

Index-based Approach in Relation to Built-up and LST Dynamics; A Study of Lahore, Pakistan

Kanwal Javid¹, Muhammad Ameer Nawaz Akram², Shazia Pervaiz³, Rumana Siddiqui⁴, Nausheen Mazhar⁵

¹Department of Geography, Government College University Lahore, Pakistan

²State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS), Wuhan University, China

³Environmental Protection Agency Punjab, Pakistan

⁴Department of Geography, Queen Mary College, Lahore, Pakistan

⁵Department of Geography, Lahore College for Women University, Lahore, Pakistan

*Email: Kanwal.javid@web.gcu.edu.pk

Abstract: In 21st century, cities outpaced in size and also in density due to development of economic sector. Consequently, the wide spread expansion of urban areas is resulting in the loss of productive green cover and water bodies. Therefore, realizing this alarming situation, the present study is aimed to investigate and evaluate the pattern of urban expansion by considering two major land cover types (i) built-up area (ii) other classes (vegetation, waterbody, soil etc.) during the last six years (2015-2020). For this study Sentinel imagery was acquired from USGS Earth Explorer, while Modis Terra images were acquired from World View NASA. New built-up area index (NBUI), normalized difference vegetation index (NDVI), worldview water index (WV-WI) and land surface temperature (LST) were calculated in order to analyze variations in Lahore's major land cover types and its varying temperature patterns. Spatial analysis presented the obvious impacts of land development on Lahore. NBUI indicated that the built-up area has increased drastically from 34.0% in 2015 to 84.2% in 2020; NDVI analysis depicted a decline from 0.76% to 0.73%, in the green spaces of Lahore during the study period; WV-WI portrayed inconsistent values of water bodies, a gift of massive rise in the built-up area in Lahore. LST results presented that the temperature was 42.21°C in 2015, which simultaneously increased and recorded at 49.51°C in 2020. The increase in LST exhibited the alarming situation for urban environment and can become threat to increase the air pollution level in Lahore. Therefore, this study will serve as a snapshot for policy makers to control the menace of unplanned urbanization by formulating stringent policies to protect environment.

Keywords: Lahore environment, smog, urban heat island, urban transformation.

Introduction

Alteration in urban land cover has affected the ecosystem (Alberti, 2005), biodiversity (Veach et al., 2017) and water resources (McGrane, 2016) across the globe and Lahore is one of them. Lahore, a mega city (Pervaiz et al., 2019) is the second largest populated city of Pakistan with a population of 1.13 million according to population survey of 2017 (Basheer et al., 2020). Lahore is well known for its rich, dynamic culture (Jamal et al., 2012), food business (Jalil et al., 2013), green cover (Mubin et al., 2013) and natural environment. Importantly, Lahore connects with industrial, commercial hubs and its economic corridor (Pervaiz et al., 2019) plays a vital role in strengthening the country's economy. Ironically, rapid growth of population (Hameed, et al., 2016) and consequent infrastructural development plans (Rana et al., 2018) has converted the city of gardens (Farhat et al., 2018) into the city of concrete (Masih, 2019). New housing societies (Imran and Mehmood, 2020) are emerging within the vicinity of city as well as in its peripheral areas. It is observed that the urban sprawl in the city is consuming the valuable vegetative land cover (Pervaiz et al., 2018; P). In the current scenario, this

metropolitan city (Pervaiz et al., 2020) is dealing with the havoc of population explosion (Atiq et al., 2018) and loss of vegetation cover (Imran and Mehmood, 2020) which is affecting the precious urban environment of Lahore (Nawaz et al., 2019). Thus, the present study is carried out to quantify the changes of LST occurring in Lahore from 2015 to 2020 through spatial mapping. Moreover, the previous study of (Waseem and Khayyam, 2019) has also reported the change in LST level after haphazard urban development in Gujranwala. Therefore, the aim of the present study is to examine the effect of unplanned urban development on LST from 2015 to 2020 with help of MODIS data.

