Local climate zones and its potential for building urban resilience: A case study of Lahore, Pakistan

Journal:	*International Journal of Disaster Resilience in the Built Environment*
Manuscript ID	IJDRBE-08-2021-0116.R1
Manuscript Type:	Research Paper
Keywords:	climate resilient, adaptation, land cover, urban heat island, WUDAPT, urban morphology

Local climate zones and its potential for building urban resilience: A case study of Lahore, Pakistan

Abstract

Purpose Urban built-up area has been increasing exponentially in the world. Urban population growth and migration are depleting the land resources and creating thermal discomfort. Cities all around the world are facing urban heat island effects and increased temperatures. This study aims to map land cover and formulate local climate zones for enhancing urban resilience against disaster and climate risks.

Design/methodology/approach This study uses exploratory research to identify local climate zones for Lahore, Pakistan. Landsat 8 imagery was used to develop a land use-land cover map. For mapping local climate zones, the standard WUDAPT procedure was used.

Findings Results have revealed that Lahore has grown exponentially. Compact low rise and open low rise were the two most common local climate zones prevalent in the city. In contrast, the outer regions of the city consisted of LCZ D (low plants) and LCZ F (bare soil).

Originality Local climate zone studies are missing in Pakistan. This study has empirically analyzed the ground situation of local climate zones for Lahore metropolitan city. This study will provide baseline support for future studies on urban heat island and climate change adaptation planning.

Practical implications This study highlights the need to consider local climate zones in future development plans and policies for ensuring sustainable, resilient, and climate-friendly cities.

1

1 Introduction

Cities are the center of innovation and economic growth. Living in cities provides many opportunities and incentives like education, high income, and better facilities. This leads to the consistent migration of people from rural regions to urban centers. There are pros and cons associated with living in metropolitans, such as better housing, education, jobs, and infrastructural facilities, but also pollution and congestion (Bertinelli and Black, 2004). This migration is the leading cause of unplanned growth and rapid urbanization. This phenomenon occurring worldwide contributes to the changing landscape and land use patterns (Deng *et al.*, 2009). The global urban population increased by 20% in the last 50 years (Cui *et al.*, 2019). It is expected that up till 2025, more than 65% of the population will be living in cities (Schell and Ulijaszek, 1999). This rapid growth is also affecting the environmental conditions of the cities. Green spaces affect the environmental conditions of the cities (Zhou and Wang, 2011). The presence of green spaces is good for mental health as well. They also help mitigate the urban heat island effects (Yuan and Bauer, 2007). Loss of green spaces to accumulate the rapidly growing population is not the only consequence associated with faced paced urbanization. Still, it also leads to excessive energy consumption and excessive carbon dioxide emissions, a major cause of climate change (Zhou and Wang, 2011). Although urban areas only occupy 3% of the land; they consume around 70% of the resources and are a source of 60 to 80% of the CO2 emissions, according to a United Nations' report (2012). Anthropogenic climate change accelerated due to carbon emissions, causing an increase in extreme events like floods, droughts, etc. (Baker *et al.*, 2018). The future occurrence of these events is likely to increase if not managed properly (Ching *et al.*, 2018). To protect the people and planet, the United Nations has developed goals to promote sustainable development and improve the environment. Sustainable goal 11 is linked to building sustainable cities and communities (Griggs *et al.*, 2013). Therefore, it is needed to follow the goals and promote actions and policies to create climate-friendly and resilient development.

The major contributor to climate change is anthropogenic activities. This phenomenon is occurring all around the world. It has also increased the risk of weather-related damages (Smith and Matthews, 2015). Pakistan is a country that is ranked among the top countries that will be affected by this changing climate (Khan *et al.*, 2016). It is ranked 10th in vulnerability to climate change by the Germanwatch Global Index, while it is ranked 5th according to the Global Climate risk index 2020. Hence the effects linked to this climate change are inevitable, and if it is not managed properly, it will lead to severe

problems in the longer run. Thus, it is imperative to promote policies and strategies to help achieve sustainable development goals and mitigate the risks associated with global warming.

