Elevation-Wise and Direction-Wise Distribution of Land Surface Temperature in Jeju Island using Landsat 7 Data

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Abstract
In the present research, the Land Surface Temperature (LST) has been calculated from Landsat 7 data of Jeju Island to understand the spatial distribution of temperature on the island which would be strongly related to the ecological characteristics of the island. The dates were selected based on seasons (winter and summer) March 12 and September 19, 2020, respectively. Results calculated from a thermal band of Landsat 7 revealed the temperature variations on the island. Winter temperature varies from -3.7 to 31 °C while the summer season temperature varies from 20.6 to 43.1 °C. The surface temperature was also calculated at elevations of 100m and 500m for both seasons. It was found that on 100 m elevation, in winter the North and South directions have the same temperature, comparatively, in summer the North direction has a 0.97 °C higher temperature than the South. The East direction showed a 0.55 °C higher temperature as compared to the West in winter but in the summer season the case was opposite and the West had a 1.46 °C higher surface temperature than the East. Interestingly at 100 m height in summer, the North, and West has also the same temperature (34.25 °C). In the second case, on 500 m height for all four directions, the LST was compared and results showed that the South has 0.58 and 1.52 °C higher temperatures in winter and summer seasons respectively from the North. On the contrary, the West has 3.33 and 0.5 °C higher temperatures than the East in winter and summer seasons respectively. It revealed that seasons and altitude have a great impact on the LST in different cardinal directions of the island. From the results, it can be assumed that the island's ecological diversity would be strongly related to the geographical distribution of temperature.

Keywords: Elevation, LST, Optical Remote Sensing, Seasons, Thermal Band

1. Introduction

The climate is rapidly changing within and surrounding the cities due to the urbanization process. The intervention of anthropogenic activities in land use (LU) and absorption of solar radiation by impervious surfaces lead to high land surface temperature (LST) in cities [1]. Therefore, urban areas experience high surface temperatures as compared to rural areas, and this phenomenon is known as urban heat islands (UHI). More than 50% of the world's population is living in urban areas and it is predicted that in 2050 this figure will reach 70% which is one of the most significant factors of climate change [2] and [3]. LST has a substantial role in the environmental process because it can give some useful information about the physical properties of the earth's surface [4]. Land use land cover (LULC) and fast growth in urbanization and a number of cities have put a substantial amount of pressure on the earth's surface [5] and [6]. LST is a prominent factor in indicating the balance of earth's surface energy at a local and global level [7] and [8]; moreover, it represents the temperature of bare soil, buildings, roads, vegetation, or grass [9] and [10] and can be determined by the impact of radiating heat of the surface which can control the physical, chemical and biological processes of the earth and use to study the urban climate [11] and [12]. LST is one of the significant climatic parameters that exert control over splitting the energy into sensible and latent heat flux [13] and [14].

It can be used to retrieve the significant climatic variables i.e., air temperature and water vapor. LST has proved its significance in a variety of studies i.e., melting of glaciers [15] [16] and [17], effects of LULC on UHI [6] [18] and [19], and thermal-derived LST can also predict the suitable areas for vector-borne disease [20]. Streutker [21] mentioned that remote sensing (RS)-based LST made it possible to study the impact of urbanization on climate at local and global levels which was challenging with ambient air temperature. Another author Cheval [22] concluded that RS-based LST proved better efficiency compared to air temperature.

In this study RS (thermal band) derived LST data has been used because it is the best method as compared to the temperature sensors mounted on the car or near-surface air temperature from weather stations. Air temperature has very limited use in urban heat/cool island studies because of the few number of met stations and it is the temperature of the air, not the surface temperature. Due to this limitation, RS-derived LST has taken over in many studies on various relevant topics. RS-based LST is the direct temperature of the surface and is considered the skin temperature of the earth's surface. It has advantages that it is available in high spatial and temporal resolution, and it can measure the condition of the earth's surface [9] and [3]. RS-based LST has significance over other temperature sensors that it can obtain the temperature information for any kind of LULC class. There are many RS-based thermal sensors available i.e., Geostationary operational environmental satellite (GOES) (4km spatial resolution), MODIS (1km spatial resolution), ASTER (90m spatial resolution) but high spatial resolution thermal band (10.4 – 12.5µm, 30m) of Landsat 7 in this study to extract the LST. To the best of my knowledge except for Khandelwal [4] and a few more studies no one has studied the altitude impact on LST. Therefore, the present research was conducted with the aim to study thermal sensed derived LST in reference to direction and elevation with seasonal variations. Though it is widely understood that temperature decrease as the elevation increases but now the elevation dependent warming (EDW) concept arises in the mountainous region. EDW refers to the phenomena where the temperature changes vary with elevation. It is a subset of the broader concept of climate change, where the effects of rising global temperature are not uniform across all the elevation bands. Therefore, in this study the correlation between elevation and temperature has been estimated.

