Adapting cities to climate change: Remote sensing tools for identification of urban areas exposed to heat waves

Luigi Passariello (INGV), Michele Russo (**), Giuseppe Passariello (***), Michele Passariello (***)

* National Institute of Geophisics and Vulcanology (INGV), Rome
** Di Pietro Group S,p,A.
*** Ma.Pa.COM.

Abstract

Heatwaves are increasingly frequent in the Mediterranean basin; in Italy excess deaths in the summer are predicted to increase significantly in the coming decades. The risk is particularly high in urban areas also because of the heat island covering. Artificial covers may, in fact, determine an absorption of 10% more solar energy compared to green areas. Both daytime and night-time air temperatures can be up to 12 degrees higher than those of the surrounding natural areas. The strategic positioning of trees, however, is capable of dropping the mercury by as much as 2-8 Celsius degrees. According to Food and Agricultural Organization (FAO), urban greenery contributes to reducing air conditioning consumption by 30% and, by ensuring better thermal comfort, saving 20 to 50% of the energy needed for heating. Based on these premises, our contribution discusses the development of urban greenery as an essential tool in the sustainable development path of metropolitan regions. We specifically debate on urban greening as facilitating the intrinsic adaptation of local systems to climate warming, mitigating the impact of extreme events such as heat waves, droughts and floods. We also focused on the mitigation of emergency conditions, since urban greening contributes in turn to the absorption of carbon dioxide. Finally, the presence of trees, parks and gardens also slows down land consumption, preventing new structures, buildings and artificial roofs from fueling land degradation.

Key-words: urban greening; green infrastructures; metropolitan regions; global change; local warming; Italy.

Introduction

The world has never been so urbanized: about 15 years ago, for the first time in history, the population living in cities exceeded that living in the countryside. Today, 4.2 billion people live in urban areas, around 55% of the global population, and this trend is constantly growing: according to official estimates, it will reach 70% by the end of 2050. Even though cities occupy only 3% of the world surface, they are responsible for over 70% of CO_2 emissions, the main factor of global warming. It is therefore inevitable that the fight against climate change is also run in a local scale, since the development of sustainable cities is essential to reverse this trend and guarantee a future for our planet. The presence of trees, parks and gardens in cities is essential to fight climate warming and improve individual health conditions. The improvement of city greenery should adopt a logical framework that takes account of climate change and how it influences urban areas, assumed as the location where a greater concentration of people lives. Our study examines and discusses some technological criteria determining priority interventions in urban areas, taken as locations mostly exposed to become heat islands, with negative effects on resident population. Reforestation actions – seen as the most appropriate and natural actions to cope with climate change in cities - should be accompanied with an adequate knowledge of local territories and background conditions, based on management and monitoring plans. For this reason, innovative tools are increasingly required to inform plans enhancing greenery in urban areas.

In this context, the development of urban greenery is considered essential in the sustainable development path of metropolitan regions for at least two reasons: first, it facilitates adaptation to climate warming, mitigating the impact of extreme events such as heat waves, droughts and floods. Second, it favors the mitigation of emergency conditions, contributing in turn to the absorption of carbon dioxide. Finally, the presence of trees, parks and gardens also slows down land consumption, preventing new structures, buildings and artificial roofs from fueling land degradation. The most important advantage of urban greenery is the improved thermal comfort and defense against heat waves. Heat waves are increasingly frequent in the Mediterranean basin; in Italy excess deaths in the summer could increase significantly in the coming decades. The risk is particularly high in urban areas also because of the heat island covering. Artificial covers may, in fact, determine an absorption of 10% more solar energy compared to green areas. Both daytime and night-time air temperatures can be up to 12 degrees higher than those of the surrounding natural areas. The strategic positioning of trees, however, is capable of dropping the mercury by as much as 2-8 Celsius degrees. According to Food and Agricultural Organization (FAO), urban greenery contributes to reducing air conditioning consumption by 30% and, by ensuring better thermal comfort, saving 20 to 50% of the energy needed for heating.

Methodology

We used the data from LANDSAT 8 and those from GMES-Land-COPERNICUS initiative employing Sentinel 2 imagery. This choice is motivated with their free availability, in line with the purpose of our work (identifying the location where heat islands can expand as a result of climate change). We have chosen Turin as the study area because it has been subjected to heat waves in recent years. We used Quantum GIS (QGIS) WebGIS software applications. It is a user friendly and open-source GIS Desktop client for managing, viewing, editing, and analyzing geographical data and maps. It provides powerful analytical capabilities through integration with another software for spatial analysis, GRASS. QGIS runs on Linux, Unix, Mac, OSX, and Windows and supports vector, raster and database data formats.

