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Article

The Role of Vegetation in Mitigating Urban Land Surface Temperatures: A Case Study of Munich, Germany during the Warm Season

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Abstract: The Urban Heat Island (UHI) is the phenomenon of altered increased temperatures in urban areas compared to their rural surroundings. UHIs grow and intensify under extreme hot periods, such as during heat waves, which can affect human health and also increase the demand for energy for cooling. This study applies remote sensing and land use/land cover (LULC) data to assess the cooling effect of varying urban vegetation cover, especially during extreme warm periods, in the city of Munich, Germany. To compute the relationship between Land Surface Temperature (LST) and Land Use Land Cover (LULC), MODIS eight-day interval LST data for the months of June, July and

August from 2002 to 2012 and the Corine Land Cover (CLC) database were used. Due to similarities in the behavior of surface temperature of different CLCs, some classes were reclassified and combined to form two major, rather simplified, homogenized classes: one of built-up area and one of urban vegetation. The homogenized map was merged with the MODIS eight-day interval LST data to compute the relationship between them. The results revealed that (i) the cooling effect accrued from urban vegetation tended to be non-linear; and (ii) a remarkable and stronger cooling effect in terms of LST was identified in regions where the proportion of vegetation cover was between seventy and almost eighty percent per square kilometer. The results also demonstrated that LST within urban vegetation was affected by the temperature of the surrounding built-up and that during the well-known European 2003 heat wave, suburb areas were cooler from the core of the urbanized region. This study concluded that the optimum green space for obtaining the lowest temperature is a non-linear trend. This could support urban planning strategies to facilitate appropriate applications to mitigate heat-stress in urban area.

Keywords: Surface Urban Heat Island (SUHI); Land Surface Temperature (LST); urban vegetation; climate change; heat waves

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1. Introduction

Humans have actively managed and transformed the world's landscapes for millennia. During the last 300 years, in response to the industrial revolution, the extent of landscaping and the trends associated with such activities affecting the land surface have accelerated [1]. Urbanization is an extreme factor of Land Use and Land Cover Change (LULC) that occurs when the natural vegetation of an area is replaced with buildings and roads, which tend to have significantly higher air temperatures than their rural surroundings. This phenomenon is described by the term Urban Heat Island (UHI) [2]. There are two main reasons for this elevated heating in built-up areas: urban materials are often water resistant so evapotranspiration does not take place. Furthermore impervious surfaces absorb and retain more of the sun's heat rather than natural vegetation does [3] due to the darker color. Therefore, most of the world's cities experience higher temperatures in their urban core than in the surrounding sub-urban and rural areas. However, in this regard arid or semi-arid regions are exceptions to this pattern as the center of these cities may be cooler than its surrounding area. This could be an effect that is caused by irrigated gardens [4]. There are other factors affecting temperature such as wind speed, latitude, height above sea level, topography and city size [5]; atmospheric stability [6] is another consideration that may contribute to the formation and intensification of UHIs.

The thermal comfort of city inhabitants is directly [7,8] and indirectly [9] affected by UHIs. UHIs not only influence water use and biodiversity change but also contribute to human discomfort by increasing the cause of mortality and disease [10]. For example, the heat wave in 2003 increased mortality by 7.6% in Munich, Germany, [11] and was declared responsible for 70,000 deaths in Europe [12]. Doick and Hutching (2013) [13] claimed that people with respiratory or cardiovascular diseases are not the only group of people prone to be challenged by the heat stress but it is a phenomenon having direct relation to the age (less than four years or over 75 years are major vulnerable group). In addition, UHIs generate more CO_2 emissions by increasing the energy consumption for cooling [14]. The consequences of UHIs aggravate social and environmental quality in cities, which collectively contributes to global challenges. It is likely that global climate challenges will cause more frequent occurrences of extreme events, which will be more intensive and longer lasting in upcoming decades in many places of the world (IPCC).

Remote sensing data has proved to be a useful for cross-scale ecological research at various spatial, temporal, and spectral scales. Compared with *in situ* air temperature measurement, remote sensing provides not only the detailed land cover/land-use information but also the land surface temperature (LST) observation with a more complete and uniform sampling.

Considering the strong relationship between LST and air temperature [15], UHI have been modeled using various satellite data sources [16]. Remote sensing data has proved to be the most appropriate tool studying spatial pattern and temporal dynamics of urban thermal landscape, as well as urban surface energy budget [17]. Remote sensing studies of vegetated surface in general—and urban green vegetation in particular—showed cooler temperature than impervious surface of cities [18,19]. Therefore, urban vegetation can have a role in local and global climate change mitigation not only through several mechanisms of cooling simultaneously (shading, increasing albedo and evapotranspiration) but also through lower summertime energy demand to cool the indoor climate, which decreases CO_2 emissions. "Urban greening" has also been proposed as one approach to mitigate the human health consequences of increased temperatures resulting from climate change. However, urban vegetation not only regulates climate [18] but also acts as a supporting fact in the social cohesion and wellbeing of urban life [20]. For example, Peng *et al.* (2012) [21] used MODIS LST to report surface temperature differences between urban areas and suburban areas across 419 large cities around the globe. This study has also been performed on relationships between daytime and nighttime Surface Urban Heat Island (SUHI) with urban vegetation cover. Schwarz *et al.* (2011) [22] has also used MODIS to quantify the LST of 263 European cities. Hung *et al.* (2006) [23] used MODIS LST to report on 18 Asian mega city SUHIs, which are correlated with city population, building density and vegetation cover. The research explored the relationship between surface properties and UHIs and confirmed the importance of vegetation in the partition of sensible and latent heat fluxes. However, a time series analysis on a regional scale where the cooling effect of different proportions of urban vegetation has been studied is still lacking. This study could be important because of its strong implications for urban planners and risk managers.

