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## **The Land Surface Temperature Dynamics and Its Impact on Land Cover in District Peshawar, Khyber Pakhtunkhwa**

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## Research Article

# The Land Surface Temperature Dynamics and Its Impact on Land Cover in District Peshawar, Khyber Pakhtunkhwa

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## Abstract

The landcover has most essential impact on the climatic condition of any region. The rapid urbanization induces key changes into the climatic condition of any region. This changing pattern of urbanization has induced micro level climatic changes with demographic variation as the key factor. In this study we analyzed the effect of landcover classes on the LST in the Peshawar for 1990, 2000, 2010 and 2019. The results revealed that the builtup area has been increased from 14.20% to 20.22% during 1990 to 2019. The results also show that the LST values are between the ranges of 25°C to 36°C. The air temperature and LST have very compromising correlation. The hype and increase in the UHI zones are resultant to rapid urbanization and expansion of Old Municipal Corporation with initiation of developmental projects in the area. This study will help urban planners and decision makers in landuse planning and management to mitigate the increase in LST with the replacement of possible impervious surfaces with green built and road side plantation for comfortable urban environment.

**Keywords:** Landcover, Climate, Urbanization, LST, Environment

## Introduction

The urban expansion involves the replacement of foliage and topsoil with concrete surfaces of commercial, residential and industrial buildings, roads and bridges (Estoque et al., 2017; Sultana et al., 2019). Conversion of the natural earth surface to impervious surface leads to modification in the biophysical climate changes and an increase in land surface temperature (LST) (Khan et al., 2020). About 54% of the biosphere's human population lives in urban areas and projected to rise to 70% by 2030 (Tursilowati, 2018; Zhang et al., 2017). Despite the fact that urban development has brought facilities to people, it has also caused severe harm to the natural environment from a global to local scale (Shiflett et al., 2017). The rapid urban expansion has altered the energy balance between the earth and atmosphere with an increase in low heat transfer capacity resulting in the urban heat island (UHI) phenomenon (Islam et al., 2016; Tran et al., 2017; Njagi et al., 2022).

The UHI formation has a linear correlation with the transformation of vegetated areas to concrete surfaces resulting in an increase in LST (Ranagalage et al., 2018; Tran et al., 2017). The UHI negatively affect energy consumption with higher emission and increased air pollution (Ranagalage et al., 2018; Ranagalage et al., 2017). It elevates greenhouses gases compromising on human health and comfort (Ranagalage et al., 2017). Therefore, due to its adverse effects on the urban environment and the overall livability of cities (Zhang et al., 2017), the UHI effect has become important research

attention in different interconnected fields, comprising urban climatology, urban ecology, urban planning, and urban geography. (Estoque et al., 2017; Feng et al., 2014; Lin et al., 2017; Oleson et al., 2015; Son et al., 2017; Tran et al., 2017; Esetlili et al., 2018; Çelik et al., 2019). The advances in thermal remote sensing has brought significant improvements to understand and project the UHI effects on physical and social environments (Ranagalage et al., 2017). The global coverage, free availability, increasingly high temporal and spatial resolution of the thermal remote sensing images are providing an opportunity to evaluate the temporal and spatial dynamics of the LST and correlate it with the urban expansion and varying environmental phenomenon (Liu et al., 2011; Sutariya et al., 2021).

Like many other countries, Pakistan is facing growing urbanization for the past few decades (Wareing et al., 2010). The major cities of Pakistan like Karachi (Mahboob et al., 2015), Lahore (Saleemi, 2015), Faisalabad, Multan are exposed to rapid urbanization and associated impacts. Like other cities of Pakistan, Peshawar city is also affected by rapid urbanization (Mehmood et al., 2017). Peshawar hosts millions of international refugees from Afghanistan (Ghufran, 2011; Mehmood et al., 2017; Wareing et al., 2010). Moreover being the provincial capital and security issues in other parts of the province during the last two decades, Peshawar has received unprecedented internal migration that results in immense pressure on the resources and environment and accelerated the urbanization (Ali et al., 2012; Mehmood et al., 2016). This study aims to

evaluate the impact of augmented urbanization on the land-use land cover and its impact on temperature and UHI formation in Peshawar. The study shall provide a detailed insight into the urban-rural changing LST values aided with air temperature and its correlation with LST.

#### Study area:

The district Peshawar is the capital city of Khyber Pakhtunkhwa province, Pakistan with an area of 1257 km<sup>2</sup>, a population of 4.269 million, a population density of 2761 people/km<sup>2</sup> (Figure 1). The annual mean monthly outdoor temperature ranges from 10.1°C to 31.2°C and average annual rainfall is 384 mm (Nicol et al., 1999; Salma et al., 2012).

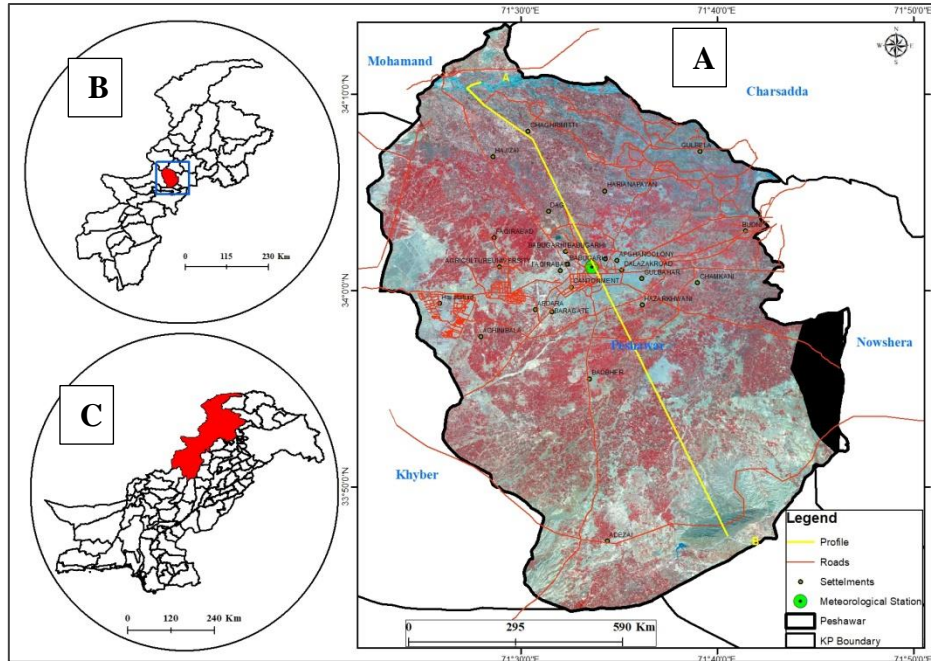


Fig. 1 shows the (A)Location map of district Peshawar (B) Khyber Pakhtunkhwa Province (C) Pakistan.