This study analyzes the development patterns and land cover conditions in Lahore. Apart from that, this study also considers the urban morphology of the city and its effect on thermal stress levels. Moreover, this study also provides a basic framework that will help urban temperature studies and can be used in future development plans and policies. This study promotes an integrated approach that will involve urban planners, climatologists, and architects to promote climate-resilient and sustainable development.

2 Local climate zones

There have been many studies done all around the world regarding the urban heat island and its impacts. Earlier, most of these studies classified the area as urban and rural to observe their temperature differences. This can be used to get a general idea about the thermal conditions. However, this approach was not useful for assessing detailed studies at the micro-scale level. To overcome the problems associated with it, a scheme of local climate zones has been proposed by Stewart and Oke (2012). It is a basic and standard method that can be applied anywhere in the world without requiring any extra expertise and knowledge.

Local climate zones are the areas that possess uniform properties of surface coverage and structure, having similar anthropogenic activities and unique air temperatures at the height of 1-2 m above the ground. The areas are classified into 17 classes, out of these 10 for the built-up land and 7 for the vegetative land (Stewart and Oke, 2012). It observes the temperature differences between different LCZ classes (ΔT LCZ 1 – LCZ D) to study them. This initiated a standardized process for urban heat studies, but detailed spatial data regarding the function and forms of cities is still missing. To fill this gap World Urban and Access Portal Tool (WUDAPT) project was started (Bechtel *et al.*, 2015). This online portal contains training areas of some of the major cities. It can also be used as a guide to map the LCZs of the desired cities. This is an easy method as it requires freely available remote sensing data that can be obtained from the United States Geological Survey (USGS) site. Apart from using the Landsat 8 imagery, many studies have also used Sentinel imagery (Hu et al., 2018) and Lidar data (Koc et al., 2018) to get better information about the urban forms and thus helping in mapping the Local climate zones. The training areas can be digitized on Google Earth, while the mapping can be done in SAGA GIS software using the Random Forest algorithm. Some studies have also utilized site photographs (Unger *et al.*,

2014)for better identification purposes. Detailed GIS data from governmental departments have also been used (Geletič and Lehnert, 2016). The use of Open Street Maps has also improved the accuracy of the classification (Fonte *et al.*, 2019).

The standard WUDAPT procedure that has been used in many of the studies done all around; a study conducted in Kyiv and Lviv (Ukraine) (Danylo *et al.*, 2016), Al Ain (UAE)(BANDE *et al.*, 2019) and Szeged (Hungary) (Skarbit and Gál, 2016) followed the same procedure. Moreover, many new methods have also been developed for mapping and improving accuracy. Some studies have used GIS-based methods for mapping the LCZs, like a study conducted in Sydney (Australia)(Rajab, 2018) and Beijing (China) (Quan, 2019). Similarly, a study conducted in Amsterdam, Chicago, Madrid, and Xi'an used different classification algorithms (dos Anjos *et al.*, 2017) for mapping the LCZs. Studies have been carried out on the transferability of the training areas (Kaloustian *et al.*, 2017) to be made faster and more efficient. Apart from mapping and assessing the thermal conditions, the LCZ map can be used for climate modeling (Verdonck *et al.*, 2017). So LCZ can provide information regarding the urban forms and functionalities and the thermal conditions. Along with this, LCZs can be used as an input in modeling the urban climates. They can help us improve the living conditions of the city by improving the built environment by increasing the green spaces. Urban planners can use these LCZ maps to tackle the future extreme weather events and for developing future plans and policies for promoting climate-resilient and sustainable development (Verdonck *et al.*, 2018). It can help understand the built environment and its effect on the local climate so that they can incorporate the knowledge for future plans to promote sustainable development (Cai *et al.*, 2019; Tse *et al.*, 2018). Several studies have used the local climate zone framework for identifying vulnerable areas (Savić *et al.*, 2018). A study conducted in Germany used these LCZ maps and proposed adaptation strategies needed to combat the thermal stress. The study suggested proper ventilation paths and parks with long shady trees to adapt to the changing conditions (Müller *et al.*, 2014). Similarly, a study in Glasgow (UK) maps used LCZ development of a heat assessment tool. The study suggested using more green cover as an adaptation strategy to survive the warming effect (Emmanuel and Loconsole, 2015). Different urban morphology parameters such as sky view factor, building height, albedo, pervious and impervious surface fraction, anthropogenic heat flux, building surface fraction used in the LCZ mapping can also prove valuable for the urban planners in the physical development of a city.

