

Analysis of Hydrogeological Risks Related to Climate Change: Testing the ClimeApp Assessment Tool on the Torino Nord Homogenous Zone

*Original*

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The Urban Book Series

Grazia Brunetta  
Patrizia Lombardi  
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# Post Un-Lock

From Territorial Vulnerabilities to Local  
Resilience

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Grazia Brunetta · Patrizia Lombardi ·  
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### *Editors*

Grazia Brunetta  
DIST—Interuniversity Department  
of Regional and Urban Studies  
and Planning  
R3C—Interdepartmental Responsible Risk  
Resilience Centre  
Politecnico di Torino  
Turin, Italy

Patrizia Lombardi  
DIST—Interuniversity Department  
of Regional and Urban Studies  
and Planning  
Politecnico di Torino  
Turin, Italy

Angioletta Voghera  
DIST—Interuniversity Department  
of Regional and Urban Studies  
and Planning  
R3C—Interdepartmental Responsible Risk  
Resilience Centre  
Politecnico di Torino  
Turin, Italy



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# Preface

This book is the first result of the “Post Un-Lock” research project, funded by the Interuniversity Department of Regional and Urban Studies and Planning (DIST) of the Politecnico di Torino, a three-year work involving the collaboration of a large number of researchers belonging not only to different departments and institutions but also to diverse disciplinary areas.

The research involves teams from the Department of Environmental, Land, and Infrastructure Engineering (DIATI) of the Politecnico di Torino (such as environmental and geomatics engineers), the Department of Mathematical Sciences “Giuseppe Luigi Lagrange” (experts in mathematical statistics), and the Department of Medical Sciences of the Università di Torino (researchers in the field of medical statistics and epidemiology), committed to reflecting on the territorialization of the pandemic and the effects of pollution on health in cities.

The Post Un-Lock research took shape in the last months of 2020, triggered by the scientific impulse of the international goals of sustainability and resilience in the perspective of the post-carbon city and the overcoming of environmental, economic, social and health crises. Scholars have collaborated and tested on case studies methodologies, approaches, and tools capable of re-imagining cities and regions to overcome vulnerabilities and to innovate the socio-ecological system on the basis of the ideal-typical model of Local Resilience Unit.

With this in mind, we would like to thank, in addition to the authors of the chapters and their collaborators: the partners of the research such as the Inter-departmental Centre Responsible Risk Resilience Centre (R3C), the SDG11LAB, the S3+Lab (Urban Sustainability and Security Laboratory for Social Challenges), the CED PPN (European Documentation Center on Natural Park Planning), the Living Lab and the PIC4SER of Politecnico di Torino. We would also like to thank the external supporting institutions such as IUGA of Grenoble, University of South Denmark, CMCC (Euro-Mediterranean Center on Climate Change), and the administrations involved in the case studies, whose suggestions provided crucial support for the outcomes of this publication. Other institutions and people we would like to thank are: Nicola Tollin, Professor with special responsibilities in Urban Resilience, UNESCO Chair at University of Southern Denmark (SDU), ITI,

Civil and Architectural Engineering; Joe Ravetz, Co-director of the Collaboratory for Urban Resilience and Energy at the Manchester Urban Institute, University of Manchester; Jordi Morató, Director UNESCO Chair on Sustainability at Polytechnical University of Catalonia; Michele Talia, Istituto Nazionale di Urbanistica (INU); Stefania Crotta, Direzione Ambiente, Energia e Territorio of Regione Piemonte; Milena Maule, Associate Professor of Medical Statistics and Epidemiology at Department of Medical Sciences of Università di Torino (UNITO); Egidio Dansero, Professor at Department of Cultures, Politics, and Society (UNITO) and delegate at RUS; Alessio Malcevski, Professor at Università di Parma, RUS delegate; Stefano Armenia, Senior Research Fellow at Link Campus University, president of System Dynamics—SYDIC; Rosa Gilardi, Director of Area Urbanistica e Qualità dell’Ambiente Costruito, Città di Torino; Gilles Novarina, Laboratoire Architecture Environnement and Cultures Constructives at Université Grenoble Alpes—École Nationale Supérieure d’Architecture; Guglielmo Filippini, Direzione Risorse Idriche e Tutela dell’Atmosfera at Ufficio Pianificazione e Controllo delle Risorse Idriche of Città Metropolitana di Torino.

