ISSN: 2239-267X

A method of heat risk territorial assessment to support the urban planning[1]

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KEYWORDS: territorial risk assessment, urban planning, heat risk mapping, climate transition, adaptation to climate change

ABSTRACT

The heat risk territorial assessment is a tool for evaluating strategies and actions to combat high temperatures because it can consider the spatial factors and trends and to identify the places of greatest risk. This tool requires the use of a method based on the mapping of hazard, exposure and vulnerability factors.
This article is the report of two complementary and integrated activities that describes an elaboration path not yet concluded. The first activity concerns the continuation of the development of a functional evaluation method for integrating territorial risk analysis with urban planning tools; the second activity, carried out as part of an applied research on climate change adaptation actions, concerns the application of a method of heat risk territorial assessment of the population. This application was made on a municipality of the Città metropolitana di Milano where we were able so far to develop only some aspects of the risk analysis, while later we will integrate this application with the urban plan. However, the repercussions on urban planning decision-making processes that the aim is to achieve range from pervasive and aware management of urban transformations oriented towards the overall reduction of heat risk levels to the realisation of resolutive punctual interventions.

[1] With the contribution of Nicola Colaninno for mapping.

INTRODUCTION

The increases in temperature and magnitude and frequency of heat waves due to climate change increase the endanger health and comfort of people in urban areas, especially on the most vulnerable population. Since the cities are not evenly exposed to hazards, it gets very useful to identify hotspots of higher risk within an urban area. Therefore, the heat risk territorial assessment based on the mapping of hazard, exposure and vulnerability is a fundamental tool for the development of effective strategies and contrast actions based on interventions on physical-morphological, socio-economic and organizational factors of a city (Wang et al. 2016, Bernatik et al. 2013, Kleerekoper et al. 2012). These factors, unlike those used for the elaboration of emergency strategies and actions, have a predominantly structural nature and require longer intervention times to obtain a significant, but lasting, reduction in risk levels (Klinke, A. and Renn O., 2002; Renn and Klinke, 2013). Therefore, from the planning point of view it is necessary to integrate the heat risk territorial analysis with the typical processing paths of urban planning tools (Renn and Klinke, 2013; Georgi et al. 2012; Birkmann, 2007).

Within this process of integration, the mapping of heat risk factors constitutes key steps in applied research to give methodological and applicative completeness and solidity to this tool starting from some operational steps such as the representation, evaluation and the weighting of risk factors. Starting from consolidated and worldwide recognized procedures EU, 2010; IPCC, 2018 and 2022; C40 Cities, 2018; JRC, 2021; ISO 14091:2021; UNDRR, 2022), in recent years, this result has been much less difficult to achieve due to the greater availability of digital data, including those remotely detected with high spatial resolution (soil temperatures, vegetation shading, land uses, ...) which allow the use of models and produce sufficiently accurate maps for risk assessment (Perge et al. 2014, Bechtel et al. 2015, Middel et al. 2022).

This article is a contribution towards the development of effective methods of heat risk territorial assessment to support the development of risk reduction strategies integrated with urban planning. Such assessments must be based on open, flexible and repeatable mapping systems, which is also an important requirement to support stakeholder participation and the adoption of co-design practices.

The paper is divided into three parts.

The first part describes the theoretical and applicative characteristics of a method of heat risk territorial assessment functional to the elaboration of plans, programs and strategies for the reduction of this risk.

The second part is dedicated to a brief illustration of an application case, carried out in the context of an applied research funded by the Italian Ministry for Climate Transition (AP+A 2022), concerning the elaboration process of the summary maps of the heat

risk territorial assessment of the population of a municipality in the Città metropolitana di Milano.
The third part reports the main theoretical and applicative problems encountered in the development and application of this method and indicates the probable future developments to be implemented.

1. A METHOD OF HEAT RISK TERRITORIAL ASSESSMENT

1.1. Assessment and methodological characters

1.1.1. Theoretical references

This method can be placed in the set of methods, not formally defined, which assume the following two principles as guidelines:

1. rigorous use of risk analysis criteria as defined by the main international players dealing with risks due to climate change (United Nations, European Union and IPCC);
2. adoption of a rigorous approach in the development of the evaluation method and in its application in planning processes, the steps of which must achieve a coherent succession in logic and content.

The use of risk analysis criteria requires that the assessment process is based on the interaction of the three classic risk factors, of which we recall the characteristics that are assumed in this method (Author, based on EU 2010 and IPPC, 2018):

- the hazard, which indicates an event or a phenomenon whose occurrence generates negative impacts (damages and losses) on the territorial system, understood here as a complex system which includes not only the physical-natural elements, but also socio-economic and cultural ones, and whose dangerousness is a function of the probability that it will occur and of its intensity, frequency and spatial dimensions;
- the exposure to hazard of the territorial system, which indicates the total value of people, goods, ecosystems, etc. which could suffer the negative effects of the hazard on their structures, functions and capacity to cope and adapt;
- the vulnerability of the exposed territorial system, which indicates it, and its elements, propensity or predisposition to be adversely affected by a hazard and therefore to suffer losses and damage to their structures, functions and capacity to cope and adapt. Vulnerability depends on socio-economic, environmental and institutional factors and the characteristics of the built environment, the uses of resources and the activities that take place there.

In order to obtain a coherent and consistent succession of the various phases of elaboration of this method, it is necessary to clearly define and appropriately develop, possibly sharing them with the stakeholders, the following evaluation steps: (Papathoma-Köhle et al. 2016b; Roeser et al., 2012, Renn and Klinke, 2013; Renn, 2008; Basta, 2012; Birkmann, 2007):

- identification of the risk, understood as the identification of the context and basis of the risk assessment;
- type of use of risk analysis, which can support plans, programs or projects or monitoring systems;
- definition of risk criteria, to decide to what extent a risk is acceptable, tolerable or intolerable (eg number of deaths, number of medical interventions, material damage, financial losses);
- the basis of the risk assessment, characterized by the type of hazard, territorial scale (regional, urban, neighbourhood, ...), elements at risk (people, ecosystems, buildings, ...), and the metric used to express the risk (Papatoma-Köhle et al. 2016a);
- identification, processing, mapping, measurement and evaluation of indicators sufficiently representative of the object of evaluation and consistent with the set of factors defined for risk analysis.

To these two principles we can add the adoption of Local Climate Zones (LCZs) as functional and territorial units of hazard assessment. The "LCZ system" was developed by Stewart and Oke over 10 years ago (Stewart and Oke, 2012) and has been adopted and developed in numerous applications in different countries around the world (Bechtel et al. 2015, Lelovics et al. 2016). In this process, the use of LCZs serves both to identify the different areas of a territory that have a homogeneous character from the point of view of determining the intensity of heat, and to support, in the design and implementation phases of the urban plan, the intervention criteria.