Study Area

The study area (Lahore) belongs to Punjab Province and consists of nine administrative towns (Pervaiz et al., 2020) having an area of 1772 km² (Akbar et al., 2019) (Fig. 1). Spatially, Lahore is located between 31.5204° N, 74.3587° E. Climatically, Lahore falls under semi-arid zone (Köppen atmosphere grouping BSh) (Composite rainstorm atmosphere) (Javid et al., 2019) by having significant five seasons: foggy winter

(15 Nov – 15 Feb) with scarcely any western unsettling influences causing precipitation; lovely spring (16 Feb – 15 April); summer (15 April – June) with dust, downpour tempests and warmth wave periods; stormy rainstorm (July – 16 September); and dry fall (16 September – 14 November).

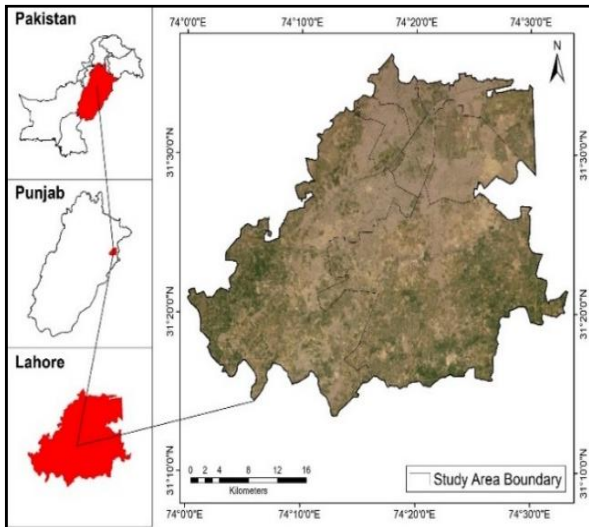


Fig. 1. Location of the Study Site

Materials and Methods

In order to efficiently monitor the urban transformation, the multispectral Sentinel 2 (Helber et al., 2019) and MODIS Terra (Javid et al., 2018; Helber et al., 2019) images with the resolution of 10 and 250 meters with false color composite RGB (4, 3, 2) and monochromatic band were used. The Sentinel and MODIS images were acquired from the U.S Geological Survey and Worldview NASA consisting

on a span of 6 years *i.e.*, 2015, 2016, 2017, 2018, 2019 and 2020 (Table 1) (Basheer et al., 2020). In addition to this, the change detection has been evaluated on the basis of four indices *viz.* new built-up index (NBUI)-equation 1, normalized difference vegetation index (NDVI)-equation 2, world view water index (WV-WI)-equation 3 and land surface temperature (LST)-equation 4. These indices are the most suitable to meet the objectives of this study. Moreover, these equations are used for similar analysis in recent studies (Sinha et al., 2016; Basheer et al., 2020). In the equations provided below, SWIR is the shortwave infrared band which is band number 11, RED is red band that is band number 4 and NIR is near Infrared band that is band number 8 in sentinel 2 imagery. Similarly, DN is digital number of MODIS imagery.

$$NUBI = \frac{SWIR - NIR}{10\sqrt{SWIR+TIR}} - \left(\frac{(NIR-RED)*1+I}{NIR-RED+1} + \frac{GREEN-SWIR}{GREEN+SWIR} \right) \text{----- (Eq. 1) (Sinha et al., 2016)}$$

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \text{----- (Eq. 2) (Basheer et al., 2020)}$$

$$WV-WI = \frac{Coastal - NIR}{Coastal + NIR} \text{----- (Eq. 3) (Sinha et al., 2016)}$$

$$LST = DN * 0.02 - (273.15) \text{..... (Eq. 4) (Javid et al., 2019)}$$

Table 1. Description of Sentinel Images Spatial Data.

Satellite	Sensor Type	Band No	Data Acquisition	Spatial Resolution (meters)
Sentinel	S2A	12	2015, 2016, 2017, 2018, 2019, 2020	10

