Investigating Urban Growth Dynamic – Land Surface Temperature Relationship

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Abstract. According to the United Nations, 68% of the world's population is expected to live in urban areas by 2050. This makes urban growth one of the cornerstones of sustainable development policies that must be implemented from the outset. Well-managed urbanization is essential to minimize environmental degradation and land use, while maximizing the benefits of agglomeration and ensuring the expected well-being of all city dwellers. On the other hand, it is equally important that these growth dynamics interface systematically with ongoing climate change and its expected effects on the urban environment. Local climate regulation is a crucial urban ecosystem service as it directly affects the quality of urban life. Although its link with soil sealing and land-use change is theoretically known, it is worth explaining this relationship in terms of significant parameters of both altered surfaces and type of urban expansion.

This paper simultaneously analyzes the artificial soils dynamics transformation and land surface temperatures (LST) time series derived by MODIS satellites in a study area, the Basilicata region, widely affected by urban sprinkling and a marked depopulation.

Our results show a strong relationship between the increase in recorded minimum temperatures and the expansion of urban areas, especially where the main growth dynamic is compaction.

Keywords: Urban growth · Local worming area · LST · Urban dynamics

1 Introduction

The United Nations predicts that by 2050, 68% of the world's population will live in urban areas while the rural population is expected to decline to around 3.1 billion people [1]. This, together with expected climate change impacts, whose most considerable effects are likely to be experienced in urban areas [2], poses a challenge to urban and territorial planners: to develop effective tools capable of supporting sustainable development policies. Actually, the focus of the debate centres on the very concept of sustainable urban development because the question arises as to whether this should aim to increase population density or to allow urban expansion [3].

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Within the Italian context, further due consideration should be given to the modalities with which the growth of urban settlements has taken place in the last decades. In fact the globally widespread sprawl model is also flanked by sprinkling, technically defined as land take with a partially spontaneous development or subject to low controls and characterized by not homogeneous built-up areas and coexisting rural/residential/industrial/tertiary functions with very low building and population density [4].

The need to distinguish the evolutionary dynamics of settlements is due to the intensity of the ensuing effects. Damages due to urban sprinkling are much more serious than that caused by sprawl [5] and remedying in the long run is very difficult because it implies, for example, ecosystem fragmentation and thinning of biodiversity hotspots [6].

Assuming that urbanization is always matched by an increase in demand for ecosystem services (ES), what is needed for planning purposes is a deep understanding of ES spatial pattern and their trade-offs [7] resulting from land use/cover changes.

Increasingly within the scientific literature is the recourse to the ES methodological framework to analyse and evaluate change-related scenarios both in urban [3, 8–10] and regional context [11–14].

It is expected to be an useful tool to design land cover/land use change for the purpose of sustainably providing ecosystem services while recognizably meeting societal needs and respecting societal values [15] and therefore capable, when applied to the context under examination, of providing significant support during the policy definition processes that will then regulate urban expansion.

This work, in order to make a contribution to the study of local climate regulation ecosystem services, aims to investigate the relationship between temperature variations that occur between areas characterized by different levels of urbanization and the related development dynamics. It is deemed that climate regulation should be a key aspect of future planning activities because it produces a transversal impact with respect to the dimensions of well-being identified by the Millennium Ecosystem Assessment [16]: it influences the quality of life and the population health [17], effects ecological functions, such as air conditioning [18], and biodiversity [19, 20].

2 Materials and Methods

ES approach proves to be more and more promising both in assisting decision-making processes of local and regional environmental management [21] and in providing tools for the evaluation of all the connections between territory and human well-being [22]. The aim of this work is to investigate the relationship between urbanization and local climate regulation ecosystem service, whose importance within the urban context is shown to be growing globally.

Employed methodology is therefore structured into three macro-stages: i. Urbanization and temperatures data historical analysis; ii. Evaluation of the relationship between urban expansion phenomenon and land surface temperatures trend; iii. Discussion of results and conclusions.

In order to understand how the relationship between urbanization and temperature changes on the basis of different variables (e.g. fragmentation degree), the methodology was applied in the Basilicata region, interested by a marked sprinkling and a relevant depopulation [23, 24].

2.1 The Basilicata Case Study

Study area is located in Basilicata, a region in Southern Italy with an area of about 10,000 km^2 and a population of 567,118 inhabitants [25].

A constantly decreasing birth rate, a natural rate tending to zero and a large migration outflows have led to a constant decline in the population since the 80s.

Despite its population density as of 2014, equal to 57,2 inhabitants per km^2, is second only to that of Valle d'Aosta region, Basilicata is not exempt from land take phenomenon. Recent studies [26] confirm that it is among the regions of Southern Italy that show a greater correlation between the variation rates of urbanization and population trend and the highest urban development rates corresponding to the demographic variations.