Table 1: Shows the parameters of the Landsat TM/OLI images used in the study.

Date of Images	Sensor Name	Spatial Resolution	Thermal Band Resolution
08-Oct-2019	Landsat 8 OLI	30×30(15m Panchromatic )	120×120
08-Oct-2019	Landsat 8 OLI		
15-Oct-2010	Landsat 5 TM		
15-Oct-2010	Landsat 5 TM		
19-Oct-2000	Landsat 5 TM	30×30	120×120
19-Oct-2000	Landsat 5 TM		
08-Oct-1990	Landsat 5 TM		
08-Oct-1990	Landsat 5 TM		

#### Material and methods:

##### Remote Sensing Data and Pre-Processing:

Multispectral data of the Landsat-5 Thematic Mapper (TM) and Operational Landsat Imager (OLI) Landsat-8 Enhanced Thematic Mapper (ETM) was downloaded for the years 1990, 2000, 2010 and 2019 from USGS (United States Geological Survey)(USGS, 2012) (Table 1). The visible and NIR bands (4, 3, 2) of the Landsat imageries were used for land cover mapping and thermal bands (10, 11) for the retrieval of LST. The atmospheric and radiometric correction, layer stacking and study area extraction are the pre-processing steps followed for all Landsat images. A supervised classification method was used for the generation of LULC. The air temperature

and rainfall data for the respective dates and years were collected from the Pakistan Meteorological Department.

##### Land Cover Classification and Accuracy Assessment:

The Near Infrared (NIR), Red and Green bands along with a panchromatic band of 15 m resolution were stacked and then pan-sharpened. The study area was extracted from the pan-sharpened stacked image. To classify the images for land cover, six sets of training samples were created based on the number of classes in land cover classification i.e. agricultural land, barren land, built up, forest, and rangeland and water bodies (Table 2). Maximum 15 training samples were created for each class to accurately map the land cover of the study area. Supervised classification maximum likelihood process was carried out for land cover

mapping. Subsequently, the developed land cover was visually interpreted with Google Earth Imageries and with SPOT 5 image for 2010 only. The accuracy assessment of land cover maps was analyzed using Kappa's Coefficient Analysis.

#### **Land Surface Temperature:**

To calculate the LST from Landsat imageries, Thermal bands 8 of Landsat 5 TM and band 10 and 11 of Landsat 8 OLI were used. The semi-Automatic classification algorithm was used in GIS to extract the brightness temperature from the thermal bands. The band 10 and 11 results were then merged using cell statistics analysis resulting into the production of a single band LST derivative.(Chen et al., 2006).

#### **Thermal Profiling, Air Temperature and Rainfall Data:**

To investigate the effects of LULC on the LST, a profile (A-B) was drawn along the study area. The profile points (figure 1) were generated along the line A-B. The values from the LULC and LST of 1990, 2000, 2010 and 2019 were extracted to the point data. The LST values and air temperature data was correlated with each other to study the correlation.

#### **Census Data**

The Census data of population of the Peshawar was acquired from the Pakistan Bureau of Statistics from 1951 to recent 2017 Census.

#### **Results**

##### **LULC Pattern and Changes for 1990, 2000, 2010 and 2019:**

The land cover classification results show that there has been a significant increase in the built-up area in Peshawar. In 1990, the built-up area was 181.41 km<sup>2</sup> with a total of 14.20%. The built-up area increased to 201.02 km<sup>2</sup> and contributes as 15.73% in year 2000. Later, urbanization has been geared up with an increase of 208.70 km<sup>2</sup> with a percentage of 16.33% in the year 2010. The built-up area has increased to 264.72 km<sup>2</sup> with 20.72 % in 2019. The classified barren land has a contribution of 138.35 km<sup>2</sup> area with 10.83% in 1990 and 10.88% 2000. The barren land has been decreased in 2010 to 85.27 Km<sup>2</sup> contributing as 6.67% of total area. However, 2019 result shows a significant decrease in barren land due to a decrease in vegetation practices and rapid urbanization with increase in population and demand for housing in the study area. The barren area decreased to 70.63 Km<sup>2</sup> (Table 3) contributing as 5.52% of the total area in 2019.

Table 2: shows the landcover classes extracted from Landsat 5 TM and Landsat 8 OLI data

Land Cover Classes	Description
Agriculture Land	Slight vegetation and cultivated land
Barren Land	topsoil/rock surfaces
Builtup	Road and rail network, buildings, and concrete
Forest	Subtropical broadleaves and pine forests
Range Land	Hilly area with bare rock and soil.
Water Bodies	Watercourse, open water, lakes, and ponds

Table 3: Shows the landcover change statistics from 1990 to 2019.