3   The case study area

Lahore is the capital of Punjab province and the 2nd largest city of Pakistan ("Pakistan: Provinces and Major Cities", 2018). Relatively, it is highly developed compared to other cities of the province (Rana *et al.*, 2020). It is seen the It is located between the districts of Sheikhupura and Kasur with touching the Wagah border at one end, and is lying at an elevation of 217m. It has a population of 11,126,285 (Pakistan Bureau of Statistics, 2017), which is increasing consistently, and it is expected that the built-up area will increase significantly with it (Bhatti *et al.*, 2015). Lahore is considered "the heart of the country" due to its cultural, political, and historical importance. Most of the city's architecture has been preserved from the Mughals and the colonial period ("Lahore Cantonment", 2020). It is a major tourist destination. It exhibits several mosques, temples, tombs, parks, and gardens, including some prominent places like Badshahi Mosque, Lahore Fort, Shalimar Garden, Minar-e-Pakistan, Wazir Khan Mosque. Lahore is further divided into nine administrative zones and a cantonment, a total of 10 zones. The other nine administrative zones of Lahore include Aziz Bhatti Town, Data Ganj Bakhsh Town, Gulberg Town, Iqbal Town, Nishtar Town, Ravi Town, Samanabad Town, Shalimar Town, and Wagah Town ("City District Governments", 2009).

[Insert Figure 1]

The six major roads that connect Lahore to other surrounding cities are Jaranwala Road, G.T. Road, Raiwind Road, Sheikhupura Road, Multan Road, and Ferozepur Road. According to an estimate by the highway department, around 1265 sq. km. of the city's area is occupied by roads ("Punjab Development Statistics | Bureau of Statistics, Punjab", 2015). The city also has a railway line that connects it to the remaining country (Lahore Development Authority, 2004). Apart from the routes to other cities, there are transport facilities for an easy commute like Metro (rapid bus system) and Orange Line (train system). The second-largest airport in the country, known as Allama Iqbal International Airport, is situated in the city. It is also considered the most developed city in the province of Punjab regarding socioeconomic and infrastructure development (Rana *et al.*, 2017).

Lahore city has started seeing climate-induced disaster events, such as flash floods (DAWN NEWS, 2019), heat waves (Raza, 2017), excessive rainfall (Kapadia, 2014), etc. Heatwaves are the most likely event affecting the urban population, and their mortality rates are also the highest worldwide. Lahore has also been facing severe heat events. A study conducted observed the land surface temperature (LST) of Lahore from 2007 to 2018 for the month of June, the average LST values were higher in the areas that

were densely populated and hence higher exposure to LST they face adverse health effects (Zuhra *et al.*, 2019). In June 2019, the temperature in Lahore reached 46°C (The NEWS, 2019), and during July 2021, the temperature touched 44.1°C (The NEWS, 2021)

Different organizations in Lahore are managing the city. In the beginning, Lahore Improvement Trust was set up in 1936 to oversee housing demands and needs (Groote *et al.*, 1989). Later, a principal agency named Lahore Development Authority (LDA) was created under the LDA Act 1975. It took over the Lahore Improvement Trust ("Lahore Development Authority", 2014). Along with LDA, some other organizations are tasked with providing and maintaining infrastructure, development control, and land development, such as Defence Housing Authority, Cantonment Board, Model Town Society, Walled City Development Authority, etc. Moreover, private housing schemes/organizations are also working to meet the continuously growing housing demands. However, LDA is responsible for developing master plans for the entire city. Still, as there is no proper coordination between all these organizations, no plan has been implemented across the whole city due to jurisdictions and financial problems (Hameed and Nadeem, 2008).