The goal of this paper focuses on the relationship between land surface temperature and the ratio of impervious surfaces to urban vegetation in the city of Munich, Germany. We studied the temperature patterns of urban vegetation over 11 years, especially during the European heat wave 2003. Consequently, it is first hypothesized that a linear relationship exists between the trend of LST with the proportion of impervious surfaces and urban vegetation. Second, we hypothesize a threshold for the cooling effect of urban vegetation is expected during an extreme warm period (such as a heat wave), similar to any natural and ecological ecosystem which has a certain tolerance and resiliency because green vegetation is becoming dry, and the cooling effect due to evapotranspiration is reduced during such drought phases.

2. Methodology

The relationship between impervious surface cover and urban vegetation with the LST during 11 years has been computed using a quantile regression analytical technique. Figure 1 presents the overall conceptual flow of the study in brief.

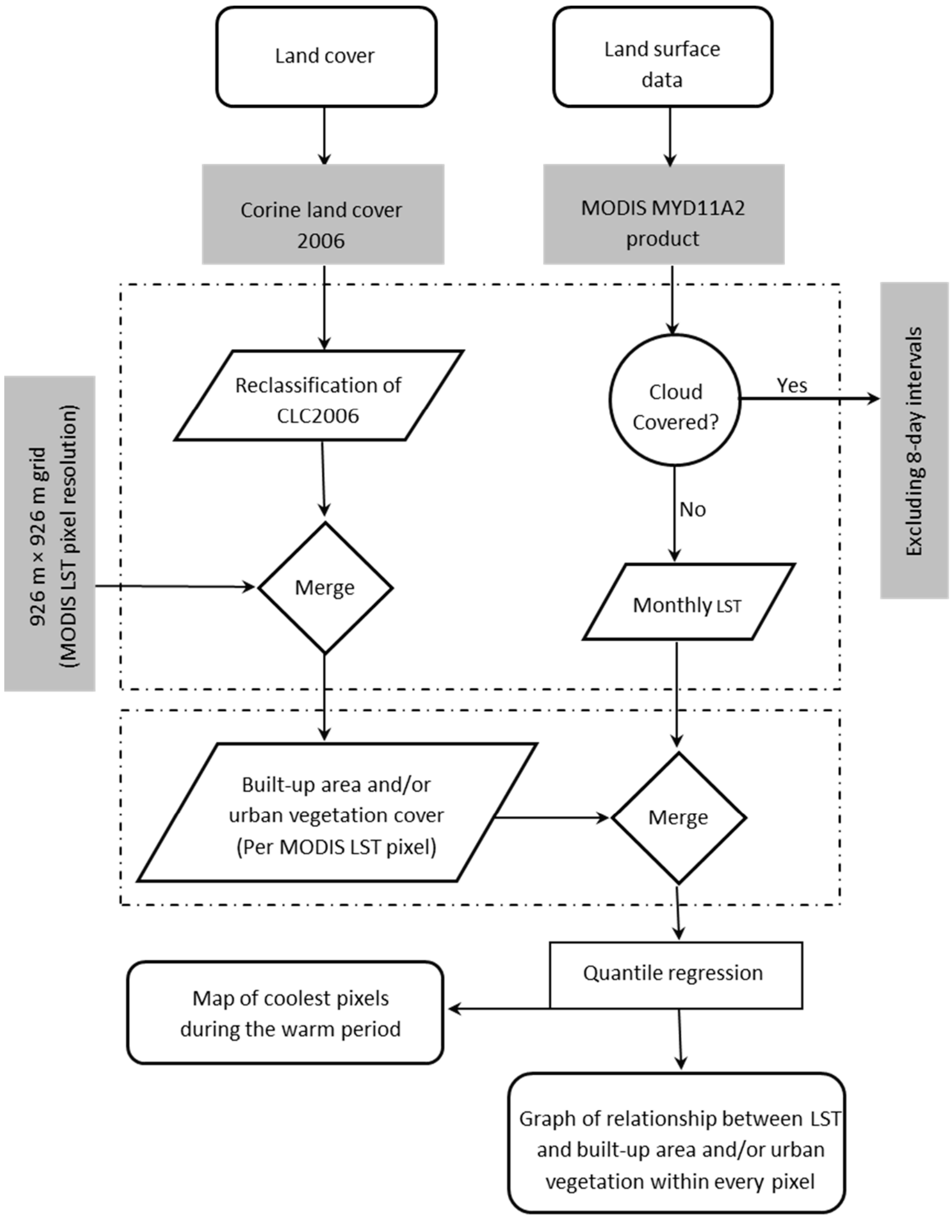

Figure 1. Flowchart of the study framework.

2.1. Study Area

The case study region is situated in the southeast of Germany (Figure 2A). Munich is the capital and the largest city of the German state of Bavaria and the third largest city in Germany after Berlin and Hamburg. It stretches over an area of approximately 310.43 km^2 and was home to 1.37 million inhabitants in 2011 (*Bayerische Landesamt für Statistik*). The case study region lies at 520 m above the sea level and approximately 50 km north of the northern edge of the Alps. In close proximity to the

Alps, the climate in Munich is clearly affected by its sheltered position and is classified as a humid continental climate with warm summers and no dry season. Over the course of a year, the temperature typically varies from −4 °C (January) to 24 °C (July), with annual precipitation of 967 mm (German weather Service). Munich is a developed city and a stable region in terms of land use and land cover during the period 2002 to 2012. The distribution of green parks within the administrative area of the city (33.8 m^2 per person) (*Landeshauptstadt München*) is used to develop an understanding of the effect of urban vegetation on cooling during the heat wave in 2003.