1.1 Study Area

Jeju island is in the Southern part of South Korea and was chosen for this study it is spread over an area of 1850 km^2 and stretches between 126.08 E to 126.97E longitude to 33.10N to 33.59N latitude with the longest length between East to West (73 km) and shortest length between North to South (31 km). The conical shape of Hallasan Mountain the highest point (1920 m) in the country located in the center of the Island (Figure 1) [8], and [23]. Mostly the Island is flat as more than 80% of the Island area has less than 500m elevation (Figure 1). The Island is characterized by humid climatic conditions, in summer it receives lots of rainfall and in winter the precipitation pours in the form of snow. The average annual rainfall on the island is 1500mm with 15 ^{o}C of mean temperature [23] and [24].

2. Material and Methods

In this study, Landsat 7 data has been used to estimate the spatial distribution of LST for two seasons (winter and summer). Landsat satellites have been monitoring the earth's surface for nearly the last half-century and are the longest-running satellite program by the United States Geological Survey (USGS) and NASA. The thermal band was started from Landsat 4 in 1982. From the thermal band, it can calculate the surface temperature of the earth and can also study the global warming phenomena. The spatial resolution of a thermal band of Landsat 7 is 30 meters. The Landsat 7 data of Jeju Island for two different dates (12 March 2020 and 19 September 2020) has been downloaded from the USGS (https://earthexplorer. usgs.gov/) website. The thermal band was chosen to study the impact of altitude on surface temperature in four cardinal directions for the winter and summer seasons. The thermal band was projected to WGS (World Geodetic System) 1984 UTM (Universal Transverse Mercator) Zone 52N. We have extracted Jeju Island from the thermal band and performed the atmospheric correction. The post-processed thermal band was further used to calculate the surface temperature of the Island. The first level shapefile of the Island was downloaded from DIVA-GIS (https://www.diva-gis.org/) and was provided by the University of California.

2.1 Land Surface Temperature (LST)

The LST was calculated from the thermal band (band 6) of the Landsat 7 satellite image. Since May 2003 the Landsat 7 ETM+ sensor has had data gaps after the failure of Scan Line Corrector (SLC).

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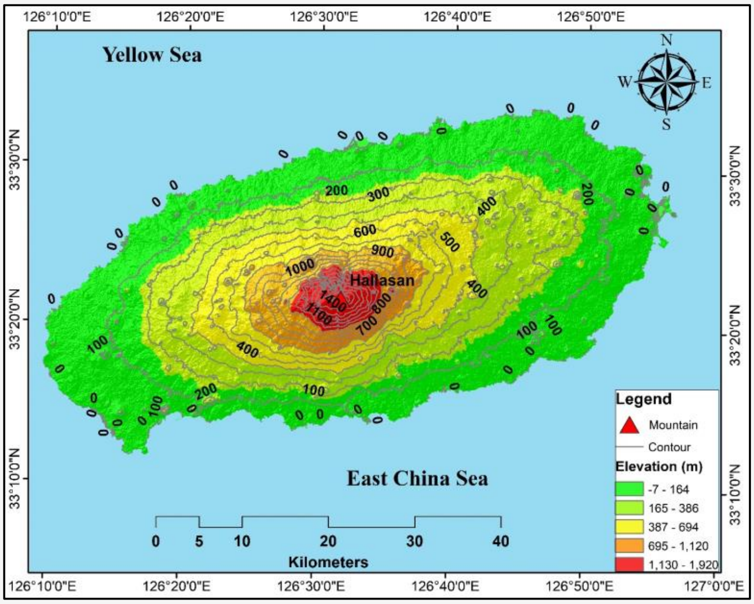

Figure 1: Location map with 100 m interval contours generated from ASTER (30 m) DEM overlaid on the elevation of the study area

