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Assessment and Validation of Land Surface Temperature (LST) Dynamics using Geo-spatial Techniques in Dera Ghazi Khan City, Pakistan

Original Article

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The integrated practice of remote-sensing and GIS techniques provides an active tool for assessment of spatial and temporal variability of land features. Based on literature, it can be suggested that various studies over the recent years have been carried out to explore the potential of geospatial techniques and were found highly efficient to understand the interdependency of landscape changes, land surface temperature changes (LST) and creation of Urban Heat Island (UHI) in major cities around globe. The current research was conducted in Dera Ghazi Khan, Punjab- Pakistan which is located at latitude 30.04587 N and longitude 70.64029 E. The Landsat 8 TIRS and OLI images were obtained free of cost from USGS e-data portal. These images have already been rectified to WGS-1984-UTM-Zone_43N. The meteorological data file (MTL) for Dera Ghazi Khan-contains the study was acquired from Pakistan Meteorological Department. As per results vegetation cover has been decreased up to 15 % from 2001 to 2021, which was directly affecting the land surface temperature. It has been observed that LST derived from the satellite was closely matched with ground climatic data; there was a mere temperature difference of 2°C to 3°C. It is concluded that LST was negatively correlated with vegetation cover of the area under study. It is suggested to implement road map as provided in Dera Ghazi Khan Master Plan-2021 in order to have a control on unplanned landscape changes, urban evolution and rapid population growth.

Keywords: Land Surface Temperature, Geo-spatial, Urban heat Island, DG Khan,

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Author's Contribution. The first author conceptualizes the idea and devised the methodology while second author wrote first draft as well edited its language to bring it at journal's minimum requirements.

Project details. This article is part of the first author's PhD dissertation

INTRODUCTION

Land surface temperature (LST) is significant factor which plays vital role in determining different biological and climatic processes and affects functioning of ecosystem at local as well as global level. LST involves measurement of Radiative temperature of earth's surface and have widespread applications in diverse fields such as monitoring of vegetation, evapotranspiration, crop yield, urban climate change, forest fire detection etc. [1]–[8]. It is also helpful in estimation of soil moisture of a particular area of interest [9], [10]. Moreover, LST has an imperative role in determining the climatic variations over certain years. It has been reported that higher land surface temperature warms the atmosphere consequently increases the probability of enhanced evaporation from river, oceans and land [11]. Furthermore, it has been reported that increase in built-up area (concrete zone) completely alter the landscape and land use land cover (LULC) of that particular area which make it warmer as compared to the surrounding areas. Landscape changes pose significant effects on land surface temperature and relative increase in LST particularly in urban areas is a long term consequence of landscape changes [12]–[15]. Urbanization involves transformation of marshy, vegetative and agricultural lands in to built-up areas and act as catalyst in landscape changes which ultimately rises the LST of urban areas [15]–[18]. Urban growth has altered the surface energy budgets through altering natural LULC in to impervious artificial surfaces consequently disturbing the hydrological cycle and influencing other physical features of land surface which significantly affects the LST and climate at local, regional and global level [19] reported that LST in urban areas is mostly 2-4 °C higher compared to the rural areas. According to IPCC, average global LST is expected to increase up to 1.4-5.8 °C by 2100 and the concentration of CO_2 in atmosphere would get double as compared to the CO_2 levels of pre-industrial era [20], [21]. Although urban areas cover only 2% of total earth's surface but absorb about 75% of total energy and responsible for generation of almost 75% of total garbage so, it can be suggested that landscape changes associated with urban growth exhibit deteriorating effects on land, water, surface temperature, ecology and environment [22]. LST varies rapidly with the transformation in geography of land e.g., vegetation cover, soil type, surface roughness etc. All these factors inherit spatial and temporal variability in LST [23]. Therefore, it is necessary to monitor the LST patterns especially in urban areas in relation to landscape changes with focus on loss of vegetation cover.