1.1.2. The aim of this method

The general aim of this method is to support plans, programs, strategies and projects to the reduction of the heat risk, especially in the urban areas. To reduce significantly the heat risk, the activation of a long process based on an in-depth knowledge of the causes and potential effects of the adverse phenomena in order to identify and implement the most effective strategies and actions to combat is required. It is therefore necessary to plan, program and project the most suitable interventions, from the urgent ones to those that can be carried out in subsequent phases, from those functional to reduce or eliminate the hazards to those aimed at adapting to the impacts of residual hazards.

The aims of the heat risk territorial assessment can be grouped in three categories of support:

- to the construction of risk scenarios resulting from climate change, which generally refer to the pessimistic, optimistic and most probable conditions among those expected to occur in the future in the area;
- to the development of strategies and the identification of actions and interventions useful for reducing risk levels based on the identification of the areas on which to intervene and on the assignment of intervention priorities;
- to the monitoring of the actions carried out, with the evaluation of their effectiveness with respect to the project scenario. Besides, the support to measure and evaluate the impacts over time of urban and territorial transformations on the heat risk levels, including the effects of the actions on the intensity of the urban heat island, fall into this category.

In planning and strategic processes, the heat risk assessment is often revised and must be changed over time. Therefore, all informative, cognitive and evaluative steps should always be updatable or editable and integrable even with new themes. This requires that all the elaborations can be retraced in case of redefinition of criteria, functions and / or transformation parameters or addition of further information. In this way, it is also possible to carry out more assessment paths based on different criteria and parameters, thus favouring the participation of stakeholders and citizens in the assessment and decision-making processes and improving the information on which decisions are made.

The heat risk territorial assessment should consider, compatibly with the availability of data, the following impacts:

- the climatic malaise that affects the inhabitants and workers of a place;
- the triggering or worsening of diseases and increasing the probability of death in the most vulnerable and fragile people;
- the degradation of urban greenery and the death of trees;
- the increase in forest degradation and the likelihood of fire, resulting in the death of wild animals;
- the climatic malaise of farm animals.

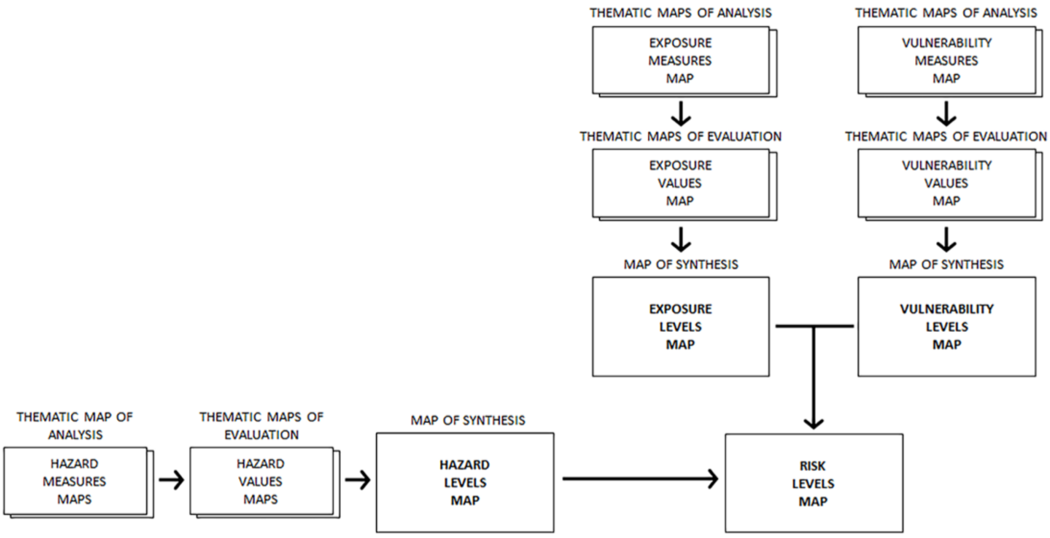
Water scarcity should not be considered since this phenomenon does not significantly affect the spatial factor as it is determined by the methods of water management and water infrastructures. Therefore, the assessment of the effects of this impact must be carried out through water balances of the area.

To assess the territorial heat risk is necessary to use a special map system functional to respond to the aims described in this and the previous section.

1.1.3. The maps system and its use in the planning processes

To spatially represent the heat risk levels in order to support urban and territorial planning processes, it is not enough to draw up summary thematic maps for each risk factor, but it is necessary to build a digital map system in which the various application steps are well structured (see figure 1). This system, based on the overlay mapping technique, must be structured with respect to the three risk factors indicated in the previous section, which are represented by as many thematic maps defined by us respectively Map of Danger Levels, Map of Exposure Levels, Map of Vulnerability Levels. To these maps must be added the Risk Levels Map, which is the final product of this map system. This system must also support the forecasting, design and evaluation process typical of planning, in which the maps of synthesis must have further versions in order to support the representation and the evaluation of the evolutionary and design scenarios of the heat risk and the relative monitoring.

Figure 1 - Structure of the digital map system for territorial risk assessment



Source: Authors' Elaboration

The Hazard Levels Map is functional to identify the most critical areas of a territory and to know the factors that determine them, in order to identify the most effective places and interventions to reduce the hazard. The territorial distribution of heat hazard levels depends on meteorological factors that are influenced by the characteristics of urban settlements and rural and natural stands, such as air temperature, relative humidity, radiant heat and ventilation (Lai, 2020). The phenomenon of heat waves, on the other hand, has no significant effects on the territorial distribution of the hazard, so it must be considered in the measurement or estimation of the previous meteorological factors.

The Exposure Levels Map represents the entity or density of one or more of the exposed elements of a territory to heat stress, which can be: inhabitants, workers and city users; urban green areas and trees; farm animals and crops; natural habitats and wild animals.

The Vulnerability Levels Map considers the socio-economic, territorial, environmental and institutional factors that can influence the effects of heat stress on one or more of the exposed elements and which therefore influence the types and intensity of losses and damages (Krellenberg et al., 2017; Sera, 2019). These factors are the sensitivity to the hazard of the exposed elements, the ability of each of them to protect themselves, the vulnerability of the territorial system and its individual elements and the potential adaptation capacity of the system.

The Risk Levels Map is generated by overlapping the three previous maps and the risk levels are assigned based on the previously attributed hazard, exposure and vulnerability levels.

These three maps constitute synthetic thematic maps, being obtained by the overlapping of elementary thematic maps, i.e. maps referring to single indicators, each of which is generated by the elaboration, in succession, of two types of elementary thematic maps: analysis thematic maps, which represent the territorial distribution of the measures or characteristics of the indicators considered, and the evaluation thematic maps, which represent the territorial distribution of the values attributed with respect to the measures previously obtained.