Up till now, many efforts have been made to develop the master plan of the city. The first time preparing the Master plan for Lahore city started in 1961, and the authority that undertook this job was formed specifically for this task by the Government of Punjab. The plan remained pending for a long time and was approved in the year 1971. At that time, the whole scenario that was considered while planning was transformed, so the master plan became outdated (Hameed and Nadeem, 2008). Another plan, named Structure Plan, proposed for 20 years (1981-2000), failed in its execution due to lesser citizens participation and following the same outdated master plan. A private firm prepared the latest Master plan of Lahore under the supervision of LDA, and it is known as the Integrated Master Plan for Lahore 2021, approved in the year 2004. Although some of the plans are implemented, there is still a need for better coordination among the departments.

4 Data and methods

4.1 Data collection and sources

This study analyzes the surface and land cover conditions of Lahore city. It provides a framework for urban temperature studies that can be used as a standard in future plans and policies for unplanned cities of the developing world. To accomplish these tasks, images of the year 2019 were used. Landsat

images were downloaded from the freely available and accessible site of USGS Earth Explorer (http://earthexplorer.usgs.gov/). The images obtained were used for land cover mapping and preparing a local climate zone map using the standard WUDAPT methodology. The input data and source used in the study have been provided in table 1 below.

Table 1 Data sources and its description

Analysis	Data	Source	Images Details
Land use land cover change	Landsat 8	USGS Earth Explorer	LC08_L1TP_149038_20190519_20190522_01_T1
Local climate zone classification	Landsat 8	USGS Earth Explorer	LC08_L1TP_149038_20190401_20190421_01_T1
			LC08_L1TP_149038_20190519_20190522_01_T1
			LC08_L1TP_149038_20191026_20191030_01_T1
	Training areas	Google Earth	

4.2   Data analytical methods

The data collected was processed and analyzed to identify the built-up area and LCZ classes. In the first step, the land use land cover mapping was done for Lahore city. For this purpose, the Landsat image of the year 2019 was used. For the collection of signatures after layer stacking, different band combinations were used for better identification. For built-up land and vegetation, false-color images having a band combination of 542 were used. One thing that should be kept in mind while collecting signatures is that they should be collected randomly and distributed evenly across the whole area. After acquiring the signatures, the Maximum Likelihood Classification was done. The software used for land use land cover mapping was ArcMap. A detailed flowchart of the methodology has been given in figure 2.

[INSERT Figure 2]

In the next step, the mapping of local climate zones was done. The standard WUDAPT procedure was followed for it. The Landsat images of multiple time periods of the year 2019 required for mapping were imported to SAGA GIS and cropped according to the region of interest (ROI). The resampling of the images was done to 100m, mostly used, but it can be changed according to the needs (Bechtel *et al.*, 2015). For this purpose, training samples were required from each class. The collection of the training areas from the Google Earth sample template file was downloaded from the WUDAPT site. It contained class names, and amendments were made to it according to the needs. The file was uploaded on Google

Earth, and training areas were digitized for each class. After the samples were digitized, the file was saved in KML format. After importing the file, the projection system was transformed into Universal Transverse Mercator (UTM) so that both datasets have the same reference system. The algorithm used for mapping the LCZs is Random Forest. The output file saved in KML format was uploaded to Google Earth for post-classification accuracy assessment. In case of unsatisfactory results, more samples were collected, and the classification was done again. This same process was done repeatedly until the desired, and satisfactory results were obtained.

5   Results and discussion

5.1   Land cover

The land cover map shows the areas occupied by vegetation, built-up, soil, or water. Satellite images from Landsat 8 were used for the month of May. The Land cover map was prepared in ArcMap using the Maximum likelihood classification. The map of 2019 reveals that most of the space has been occupied by bare soil with an area of 928.55 sq. km. Built-up land is spread over 478 sq. km out of a total of 1791 sq. km. area, with the percentage that has now crossed 26%.