Therefore, before using the thermal band of Landsat 7 the data gaps were filled using the "Fill no data" tool in QGIS Software. Afterward, some of the necessary steps were taken to calculate the LST from the Landsat 7 thermal band. In the first step, the digital number (DN) values were converted to spectral radiance. The procedure given by [25] was followed in this study for the conversion of DN values to spectral radiance which is given below in Equation 1.

$$L_{\lambda} = \left(\frac{L_{MAX\lambda} - L_{MIN\lambda}}{QCAL_{MAX} - QCAL_{MIN}} \right) \left(QCAL - QCAL_{MIN} \right) + L_{MIN\lambda}$$

Equation 1

Where,

L_{λ} is Top of Atmosphere (TOA) spectral radiance [$wm^{-2}sr^{-1}mm^{-1}$]

$L_{MAX\lambda}$ is spectral radiance scaled to $QCAL_{MAX}$

$L_{MIN\lambda}$ is the spectral radiance scaled to $QCAL_{MIN}$

$QCAL_{MAX}$ is maximum quantized calibrated DN pixel value

$QCAL_{MIN}$ is minimum quantized calibrated DN pixel value

$QCAL$ is quantized calibrated DN pixel value

Afterward, the actual temperature captured by the satellite image was calculated [26] using Planck's theory [27] as given below in Equation 2.

$$LST = \frac{K2}{\ln\left(\frac{K1}{K2} + 1 \right)} - 273.5$$

Equation 2

LST is the surface temperature (°C), and *K1* and *K2* are the constant calibrated values taken from the metadata file of the Landsat 7 image. L_{λ} is the radiance value which is computed in the previous step.

2.2 ASTER GDEM

In this research, the evaluation of elevation with LST employed the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model version 3 (GDEM v3). The data was accessed from the USGS (https://earthexplorer.usgs.gov/) website. The release of ASTER v3 in August 2019 marked an enhancement, incorporating over 350,000 additional ASTER stereo pairs to refine global coverage, and bolstering both vertical and horizontal accuracy. The ASTER GDEM v3 maintains the same gridding and tile structure as its predecessors, retaining a spatial resolution of 30 meters [28]. In this study, a sample of 35,000 points was generated which is approximately 5% of the total number of pixels, to plot the relationship between LST and elevation.

3. Results and Discussion

In the present study, the computed LST of the summer and winter seasons has been tested with two different conditions: [(1) 100 m height, (2) and 500 m height] to find the variations in temperature for both seasons for all cardinal directions. Figure 2 below is showing the spatial distribution of temperature in Jeju Island for the winter and summer seasons (month of March and September 2020 respectively). It can be observed from the figure that summer temperature varies between 20 – 43 °C and mostly the highest temperature is observed in the urban area (in the North there is Jeju City and Seogwipo City is in the Southern part of the island). Interestingly the winter season temperature varies between -3 to 31 °C (Figure 2). The summer and winter temperature profile is indicating that temperature is decreasing from all sides towards the center of the island because the center of the island is mostly covered with the forest region [24]. Next, four random points have been taken from the forest area of the classified LULC map of Jeju at 100 m and 500 m height in all cardinal directions to test the effect of elevation on temperature for both seasons (Figure 3). The results revealed that in the winter season, the North and South part has the same temperature at 100 m elevation but the North has a 0.97 °C higher surface temperature than the South in the summer season (Figure 4(a)).

It means that in winter Jeju and Seogwipo City have the same temperature but in summer Jeju City is 0.97 °C hotter. On the other hand, it has been observed that the East side of the Island has a 0.55 °C higher temperature than the West in winter, but the case was opposite for the summer season as the West has a 1.46 °C higher temperature than the East on 100 m elevation (Figure 4(a)).

