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Civil Engineering Journal

Vol. 5, No. 8, August, 2019

Spatiotemporal Dynamics of Land Surface Temperature and Its Impact on the Vegetation

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Received 03 April 2019; Accepted 08 July 2019

Abstract

Due to global warming under climate change scenarios, Indus delta region of Pakistan is under serious threat since the last few decades. The present study was thus conducted to determine the spatiotemporal variations in the LST and its impact on the vegetation of the Indus delta, using satellite data for the past 27 years (1990-2017). The analysis revealed that on average, there was an increase of 1.74 °C in LST during the last 27 years. The temporal variation in the Normalized Difference Vegetation Index (NDVI), an indicator of vegetation, showed the highest NDVI of 0.725 in the year 2005 followed by the year 2010 with NDVI of 0.712. While the lowest NDVI of 0.545 was observed during the year 2017. The LST was integrated with NDVI which showed a fair but negative statistical correlation with a coefficient of determination $R^2 = 0.65$. A correlation analysis between NDVI and the yield of the wheat crop of the Delta showed a positive relationship with $R^2 = 0.89$. Several factors may contribute to an increase in LST, such as an increase in residential areas, change in the cropping pattern and overall global climate change. Such studies are important for determining the climatic influences on ecological parameters.

Keywords: LST; NDVI; Crop Yield; Spatiotemporal Analysis; Coastal Areas.

1. Introduction

Due to the global climate change issues, the land surface temperature (LST) has increased, which has affected land use, land cover, vegetated areas, water resources, etc. Chan and Yao [1], and Choudhury et al. [2] reported that such changes are responsible for various environmental problems. LST refers to the temperature of the earth surface including the temperature of bare soil, the canopy of vegetation, etc. [3-4]. For hydrologists, agronomists, amenagists, meteorologists, the information of different terms, which interfere with the energy balance of the surface is very important. However, the LST is one of the key parameters which plays a vital role in the processes of interaction between hydrosphere, biosphere, and atmosphere. The LST is also used in many fields such as climate change, evapotranspiration, hydrological cycle, vegetation, etc. [5]. It is the main parameter which is affected by the properties of land surface such as land use, land cover, vegetation, and type of vegetation as well as the permeability of the surface of the soil [3]. Numerous studies have been conducted to observe the changes in the LST in the result of variations in land use land cover, vegetation. Most of the studies have reported an inverse relation between LST and vegetative cover, which refers that crop cover decreases the LST.

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http://dx.doi.org/10.28991/cej-2019-03091368

At present, many researchers use the GIS and Remote Sensing techniques to explore the relation between LST, NDVI and land use land cover [6]. Dagliyar et al. [7] described that thermal bands of satellite imagery can be used to determine the LST. They determined the LST in the Erzurum, Turkey, using the OLI/TIRS data acquired on July 25, 2014. Various types of vegetation indices are available which can be used to observe changes in the vegetative area. But NDVI is one of the efficient, simplest and widely used index [8]. Using this index, the changes occurred in the vegetation for any specific area can be quantified. Two types of approaches such as the conventional approach and the approach of Remote Sensing (RS) can be used to quantify the LST. In the conventional approach, the LST is determined from weather stations, while by RS make it possible to estimate it through the model of the energy balance of surface [9]. Rajendran and Mani [10] stated that LST is a significant variable of microclimate and transfer of radiation within the atmosphere. GIS and RS tools integrated with ground truthing field data are recommended to assess the spatiotemporal variations in the LST. In a study conducted on LST in Thiruvananthapuram, city of India using the thermal bands of Landsat 8, OLI/TIRS imagery revealed that LST is a function of water content and vegetative cover of soil. Yue et al. [11] used satellite data to determine the relationships between the LST and NDVI in the Shanghai city of China and reported GIS and RS tools as effective in determining the climatic influences on the ecosystem. Fast changes in patterns of land use and land cover have brought significant changes in LST.