Land cover	1990		2000		2010		2019	
	Area (km <sup>2</sup> )	Percentage	Area (km <sup>2</sup> )	Percentage	Area (km <sup>2</sup> )	Percentage	Area (km <sup>2</sup> )	Percentage
Agriculture	844.55	66.11	823.93	64.50	869.42	68.06	815.90	63.87
Barren Land	138.35	10.83	138.99	10.88	85.27	6.67	70.63	5.52
Built-up	181.41	14.20	201.02	15.73	208.70	16.33	264.72	20.72
Water Bodies	44.90	3.51	44.90	3.51	45.50	3.56	58.37	4.56
Forest	7.98	0.62	8.12	0.63	8.12	0.63	13.92	1.09
Range Land	60.20	4.71	60.43	4.73	60.37	4.72	53.85	4.21

The agriculture is shrinking in both north and south (figure 2) of the city. The city has been expanded in both north south east and western directions. Small patches of built up area in north and southern portion was observed during 1990, which is expanded gradually in 2000, 2010 and 2019. The new patches of built up has also been observed in north and south side of the study area. There has been a significant decrease in agriculture land (figure 2 and 3) from 844.55 km<sup>2</sup> to 815.90 Km<sup>2</sup> during 1990 to 2019. The agriculture land has suddenly

been increased from 823.93 km<sup>2</sup> in 2000-2010 to 869.42 km<sup>2</sup> in south western part figure 3.1b) due to conservation of barren land into agriculture land. The main reason for this abrupt change is the construction of the Azakhel reservoir and canal network in the region (Sattar et al., 2020). In 2019 the forest cover has been increased due to the Billion Tree Afforestation Project (BTAP) in Khyber Pakhtunkhwa. The forest area (figure 3.2) has been increased from 7.98 to 13.92 km<sup>2</sup> during 1990 to 2019.

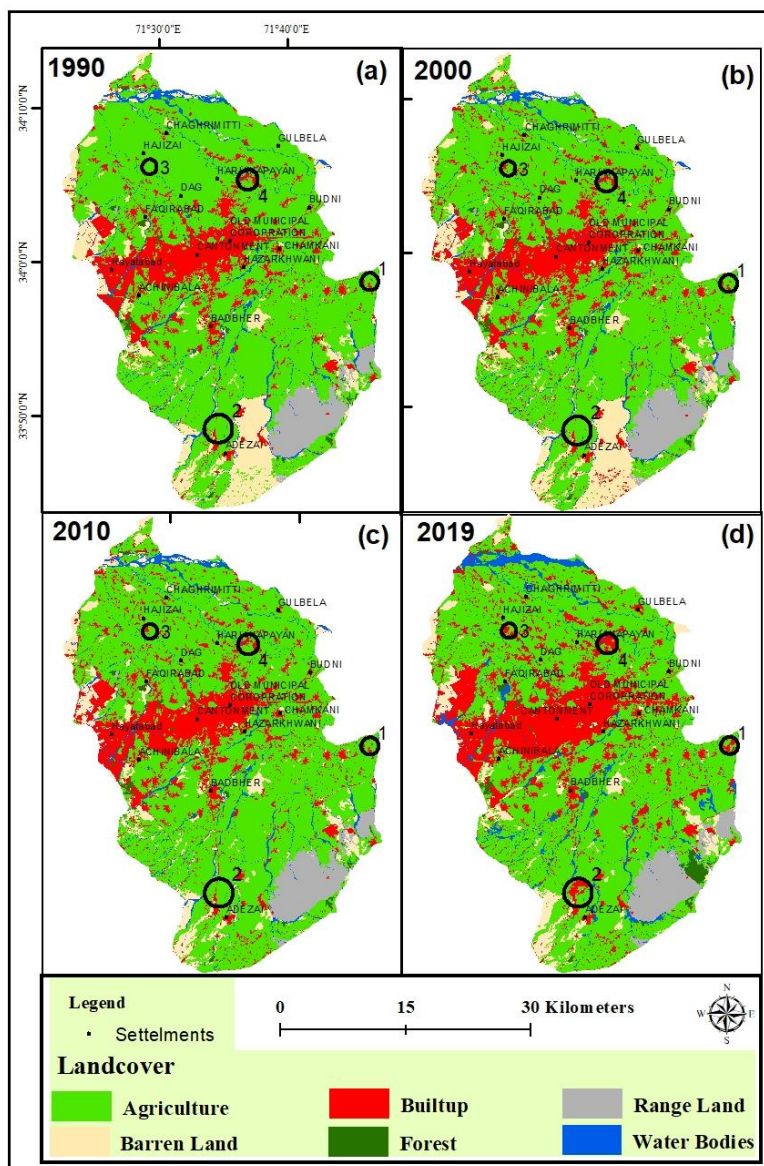


Fig. 2: shows the land cover generated from Landsat data for the period (a) 1990, (b) 2000, (c) 2010 and (d) 2019 respectively.

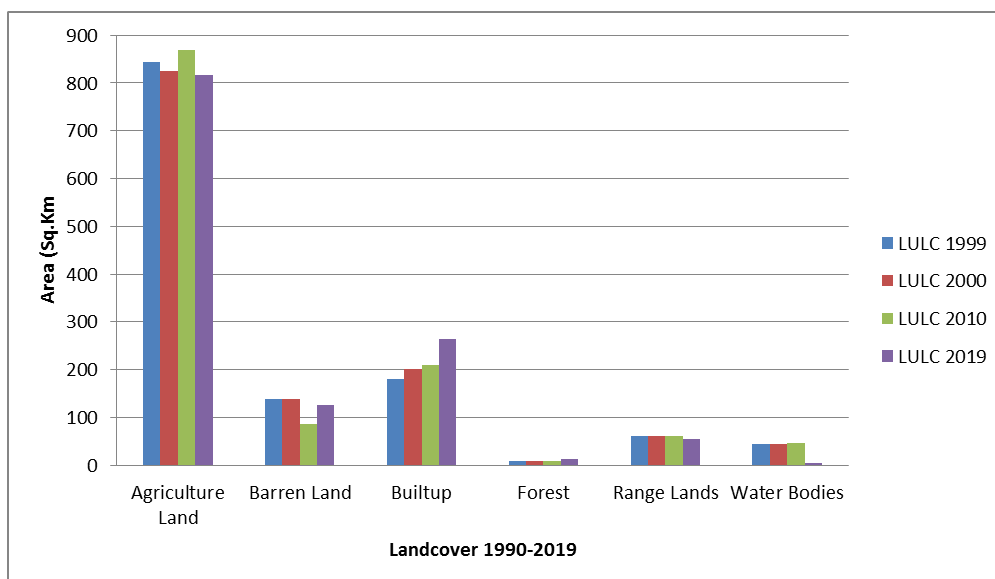


Fig. 3: shows the graphical changes of land cover for 1990, 2000, 2010 and 2019.