Results and discussion

With reference to urbanized environments, to identify the location where head waves occur more frequently, we used the Land Surface Temperature (LST), an index measuring the current temperature of a given territory. Satellites and sensors used to calculate the LST include free of charge LANDSAT 8 and COPERNICUS Sentinel 2. Figure 1 highlights temperatures varying from a minimum of 21.9°C to a maximum of 34.4°C, divided into 10 classes, where the blue color indicates the areas with a cooler temperature and the red classifies the areas with higher temperatures.

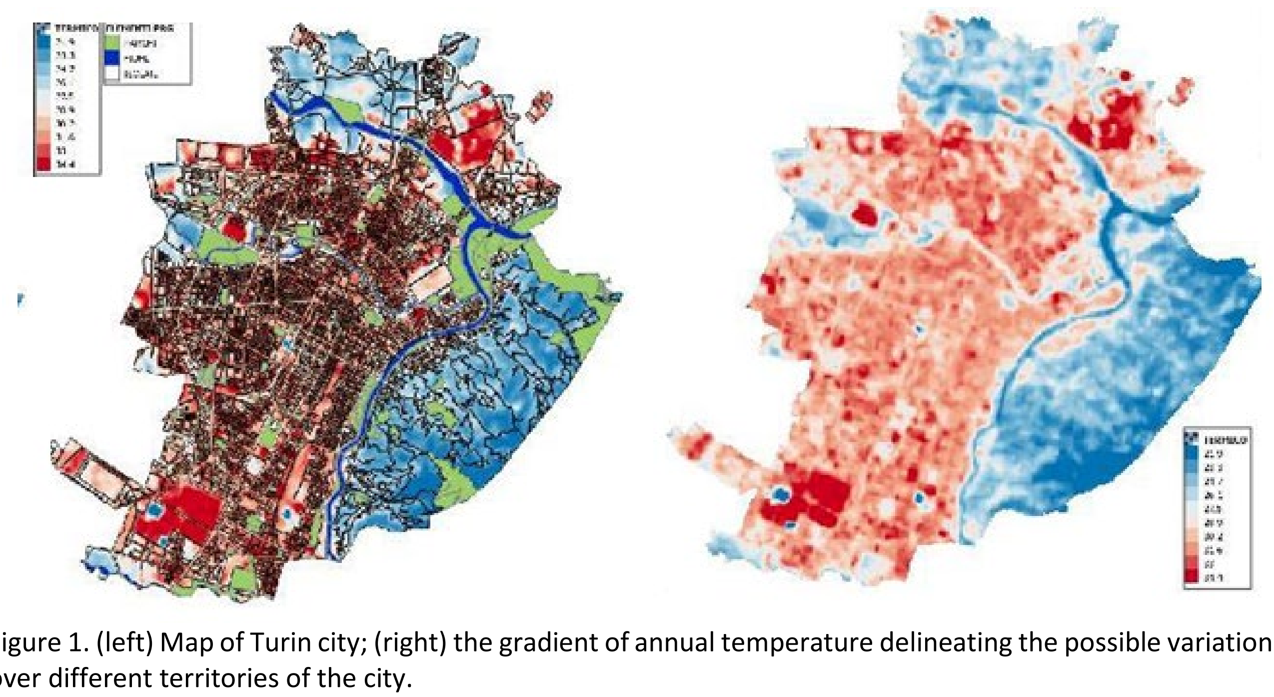

Figure 1. (left) Map of Turin city; (right) the gradient of annual temperature delineating the possible variation over different territories of the city.

This map confirms how locations with higher temperatures coincide with the urbanized area of the city, while areas in blue mostly correspond with green areas and public parks. Various intensities of red indicate those parts of the soil that have high temperatures, ranging from a minimum of 28.9°C up to a maximum of 34.4°C. Blue areas indicate temperatures ranging between 27.5°C and 21.9°C. Diverse types of land surfaces influence the differential temperature level, since red areas refer to more urbanized soils such as asphalted surfaces and sealed soils absorbing and retaining greater heat. Blue areas correspond with pervious soils that allow adequate transpiration and evaporation, such as rural areas with high vegetation or wetlands lowering urban temperatures. From the elaboration of these two maps, it is demonstrated how green areas in Turin may lower temperatures up to 10 degrees.