The transition from measures to values[2], see for example the attribution of the hazard levels to the temperature measures of the cells into which a territory is divided, and therefore from the thematic maps of analysis to those of evaluation, must carried out using criteria and transformation functions specific to each indicator. The same operation must be done for the generation of the summary thematic maps, which are obtained by superimposing two or more evaluation thematic maps, in order to obtain a representation of the territorial distribution of the summary values of the indicators considered. The Risk Levels Map is finally obtained by overlaying the three previous summary maps using criteria and/or functions for transforming the related summary values into final summary values.

To measure and evaluate the effects over time of urban and territorial transformations on the heat risk levels, the "baseline synthetic maps" must be drawn up, with which

[2] By measurement we mean the direct or indirect comparison of a physical quantity with its unit of measurement in order to determine the extent of this quantity. By evaluation we mean the determination of the value of a physical or abstract quantity for the purpose of formulating a ranking, a judgment or a decision. The determination of the value is made by individuals, stakeholders or segments of the population. In determining the values of this type of maps, thresholds of hazard, vulnerability and risk based on available knowledge and experience are considered. Weighting is the attribution of weights or levels of importance to the evaluation factors considered based on subjective criteria possibly oriented by the knowledge or measures of the phenomena considered.

the measures and values of the indicators at the beginning of the risk assessment process are represented. We will thus have the following maps: Baseline Map of Hazard Levels, Baseline Map of Exposure Levels, Baseline Map of Vulnerability Levels, Baseline Map of Risk Levels.

The elaboration steps of the Baseline Maps also constitute the references for the elaboration of all kinds of synthetic maps.

For the assessment of the risk scenarios, the Hazard Levels Maps for each climate change scenario considered must be elaborated and then the corresponding Risk Levels Maps must be elaborated using the Baseline Maps of Exposure and Vulnerability Levels.

For the assessment of the project scenarios, the set of synthetic maps (hazard, exposure, vulnerability and risk) must be developed, estimating the effects of the actions and interventions envisaged.

For monitoring, comparisons must be made between the set of Baseline Maps and the corresponding maps developed for the period being monitored, thus being able to measure the modifications of these levels with respect to the interventions carried out to mitigate the heat risk and the ordinary urban transformations. This operation also allows to evaluate the effectiveness of the various actions carried out and therefore to be able to identify any changes to the strategy or plan developed.

1.2. - The heat risk territorial assessment for the population

1.2.1. The territorial assessment of heat hazard levels

The physical-natural characteristics of a territory, and the human activities that are done inside, are the factors that most influence the microclimatic conditions of urban, rural and natural areas and are those factors that determine the formation of urban heat islands. These characters belong to the set of territorial factors that determine the levels of hazard, exposure and vulnerability and which are therefore the main objects of the heat risk territorial assessment to support the development of strategic and planning tools.

To evaluate the structural factors that influence the heat hazard, LCZs are used, which, however, represent relative and not absolute levels of that indicator, so that they can only be comparable within the same city or territory (Geletic et al. 2016). In fact, the LCZs that are physically equivalent but located in cities at different latitudes, as Helsinki and Nairobi, do not have the same hazard levels and therefore they must be considered differently. Therefore, the hazard levels should be attributed to the different LCZs on the basis of the specific parameters that have been measured or estimated. Precisely because the LCZs represent the structural factors of a territory and therefore change slowly over time, they can be used as territorial units of the set of synthetic maps of the heat risk territorial assessment.

The climatic parameters that have different trends on the territory and that can therefore be measured to attribute the hazard levels for heat-stress to the LCZs can range from simple temperature to the combination of temperature and relative humidity, see HUMIDEX index, to more sophisticated parameters such as UTCI (Universal Thermal Climate Index)[3]. Since the climatic parameters have different trends both during the single hot seasons and between the hot seasons of different years, the measures to be considered will be identified with respect to past climate scenarios or, when it is possible, the future ones.

To measure the effects over time of urban and territorial transformations on climatic hazard and comfort, including interventions aimed at reducing the intensity of the urban heat island, it is necessary to develop the Baseline Map of (Heat-Stress) Hazard Levels, which it can constitute the base map on which to evaluate the effectiveness of planning and strategic tools. The following procedure for making this map also constitutes the procedure for elaborating the hazard maps for subsequent years:

1. identification and first delimitation of the LCZs through the analysis of the physical-morphological characteristics of the territory based on elaboration of satellite imagery possibly integrated with land use maps;
2. definitive delimitation of the LCZs through the overlap of a grid, whose dimensions should fall between 30x30 and 100x100 meters, in which the reference temperatures of a hot day or the average of the temperatures of several hot days obtained through the elaboration of satellite imagery (Eldesoky et al., 2019). This overlap allows to verify the level of adherence of the LCZs to the real temperature trend, reviewing the unsatisfactory perimeter of the LCZs and refining the uncertain ones;
3. identification, based on the climatic parameter to be considered (temperature, HUMIDEX, UTCI), of the scenario deemed most significant with respect to the use of the Hazard Levels Map to be made and attribution to the LCZs of the hazard measurements thus obtained;
4. elaboration of the function of transforming the hazard measurements into hazard levels, which are assessed with respect to the impacts on human health (see point 1.2.2.);

[3] In assessing the heat hazard, the PET (Physiological Equivalent Temperature) index is not indicated here because it also considers the activities that people perform and the clothing they wear. Since these two parameters are representative of the vulnerability of people and not of the heat waves hazard, as well as a theoretical inconsistency, its use could lead to an overestimation of these parameters.

5. drafting of the Baseline Map of Hazard Levels, which is used both to continue the assessment of the risk related to heat-stress, and to evaluate the temporal and spatial trends of the hazard. This map is generated by transforming the measures into hazard levels based on the transformation function elaborated in the previous step.

1.2.2. The assessment of the heat sensitivity levels of the population

The effects of excess heat on health range from premature death to the lack of climatic comfort, through the reduction of physical capacities and the presence of symptoms that require the use of first aid. These effects become more relevant with the occurrence of heat waves and as a function of their intensity, lengths and frequencies. During a heat wave, the risk of mortality is a function of both the maximum daytime temperatures and the minimum night temperatures and relative humidity (D'Ippoliti 2010, Smargiassi 2009). In fact, the absence of nocturnal remission from high daytime temperatures reduces the recovery of the human body's thermoregulation mechanisms. Furthermore, the effects of heat waves also depend on how they manifest themselves. When they occur at the beginning of the summer season, they have a greater impact than those of equal intensity that occur subsequently, this due to both a progressive adaptation of the population to climatic conditions, and a lower presence of very sensitive people due to previous deaths.

The physiological and cultural adaptation of populations to heat is a protective factor. In tropical regions, characterized by permanently high and prolonged warm temperatures, the effects on the inhabitants only manifest themselves starting from temperatures significantly higher than those to which equivalent effects occur in temperate regions (Hajat 2010). For example, the temperatures in which the minimum daily mortality is observed vary from 21°C to 24 °C among the north-continental cities, while among those in the Mediterranean area they vary from 27°C to 33°C (Gasparrini et al. 2015).