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Patrizia Lombardi  
Angioletta Voghera

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# Chapter 9

## Analysis of Hydrogeological Risks Related to Climate Change: Testing the *ClimeApp* Assessment Tool on the Torino Nord Homogenous Zone



Elena Pede, Mattia Scalas, and Luca Staricco

**Abstract** The current changes in temperatures and precipitations can lead to increased frequency and magnitude of natural hazards such as floods, resulting in forthcoming losses of life and damages to private and public properties. This paper presents an applied hydrogeological risk assessment methodology developed as part of an interdisciplinary European project between France and Italy (Interreg Alcotra ARTACLIM). A practical framework is proposed to assess the risk for urban settlements and infrastructural assets at a sub-regional level, within one of the 11 homogeneous zones of the Turin Metropolitan City, the “Torino Nord” Homogeneous Area of Pinerolo (ZOP). Based on the most reliable guidelines of institutions and organizations such as IPCC, United Nations, Covenant of Mayors for Climate & Energy EUROPE, the methodology here presented identifies risks related to climate change as a function of hazard (H), exposure (E) and vulnerability (V) factors, the latter one being in turn a function of sensitivity (S) and adaptive capacity (AC). Each factor is operationalized through specific indicators. The results of the analysis generate a geo-localized risk score that can be used to support urban planners and local policy-makers to prioritize the adaptation measures required for reducing hydrogeological damages related to climate change.

**Keywords** Risk assessment · Climate change · Hydrogeological risk · ClimeApp · Turin Metropolitan Area

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E. Pede (✉) · M. Scalas · L. Staricco  
DIST—Interuniversity Department of Regional and Urban Studies and Planning,  
R3C—Interdepartmental Responsible Risk Resilience Centre, Politecnico di Torino, Turin, Italy  
e-mail: [elena.pede@polito.it](mailto:elena.pede@polito.it)

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## 9.1 Introduction

It is well-acknowledged that climate change can lead to increased frequency and magnitude of natural hazards such as landslides, rock falls, debris flows, avalanches, forest fires and floods (Field et al. 2012), which can generate potential negative impacts on infrastructures, socio-economic and cultural activities, ecosystems and so on. Most of these impacts—floods, in particular—cannot be effectively faced at the local level, but require conceiving and implementing adaptation strategies at a sub-regional, inter-municipal level (Birkmann 2011).

This article presents *ClimeApp*, a spatial risk assessment tool developed in the framework of the European Interreg research project ARTACLIM (<http://artaclim.eu>) to assess the main challenges related to natural hazards due to climate change at the sub-regional level. *ClimeApp* allows to evaluate how climate change can increase risks in terms of natural hazards (floods, landslides, avalanches, forest fires and droughts) on built settlements, infrastructures, tourism, agriculture, forests and biodiversity. *ClimeApp* assessments can be developed with reference to two representative concentration pathway (RCP) scenarios (the IPCC RCP4.5 and RCP8.5 scenarios; see IPCC 2014) and two time periods (2021–2050 and 2070–2100).

In the next sections, after a short presentation of the methodology at the basis of the tool, a pair of *ClimeApp* experimentations will be illustrated. They concern two of the eleven so-called *homogeneous zones* in which the Metropolitan City of Turin (chief town of the Piedmont region) is articulated; this spatial scale was chosen as it is often considered the more suitable administrative dimension to elaborate ad hoc adaptation strategies and measures. The two experimentations will show how *ClimeApp* can be used as a spatial decision support system for public administrations and local stakeholders in order to identify how hydrogeological risks due to climate change are (and will be in future) distributed inside a homogeneous zone, and which adaptation measures can be implemented to face these expected risks for built settlements and infrastructures.

## 9.2 The ClimeApp Assessment Tool

ClimeApp is based on the guidelines developed by institutions and organizations such as IPCC, United Nations, Covenant of Mayors for Climate & Energy EUROPE and the Alpine Convention (Bertoldi 2018; Probst et al. 2013; Schindelegger and Kanonier 2019; Zollner 2018), which identify risks related to climate change as a function of *Hazard* (H), *Exposure* (E) and *Vulnerability* (V) factors, the latter one being in turn a function of *Sensitivity* (S) and *Adaptive Capacity* (AC).