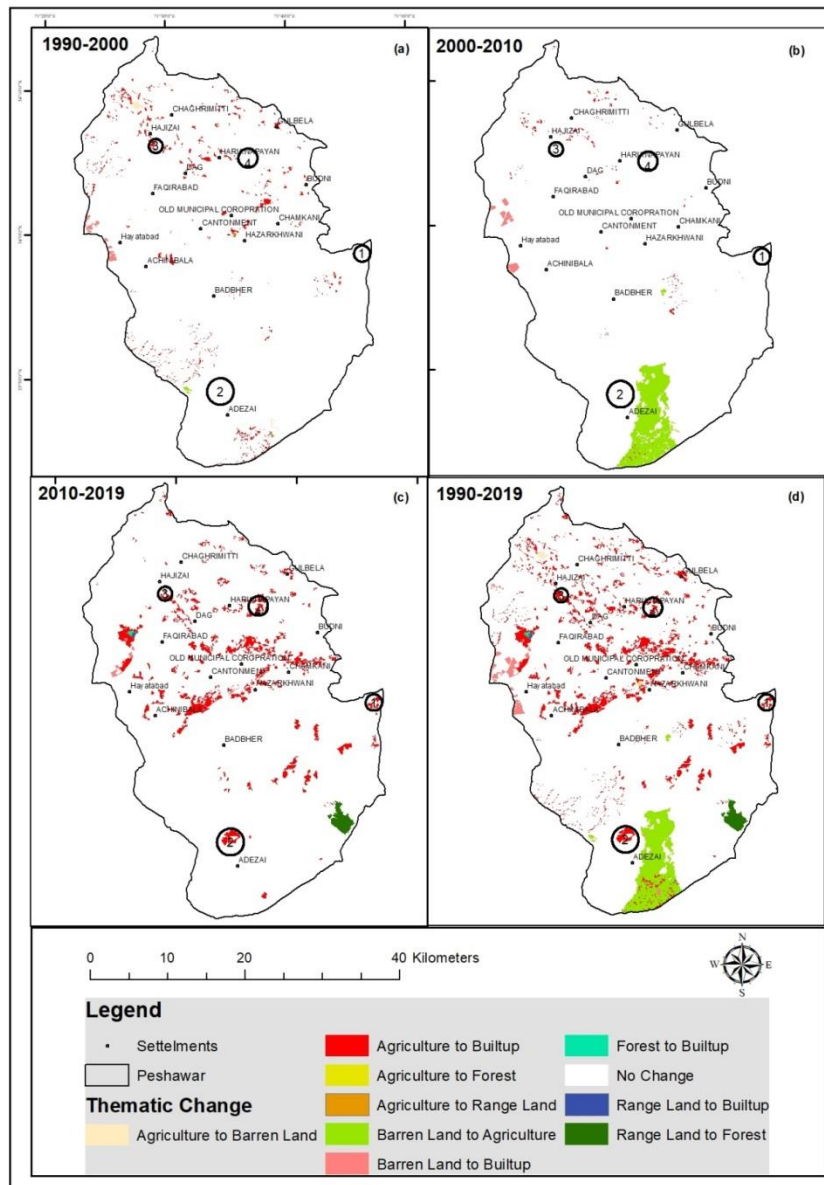


Fig. 4: shows the land cover thematic change map

Table 4: Landcover thematic change descriptive statistics

LAND COVER	1990-2000		2000-2010		2010-2019		1990-2019	
	Area (Km2)	%	Area (Km2)	%	Area (Km2)	%	Area (Km2)	%
Agriculture to Forest		0.007					0.09	0.007
Agriculture to Barren Land	2.51	0.13					1.77	0.13
Agriculture to Builtup	19.42	5.9	3.72	0.29	53.89	4.21	75.38	5.9
Barren Land to Agriculture	0.43	3.82	49.2136	3.85			48.88	3.82
Barren Land to Builtup	2.74	0.59	3.96156	0.31	1.77	0.13	7.55	0.59
Forest to Builtup		0.03			0.43	0.034	0.43	0.034
Range Land to Forest		0.48			6.24	0.48	6.24	0.48
Range Land to Builtup		0.02			0.28	0.02	0.28	0.021

**Landcover thematic change detection:**

From 1990 to 2000, as shown in figure 4 (a) the thematic change map as shown in the figure 3.3, shows that 19.42 Km<sup>2</sup> of agriculture land is converted to impervious structures i.e. concrete structures, roads etc. About 2.74 Km<sup>2</sup> of barren land is also converted to builtup areas. While 0.43Km<sup>2</sup> of barren land is converted to agriculture land. About 2.51Km<sup>2</sup> of agriculture land is converted to

barren land during 1990 to 2000. During the year 2000 to 2010, (figure 4) 3.72 Km<sup>2</sup> of agriculture land is converted to builtup and 3.96 Km<sup>2</sup> of barren land is converted to builtup area. About 49.21 Km<sup>2</sup> (table 4) of barren land is converted to agriculture land. During year 2010 to 2019 (figure 5), about 53.89 Km<sup>2</sup> of area is converted to builtup area while 1.77 Km<sup>2</sup> of barren land is also converted to builtup areas. Forest land of 0.43

Km<sup>2</sup> is converted to builtup area however, 6.24 Km<sup>2</sup> of range land is converted to forest land during BTAP in Garhi Chandan of district Peshawar. Summarizing the whole thematic change in district Peshawar from 1990 to 2019 (figure 4 and figure 5), as a whole, 75.38 Km<sup>2</sup> of agriculture land is converted to builtup. 7.55 Km<sup>2</sup> of

barren land is converted to builtup and 0.43 Km<sup>2</sup> of forest also converted to builtup. About 48.88 Km<sup>2</sup> of barren land is converted to agriculture land and 6.24 Km<sup>2</sup> of range land (figure 4) is also converted to forest during BTAP activities.