Similarly, the vegetative cover occupies an area of 378.02 sq. km. The water body occupies a minimum area of around 6.08 sq. km, having only a percentage of 0.33 in the overall share. From the land cover map, it is clear that most of the area of Lahore has been occupied by bare soil (Figure 3). Hence, it is needed to convert the bare soil areas into vegetative land to help reduce the city's thermal stress. Most of the bare soil land in the area is due for construction purposes, and the land has been cleared for built-up purposes. Along with development, it is also needed to work on the development of green areas and parks. Apart from the overall land cover of the city, the conditions are observed at the union council level (Figure 3). The detailed analysis can help transform the city conditions from bottom to top. Smaller unit-level analysis helps identify the problems at a smaller level that can help formulate better plans and policies. In short, proper planning is required to stop this rapid and unplanned growth. Strict actions are needed to focus the shift from unplanned haphazard development to planned and sustainable development to make the city environmentally friendly, improve the life quality, and preserve green areas.

[Insert Figure 3]

5.2   Local climate zones of Lahore

After conducting the land cover analysis and getting a general idea about the land cover types in Lahore, the area was classified in local climate zones using the WUDAPT procedure to analyze the urban morphology and surface cover characteristics and observe the city's thermal conditions thoroughly. To get an idea about the classes, the Google earth view has been provided in figure 4. The LCZ map shows different zones classified in the area. The type of development pattern followed by Lahore can be determined from the prepared LCZ map (Figure 5, 6). A total of 16 land cover classes were determined in the area except for the LCZ 1, i.e., compact high rise based on knowledge and understanding.

[Insert Figure 4]

The basic layout or the development pattern is presented in the maps below (Figure 5). The central part of the city, referred to as a Walled City, falls in the LCZ 3 category, i.e., compact, low rise. The center of the city is compactly developed. Areas like Badami Bagh, Gulshan-e-Ravi, Shahdara, and Model Colony fall under this category. Moving outwards mostly the areas of DHA, Wapda Town falls in the LCZ 6 category, i.e., open low-rise. The new development that has been done falls in the LCZ 6 category. The most dominant class in Lahore is LCZ 3, i.e., compact low-rise, followed by open low-rise, i.e., LCZ 6. Other zones like LCZ 2, 4, and 5 are not as dominant compared to the other two LCZ types, i.e., LCZ 3 and 6. LCZ 2, i.e., compact mid-rise, was spread throughout the city in smaller portions, areas like Askari 11 sector B, Ashiana Quaid Housing Scheme, and so on. LCZ 4, i.e., the open high-rise, was minimally represented. LCZ 5, i.e., open mid-rise, consisted of areas like Railways Officers Flats present in the center of the city, Shuhada Town located in the outskirts of the city, and some commercial zones. Some large-low rise, lightweight low-rise, and sparsely built settlements, i.e., LCZ 7, 8, 9, also exist in the outskirts. The city is expanding in the south and east direction. LCZ A, i.e., dense trees, was present along the (water body) LCZ G present in the west direction of the city. Whereas some of the areas around the LCZ G belonged to LCZ C (scrubs and bushes) and LCZ F, i.e., bare soil or sand, that was also present on the outskirts of the city in the south and east direction.

[Insert Figure 5]

Lahore is a big city with nine administrative towns and a cantonment board (Mahmood *et al.*, 2019). The land cover and urban morphology analysis provided significant details regarding Lahore city and its administrative zones. For overall Lahore city, the land cover type of bare soil occupies most of the area (Figure 6) with the percentage of 51.82 %, and after that, built-up had an area of 26.7%. The combined

percentage of built-up and bare soil is 78.7%, while the land occupied by vegetation and water is only around 21.3%. The most dominant built-up LCZ classes in Lahore are LCZ 3(compact low rise) and LCZ 6 (open low rise). The land cover conditions of the nine administrative towns and a cantonment of Lahore are also discussed here in detail. After assessing the standard land cover conditions, the detailed urban morphology of the area is studied using the LCZ map of Lahore. The LCZ classes present in these towns are also assessed. It is one of the oldest towns of Lahore, located in the northwest direction of the city, geographically located at 31° 32' 25" North and 74° 18' 25" East.