From previous works [23, 24], it also appears that even urban development dynamics are not typical of the sprawl that characterizes most of the European continent, but attributable to the so called sprinkling [4], very common in the Iberian, Mediterranean and Balkan areas [5].

This expansion model is substantially characterized by very low population and building densities and a high degree of fragmentation with all that follows in terms of social, economic and environmental impacts [27–32].

2.2 Dataset

Land Use Change/Urban Growth

All data on urban areas and aggregates number were calculated regarding a period ranging from 1998 to 2013 and on the basis of geo-topographic regional database (Regional Spatial Data Infrastructure – RSDI [33]) and satellite photos from the national geoportal of the Italian Ministry for the Environment, Land and Sea Protection.

Starting from the latest data on building stock taken from the Regional Technical Map and available at a scale 1:5000, photo-interpretation has been used to create the database for 1998. What is thus obtained is a shapefile of all the buildings featured in the two dates.

In order to identify areas where an increment in urban areas was matched by an increase in fragmentation or in compaction, buildings features have been aggregated.

Every aggregate corresponds to a complex polygon that includes at least two buildings at a relative maximum distance of 50 m. This distance-threshold was driven by the need to better represent the Basilicata settlement system.

Land Surface Temperature (LST)

Apopular source of Earth's surface temperature estimates based on remote sensing are Moderate Resolution Imaging Spectroradiometer (MODIS) (LST) images, derived from the MODIS temperature bands [34]. MODIS data from the TERRA [35] and AQUA [36] sensors downloaded through the MODIStsp tool of R [37], a tool for

automatic preprocessing of MODIS time series, available in open format. In particular, used images have a geometric resolution of 1 km per pixel and a temporal resolution of 8 days. Images of the LST temperature during daylight hours were used for a period between January 2001 and December 2017.

Previous studies [38, 39] have highlighted the variability of LST depending from air temperature and all the factors related to it: altitude, wind speed, surface emissivity, precipitation incidence, time of day, presence of clouds, characteristics of the satellite sensor and mathematical model for LST derivation. However, the purpose of this analysis is investigating the relationship between LST temperature and urban transformation so we considered not very significant this variability.

2.3 Methods

The study region has been discretized in a square mesh grid with a size of 1 km. This dimension corresponds to the maximum level of possible detail as it corresponds to the resolution of Modis LST.

Classification of all the cells by evolution dynamic was carried out by jointly considering the change both in artificial surface and in the number of aggregates.

Meshes with any urbanized surfaces in both time sections investigated were classified as "No urbanized" (NO URB); "Not transformed" (NO TRANSF) is instead referred to meshes that have not undergone any change in urbanized areas.

Areas that have been subjected to an increase in artificial surfaces have been further distinguished on the basis of expansion dynamics: "fragmented" (FRAGM) identifies all the areas in which anthropized surfaces increase corresponds to a growth in aggregates number; a reduction in aggregates number and therefore a densification of urban fabric occurred in meshes designated as "compacted" (COMP).

To these classes was added an additional one, named "Unchanged aggregation" (UN_AGGR), in which aggregates have grown in size but not in number. Designations and classification criteria are summarized in Table 1.

Table 1. Criteria for classifying evolution dynamics

Classification	Anthropized surface variation	Variation in aggregates number
NO URB	NULL	NULL
NO TRANSF	0	0
FRAGM	+	+
COMP	+	–
UN_AGGR	+	0

For each mesh of this grid, resulting coverage percentage were also calculated.

As far as temperatures are concerned, all the series referring to daytime hours and acquired during the entire period from 2001 to 2017 have been analyzed.

Using GIS raster automated processes, for each cell and for every year considered, maximum daytime temperatures series were computed.

In order to identify the areas that show an aptitude to generate local warming areas, year by year were highlighted the cells in which the minimum temperature was higher than the average for the same year plus once the standard deviation.

Particular attention was therefore paid to the cells that show a change in this behavior as a result of a process of sealing and/or urban growth.

3 Results

First analysis aimed at comparing temperature trends and types of evolutionary dynamics. For each cell, classified on the basis of criteria described in Table 1, temperature trend has been then graphically displayed. Minimum, maximum and average values of the data set for the entire period have been graphed.

As it is possible to see on the graphs, a significant trend emerges especially with reference to minimums of maximum daytime temperature. In fact, it emerges that not only are the recorded temperatures higher in cells in which compaction occurred, but also the growth rate is higher than in the cells characterized by different evolution dynamics (Fig. 1).