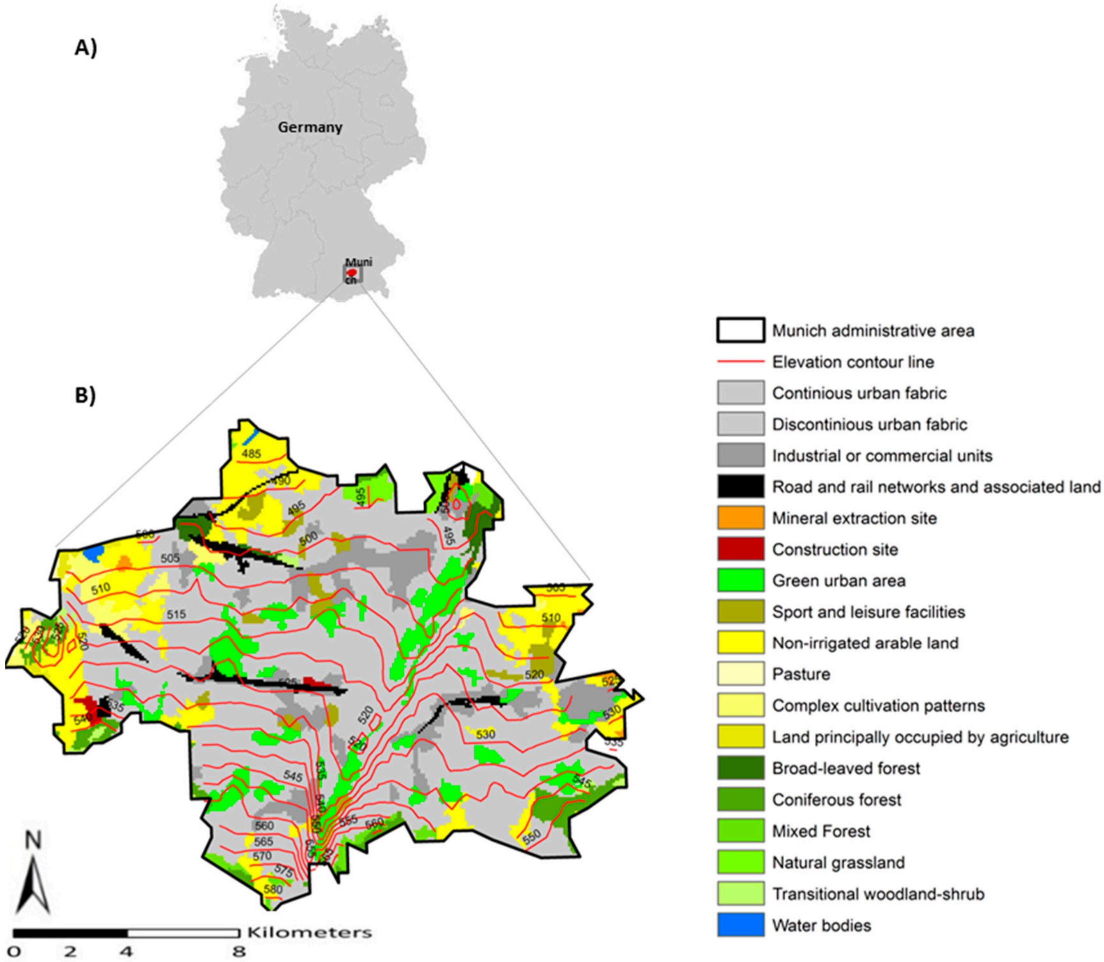

Figure 2. Location and the distribution of different land covers of the study region: (**A**) Study region is presented in red spot; (**B**) Land cover map of the study area (Corine Land Cover 2006).

2.2. Land Cover Data

The Corine Land Cover (CLC) is a vector map at a scale of 1:100,000, with a minimum cartographic unit (MCU) of 25 ha, mapping homogeneous landscape patterns. The implementation of the CLC focused mainly on identification and mapping of land cover and land cover changes for more than 25 European countries. The CLC distinguishes 44 classes, of which Table 1 shows the classes used in this study. Figure 2B illustrates the CLC for the study area.

Table 1. Homogenous land cover classes for Munich, based on Corine Land Cover (CLC) 2006 [24].

CLC Classes			Homogenous Class
Level 1	Level 2	Level 3	
1. Artificial surface	11. Urban fabric	111. Continuous urban fabric 112. Discontinuous urban fabric	Built-up area
	12. Industrial, commercial and transport units	121. Industrial or commercial units 122. Road and rail networks and associated land 124. Airport	
	13. Mine, dump and construction sites	132. Dump sites 133. Construction sites	
	14. Artificial, non-agricultural vegetated areas	141. Green urban areas 142. Sport and leisure facilities	Urban vegetation
3. Forest and semi natural areas	31. Forest	311. Broad-leaved forest 312. Coniferous forest 313. Mixed forest	
	32. Scrub and/or herbaceous vegetation associations	321. Natural grasslands	

The CLC data from 2006 with a geometric accuracy of 250 m were used in this study [24]. The CLC 2006 database was used to facilitate a better understanding of the relationships between LULC and LST. The growth of built-up area in our study area, during selected temporal frame, is considerably low—in fact one of the lowest among other European cities [24]. The built-up growth of the study area, beyond its administrative borders, is known as Munich's metropolitan region (*Landeshauptstadt München*) [25]. Therefore using the same land cover database (*i.e.*, CLC 2006) will not influence the MODIS pixel values having a resolution of 1 Km^2. From commercial areas to residential and non-urban areas, such as crops and forested lands, temperature gradually decreases [26]. Thus artificial surfaces and natural area of the land cover data (level 1) were used to reclassify the CLC classes to form a new homogenized class. As shown in Table 1, land cover classes such as continuous urban fabric, discontinuous urban fabric, industrial or commercial units, road and rail networks were considered as one urban class, and different types of green vegetation within the administrative area of Munich have been counted as urban vegetation.

The homogenized map was merged with a grid cell of 926.6 m × 926.6 m. The new map facilitated evaluations of the ratio of built-up area and/or urban vegetation in each grid cell. This ratio was divided according to the area of each MODIS LST pixel (0.85 km^2). The results were different proportions of LULC within every grid cell presented in a percentage. Thus the relationship between monthly LST and the ratio of built-up area and/or urban vegetation within every grid cell was computed.