For the risks, we are considering in this paper, e.g., hydrogeological risks for built settlements and infrastructures, the *Hazard* represents the past and future occurrence of hydrogeological events due to the changes in the temperature and rainfall patterns (Oppenheimer et al. 2014). The *Exposure* refers to the built settlements

and to the infrastructural systems that can be hit by these hydrogeological events. *Sensitivity* measures the degree to which the built and infrastructural systems can be unfavourably or beneficially affected by a certain climate change (GIZ 2017), while *Adaptive Capacity* refers to the ability of those systems to adapt to this change and its consequences (Oppenheimer et al. 2014).

Each factor is operationalized through specific indicators,<sup>1</sup> which are calculated for each of the municipalities within the considered homogeneous zone. In order to be aggregated in *Hazard*, *Exposure* and *Vulnerability* indexes, all indicators are normalized by applying the Min–Max method (Ellena et al. 2020; GIZ 2017), which translates their values into scores between 0 and 1. For some indicators, lower values reflect positive conditions; in this case, an operation of *conversion* is made by reversing the direction of the value range in order to have all indicators in the same normalization ranking (from 0 to 1). *Hazard*, *Exposure*, *Sensitivity* and *Adaptation Capacity* indexes are calculated as a weighted average of their normalized indicators; *Vulnerability* is calculated as the average of *Sensitivity* and *Adaptation Capacity*. At the end, the final risk value for each municipality is calculated as the product of the values of the *Hazard*, *Exposure* and *Vulnerability* indexes.

A *Geographic Information System* (GIS) spatial analysis tool is provided by *ClimeApp* to map and represent the distribution of the values of the indicators and indexes inside the considered homogeneous zone.

### 9.3 Testing *ClimeApp* on the Homogeneous Zone of Pinerolo

The *ClimeApp* tool has been tested as first instance in the framework of the ARTA-CLIM project on the *Homogeneous Zone of Pinerolo* (HZP), due to its geographical structure and the economic vocation based on outdoor sports (Ellena et al. 2020). From a geomorphological point of view, the HZP can be divided into three parts: an agricultural plain (12 municipalities), a hilly belt around the main town of Pinerolo (10 municipalities) and a mountainous area which borders on France and includes three valleys lying end to end (Val Pellice, Val Germanasca and Val Chisone) (23 municipalities).

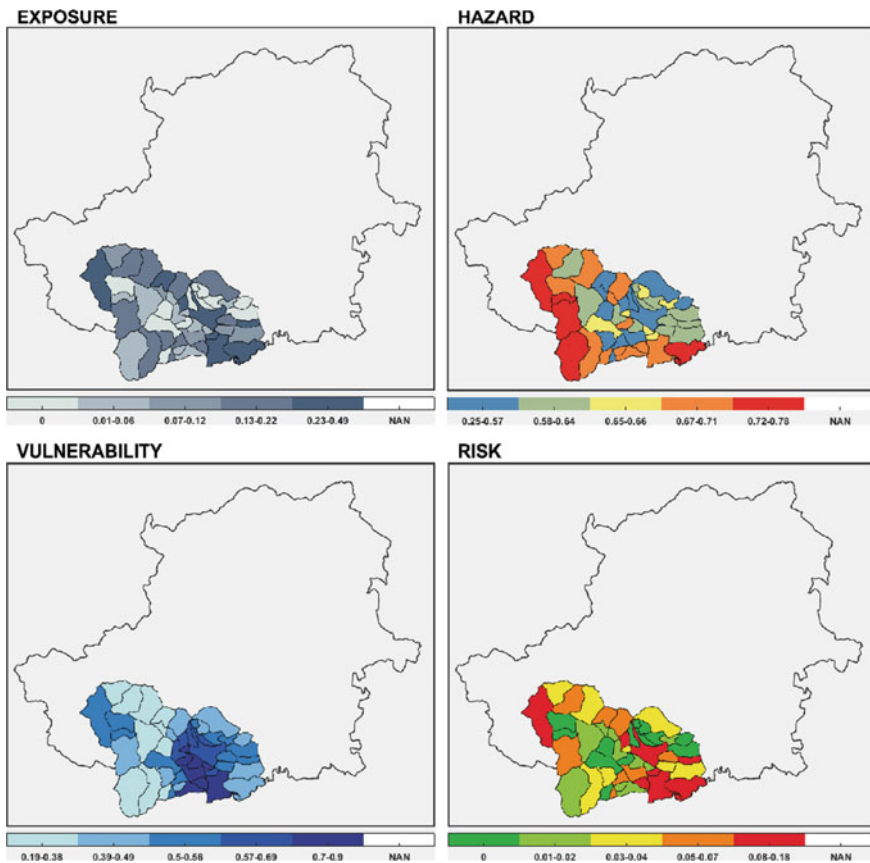
Observing the climatic variations, results highlight a general increase in temperatures, more pronounced in the long-term period with the RCP 8.5 scenario. Looking