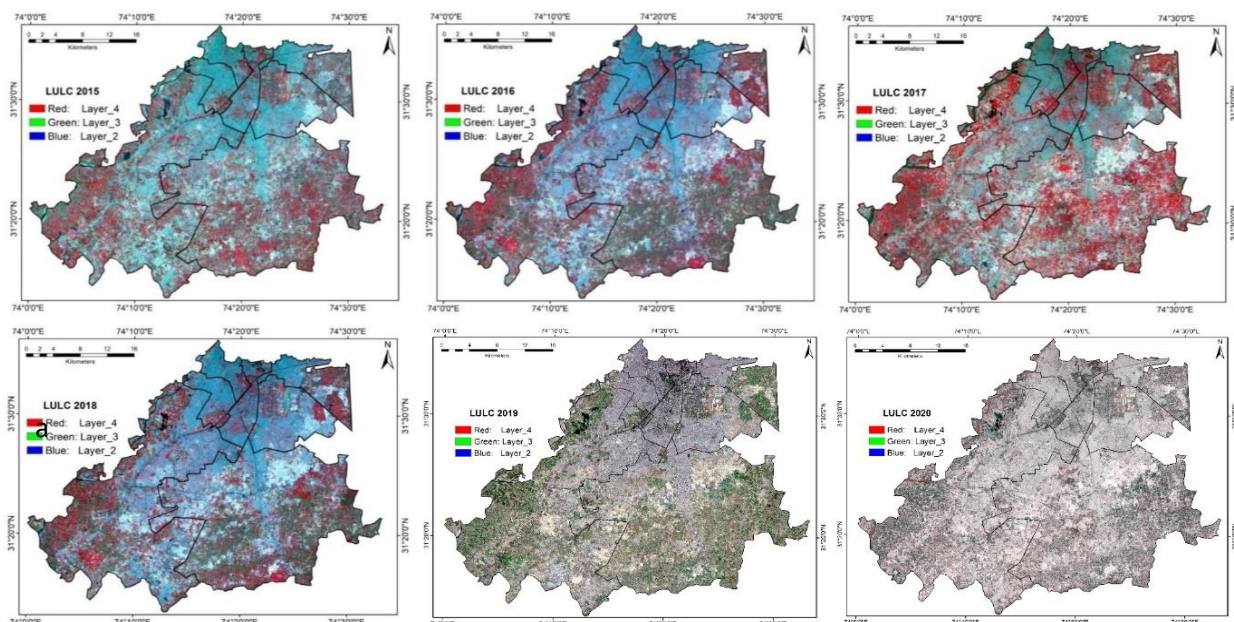


Fig. 2. Land covers classification map using false color composite of Lahore for year a (2015), b (2016), c (2017), d (2018), e (2019) and f (2020).

MODIS	MOD11A2	32	2015, 2016, 2017, 2018, 2019, 2020	250
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Results and Discussion

Land cover assessment using false colour composite

makers instead of peasants for the better profit (Singh and Asgher, 2005). Variations of false color composite (RGB) show the changes in economic activities from 2015 to 2020. Comparing results of figures 2 to 6, it is clearly observed that unplanned growth of city is one of major threats to reduce the vegetation cover and water bodies which support the similar findings of the

Table 2. Land Cover Classification of Lahore from 2015 to 2020.

Classes	2015		2016		2017		2018		2019		2020	
	%	Sum_area Sq.km	%	Sum_area Sq.km	%	Sum_area Sq.km	%	Sum_area Sq.km	%	Sum_area Sq.km	%	Sum_area Sq.km
build-up	34.01	419.80	45.52	560.50	48.31	595.80	78.90	972.81	79.62	981.01	82.21	1013.71
other	66.01	813.11	54.52	672.50	51.76	637.01	21.11	260.01	20.41	251.72	17.80	219.10