[Insert Figure 6]

The detailed analysis of the administrative towns helped identify the dominant land cover types and LCZs in the respective zone. The biggest of these towns is Iqbal town, with an area of around 520 sq.km., followed by Nishtar and Wagha, having an area of 497 and 440 sq. km. The smallest is the Shalimar town occupying an area of around 24 sq. km. The conditions of these zones of Lahore are provided in detail (Table 2).

The first town discussed is Wagha town. The population of the town is 293,000. Most of the area of the town is occupied by bare soil followed by vegetation. Out of the total area of 440 sq.km., around 228 sq. km. is covered by bare soil. The most dominant LCZs observed in the town are LCZ D, i.e., low plants, and LCZ F, i.e., bare soil. For the built-up types, LCZ 6 (open low-rise) followed by LCZ3 (compact low rise) are present at some places. In the case of Nishtar town, it is the second largest town in terms of an area having only a population of 599,000. Around 66% percent of the land in the town is occupied by bare soil. The built-up land covers an area of 72.12 out of 497 sq. km., i.e., around 14%. The built-up land mostly belonged to the LCZ 6(open low rise) and LCZ 9 (sparsely built settlements). The most dominant LCZ present in the area is LCZ D (low plants) and LCZ F (bare soil).

The third town is Shalimar town. It has an area of 24.3 %, which is the smallest of all the other administrative zones/towns. Most of its area is occupied with the built-up land having a percentage of 78.5%. The most dominant built-up zone is LCZ 3 (compact low rise), with some proportions of LCZ 6(open low rise). The area also contains LCZ C (bushes and scrubs) and LCZ D (low plants). The fourth administrative zone is Aziz town/zone. It is present between Wagha, Shalimar, Cantonment, and Gulberg town. The total area is 69.05 sq.km., with vegetation occupying an area of 15.19 sq.km., built-up 28.87 sq.km., and bare soil 24.98 sq. km. with a very small proportion of water bodies. The most dominant LCZ is LCZ D (low plants), followed by LCZ 3 (compact low rise) and LCZ 6 (open low-rise).

Another dominant LCZ present in the area is LCZ F (bare soil). The vegetation and bare soil occupy nearly 58% of the area, which comes under LCZ D and LCZ F.

The fifth administrative zone is Samanabad. It is one of the oldest areas of Lahore. It is also an important educational hub, with many public and private sector institutes. It is located between Data Gunj Baksh Town, Iqbal Town, and Gulberg Town. The population of Samanabad is 1,086,000 (Population Council, 2016). The total area of Samanabad is 37.51 sq. km. Most of the land is occupied by the built-up land consisting of 28.13 sq. km. area having a percentage of around 74.9, followed by vegetation with an area of 4.28 sq. km. and bare soil occupying 4.38 sq. km. of the area. The most dominant built-up LCZ class present in the area is LCZ 3, i.e., compact low-rise, followed by LCZ 6, i.e., open low-rise. In the vegetative classes, most of the land is occupied by LCZ D, i.e., low plants with some proportions of LCZ C (bush and scrubs), LCZ B (scattered trees), and rarely LCZ A (dense trees). LCZ F, i.e., bare soil is scattered throughout the area. The next area is the Cantonment board. Its population is 892,000, and the total area is 97.76 sq.km., out of which built-up land occupies an area of 59.54 sq. km. and bare soil an area of 28.15 sq. km. Hence, around 90 % of the total land has been covered with built-up and bare soil; only 10% of the land constitutes vegetation. From the LCZ map, it has been observed that most of the development in the area is in the form of LCZ 6 (open low rise) followed by LCZ 3(compact low rise). LCZ D (low plants) and LCZ F (bare soil) are the two vegetative classes predominantly found in the study area.