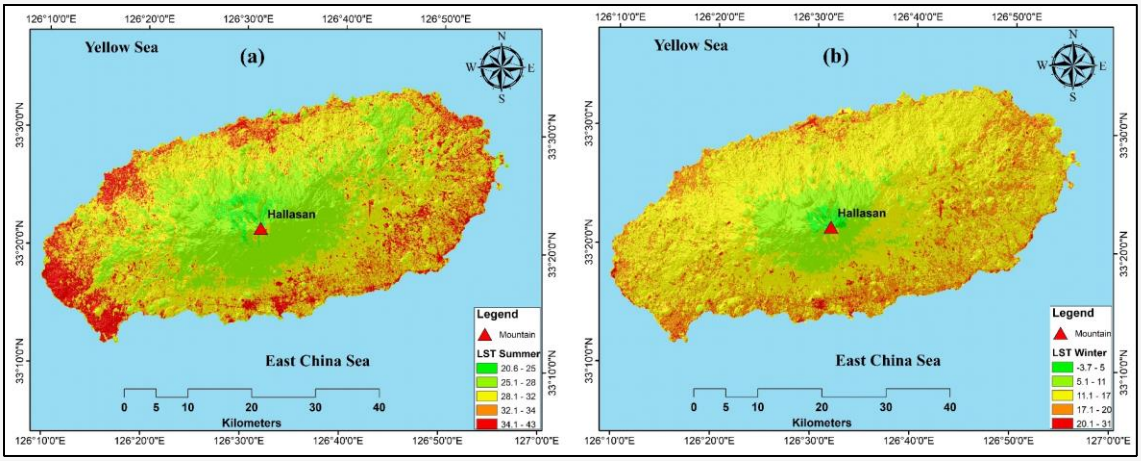

Figure 2: Land surface temperature of the study area (a) Summer season, (b) Winter season

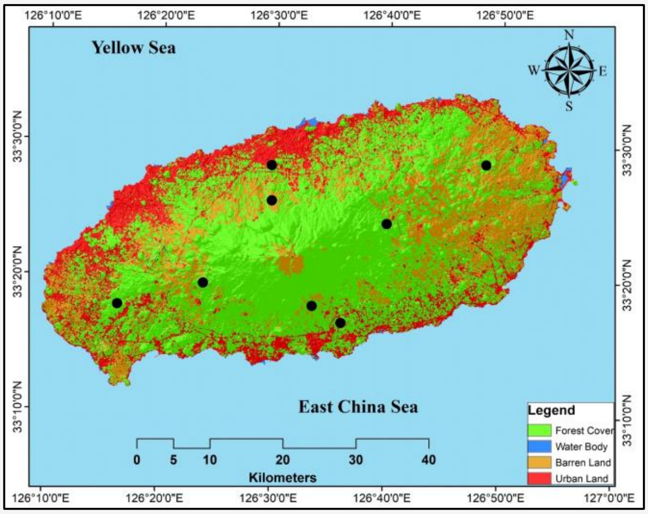

Figure 3: Jeju LULC map with sample points taken for temperature

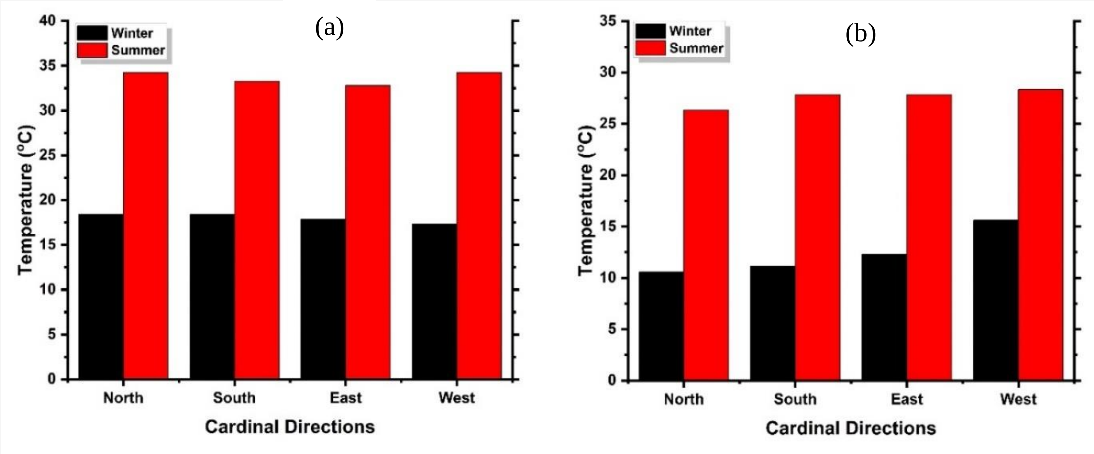

Figure 4: Surface temperature in all cardinal directions at (a) 100 m, (b) 500 m altitude (MSL) for both seasons (Winter and Summer)

