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EXTREME WEATHER EVENTS CAUSED BY CLIMATE CHANGE

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Editorial correspondence
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples
web: www.tema.unina.it
e-mail: redazione.tema@unina.it

Cover Image: Wind travels across Lake Washington, buffeting the 520 floating bridge as the storm grows in strength. (Steve Ringman / The Seattle Times).

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TeMA Journal of
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Contents

FOCUS

LAND USE, MOBILITY AND ENVIRONMENT

109

REVIEW PAGES

Gennaro Angiello, Gerardo Carpentieri,
Chiara Lombardi, Laura Russo, Andrea Tulisi

TeMA

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GREEN INFRASTRUCTURE AND CLIMATE CHANGE ADAPTATION

KONSTANTINA SALATA[a], ATHENA YIANNAKOU[b]

[a,b] School of Spatial Planning and Development, Aristotle University of Thessaloniki
[a] e-mail: salatadg@plandevel.auth.gr
[b] e-mail: adgianna@plandevel.auth.gr

ABSTRACT

One of the main challenges urban areas, and more particularly the compact ones, are facing is their adaptation to climate change. In recent years, is had been recognized that a more ecosystem approach to spatial planning can play a critical role in meeting these challenges. Green Infrastructure (GI) and its integration in spatial planning emerges as one of the most appropriate and effective ways to improve microclimate and tackle the impacts of climate change and mainly the Urban Heat Island (UHI) effect. This paper initially attempts to clarify the term GI and portrays its benefits and its role as an important spatial planning tool to fulfill different environmental, social and economic needs of urban areas. Then, the paper proceeds to an empirical evaluation of the role of GI in reducing the vulnerability to UHI effect in a compact urban area of the city of Thessaloniki. For this reason, a simple methodology is developed with a twofold purpose: to recognize the risks posed by climate change and especially UHI and to assess the potential offered by available in a compact area GI assets as well as by their redesign in order to maximize their contribution to climate change adaptation.

KEYWORDS:
Green Infrastructure; Urban Heat Island; Climate Change Adaptation; Thessaloniki.

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绿地系统建设及其对气候变化的适应性

KONSTANTINA SALATA[a], ATHENA YIANNAKOU[b]

[a,b] School of Spatial Planning and Development, Aristotle University of Thessaloniki
[a] e-mail: salatadg@plandevel.auth.gr
[b] e-mail: adgianna@plandevel.auth.gr

摘要

适应气候所带来的变化是居住在城区，尤其是紧凑区域的人们所面临的主要挑战之一。近年来，人们越来越意识到在空间规划中运用更加生态系统的方法能够起到应对挑战的关键作用。绿地系统建设及其整体空间规划正是改善局部环境、解决环境变化，尤其是城市热岛效应中最合适和最有效的方法。首先，本文试着阐明绿地系统建设的定义和优势，并描述其在实现城区不同环境、社会和经济需求中作为空间规划工具的重要作用。其次，本文从经验的角度评估了绿地系统建设在降低塞萨洛尼基城密集区的热岛效应中所发挥的重要作用。基于这个原因，我们开发这个简单的方法论是有双重目的的。首先是认识到由气候变化，尤其是城市热岛效应引起的风险；其次是评估在密集区域中绿地系统建设和重新设计对扩大其对气候改变适应性的可行性。

关键词：
绿地系统建设；城市热岛；对气候变化的适应性；塞萨洛尼基城.

1 INTRODUCTION

The interactive relation between climate change and urban areas has long been recognized and documented in a range of studies (Bulkeley & Betsill, 2003; OECD, 2008; Toly, 2008; Kern, 2010; World Bank, 2010; UN-Habitat, 2011, Bulkeley, 2013). Urban areas show obvious signs of what has been called inadvertent climate modification (Oke, 1987). This is due to the process of urbanization and all human, social and behavioral activities related to it, which have intensified environmental problems. Urban environmental problems extend beyond the boundaries of urban areas, thus contributing to global environmental degradation (Gorsevski, Taha, Quattrochi, and Luvall, 1998; Toly, 2008; Bai, McAllister, Beaty, and Taylor, 2010). On the other hand, as relevant literature has highlighted, urban areas are also severely threatened by climate change, displaying a high level of vulnerability to environmental hazards. The emergence of the Urban Heat Island (UHI) -the phenomenon whereby cities appear to be warmer than the surrounding rural area- has been noted as one of the main effects (Oke, 1987; Roth, 2002; Wania, 2007; Memon, Leung, and Chunho, 2008). All of these indicate a rupture in the balance between human and natural eco-systems, resulting in people being cut off from valuable ecosystem services, which in turn has led to a range of consequences including the inability to adapt to, or mitigate the effects of, climate change. At the same time, however, there is a growing recognition, that urban areas represent the best loci both for adaptation to the new and changing conditions resulting from climate change, and for the creation of a sustainable future (Roth, 2002; Toly, 2008; OECD, 2008; Bai, et al., 2010).

Given the local character that both spatial planning and adaptation exhibit, spatial planning, and land use planning in particular, is emerging as a key factor both in sustainable development and in tackling climate change (Davoudi, 2009; Davoudi, Crawford, and Mehmood, 2009; Biesbroek, Swart, and van der Knaap, 2009; Planning and Climate Change Coalition, 2010; Measham, Preston, Smith, Brook, Gorddard, Withycombe, and Morrison, 2011; Yiannakou & Salata 2012; Cashmore & Wejs, 2014). Spatial planning influences the distribution and the spatial dimension of activities and investments of current and future generations. Therefore, spatial planning tools potentially can make a significant contribution in tackling the uncertainty and complexity of climate change. Furthermore, the potential of planning to manage conflicting interests that emerge, to act independently of administrative boundaries and scale governance, to promote participation and to help to generate and disseminate knowledge and best practices, all contribute considerably to the sustainability and resilience of urban areas. At the same time, climate change has had new and unforeseen effects on lifestyle, work, recreation and transport, all of which pose a challenge for planning (Blakely, 2007; Davoudi, 2009; Biesbroek et al., 2009; Yiannakou & Salata, 2012; Hurlimann & March, 2012; Cashmore & Wejs, 2014; Salata & Yiannakou, 2013; van Buuren, Driessen, van Rijswick, Rietveld, Salet, Spit, and Teisman, 2013).