Finally, there is a synergistic effect between atmospheric pollutants and heat on the increase in mortality to be considered, especially due to the high concentrations of PM10, sulphur dioxide and ozone.

If the exposure of inhabitants and workers is given by their density, their vulnerability to heat depends on numerous factors, the main ones are: age, health conditions, socio-economic conditions, behaviour (Stafoggia et al. 2005, Wilhelmi and Hayden 2010, Basagaña et al. 2011). The most sensitive people are the elderly, children and infants, pregnant women, those who regularly take drugs, the chronically ill - especially with cardiovascular and pulmonary diseases, diabetes and kidney failure - and people with mental diseases or who use alcohol and drugs (Kovats et al. 2008). Furthermore, socio-economic factors, such as poverty, isolation, poor knowledge of the local language and

limited access to the media, increase the conditions of fragility because they reduce risk awareness, limit access to emergency solutions, do not allow temporarily move to cooler areas or install air conditioners in their homes.
Since only demographic data are often available, as it is difficult and burdensome to collect georeferenced socio-economic data, and that the age of people is a good indicator of the population's sensitivity to heat, a map can be directly drawn up in which the densities of the inhabitants are distinct with respect to the age groups representative of the different levels of sensitivity to heat. This map can become the map of the population's sensitivity to heat through the development of a function that attributes a level of sensitivity equivalent to heat to the age classes of inhabitants and workers. Furthermore, if there is not enough georeferenced data on the system vulnerability, the map of the sensitivity of the population could become the map of the vulnerability levels.

2. PROCESSING OF HEAT RISK MAPS FOR THE POPULATION OF TRezzano SUL NAVIGLIO

2.1. The methodological steps

The Municipality of Trezzano sul Naviglio has a population of over 20,000 inhabitants, an area of almost 11 sq km and is in the South-West quadrant of the Milan metropolitan area (see figure 2). Its urban structure is characterized in the centre by the rural village surrounded by areas of small villas and condominiums with a high share of private greenery and by the presence around it of large industrial and productive areas, including the vast commercial areas along one of the main radial roads to the city of Milan.

Figure 2 - Location of the municipality of Trezzano sul Naviglio in the Northern Italy

Source: Authors

The elaboration of heat stress risk maps of the productive and residential areas of Trezzano is one of the first applications of this method. These maps are functional for identifying the most critical areas of the municipal territory in order to establish an order of priority for urban cooling interventions. The need to carry out these elaborations in a limited time and the reduced availability of the necessary data has led to a simplified application of this method, an application which we report here in order to clarify the elaborations to be carried out. In this regard, the data available were the following:

- the data to identify the LCZs, which constitute the territorial units of hazard levels;
- the data of the average temperatures of each LCZ, obtained through a geostatistical model that estimates the air temperature at about 2 meters above the ground starting from the data measured by the weather stations and thermal images derived from the Earth (equipped with MODIS sensors) and Landsat satellites at 10:30 and 21:30 solar hours on 4 August 2017. The day chosen is the hottest day recorded in that year by the main weather station in the area. Since the times considered do not represent the hottest day time nor the coolest night-time, they are not representative of the absolute heat-stress hazard, but of the relative one between the different LCZs. Consequently, the Map of Heat Risk Levels is defined Map of Relative Heat Risk Levels;
- data on the number of workers and the number of residents by age referred to the census sections, which constitute the territorial unit used for the preparation of the vulnerability map. Since the georeferenced data on the age, sick days and pathologies of workers, on the health and economic conditions of residents and on the adaptive capacity of the population and of public and private structures in the area are not available, for the assessment of vulnerability it was only possible to consider the sensitivity of the population.

The processing of the Map of Relative Heat Risk Levels was made by the following steps:

- identification of LCZs through a cluster analysis for the automatic classification of areas with similar type-morphological characteristics. Four variables were considered: building height, Sky View Factor, albedo and vegetation. The latter was quantified on the basis of the Normalized Difference Vegetation Index, a vegetation indicator detected by satellite imagery;
- definition of the criteria for attributing relative hazard levels to LCZs and drafting of the Map of Relative Heat Hazard Levels;
- elaboration of the function for the attribution of the sensitivity values of exposed population and drafting of the Map of Heat Vulnerability of Exposed People Levels;

- elaboration of the function for the attribution of heat risk levels based on the relative hazard levels and vulnerability levels of the population and drafting of the Map of Relative Heat Risk Levels.

To facilitate the interpretation of risk levels in identifying the intervention actions, the hazard and vulnerability levels have been limited to 5 for each factor.

2.2. Map of Relative Heat Hazard Levels

This map assumes the LCZs as the reference territorial unit, to which the relative hazard levels are attributed on the basis of the temperatures estimated through satellite images.

The day and night temperatures have different representativeness characters of the relative hazard. The diurnal ones, which were detected at an early morning time (10:30 solar time), are a representation of what could be the relative conditions of the different LCZs in the hottest hours, while the night temperatures, measured shortly after sunset (solar time 21:30), do not return the conditions of greater hazard due to the night-time heat, which are instead represented by the minimum night temperatures, indicative of an overall nocturnal condition in which people have difficulty recovering the stress due to the daytime heat. Therefore, the Map of Relative Heat-stress Hazard Levels was obtained starting from the Map of Daytime Heat Hazard Levels, on which the Map of Night-time Heat Hazard Levels was overlayed. The daytime hazard levels were therefore replaced with the night-time hazard levels where these were higher. With this criterion, the worst relative conditions between day and night-time were represented.

For the processing of the Map of Relative Heat Hazard Levels the following steps were carried out:

1. calculation of the 5 relative hazard levels for daytime heat (h 10:30) of the LCZs based on the proportional division of the difference between the maximum and minimum temperatures estimated for all the LCZs (see table 1 and figure 3);