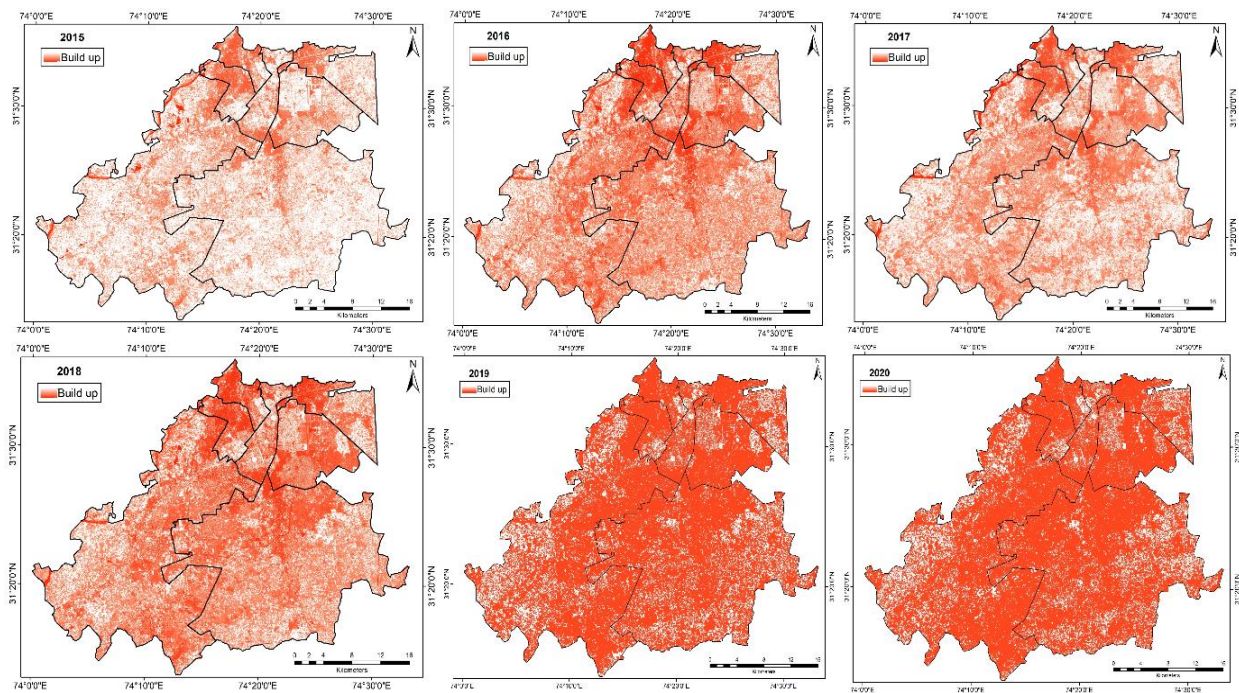


Fig. 3. Spatial extent of built-up area of Lahore for year a (2015), b (2016), c (2017), d (2018), e (2019) and f (2020).

from 2015 to 2020

Figures 2(a, b, c, d, e and f) illustrate the false colour In these figures, the red from false color composite (RGB) depicts the available vegetation cover of district Lahore. The deep red presents the dense vegetation and the light red tone shows the sparse vegetation. Further, the relatively blue areas present the built-up area of the city (Vital, 2008). In addition, the deep dark blue shows water bodies and light blue depicts the seasonal trend of rain fed pools in the city. Analysis of Figure 6 demonstrates that the highest conversion of green cover into built-up area has reduced the production of crops (Zaman, 2012) in Lahore with the passage of time. Furthermore, most of arable land is used commercially to set brick kiln units in the city to meet the demands of urban dwellers. In addition, the land owners prefer to give their land on lease to brick

study conducted in Assam, India (Kumar, 2017). Hence, in the current scenario the built-up environment aggravates the risk of air, water and land pollution (Naeem, 2018) and elevates the tremendous pressure on the ecosystem and indigenous biodiversity of Lahore.

Change Detection Analysis of Land Cover from 2015 to 2020

From 2015 to 2020, Lahore experienced massive increase in built-up class and this expansion was at the expense of other classes (Table 2). The built-up class consumed other classes i.e., vegetation, waterbody, soil etc. at a rapid pace during the 6 years under study. The built-up area increased drastically from 34.0% to 82.2% within the past six years. Further, the results of other classes (vegetation, water soil) exhibit that 66.0%

is sharply reduced into 17.8% during the study period (Fahad et al., 2020). So, the yearly variation in other classes like vegetation, water and soil show the negative trend for the environment of Lahore. Though, the growth of built-up area indicates the economic development but the haphazard unplanned development in terms of built-up area engulfed valuable arable land (Sharma et al., 2015; Yar et al.,

plans (Zaman, 2012) and urbanization that resulted in extensive reduction of green cover reservoir. Subsequently, it can be said that the conversion of green cover into built-up area is directly associated with the development activities (Mallupattu and Sreenivasula, 2013; Alipbeki et al., 2020) and commercial utilization of urban land. The expansion of new built-up environment is over the cost of natural