Of particular interest for adaptation is the case of compact cities which, while being widely accepted as representing both the most suitable urban form and the one most appropriate for mitigation, are also faced with the most difficulty coping with climate change adaptation (Pizzaro, 2009). These cities are expected to experience the effects of climate change more intensely, due to their specific characteristics, such as high densities, high traffic rates, congestion, problematic layout plans, lack of open space, decaying building stock and high rates of poverty. All these features are, to a large extent, shaped by spatial planning at the local level (Bulkeley & Betsill, 2003). These inherent features of the compact-city systems constitute the defining factors of its vulnerability, when the latter is defined as a "state" existing within a system before a hazard event occurs (Adger, Brooks, Bentham, Agnew, and Eriksen 2004). Using the concept of "Risk Triangle" suggested by Crichton (1999), "risk" depends on three elements, hazard, vulnerability and exposure, which represent the three sides of a triangle. According to this concept, if we shorten one of the triangle's sides then the size of the area representing the risk is reduced (Figure 1). If the vulnerability of the compact city is regarded as a state, then it could be argued that by intervening in its inherent features -especially those related to urban structure- through spatial planning, we reduce vulnerability and therefore the size of the risk faced by these cities.

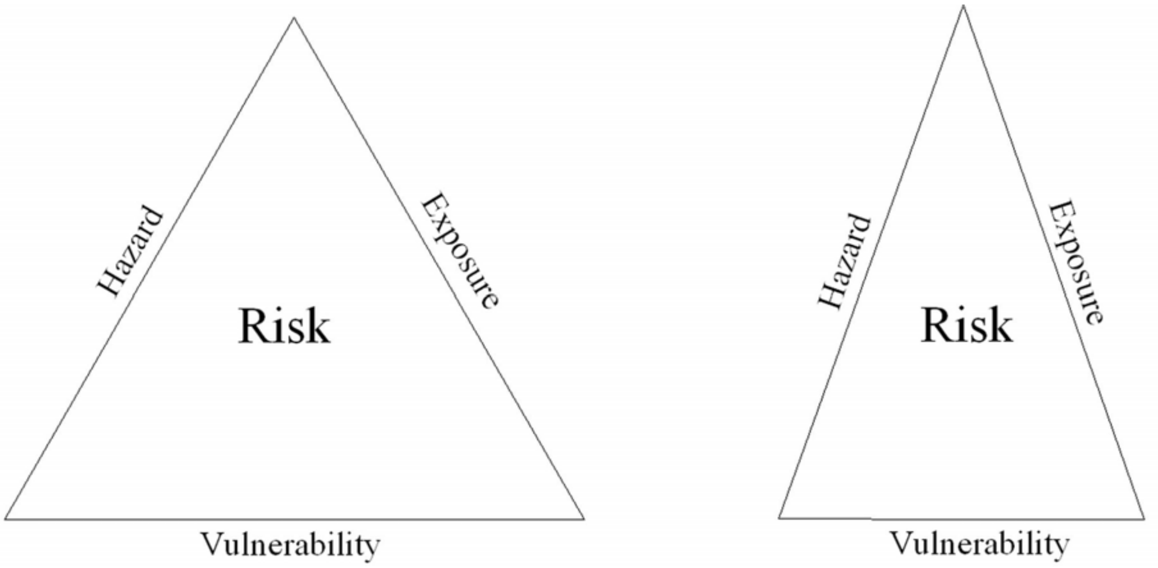

Fig. 1 Risk Triangle (after Crichton, 1999; modified)

One of the tools of spatial planning, land use planning and detailed urban design in particular, is the provision of Green Infrastructure (GI), the latter being recognized in recent years as playing a critical role in meeting the challenge of climate change adaptation. After this brief introduction, the second section of this paper provides an analysis of the term GI and its basic features based on a literature review. In the third section, and using a simple methodology, we proceed to an empirical evaluation of GI assets that are usually available in compact and densely built-up areas, and their potential for reducing a compact's area vulnerability to UHI. The case study was conducted in one of the municipalities of the compact area of the city of Thessaloniki, the Municipality of Kalamaria. Finally, some conclusions are drawn regarding the prospect of incorporating GI into an integrated spatial strategy for climate change adaptation.

2 GREEN INFRASTRUCTURE: DEFINITION AND BASIC FEATURES

Many ecosystem-based approaches for spatial planning have adopted a redefinition of the relations between biotic (people, flora, fauna), abiotic (soil, water, air), cultural and artificial (buildings, roads, infrastructure) components and functions of the urban ecosystem, so as to foster a sustainable coexistence between natural and built (gray infrastructure) environment (Brady, Brake, and Starks, 2001; Schäffler & Swilling, 2013). One of the best and most appropriate planning tools based on this approach, using the method of restoration of ecosystem services and therefore adaptation to climate change (including to UHI), is the provision and design of GI.

Following the definition given by Natural England's Green Infrastructure Guidance (Natural England, 2009), the term GI essentially refers to a multifunctional network of environmental and other assets, public and private, existing and new, covering all spatial scales, while its design and management respects and enhances the local character of the area. Such assets are street trees, green roofs and walls, private gardens, pedestrian and cycle routes, road and railway networks, pocket parks, city parks, regional or national parks, churchyards, school grounds, institutional open spaces, play areas, local nature reserves, sports pitches, allotments, vacant and derelict land, brownfield land, agricultural land, ponds/lakes, rivers and floodplains, urban-municipal plazas etc. (Landscape Institute, 2009). Although the term has been used internationally both in research and policy documents, the review of the relevant literature shows that there is no single and universally accepted and used definition for GI or for its assets. Owing to its multi-functionality, the definition may vary depending on the context (scientific background of scholars), on the stakeholder and/or on the spatial scale in which it is examined (Benedict & McMahon, 2002; Mell, 2008b; Mell, 2010; Wright, 2011; Naumann, McKenna, Kaphengst, Pieterse, and Rayment, 2011; EEA, 2011; Beauchamp & Adamowski, 2013; Hansen & Pauleit, 2014). In addition, as some GI assets are easier to monitor scientifically and to evaluate, they tend to attract more research (European Commission [EC], 2012) and, therefore, to influence the definition of GI. These observable differences in terminology may also result from difficulties in the translation and accurate interpretation of the term (Werguin, Duhem, Lindholm, Oppermann, Pauleit, and Tjallingi, 2005). This could explain the varying designations of GI as approach, concept, networks or structures/spaces (Naumann et al., 2011; EEA, 2011; Lennon, 2014).

