



Proceeding Paper

# Investigation of Thermal Heat Mapping and Vegetation Cooling Impact Using Landsat-5, -7, and -8 Imagery: A Case Study of Greater Beirut Area in Lebanon <sup>†</sup>

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**Abstract:** In this research study, we use Landsat-5, -7, -8 thermal remote sensing technology to analyze the urban heat mapping of the Greater Beirut Area (GBA) in Lebanon. The investigation is conducted within a time frame that spans over 3 decades from 1990 to 2020. For each year, we calculate the normalized difference vegetation index (NDVI) and land surface temperature (LST) statistics. Also, a spatial-temporal analysis is conducted to relate heat mapping in GBA to the topography based on the altitude. Overall results show that the temperature in GBA has increased over 3 decades, with an increase in the vegetation and urban LST by 1.10 °C and 1.26 °C, respectively. Results also show that green areas are cooler than urban areas. Local analyses show that vegetation and altitude have a cooling effect, with temperatures dropping in the high and green mountains.

**Keywords:** urbanization; population growth; Greater Beirut Area in Lebanon; normalized difference vegetation index; land surface temperature



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## 1. Introduction

Lebanon, a low-income country, is suffering from the effects of climate change and urban expansion. According to studies in 2019 [1], due to climate change, Lebanon witnessed variations in temperature and rainfall averages, which have significant impacts on the economic, social, and health situations. Furthermore, the Lebanese population growth increased from 1990 to 2020 by 243% [2]. In particular, the capital city “Beirut”, which covers only 0.95% of the total area of Lebanon, consumes 12% of the total national energy consumption [3]. It has 35.6% of the total population with a density of 25,000 people/km<sup>2</sup>. For this reason, metropolitan areas continue to expand along adjacent mountains leading to diminishing green areas [4]. Urbanization is leading Beirut to vertically rise with a shifting skyline and cumbersome infrastructure. This area has become overburdened with urbanization, which is exacerbated by the absence of future plans to predict, manage, and monitor this urbanization. Therefore, it is critical to evaluate the impact of notable urban heat islands on Beirut and to evaluate their effects [5].

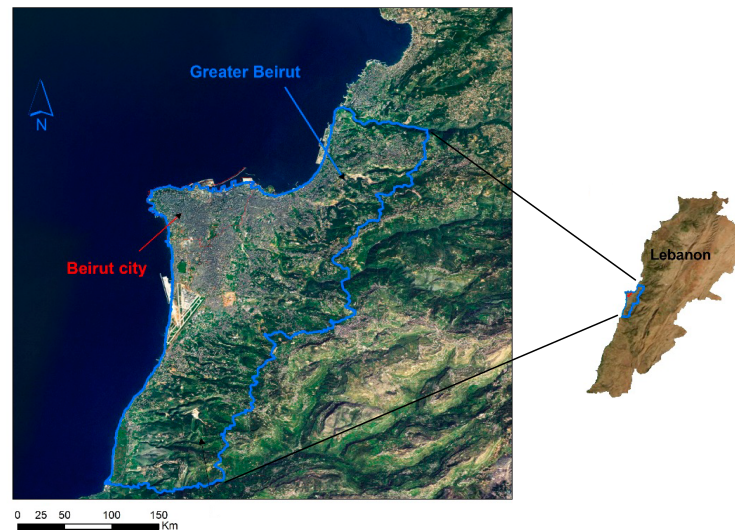
Remote sensing is increasingly being utilized to analyze urban development and population density [4]. Significant progress has been made in satellite remote sensing technology in recent years, which results in better identifying environmental changes, including man-made alterations to the natural environment. More specifically, thermal remote sensing offers the ability to study the urban thermal environment [6] at various spatial and temporal scales. Thermal imaging may be used to determine land surface temperature, which has a major effect on air temperature [7]. In this research study, we

use this cost-efficient technology to analyze the urban heat mapping of Greater Beirut in Lebanon by analyzing its urban development. Furthermore, our goal is to estimate the vegetation cooling impact as a response to rising urban temperatures.