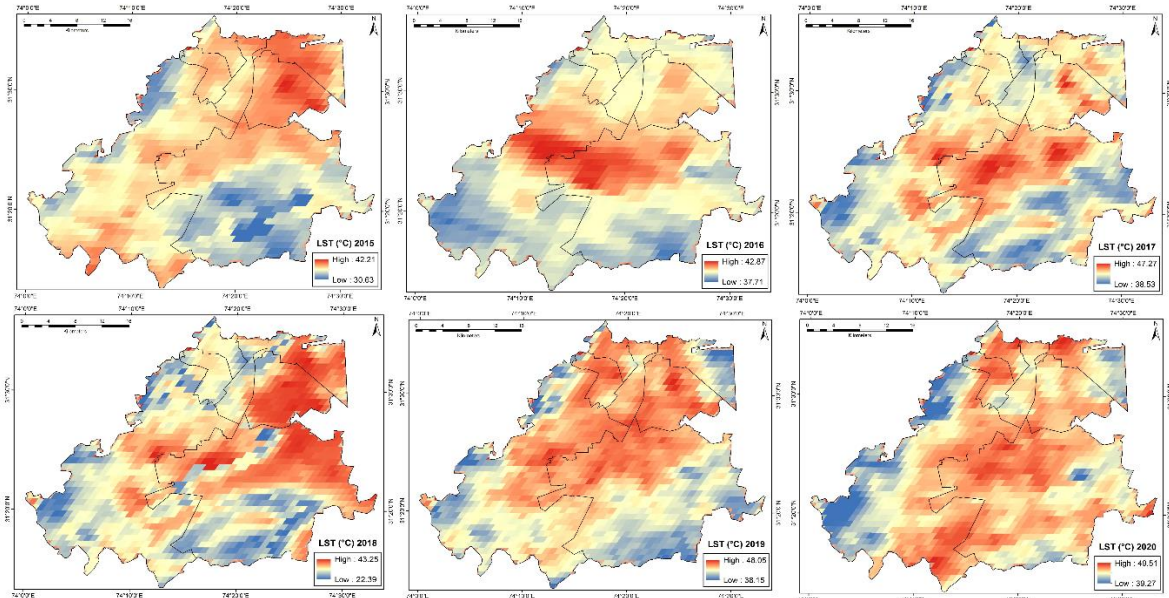


Fig.4 Land surface temperature of Lahore of year a (2015), b (2016), c (2017), d (2018), e (2019) and f (2020).

Table 3. Rate of Change of Maximum and Minimum LST (°C) of Lahore from 2015 to 2020

Year	Maximum LST (°C)	Minimum LST (°C)	Rate of Change of Max. LST (°C)	Rate of Change of Mini. LST (°C)
2015	42.21	30.63	Starting	Starting
2016	42.87	37.71	0.66	7.08
2017	47.27	38.53	4.4	0.82
2018	43.25	22.39	-4.02	-16.14
2019	48.05	38.15	4.8	15.76
2020	49.51	39.27	1.46	1.12

2016) which became a serious threat for natural environment of the metro city.

Spatial pattern of built-up area of Lahore from 2015 to 2020

Figure 3 (a, b, c, d, e, f) depict the massive increase in built-up area of Lahore that increased from 419.8 sq. km in 2015 to 1013.7 sq. Km in 2020 (Table 2). Lahore experienced built-up rise in the form of industrialization and housing schemes (Mallupattu and Sreenivasula, 2013). Many previous studies (Bhatti and Tripathi, 2014; Gashu and Gebre, 2018; Akbar et al., 2019) supported the above findings. Further, comparison of NBUI imagery from 2015 to 2020 (Figure 3) indicated that the physical expansion of built-up area increased (Akbar et al., 2019) towards the northeast, northwestern and central part of Lahore by diminishing the agricultural area of Lahore (Ather et al., 2015). Thus, the key reasons behind the built-up area expansion were the set-up of industrial zones, launch of housing societies, construction development

reservoirs (Mahmoodi et al., 2019; Roustae et al., 2018). Thus, the overall results of NBUI exhibited that the human intervention in the transformation of urban area has created adverse impact on natural climate and environment (Patra et al., 2018) of Lahore.