Vegetation assessment

After having analyzed the Land Surface Temperature (LST) through the creation of thermal maps, we moved on to the calculation and processing of NDVI (Normalized Difference Vegetation Index) maps. The NDVI is the main satellite indicator of the occurrence of living vegetation on the earth's surface. Absorption by chlorophyll influences the near infrared in which the leaves reflect the light to avoid overheating, and thus allows evaluating the photosynthetic activity (Figure 2). Index values range between -1 and +1,

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

where

ρ_{red} = BAND 4(Red), LANDSAT – 8

ρ_{nir} =BAND 5(Nir), LANDSAT – 8

We used ten classes of equal interval indicating with light blue tones the locations with a low NDVI. Darker blue indicates the areas with a higher index (ranging from 0.039 to 0.858).

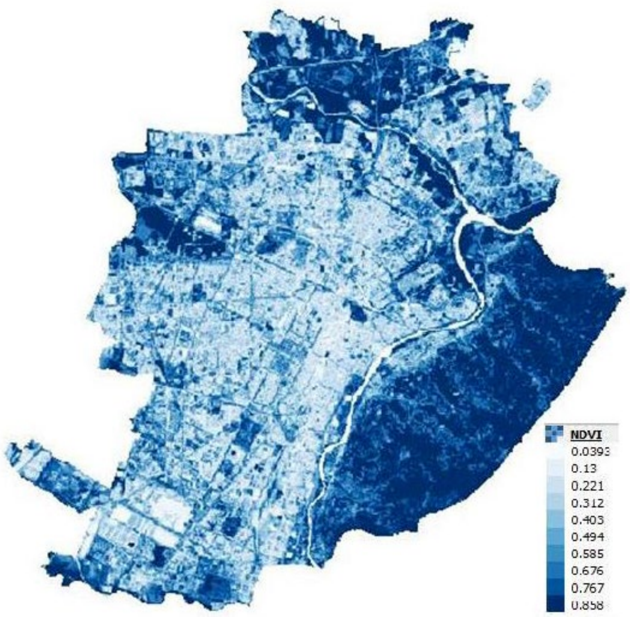

Figure 2. NDVI map of Turin.

The above map can be interpreted with the following classification (Table 1).

Table 1. Classification of NDVI values.

NDVI	Meaning
< 0.1	bare ground or clouds
0.1 – 0.2	almost absent vegetal cover
0.2– 0.3	very low vegetation cover
0.3– 0.4	low vegetal cover with low vigor or very low vegetal cover with high vigor
0.4– 0.5	medium-low vegetal cover with low vigor or very low vegetal cover with high vigor
0.5– 0.6	medium vegetal cover with low vigor or medium-low vegetal cover with high vigor
0.6– 0.7	medium-high plant cover with low vigor or medium plant cover with high vigor
0.7– 0.8	high plant cover with high vigor
0.8– 0.9	very high plant cover with very high vigor
0.9– 1	total vegetal cover with very high vigor

By comparing the thermal map (Figure 2) with NDVI (Figure 3) we found that locations with a light blue (NDVI) indicating areas with very low vegetation cover, correspond with the hottest places of the thermal map (red tones). The areas filled with a more intense blue indicate medium-high vegetation cover with low water stress; these areas correspond with places with cooler temperatures including parks, rural areas and wetlands.

Impervious land mapping

Finally, the impervious surface index (IS) was calculated using the data provided by Landsat-8 satellite. Impervious surfaces mean those land such as asphalted roads, buildings, pavements, car parks, and transport infrastructures, which do not allow water to penetrate the ground. This index is used both to analyze land urbanization processes, and as a tool to monitor the environmental issues that can affect cities including – but not limited to - surface runoff. Sealed soils create a sort of covering on the ground surface which does not allow water to infiltrate into the ground itself. This means that the water flows on the surface without ever penetrating the ground, often determining landslides and flooding. The analysis of the IS index also provides useful information regarding the quality of livability in urban areas, consequently providing a complete vision for urban planning and environmental management. The Impervious Surface index relates the percentage of impervious surface with the temperature of the earth's surface and the urban heat island effect; impervious surfaces collect solar heat, creating urban heat islands. The IS is calculated through the application of the NDVI provided by Landsat 8. The formula that allows the processing of waterproof surfaces is as follows:

$$IS = 1- \left(\frac{NDVI - NDVI_0}{NDVI_S - NDVI_0} \right)^2$$

where the numerator includes the difference between the NDVI obtained and the $NDVI_0$ which corresponds to the lowest value (0.0393). The denominator includes the difference between $NDVI_s$, corresponding with the highest value of NDVI equal to 0.858. This formula was implemented in the Raster Calculator tool of the Quantum GIS software. The lighter shades of red indicate the areas where the presence of waterproof surfaces is lower. The most built-up areas were illustrated with more intense shades of red (Figure 3).