Whatever the different definitions of the term, it is worth mentioning that GI is not new as a concept (Benedict & McMahon, 2002). It could be argued that in spatial planning one of the first references that attempted to link urban areas and ecosystem services, was Howard’s garden city, presented in 1902 in his book "Garden Cities of Tomorrow", in which the concept of GI may have its roots. It has been proposed that attempts to put the design of GI into practice date back to the late 1970s in the UK (Kambites & Owen, 2006). During the same decade, GI has also been studied in other countries, such as in Germany under the term "landscape design" (EC, 2012). The term "Green Infrastructure" appeared for the first time during the 1990s both in the United States and in Europe (Mell, 2008a; Mell, 2008b; EEA, 2011; Naumann et al., 2011; Lucius, Dan, Caratas, Mey, Steinert, and Torkler, 2011; Lennon, 2014). Yet it is still considered a relatively new EU policy instrument (EC, 2012). For this reason, many GI initiatives were established, which did not, initially, refer to themselves as such (Naumann et al., 2011). However, the different definitions and terminologies, are not contradictory, being generally related and sometimes overlapping (Kambites & Owen, 2006; Naumann et al., 2011; EEA, 2011).

In EU, the term GI was first introduced in the 2009 Commission White Paper, "Adapting to Climate Change". Almost all of the EU legislative documents (regulations, directives, recommendations, decisions etc.) use the term "Green Infrastructure" in connection with landscape resources, with particular emphasis on ecological connectivity. In contrast, the European Environment Agency (EEA) and other European programmes choose to use the term "green spaces", "green systems" or "green structure" when referring to the urban environment or other related issues, (EEA, 2011; Werguin et al., 2005). The term "Green Infrastructure", as such, is widely adopted by the UK's legislative bodies, and used in relevant studies concerning areas within the UK. It is interesting, however, that even in these cases, some important differences in definitions are recorded in the various spatial planning documents, such as the Regional Spatial Strategies (RSS) of the previous planning system in England (Natural England, 2009). For example, Gill, Handley, Ennos, and Pauleit (2007), in their study of the role of GI in adaptation to climate change in the Greater Manchester area, regard GI as a grid connected network of green spaces, defining it broadly to include natural and artificial assets such as street tree planting, green roofs and facades, ground cover, private gardens, greening railway lines, green corridors, natural reserves and sustainable urban drainage systems.

Regarding GI definitions, it is interesting to note the differences between those adopted in the USA and in Europe. In the USA, more emphasis is given to water management and rainwater, and to the connection of GI with gray infrastructure, stressing the need to protect the ecology and natural systems (Kambites & Owen, 2006; EEA, 2011; Lennon, 2014; Mell, 2014). Of course there are also studies using a more ecosystem-based approach, paying special attention to the role of biodiversity, while highlighting the need for a 'smart'/sustainable growth fostered by the development of an integrated planning process. For example, Benedict and McMahon (2002), focused on an interconnected network of green space (such as waterways, wetlands, forests, habitat, greenways, parks, farms, wildlife areas, open spaces), as well as on ecosystem services and biodiversity. Similarly, Brady et al. (2001) point out that GI consists of natural resources such as trees, to which they give particular importance, streams, wetlands, open spaces, street trees, parks, water fronts, lawns, etc., while giving greater emphasis to land use planning and water resources, and to the relationship of gray with green infrastructure. Both these studies pay particular attention to an integrated GI design process. At the EU level, a more clear ecosystem-based approach is adopted, stressing the importance of multifunctional networks of GI assets and of ecosystem services, whereas, overtime, wider and more integrated definitions are adopted. In this approach GI assets include terrestrial and marine/aquatic ecosystems and characteristics, as well as natural, semi-natural, urban and rural areas. Particular emphasis is given to the correlation between adaptation to- and mitigation of climate change, and GI across all planning scales. In relation to GI assets, some projects make a distinction between green and blue infrastructures, whereby the first includes urban vegetation (gardens, parks, productive areas, greenways, green roofs and walls) and the latter, water elements (such as water, rivers, streams, floodplains, sustainable drainage systems and general aquatic ecosystems) (Shaw, Colley, and Connell, 2007; Natural England, 2009; Natural England, 2013; EC, 2013).

Although the design, mechanisms, tools and actions for achieving GI, naturally differ across the various planning systems, given the local approach it also exhibits, this lack of a unified conceptual framework can create misunderstandings and limitations in its planning, design and implementation, as well as communication problems between all actors involved in this process (Mell, 2008a). This could have important implications for the aspirations of local authorities regarding adaptation to climate change, and to some degree, mitigation. GI assets can reduce the negative impact of urbanization in a sustainable manner, preventing urban sprawl, reducing the demand for transport (reducing congestion, noise, air pollution), promoting a land use mix and a more compact city structure, ensuring a sustainable and efficient use of resources and enhancing biodiversity. Therefore, GI has a significant role in improving the urban microclimate and hence tackling UHI, whilst also helping to reduce the risk of natural disasters. There are also some potential problems, for municipalities or individuals, with the implementation of GI: GI is an infrastructure and so it requires investments and maintenance in order to provide services and benefits. However, the implementation cost turns out to be lower than in other practices whereas the implementation of GI prevents possible future costs (Wania, 2007; Santamouris, 2007; U.S. EPA, 2008; Kleerekoper, 2009; Karhu, 2011; Naumann et al., 2011; EC, 2012; Landscape Institute, 2013; Arup, 2014). Moreover, the entire urban population can benefit from the implementation of a holistic GI planning approach (Arup, 2014).

A final factor to consider is the need for an integrated spatial planning strategy based on GI, as such a strategy would offer more efficient ways for local authorities to achieve multiple goals. Integration of GI into spatial planning, which is based on an ecosystem approach, would make the design of GI assets one of the main tools of intervention, thus building a sustainable environment, which is resistant to future challenges and adaptable to future needs. To achieve this, planning must be supported and guided by a number of key principles, which should then be specified according to the characteristics, conditions (environmental, social, political and economic) and needs of each region. Various relevant studies have proposed a number of such key principles (Brady et al., 2001; Benedict & McMahon, 2002; Werguin et al., 2005; Kambites & Owen, 2006; TCPA [Town and Country Planning Association], 2008; Naumann et al., 2011; TCPA and The Wildlife Trusts, 2012; Jaluzo, James, and Pauli, 2012; E.C., 2013; Landscape Institute, 2013; Arup, 2014). These proposals can be categorized according to the following key principles: comprehensive planning, multi-functionality, interdisciplinarity, inclusiveness, sustainable financing, strengthening local features, connectivity, accessibility and data monitoring.

3 ASSESSING THE ROLE OF GI TO CLIMATE CHANGE ADAPTATION IN A COMPACT AREA OF THESSALONIKI CITY

In light of the above discussion, the main objective of the present section is to give an empirical assessment of the role of GI in reducing the vulnerability of a compact urban area to UHI. For this reason, a simple methodology has been developed with the purpose, firstly, to highlight the risks posed by climate change, and especially UHI, in a compact area, secondly, to assess the potential of already existing GI assets for climate change adaptation and, thirdly, to assess how the redesign of these assets could contribute to maximization of this potential. This methodology comprises the following steps:

- Highlighting the vulnerability of the study area to UHI, by using the urban structure data, which include the inherent characteristics of the compact area, in order to map the parts of the built-up area which are likely to be more vulnerable.
- Analytical mapping of the available GI assets, followed by an assessment of the cooling effect of these assets, in order to define which parts of the area studied do not benefit from the cooling effects of GI assets and are, therefore, more vulnerable to UHI.
- Designation of potential planning interventions which maximize the positive effect of available GI assets on climate change adaptation.