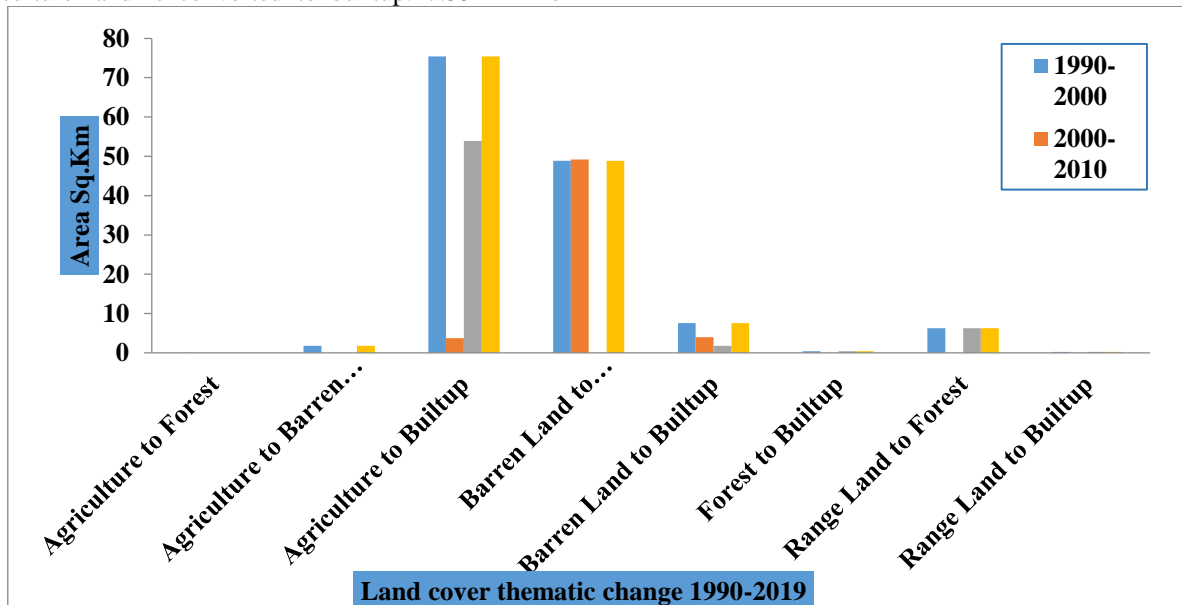


Fig. 5: shows the land cover thematic change graph.

Table 5: shows the comparison of observed air temperature and estimated surface temperature.

Date	T <sup>0</sup> (°C)	T <sup>E</sup> (°C)	Mean	STD	Variation (%)
08-Oct-90	26	25	25.5	0.5	1.96
19-Oct-00	25	24	24.5	0.5	2.04
15-Oct-10	24	26	25	1	4
08-Oct-19	29	28.84	28.92	0.08	0.27

#### ***LST and Air Temperature with Spatiotemporal pattern of land surface temperature (LST):***

The observed air temperature and estimated surface temperature T<sup>E</sup> for 1990 to 2019 was analyzed. The observed data (T<sup>0</sup>) from Peshawar meteorological observatory and LST (T<sup>E</sup>) derived from Thermal bands of Landsat archives (Table 5) shows that the lowest coefficient of variation values were observed for 08 Oct 2019 images i.e. 0.27% and highest for 19 October 2000 images i.e. 2.04%. The results show (table 5) that the estimated temperature is lower than the observed temperature for 1990 and 2019 and 2000 while it is higher for 2010. The variation in the results are due to the use of two different medium of data i.e. soil surface data (estimated temperature) and air temperature observed at Peshawar meteorological observatory.

The LST derived from the satellite imageries shows that the LST values (Figure 6) are high in builtup and barren land areas. The lowest LST is recorded in water and vegetation classes. The year 1990 LST shows that the UHIs are mostly concentrated in the barren land in the north western and north southern region which are exposed and have less foliage. The LST in the area ranges from 27°C to 35°C. The central portions of the city i.e. the old municipal corporation of the Peshawar

city show some small UHIs due to builtup but are not concentrated.

The LST values ranges from the 21°C to 27°C. This area is consistent of impervious surfaces with buildings, roads, hospital, universities and shopping malls which are making it prone for UHI effect. However, the LST result shows that the UHIs in the central portion of old municipal corporation Peshawar have expanded in 2000. The values have been changed ranging from 24°C to 29°C. The north western and north southern barren land has increase in UHIs. However, these portions of the region has been converted to builtup and shows high values of LST ranging from 29°C to 33°C. The 2010 LST shows a significant expansion in the UHIs especially in central portion of old Municipal Corporation. This expansion is the resultant of rapid urbanization and city expansion in the period 2000 to 2010. The vegetation has been transformed into builtup and some small UHIs spread along the upper north western side. The 2019 LST shows drastic increase in the LST values with highly expanded UHIs in the central region of old municipal corporation Peshawar. The LST values ranges from 29°C to 36°C. The loss of vegetation cover in the upper north western portion has transformed into built up and the UHIs are expanded due to increased built up. The LST values ranges from 19°C to 28°C. The

lower portion at north western area shows compression of UHIs due to increase of vegetation cover in the area. The LST values ranges from 26°C to 28°C. Overall, the results show that there has been a significant increase in the LST from 1990 to 2019 and 2019 has highest range of LST values (19°C to 36°C) and expanded UHIs. The rapid urbanization has disturbed the energy balance in the study area. The increase in impervious surfaces and radiations from it has thus expanded the UHIs in the

study area with a significant change in the micro-climate locally. The influence of vegetation has obvious effect on the low temperature values. It is evident (figure 6) that the south western portion of the area shows higher values of LST in uncultivated agriculture land. The bare uncultivated bright textured soil is shows higher values in respect to agriculture land due to disturbed energy balance and less absorption in bare surfaces (Ranagalage et al., 2017).