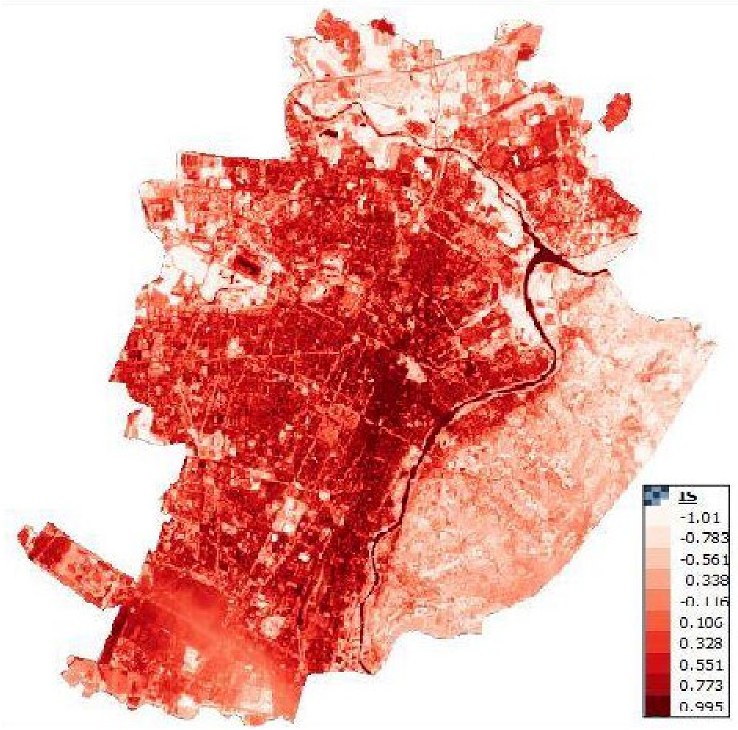

Figure 3. Impervious surface map of Turin.

IS takes on values that vary from a minimum of -1.01 to a maximum of 0.995. as shown in Figure 3. The area illustrated in light red correspond to rural areas or urban green areas corresponding to locations with a high percentage of infiltration and evapotranspiration and with a minimum percentage of runoff. Conversely, the areas with higher values marked by various shades of intense red correspond to partially or totally urbanized areas where the percentages of rainwater infiltration is low or null and the rate of soil evapotranspiration is also reduced, with increasing rates of runoff. From the comparison of the three maps (Figures 1-3), it can be seen that the highest temperatures, recorded through the thermal map dated 4 August 2017, corresponding to one of the most intense waves observed in Turin in recent times, perfectly relate with the areas where the NDVI was lower (i.e. areas with poor vegetation). Conversely, they coincided with those places where the value of impervious surfaces are greater (i.e. significant concentration of built areas). In these areas, a greater concentration of heat waves was systematically observed, possibly being correlated with formation and consolidation of heat islands.

Concluding remarks

Heat-waves are responsible, within the urbanized area of many Italian cities, for the formation and consolidation of heat islands. A methodology identifying the location where heat-waves occur from remote sensing is proposed here. Green planning in these locations is highly recommended. It is well known in the literature that trees have the dual purpose of bringing coolness, and lowering temperatures, being in turn capable of absorbing CO_2 and pollutants. Urban trees are excellent air filters capable of removing pollutants and fine particulates that are harmful to our health. Empirical studies carried out in 14 large Italian cities shows that one hectare of urban forest removes, on average, 17 kilos of PM_{10} per year and 35.7 kilos of ground-level ozone per year. A peri-urban forest, on the other hand, can absorb up to 1,005 kilos of carbon per year and hectare. Moreover, an individual tree can eliminate up to 150 kilos of carbon dioxide per year. Overall, it is estimated that urban greenery in Italy is capable of absorbing 12 million tonnes of carbon dioxide. Based on these empirical evidence, our study should be corroborated with a systemic methodology based on best practices reducing pollution levels and operated with advanced technological tools. This allows monitoring biodiversity and, at the same time, guaranteeing the improvement of the aesthetic landscape with indirect benefits on livability. This also contributes to the perceived sense of well-being and limiting the harmful effects of heat-waves on health.

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