North American Academic Research

Journal homepage: http://twasp.info/journal/home

Research

The relationship between vegetation dynamics and land surface temperature by using different satellite imageries; A Case study of Metropolitan cities of Pakistan

***Faisal Mumtaz*[1, 2], *Yu Tao*[1, 2], *Barjeece Bashir*[1, 2], *Adeel Ahmad*[1, 2], *Lingling Li*[1, 2], *Hammad Ul Hassan*[3]**

1. Aerospace Information Research Institute, Chinese Academy of Sciences; China

2. University of Chinese Academy of Sciences (UCAS), Beijing 101408, China

3. Department of Geography, Government College University Faisalabad 38000, Pakistan

***Corresponding Author:**

Yutao@radi.ac.cn

Accepted:**22 June, 2020* ***Published: *1 July 2020*

DOI: *https://doi.org/10.5281/zenodo.3923796*

Abstract: *Land surface temperature (LST) is an essential parameter for the urban thermal environment and global climate change studies. The significant of LST is being acknowledged gradually and indicates that Vegetation cover has an immediate impact of Land surface temperature (LST). The main objective of this study is, retrieval of Land Surface Temperature (LST) and its relationship with Normalized difference vegetation index (NDVI) by using the different satellite imageries including Landsat 5 (TM); Landsat 7 (ETM+); and Landsat 8 (OLI) for 1998, 2003, 2008, 2013 and 2018 in Lahore and Peshawar city (Pakistan). A combined technique of GIS and Remote Sensing has been applied for retrieval of LST and NDVI, and further, their relationship was checked by using linear correlation regression. Results indicate a rising trend of LST and decreasing trend of NDVI in Lahore, while the pattern of LST in Peshawar shows declining trend and NDVI shows an increasing trend.* R^2 *Coefficient value between LST and NDVI is very significant. The areas with low vegetation cover have a high temperature as compared to the areas which contain vegetation cover.*

***Keywords**: Geographical information system (GIS); Remote Sensing (RS); NDVI, LST, Regression Correlation*

1. Introduction:

Urbanization is a universal trend under the combined influence of biological factors and anthropogenic activities (BK, 2003; Lu et al., 2018; Seto, Fragkias, Güneralp, & Reilly, 2011; Sun, Wu, Lv, Yao, & Wei, 2013; Zhao et al., 2018). An increase in population and trend to move from rural to urban areas causes adverse growth in urbanization (Goksel, Mercan, Kabdasli, Bektas, & Seker, 2004; Goksel et al., 2006; Nasir, Tabassum, Khan, & Alam, 2012), Urbanization is the key factor of rising temperature which affects the natural resource and causes the transition of existing land use land cover (Rajeshwari & Mani, 2014). Because an increase in urban population demands metropolitan luxuries, facilities for their livings, construction of the residential area, commercial, public utility and road infrastructures which also causing LULC changes and this alteration of LULC affect the Land Surface Temperature (LST) (Kumar, Bhaskar, & Padmakumari, 2012). Because each land cover type has its unique characteristics in terms of energy radiation and absorption (Patz, Campbell-Lendrum, Holloway, & Foley, 2005). The urban extension has replaced the natural land covers to impervious surfaces that bring negative environmental, social, and economic results (Abdullahi & Pradhan, 2018; Bounoua, Nigro, Zhang, Thome, & Lachir, 2018; Liu & Zhang, 2011; Pickard, Van Berkel, Petrasova, & Meentemeyer, 2017). Various studies showed that changes in land use land cover as a result of urbanization has multiple negative impacts on land surface temperature (Balçik, 2014; Sanli, Balcik, & Goksel, 2008; Santana, 2007). Change in different land use categories specially, transformation of vegetation land to urban area can effectively influence the LST (Hope & McDowell, 1992; Julien, Sobrino, & Verhoef, 2006; Smith & Choudhury, 1990). Urbanization is changing the climate apparently, and most apparent effect is urban heat island that makes the cities warmer than the surrounding areas. It is expected that urban population would be almost double by 2050 (Baker, 2007). In south Asia, Pakistan is expected to be more urbanized in 2050 (Mustafa & Sawas, 2013). Lahore and Peshawar both are the metropolitan cities of Pakistan (Capitals of Punjab and KPK province). In recent years, as many other metropolitan cities of the world, Lahore also has experienced the massive growth, so many people from neighborhood and other different cities of the whole country move towards this city for better conditions of life, health and jobs etc. that huge acceleration of population demand the better life facilities which is leading the urbanization and disturbing the existing land use structure (Maktav, Erbek, & Jürgens, 2005). Because of Urban expansion and over cutting, the vegetation cover of Lahore has almost decreased. Moreover, Natural land has been replaced mainly by built-up areas (NESPAK, 2004). Therefore, the negative impact of urbanization on temperature in Lahore region is a necessary condition for research. Previous studies also indicate that the LST of Lahore city is going toward increasing trend (Nasar-u-Minallah, 2019). On the other hand, From 2000 to 2005, Peshawar has experienced sudden changes in population growth due to migration of people from Afghanistan, because of war and unfriendly atmosphere in Afghanistan (Raziq, Xu, Li, & Zhao, 2016). According to the 1961 census, Peshawar represents 29% of the total population of KPK. In addition to the 1998 census, 33 % of the community found and shared the entire population of KPK (Mehmood, Mehmood, Butt, Younas, & Adrees, 2016). Also, in 2013, the provisional government of KPK implemented a billion tree project in the whole region (N. Khan et al., 2019) to cover the barren land and also to control the effect of deforestation.

GIS and remote sensing are the most useful techniques for studies of thermal environment and its consequences. Recent advancement in remote sensing technology provides unique opportunity to monitor the changes in LULC, LST as well as vegetation cover at high-resolution Spatio-temporal scale (Shi, Yang, Ma, Zhang, & Luo, 2013; Tao et al., 2011; Ullah et al., 2019). Since1972, the launch of the different Landsat satellites till present, continuously providing the remote sensing data which is available free of charges at large scale for numerous applications in social, economic, and environmental characteristics of urban areas (Wulder et al., 2016). Remotely based data available from past several years can provide a better understanding to investigate the past and recent dynamics in LST, which can be helpful for the studies of the urban thermal environment (Eastman, Van Fossen, & Solarzano, 2005).