This case study was conducted in one of the municipalities of the city of Thessaloniki, the Municipality of Kalamaria, in order to demonstrate the importance of GI in a compact densely built-up area. In these areas perhaps the biggest difficulty, is deciding how to redesign the problematic sections of its layout plan, while avoiding large and costly interventions. Therefore, in these areas, only small scale planning and detailed design interventions within the existing provisions of the planning system are feasible.

3.1 RECOGNITION OF THE STUDY AREA'S VULNERABILITY TO UHI

With a total population of 90.096 inhabitants (2011 Census), the Municipality of Kalamaria, a relatively compact area of the city, is situated in the southeast coastal area of Thessaloniki. The Municipality is a middle-class area with a relatively large proportion of people in the higher professions and a lower proportion of unskilled labourers. The Municipality grew rapidly between 1971 and 2011. This trend led to increased pressure on resources such as land, energy, water and transport systems, and also to higher population densities. This increased pressure, in turn, resulted in an intensification of climate change in the area. Densities in the populated area vary from about 220 to 600 inh./Ha. The layout plan is designed with several routes which lie at right angles to the coast, and the area is built with medium rise, 4-5 storey-buildings. These features generally allow the unimpeded stream of the northwest winds, which provide sufficient ventilation.

Geographically speaking, the area has an extended sea front, with a total coastline length of about 5.5km, and an open flood-protection trench (Peripheral Trench, P.T.) lying along its northern stretch. The climate is Mediterranean, with cold and wet winters and hot and dry summers. An important climatic feature of the study area is its high humidity. Furthermore, based on available data of the Hellenic National Meteorological Service, since 1951 the temperature in Thessaloniki has been increasing, a trend expected to continue. Studies have also shown that despite an increase in humidity in recent years, Thessaloniki has actually become more arid. Moreover, while there has been significant reduction in the levels of annual rainfall itself, rain now falls more rapidly than before (YPEHODE, 2002), increasing the risk of flash floods. The average wind speed is relatively low, reaching only 5.5Kt and blowing in a northwesterly direction. Sea level is rising at higher rate -4.0mm/year- compared to the global average of 1-2mm/year. Regarding data on air pollution, in the Municipality of Kalamaria, only the concentration values for nitrogen dioxide (NO_2) and

Particle Matter (PM10), are relatively high. These higher levels are the result of the central heating systems in houses and increased traffic on the roads.

The percentage of women and the elderly in the Municipality is showing a gradual increase. These two groups are regarded as being more vulnerable to the impacts of climate change, having greater difficulty adapting to it. The effects on the Municipality of its middle-class socioeconomic composition could be interpreted in two ways: on the one hand, that the inhabitants have habits more harmful to the environment than those of lower socio-economic classes and, on the other, the satisfactory educational level of the inhabitants may indicate that they are able to understand the impacts of climate change and adapt better to it, (through information and education programs and/or creation of communication and information platforms), and to participate actively in relevant decision-making processes (Salata & Yiannakou, 2013).

The above data indicates that the Municipality exhibits a high degree of generic vulnerability[1]. In order to assess quantitatively the specific vulnerability of the built-up area to UHI, and since temperature measurements at street level do not exist, two tasks were undertaken:

First we used the equations proposed by Oke (1987 & 1988), which correlate UHI with the size of population (first equation), and with the aspect ratio of street canyons (second equation)[2]. Using the first equation it was estimated that the intensity of UHI based on the population is 5.9°C. The application of the second equation, which correlated UHI to urban geometry, in a sample group of the roads, showed that 84.3% of these roads exhibit a temperature higher than the one calculated by the first equation (Figure 1).

The first trial assessment, although it provides an indication of both the impact of UHI, and of a clear tendency of the study area to vulnerability, is rather simplified, as several important elements are not taken into account. For this reason, in a second test assessment, we used a set of urban structure data (inherent features of vulnerability), namely:

- wind direction in conjunction with roads set at right angles to the northwest sea front (in order to estimate the cooling effect inside the urban fabric produced by the unhindered movement of air masses);
- land use (emphasis was given to commercial and recreational uses to identify where more pressure is created by traffic);
- density of urban units (high densities can result in poor ventilation);
- layout pattern and form (the layout and the position of buildings create a "wall" hindering air movement, coupled with building materials, which emit heat, resulting in heat trapping);
- traffic volumes (to estimate where air pollutants concentration is higher, combined with the two previous data).

The combination of the above data resulted in an area that is anticipated to be the most vulnerable to UHI (Figure 2).

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[1] Based on Adger et al. (2004) vulnerability can be distinguished in "generic", factors that determine the vulnerability and the capacity of a system to adapt to a wide range of hazards, and "specific", properties of a system that will make it more vulnerable to certain types of hazard than to others.

[2] The first equation correlates UHI with population, through the formula $\Delta T_{u-r(max)}=2,01 \cdot \log P - 4,06$. The second equation relates UHI with the aspect ratio of street canyons (H/W, where H is the average height of the canyon walls (buildings) and W is the canyon width), through $\Delta T_{u-r(max)}=7,54 + 3,97 \cdot \ln(H/W)$ (Oke, 1988).