Rapid urbanization has resulted in loss of vegetation cover which led towards increased LST and interrupts ecological functions of urban ecosystem including alterations in local climatic conditions [24], [25]. All these LULC changes in DG Khan are expected to induce land surface temperature changes. Although, few researchers have focused on assessment of landscape changes in DG Khan but no information regarding the assessment of land surface temperature changes is associated with landscape (LULC) changes particularly in DG Khan are currently available. Based on the more economic opportunities, urban growth is increasing day by day in DG khan that has led to an influx of population from surrounding regions, it is matter of great concern to estimate the LST changes and its relationship with vegetation loss which will be helpful in understanding the impacts of LST in climatic changes and devising strategies for urban planning on sustainable basis. In this context, present study was conducted for evaluation of LST changes with special focus on vegetation abundance in DG Khan over last 40 years. The main objectives of the present study is to estimate the LST from Landsat 7 and 8 during last 20 years and to validate/correlate the satellite based results with the metrological data obtained from Pakistan Meteorological Department from the years 2001 to 2021. Furthermore, the study analyzes the vegetation cover changes through NDVI and LST during 2001 to 2021 and to establish the correlations between the empirical variables.

Material and Methods

Dera Ghazi Khan (DG Khan) is an important city of the Punjab province and lying at 30°1'59" N, 70°38'24" E. DG Khan consisting of four different tehsils including DG Khan, Taunsa Sharif, Koh- e-Sulaiman and Kot Chutta. According to Census of Pakistan conducted in 2017, the total population of DG Khan is 2,872,201 persons which have significantly increased from the time of Independence in 1947. It has been studied that build-up areas in Dera Ghazi Khan were increased from 180.6 Km^2 to 275.64 km^2 during the years 1989-2016. Moreover, 5.29% of vegetation cover in DG Khan was converted in built-up area and bare soil areas also exhibited increased up to 7.78% during last 28 years. It was further noticed that water bodies also exhibited a decreasing trend up to 0.04%

Methodology

Empirical meteorological data as well as Landsat 8 TIRS and OLI imageries for Dera Ghazi Khan were obtained from the free-web of US Geological Survey's Earth Explorer website and Pakistan Meteorological Department. Images of satellite were rectified to WGS 1984 Universal Transverse Mercator and then multiple steps were adopted to calculate surface temperature from thermal band of satellite image. 1st was to convert DN values (Digital Number) to TOA (Top of Atmospheric Reflectance). TIRS data can be converted to the temperature brightness of image with the help of MTL file of Landsat 8. Table mentioned below is showing the derived values from the acquired digital data. In this study Band10 is used to calculate LST for Landsat 8 and B6 for Landsat 7.

Table 1. Characteristics of Landsat digital data

Landsat 7		Landsat 8	
Path/Row	151/039	Path/Row	151/039
Date	20010322	Date	20210319
Resolution	30 Meter	Resolution	30 Meter
Cloud Cover	0%	Cloud Cover	0%

With the help of algorithm named SW, Land Surface Temperature (LST) of any region can be extracted from satellite imagery. In this study, for the estimation of LST, OLI and TIR bands of Landsat were used for 2001 to 2021. Following method was adopted to calculate the LST. Therefore, we can calculate the Brightness Temperature (TB) of an area only when the microwave radiations arise from the atmosphere of earth. In present work the calibration process was carried out by converting the thermal DN values of thermal bands of TIR to TB. The Spectral Radiance was important to extract the brightness temperature of study area. By the help of given formula TB value can be calculated,

Brightness temperature BT = K2 / Ln ((K1 / L ʎ) +1) - 272.15

Where,
K1 and K2- thermal conversion constant
Lλ – Top of Atmospheric spectral radiance.

Table 2. Parameters used in calculations

Landsat 7		Landsat 8	
K1 Constant Band 6	666.09	K1 Constant Band 10	774.8853
K2 Constant Band 6	1282.71	K2 Constant Band 10	1321.0789
Radiance Add Band 6	-0.06709	Radiance Add Band 10	0.10000
Radiance Multi Band 6	0.67087	Radiance Multi Band 10	0.0003342
ʎ wave length Band 6	11.335	ʎ wave length Band 10	10.895

Top of Atmospheric Spectral Radiance (TOA)

In this research, following rescaling factors were formulated through given formula to find the value of TOA.