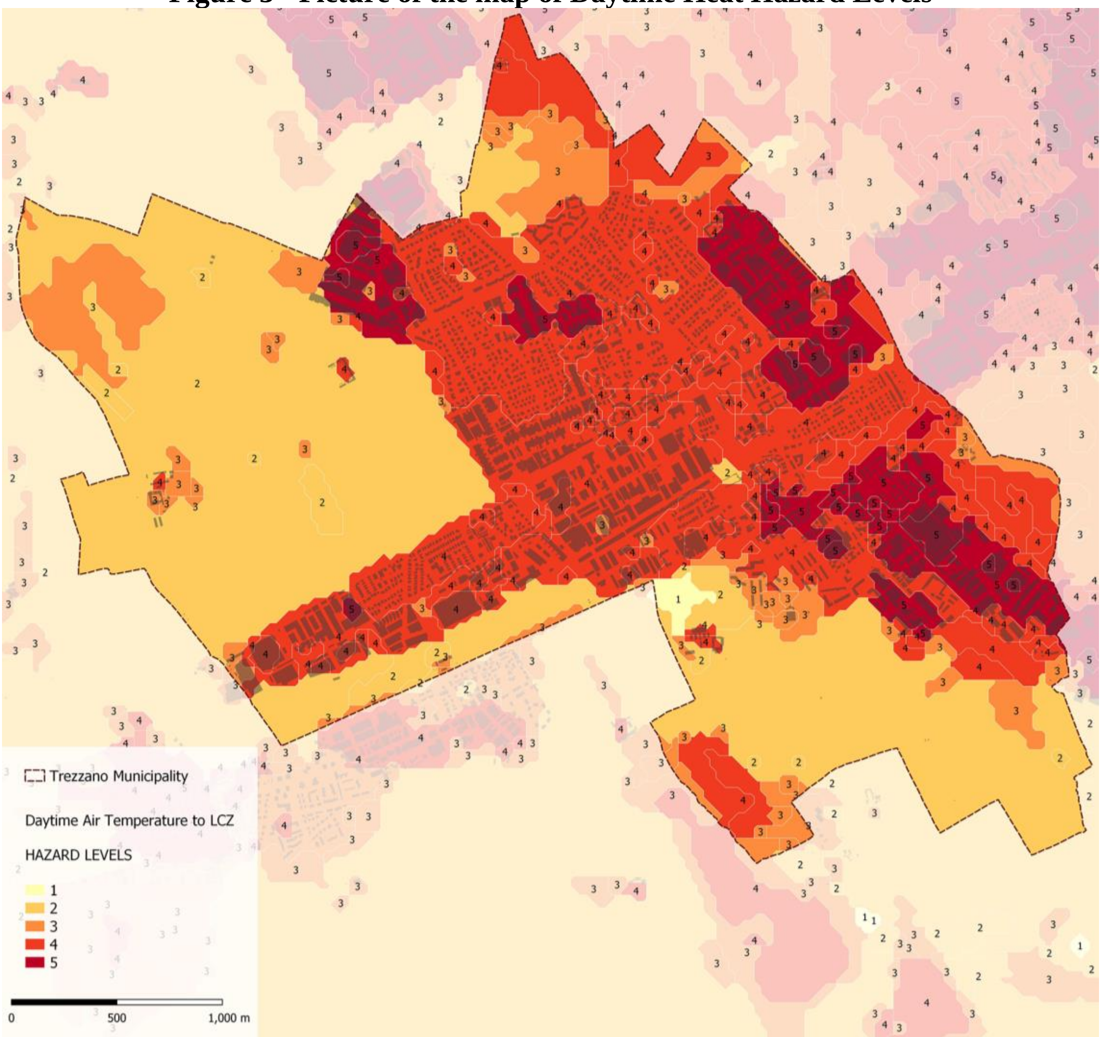
Table 1 – Formulas to calculate the relative hazard levels of the LCZs

Levels	Formulas	
Low	from Tmin to Tmin + ((Tmax - Tmin) / 5)	
Mid-Low	from Tmin + ((Tmax - Tmin) /5) to Tmin + (((Tmax - Tmin) /5) *2)	
Middle	from Tmin + (((Tmax - Tmin) /5) *2) to Tmin + (((Tmax - Tmin) /5) *3)	
Mid-high	from Tmin + (((Tmax - Tmin) /5) *3) to Tmin + (((Tmax - Tmin) /5) *4)	
High	from Tmin + (((Tmax - Tmin) /5) *4) to Tmax	
where	Tmin	minimum temperature of all the LCZs
	Tmax	maximum temperature of all the LCZs

Source: Authors

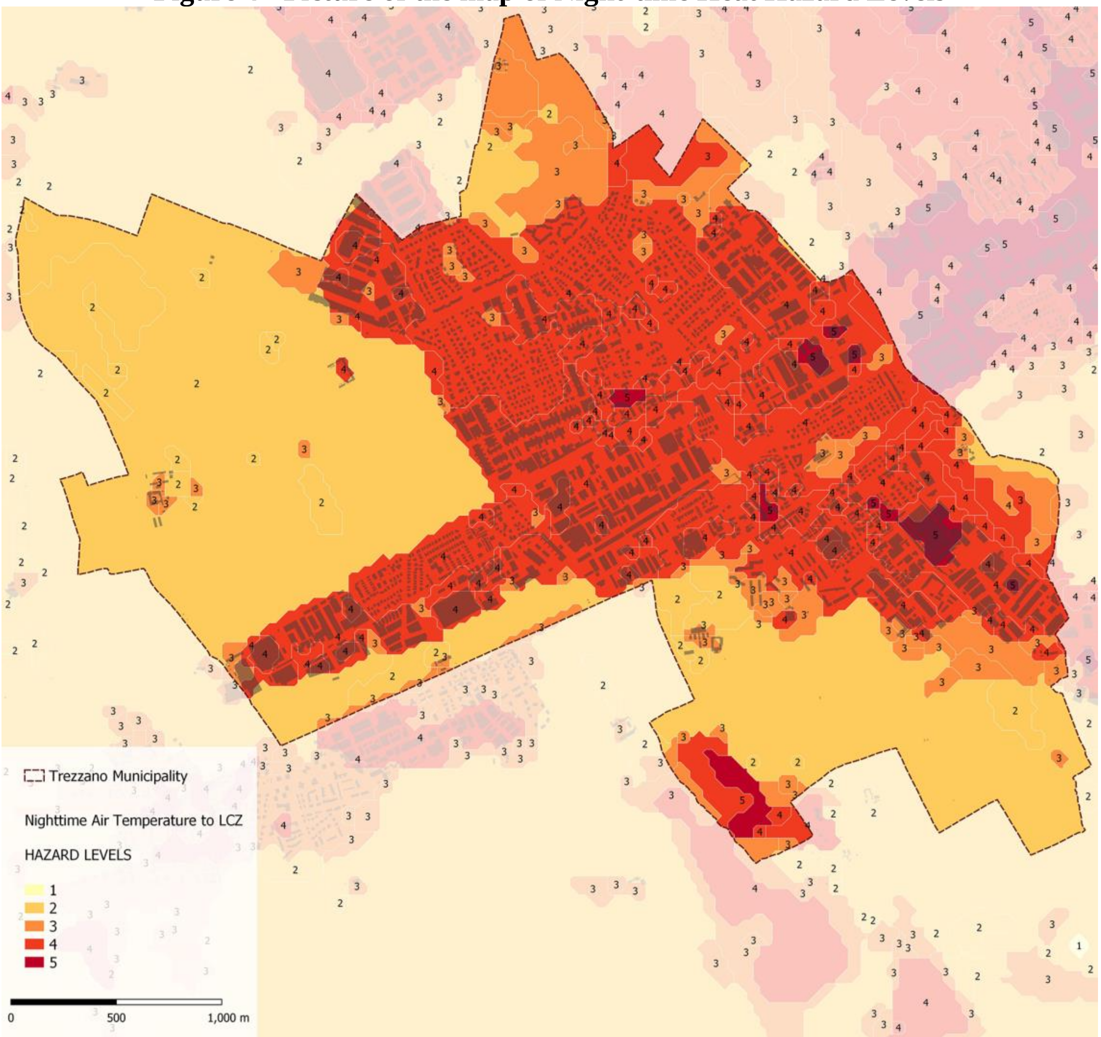
2. calculation of the 5 relative hazard levels for night-time heat (h 21:30) of the LCZs based on the proportional division of the difference between the maximum and minimum temperatures estimated for all the LCZs (see table 1 and figure 4);
3. identification of the differences between the day and night relative hazard levels by overlapping the Map of Daytime Heat Hazard Levels and the Map of Night-Time Heat Hazard Levels (see figure 5);
4. processing of the Map of Relative Heat Hazard Levels, obtained by replacing the daytime relative hazard level with the night-time relative hazard levels when these were higher (see figure 6).