2.3. Land Surface Temperature Data

Data were obtained from the EOS-MODIS V5 from the MODIS (MODerate-resolution Imaging Spectroradiometer) sensor, flown aboard the National Aeronautics and Space Administration's (NASA) two satellites, Aqua and Terra. The Terra satellite provides images for 10:30 a.m. and 10:30 p.m. local solar times, while the Aqua satellite conducts monitoring at 01:30 a.m. and 13:30 p.m. Images provided by the Aqua satellite were used for this study. The LST product MYD11A2, with a spatial resolution of approximately one kilometer (926.6 m) and aggregated for eight consecutive days, were used. Wan (2008) [27] reported that the accuracy of the MODIS products was better than one degree Kelvin for most cases of validation and found larger biases for vegetation at some sites.

To study UHIs during the warm period, data were taken for June, July and August of 2002 to 2012 and attention was focused on daytime values. Pixel values were presented in Celsius. Within the study period, some of the 8-day interval images were subject to heavy cloud cover due to the dominant climatic conditions, which are typical of the study area. Heavy cloud covered images were left out of the analysis, as they result in no data. Data on the available 8-day intervals were merged with the homogenized LULC map derived from the CLC. To calculated and determine the relationship between the ratio of built-up area and urban vegetation, quantile regression was used.

2.4. Statistical Methods

Evaluations of LST and its relationship with the extent of each LULC within each pixel were computed with the Kernel Quantile Regression algorithm (KQR). Quantile regression [28] performs non-parametric regression and is a method for estimating functional relations between variables for all portions of a probability distribution. Whereas the method of the classical least squares results in estimates that approximate the conditional mean of a response variable given certain values for predictor variables, quantile regression aims at estimating either the conditional median or other quantiles of the scale and shape of the distribution of the response variable [29].

Kernel quantile regression was used to compute the matrix resulting from merging both the LST map and the homogenized LULC map of the study area. This computation was performed for data collected from 8-day intervals in June, July and August of 2002 to 2012. Considering the vast amount of 8-day interval data covering 11 years, it was necessary to define a meaningful and reasonable methodology. This was achieved by considering monthly datasets for computation instead of data from 8-day intervals. For this purpose, 8-day interval data for every month of each year were combined. In other words, plotted values represent the relationship between LST and LULC in each grid cell for a specific month of a certain year. Quantile regression was calculated for the 25, 50 and 75 quantiles for each month, which illustrates the change of LST in built-up areas and urban vegetation. Furthermore, a single-step multiple comparison procedure and statistical test, the TukeyHSD (Honestly Significantly Difference), was computed to create a set of confidence intervals on the differences between the means of levels of a factor with the specified family-wise probability of coverage [30]. The TukeyHSD was computed to distinguish the heat pattern of the built-up area and the cooling effect of urban vegetation from one year to another over the 11-year period of the study to understand the cooling effects of the urban vegetation, particularly during heat waves. The software R version 2.14.0 and RStudio version 0.97.309, including packages *quantreg* version 4.98 and *kernlab* version 0.9-18, were used to develop and compute the statistical analysis. For GIS mapping and spatial analysis the software ESRI ArcMap desktop was used.

3. Results

3.1 Relationship between LST and the Ratio of Urban and/or Urban Vegetation

The time series analysis of the study area over 11 years showed the inner-city daytime SUHI temperature is higher and more positive than temperatures of the surrounding areas. This feature is due to the thermal emissive properties of the urban surfaces and heat capacity, which increases temperature patterns in urban regions. Figure 3A shows the mean daytime LST (°C) for the warmest months (June, July and August) of 2002 to 2012. The temperature change of the study area for the warmest months of 2002 to 2012 is animated in supplementary materials as an animation. In Figure 3A, the enclosed green lines show urban vegetation. Higher surface temperature (red color) is observed in dense built-up area in comparison with the lower surface temperature of the inner-city urban vegetation and surface water (green color). Figure 3B illustrates the percentage of urban vegetation within every grid cell. Later, every LST pixel value and the percentage of each land cover in it were related. Thus the relationship between monthly LST and the ratio of built-up area and/or urban vegetation within every grid cell was computed.

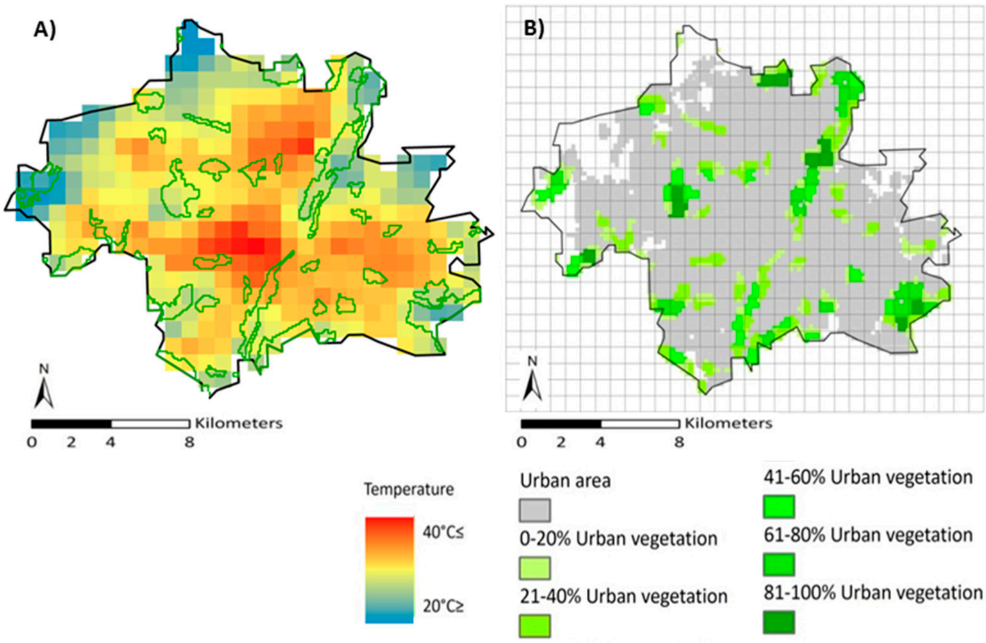

Figure 3. (**A**) Munich area map of mean daytime land surface temperature (LST) (°C) for June, July and August of 2002 to 2012 with spatial resolution of approximately 1 km × 1 km presented in pseudocolor; (**B**) Proportion of urban vegetation in each grid cell with spatial resolution of approximately 1 km × 1 km presented in percent's.