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<sup>1</sup> For a detailed description of the indicators used in the case of hydrogeological risks for built settlements and infrastructures, see Ellena et al. (2020). Hazard indicators measure, in particular, the increase of temperature and precipitation frequency (through, for example, the annual total precipitation in wet days, the total number of days when precipitation > 1 mm, etc.). Examples of exposure indicators are the number of residents (or the hectares of industrial and commerce buildings) in places that could be negatively affected by floods. Sensitivity can be assessed using indicators such as the percentage of buildings in bad condition on the total number of buildings at the municipal level, or the number of inhabitants over 75 years old on the total population. The number of voluntary organizations active at municipal level and the percentage of dwelling units served by ultra-wide band technology are example of indicators for the adaptive capacity.

back to the phase 1981–2010, the observed climate evolution in terms of precipitation regimes and thermal increase has affected mainly the municipalities in the lower valleys, while it has had little impacts in the mountainous area until now. In future, projections may follow opposite trajectories. A strong reduction in the number of days with minimum and maximum temperature lower than 0 °C is expected over the area, but more pronounced in the high-elevation municipalities. Besides, the climate models predict a reduction in the number of rainfall days, more pronounced in the Alps, but an increase in precipitation intensity especially over the plains.

The final result is an overall increase of hydrogeological instability over the HZP with different levels of risk according to the kind of natural hazard addressed, the temporal frame considered and the three indexes' values (*Hazard*, *Exposure* and *Vulnerability*, Fig. 9.1). Therefore, these risk levels distribute very differently depending on elevation and morphology.



**Fig. 9.1** From top left: exposure, vulnerability, hazard and risk (RPC4.5, 2021–2050, settlement and flooding) in HZP from ClimeApp visualizations

With reference to floods, settlements in high mountains and hilly territories will be increasingly vulnerable because of poor building conditions, high percentages of land use consumption and low adaptive capacity levels.

Flat and low hill areas of the HZP, however, will be most affected (specifically, municipalities located between the confluence of the Chisone and Pellice rivers). Even if a modest increase is expected in rainfall frequency and intensity (hazard), the exposure will be high due to the number of buildings and infrastructure systems considered at risk of flooding and to the number of inhabitants located in the same areas.

Finally, in the mountain area the hydrogeological aspects are complicated by the instability of the slopes and the increase of avalanches.

The significant rise of temperatures and the changes in the rainfall regimes will also have indirect consequences. The local economy is mainly based on outdoor sports and active tourism; being mainly dependent on natural resources and climate, this key sector is therefore particularly vulnerable to impacts of climate change.

In particular, a reduction in the frequency and intensity of snowfall will force the tourism sector to concentrate skiing activities at altitude over 1500 m. The negative impacts could be partially balanced for the high-elevation municipalities by increased opportunities related to summer tourism. The limited expected temperature increases and the decreases in precipitation, indeed, will extend the typical length of the summer season and, at the same time, the hills and the plain will be more hit by heat waves leading more people to look for coolness at a higher altitude.

However, these effects could be exacerbated by the increase of hydrogeological instability. This means that even if the touristic municipalities in the mountain part of the HZP are not significantly affected by climatic risks, they can be indirectly harmed in terms of accessibility of the infrastructural system due to the intensification of extreme events.