Figure 3 - Picture of the map of Daytime Heat Hazard Levels



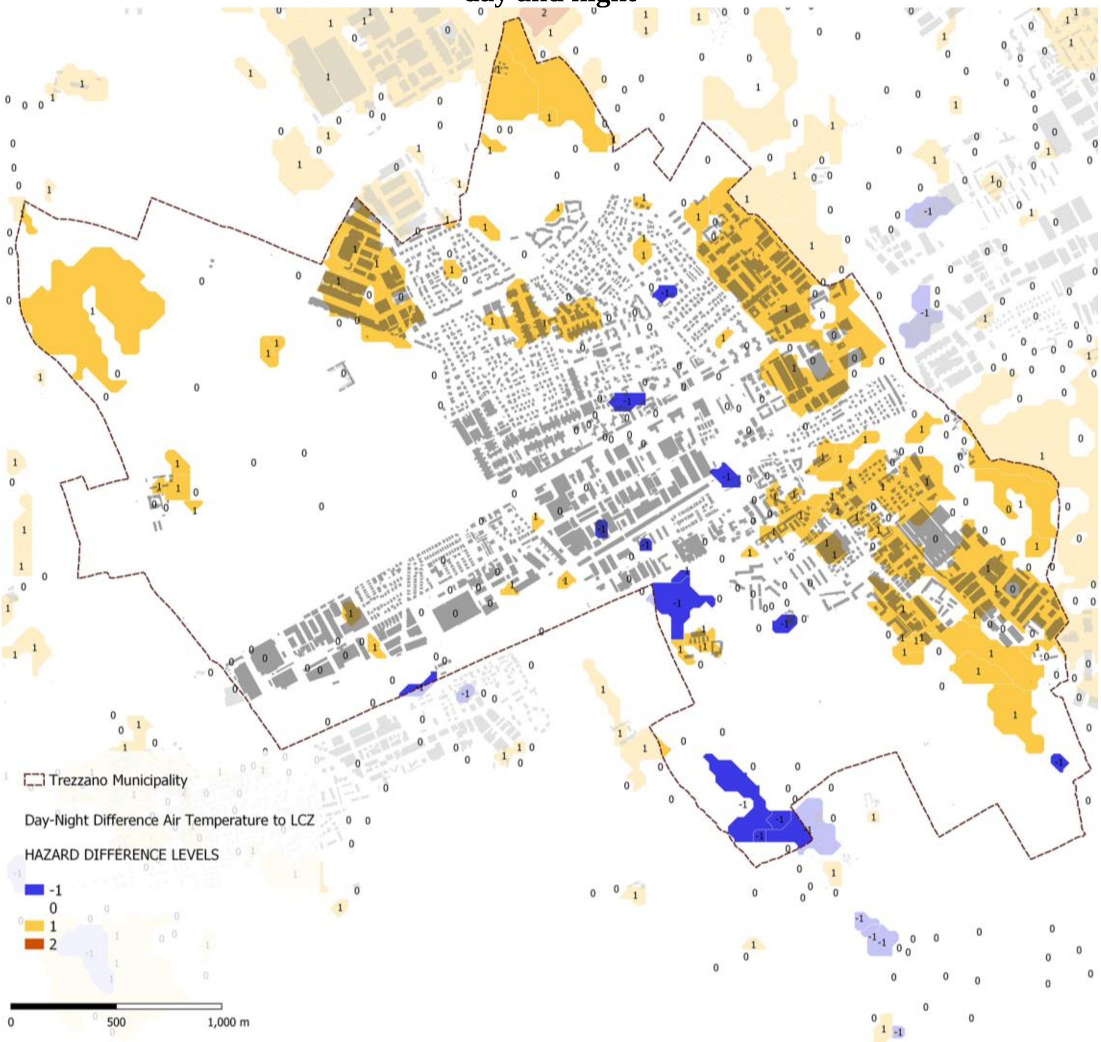
Source: Authors

Figure 4 - Picture of the map of Night-time Heat Hazard Levels



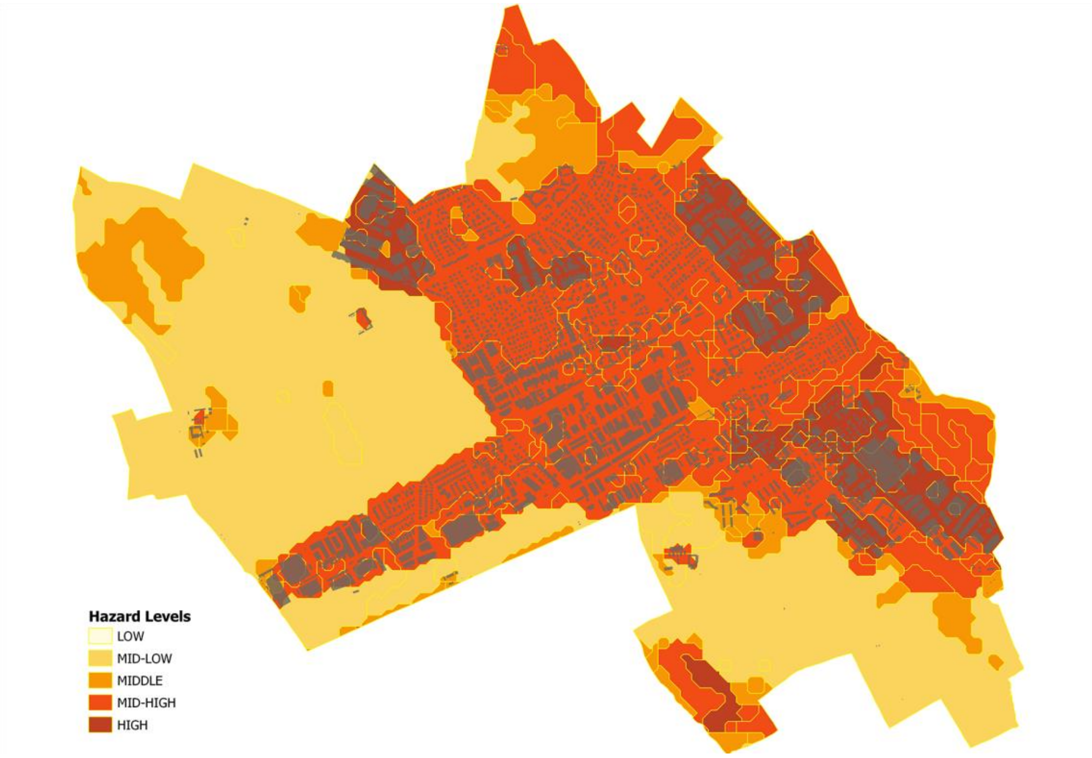
Source: Authors

Figure 5 - Picture of the map of the differences in the relative hazard levels between day and night



Source: Authors

Figure 6 - Picture of the map of Relative Heat Hazard Levels



Source: Authors

2.3. Maps of Heat Vulnerability of Exposed People Levels and Relative Heat Risk Levels

In this application, it was possible to evaluate the vulnerability only with respect to sensitivity based on age classes. Therefore, it was not necessary to elaborate the Map of Heat People Exposure Levels to directly develop the Map of Heat Vulnerability of Exposed People Levels. In that last map, the equivalent sensitivity density of inhabitants and workers is taken as indicator.

The inhabitants and workers sensitivity levels to heat were evaluated with respect to the effects of heat such as thermal distress, morbidity and mortality (Aldighieri et al. 2022, Ministero Salute 2022, Baccini et al. 2008). These effects mainly affect two categories of people: the elderly and children. The elderly, especially if they are chronically ill (cardiopathic, diabetic, hypertensive, etc.), are the people most at risk due to a greater sensitivity to heat, a lower stimulus of thirst and a reduced efficiency of thermoregulation. Furthermore, they may have a lower capacity to defend themselves from the heat if they have a reduced mobility and live alone. Children and, even more so, infants, due to their lower capacity to thermoregulate and the inability to express any discomfort related to environmental conditions, are more exposed to

the risk of excessive increase in body temperature and dehydration, with possible consequences harmful to the cardiovascular, respiratory and neurological systems.
On the base of the indications of the studies listed above, the sensitivity of the inhabitants to heat was structured by the authors on 6 age groups. Minors were divided into infants, from 0 to 2 years, children, from 3 to 12 years, and adolescents, from 13 to 18 years, while the elderly were divided into elderly, from 60 to 75 years, and very elderly, over 75 years old. To these 5 classes was added the class of adults, from 19 to 59 years old.