3.2 Built-Up Area and Urban Vegetation LST Patterns

Figure 4 illustrates the overall LST pattern for both urban and urban vegetation for the 11 years of data covered in the study area. One can see cooler LST values for urban vegetation cover in comparison to the corresponding built-up areas. Additionally, an increase or decrease in urban LST resulted in a corresponding change in the urban vegetation LST. The year 2003 is a good example of this finding because of its high LST values due to the well-known heat wave in Europe. There is a statistically significant difference between that year and the other years as determined by the TukeyHSD test for both land covers. This significant difference for built-up areas was $F(10,16435) = 159.30$, $p = 0.00$ and for urban vegetation was $F(10,1896) = 31.390$, $p = 0.00$.

Kernel quantile regression was used to quantify temperature similarities and differences within and between LULC types. For a better understanding of temperature variations, quantile regression has been computed for the 25% quantile, 50% quantile and 75% quantile. The results for built-up areas and urban vegetation are presented in separate figures.

A relationship was found between the LST and the ratio of extent for each type of LULC in each grid cell, as depicted in Figure 5. Due to the long and extensive measuring process used in this study (11 years), which amounted to a total of 64 figures (supplementary figures from S1 to S11), Figure 5 illustrates the hottest (year 2003) [11] and the coolest (year 2005) [31] warm period of the years from 2002 to 2012 as a summary of all results. Figure 5 shows a moderately decreasing trend in all quantile regressions for urban vegetation for the hottest and the coolest summer and an increasing trend in all quantile regressions for built-up area shown in supplementary materials (S1 to S11). In other words, a larger urban proportion within each grid cell corresponds to a higher LST, whereas an increase in the proportion of urban vegetation within each grid cell results in a decrease in LST.

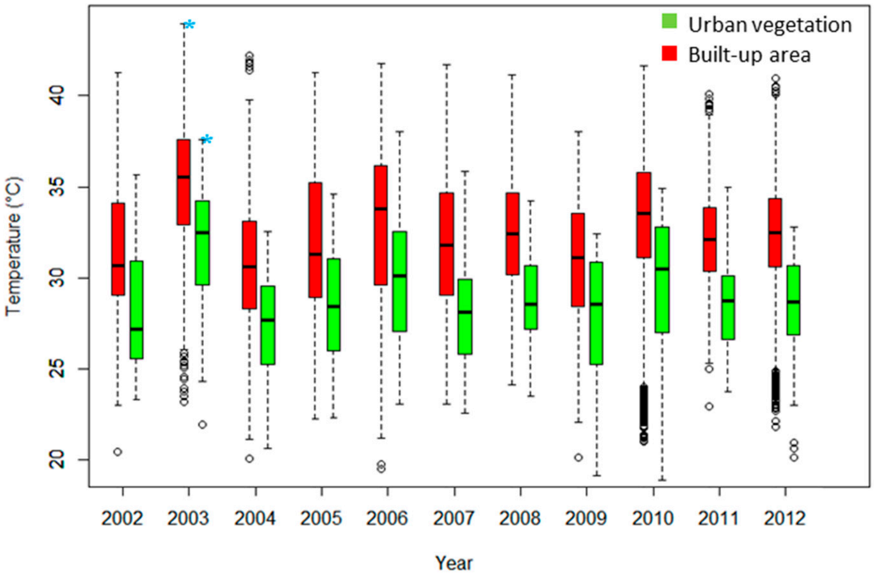

Figure 4. LST pattern of pixels completely covered with built-up area (100 percent) and pixels covered fully with urban vegetation (100 percent). Every year consists of June, July and August only. Urban vegetation cover shows cooler LST values than the built-up areas in range, as well as in maximum, upper quartile, median, lower quartile and minimum values. However, year 2003, due to strong European heat wave, shows higher LST values. Year 2003, for both built-up area and urban vegetation, shows a statistically significant difference (shown with *) to other years.