## **9.4 The Application of *ClimeApp* to the Homogeneous Zone of North Turin**

### **9.4.1 Context and Methodology**

In the framework of the Post Un-Lock project, a second application of *ClimeApp* was carried out on the Homogeneous Zone 4 of North Turin (HZNT). It includes the seven municipalities of Borgaro Torinese, Caselle Torinese, Leinì, San Benigno Canavese, San Mauro Torinese, Settimo Torinese and Volpiano. Since 2017, these municipalities have been joined by a new one, Mappano, which was instituted as a result of the separation of portions of the territory of Caselle Torinese, Borgaro Torinese, Settimo Torinese and Leinì.

HZNT is one of the smallest homogeneous zones in the Metropolitan City of Turin, both in terms of surface area (165.3 km<sup>2</sup>) and number of component municipalities.

However, it is densely populated (129,721 inhabitants in 2019) as it includes some of the most populous municipalities in the entire Metropolitan City.

It hosts a relevant infrastructural system, which includes the Turin-Milan high-speed railway line, the A5 and A4 motorways, the international airport of Turin-Caselle. It connects the city of Turin with the areas of Ciriacese to the west, Canavese to the north and Chivassese to the east.

At morphological level, the area is predominantly flat, characterized by a strong territorial homogeneity and by dependence relationships with the nearby chief town of Turin, of which it constitutes a northern hinterland area. A relevant aspect of the area is the relationship between the settlement fabric and the configuration of the local hydrographic network (made up of rivers and a system of historical channels, the so-called *bealere*), which exposes it to hydrogeological risks due to fluvial–torrential dynamics.

This relationship between the river and canal network and the high concentration of population has stimulated the experimentation of *ClimeApp* with reference to the flood risks for the built settlement, analysed according to the two IPCC emission scenarios RCP4.5 and RCP8.5 and with a medium, 2021–2050, and long-term time horizon, 2071–2100. Both scenarios (2021–2050 and 2071–2100) are compared with the period 1981–2010. RCP4.5, the *Strong Stabilisation* scenario, expects emissions to fall below current levels by 2070, while RCP8.5, the *Business-as-usual* scenario, assumes growth to continue at current rates, with an estimated increase by the end of the century of between 840 and 1120 ppm.

As in the HZP case study, the Climate Hazard indicators have been calculated by the CMCC Foundation within the EURO-CORDEX project.

The *Exposure* indicators used open-source data accessible through the regional geo-portal, the National Institute of Statistics (ISTAT) and data released by governmental agencies—e.g. those relating to the average taxable income per taxpayer. These indicators make it possible to model the presence of human activities with particular attention to settlement, production, areas classified as flood risk, services, and agricultural and cultural heritage assets. *Sensitivity* indicators, on the other hand, investigate phenomena such as the impact on the population of younger and older people, income, land consumption and the reduction of ecosystem services. *Adaptive Capacity* indices map the presence of services and initiatives that decrease vulnerability, such as the presence of hydraulic works, the level of digital connectivity ensured by ultra-wideband, the presence of institutions with volunteers, the involvement into institutional processes oriented towards adaptation and sustainability and the openness towards these issues.

#### 9.4.2 Cross-Cutting Remarks and Indicators

The calculation of the indicators was carried out with GIS tools for all those indices related to areas such as hectares of residential buildings, agricultural and so on, or by counting, as in the case of the presence of hydraulic constructions. For the other

indicators, operations were carried out through direct consultation of sources. In some cases, particularly regarding institutional indicators of *Adaptive Capacity* such as the level of openness to environmental sustainability issues, research was carried out to map the presence of institutions, health centres, universities or other legal forms whose very presence is indicative of attention to this issue. It should also be noted that for some indicators, the ISTAT data used dates to 2011, the year of the most recent census published by the Institute, which could differ significantly from the current demographic condition of the study area.

The indicators of *Exposure*, *Adaptive Capacity* and *Sensitivity* are used as a basis for the calculation of the risk together with the *Hazard* indicators, calculated according to the IPCC scenarios. Before describing the variation of the risk in the four scenarios, it is therefore appropriate to proceed with the description of the *Exposure*, the *Adaptive Capacity* and the *Sensitivity* that frame the situation of the HZNT in 2021. It should be noted that for the Municipality of Mappano, it was not possible to calculate numerous specific indicators as the Municipality had not yet been established at the date of acquisition of the necessary datasets. In any case, the values assumed by the neighbouring municipalities in the portion of the territory that these same municipalities have given to the new municipality can be referred to Mappano.