This study made an attempt to retrieval of Land Surface temperature (LST) and its relationship with Normalized difference vegetation index (NDVI) by using the satellite imageries of different periods including Landsat 5 (TM); Landsat 7 (ETM+); and Landsat 8 (OLI) for the time period of 1998, 2003, 2008, 2013 and 2018 in Lahore and Peshawar city (Pakistan).

2. Material and methods

2.1 Study Area:

2.1.1 Peshawar:

Peshawar, the capital of KPK, Pakistan situated adjacent to the eastern end of the historic Khyber Pass, close to the border with Afghanistan, Known as the heart of Khyber Pakhtunkhwa Pakistan and also carrying multicultural resident of the province. Peshawar city is a beautiful and vital hub economically, politically and military for the region and Pakistan. City is located at 44°15' North Latitude; 71°42' East Longitude with spatial extent of 12 sq. kilometer and an average elevation of 1086 ft.

2.1.2 Lahore

Lahore is the second largest metropolitan city in Pakistan and also the capital of the Punjab Province. It lies between 31°15′—31°43′ N and 74°10′—74°39′ E, a total area of is 1,842 km2 (GoP, 2000). So, the adverse effects of urbanization on the temperature in the Lahore

Metropolitan Area are essential to be studied. The factors responsible for increasing temperature include conversion of land from vegetation cover to impervious surface housing schemes, industrial and commercial activities, deforestation, and emission of GHGS and exhausts of vehicles. It covers an area of 1842 sq. Km, 208 to 213 m above the mean sea level. The study area slopes from north-east to the south-west and is located on the alluvial soil of River Ravi (NESPAK, 2004).

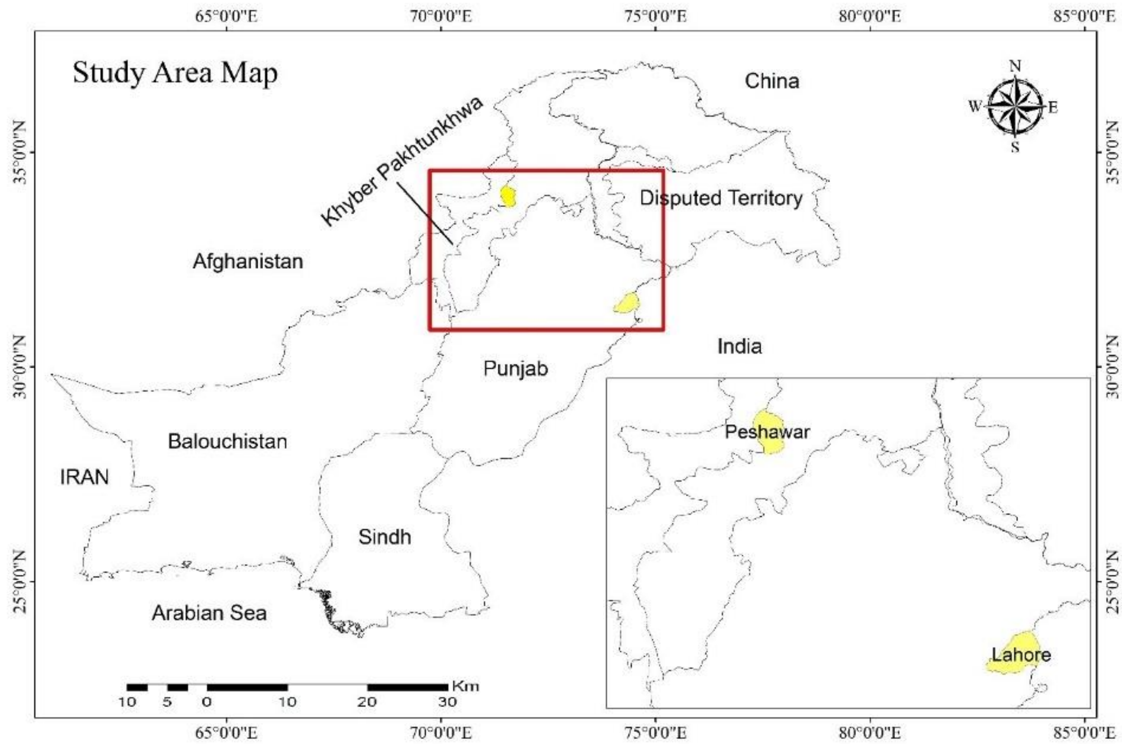

Figure 1: Study Area Map

2.2 Data collection and preprocessing

These studies analyze the relationship between LST and vegetation cover of Lahore and Peshawar city. Data of different Landsat Products (Landsat5 TM; Landsat7 ETM+ and Landsat8 (OLI)) was collected on the temporal resolution of 16 days and spatial resolution of 30m for the period of 1998-2018. All images were freely downloaded from USGS Earth Explorer (http://earthexplorer.usgs.gov). After the preparation of the satellite images vector layer of the administrative boundary of the Study area Lahore and Peshawar was utilized as masks to subset image for clipping the area of interest (AOI) from the Tagged Image File Format (.TIFF) downloaded by USGS website. Radiometric and geometric corrections were done to prepare data for processing and extraction of useful information (Bhatti & Tripathi, 2014; Deng & Wu, 2013; Modica et al., 2016; Rimal, Zhang, Keshtkar, Wang, & Lin, 2017; Sothe, Almeida, Liesenberg, & Schimalski, 2017). Landsat products with different spectral bands were mosaicked, layer stacked and processed for spatial, spectral, and geometric corrections. After geometric and atmospheric correction these spectral bands were employed to derive the LST by using Mono Window algorithm method (Jiménez-Muñoz & Sobrino, 2003; Qin, Karnieli, & Berliner, 2001). In order to derive LST, the first digital number of spectral bands were converted into radiance and finally into reflectance value. The detailed procedure about the derivation of radiance and reflectance is explained below.