Since the most part of workers is in adulthood and in good health, not going to work in case of illness, and being present in the workplace for about 8 hours a day, 5 days a week, their exposure and, in this application, their vulnerability is lower than that of the adult class of residents.
The function of transforming the inhabitants by age groups and workers into sensitivity values is shown in the following table. The sensitivity values were attributed by the authors using the pairwise comparison technique supported by a hierarchical ordering of the different classes of inhabitants and by interpreting the indications contained in the studies on the effects of heat on humans. Those values can be attributed more rigorously when consolidated statistical surveys consistent with this type of evaluation will be available.

Table 2 - Transformation function of inhabitants by age group and of workers into sensitivity values

People classes	Sensitivity value
Workers	0,1
Inhabitants from 20 to 59 years	0,3
Inhabitants from 15 to 19 years	0,4
Inhabitants from 5 to 14 years	0,5
Inhabitants under 5 years	0,6
Inhabitants from 60 to 74 years	0,8
Inhabitants over 74 years	1,0

Source: Authors

The Map of Heat Vulnerability of Exposed People Levels (see figure 7) was therefore produced by multiplying, for each census section, the number of workers and the number of inhabitants for the age groups indicated in table 2 by the values reported in it, obtaining in this way the partial sensitivity values. By adding these partial values in each census section and dividing them by the surface of these sections, the overall values of sensitivity to heat have been obtained (see table 3).

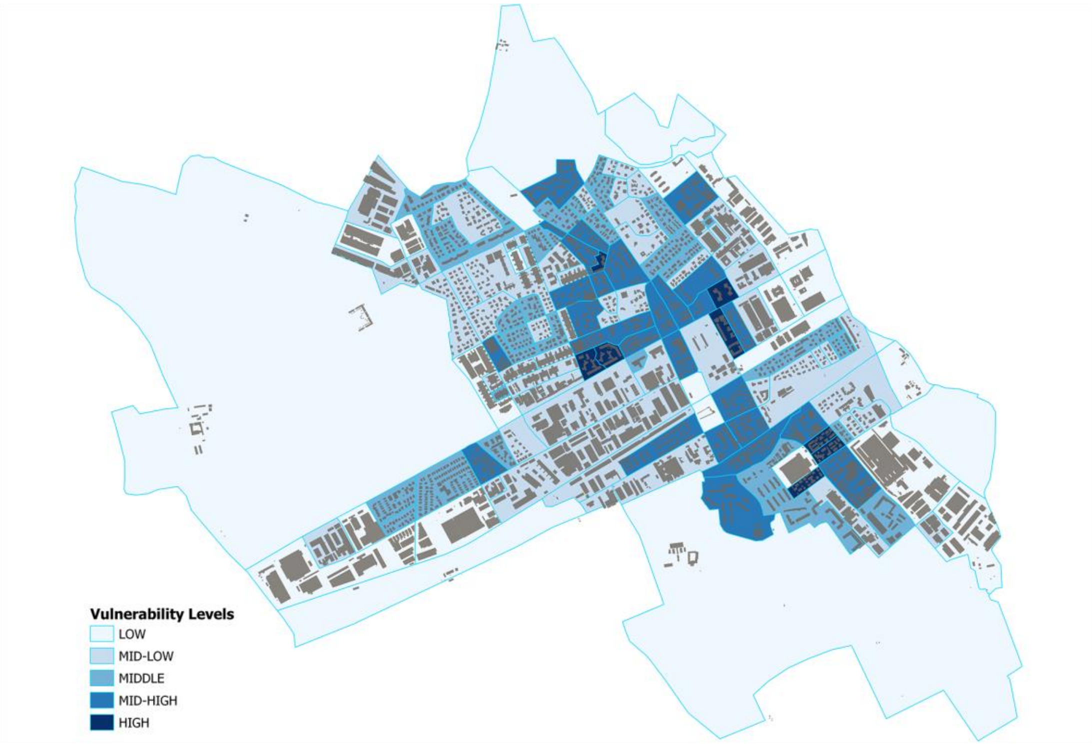
Table 3 – Formula to calculate the values of sensitivity of the census sections

C = ((W *0,1) + Σ (In * Sn)) / A		
where	C	census section
	W	number of workers
	I	number of inhabitants of the nth class
	S	number of sensitivity value of the nth class
	A	area of census section in square meters

Source: Authors

Those values were then classified with the same criteria (proportional attribution of levels based on the division into 5 parts of the difference between the maximum and minimum values found in the various census sections) and formulas used for the levels of hazard into 5 levels of heat vulnerability.