Similar is the case of the Indus delta, Sindh, Pakistan, where, increasing LST has significantly affected the vegetative cover of the region [12]. Rehman et al. [13] also reported that the LST in the Keti Bandar area of Sindh province of Pakistan is increasing, and adversely affecting the vegetation of the area. It has been reported that due to global warming and climatic change, coastal areas of Sindh, Pakistan are under serious threat since the past few years. Keeping in view and gravity of the problem, the present study was carried out to determine the spatial and temporal variation in LST of the Indus Delta, Sindh, Pakistan using multispectral satellite data for the period of the last 27 years (1990-2017). The extracted LST data were integrated with NDVI to see the relationship between these parameters. Also, NDVI of the delta was correlated with wheat crop yield using the Pearson correlation model. The findings of the study will be useful for environmentalists, policymakers, farmers of the area for taking remedial measures to mitigate climate change impacts in the region

2. Study Area

The Indus River makes its delta when it empties into the Arabian Sea. Most of its area stretches in two district administrative boundaries of Sindh Province, Pakistan, i.e., Thatta, and Sujawal (Figure 1). The area hardly receives about 220 mm of rainfall annually [14-18], mostly falls during monsoon periods. According to the 2017 Census, about 1.76 million people are living in these two districts. In the past, the delta was counted as one the prosperous areas of Indus civilization, but now it is counted as poorest areas of Pakistan. Due to climate change scenarios, the delta is shrinking and degrading at an alarming rate [19-20]. Reduction of freshwater flows and entry of nutrient-rich sediments into the Indus River and resulting seawater intrusion into its delta have adversely affected the vegetative cover, flora, fauna, water resources, soil fertility, as well as socioeconomic conditions of the community.

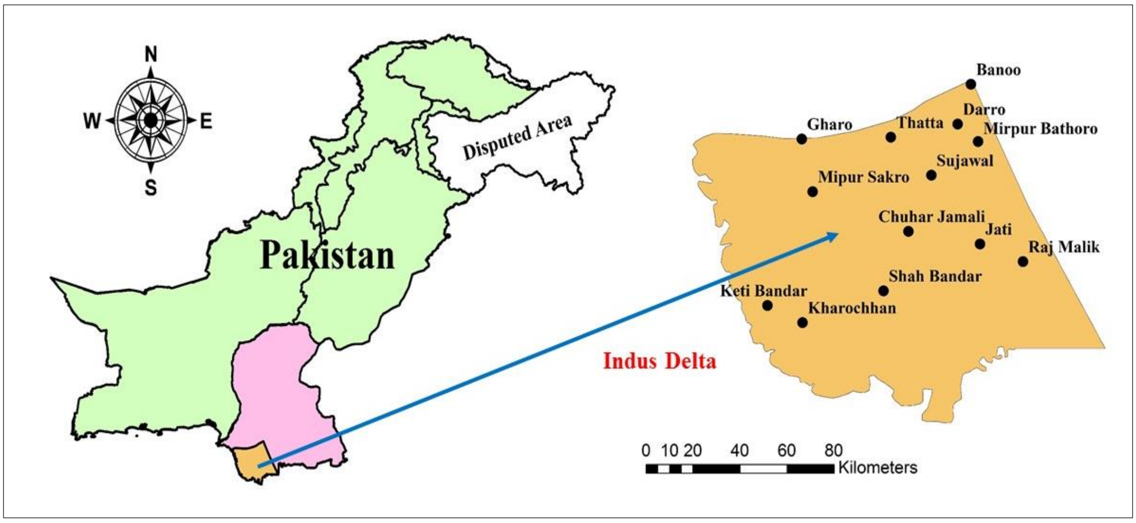

Figure 1. Location Map of the Study Area

3. Materials and Methods

3.1. Quantification of Land Surface Temperature (LST)

To determine the relation between LST and vegetation of the Indus delta, thermal bands of satellite imageries for the last 27 years (1990-2017) as described in Table 1 were used. The satellite data of the TM (thematic mapper), ETM^+

(enhanced thematic mapper plus), and OLI/TIRS (operational land imagery/thermal infrared sensor) sensors for the years, 1990, 1995, 2000, 2005, 2010, 2015, and 2017 were downloaded from United States Geological Survey-USGS Earth Explorer website. The digital numbers (DNs) of the thermal bands (band 6 for Landsat 5 and 7 and band 10 for Landsat 8) of the AOI (area of interest) were first converted to top of atmospheric spectral radiance (ToA_r) and then to LST using following two steps.

3.2. TOA Radiance Conversion

Some thermal, electromagnetic energy is reflected by every object when it is placed in temperature >0, which is known as absolute zero [2]. According to this principle, the thermal sensors receive signals, which can be converted into at-sensor radiance. In the present study, the spectral radiance (L_λ) was calculated using Equation 1.

$$L_\lambda = M_L\, Q_{cal} + A_L \qquad (1)$$

Where, L_λ - Top of Atmosphere Spectral Radiance (TOA_r);

M_L - Band-specific multiplicative rescaling factor obtained from the metadata file;

A_L - Band-specific additive rescaling factor obtained from the metadata file;

Q_{cal} - Quantized and calibrated standard product pixel values (DNs).