Landsat Satellite	Sensor	Spatial Resolution	Row/Path (Peshawar)	Row/Path (Lahore)
Landsat 5 &7	TM & ETM+	30m	151/036 151/037	149/036
Landsat 8	OLI	15m	151/036 151/037	149/036

Table 1: Satellite Images Description

2.2.1 Conversion of Digital Number into Radiance

Digital number of spectral bands was firstly converted into spectral radiance (Lλ) using this formula (Chen, Zhao, Li, & Yin, 2006)

$$L\lambda = \frac{L_{max\lambda} - L_{min\lambda}}{(Qcal_{max} - Qcal_{min})} \times (Qcal_{max} - Qcal_{min}) + L_{min\lambda} \qquad (1)$$

Where,

L_λ= Spectral radiance (W/m2 sr-1 $\mu m - 1$)
Qcal = Pixel values in DN
Qmax = Maximum Quantized calibrated pixel value (DN)
Qmin = Minimum Quantized calibrated pixel value (DN)
Lmax= Spectral radiance scaled to Q max
Lmin= Spectral radiance scaled to Q min

2.2.2 Conversion from Radiance to Reflectance

NIR and RED spectral bands after radiance were converted into reflectance using the following relations.

$$r = \frac{\pi \times L_\lambda \times r^2}{E_{sun} \times Cos\o \times dr} \qquad (2)$$

Where,

r = Planetary reflectance (dimensionless)
Lλ = Spectral radiance at the sensor aperture (watt m-2 ster-1 µm-1)
dr = Inverse square of the earth-sun distance (astronomical unit).
dr = 1 + 0.033Cos (D × 2 × 3.14)/365)

Where, D = Day of the year, Esun = Mean solar atmospheric irradiances (watt m-2 µm-1) θ = Solar zenith angle (degree), θ = (90 - B), and B = Sun elevation angle. Information regarding all constant parameters was taken for NIR and RED bands from the LANDSAT metadata header file.

2.3 Retrieval Land Surface Temperature (LST)

In this study, LST was derived from thermal bands of Landsat products using the methodology recommended by (Sekertekin, Kutoglu, & Kaya, 2016). The following procedures were adapted to retrieve LST.

In the first step, the radiance of the thermal spectral band retrieved in the previous section was converted into brightness temperature (TB) using the following equation.

$$TB = \frac{K_2}{ln\left[\left(\frac{K_1}{L_\lambda}\right)+1\right]} \quad (3)$$

Where; K1 and K2 are the conversion constant, Lλ is a spectral radiance and T is brightness temperature. For Landsat8 OLI, K1 = 774.89 mW/cm2/sr/ µm and K2 = 1321.08 Kelvin, for Landsat7 ETM+, K1 = 666.09 mW/cm2/sr/µm and K2 =1282.71 Kelvin; Landsat5 TM, K1 = 607.76 mW/cm2/sr/µm and K2 = 1260.56 Kelvin. In second step, land surface temperature was derived using following relation (Bhalli, Ghaffar, Shirazi, Parveen, & Anwar, 2012)

$$LST = \frac{T_B}{1+\left(\frac{\lambda T_B}{\rho}\right)\ln\epsilon} \quad (4)$$

λ (≈ 11.5 µm) is the effective wavelength of thermal bands. $P= \frac{hc}{\sigma}$ = 1.438 × 10 2 mK, where 'σ' is the Boltzmann constant (1.38 × 10-23 JK-1), h is Planck constant (6.626 × 10-34 Js) and c is the speed of light (3.0 × 108 ms-1), ϵ is the land surface emissivity with 0.95, 0.92 and 0.9925 for vegetation, build-up and water surfaces, respectively (Nichol, 1994). Land surface emissivity (Ɛ) was estimated using the NDVI thresholds method as proposed by (Jiménez-Muñoz & Sobrino, 2003), according to the following equations.

$$d_{\varepsilon} = (1\_\varepsilon_s) \times (1-p_v) + F \times \varepsilon_V \quad (5)$$

Where;

ε_v = vegetation emissivity, Ɛs = the soil emissivity, F = shape factor and its value if 0.55, Pv = vegetation proportion and it was obtained according to equation (Bhalli et al., 2012)

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \quad (6)$$

2.4 Derivation of Normalized difference vegetation index (NDVI)

In this study, NDVI is used to recognize the correlation between Land surface temperature and vegetation cover. It facilitates the analyst to recognize relationship between land use type and estimate surface temperature quantitatively (Schmidt & Karnieli, 2000) NDVI is derived by using the equation 7 (Peijun, Xingli, Wen, Yan, & Zhang, 2010)

