in the area and the will to learn from past experience, depending on:

- The existence of a **database** that gathers the "historical memory" of people and community on all past landslide magnitudes, damages caused and degree of functioning after the damage was caused: this could be measured by the analysis of the amount and quality of data available at public offices and at privates'. It could also be indirectly measured comparing the actual damages caused in the past (quantified in money) and the real amount of money spent: the higher the ratio, the more functionality has been guaranteed after the damage. It can also be indirectly measured going back to past events and verifying how much time has passed between damage and full functionality of services etc.

- The **political will** to invest resources on mitigation actions, monitoring plans, systems and services recovery: it can be measured by analysing the flow of public acts signed by the local and provincial Administrations regarding those specific issues.

4.3.4 Resilience

The keyword we selected for this last matrix are **capacity to recover** and **weakness reduction**.

The systems are again (Table 5): the natural and the built environment (both structures and infrastructures), while the agents are: single residents, owners of hotels, huts, ski resorts, local public Administration, Province and the scientific community.

The main parameter is certainly the presence of a **Civil Protection Plan**, which is the case for Corvara as for all municipalities in Italy. We could not assess the state of the art of that particular Plan, but it could be done checking the following parameters: amount of money available for it, number of people involved, frequency of implementation of knowledge, frequency and quality of training, availability of vehicles, helicopters etc., distance of first aid structures, adaptation to different atmospheric conditions, accessibility to refurbishment facilities and so on.

This could be sufficient for a recovery strategy, while for a weakness reduction strategy we inevitably should go back to what we have stated in matrix 1 about "prevention", thus going back following the backward arrow along the timeline axis of the proposed scheme.

What has been said about the existence of hazard and risk plans can be replied also here, since those plans are the basic starting point for a good prevention (mitigation?) strategy (which is a synonym of pre-event weakness reduction).

The consequent indicators to measure to quantify the goodness of those plans are as follows: the number of updates on both hazards and elements at risk (since we said that a hazard and risk plans are always static pictures of reality), the availability of a continuously updatable database (GIS or web-GIS), the number of new monitoring and alert devices put on (and in) ground, the number of new mitigation works and/or the frequency of their maintenance.

Table 5: Resilience: mitigation capacities in the long run (ENSURE Matrix 4)

	System	Aspect	Parameters	Criteria for assessment	Descriptors	Application to case study
Natural environment	*Natural ecosystems*	Are natural environments hit by the event able to recover from damages to species and ecosystems?	Type of forests damaged by landslide;	depending on vegetation characteristics		
			frequency of activity of landslide movements	depending on meteorological and geological factors and on vegetation characteristics		
		Are natural environments and ecosystems able to recover from mitigation measures that have a relevant negative impact?	type and extent of mitigation measures	depending on vegetation characteristics		
			Type of forests damaged by landslide;	depending on vegetation characteristics		
		Structural defenses	Consolidation and drainage	expert judgment;	feasible/not feasible;	Projects of feasible structural

			works	evaluation of improvement/worsening of landslide dynamics	funding mechanisms in the reconstruction program	works to improve the drainage in the landslide area have been already designed. After an event there may be the conditions for funding such works particularly in the rich province of Bolzano
Built environment	*Exposure and vulnerability of built environment*	Is the urban fabric/built environment able to recover reducing pre-event vulnerability?	New development and reconstruction programs include risk prevention as an everyday activity	degree	yes/partially/no	There is a very strong pressure in the area as a consequence of flourishing tourism. Restrictions on buildings are unlikely.
			Detailed analysis of damage	degree and scale	yes/partially/no; at individual building/neighborhood/ municipal scale	
			Lessons from landslides impact is considered for new construction and retrofitting	degree	yes/partially/no	
			Availability of partial relocation programs during reconstruction for the most critical situations	binary	yes/no	
			Relevance of potentially affected settlements in geographic/economic terms	degree of relevance	Central/peripheral	The area is very central to the region economy and certainly also important for the local economy
Infrastructure and tourist facilities	*Critical infrastructures*	Are there tools to recover critical infrastructures rapidly and at low costs?	Computerized mapping systems of infrastructures	binary	yes/no	
			In site devices for quick survey of damaged parts	binary	yes/no	
			Availability of personnel and spare materials for repairs	binary; time needed to bring on site spare materials	yes/no; < a day/>1 day	
			Existence of protocols to proceed with repairs requiring inter-lifelines interventions	degree; number of different stakeholders to be coordinated in repair efforts	yes/partially/no; protocols among all companies or coordinated by authorities/limited agreements	
			Lessons from landslides impact is considered for lifelines repair	degree	yes/partially/no	
	Tourist facilities		Temporary transferability of economic activities in case of need	binary	applicable/not applicable	Transferring hotel and other tourists' activity is very difficult. One may change valley but this would not imply the temporary transfer of an economic activity in another side, but rather the net profit of other areas at the expense of those damaged
			Existence of funds for fast repairs	binary	yes/no	
			Existence of inspection and guiding personnel for correct repairs	binary	yes/no/forecasted in the recovery plans	