Figure 7 - Picture of the map of Heat Vulnerability of Exposed People Levels



Source: Authors

Finally, the Map of Relative Heat Risk Levels is obtained by overlaying the Map of Relative Heat Hazard Levels, which adopts the LCZs as a territorial unit, with the Map of Heat Vulnerability of Exposed People Levels, which adopts as territorial units the census sections. Therefore, this map consists of territorial units which are the polygons obtained by crossing the LCZs with the census sections.

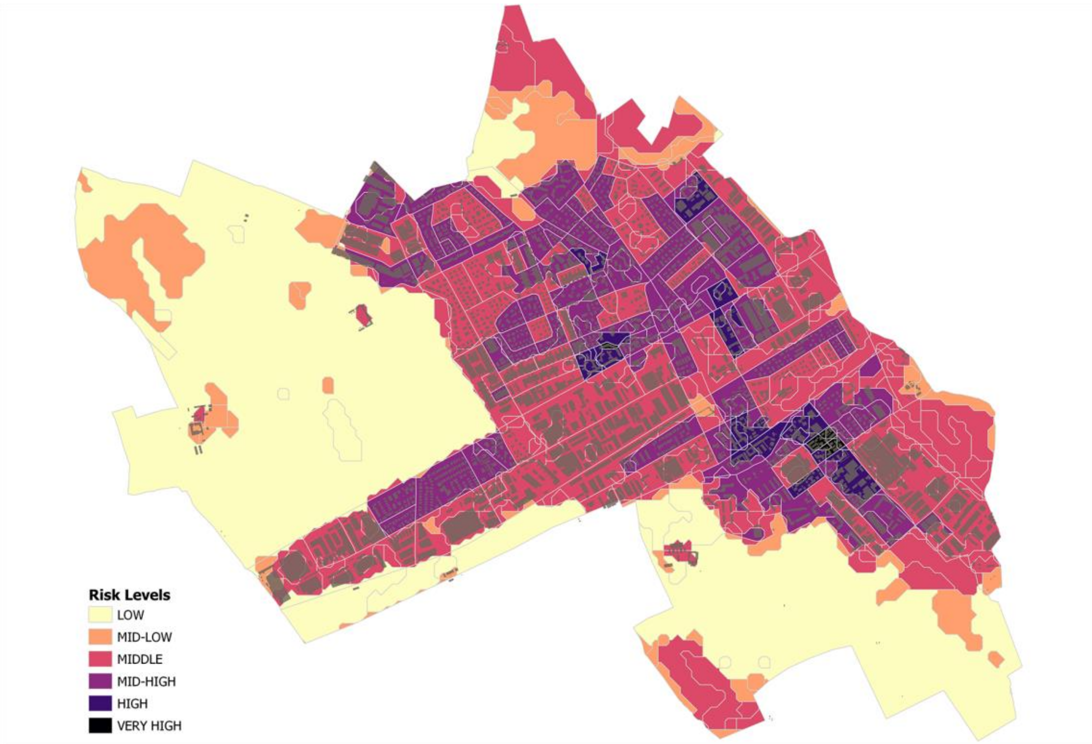
The risk levels, assigned to the new territorial units on the basis of the attribution of a slight prevalence to the hazard compared to the vulnerability (see table 4), made it possible to produce the map shown in figure 8.

Table 4 - Transformation function of relative hazard and vulnerability levels into heat-stress relative risk levels

Relative Hazard levels	Vulnerability levels				
	LOW	**MID-LOW**	**MIDDLE**	**MID-HIGH**	**HIGH**
LOW	VERY LOW	LOW	MID-LOW	MID-LOW	MIDDLE
MID-LOW	LOW	MID-LOW	MID-LOW	MIDDLE	MIDDLE
MIDDLE	MID-LOW	MIDDLE	MIDDLE	MIDDLE	MID-HIGH
MID-HIGH	MIDDLE	MIDDLE	MID-HIGH	MID-HIGH	HIGH
HIGH	MIDDLE	MID-HIGH	MID-HIGH	HIGH	VERY HIGH

Source: Authors

Figure 8 - Picture of the map of Relative Heat Risk Levels



Source: Authors

3. PROBLEMS AND PERSPECTIVES

This method of heat risk territorial assessment, whose function is to support urban and territorial planning processes and whose experimentation is currently being carried out on two other territories in northern Italy (ties of Brescia and Metropolitan City of Milan), has still not been sufficiently developed in its application due to the delay with which the elaboration of the plans in which it will have to be integrated is being carried out. However, these experiments have brought to attention various theoretical-methodological questions, which are also found in the assessment of other types of risk, to which we are trying to give ever more comprehensive answers. Most of these issues can be referred to the need to produce a single final map of the set of impacts deriving from heat excess, a functional operation to represent, compare and/or communicate the partial and final results of a complex and articulated assessment and mapping. This path requires to arrive at attributing comparable values to the different types of exposure and vulnerability using tools such as digital maps, functions for transforming measures into values, weighting methods and mathematical models. In this regard, the structure of this method has the characteristics to allow to differentiate the assessments of the different types of exposure and vulnerability and to rigorously manage the production and use of the maps, keeping them separate or integrating them according to their function, which can range from the identification of intervention strategies and actions to their monitoring and evaluation of their effectiveness and efficiency in solving the problems faced.

The partial experimentation of this method has not yet made it possible to verify its capacity to achieve a good level of transparency in the performance of the related processing, sharing it with stakeholders and citizens, and the use of maps in urban plans. Therefore, the development of this method is moving in three directions.

The first concerns the expansion of the experimentation of the specific heat stress assessment techniques, such as those relating to the types of impact (illnesses and premature deaths of people, thermal discomfort, tree die-off, ...), to the elements exposed (city users, trees, crops, ...), vulnerabilities (sanitary structures, tree species, ...), to the mapping techniques and evaluation criteria.

The second concerns the development of techniques and assessments of other risks due to climate change to achieve the most comprehensive possible assessment and mapping method. In this regard, an important step concerns the integration of heat risk with flood risk, on which some applications have already been made, as they have the most impact on urban areas.

The third concerns the experimentation of different ways of representing and communicating information to support both the planning processes and the co-planning activities to be carried out with stakeholders, professionals and public administrators.

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