$$NDVI = \frac{NIR - RED}{(NIR + RED)} \quad (7)$$

3. Results and Discussion:

3.1 Spatial pattern of LST for Lahore (a) and Peshawar (b) from 1998-2018

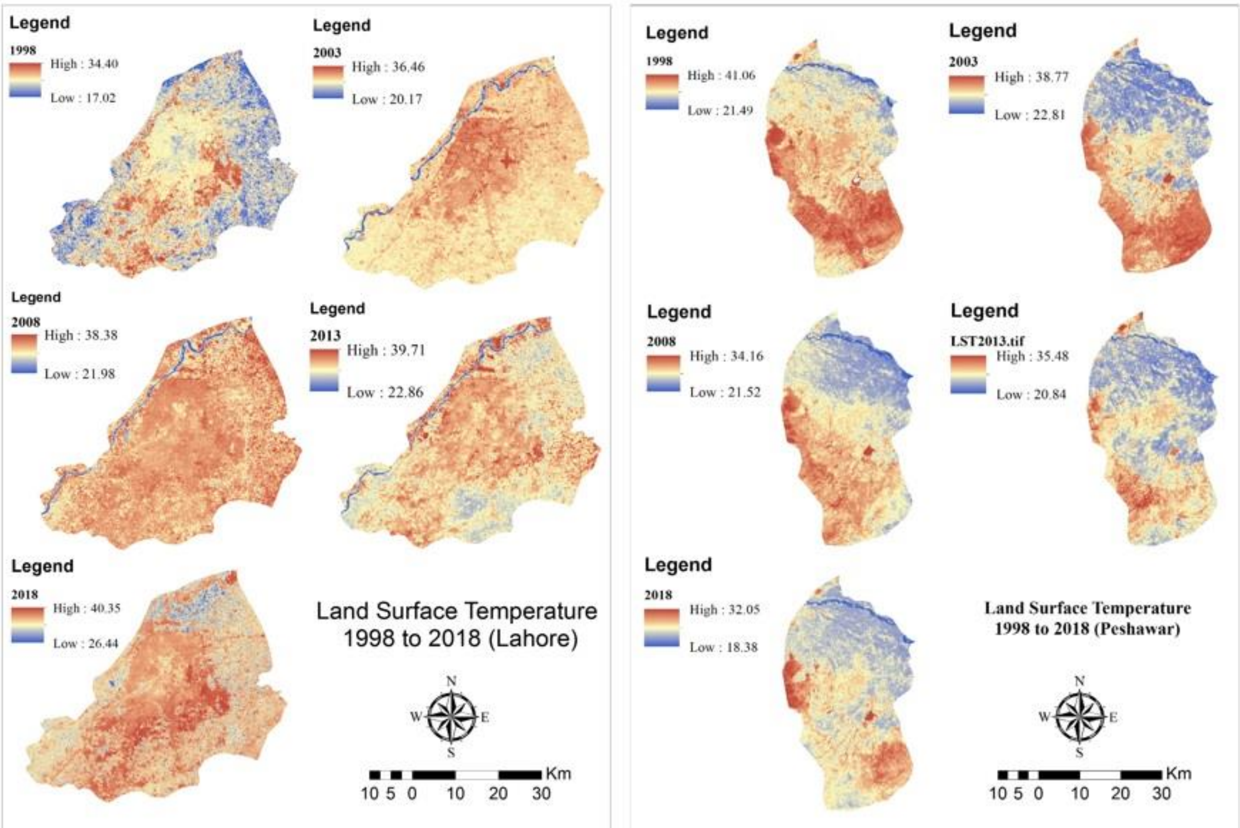

Figure 2: spatial pattern in land Surface temperature (LST) changes in two major cities (a) Lahore and (b) Peshawar from 1998-2018.

Adhered to climate studies, LST is an important parameter. Figure 2 displays the spatial patterns of land surface temperature of (a) Lahore and (b) Peshawar from 1998 to 2018, which were revealed from the thermal bands of different satellite imageries including (Landsat5 (TM); Landsat7 (ETM+) and Landsat8 (OLI). Figure 2 (a) indicates that the pattern of LST is going toward an increase in Lahore city. An increasing trend can be seen in both High and low LST. For year 1998, 2003, 2008, 2013 and 2018 the High LST is 34.40, 36.46, 38.18, 39.71 and 40.35. Moreover, low LST is 17.02, 20.17, 21.98, 22.86, and 26.44. Some previous studies also indicate that the LST of Lahore city is going toward increasing trend (Nasar-u-Minallah, 2019). However, Figure 2 (b) indicates that the pattern of LST is going toward a decrease in Peshawar city. The decreasing trend can be seen in both High and Low Land Surface Temperature. For the year 1998, 2003, 2008, 2013 and 2018 the High LST is 41.06, 38.77, 34.16, 35.48 and 32.05 but at the same time, the Low LST also have a decreasing trend as 21.49, 22.81, 21.52, 20.84 and 18.38 for the year 1998, 2003, 2008, 2013 and 2018.

3.2 Spatial pattern of NDVI for Lahore (a) and Peshawar (b) from 1998-2018

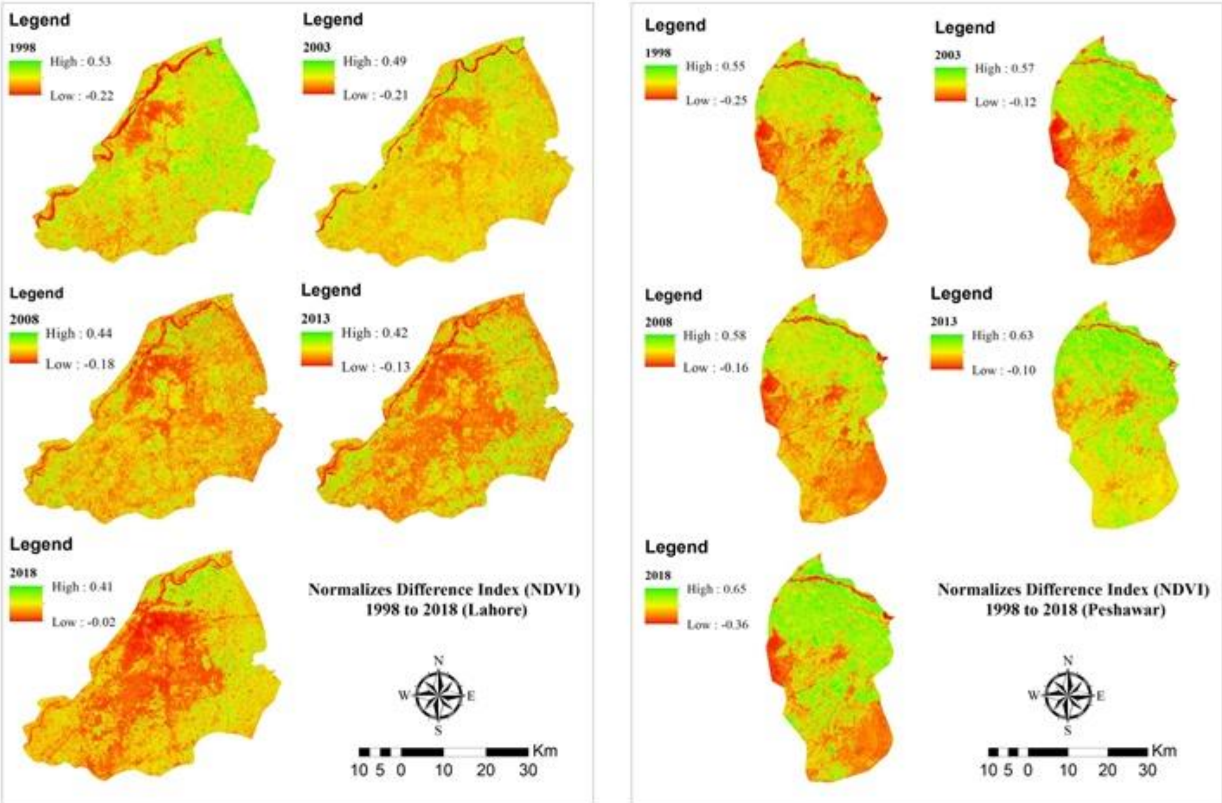

Figure 3: Spatial pattern of Normalized Vegetation index from 1998-2018 (a) Lahore (b) Peshawar