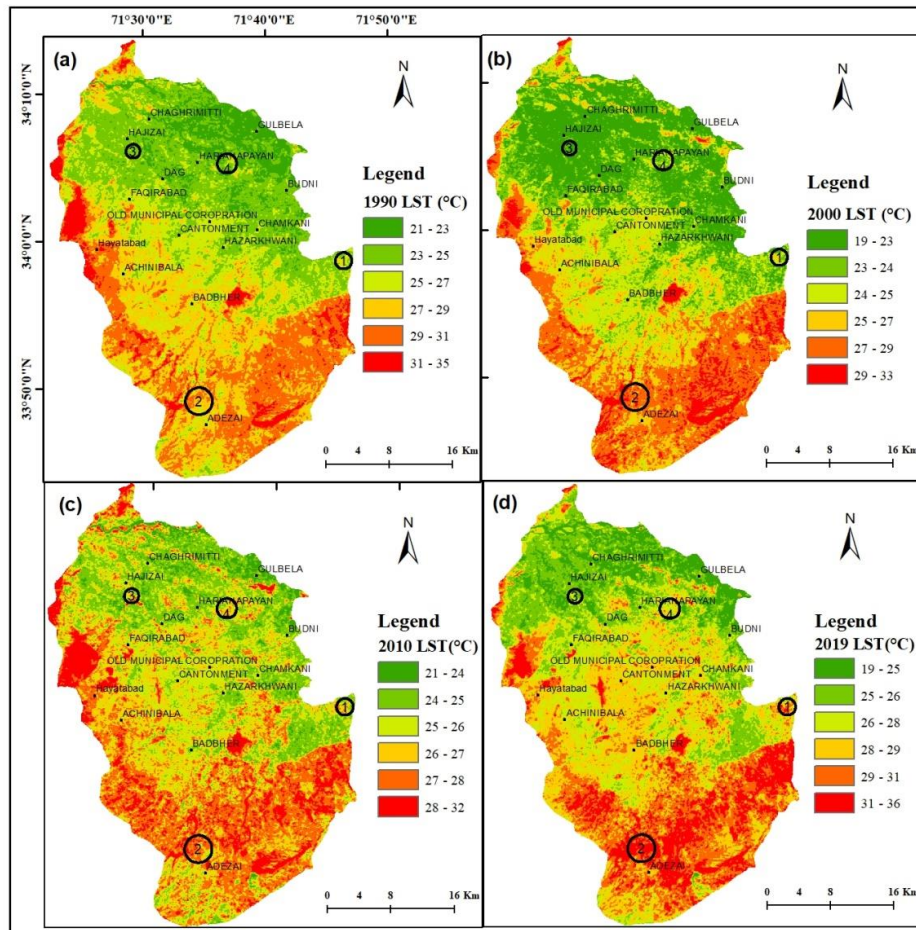


Fig. 6: shows the a) mean LST for the year 1990 b) mean LST for the year 2000 c) mean LST for the year 2010 and d) mean LST for the year 2019.

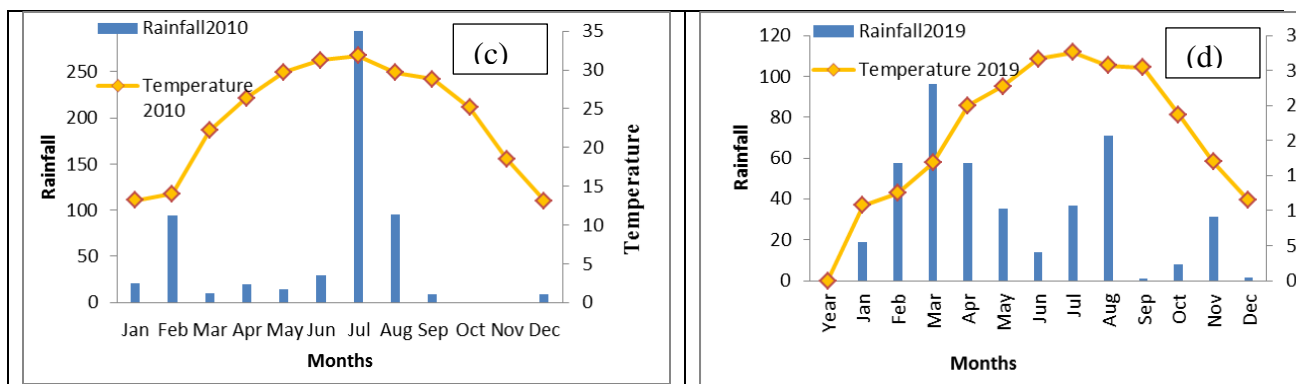


Figure 7: shows the mean monthly temperature with mean monthly rainfall of (a)1990, (b) 2000, (c) 2010 and (d) 2019.

The air temperature and rainfall data of Peshawar was analyzed for year 1990, 2000, 2010 and 2019 respectively. The study area received rainfall ranging from 15 to 70 mm (figure 7a) during January to April

1990. The temperature was low during these months and gradually starts increasing during April 1990. The area received less rainfall during monsoon season from May to July ranging from 0 to 15 mm with a surge in

temperature from 15 °C to 34 °C. However, during August 1990, the area received rainfall of 75 mm and the temperature started declining. The rainfall values remained between the ranges of 40 to 40 mm with a gradual decrease in temperature from 25 to 5°C from September to December 1990. The study area received rainfall ranging from 5 to 40 mm (figure 3.4b) during January to April 2000. The temperature was low during these months and gradually starts increasing during April 2000. The area received less rainfall during monsoon season from May to July ranging from 0 to 15 mm with a surge in temperature from 15 °C to 37 °C. However, during September 2000, (figure 7b) the area received rainfall of 45 mm and the temperature started declining. The rainfall values remained between the ranges 5 to 45 mm with a gradual decrease in temperature from 30 to 10°C from September to December 2000. There is a sudden increase in rainfall (figure 7 c) during July 2010. The area received a record amount of rainfall in 2010 (figure 7c) resulting into flood in Peshawar region. The area received a total of 294 mm rainfall in July. The temperature ranged between 20 °C to 30 °C in Monsoon season during 2010. About 45 mm of rainfall was also recorded in August 2010. The temperature started

declining from August 2010 and onward. The area received about 5 to 100 mm rainfall (figure 7d) during January to March in 2019. Temperature was low ranging from 0°C to 15°C. During the Monsoon, the area received less rainfall and the temperature surged from 15°C to 35°C. In August the rainfall values raised to 60 mm. The temperature starts declining from August and onward.