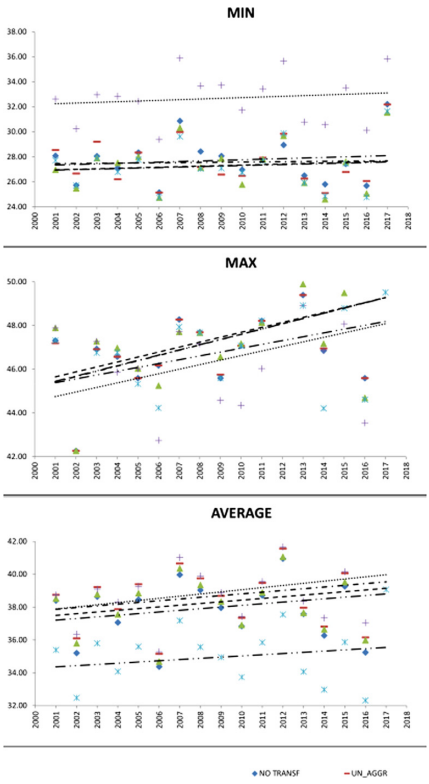


Fig. 1. Trend in minimum, maximum and average values of maximums daytime series in relation to evolution dynamics

On the basis of this dataset, local warming areas (LWA) defined on the following criterion have been searched:

$$\mathbf{LWA}: \textit{Registered temp.} > (\mathbf{mean\ temp.} + \mathbf{1} * \mathbf{st.dev.}) \quad (1)$$

Analyzing the entire period, areas that show this behavior correspond for Basilicata region to the main industrial areas. Although they have not undergone large variations in anthropized surfaces, their coverage percentage is greater than those registered in correspondence of residential centers.

For the purposes of this work, however, analyses focused on those cells that showed abnormal temperature behavior as a result of artificial surfaces changing.

Within the Basilicata region, in one particular area (see Fig. 2) a considerable result is observed, since a significant increase in the artificial surface corresponds to an anomaly in the behavior of temperatures.



Fig. 2. Sealed surface increase in one the LWAs within Basilicata Region

This area is located in the eastern part of the Potenza urban aggregate and extends for 4 Km^2 around the major highway infrastructure serving the city. Between 2000 and 2016, artificial surface area increased by about 9% from 38 to 41 ha/km^2 resulting in a total sealing surface value of 165 ha.

The type of transformation was characterized by compaction with an increase in artificial surfaces due to both new buildings construction and sailing soil to be used for parking and storage of goods and vehicles.

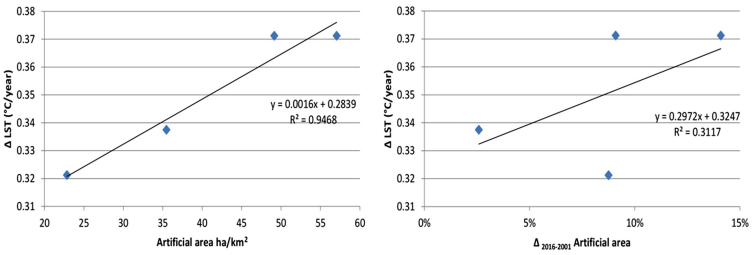


Fig. 3. Relationship between average annual LST variation and artificial surfaces increase in terms of final coverage degree (left) and percentage increase (right) in Basilicata case study

In the same period MODIS LST followed a growing trend showing from 2012 onwards a typical behavior of LWA growing at a higher speed than all the cells characterized by the same evolution dynamic.

The relationship between temperature variation and sealed surfaces increase was then analyzed by means of a regression analysis between the average annual increase in recorded temperatures and, respectively, the percentage variation in sealed soil and final coverage value expressed in ha/km^2.

As it is possible to see from Fig. 3, a relevant correlation ($R^2 = 0.95$) exists between temperature increase and final coverage degree.

4 Conclusions

City's population growth, and the consequent need to densify urban aggregates, is increasingly conflicting with the theme of livability of urban spaces and the services they provide for citizens' well-being.

The methodological framework of ecosystem services can be a support in developing an evaluation panel [40–42] of different transformation kind carried out in urban environment [43] as well at a regional scale.

This work was aimed at investigating the relationship between growth pattern (compaction or fragmentation) and recorded surface temperature, assumed significant for an ecosystem service regulating local climate of urban spaces.

Our results highlight that: 1. cells that have undergone compaction show simultaneously higher temperatures and a faster trend of growth over time; 2. within these areas, the strongest relationship occurs between recorded temperatures and artificial surface ratio.

Deepening this type of approach is considered to be useful in supporting the decision-making process underlying future urban policies and in assessing development scenarios in relation to both environmental sustainability and quality of life.

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