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The impact of built-up surfaces on land surface temperatures in Italian urban areas

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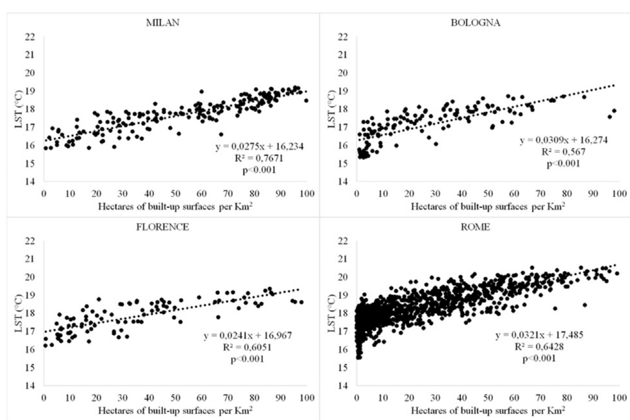
HIGHLIGHTS

- Information on the impact of built-up surfaces on LST is currently lacking in Italy.
- A very high-resolution cartography of sealed soils was compared with LST variations.
- Linear relationships between LST variations and built-up surfaces were observed.
- Daytime and nighttime LST slope patterns depend on city size and urban morphology.
- Critical areas "Hot-Spots" for mitigation actions are identified.

GRAPHICAL ABSTRACT



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ABSTRACT

Urban areas are characterized by the very high degree of soil sealing and continuous built-up areas: Italy is one of the European countries with the highest artificial land cover rate, which causes a substantial spatial variation in the land surface temperature (LST), modifying the urban microclimate and contributing to the urban heat island effect. Nevertheless, quantitative data regarding the contribution of different densities of built-up surfaces in determining urban spatial LST changes is currently lacking in Italy. This study, which aimed to provide clear and quantitative city-specific information on annual and seasonal spatial LST modifications resulting from increased urban built-up coverage, was conducted generally throughout the whole year, and specifically in two different periods (cool/cold and warm/hot periods). Four cities (Milan, Rome, Bologna and Florence) were included in the study. The LST layer and the built-up-surface indicator were obtained via use of MODIS remote sensing data products (1 km) and a very high-resolution map (5 m) of built-up surfaces recently developed by the Italian National Institute for Environmental Protection and Research. The relationships between the dependent (mean daily, daytime and nighttime LST values) and independent (built-up surfaces) variables were investigated through linear regression analyses, and comprehensive built-up-surface-related LST maps were also developed.

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Statistically significant linear relationships ($p < 0.001$) between built-up surfaces and spatial LST variations were observed in all the cities studied, with a higher impact during the warm/hot period than in the cool/cold ones. Daytime and nighttime LST slope patterns depend on the city size and relative urban morphology. If implemented in the existing city plan, the urban maps of built-up-surface-related LST developed in this study might be able to support more sustainable urban land management practices by identifying the critical areas (Hot-Spots) that would benefit most from mitigation actions by local authorities, land-use decision makers, and urban planners.

1. Introduction

The 2014 Revision of World Urbanization Prospects (United Nations, Department of Economic and Social Affairs, Population Division, 2014) revealed a reverse situation between rural and urban population: globally, more people live in urban areas (54%) than in rural ones.

The rapid and unplanned urban growth results in a continuous increase of land take, defined as the conversion of open spaces into artificial surfaces (i.e. built-up areas, road and rail networks) as well as green urban areas and sporting and leisure facilities (Artmann, 2014; Prokop et al., 2011). The most intense form of land take is represented by soil sealing (or imperviousness), defined as the permanent covering of soil by completely or partly impermeable artificial materials (i.e. asphalt, concrete, brick) (European Commission, 2012). The impervious surface area has been identified as an important environmental indicator (Arnold and Gibbons, 1996) and represents a good proxy measure of the human ecological footprint (Sutton et al., 2009).