3.1.2. Conversion of Spectral Radiance (L_λ) into Brightness Temperatures (LST)

Then thermal band data were converted from TOA_r to land surface temperature (LST). As the LST data were obtained in the Kelvin scale, which is not common now, hence, it was converted to centigrade scale by subtracting 273 from every pixel, using ArcGIS 10.5 software, as explained in Equation 2.

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} - 273 \qquad (2)$$

Where; T - At-satellite brightness temperature (K);

L_λ - TOA spectral radiance;

K_1, *and* K_2- Band-specific thermal conversion constants from the metadata;

The satellite images used in the study along with values of band-specific multiplicative rescaling factor (M_L), band-specific additive rescaling factor (A_L), and thermal conversion constants (K_1 and K_2) are summarized in Table 1.

Table 1. Landsat Satellite imagery (1990-2017) used for the LST analysis

Acquisition date, Year	Row	Path	Band Number	A_L	M_L	K_1	K_2
Feb. 10, 1990	43	151[1]	B-6	1.18243	0.055375	607.76	1260.56
Feb. 17, 1990		152[1]	B-6	1.18243	0.055375	607.76	1260.56
Feb. 24, 1995	43	151[1]	B-6	1.18243	0.055375	607.76	1260.56
Feb. 15, 1995		152[1]	B-6	1.18243	0.055375	607.76	1260.56
Feb. 14, 2000	43	151[2]	B-6	-0.06709	0.067	666.09	1282.71
Feb. 05, 2000		152[2]	B-6	-0.06709	0.067	666.09	1282.71
Feb. 27, 2005	43	151[2]	B-6	-0.06709	0.067	666.09	1282.71
Feb. 18, 2005		152[2]	B-6	-0.06709	0.067	666.09	1282.71
Feb. 09, 2010	43	151[2]	B-6	-0.06709	0.067	666.09	1282.71
Feb. 16, 2010		152[2]	B-6	-0.06709	0.067	666.09	1282.71
Feb. 15, 2015	43	151[3]	B-10	0.10000	0.000334	774.89	1321.08
Feb. 06, 2015		152[3]	B-10	0.10000	0.000334	774.89	1321.08
Feb. 20, 2017	43	151[3]	B-10	0.10000	0.000334	774.89	1321.08
Feb. 11, 2017		152[3]	B-10	0.10000	0.000334	774.89	1321.08

[1] Landsat 5; [2] Landsat 7; [3] Landsat 8.

3.2. Method for Calculation of Normalized Difference Vegetation Index (NDVI)

The relation between LST and vegetation of the Indus delta in terms of a spectral index NDVI (normalized difference vegetation index) was calculated using satellite data and ArcGIS 10.5 software. This index was calculated from the NIR (near-infrared) and red bands as explained in Equation 3 [2, 21]. This index has been widely used by various researchers around the globe as an indicator of greenness. For Landsat 5 and 7, bands 3 and 4, however, for Landsat 8/OLI, bands 4 and 5 were used to calculate NDVI. The index values vary from -1 to +1. A value of -1 characterizes a non-vegetated area, while +1 represents the vegetative area.

$$\text{NDVI} = \frac{\text{Near Infrared} - \text{Red}}{\text{Near Infrared} + \text{Red}} \tag{3}$$

3.3. Effect of LST on the Vegetation of the Delta

To see the effect of LST on the plants/vegetation of the Indus delta, the LST was integrated with NDVI. Regression analysis was performed between these two parameters to show how the changing LST create an effect on the vegetative cover of the Indus delta, as explained by Choudhury et al. [2].

3.4. The Relation between NDVI and Crop Yield of the Delta

To see the relation between NDVI and wheat crop yield of the Indus delta (collected from Sindh Agricultural Extension Department), a regression analysis was performed between these two parameters. Figure 2 shows the flowchart of the methodology adopted in this study for determination of LST and its impact on the vegetation.