Figure 3 indicate the trend of Normalized vegetation index in both cities from 1998 to 2018 and results highlight that Lahore city is losing their Vegetation day by day and for each study year their NDVI trend is toward decreasing. Still, on the opposite side for Peshawar, the NDVI trend is +ve, and the city is gaining the vegetation. In Lahore city the NDVI values was 0.53 high NDVI / -0.22 low NDVI in 1998 and throughout the study year the value of NDVI is decreasing and has been decreased to 0.41 high / -0.02 Low NDVI in 2018. On the other side, the NDVI values of Peshawar city have an opposite trend as compare to Lahore city. In 1998 the high/low NDVI values was 0.55/-0.25 which have been increased to 0.65/-0.36 Low NDVI. The trend of NDVI values was seen growing during all the study years for Peshawar.

3.3 Correlation between Land Surface Temperature and NDVI

After the retrieval of Land Surface Temperature and NDVI for the study area under all study years, the linear regression model was applied to check the correlation between LST and NDVI maps. Figure 4 and Figure 5 indicate the correlation between LST and NDVI for both studies including Lahore and Peshawar

3.1.1 Linear regression between LST and NDVI for Lahore city (1998-2018)

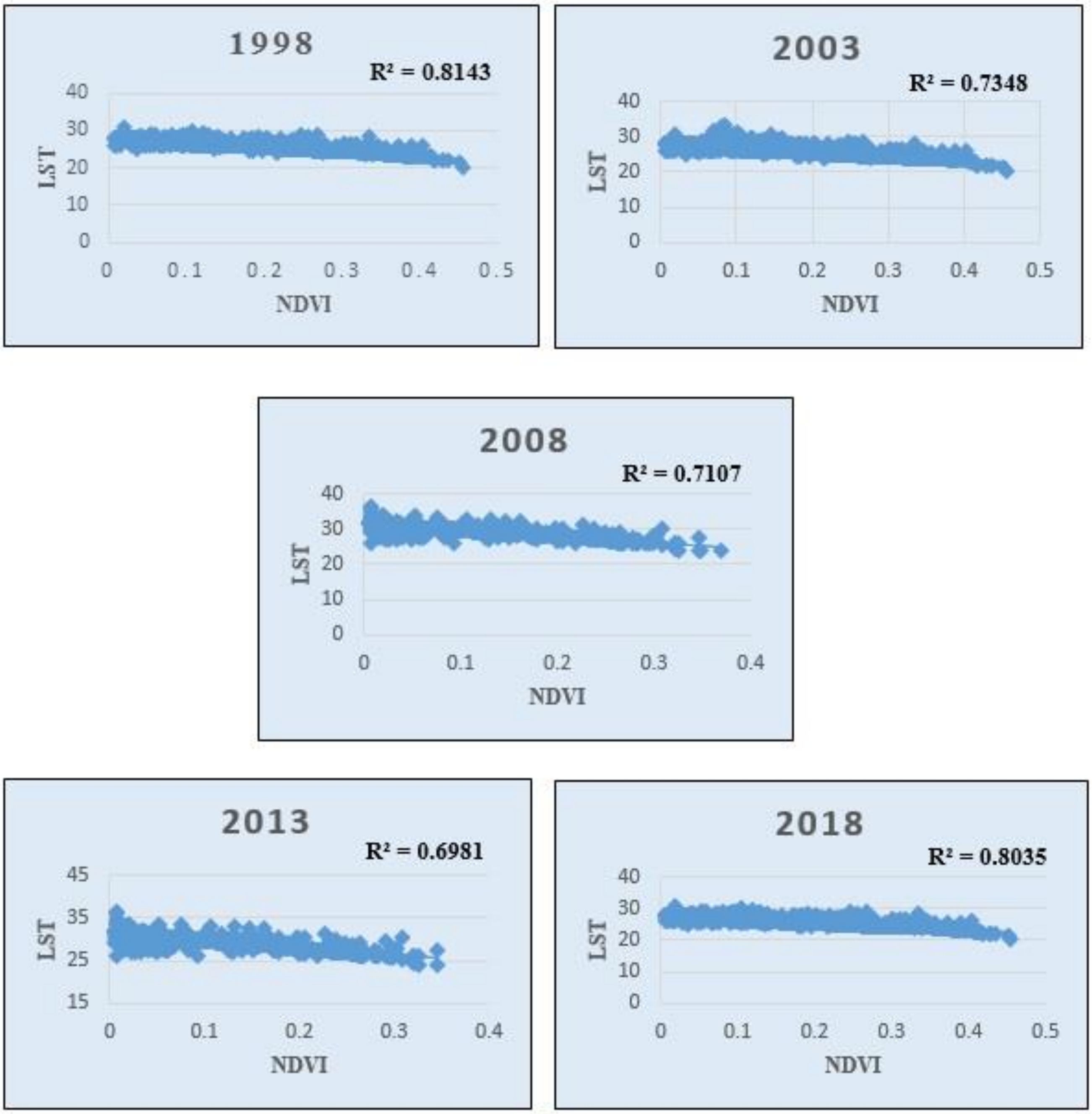

Figure 4: Linear regression between LST and NDVI for Lahore city (1998-2018)