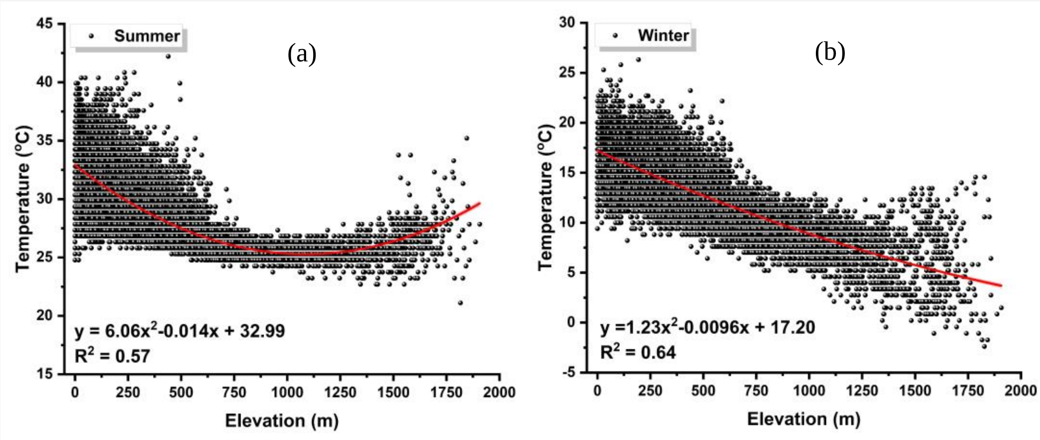

Figure 5: Correlation between LST and elevation for (a) Summer, (b) Winter season

However, the West and North have the same temperature in the summer season. Again, four random points have been taken at 500 m elevation in all cardinal directions for testing the impact of altitude on temperature. It has been observed that the west is 3.33 ºC and 0.5 ºC hotter than the East side in winter and summer seasons respectively. In winter South part of the island was 0.58 ºC hotter than the North while it was 1.32 ºC hotter than the North in summer (Figure 4(b)). Lee [7] has also found a similar pattern in his study of the Island. It was assumed that the spatial distribution of LST has a relationship with altitude in all cardinal directions which is also discussed by Khandelwal [4]. Therefore, it has been tested and observed that temperature and elevation have an inverse relationship. Temperature difference between 100 m and 500 m elevation for the North-faced region in both seasons (winter & summer) was 7.86 ºC and 7.93 ºC respectively which is the highest one followed by the South (7.28 ºC & 5.44 ºC), East (5.59 ºC and 4.95 ºC) and West (1.71 ºC and 5.91 ºC) which proves our assumptions and it is also consistent with a study conducted by [4] and [26].

Figure 5 illustrates the relationship between LST and elevation for the summer and winter seasons. A strong relationship has been observed between elevation and winter LST while elevation has a moderate relationship with summer LST (Figure 5(a), and Figure 5(b)). The polynomial regression values for the summer and winter seasons are 0.57 and 0.64 respectively. Figure 5 also represents the equation of the relationship between LST and elevation. It can be observed from the figure that LST is falling with high elevation while increasing with low elevation. The polynomial regression trend line for winter is marginally steeper as compared to the summer season. The distinct slope lines observed for the winter and summer season could be attributed to the diverse ways in which the land surface interact with the energy during both seasons.

4. Conclusion

In this study the investigated spatial distribution of LST at two different elevation levels in four cardinal directions of Jeju Island which covers an area of 1850 km^2. It is observed that in winter the minimum surface temperature of the Island drops below freezing point and maximumly reaches 30 ºC; however, in summer the highest surface temperature reaches to 43 ºC. Results revealed the temperature differences direction-wise at two different elevation levels (100 m and 500 m). The Northern part (Jeju) of the Island is 0.97 ºC hotter than the Southern part (Seogwipo) in the summer season but at 500 m elevation this difference was increased to 1.52 ºC but in the opposite direction (South). The surface temperature of the East and West was also compared and it was observed that the West has high surface temperature than the East side in the summer season but this difference was decreased as the elevation level increased. Interestingly the East and North side was colder than the West and South at 500 m elevation respectively. The correlation between LST and elevation for winter and summer seasons was derived and results revealed a falling trend of temperature with increasing elevation for both seasons. The falling degree of LST with increasing elevation was different for both seasons in all directions and varies between 1.71 – 7.86 ºC (Winter), 4.95 – 7.93 ºC (Summer). Elevation has an important role in the dynamics of LST. The results of this study do not apply to other kinds of climate conditions because Island has a subtropical humid climate.

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