## 2. Materials and Methods

### 2.1. Study Area

Lebanon is a small country on the eastern coast of the Mediterranean Sea, with a total land area of 10,452 km<sup>2</sup>. The study area is in Lebanon's central coastline region, the Greater Beirut area (GBA), which has a total size of 233.2 km<sup>2</sup>, accounting for 2.2% of the Lebanese territory. As shown in Figure 1, GBA stretches towards the south, east, and north of Beirut. It is bounded by the Mediterranean from the west. GBA's topography increases in elevation from the west coastline at 0 m and extends to an elevation of 989 m. Due to demographic and economic growth pressures, many areas in GBA are transformed from green spaces, forests, and agricultural regions into residential structures, industrial areas, and other public facilities. The direct influence was to reduce the forested lands and increase surfaces with asphalt and concrete, which are utilized in urban construction and considered impermeable materials that absorb and store solar radiation [8].



**Figure 1.** Greater Beirut Area in Lebanon, with decimal-degrees coordinates of (33.87846, 35.50725) [4].

### 2.2. Satellite Datasets

Land surface temperature (LST) is an important environmental indicator since it enables the monitoring of landscape processes and reactions. Because the Landsat-5, -7, and -8 satellites all include thermal infrared radiometers, their data may be used to determine LST. The investigation is conducted within a time frame that spans over 31 years (3 decades) from 1990 to 2020. We use Landsat-5, -7, and -8 thermal infrared radiometer imagery for the specified time frame. The different spatial resolutions of the thermal bands are resampled to a spatial resolution of 30x30 m using a nearest neighbor resampling approach. The dataset contains 524 images, each representing the surface reflectance from the Landsat sensors. The dataset is atmospherically corrected using the LST product USGS Landsat level-2. Based on the quality assessment (QA) band, we account for cloud masking by removing the pixels containing clouds.

### 2.3. Methods

Healthy plants have a high reflectance in the near-infrared spectrum (NIR). This is related to the interior structure of plant leaves. Therefore, using the dataset, we calculate

the normalized difference vegetation index (NDVI) using two bands with high reflectance in the NIR and high absorption in the Red wavelength, given as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

Bands 3 and 4 are used for Landsat-5 and -7 data, for RED and NIR respectively, whereas bands 4 and 5 are used for Landsat-8. NDVI statistics including the minimum, maximum, median, and average values are calculated for each year from 1990 to 2020, yielding a set of 31 images. Maximum values are utilized while taking the minimum value of 0.18 as the NDVI threshold to be considered as vegetation. Then, we create an overlay between each image and GBA topography to measure the vegetation area in each region.

Similarly, thermal bands in Landsat-5, -7 (band 6), and -8 (bands 10 and 11) are used to calculate the urban LST statistics to monitor landscape processes and reactions. Again, LST statistics that include the maximum, median, mean, and standard deviation values for each year are used. The steps used to calculate LST values are summarized in Algorithm 1 using the following thermal bands' constants: the radiance multiplier (RM) is 0.0003342, the radiance add (RA) is 0.1, the band-specific thermal conversion constants are K1 = 774.89 and K2 = 1321.08. Cloud masking pixels are replaced by linearly interpolated pixels based on the annual statistics of the LST.

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**Algorithm 1** Calculation of LST Values Excluding the Atmospheric Correction

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- 1: Using Thermal Bands Constants: RM, RA, K1, K2
  - 2:   **1.** Calculate Top of Atmosphere (TOA) Radiance
  - 3:     TOA = (RM x thermal bands) + RA
  - 4:   **2.** Calculate Brightness Temperature (BT)
  - 5:     BT = (K2 / (ln (K1 / TOA) + 1)) - 273.15
  - 6:   **3.** Calculate NDVI according to Equation (1)
  - 7:   **4.** Calculate Proportion of Vegetation (Pv)
  - 8:     Pv = ((NDVI - NDVImin) / (NDVImax - NDVImin))<sup>2</sup>
  - 9:   **5.** Calculate the emissivity (ε)
  - 10:    ε = (0.004 x Pv) + 0.986
  - 11:   **6.** Calculate LST
  - 12:    LST = (BT / (1 + (0.00115 x BT / 1.4388) x Ln(ε)))
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**3. Results and Discussions**

A diachronic analysis of the GBA is provided across the three decades for the NDVI and LST. Moreover, a detailed spatial analysis for the LST is performed. Results in Table 1 show the mean LST values for urban and vegetation zones in GBA across the three decades from 1990 until 2019.