3.1.2 Linear regression between LST and NDVI for Peshawar city (1998-2018)

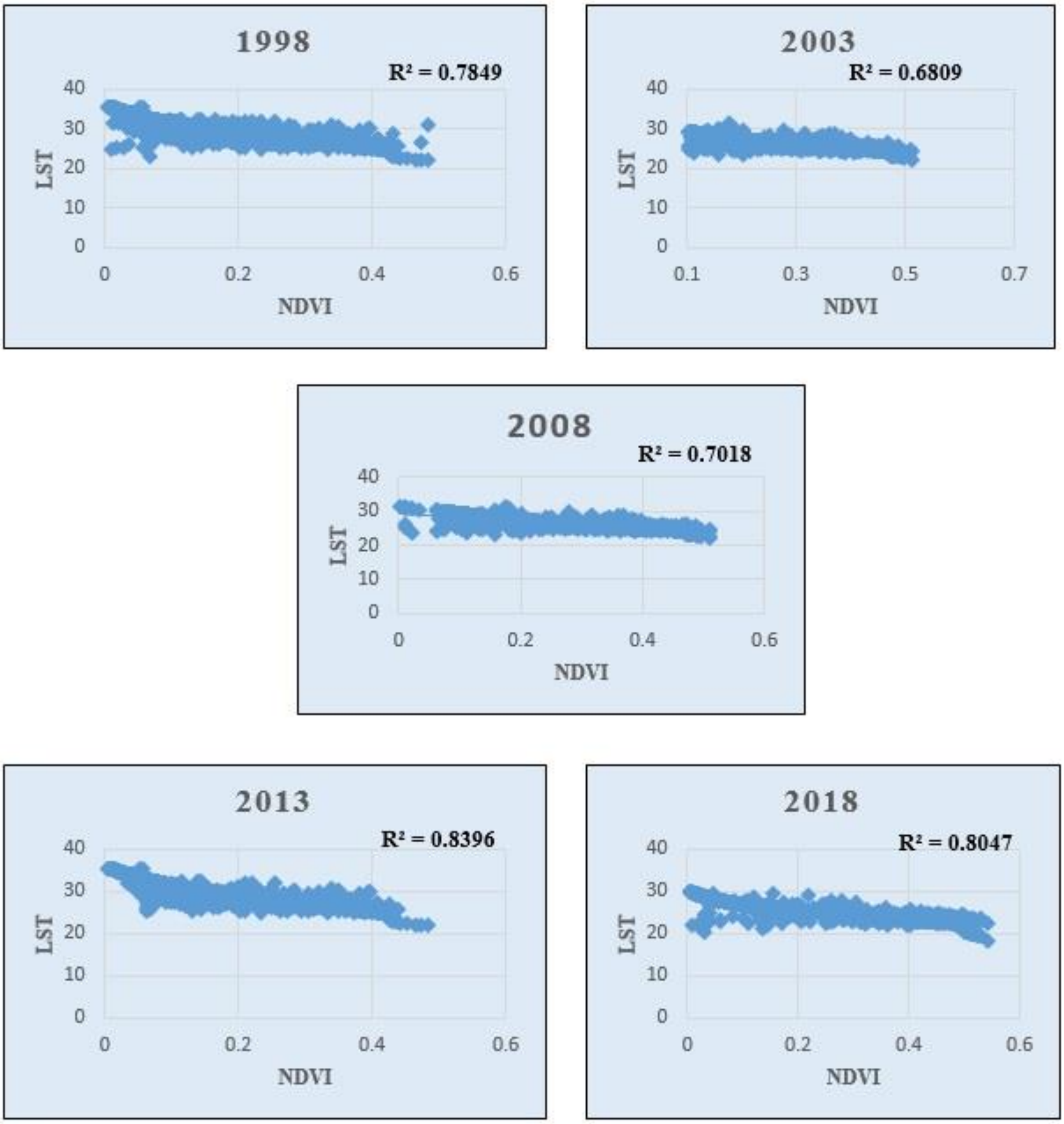

Figure 5: Linear regression between LST and NDVI for Peshawar city (1998-2018)

Figure 4 and Figure 5 represent the correlation between LST and NDVI of Lahore and Peshawar from 1998-2018 is depicted above. The increase in LST values represented together decrease in NDVI values. From the results, it has been concluded that there is a negative correlation concerning normalized LST and vegetated cover and the value of R^2 is high and above than 0.7, which indicating that the LST is strongly correlated with NDVI. Many previous studies have reported the negative relation between LST and NDVI (Shi et al., 2013; Zhang et al., 2013). The correlation between LST and NDVI was expressed using

Linear regression in figure 4 and Figure 5 the coefficients (R^2) was 0.81, 0.73, 0.71, 0.69 and 0.81 in Lahore, while the value of coefficients (R^2) for Peshawar was 0.78, 0.68, 0.70, 0.83 and 0.80. This range of coefficients (R^2) indicated that NDVI and normalized LST had a good relationship.

The lowest NDVI value was considered in the urban and barren lands while the highest value was in the vegetation cover areas and water. Generally, low NDVI value supports high LST, while High NDVI values indicate low LST. From results, it is concluded that NDVI values are increased with vegetation cover, and consequently, it decreases LST value. While the build-up land has very low NDVI that represents the high temperature inside this buffer. During 1998 the build-up area of Lahore was quite low as compared to 2018, over time the urban area has been increased. The vegetation cover of Lahore is decreasing because of urban growth and utilizing their natural land and barren land for different projects under Lahore Development Authority (LDA) and other developers (NESPAK, 2004; Shah & Ghauri, 2015), while in Peshawar city the build-up area in 1998 was quite low and barren land was so high, but over time the urban area has been increased but also their vegetation cover in increasing day by day, especially after one billion tree project of KPK government in 2013 (N. Khan et al., 2019). That alteration of land used land change cover in both cities affecting the local climate and had a strong effect on it. The areas which are covered with water and vegetation have the lowest temperature as compare to the Built-up area and barren land. LST is also affected by land-use changes (Foley et al., 2005). Because of urban Expansion, LULC has a profound impact on local and regional climate (Jiang & Tian, 2010; I. Khan & Zhao, 2019). Such a change in the land surface also causes the manipulation in temperature and topography of the neighborhood (Goksel et al., 2004; Goksel et al., 2006). LST variation can be associated with various factors included Land Surface parameters, LULC, Climate change, Population growth, and economics (Jiang & Tian, 2010).