Urban areas are characterized by the highest degree of soil sealing and continuous built-up areas (Artmann, 2014) with a very negative impact on the ecosystem services, including the irreversible loss of soil, biodiversity and its biological functions, landscape fragmentation, loss of agricultural areas and fertile soils useful for future generations (Prokop et al., 2011), and loss of urban green areas that provide recreational spaces (Lafortezza et al., 2009). Furthermore, the increase in impervious artificial surfaces leads to the increased hazard of surface water runoff (Haase and Nuissl, 2007) and also modifies the urban microclimate. The artificial impervious surfaces (sealed soils) cause a rise in heat storage during the day and a slower release at night. This condition generates alterations to the energy budget of the surfaces, producing a rise in the city temperature and contributing to the urban heat island (UHI) effect. The latter phenomenon triggers a rise in local surface and air temperatures in densely built-up cities that are consistently higher than the temperatures observed in surrounding rural areas (Oke, 1973). The conversion of natural land to urban land, with the consequent UHI effect, represents one of the most significant human-induced changes to the Earth's surface climate (Zhao et al., 2014).

This introduction justifies the need to improve knowledge about the influence of urban imperviousness on local climate, with particular focus on intra-urban temperature changes.

Because it is well known that temperature has a great spatial variability in metropolitan areas, the use of meteorological station networks (in generally scattered locations, often in suburban areas) only provides partial representations of air-temperature variations in heterogeneous urban/suburban environments (Morabito et al., 2015). An alternative to measuring the urban thermal environment is the use of remote sensing data sources, such as the land surface temperature (LST), widely adopted in previous urban environmental studies (Chakraborty et al., 2015; Kloog et al., 2012).

Many techniques have been applied to characterize and quantify urban impervious surfaces and a detailed description of these methods has been reported in a recent review (Weng, 2012).

With the introduction of high-resolution satellite imaging and more efficient image processing techniques implemented by GIS software tools, advanced technologies are today available for mapping and quantifying impervious surfaces.

Several examples of impervious surface mapping obtained by using high-resolution satellite imagery (i.e. IKONOS, Quickbird, RapidEye) are only available for limited geographical areas as specific case studies (Lu and Weng, 2009; Wu, 2009; Zhang and Guindon, 2012).

More recently, within the Copernicus programme of the European Commission, previously known as Global Monitoring for Environment and Security (GMES), the Italian National Institute for Environmental Protection and Research (ISPRA: Istituto Superiore per la Protezione e la Ricerca Ambientale) developed a very high-resolution map (5 m) of built-up surfaces for the entire Italian territory (Munafò et al., 2015). This is a binary indicator of urbanization (built-up or non-built-up surfaces) derived through further improvements of built-up surface detections and by applying a threshold to the degree of the sealing layer (Maucha et al., 2011).

This data set has the great advantage of increasing the previous spatial resolution of imperviousness obtained in the field of the Copernicus programme (20 m), thereby allowing for a more detailed environmental analysis on a local (i.e. urban) scale.

This very high spatial resolution indicator of urbanization was used in this study for the first time to spatially investigate the daily, daytime and nighttime built-up-surface-related LST in several Italian cities and at different times of year.

This topic is of particular interest because, according to recent estimations of the artificial land cover (Eurostat, 2012), Italy is the fifth European country (after Malta, Belgium, the Netherlands and Luxemburg) to have the highest artificial land cover rate. Nevertheless, quantitative data regarding the contribution of different densities of built-up surfaces in determining urban spatial LST changes is currently lacking in Italy.

For this reason, the aim of this study was to provide city-specific, clear and quantitative information on the LST modifications resulting from the increased urban built-up coverage. We verified the hypothesis that the use of a very high-resolution map of built-up surfaces might represent a useful quantitative tool to assess the intra-urban LST variations in Italian cities.

Greater knowledge of the thermal consequences of sealed soils could be very useful for urban planners and land-use decision-makers for promoting an efficient soil sealing management approach in urban environments.

2. Materials and methods

2.1. Period and study-areas

This study was carried out over a 13-year period (2001 − 2013) and it was conducted generally throughout the whole year, and specifically in two distinct periods with different thermal characteristics: 1) the cool/cold period, including the autumn and winter months (from September to February); 2) the warm/hot period, including the spring and summer months (from March to August).

The city selection criterion was based on the size of the resident population (Supplemental Table 1): one northern (Milan) and one central (Rome) city with more than 1 million of residents; one northern