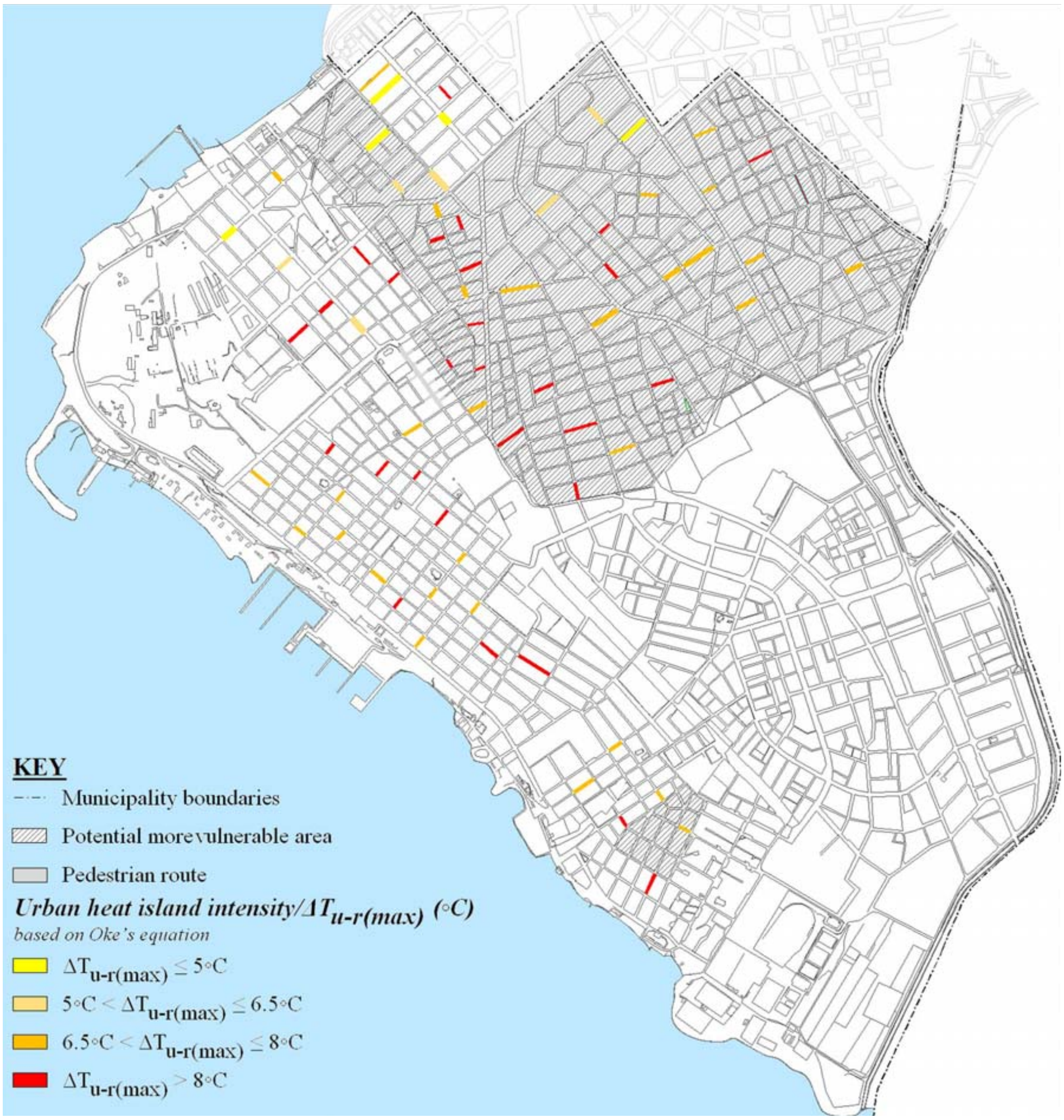

Fig. 2 The most vulnerable area to UHI

3.2 ASSESSMENT OF GI IN THE STUDY AREA

3.2.1 MAPPING OF GI ASSETS

- Detailed field records showed that the main GI assets in the study area can be divided into two categories:
- GI assets of public, or potentially public, character, such as existing and planned open and green spaces, green niches, pedestrian routes and tree-lined streets. Other potential GI assets in this category, such as school and church yards, were also recorded in an attempt to identify potential spaces which either act as, or could be transformed to, green spaces.
- GI assets of private character, such as uncovered parts of private blocks and private gardens, whose preservation as open spaces is relatively manageable with simple land-use planning tools and at no cost.

Mapping of the GI assets in the first category (Figure 3) indicates that the Municipality has a fragmented pattern of small sized urban GI assets, mainly small green spaces, urban parks and tree planting along a large part of the road network. The GI assets of public character which occupy an area of 124.61ha, and which represent 17.31% of the total area of the Municipality, include green spaces, church and school yards which are planted, sports pitches, cemeteries, the Peripheral Trench and pedestrian routes. Almost 36% (44.97ha) of the total GI assets area have already been designated as green spaces by the statutory plan. However, this measure has yet to be implemented due to planning complications related to their property status or initial uses One example of this would be the case of the two barracks in the study area, one of which has been a large brownfield for many years, and the other, which remains with its initial use. Another example would be the case of designated open spaces which haven't been taken over by the local council yet and therefore remain private property (Figure 2). Another problem is the lack of both a network of open and green spaces and of their interconnection with blue infrastructure, leading to a lack of sufficient air flow and the reduced renewal of air. This situation can cause problems, such as intensity of the UHI effect, localized flooding from overburdened drains and intensive precipitation.

Moreover, it was observed that some of the existing public green spaces are not categorized as such in the statutory land use plan, either being included in the road network, or functioning as green spaces while having a different statutory use. Most green spaces are practically deserted and therefore not configured nor maintained correctly, functioning only as open spaces covered either with grass, or worse, with soil. This situation makes the provision of cooling during the day difficult. Thus, these spaces may contribute to the intensity of UHI, especially on hot days, an effect which is intensified in those neighborhoods where there are also some non-built up sections covered by soil. Very few green spaces incorporate blue infrastructures, which would help in improving the microclimate and tackling UHI effect. The existing pedestrian routes are not linked to form a complete network, while the entire Municipality also lacks a network of bicycle lanes.

Interestingly, several green niches within the network of streets occupy a larger area than that of small parks. This fact emphasizes the importance that should be given to their management, aiming at facilitating natural ventilation and reducing air pollution and urban noise. Other important GI assets are the physical configurations of the sea front and the P.T., the main flood protection of Eastern Thessaloniki. This essentially functions as a long green corridor connecting the surrounding natural green elements of the city of Thessaloniki (mountains, sea, rivers). Finally, regarding GI assets of a private character, field recording has shown fairly satisfactory planting of private gardens, flower beds on the pavements and uncovered parts of the blocks. Green facades and roofs were not recorded.

3.2.2 EVALUATION OF GI ASSETS IN RELATION TO THE UHI EFFECT

In order to make a more accurate assessment of GI assets and to demonstrate both the potential and shortcomings of the study area, a set of criteria were constructed to define the relationship between the size of urban parks and their cooling effect (Park Cool Island-PCI). These criteria were based on a synthesis of studies which provide field measurements of temperatures as an effect of PCI in relation to the size of urban parks (Shashua-Bar & Hoffman, 2000; Feyisa, Dons, and Meilby, 2014; Cheng, Wei, Chen, Li, and Song, 2014). Based on this synthesis we propose the following categories of catchment area:

- 100m of catchment area (cooling effect) from GI assets of minimum size 0.15ha and maximum 2ha;
- 200m of catchment area from GI assets of a size at least 2ha;
- 300m of catchment area from GI assets of a size greater than 20ha.