4. Conclusion

The study examines the impact of vegetation dynamics on land surface temperature; Results indicate that the trend of LST in Lahore city is going toward increase and their NDVI (vegetation cover) has a decreasing trend. While in Peshawar city, the Trend of LST is going toward a decrease, and NDVI is going toward increase. The coefficients (R^2) value was 0.81, 0.73, 0.71, 0.69 and 0.81 in Lahore for the years of 1998, 2003, 2008, 2013 and 2018, while the coefficients (R^2) value for Peshawar was 0.78, 0.68, 0.70, 0.83 and 0.80. The Correlation regression values between LST and NDVI is above than 0.70, which reveals that changes in vegetation cover have an immediate impact on LST. The vegetation areas have the highest values of NDVI as compared to the urban built-up area. Results revealed that the urban areas accompanied the vegetated areas that highly modifying the thermal eco-environment. Built-up and barren land has higher LST as compare to water areas and vegetation cover. The effect of building phenology, greenhouse gas emission, LULC changes, and dangerous climate /extreme weather conditions can counter by forestry and land-use practices. It is recommended that these practices should be following; 1) use of reflective surfaces to increase albedo, and decrease surface roughness so that electromagnetic radiations gets reflected from earth surface; 2) increase vegetation and water cover to minimize the thermal effects by cooling and also manage forests and cultivation practices to increase the carbon storage factor. All such land use land cover change practices can make it possible to reduce land surface temperature, especially in urban areas.

5. Reference:

Abdullahi, S., & Pradhan, B. (2018). Land use change modeling and the effect of compact city paradigms: integration of GIS-based cellular automata and weights-of-evidence techniques. *Environmental earth sciences, 77*(6), 251.

Baker, J. L. (2007). Bangladesh-Dhaka: Improving Living Conditions for the Urban Poor.

Balçik, F. B. (2014). Determining the impact of urban components on land surface temperature of Istanbul by using remote sensing indices. *Environmental monitoring and assessment, 186*(2), 859-872.

Bhalli, M., Ghaffar, A., Shirazi, S., Parveen, N., & Anwar, M. (2012). Change detection analysis of land use by using geospatial techniques: a case study of Faisalabad-Pakistan. *Science International (Lahore), 24*(4), 539-546.

Bhatti, S. S., & Tripathi, N. K. (2014). Built-up area extraction using Landsat 8 OLI imagery. *GIScience & Remote Sensing, 51*(4), 445-467.

BK, K. (2003). Internal migration in Nepal: Population Monograph of Nepal 2003, II: Kathmandu: Central Bureau of Statistics.

Bounoua, L., Nigro, J., Zhang, P., Thome, K., & Lachir, A. (2018). Mapping urbanization in the United States from 2001 to 2011. *Applied Geography, 90*, 123-133.

Chen, X.-L., Zhao, H.-M., Li, P.-X., & Yin, Z.-Y. (2006). Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. *Remote sensing of environment, 104*(2), 133-146.

Deng, C., & Wu, C. (2013). A spatially adaptive spectral mixture analysis for mapping subpixel urban impervious surface distribution. *Remote sensing of environment, 133*, 62-70.

Eastman, J., Van Fossen, M., & Solarzano, L. (2005). Transition potential modeling for land cover change. *GIS, spatial analysis and modeling*, 357-386.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., . . . Gibbs, H. K. (2005). Global consequences of land use. *Science, 309*(5734), 570-574.

Goksel, C., Mercan, D. E., Kabdasli, S., Bektas, F., & Seker, D. Z. (2004). Definition of sensitive areas in a lakeshore by using remote sensing and GIS. *Fresenius Environmental Bulletin, 13*(9), 860-864.

Goksel, C., Musaoglu, N., Gurel, M., Ulugtekin, N., Tanik, A., & Seker, D. Z. (2006). Determination of land-use change in an urbanized district of Istanbul via remote sensing analysis. *Fresenius Environmental Bulletin, 15*(8), 798-805.

Hope, A. S., & McDowell, T. (1992). The relationship between surface temperature and a spectral vegetation index of a tallgrass prairie: effects of burning and other landscape controls. *International Journal of Remote Sensing, 13*(15), 2849-2863.

Jiang, J., & Tian, G. (2010). Analysis of the impact of land use/land cover change on land surface temperature with remote sensing. *Procedia environmental sciences, 2*, 571-575.

Jiménez-Muñoz, J. C., & Sobrino, J. A. (2003). A generalized single-channel method for retrieving land surface temperature from remote sensing data. *Journal of Geophysical Research: Atmospheres, 108*(D22).

Julien, Y., Sobrino, J. A., & Verhoef, W. (2006). Changes in land surface temperatures and NDVI values over Europe between 1982 and 1999. *Remote sensing of Environment, 103*(1), 43-55.

Khan, I., & Zhao, M. (2019). Water resource management and public preferences for water ecosystem services: a choice experiment approach for inland river basin management. *Science of The Total Environment, 646*, 821-831.

Khan, N., Shah, S. J., Rauf, T., Zada, M., Yukun, C., & Harbi, J. (2019). Socioeconomic impacts of the billion trees afforestation program in Khyber Pakhtunkhwa Province (kpk), Pakistan. *Forests, 10*(8), 703.

Kumar, K. S., Bhaskar, P. U., & Padmakumari, K. (2012). Estimation of land surface temperature to study urban heat island effect using LANDSAT ETM+ image. *International journal of Engineering Science and technology, 4*(2), 771-778.

Liu, L., & Zhang, Y. (2011). Urban heat island analysis using the Landsat TM data and ASTER data: A case study in Hong Kong. *Remote Sensing, 3*(7), 1535-1552.

Lu, Q., Chang, N.-B., Joyce, J., Chen, A. S., Savic, D. A., Djordjevic, S., & Fu, G. (2018). Exploring the potential climate change impact on urban growth in London by a cellular automata-based Markov chain model. *Computers, Environment and Urban Systems, 68*, 121-132.

Maktav, D., Erbek, F., & Jürgens, C. (2005). Remote sensing of urban areas. *International Journal of Remote Sensing, 26*(4), 655-659.

Mehmood, R., Mehmood, S. A., Butt, M. A., Younas, I., & Adrees, M. (2016). Spatiotemporal analysis of urban sprawl and its contributions to climate and environment of Peshawar using remote sensing and GIS techniques. *Journal of Geographic Information System, 8*(2), 137-148.

Modica, G., Solano, F., Merlino, A., Di Fazio, S., Barreca, F., Laudari, L., & Fichera, C. R. (2016). Using Landsat 8 imagery in detecting cork oak (Quercus suber L.) woodlands: a case study in Calabria (Italy). *Journal of Agricultural Engineering, 47*(4), 205-215.