Social system (agents)	*People/ individuals*	Are people in the position to be resilient in the face of a catastrophe?	Availability of private resources to resettle/repair	binary and level of support by public organizations	yes/no; highly supported/lack of advisory personnel	Yes, high income
			Access to insurance	binary; percentage of coverage	yes/no; % without insurance	I guess no
	Community	Is the affected community resilient to the consequences of a catastrophe?	Employment rate	degree	high/medium/low	The Corvara area has experienced in the last years a renovated migration of younger couples, attracted by the beauty of the place and encouraged by the income guaranteed by the tourist sector
			Annual population growth rate (over the last five years)	trend	high/medium/low/negative	
			Immigration index	new immigrants/emigrants	high/medium/low/negative	
			Social networking	qualitative judgment	high/medium/low/negative	high social networking due to: high density of family relationships; existence of a very ancient cultural community (ladinians); relatively low number of inhabitants
			Criminality rate	degree	high/medium/low	
			Conflict among social/ethnic groups	degree	high/medium/low	
			Condition of affected part of the community with respect to the wider provincial context	degree	strongly connected/integrated/marginalized	
	Institutions	Are institutions in charge of reconstruction transparent, reliable and trustable?	Degree of trust in institutions	degree	high/medium/low (from sociological surveys when available)	The Bolzano province has the status of an autonomous entity, with large autonomy with respect to the central government; decisions and funds can be allocated locally without significant constraints form outside
			Transparency in funds allocation	binary	Existence (yes/no) of public information and independent control mechanisms	
			capacity to take action in tight relation to the scientific world	Degree		operative relationship lasting more than 10 years between the Municipality, The University of Modena and Reggio Emilia, The CNR of Padova and Ufficio Prove e Materiali of the Autonomous Province of Bolzano
			Capacity to pursue mitigation strategies	Degree	yes/only partially/no	
	Economic stakeholders	Are economic stakeholders capable/ wishing to reinvest in affected areas?	Insurance coverage for direct damage and loss of workdays	binary; percentage of coverage	yes/no; % without insurance	yes
			Dependence of economic actors on loss of environmental goods	Prevalent tourist activity; agricultural activity	percentage	Very high as the tourist sector is the most relevant in the mountain valley areas

4.4 Concluding Remarks for the Corvara case study

From the application of the ENSURE methodology to the Corvara case study, we can draw the following conclusions:

- The 1st matrix of the framework (*"Resilience: Mitigation Capacity*", Table 2) is the best one to implement the Corvara landslide - hazard and risk plans into the vulnerability scheme: that because those plans are the best measure to verify the capability of a municipality to cope with natural hazardous phenomena, trying to prevent their negative effects on the natural and built environments. Good alert and civil protection systems may develop only if those plans exist. The main problems found are essentially the necessity to constantly update those plans and to cope with the deterioration of mitigation works and sometimes also of monitoring systems.
- The 2nd matrix (*"Physical Vulnerability: vulnerability to stress (hazard)"*, Table 3), if a small area is considered, works properly since quantification of both impact energy and strength of structures and infrastructures can be reasonably done. That is not feasible for a wider area like a municipality and the Corvara case study showed how a more qualitative approach might give "more usable" (and more economically affordable) results.
- Regarding the 3rd matrix (*"Systemic vulnerability: vulnerability to losses"*, Table 4) within the Corvara case study not much has been done by the Community to assess capacity to recover of structures, infrastructures and systems. Nevertheless, we suggested again a more qualitative "degree-of-functionality" assessment, certainly more applicable at the meso-scale. Moreover, we stressed the need to have the best picture as possible of past events and damages (also taking advantage of experiences made in other areas) in order to forecast what degree of functionality can be expected also in the future. Qualitative results from the physical vulnerability assessment (matrix 2), have demonstrated to be useable to forecast semi-quantitative losses (direct and indirect) that may affect even the systemic economy, with all its relevant domino effects.
- Finally, the 4th matrix (*"Resilience: response capability in the long run"*, Table 5) deals partly with something that has not been considered in Corvara (i.e., Civil Protection Plan), but whose goodness depends a lot on the existence of hazard and risk plans, which we identified in matrix 1. While the value of a Civil Protection Plan depends at first sight from the availability of devices and on the preparedness of people (at all levels), it surely depends also on the presence of well-done and updated hazard and risk plans. Therefore matrix 4 leads back to matrix 1 along the timeline axis, showing that "updating of knowledge" is the most important parameter to work on.

4.5 References

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