- Multiplicative rescaling factor = (0.000342)
- Additive rescaling factor = (0.1).

TOA Radiance LÀ = ML * Qcal + Al

Where,
Lλ - Top of Atmospheric Radiance in watts/ (m2*srad*µm)

ML - Band specific multiplicative rescaling factor Radiance Multi Band (10, 6)

Qcal – Band 10 for Landsat 8, Band 6 Image for Landsat 7

AL - Band specific additive rescaling factor Radiance Add Band (10, 6)

Land Surface Emissivity/LSE

LSE/Land Surface Emissivity can be calculated by the Normalized difference vegetation index NDVI which is necessary to estimate the surface temperature of an area.

Portion of Vegetation (PV)

$$\text{PV (Proportion of Vegetation)} = (NDVI - NDVI_{min} / NDVI_{max} - NDVI_{min})^2$$

LSE and soil values are required to apply this method to find LST. LSE value of 0.99 was chosen for vegetation and to choose the LSE value for soil is difficult because high variation was found in LSE value in soil with respect to vegetation. "A possible solution is to use the mean value for the emissivities of soils included in the ASTER spectral library (http://asterweb.jpl.nasa.gov) and filtered according to band TM6 filter function". In this way LSE value for soil was was 0.973 obtained by analyses (with a standard deviation of 0.004). Using these datasets (TM6 soil and vegetation emissivities of 0.97 and 0.99, respectively), the final expression for LSE is given by.

$$E = 0.004 * PV + 0.986$$

Land Surface Temperature/LST

$$\text{Land Surface Temperature LST} = BT / (1 + (\lambda * BT / p) * \ln (e))$$

Where

p = h * c / s = 1.438x10 ^ -2 m K = 1438 um K

h is Planck's constant = 6.626*10-34 J s

c is velocity of light = 2.998.10 ^ 8 m / s

S is Boltzmann constant = 1.38*10-23 J / K.

ʎ wave length for Landsat 8 = 10.895

ʎ wave length for Landsat 7 = 11.335

e = Emissivity

BT = Brightness temperature

Table 3. Mean Monthly Maximum Temperature (°C) of Dera Ghazi Khan City 2003-2020

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2003	19.0	22.7	27.9	36.8	40.6	43.3	38.1	37.0	35.2	34.1	28.1	23.0
2004	19.9	24.7	33.2	39.3	41.3	40.6	38.9	36.9	35.8	31.5	28.3	23.7
2005	18.4	19.2	26.8	35.2	38.1	42.5	38.2	37.5	36.2	34.5	28.1	22.7
2006	20.1	26.6	28.1	37.5	43.7	41.1	40.1	37.3	36.0	33.7	26.5	20.9
2007	20.4	22.0	26.9	40.5	42.5	41.1	39.5	38.9	36.8	34.8	29.0	22.9
2008	19.1	22.6	33.3	35.4	41.5	40.8	38.7	35.9	35.7	35.1	29.5	22.1
2009	21.0	24.1	28.6	35.2	41.8	40.9	39.6	37.6	37.0	34.5	27.1	23.7
2010	19.4	24.3	31.9	39.6	41.8	41.1	38.5	34.9	36.2	35.0	29.5	23.0
2011	17.8	22.5	29.5	34.6	42.5	42.6	39.7	37.7	35.2	34.0	29.5	23.5
2012	19.7	21.6	28.6	34.7	40.5	42.3	40.4	37.9	34.8	32.9	27.9	23.0
2013	20.6	22.5	29.3	35.4	42.4	42.4	40.5	37.2	37.4	35.0	27.7	22.0
2014	21.2	22.4	26.9	34.7	39.2	43.7	40.3	39.4	38.1	33.5	27.9	20.1
2015	17.6	23.6	26.5	36.3	41.3	40.1	36.3	35.9	36.3	33.1	27.6	22.8
2016	19.2	25.2	28.0	35.4	42.4	41.8	39.1	37.7	36.7	35.7	28.9	25.2
2017	19.6	25.0	28.9	38.8	41.4	40.0	38.8	37.7	36.5	36.0	25.7	23.1
2018	21.1	24.6	31.7	37.7	40.8	41.2	39.0	37.2	36.5	33.4	27.6	22.2
2019	19.3	21.2	25.9	35.2	39.3	41.9	39.3	37.1	38.1	33.0	26.4	17.7
2020	17.8	24.4	24.8	34.0	39.6	40.8	39.2	38.0	37.0	34.5	26.4	21.3