The next town is Iqbal town. Present in the southwest of the city, it is the largest town of Lahore, having a population of 318,000. It shares most of its boundary with Nishtar town, while some with Samanabad town and Gulberg town. While analyzing the land cover conditions, bare soil occupies 54.5 % of its total area; built-up consists of 24.3 %, while vegetation and water consist of 20.4 % and 0.69 %, respectively. The most dominant vegetative class is LCZ D (low plants), followed by LCZ F (bare soil). The development in the area is mostly of open low rise, i.e., LCZ 6. Along with this, one other dominant built-up class is LCZ 9 (sparsely built settlements). Gulberg town is present in the center of the city, sharing its boundaries with many towns, i.e., Iqbal, Nishtar, Cantonment, Shalimar, Samanabad, Data Gunj Baksh, and Aziz town. Its population is 859,000, and the total area is 43.80 sq.km., with the most dominant land cover of built-up land occupying nearly 33.3 sq. km. of the area. Vegetation and bare soil are present in small amounts, covering only 14% and 9% of the area. Present in the city center, the most dominant built-up class is LCZ 3 (compact low rise), followed by LCZ 6 (open low rise) and LCZ 2 (compact mid-rise). In the case of vegetative classes, the dominant class is LCZ B (scattered trees).

11

In the northwest corner of the city, Ravi town is the most populated town with a population of 1,749,000, having only an area of 30.5 sq. km. In the town, 73% of the land has been occupied by built-up class while 12.7 % is covered by bare soil and 10.8 % with vegetation. The two most dominant built-up LCZ classes are the same as present in most of the other towns of Lahore, i.e., LCZ 3 (compact low rise) and LCZ 6 (open low rise), along with the vegetative classes of LCZ D (low plants) and LCZ F (bare soil). Data Gunj Baksh town is also densely populated, having a population of 1,070,000. Out of the total area of 30.5 sq. km., built-up land occupies 24.47 sq. km. of the area, and the vegetation occupies 3.42 sq. km. In the case of LCZ, classes for built-up LCZ 3(compact low rise) and LCZ 6(open low rise) are the most dominant, while in the case of vegetative classes LCZ B (scattered trees) and LCZ D (low plants) are present predominantly.

Table 2 Land cover and urban morphology information of Administrative Zones of Lahore

Administrative Zones	Population (approx. persons per sq.km.)	Land cover types			Dominant Local Climate Zones
		Land cover type	Area sq.km.	%age	
Wagha Town	293,000 (666)	Vegetation	133.12	30.25	LCZ D, LCZ F, LCZ 6, LCZ 3
		Water	0.28	0.06	
		Built-up	64.09	14.56	
		Bare Soil	242.58	55.12	
		Total	440.07	100	
Nishtar Town	599,000 (121)	Vegetation	93.37	18.78	LCZ D, LCZ F, LCZ 6, LCZ 9
		Water	0.07	0.013	
		Built-up	72.16	14.52	
		Bare Soil	331.44	66.68	
		Total	497.04	100	
Shalimar Town	585,000 (23655)	Vegetation	2.194	9.004	LCZ 3, LCZ C, LCZ 6, LCZ D
		Water	0.035	0.14	
		Built-up	19.15	78.56	
		Bare Soil	2.99	12.29	
		Total	24.37	100	
Aziz Town	623,000 (9022)	Vegetation	15.19	22.002	LCZ D, LCZ 3, LCZ 6, LCZ F
		Water	0.001	0.0013	
		Built-up	28.87	41.81	
		Bare Soil	24.98	36.18	
		Total	69.05	100	