Land surface temperature (LST) of Lahore from 2015 to 2020

Figure 4 (a, b, c, d, e and f) delineate the land surface temperature of Lahore. LST, is a phenomenon that is directly linked with process of rapid urbanization and furthermore it aggravates into the phenomenon of Urban Heat Island (UHI). The LST of Lahore for the year 2015 is depicted with high value in red colour which is 42.21 °C and low value with blue colour which is 30.63 °C Fig. 4 (a), For the year 2020, shows the LST of Lahore with high value in red colour which is 49.51 °C and low value with blue colour which is 39.27 °C Fig. 4 (f). These analyses pointed out that LST of Lahore increased at considerable level from 2015 to 2020. And with increase in commercial

d

e

f

activities bare lands and open lands were converted into built-up areas which triggered the increase in LST

of change of LST max and min decreased in 2018. From 2018 to 2019 max and min rate of change in LST

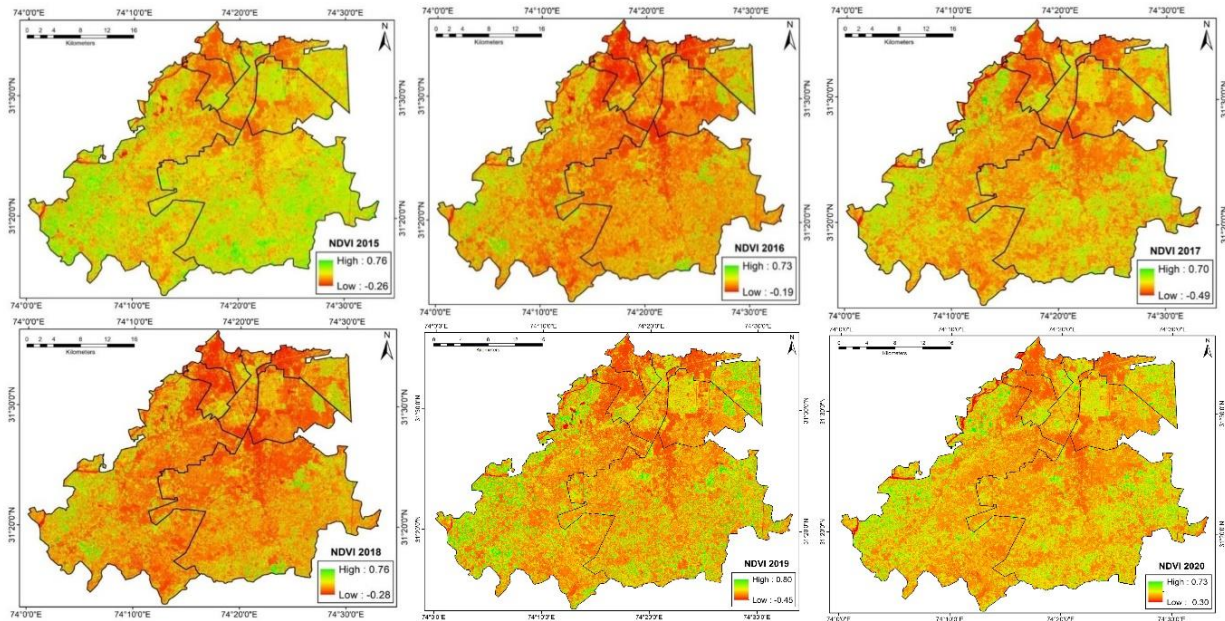


Fig. 5. Spatial pattern of green cover area of Lahore for year a (2015), b (2016), c (2017), d (2018), e (2019) and f (2020).