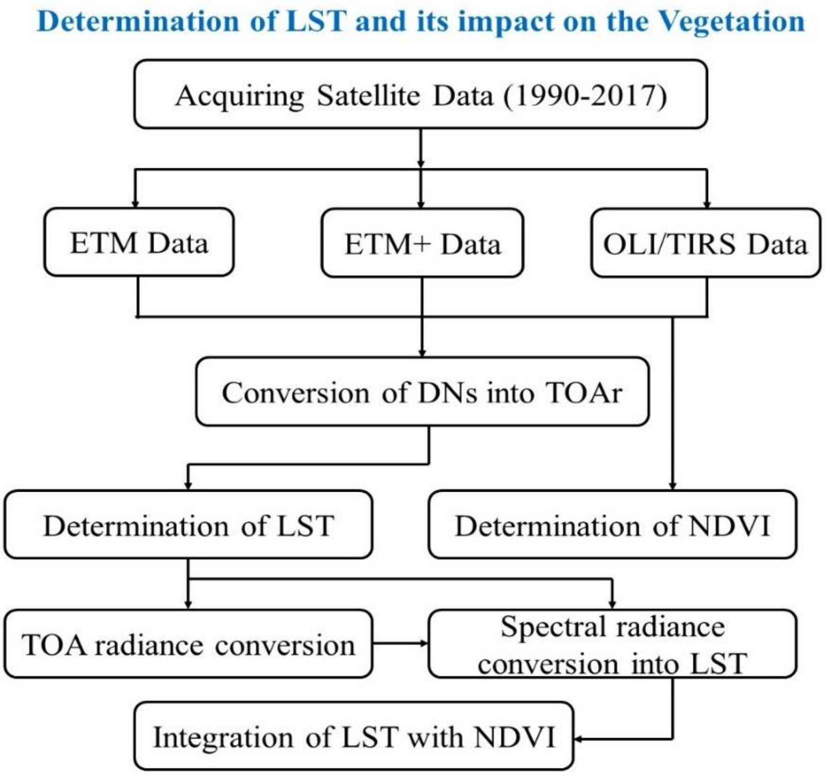

Figure 2. Flowchart of the methodology

4. Results and Discussions

4.1. Land Surface Temperature

The spatial and temporal variation in LST of the Indus delta during 1990-2017 is portrayed in Figure 3. It shows that areas with water and vegetation have lower LST compared to towns and barren land. Temporal variation in the Indus delta under different temperature ranges is quantified in Table 2. The temporal change in LST is more prominent in the south-east of the delta (near to Sir Creek). It may be because of change in hydrological features of the area due to the construction of Tidal Link Canal in the late 1990s. The area under a temperature above 30^{o} C increased temporally from 511 ha in 1990 to 115,304 ha in 2017 as shown in Figure 4, which confirms the temporal increase in LST in the delta as also reported by Rehman et al. [13]. Thus, the area of the delta having LST above 30 ^{o}C has increased more than 225 times in the last 27 years. Several factors may contribute to a temporal increase in LST, such as an increase in residential areas and overall global climate change.