**Table 1.** Mean LST (in °C) for urban and vegetation zones in GBA across three decades.

Zone	1990–1999	2000–2009	2010–2019
Vegetation	17	17	18.10
Urban	35.62	36.72	36.88

On the one hand, we notice that for the vegetation zone, there is a negligible difference in temperatures between the first two decades (1990–1999 and 2000–2009) where the land surface temperature remains 17 °C for both decades. However, the vegetation's LST mean value increased by 1.1 °C to reach 18.1 °C in the third decade between 2010 and 2019. On the other hand for the urban areas, the average LST increased by 1.1 °C from the first to second decade to reach 36.72 °C. A slightly small increase of 0.165 °C is further witnessed in the third decade where the LST reached 36.88 °C. Overall results from Table 1 show that the temperature in GBA has increased over 3 decades, with an increase in the vegetation

and urban LST by 1.1 °C and 1.26 °C, respectively. The evolution in LST values is shown on GBA’s map in Figure 2. A thorough analysis shows that LST maps revealed regions that had increasing temperatures from three decades ago, such as the Beirut Airport area (1.83 °C), Mechref (1.85 °C) and Roumie (2.15 °C).

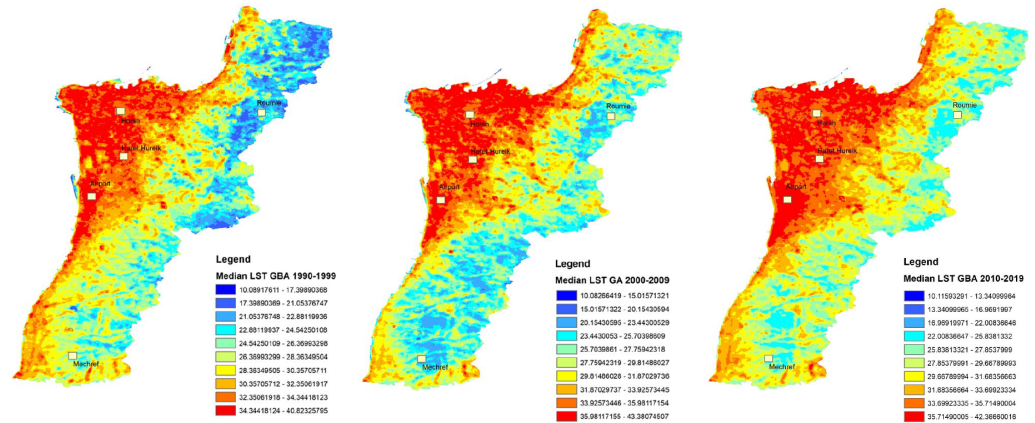


Figure 2. Median LST for GBA over three decades: 1990–1999 (left), 2000–2009 (middle), and 2009–2019 (right).

Furthermore, the elevation influences temperature, which decreases with higher altitudes. GBA has an elevation ranging from 0 m (Mediterranean Sea level) to 989 m. Based on the LST statistics according to land’s altitude, the highest LST values with a mean of 34.36°C are recorded at the lowest altitudes between 0–100 m at the coastal area, even if it is away by a 6 km distance. This is aligned with the fact that the population distribution increased the urbanized areas by a factor of 3 [9]. Although the highest altitude in Lebanon exceeds 3000 m, a big percentage of the population (up to 70%) lives at elevations of less than 200 m. For example, by having a closer look at the LST median values in 2010, we take a topographic profile in GBA as illustrated in Figure 3. It goes from the west coastline at 0 m to an endpoint (a region called Ain Saade) at a distance of 10,500 m to the east, and an altitude of 614 m. As illustrated in Figure 3, going up to 5900 m away from the coastline, the elevation of the land only increases to 50 m. It further dramatically increases to 614 m between the distance 6000 and 10,500 m.