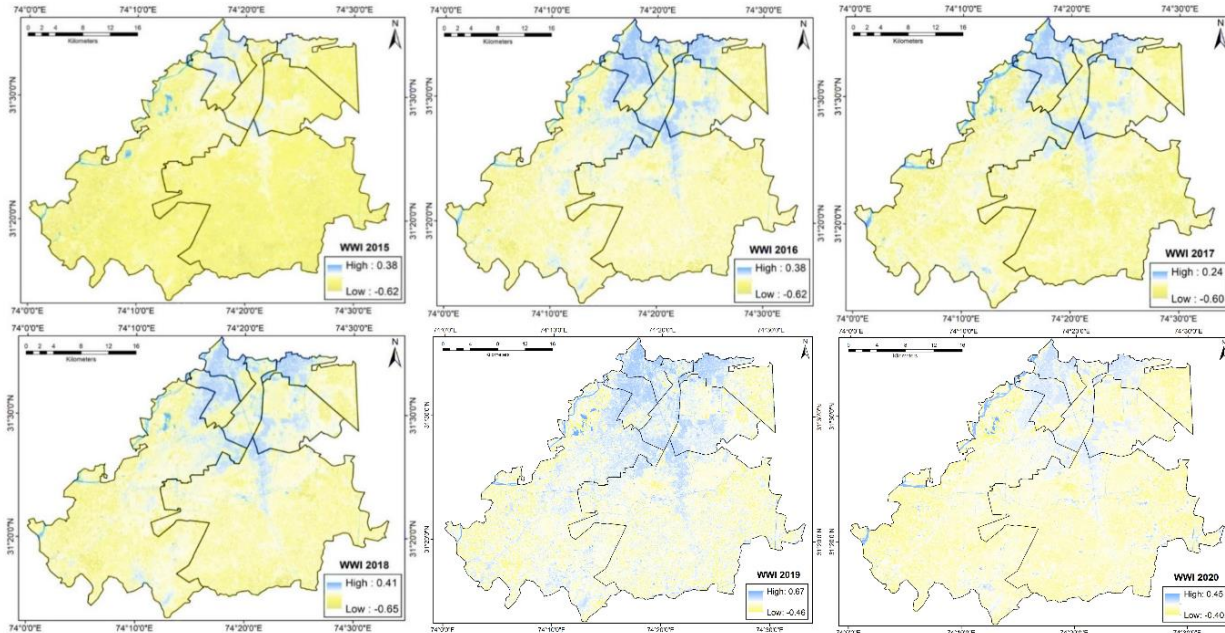


Fig. 6 Water bodies of Lahore for year (2015), b (2016), c (2017), d (2018), e (2019) and f (2020).

of Lahore.

Table 3 shows rate of change of maximum and minimum LST per year from 2015 to 2020. It is observed that from 2015 to 2016 the rate of change of LST max and min was 0.66 °C and 7.08 °C. From 2016 to 2017 rate of change was 4.4 °C max and 0.82 °C min. From 2017 to 2018 results of rate of change showed that max LST was -4.02 °C and min LST was -16.14 °C. With reference to Fig. 22, green cover of Lahore increased in 2017 as compared to 2018, 2019 and 2020. So, due to increase in vegetation cover rate

was observed which was 4.8 °C and 15.76 °C. So, in 2019 to 2020 max rate of change was 1.46 °C and min rate of change was 1.12 °C.

Spatial Pattern of Green Cover of Lahore from 2015 to 2020

Figure 5 (a,b,c,d,e and f) demonstrate the vegetation cover and non-vegetation cover of Lahore from 2015 to 2020. The NDVI (Govil et al., 2019) interpretation which was carried out within the nine administrative towns of Lahore viz. Aziz Bhatti Town, Data Gunj

Bakhsh town, Gulberg town, Allama Iqbal town, Nishtar town, Ravi town, Samanabad town, Shalamar town, Wahga town including Cantonment Area varied from 2015(a) to 2020(f) and they showed the inconsistency in growth of vegetation. Thus, town wise results illustrated the inconsistency in vegetative growth. On comparing results of spatial imageries, the highest variation was observed in the north-east and south-western part of Lahore in 2015 which is well known area of Lahore for crop cultivation (Ather and Shahbaz, 2015). In 2016, NDVI results showed the transformation in green cover in Lahore which is highly attributed to different economic activities that threaten the habitat of urban landscape. In 2017, the spatial results exhibited the improvement in green cover which could be attributed with the rotation plan of crops. In 2018, it was observed through NDVI that vegetation value of study area decreased due to urbanization. Hence, the changes in green area during the study period from 2015 (fig a) to 2020 (fig 5 f) depicted the heavy loss of vegetative cover. It is an alarming situation for Lahore as this might trigger urban flooding, urban heat island and air pollution (Pervaiz et al., 2019).