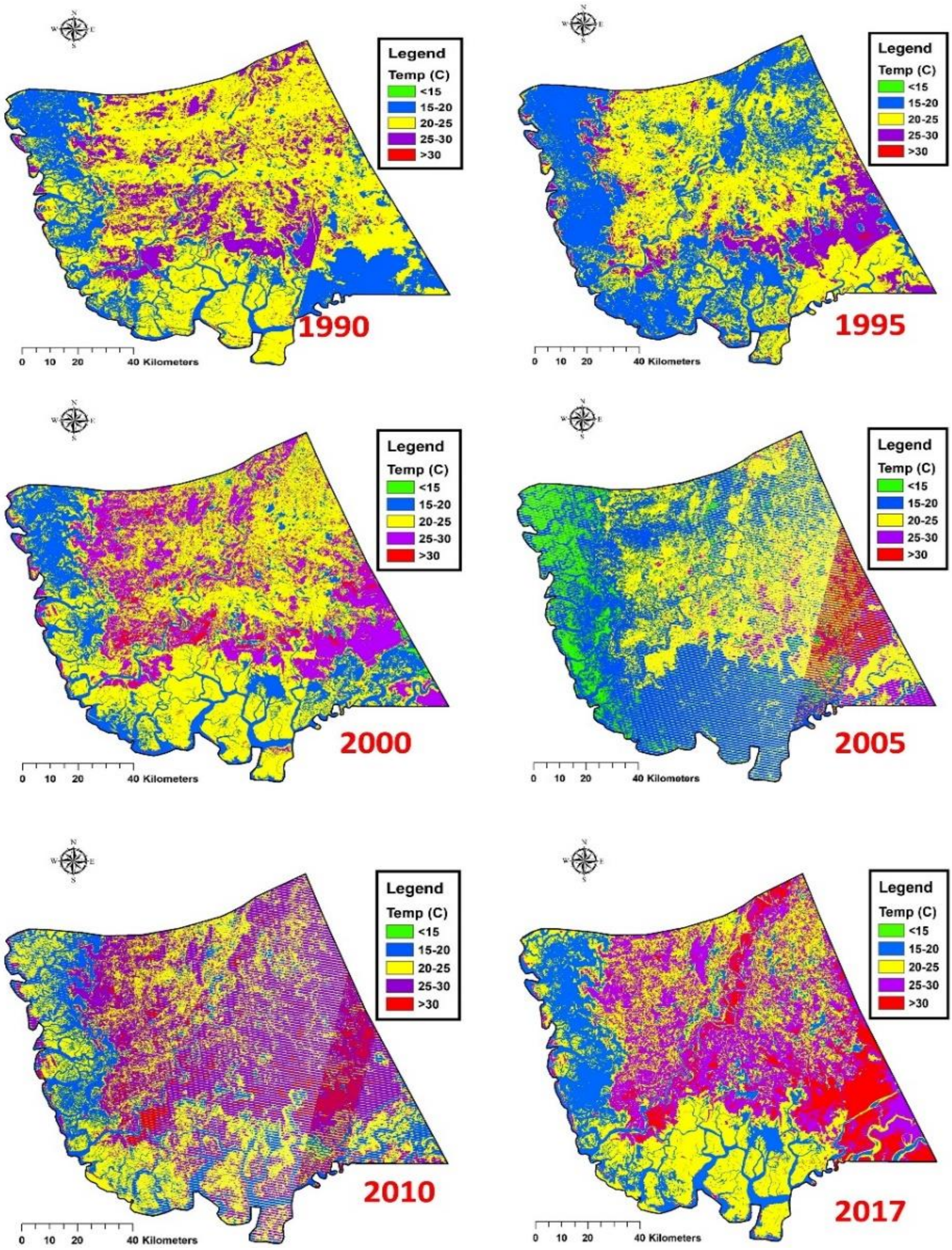

Figure 3. Spatial and temporal variation in the LST (1990-2017)

Table 2. The variation in the area under different land surface temperature ranges

Year	Land Surface Temperature												
	>15 ºC		15-20 ºC		20-25 ºC		25-30 ºC		>30 ºC		Total	%	Average LST
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%			
1990	570	0.04	319627.2	24.46	771611	59.05	214390.4	16.41	511	0.04	1306710	100	22.10
1995	0	0.00	533633.6	40.84	621326	47.55	150589	11.52	1168	0.09	1306716.6	100	21.08
2000	3228	0.25	284694	21.79	695205	53.20	305309	23.36	18281	1.40	1306717	100	22.70
2005	123948	9.49	601129	46.00	455857	34.89	85484	6.54	31873	2.44	1298291	100	20.04
2010	3.96	0.00	254956	19.51	459033	35.13	523691	40.08	58343	4.46	1296027	100	23.99
2017	52	0.00	272896	20.88	525128	40.19	393385	30.11	115304	8.82	1306765	100	23.84

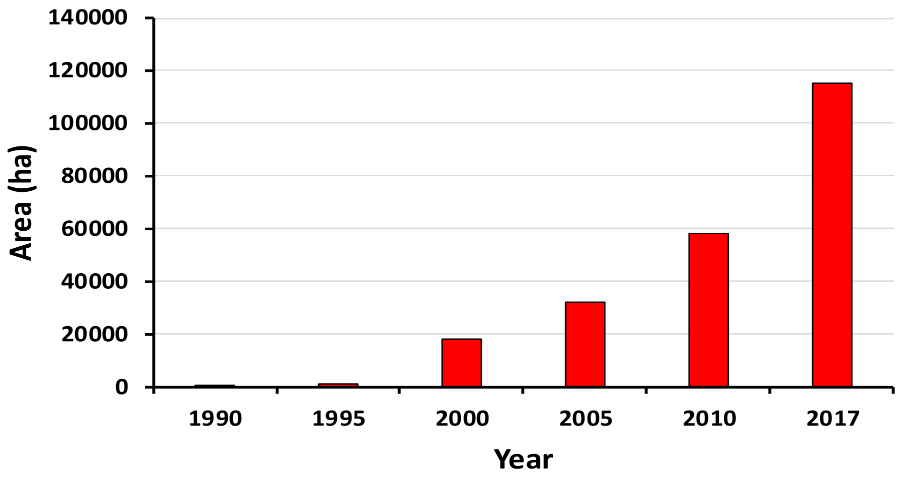

Figure 4. Dynamics the study area having LST >30 ºC during a period of last 27 years

On average, there was an increase of 1.74 ºC in LST in the Indus delta during the period of the last 27 years as described in Table 2.