It is evident from the LST histogram graph that the high values are found in the 20°C to 30°C class while lower values in 30°C to 35°C for 1990 LST. The 2000 LST (Figure 8b) graph shows that higher values in the 19°C to 25°C classes. The 2010 LST (Figure 8 c) graph shows the higher values in 24°C to 26°C class. However, the 2019 LST (Figure 8d) graph shows that the values are symmetrically distributed. The lower LST classes show low values and as the LST class values increase, the values also increases. The 27°C to 29.36°C classes have higher number of values. As the temperature classes increase further, i.e. 31°C to 36°C, the values start decreasing again. The 2019 data exhibit highest values of surface temperature which is an evidence of expanding UHIs.

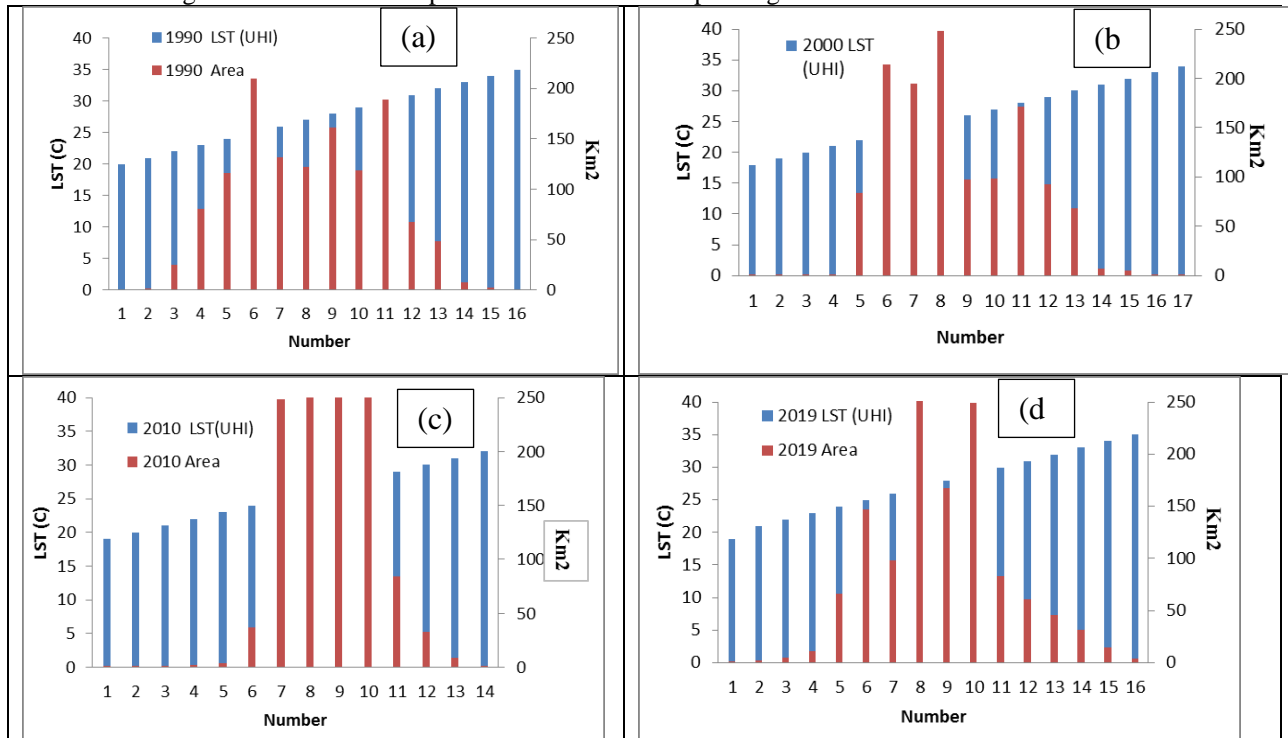


Fig. 8: shows the LST values creating UHI zones (km<sup>2</sup>) a) 1990 b) 2000 c) 2010 d) 2019.

The profile A-B was drawn (figure 1) to study variation in LST values from 1990 to 2019. It is evident from the results (figure 9) that the main changes in temperature occurred in 2010 and 2019 where the UHIs has been expanded and surface temperature has increased. The highest values of LST recorded are 25°C to 36°C. These

values are recorded in the central region i.e. built up area of the Peshawar city. These are the significant contributors to the formation of UHI effect in built up, barren and uncultivated agriculture areas. The higher values of the above range are recorded for barren land due to zero or less vegetation.

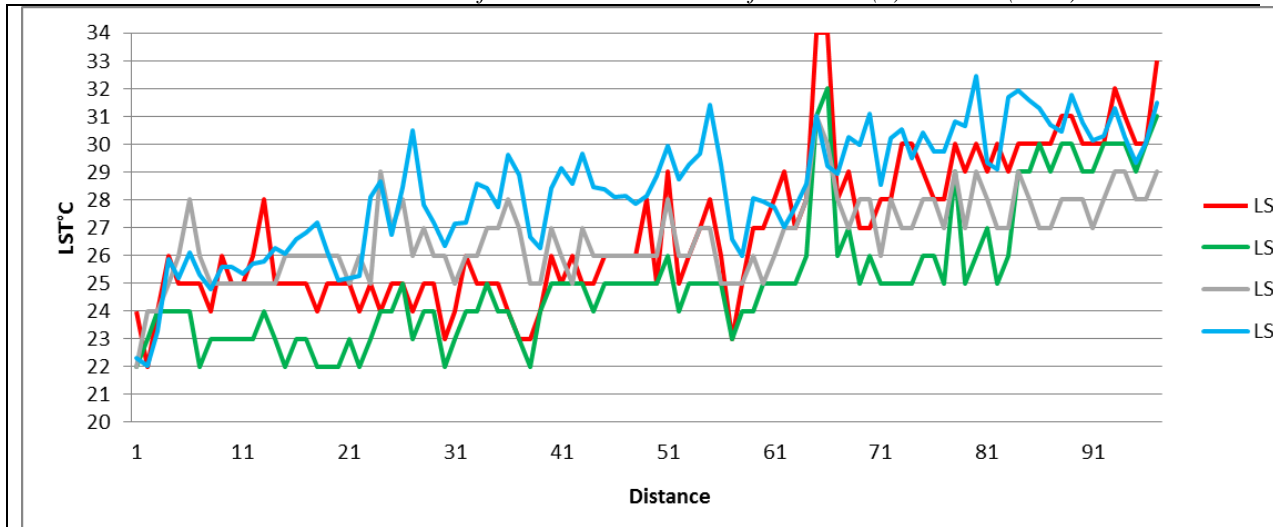


Fig. 9: show the LST variation along the profile (A-B) in 1990, 2000, 2010 and 2019.