Source: Pakistan Meteorological Department

Table 4. Mean Monthly Minimum Temperature (°C) of Dera Ghazi Khan City 2003-2020

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2003	5.9	9.7	14.7	21.1	25.3	29.1	29.0	27.7	25.2	18.2	11.3	8.4
2004	8.1	10.8	16.5	22.5	25.7	28.7	29.0	27.3	24.6	18.5	13.9	9.3
2005	7.0	9.3	16.3	19.1	24.2	28.5	28.8	28.6	25.6	19.7	13.5	6.0
2006	6.3	14.2	15.9	21.8	28.9	27.4	30.2	28.2	25.1	21.8	15.7	9.4
2007	6.9	11.9	15.3	22.6	27.3	28.9	29.4	29.2	26.6	18.5	15.6	8.4
2008	6.0	7.7	17.4	20.7	25.4	28.6	27.2	26.8	23.3	21.1	12.8	10.0
2009	8.9	11.8	15.5	20.4	26.2	26.8	28.1	27.2	24.3	19.2	11.5	8.1

2010	6.3	9.4	16.2	21.6	25.0	27.5	27.7	25.3	24.3	21.4	12.0	6.5
2011	5.4	10.0	15.1	18.7	27.4	28.9	27.9	27.7	24.5	19.6	15.9	7.0
2012	6.3	7.3	13.4	19.4	25.6	26.8	28.6	27.4	25.4	19.3	14.7	9.5
2013	6.6	10.8	15.7	20.5	26.4	29.2	29.6	27.3	26.0	22.7	13.7	9.2
2014	6.5	9.2	14.3	20.0	25.0	29.9	29.1	27.5	25.8	21.3	13.6	7.8
2015	6.8	12.1	14.3	21.2	26.6	27.8	26.9	27.1	25.2	20.6	14.1	7.6
2016	8.2	9.8	14.2	19.1	25.9	28.9	29.1	27.3	25.3	18.2	11.2	8.0
2017	5.7	8.1	13.9	21.2	26.3	27.9	28.1	27.7	23.8	17.6	11.7	5.0
2018	4.1	8.0	14.8	21.0	25.3	28.4	27.5	27.8	25.2	18.1	11.8	6.2
2019	5.2	7.7	12.9	20.4	23.9	27.4	29.1	27.8	27.1	19.0	12.7	5.9
2020	5.2	8.4	13.7	19.3	24.8	28.5	29.1	29.3	25.0	16.6	10.2	5.8

Source: Pakistan Meteorological Department

Climatic data was acquired from the Pakistan Metrological Department from 2001 to 2021 for the validation of Image based land surface temperature results. It is more authentic approach to validate the satellite-based data. By this approach better and reliable results can be extracted from satellite data.

Result and Discussion

Following results have been achieved by the applied methodology. Water bodies always have negative value of NDVI for any area, in this study NDVI values ranged between -0.98 to 0.97. Urban area of D G Khan had low value of NDVI and peri urban area had high value because of vegetation cover in peri urban area. NDVI value for the agricultural area was above 0.2 and below this value to 0 for urban and bare soil. Moreover, NDVI map 2021 revealed that the NDVI value ranged between -0.013 to 0.5. Similarly, the peri-urban areas and villages of D.G Khan City had highest NDVI value and water body had negative NDVI value (Figure 1). The NDVI value of area under vegetation was more than 0.18 and for built-up and barren land it was 0 to 0.18. As per results vegetation cover has been decreased 15% from 2001 to 2021, which is directly affecting the land surface temperature. Figure 2 is showing the NDVI changes from 2001 to 2021.