4.2. Temporal Change in the NDVI of the Indus Delta

The temporal variation in the NDVI of the Indus delta is presented in Figure 5. It shows that the highest NDVI of 0.725 was in the year 2005 followed by the year 2010 with NDVI of 0.712. While the lowest NDVI of 0.545 is for the year 2017. These NDVI values are reflected in Figure 5, which shows the temporal change in the area under vegetation of the delta. The green color in Figure depicts the positive NDVI values with lush green vegetation while brown color represents water and barren land with negative values of the NDVI.

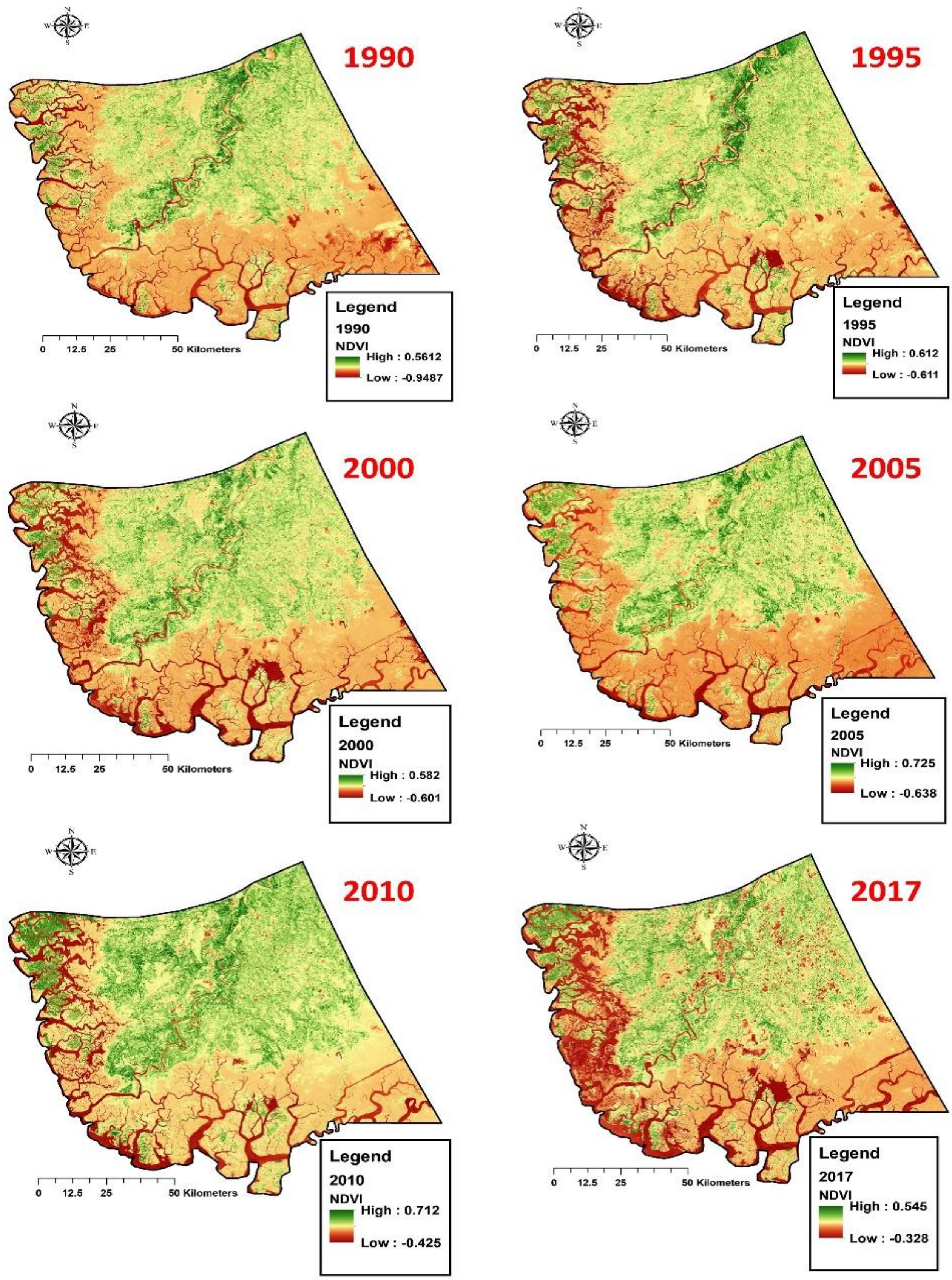

Figure 5. Dynamics of NDVI in the Indus delta for the period of last 27 Years

4.3. Effect of LST on the Vegetation of the Delta

The impact of LST on the vegetation of the delta was evaluated by correlating LST and NDVI as shown in Figure 6. It shows that there was a fair but negative statistical correlation between NDVI and the LST with a coefficient of determination of $R^2 = 0.65$ and regression Equation 4. Thus, with an increase in LST, NDVI of the delta decreased as also reported by Yue et al. [11]; Huang and Ye [22]; and Dong et al. [6].

$$LST = -19.034 \times NDVI + 34.14 \tag{4}$$

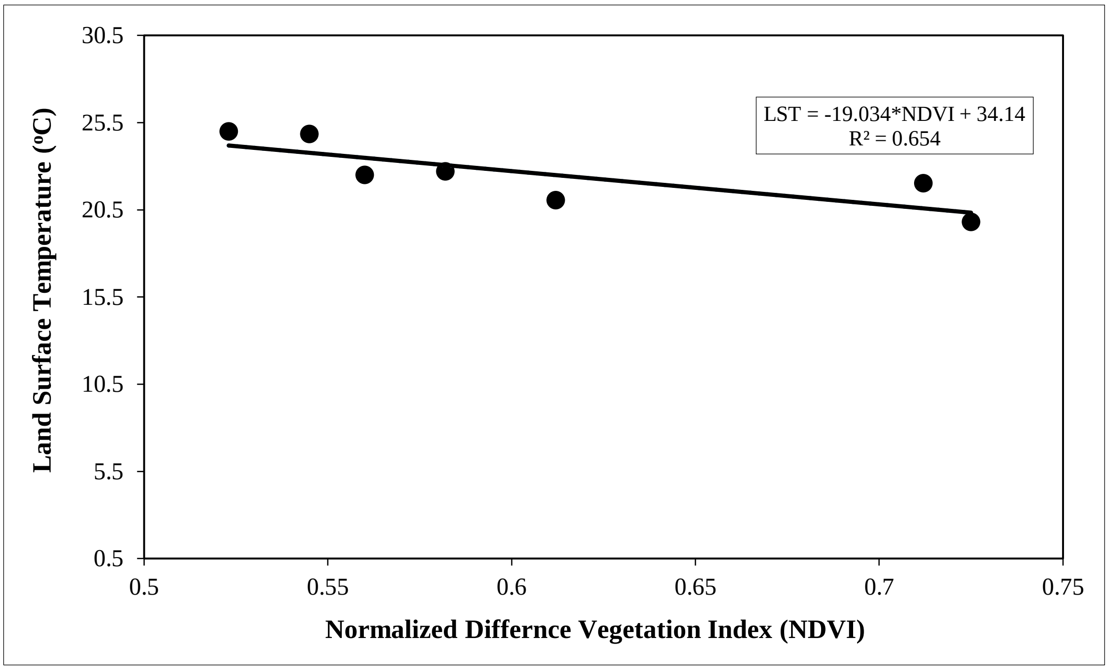

Figure 6. Correlation between NDVI and LST of the Indus Delta