Spatial pattern of water bodies of Lahore from 2015 to 2020

Lahore is categorized in the semi-arid region due to high urbanization and has a sub-tropical type of climate. Therefore, the rate of precipitation varies in different seasons (Pervaiz et al., 2020) and the highest concentration of rainfall is received during summer monsoon season. The noticeable decline in other class includes water bodies of Lahore for six years under study (Table 1). Whereas results of Fig.6 (b) show the increase in level of season-based aquifer bodies in the north and central part of the city which can be associated with the changed metrological conditions (Imran and Mehmood, 2020), expansion of built-up area and improper infrastructure of urban sprawl (Fig. 6). Moreover, the irregular patterns of water bodies were examined in the study area through spatial results. It was identified, that the northern part of Lahore is very congested area, with no proper drainage system, suffers commonly from urban flooding, which is most predominant in these parts of Lahore. Fig.6 (e, f) provide the insight of high concentration of water level in Data Gunj Bakhsh town, Samanabad town and north side of Aziz Bhatti town. Comparing Fig. 6 (a, b, c, d, e, f) it has been analyzed that water logging is attributed to torrential rains. Secondly, the city's drainage system in these towns is poor which triggers the urban flooding like Karachi and other megacities (Siddiqui et al., 2018; Akhtar and Dahnani, 2015; Anisha and Hossain, 2014).

Comparison of Built-Up Area and Maximum Land Surface Temperature (LST) of Lahore from 2015 to 2020

Table 4 shows the results of six years comparison, which depicted that the built-up area and maximum LST (°C) increased parallel to each other, from 2015 to 2020. When urbanization increases, the concrete surfaces absorbs maximum quantity of heat while the process of emission becomes slow. In contrast to urban class other classes show decreasing trend and such contrast becomes the reason of high land surface temperature as evident from this study. The increasing trend of built up (bars in red colour) and LST (°C) (line in black colour) is shown in the form of bar graph (Fig. 7). In 2015, the LST was less as compared to 2016. While the highest temperature was recorded in 2020, In addition, the results of 2020 also showed the highest urban covered area as compared to other years which conclude that urbanization became the reason of rise in land surface temperature.

Table 4. Shows Comparison of Built-Up Area with LST (°C) from 2015 to 2020

Year	Built-up Area (sq.km)	Maximum LST (°C)
2015	419.8	42.21
2016	560.5	42.87
2017	595.8	47.27
2018	972.8	43.25
2019	981	48.05
2020	1013.7	49.51

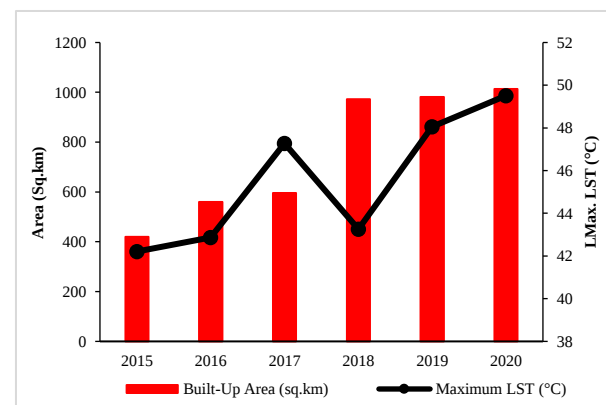


Fig. 7 Shows trend of Built-up and LST of Lahore from 2015 to 2020.

Conclusion

Spatial monitoring of urban transformation is necessary for sustainable urban planning to resolve economic and environmental pressures of the metropolitan cities. Urbanization in Lahore has influenced the city in terms of urban form. The physical and economic transformations in Lahore have given birth to critical issues of climatic and environmental hazards, climate change, urban heat island (UHI), air pollution, dengue and smog. Furthermore, the city is stretching from southern to eastern direction and 50.0% urban form transformed with an increase of 593.9 sq. km in built-up class from 2015 to 2018. In addition to this, loss of other class or features from 2015 to 2020 like vegetation, water bodies and soil is about 594 sq. km, which is highly

visible during the study period and has a negative impact on natural environment of Lahore. Similarly, the haphazard unplanned development plans increase the land surface temperature from 42.21°C to 49.51°C during six years 2020. Therefore, to overcome this problem urban forest plans should be initiated to minimize the global warming challenges and achieve the new government agenda Clean and Green Punjab.

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