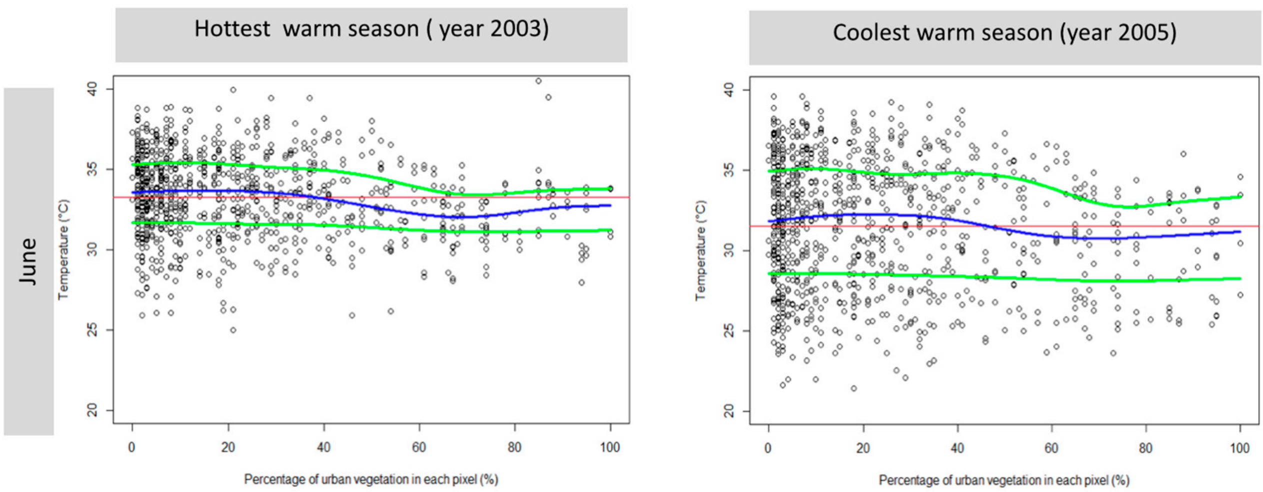

Figure 5. *Cont.*

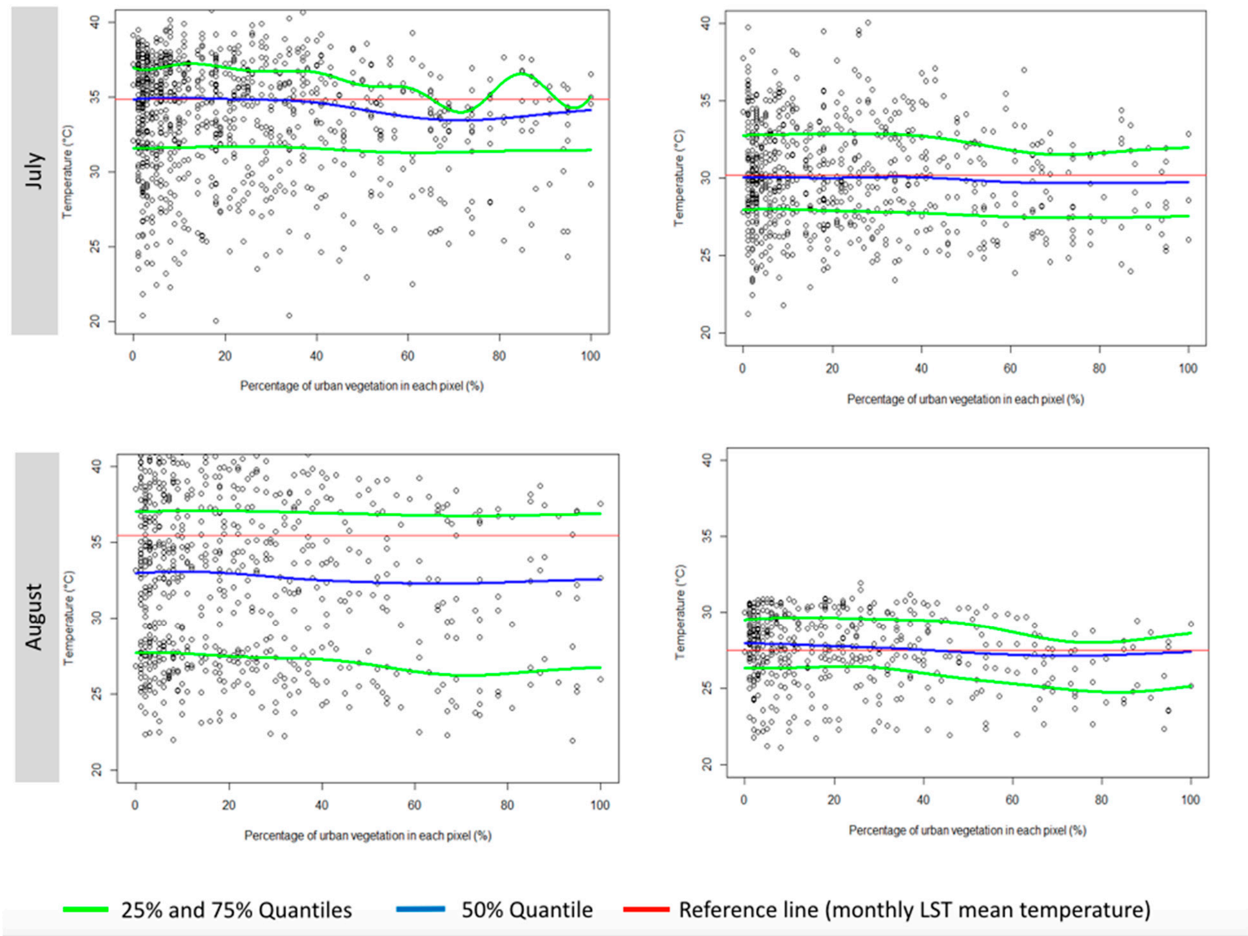

Figure 5. Relationship between the LST and the ratio of urban vegetation cover within each pixel. All figures illustrate a decreasing and a negative temperature trend with the increase of urban vegetation in each pixel. This figure compares the hottest and the coldest warm period of the years from 2002 to 2012 as the summary of all results. All the graphs from the years 2002 to 2012 are available in supplementary materials.

Figure 5 illustrates the results, which were different from original expectations, especially for urban vegetation. A linear decreasing LST trend was expected for urban vegetation by an increase in proportion in each grid cell. However, as shown in most of the urban vegetation figures, quantiles depict cooler LSTs where grid cells are covered by more than fifty percent with vegetation. Therefore, the LST of these grid cells have been extracted to present their temperature fluctuations (Figure 6).

The LSTs of grid cells containing urban vegetation have been sorted into five groups to distinguish the variation in the cooling effect for different proportions of vegetation. The first group contains those grid cells that are covered by urban vegetation at 50 to 59 percent; the second group is for grid cells with urban vegetation at 60 to 69 percent; the third group with urban vegetation at 70 to 79 percent; the fourth group with urban vegetation at 80 to 89 percent, and the last group contains grid cells that are covered by urban vegetation at 90 to 100 percent. To illustrate the cooling effect of vegetated areas, the LST of the different proportions of urban vegetation has been compared with the LST of grid cells fully covered with built-up areas and pixels less than 100% built-up area have been neglected. Figure 6 compares the LST for fully urbanized (built-up area) grid cells with grid cells vegetated more than 50 percent (presented in five groups) from 2002 to 2012.