Yue et al. [11] also reported an opposite relation between the LST and NDVI in the Shanghai city of China. Choudhury et al. [2] have also reported the decreasing trend of vegetation with respect to increasing LST in Asansol Durgapur area of the West Bengal. Dong et al. [6] explored the relationship of LST with NDVI in the Karst area and identified the opposite relation between them. Sun et al. [23] have reported a significant reduction in LST in the areas nearby water bodies, lakes, etc. in Beijing, China. Choudhury et al. [2] examined the association between LST and deriving factor such as NDVI of Asansol-Durgapur Development Region and found an inverse trend between these parameters.

Rasul et al. [24] reported that climate change is an established fact affecting food, fresh water, agriculture, natural ecosystems, health, biodiversity and socioeconomic sectors around the globe. The increase in the global temperature was recorded as 0.76 °C during the last century but in the first decade of the 21st century 0.6 °C rise has been noticed [24-25]. Pakistan is vulnerable to climate change because of its location in a geographical region where the temperature increases are expected to be higher than the global average [24-26]. Being in the arid and semi-arid region, it largely depends on the river irrigation system which is mainly fed by the Hindu Kush- Karakoram-Himalayan (HKH) glaciers which are reported melting rapidly due to global warming. Thus, the country will face risks of variability in monsoon rains, floods, and extended droughts.