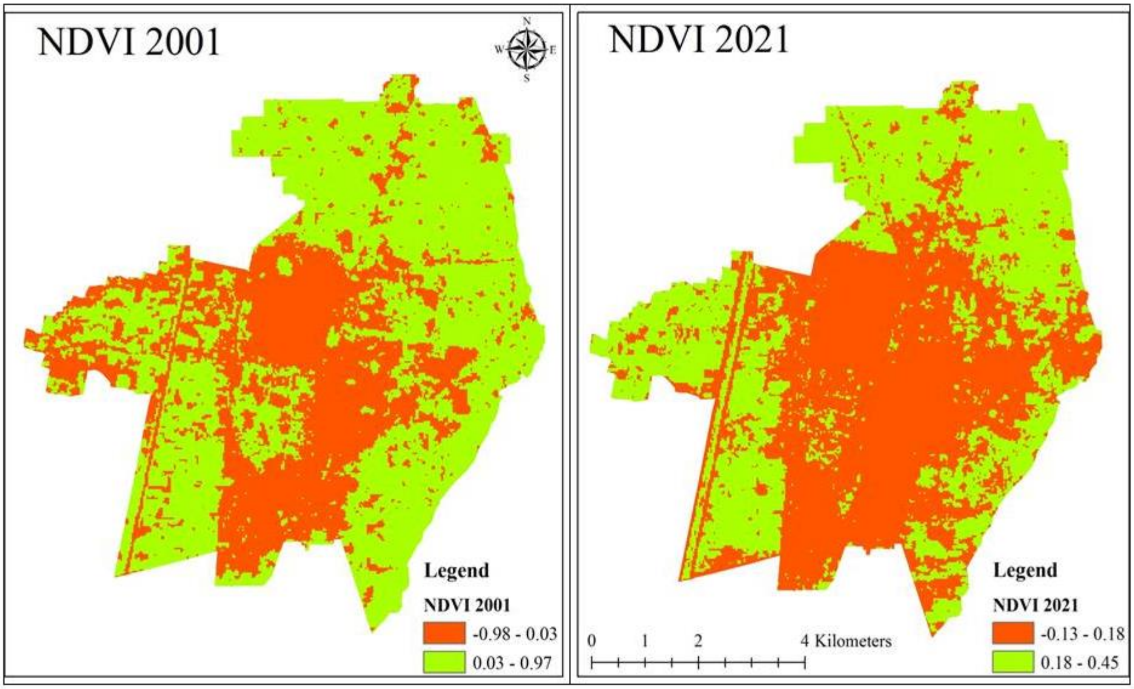
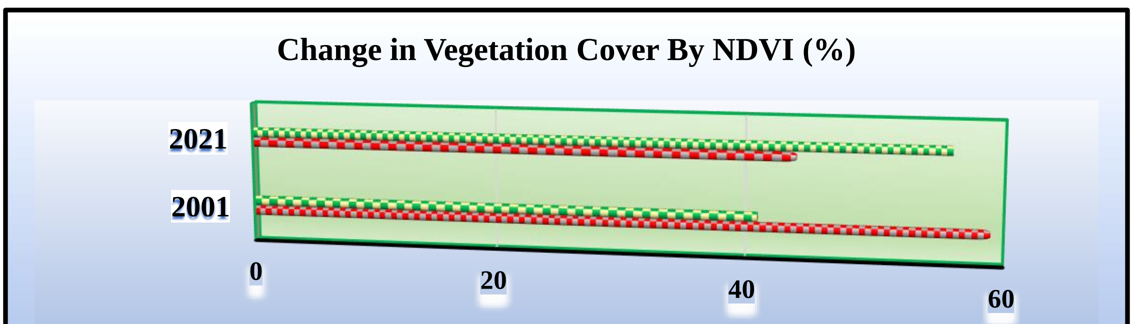