It should be mentioned that the catchment areas selected here are conditional, as there are no specific cooling effect standards set in relation to the size of a GI asset. This is due to the fact that the cooling effect of any GI asset is influenced by a number of factors and requires field temperature measurements.

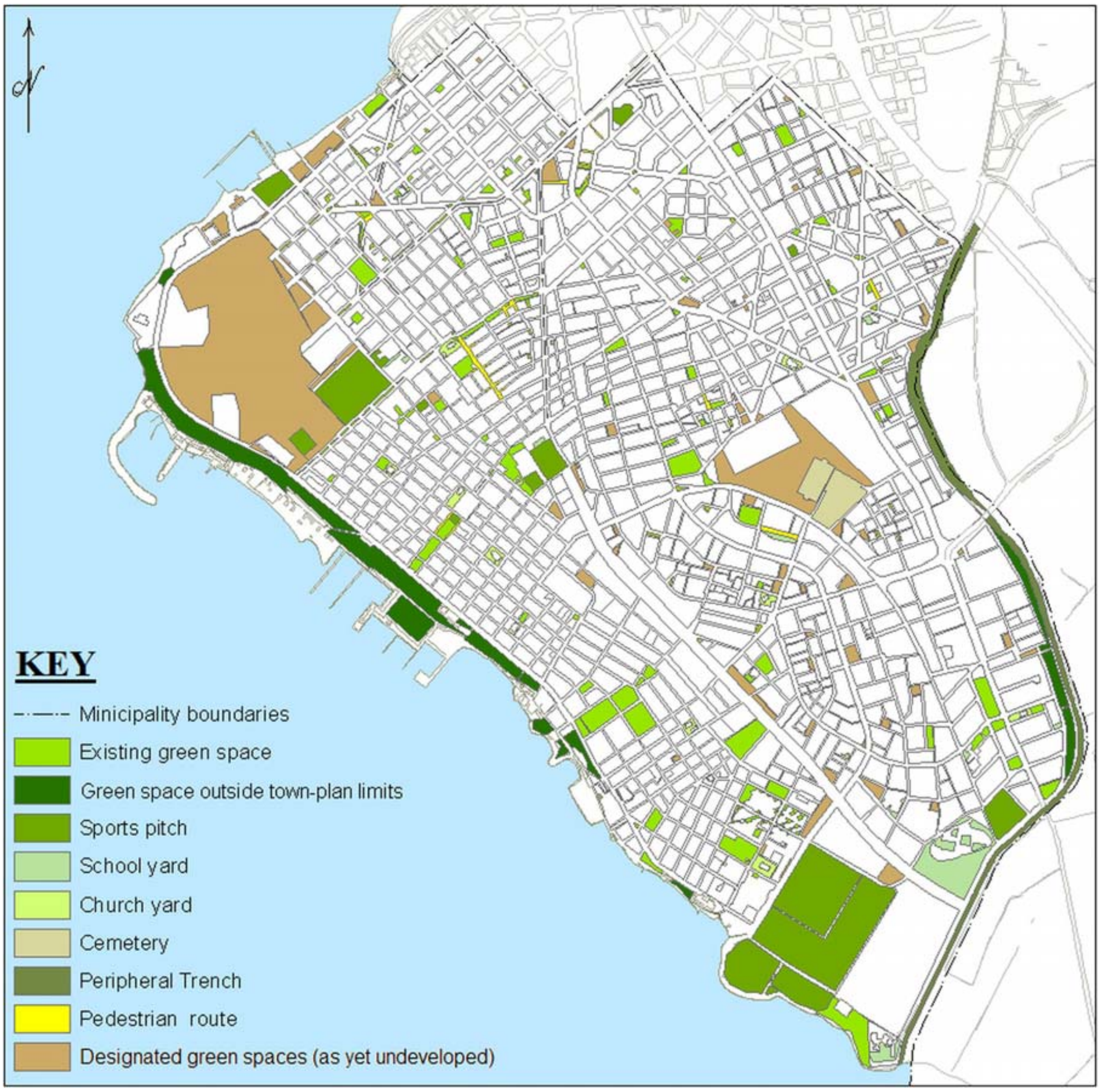

Fig. 3 Existing and planned GI assets of public character

Applying these criteria to existing GI assets in the Municipality, it appears that a large area, specifically 35.96% of the total area, is not served by the ecosystem services that GI assets can offer. This area is, therefore, particularly vulnerable to UHI and climate change (Figure 4). The best serviced areas, based on the above criteria, appear to be firstly, in the coastal area and, secondly, in the southeast area, where there are some large sports pitches and the P.T. Also in this area, there is a large old social housing block, originally designed with a satisfactory percentage of open and green spaces (Yiannakou & Eppas, 2011). The northern part of the Municipality appears to benefit less from the cooling effect of the GI assets. This section of the vulnerable zone coincides with the area defined as vulnerable to UHI, in Figure 1. It is particularly significant that none of the existing GI assets meet the third criterion. On the contrary this criterion is only met theoretically, by those GI assets which, while foreseen by the plan, have as yet, not been implemented. This situation highlights the shortage of public spaces, which concerns the city of Thessaloniki as a whole, and which is further complicated by planning deficiencies (Yiannakou & Eppas, 2011). The need for these sites, in particular the larger ones (over 0.15ha), to maintain their status as designated GI areas and to be developed as such, is illustrated in Figure 4, which shows the areas that could benefit from their GI function. Their development could contribute to a reduction of the vulnerable zone by 28.61%.

Equally important is the conservation of natural and green spaces along the entire coastal line alongside the creation of a linear, continuous green network, which under some circumstances could continue to accommodate its land uses (sport and tourism-recreation). This network may serve as a zone of protection against the expected rise in sea level due to climate change, thereby substantially increasing the adaptive capacity of the Municipality. Moreover, it would allow for the unimpeded flow of air into the urban area, which would reinforce urban cooling. This illustrates the need for both the implementation of the planned green space on the sea front and for the prevention of further reconstruction.