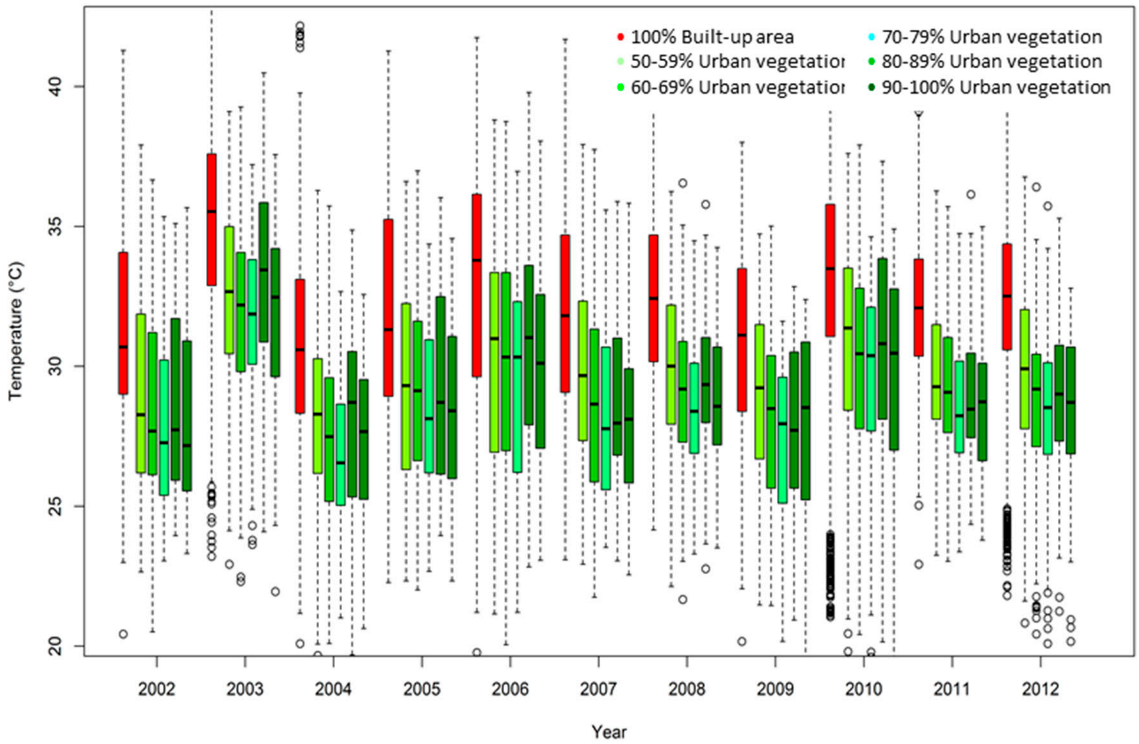

Figure 6. The LST fluctuation for fully urbanized pixels (red boxplots) and pixels covered 50 to 100 percent with urban vegetation (green spectrum) from June, July and August of 2002 to 2012. Urban vegetation shows cooler LST values than the built-up areas in range, as well as in maximum, upper quartile, median, lower quartile and minimum values. Increase in the proportion of urban vegetation within each pixel shows a non-linear trend in the cooling effect of the urban vegetation.

The results show remarkable cooling effects, specifically for those grid cells covered 70 to almost 80 percent with urban vegetation (Figure 6). To impress the coolest grid cells of the study area, we computed the difference in LST between the fully urbanized grid cells and the LSTs of the five groups of different proportions of urban vegetation. For this reason, the medians of the LSTs for the five urban vegetation groups has been subtracted from the median of the LST of the fully urbanized grid cells ($\Delta T = \breve{X}$ LST of fully urbanized grid cells $- \breve{X}$ LST of different urban vegetation groups). Figure 7 illustrates this difference in LST and the proportion of urban vegetation with the most cooling effect. Larger temperature differences (ΔT) show stronger cooling effects. The result (Figure 7) shows a stronger cooling effect for pixels covered seventy to eighty percent with urban vegetation.

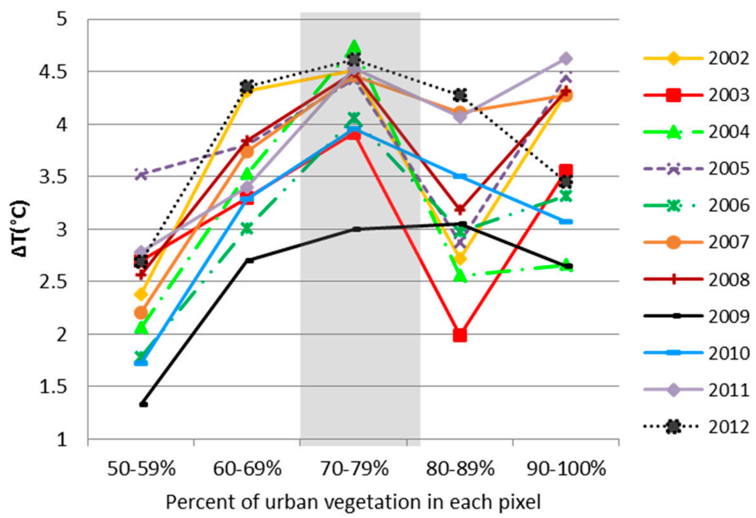

Figure 7. Difference between medians of LSTs for pixels covered fully with built-up areas and pixels covered more than 50 percent with urban vegetation. The median of the LSTs has been computed for June, July and August from 2002 to 2012. Different proportions of urban vegetation are presented in five groups. Pixels containing urban vegetation with a stronger cooling effect are highlighted in grey.