The *Hazard* indicators used to analyse the settlement system and floods framework relate to the increase in the frequency and intensity of rainfall with reference to the number of days of the year with rain, the cumulative and maximum daily precipitation over five consecutive days.<sup>2</sup>

The *Exposure* indicators considered are residential areas, industrial and commercial areas, supra-municipal services, historical and environmental assets, areas with agricultural use, areas with unrecognized use and the inhabitants settled in flood risk areas sanctioned by law (PAI areas). High exposure conditions are noted in Caselle Torinese, followed by Volpiano and Settimo Torinese.

*Adaptive Capacity* and *Sensitivity* define the dimension of *Vulnerability*. The *Adaptive Capacity* indicators considered are the presence of hydraulic infrastructures, institutional initiatives for adaptation to climate change, ultra-broadband coverage, institutions with volunteers and attention to environmental sustainability issues. Some of these indicators, especially the institutional ones, have been obtained with a qualitative survey of the plans and initiatives in force in the municipalities and at the supra-municipal level.

The *Sensitivity* indicators considered are, on the other hand, the incidence of buildings in a poor state of conservation, soil consumption, the reduction of ecosystem services in the woods, the population over 75 and children under the age of 6 and taxable income.

Overall *Vulnerability* is particularly high in the municipality of Borgaro Torinese, followed by Leini and Settimo Torinese.

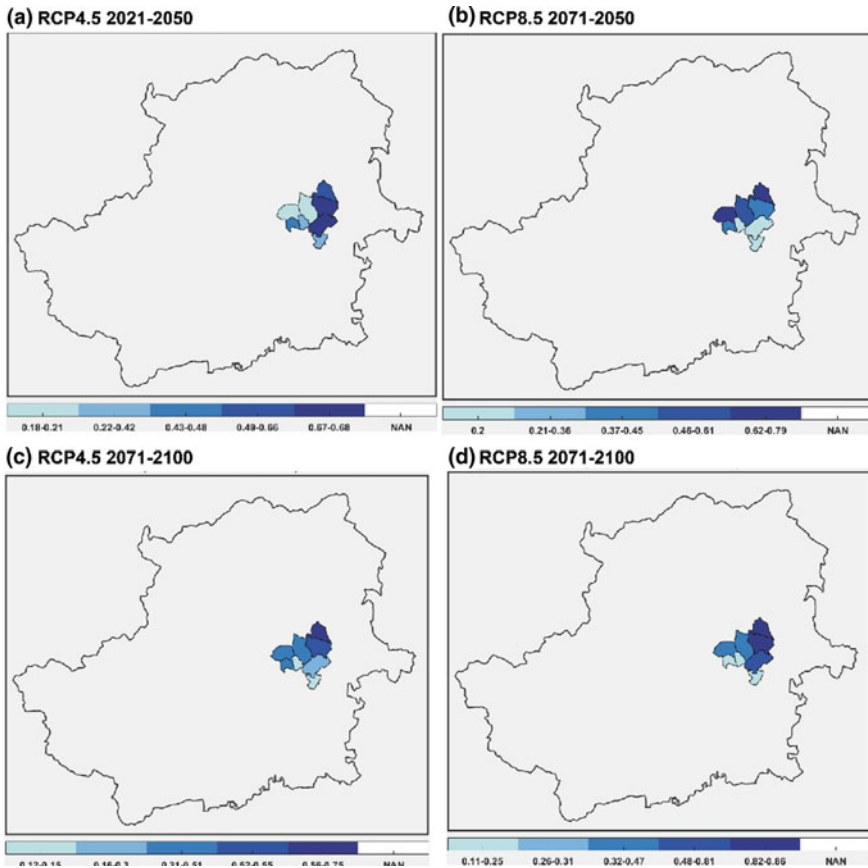
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<sup>2</sup> The complete list is available in Ellena et al. (2020).