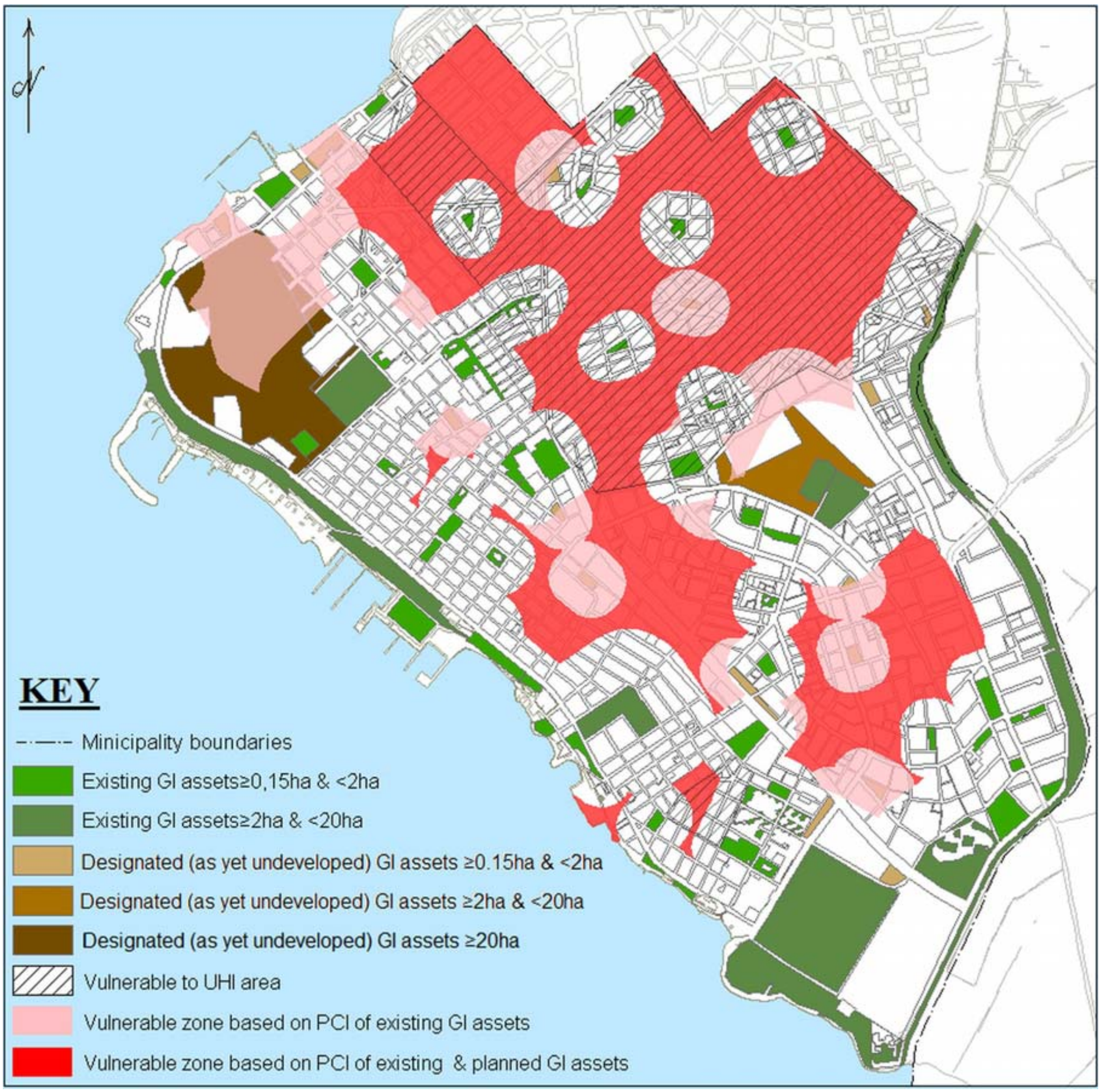

Fig. 4 Vulnerable zones to UHI after estimating the PCI of existing and planned GI assets

Of course, for a more complete evaluation of GI assets a detailed study of tree planting is necessary, as it plays an important role in ensuring that the free flow of air is not hampered. Moreover, the detail mapping of private gardens and those parts of private plots that are not built up is also necessary, because they are important GI assets, which could contribute a great deal to the reduction of the vulnerable zone.

3.2.3 POTENTIAL INTERVENTIONS FOR REDESIGNING GI ASSETS TO INCREASE COOLING EFFECTS

For the remaining parts of the vulnerable zone, which is likely to face more intense urban canyon and UHI phenomena, possible further intensified by climate change, the present study investigated the potential for changing sites of public ownership into GI assets, by making small modifications to the statutory land uses in order to maximize their contribution to climate change adaptation. Such interventions can be summarized as follows:

- Changes in the use of a few non-built-up sites, previously planned for education, sports and welfare utilities, (as they are all public land and their management is easier), provided that the need for these utilities can be met by other sections without increasing the UHI effect. If a permanent land use modification is not possible then such change could be of a temporal character (temporal land use).
- Abolition of small parking spaces and/or increase of pedestrian routes near existing GI assets, redesigning them so as to increase the GI asset’s size with the purpose of fulfilling the first or the second criterion of cooling effect.
- Connection of schools, church yards and those parts of private plots that are not built up, with GI assets, again with the purpose of fulfilling the first or the second criterion of cooling effect.
- Appropriate redesign of planned, but as yet, not implemented, non-implemented spaces for educational or sports use, wherever possible, so as to increase their open space and acquire a new GI asset.
- Redesign of currently paved open spaces, such as the central square, to incorporate GI assets connected with those in the surrounding pedestrian zone, thus contributing to a combination of GI assets.

Figure 5 shows the potential reduction of the vulnerable zone which would result from these small interventions. Estimated in terms of the area covered, this reduction could reach a figure of 35.24%, compared to the vulnerable zone after estimating the PCI of existing and planned GI assets (Figure 4).

A complementary action in addressing urban canyon and UHI phenomena would be to turn open, uncovered spaces between the buildings into the blocks and to link (e.g. through pedestrian routes) all these spaces in order to meet the cooling effect criteria and form connected areas of GI assets. Furthermore, the use of blue infrastructures would play a crucial role and should be promoted, especially in regard to sustainable drainage systems. Moreover, given the lack of available public sites, the introduction of green roofs and facades should be encouraged, especially in public buildings. Finally, attention should be given to the design of outdoor parking spaces, as the use of porous materials and vegetation, can help to reduce overheating of these areas during hot days, thereby reducing the creation of hot spots within the compact urban area. These actions, would concern the entire Municipality, not just the vulnerable zone, and may be even more efficient than other measures, as they require the direct cooperation and participation of the residents.The creation of a GI assets network is an integrated spatial strategy, contributing to the delivery of multifunctionality and ecosystem services from all the different GI assets that could be available in a compact area and maximizing their positive effects. Meanwhile, such a network could help in the movement of air masses within the compact urban area, enabling natural ventilation and cooling, resulting in the addressing of urban canyon and UHI effects, alongside the reduction of air pollution. Yet it is necessary also to incorporate pedestrian and cycle networks and to take account of bus routes and the metro line stops. In this way the promotion of environmentally friendly transports will be possible, creating direct benefits for residents’ health, while contributing to the reduction of the use of private cars. In conclusion, such a network could contribute to improving both the microclimate and the image of the Municipality. It should be emphasized, however, that such a strategy requires detailed study, mapping and evaluation of the current state of GI assets. It would also require the finding of potential and future sites and GI assets. Existing and statutory land use should also be taken into account.