4. Discussion

The results of this study demonstrated the following. A time series analysis of 11 years (from 2002 to 2012) of warm seasons over the study area showed a higher daytime surface temperature in dense built-up area rather than well-vegetated urban area. This variation in urban temperature patterns might be explained by differences in their 3D form, heat capacity and thermal emissivity of the urban fabric [4]. We did find a decreasing trend between the LST and the urban vegetation appeared within every grid cell. Other studies that are based on remote sensing did find similarly a strong negative correlation between LST and the degree of vegetation cover as well as NDVI [32,33]. The methodology applied in this study (quantile regression) suggests that there is a non-linear trend in the relationship between LST and presence of urban vegetation within each area. Vegetation can be effective as it delivers several mechanisms of cooling simultaneously and in a complementary manner. Urban vegetation reduces heat islands through shading and evapotranspiration. Doick and Hutching (2013) [13] found that shading is reducing the penetration of sunlight and reduces the energy storage in the soil. At the same time, the evaporation processes in which the plants convert liquid water to water vapor is energy intensive and is reducing therefore the sensible heat [34]. In consequence well-vegetated areas show lower air temperature [23]. Therefore, fully vegetated pixels are expected to have a cooler surface temperature.

However, our results show a remarkable decrease in temperature in regions where the proportions of vegetation cover in a grid cell was recorded as 70 to 79 percent. This amounts to 0.60 km^2 to 0.67 km^2 of vegetation cover to gain the most cooling effect from urban vegetation in every LST grid cell (0.85 km^2). Better airflow and convection, which are lower in densely vegetated areas, might be the reason for this finding. Another reason might be edge effects due to their spatial position. The results showed that the location of urban vegetation and its distance to fully urbanized regions (built-up area) might play an important role in the cooling, while the extracted coolest vegetated grid cells (70 to

79 percent vegetation cover within each grid cell) were far from dense urbanized regions and closer to the edges of the administrative area of Munich. Other studies found that the spatial pattern of the SUHIs is strongly determined by the spatial arrangement of built-up area [33,35].

Although LST values of urban vegetation were lower than those of built-up areas (as delineated in results), this trend is subject to change from one year to another. A good example is the year 2003, when LST increased in comparison with records of previous years as a result of the well-known heat wave in Europe. The results of this study demonstrate that LST of urban vegetation is related to the temperature of its urban surrounding. Therefore, dependency may differ according to the size, shape and location of the vegetated area. The cooler surface temperatures of well-vegetated areas under heat wave conditions (2003) reveal that the cooling effect of urban vegetation functions under extreme hot weather conditions. However, as hypothesized, the cooling effect during 2003 is less pronounced compared to other years as depicted in Figure 7. This might be due to the fact that during heat waves vegetation dies back due to water shortage. Cooling though direct shading and indirectly through evapotranspiration is reduced under such conditions.

In between different land covers, impervious surfaces and built-up areas generally increase the spatial variables of temperature due to dark colors and water resistance. The problem for sustainable development of cities is certainly how to adapt them to more frequent heat waves, which are potentially expected due to climate change [36]. In addition more energy consumption will increase waste heat released in the urban areas [37]. Vegetation, in particular trees, can be very effective at contributing to the overall temperature regulation of cities. The extent to which vegetation cools the urban climate depends on species selection and strategic placement. Green infrastructure in cities, including parks, trees, green roofs and lakes, can reduce the UHI effect and cool the air by between 2 and 8 °C as reported by Taha *et al.* (1988) [38]. Green infrastructure can not only reduce heat-related stress and premature death during high-temperature events, which mainly threaten the young and the elderly but also improve the socio-environmental quality of life in cities. Therefore, this research could provide urban planners and landscapers with strategies for mitigating the UHI effect through the strategic placement of urban vegetation.

Some limitations of this study should be mentioned. First, the MODIS LST pixel resolution is almost 1 km. Therefore, using higher resolution satellite products might increase the precision of the results, especially for cases with a small distribution of urban vegetation within a city. Second, because of the MODIS-Aqua launch date (2002), the behavior of earlier heat waves could not be studied. Third, due to the unstable climatic conditions of the study area, even during the warm period, some of the MODIS 8-day interval images could not be used because they were subjected to heavy cloud cover.

5. Conclusions

A time series analysis of MODIS LST data showed a good proficiency for studying UHIs, the role of urban vegetation in cooling impervious surfaces and the optimum green space for obtaining the lowest temperature. The methodology that was developed and applied in this study, especially the statistical method, improves our understanding of the different proportions of urban vegetation and its relation to surface temperature. The results showed a decreasing and negative relationship between LST and the proportion of urban vegetation in an area. However, this trend is non-linear and shows cooler surface temperatures where the proportion of urban vegetation is between seventy to eighty percent.

Studies on the thermal properties of UHIs and urban vegetation distribution, especially during the summer, not only improves our understanding of urban ecology and moderating urban outdoor thermal comfort and quality of life with ecosystem services but also helps to decrease power consumption needed for cooling in cities, CO_2 emissions and pollution with better adaptation to regional and global climate change. Therefore, it is suggested that further studies determine the regional and local scale effects of urban green infrastructure by combining satellite data with ground measurements to mitigate the impact of CO_2 emissions, where rapidly urbanizing landscape could be investigated under different climate change scenarios.

Supplementary Materials

Supplementary materials can be accessed at: http://www.mdpi.com/2071-1050/7/4/4689/s1.

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Author Contributions

Sadroddin Alavipanah conceived and executed the research and drafted the manuscript. Thomas Koellner and Martin Wegmann supervised the research and help writing and improving the draft manuscript. Salman Qureshi and Qihao Weng critically revised and edited the manuscript. All authors read and approved the final manuscript for submission.

Conflicts of Interest

The authors declare no conflict of interest.

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