### 9.4.3 Results

The first risk scenario (RCP 4.5, 2021–2050) considers the IPCC RCP4.5 emission scenario with a medium-term time horizon (Fig. 9.2a). The level of risk propensity compared to the current scenario for the settlement system with respect to the flood risk is higher in the municipalities of Settimo Torinese, Volpiano and Borgaro compared to the rest of the homogeneous area. The risk is related to a significant increase of *Hazard* in the eastern part of the territory, in particular in the three municipalities of San Benigno, Volpiano and Settimo Torinese.

The second scenario (RCP 4.5, 2071–2100), the simulation uses the same emission scenario but is projected over the period 2071–2100 (Fig. 9.2b). The most significant growth in risk compared to the current state is found in the three municipalities of Caselle Torinese, Leinì and Volpiano. The *Hazard* indicators in this case show a high



**Fig. 9.2** From top left: Hazard scenarios: RCP4.5 2021–2050, RCP8.5 2071–2050, RCP4.5 2071–2100, RCP8.5 2071–2100

incidence in the north-northeast area of the territory, in particular in the municipalities of San Benigno and Volpiano followed by Leini, Caselle and Borgaro.

The third scenario (RCP8.5, 2021–2050) uses the RCP8.5 emissions scenario, projected to the period 2021–2050 (Fig. 9.2c). The overall risk propensity with respect to flooding dynamics on the settlement system is increasing more markedly in the municipalities of Caselle Torinese and Leini. In terms of *Hazard*, also in this case there is a higher incidence of indicators in the northern part of the area, with peaks in the municipalities of Caselle and San Benigno.

The fourth and last scenario (RCP8.5, 2071–2100), again adopting the RCP8.5 emission scenario, refers to the 2071–2100 timeframe and indicates a more marked propensity to risk in the entire central area, particularly in the Volpiano and Settimo Torinese territories (Fig. 9.2d). *Hazard* indicators related to flooding phenomena show more consistent growth in the whole northern and eastern area, in particular in the municipalities of San Benigno Canavese, Volpiano and Settimo Torinese.

#### 9.4.4 Discussion and Conclusion

As the two case studies have shown, a tool such as *ClimeApp* can be a useful support for planning adaptation to climate change in areas where hydrogeological risks are relevant. As a matter of fact, *ClimeApp* allows to study how and where foreseen long-term changes in temperature and precipitation can increase these risks due to the increasing frequency and intensity of natural hazards. Moreover, the tool offers the opportunity to identify how much the risks are related to these hazards, or to features of the studied area such as its *Exposure*, *Sensitivity* and *Adaptive Capacity*. In these senses, the simulations carried out for the HZP and the HZNT have contributed to identify in which municipalities inside each of the two homogeneous zones is prior to promote adaptation; they also highlighted on which exposure and sensitivity factors it is important to focus actions in order to reduce the overall risks. At the same time, a comparison between the two—quite different—cases of application of the tool (Fig. 9.3) presented in this chapter let emerge some of its limits. Whereas the HZP is characterized by great heterogeneity between its components (three valleys, a wide plain, a hilly part, etc.) and the municipalities that make it up, the HZNT has a high level of internal homogeneity, also at a morphological level (Fig. 9.3). In the first case, it turns out to be difficult to compare the levels of hydrogeological risks among very different sub-areas inside the HZ; in the second case, conversely, the tool fails to identify consistent differences within the HZ. Probably, a level of heterogeneity intermediate between those of the HZP and the HZNT is the most appropriate for *ClimeApp*. A second limit is related to the relative—and not absolute—nature of the results that *ClimeApp* elaborates, due to the normalization processes that it uses. Indeed, *ClimeApp* specifies for each municipalities how great the level of risk is, not in absolute terms, but relatively to the levels of the others municipalities inside the HZ. If some of the indicators are changed for a municipality (e.g. simulating



**Fig. 9.3** Location of HZP and HZNT homogeneous zones in the territory of the Metropolitan City of Turin, Piedmont, Italy

some adaptation actions), *ClimeApp* shows how much the risks are reduced for this municipality in comparison with the risk levels of the others.

Considering these cautions, *ClimeApp* can support effectively public administrations in testing and defining adaptation strategies at an over-municipal scales, in particular at highlighting where and on which factors it is prior to focus actions and measures. This approach is particularly important for hydrogeological hazards and risks, which can be successfully faced only and just at a wide-area scale.

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