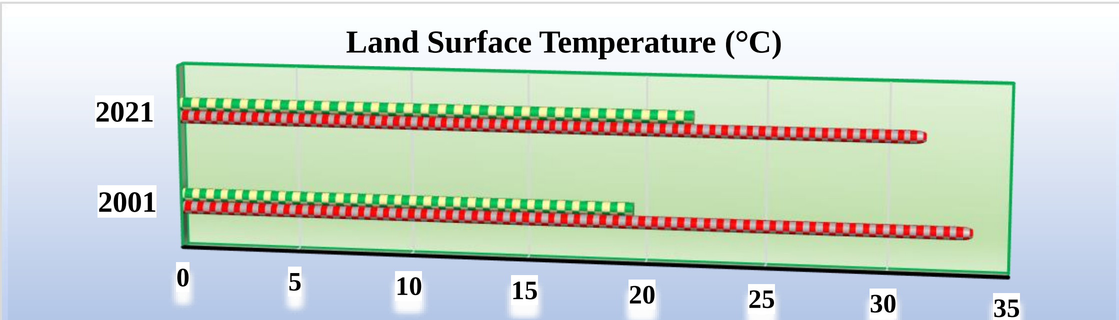
Figure 1. Normalized Difference Vegetation Index (2001 to 2021)



	2001	2021
Buildup	41	56
Vegetation	59	44

Figure 2. Normalized Difference Vegetation Index (2001 to 2021)

Figure 3 has been made using Land Surface Emissivity, BT (brightness temperature) and E (emissivity) difference between LSE of band 10 of TIR and Band 6 of Landsat 7. LST production depicted that it varied from less than 19°C to more than 33.5°C in 2001 and from 22°C to 31.5°C in 2021. The highest LST of more than 34°C in 2001 was found in the central part of the study area. The 19°C to 25°C LST was traced in the area where agriculture activity is being practiced. Likewise, the regions of temperate vegetation had 24°C to 25°C. Moreover, LST had been increased by 3°C in whole study area as it can be seen in the Figure 4.



	2001	2021
Low	19.5	22
High	33.5	31.5

Figure 3. Land Surface Temperature (2001 to 2021)