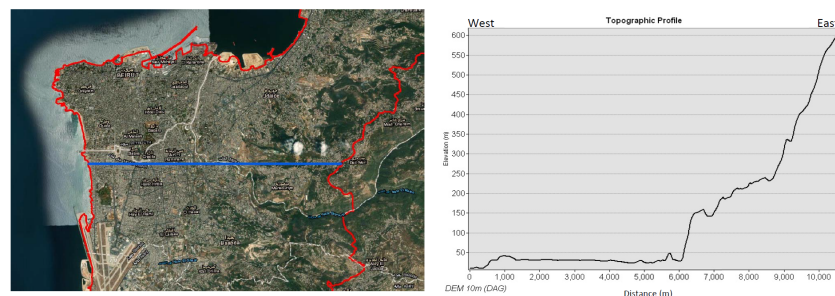
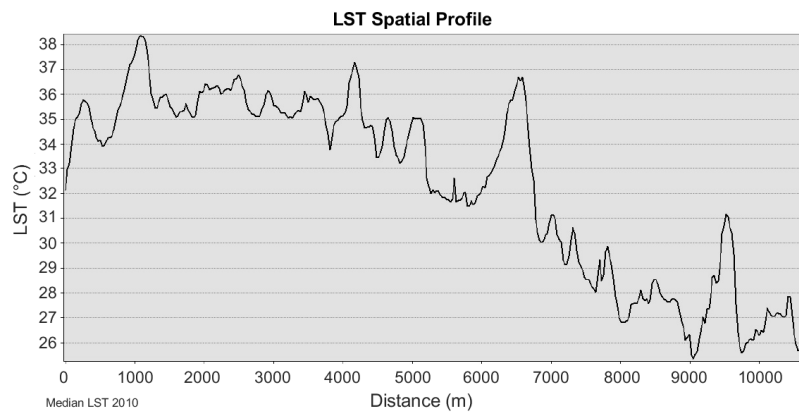


Figure 3. The topographic profile taken (left). The land elevation and distance from the West according to the topographic profile (right).

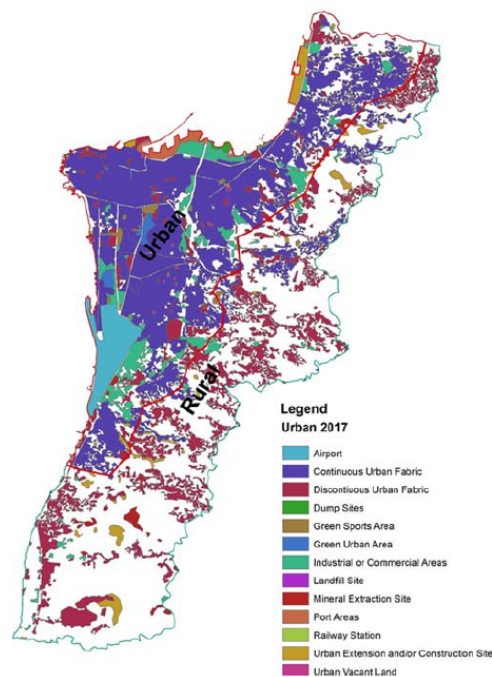
Figure 4 shows the median LST that is measured in relation to distance. The average LST from 0 to 1500 m is recorded as 35.55 °C where the average altitude is 26.84 m. However, it decreases to 27.21 °C between 9000 and 10,500 m where the average altitude is 464.69 m. Results show how a substantial drop in LST values is witnessed when the elevation increases, which is explained by the fact that urbanization dominates in the coastal area. Moreover, at higher altitudes in GBA, rural areas are combined with vegetation and mountains exist with vegetation growth.