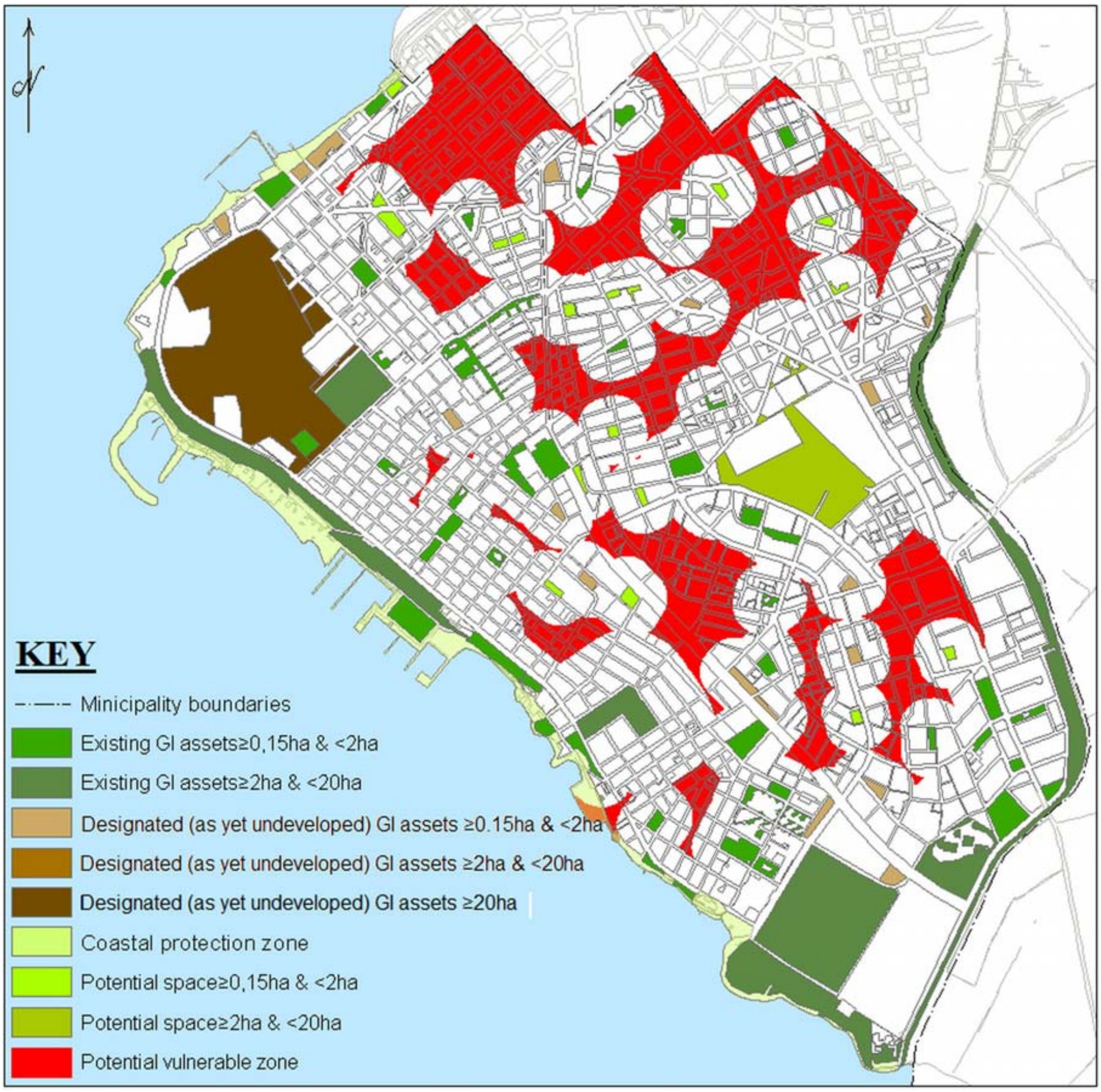

Fig. 5 Vulnerable zone to UHI after maximizing the potential of GI assets

4. CONCLUSIONS

Any strategy of adaptation to climate change for compact cities should recognize that their vulnerability is strongly related to a number of their inherent features relating to the way they are planned. If the degree of vulnerability of an area, and therefore the degree of risk to the impact of climate change, are to be reduced, then, these inherent features, especially those related to urban structure, need to be improved through spatial planning. The provision of GI has been widely recognized as playing important role in meeting the challenge of climate change adaptation. Integration of GI into more ecosystem-based spatial planning, makes the design of GI assets a crucial planning tool for building more sustainable urban environments, resistant to future challenges and adaptable to future needs. As the case study of the role of GI in the Municipality of Kalamaria in Thessaloniki illustrates, the compact city is a place faced by a number of impacts related to climate change, while at the same time offering opportunities for adapting to climate change. Thus in these cities, or parts of cities, it is possible to formulate effective adaptation strategies, adjusted to the local level and to the area's specific features of compactness. The effort to implement an adaptation strategy based on GI in the Municipality of Kalamaria, shows that such a planning and design approach is feasible without necessitating major changes or modifications to existing statutory plans. Basically, this case study highlights the fact that planning GI requires the creation of an integrated network of assets, and that the scattered existence of these assets is not sufficient. Emphasis should be given to updating reliable data and verifying measurements of urban structure, atmospheric pollution and climate-meteorological data, which countries like Greece generally lack. At the same time, there should be detailed and accurate mapping of existing GI assets, especially private gardens and uncover parts of blocks, in order to include them in the integrated GI network. This process is important, given the lack of public spaces in compact areas, along with limited public finances. Information and participation of residents and other actors, and their contribution through volunteer work and funding is also crucial. On the whole, integration of GI into spatial planning, both in existing compact urban areas and in new developments, should be seen as a challenge for the planning systems, as these systems are called on to specify the tools for adaptation to climate change, based on previous knowledge and good practice that has been acquired in relation to the impacts of climate change, such as UHI. An effective adaptation strategy adjusted to the local level and to the specific features of compactness can also contribute, to some extent, to the mitigation of climate change effects.

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IMAGE SOURCES

Fig. 1: modified form Crichton, D. (1999). The risk triangle, in Ingleton, J. (Ed.), Natural Disaster Management (pp 102-103), Tudor Rose, London.

All other images are by the Authors.

AUTHOR’S PROFILE

Konstantina-Dimitra Salata

PhD Candidate in the School of Spatial Planning and Development at Aristotle University of Thessaloniki.

Athena Yiannakou

Associate Professor in the School of Spatial Planning and Development at Aristotle University of Thessaloniki.