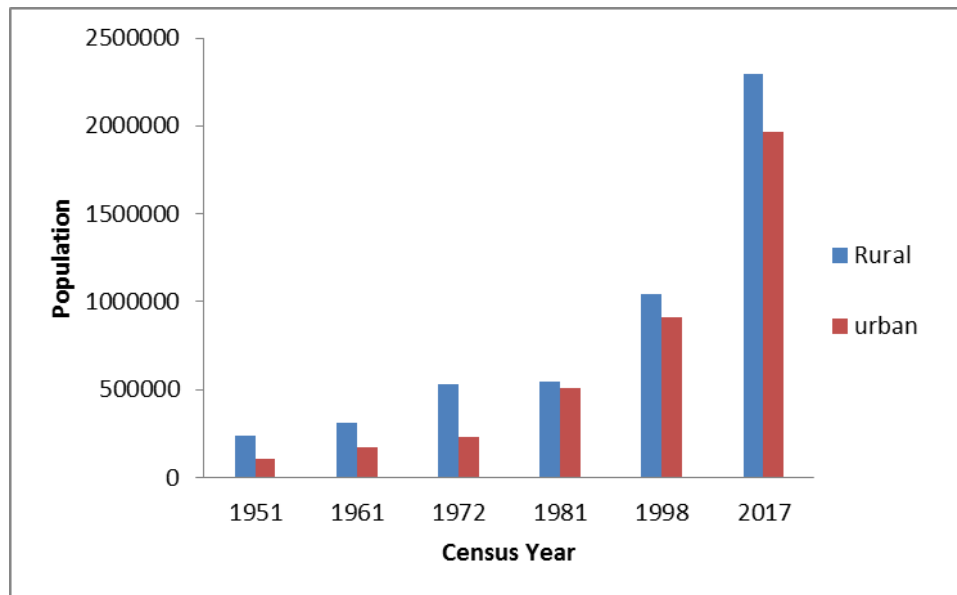


Fig. 10: shows the urban and rural population statistics of the Peshawar from 1951 to 2017.

### Population nexus urbanization:

Since the oldest times, Peshawar has been on the most important place for business in Khyber Pakhtunkhwa, Pakistan. Its geostrategic location and center for business, health and education facilities has played a major role in the rapid urbanization of the city. Owing to the various developmental projects, Peshawar has been rapidly urbanized. The most developmental activities were concentrated in the old municipal corporation. This has resulted into the increasing urban population and to cope with the needs of the community, it has been transformed to highly urbanized city. In 1951, the urban population of the city remained 0.1 million, (figure 10) which was increased to 0.17 million in 1961. The population has increased to 0.22 million (figure 10) in 1972 and it increased to 0.50 million (figure 10) in 1981. However the rapid changes in the demography occurred, increasing the population of urban areas of Peshawar by 0.91 million. During the Census 2017, the urban population has been increased drastically to 1.97 million

(figure 10) contributing as 46% of the total population. However, the 54% of the population i.e. 2.2 million (figure 10) population is living in the urban areas of the Peshawar.

### Discussion

Besides, low spatial resolution, the Landsat is most widely used remote sensing satellite for land cover and LST based research. The rapid changes in the landscape have resulted into the increase of the builtup area due to replacement of the barren and agriculture land with the impervious surfaces. The results show that this conversion of vegetated land i.e. 5.9% of agriculture land into impervious surfaces is the main cause for increase in LST along the study area and most specifically in the Old Municipal Corporation of Peshawar. Overall, the findings demonstrate that the average LST recorded between the years, 1990 to 2019 remained in the range of 25°C to 36°C. The same trend of urban expansion along with changing LST values has

been reported in other major cities of Pakistan. In the Lahore, the urban expansion has been increased by 20% resulting into the changing LST values reported by Saleemi, (2015). Similarly, Raziq et al., (2016) analyzed found that the urban areas have been expanded by 26.59% in the Peshawar. Khan et al., (2020) analyzed that the Islamabad urban area has been expanded by 11.9% with significant increase in the RLST. The changing demography of the Peshawar (Figure 10) is playing a key role to encourage the urban expansion. The LST and air temperature data shows a strong correlation authenticating the methodology used for the derivation of LST. The changing pattern of rainfall has induced the micro level climate changes in the study area resulting into sudden hype in the air and surface temperature. This study also had certain limitations. A ten year of temporal resolution was used from 1990 to 2019. However, the rainfall and temperature data was collected from single meteorology observatory. A high resolution of satellite data like SPOT and QuickBird is recommended for LULC generation. A well spread metrological data on daily basis may be analyzed to understand the correlation between LST and air temperature for future research.

### Conclusion:

The land cover and LST is a well-known phenomenon in research. This study focused on the relationship between the LULC and LST using remote sensing data and meteorological data. The LST has a positive correlation with LULC. This rapid change in the land cover classes are due to the increased population. This study signifies the use of multi temporal satellite imageries to study the LULC and LST based UHIs development. The land cover has a great impact on the local micro climate. The Peshawar district have high values of LST in north western, north southern and north central region due to buildup and barren land. The UHIs studies can be carried out using thermal bands of satellite imageries. The highest values of LST are recorded in 2010 and 2019 which are resulted due to decrease in vegetation and increased impervious surfaces. The study shows that more detailed research on land cover and LST is mandatory due to progressive urbanization activities around the globe.

To properly mitigate the consequences of changing urban climate, it is necessary for the policy makers to do some speedy intervention for growing urbanization with an planned yet controlled manner. This study can help policy makers to understand the negative effects of changing urban climate with increased LST due to decreasing agriculture land. The study also recommends more research especially analyzing the effect of increasing LST on green spaces in comparison with increasing population and air pollution.

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