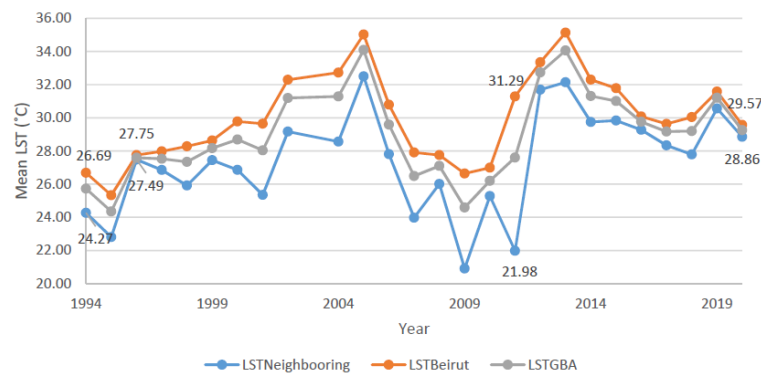


**Figure 4.** Median LST according to the distance from the coastal line to the east.

To confirm this correlation between the cooling effect of the vegetation growth and LST values, we compare the LST values of the Beirut district to its adjacent urban and rural borders in GBA as shown in Figure 5 as more evidence of the vegetation’s low LST values and urban areas’ high LST values. For this, we calculate the mean LST values for the Beirut district (in orange) and its rural surrounding areas (in blue) to assess their contributions to the LST values for GBA (in gray). These values over the three decades are presented in Figure 6. Results show that the highest LST values are recorded in the Beirut district’s urban area and increased by 2.88 °C from 26.69 °C in 1994 to 29.57 °C in 2020, while the lowest values are in adjacent rural areas, which increased by 4.59 °C from 24.27 °C in 1994 to 28.86 °C in 2020. LST values for the GBA are the combination of both previous values of the two regions with a total increase of 3.52 °C, from 25.73 °C to 29.25 °C. This demonstrates that the temperature in the vegetation area is lower than in the urban area. A noticeable point here is that LST values increased on average over the three decades more in the surroundings of Beirut than the district, which further highlights the urbanization witnessed in the rural surrounding areas of the Beirut district.

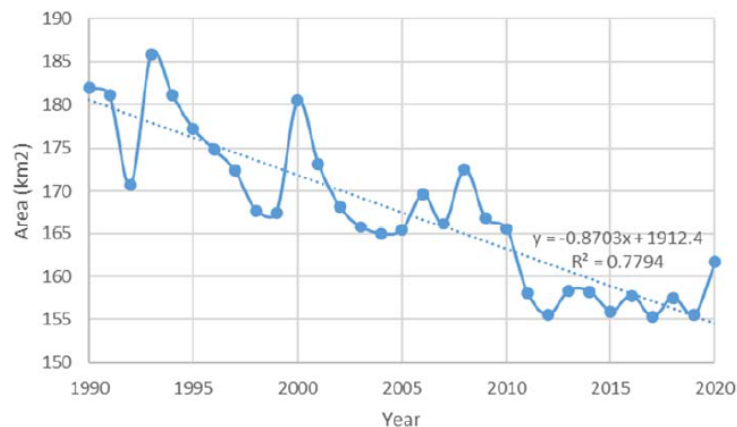


**Figure 5.** Urban and Rural borders of Beirut in GBA.



**Figure 6.** Mean LST for Beirut (orange), its rural surrounding areas (blue), and GBA (gray).

To detect plant growth and vegetation dynamics, we analyze the evolution of green areas in the same GBA area over the three decades as shown in Figure 7. Results show that due to human expansion, urbanization has reduced the vegetation in the GBA with a 20 Km<sup>2</sup> drop in green areas from 181 to 161 km<sup>2</sup> over the 3 decades. Figure 7 also shows how this evolution over the years is approximated by the linear regression model (dashed data line) with the coefficient of determination, R<sup>2</sup>, of 0.7794.



**Figure 7.** Evolution of green areas (in km<sup>2</sup>) in GBA.

#### 4. Conclusions

This research study shows that due to urbanization and the degradation of green spaces in GBA, LST peak values are increasing. This is significantly worrying, particularly in terms of urban inhabitants’ thermal comfort and well-being. The study highlights the need to consider urban heating in the legal urban planning code. It is an effort to review and modify the code accordingly. Otherwise, higher LST values will lead to urban heat islands that severely affect human health, activity, productivity, and satisfaction with the thermal environment surroundings.

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