4.4. Relationship between NDVI and Wheat Crop Yield

Based on the data of wheat crop yield of the Delta of different years, a statistical relationship between the wheat crop yield and NDVI of the delta was developed as shown in Figure 7. It shows a linear and positive relationship between the two variables, and it is described by the regression Equation 5 with a coefficient of determination of $R^2 = 0.89$.

$$Yield\ of\ wheat\ crop = 3.241 \times NDVI - 0.3123 \tag{5}$$

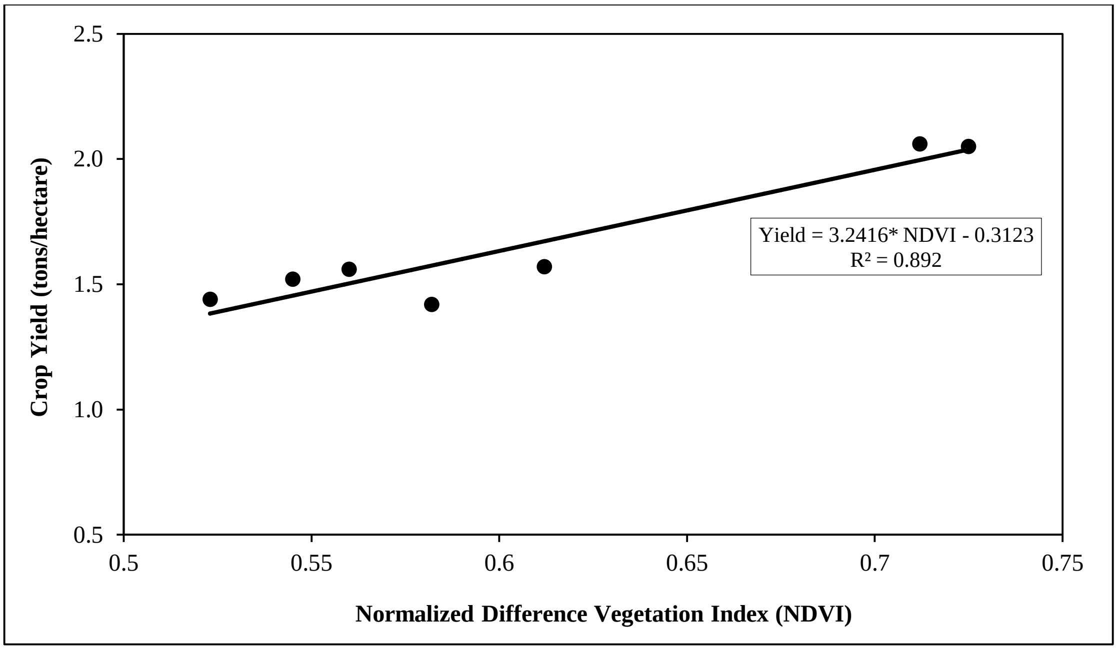

Figure 7. Correlation between NDVI and the wheat crop yield of the Indus Delta

5. Conclusion

Variations in the LST of the Indus delta for the last 27 years (1990-2017) and its impact on the vegetative cover was analyzed. Altogether, a relationship between NDVI and the yield of the wheat crop was observed. The analysis revealed that on average, there was an increase of 1.74 ºC in LST of the Indus delta during the last 27 years. The temporal variation in the NDVI of the Indus delta showed the highest NDVI of 0.725 in the year 2005 followed by the year 2010 with NDVI of 0.712. While the lowest NDVI of 0.545 was observed in the year 2017. There was a fair but negative statistical correlation between NDVI and the LST with a coefficient of determination of R^2 = 0.65. From NDVI maps, the decreasing trend in vegetative cover in the Indus delta is clear. A positive linear relationship between the NDVI and the yield of the wheat crop with a coefficient of determination of R^2 = 0.89 was observed. Such studies are essential for the guidance of policymakers for taking measures for mitigating adverse impacts of climate change on the environment.

6. Acknowledgements

We are highly grateful to the U.S.-Pakistan Centre for Advanced Studies in Water (USPCAS-W), Mehran UET, Jamshoro, Pakistan for funding the project “Assessing Impact of Seawater intrusion on soil, water and environment in the Indus delta using GIS and RS tools”. We are also thankful to the USGS (United States Geological Survey), Crop Reporting Services (CRS) Sindh, Google Earth for providing the necessary data.

7. Conflict of Interest

The authors declare no conflict of interest.

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