Mustafa, D., & Sawas, A. (2013). Urbanisation and political change in Pakistan: Exploring the known unknowns. *Third World Quarterly, 34*(7), 1293-1304.

Nasar-u-Minallah, M. (2019). Retrieval of land surface temperature of Lahore through Landsat-8 TIRS data. *International Journal of Economic and Environmental Geology, 10*(1), 70-77.

Nasir, M. J., Tabassum, I., Khan, A. S., & Alam, S. (2012). Land Use Temporal Changes: A Comparison Using Field Survey and Remote Sensing.(A Case Study of Killi Kambarani & Satellite Town, Quetta City). *Putaj Sciences, 19*.

NESPAK, L. (2004). Integrated Master Plan for Lahore-2021. *Lahore, Pakistan: Lahore Development Authority*.

Nichol, J. E. (1994). A GIS-based approach to microclimate monitoring in Singapore's high-rise housing estates. *Photogrammetric Engineering and Remote Sensing, 60*(10), 1225-1232.

Patz, J. A., Campbell-Lendrum, D., Holloway, T., & Foley, J. A. (2005). Impact of regional climate change on human health. *Nature, 438*(7066), 310.

Peijun, D., Xingli, L., Wen, C., Yan, L., & Zhang, H. (2010). Monitoring urban land cover and vegetation change by multi-temporal remote sensing information. *Mining Science and Technology (China), 20*(6), 922-932.

Pickard, B. R., Van Berkel, D., Petrasova, A., & Meentemeyer, R. K. (2017). Forecasts of urbanization scenarios reveal trade-offs between landscape change and ecosystem services. *Landscape ecology, 32*(3), 617-634.

Qin, Z., Karnieli, A., & Berliner, P. (2001). A mono-window algorithm for retrieving land surface temperature from Landsat TM data and its application to the Israel-Egypt border region. *International Journal of Remote Sensing, 22*(18), 3719-3746.

Rajeshwari, A., & Mani, N. (2014). Estimation of land surface temperature of Dindigul district using Landsat 8 data. *International Journal of Research in Engineering and Technology, 3*(5), 122-126.

Raziq, A., Xu, A., Li, Y., & Zhao, Q. (2016). Monitoring of land use/land cover changes and urban sprawl in Peshawar City in Khyber Pakhtunkhwa: An application of geo-information techniques using of multi-temporal satellite data. *Journal of Remote Sensing & GIS, 5*(4), 174.

Rimal, B., Zhang, L., Keshtkar, H., Wang, N., & Lin, Y. (2017). Monitoring and modeling of spatiotemporal urban expansion and land-use/land-cover change using integrated Markov chain cellular automata model. *ISPRS International Journal of Geo-Information, 6*(9), 288.

Sanli, F. B., Balcik, F. B., & Goksel, C. (2008). Defining temporal spatial patterns of mega city Istanbul to see the impacts of increasing population. *Environmental monitoring and assessment, 146*(1-3), 267-275.

Santana, L. M. (2007). Landsat ETM+ image applications to extract information for environmental planning in a Colombian city. *International Journal of Remote Sensing, 28*(19), 4225-4242.

Schmidt, H., & Karnieli, A. (2000). Remote sensing of the seasonal variability of vegetation in a semi-arid environment. *Journal of arid environments, 45*(1), 43-59.

Sekertekin, A., Kutoglu, S. H., & Kaya, S. (2016). Evaluation of spatio-temporal variability in Land Surface Temperature: A case study of Zonguldak, Turkey. *Environmental monitoring and assessment, 188*(1), 30.

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PloS one, 6*(8).

Shah, B., & Ghauri, B. (2015). Mapping urban heat island effect in comparison with the land use, land cover of Lahore district. *Pakistan Journal of Meteorology Vol, 11*(22).

Shi, T., Yang, Y., Ma, J., Zhang, L., & Luo, S. (2013). Spatial temporal characteristics of urban heat island in typical cities of Anhui Province based on MODIS. *Journal of Applied Meteorological Science, 24*(4), 484-494.

Smith, R., & Choudhury, B. J. (1990). On the correlation of indices of vegetation and surface temperature over south-eastern Australia. *International Journal of Remote Sensing, 11*(11), 2113-2120.

Sothe, C., Almeida, C. M. d., Liesenberg, V., & Schimalski, M. B. (2017). Evaluating Sentinel-2 and Landsat-8 data to map sucessional forest stages in a subtropical forest in Southern Brazil. *Remote Sensing, 9*(8), 838.

Sun, C., Wu, Z.-f., Lv, Z.-q., Yao, N., & Wei, J.-b. (2013). Quantifying different types of urban growth and the change dynamic in Guangzhou using multi-temporal remote sensing data. *International Journal of Applied Earth Observation and Geoinformation, 21*, 409-417.

Tao, S., Yuan-jian, Y., Ai-min, Z., Yue-lin, J., Shang-pei, X., & Hong-qun, Z. (2011). Study of Thermal Environment of Hefei City based on TM and GIS. *Remote Sensing Technology and Application, 26*(2), 156-162.

Ullah, S., Ahmad, K., Sajjad, R. U., Abbasi, A. M., Nazeer, A., & Tahir, A. A. (2019). Analysis and simulation of land cover changes and their impacts on land surface temperature in a lower Himalayan region. *Journal of Environmental Management, 245*, 348-357.

Wulder, M. A., White, J. C., Loveland, T. R., Woodcock, C. E., Belward, A. S., Cohen, W. B., . . . Roy, D. P. (2016). The global Landsat archive: Status, consolidation, and direction. *Remote sensing of Environment, 185*, 271-283.

Zhang, H., Qi, Z.-f., Ye, X.-y., Cai, Y.-b., Ma, W.-c., & Chen, M.-n. (2013). Analysis of land use/land cover change, population shift, and their effects on spatiotemporal patterns of urban heat islands in metropolitan Shanghai, China. *Applied Geography, 44*, 121-133.

Zhao, M., Cheng, W., Zhou, C., Li, M., Huang, K., & Wang, N. (2018). Assessing spatiotemporal characteristics of urbanization dynamics in Southeast Asia using time series of DMSP/OLS nighttime light data. *Remote Sensing, 10*(1), 47.

Conflicts of Interest

There are no conflicts to declare.