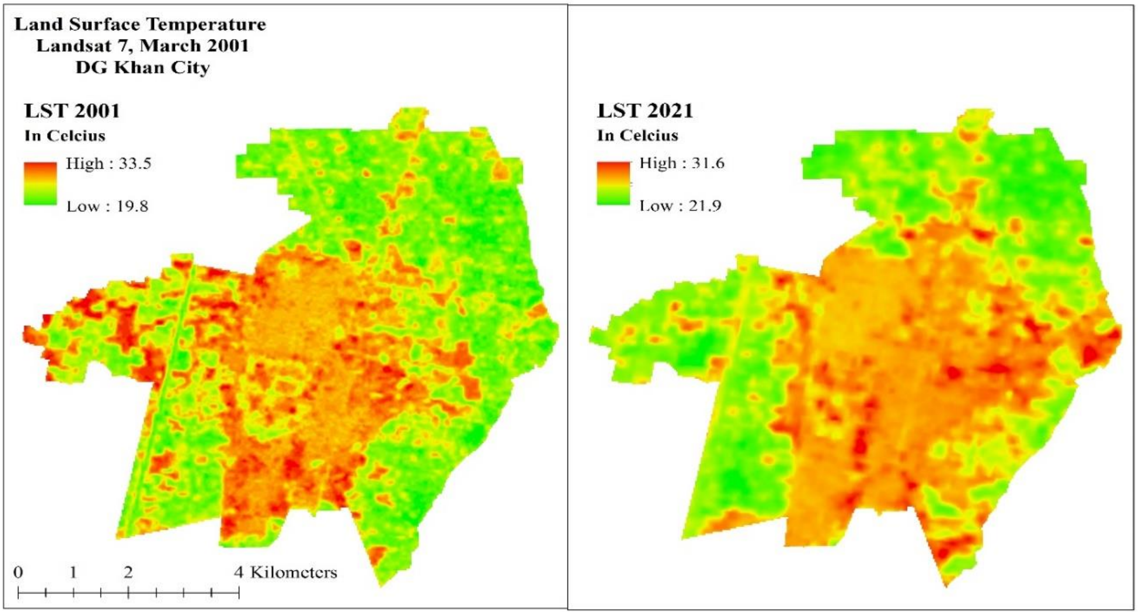


Figure 4. Land Surface Temperature (2001 to 2021)

It is most important to validate the satellite based LST results with the climatic data of Pakistan. Climatic data had been acquired from the Pakistan Meteorological Department and after with the help of co-relation method, Figure 5 was created to check the authenticity of satellite-based results of LST 2001 to 2021. In this figure it can be seen that LST derived from the satellite is closely matched with climatic data. There was a slight difference of 2°C to 3°C.

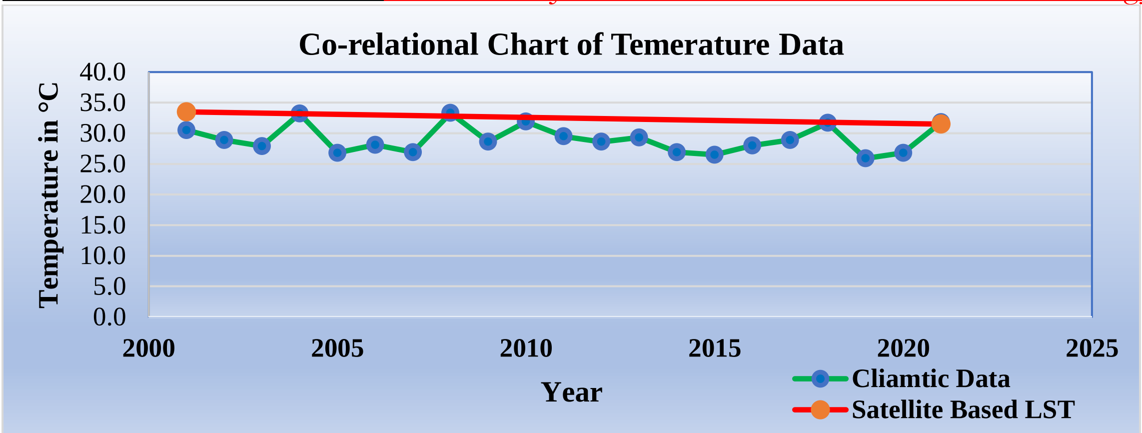


Figure 5. Co-relational chart of Temperature Data.

Conclusion

This research proves the importance of remote sensing data to examine the surface temperature variations in study area (DG Khan City). The Landsat data have been used to estimate the LST variation efficient and cost effective. Results from the remote sensing of LST was validated by the climatic data which shows slight difference. The research clearly revealed that as the study area had more vegetative cover in 2001 and comparatively less in 2021 hence about 15 % change can be observed in vegetation cover. Moreover, in study area uncultivable land and urban areas experienced high LST in both years 2001 and 2021. To calculate the land surface temperature of the study area, Single Window (SW) method was applied. Different surface patterns revealed the variations in temperature of surfaces because heat energy is radiated by the surface of the earth with different factors like type of land uses and vegetation cover. Surface heat can be controlled by the surface variations which affects the climate change of any region. Though some climatic phenomena play a minor role in temperature variation and land conversion into barren land, however landscape changes play major role to increase the surface temperature. The process of urbanization is the major factor to increase automobile carbon emission, firewood combustion from kitchen, periodical removal of firewood which increases the land surface temperature. The remote sensing data for instance Landsat data is an efficient way to estimate the land surface temperature (LST).

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