Samanabad Town	1,086,000	Vegetation	4.28	11.41	LCZ 3, LCZ D,
	(28952)	Water	0.71	1.902	LCZ 6, LCZ F
		Built-up	28.13	74.99	
		Bare Soil	4.38	11.69	
		Total	37.51	100	
Cantonment	892,000	Vegetation	10.06	10.29	LCZ 6, LCZ 3,
	(9124)	Water	-	-	LCZ D, LCZ F
		Built-up	59.54	60.90	
		Bare Soil	28.15	28.80	
		Total	97.76	100	
Iqbal Town	318,000	Vegetation	106.26	20.44	LCZ D, LCZ 6,
	(612)	Water	3.612	0.69	LCZ 9, LCZ F
		Built-up	126.67	24.36	
		Bare Soil	283.46	54.51	
		Total	520.01	100	
Gulberg Town	859,000	Vegetation	6.526	14.899	LCZ 3, LCZ 6,
	(19612)	Water	0.002	0.0041	LCZ B, LCZ 2
		Built-up	33.238	75.87	
		Bare Soil	4.039	9.22	
		Total	43.80	100	
Ravi Town	1,749,000	Vegetation	3.321	10.867	LCZ 3, LCZ D,
	(57232)	Water	0.994	3.254	LCZ F, LCZ 6
		Built-up	22.34	73.095	
		Bare Soil	3.906	12.78	
		Total	30.56	100	
Data Gunj Baksh Town	1,070,000	Vegetation	3.42	11.19	LCZ 3, LCZ 6,
	(35003)	Water	0.35	1.15	LCZ B, LCZ D
		Built-up	24.47	80.05	
		Bare Soil	2.322	7.596	
		Total	30.57	100	

(*Punjab Development Statistics*, 2015)

5.3   Implications for future growth

Due to the rapid urbanization and the migration of people from nearby villages, the city population is increasing exponentially, putting immense pressure on the infrastructure and services demand. The population of Lahore, which was around 3 million in the year 1980, is now crossing 11 million. In the year 1998, it was around 6 million, so in the first phase in the time gap of 18 to 20 years, the population increased by 3 million. But, in the next phase, from the year 1998-2017, there has been a rapid increase

13

in the population. The population increased from 6,340,114 to 11,119,985 (Bureau of Statistics, 2017). The increased migration and urban population put immense pressure on the available resources like housing demands, jobs, educational facilities, recreation, etc. Consequently, this has led to unapproved and haphazard growth. A study conducted in Lahore observed the transition of this built-up area from the year 1999-2011. It was found that the built-up area doubled during that time. Apart from the growth towards the south, there has also been an extension in the built-up area towards northwestern and eastern parts, which increased from 47% to 57% from the year 1999 to 2011 (Bhatti *et al.*, 2015). The master plan of the city recommended the future physical growth towards the south and southwest direction in Lahore (Lahore Development Authority, 2004), while they were restricted towards the north and west directions. Thus, the development that occurred towards the northwestern direction is unplanned. Many new and unapproved societies have been made to meet the city's housing demand by compromising the agricultural area, leading to rapid expansion, and increased built-up area. This urban sprawl is utilizing valuable and scarce land resources and adversely affecting the environment (Rana and Bhatti, 2018).

This study has analyzed the effect this urbanization has caused on the land cover conditions of the city and the most dominant types through land cover maps. Apart from that, a step further has also been taken, along with analyzing the land cover types, the local climate zones present in the area has also been mapped. By incorporating both factors, a better understanding of the thermal and surface cover conditions can be collected to provide insight for future climate-resilient development. The land cover maps helped analyze the standard land cover types and their areas and identify the most dominant class. This map showed that bare soil and built-up are the most dominant classes in the study area. Moreover, the local climate zones map prepared of the city Lahore can serve as the basis for urban temperature studies and manage the city's thermal stress conditions. This mapping has been done using the standard WUDAPT procedure, collecting training samples from Google Earth and using Landsat 8 images for mapping.

The LCZ maps of the city depict that most of the city's old areas fall under the category of compact-low rise development (LCZ-3). These areas are present in the core of Lahore city that is unplanned. Moving outwards, the city has undergone a rapid transition phase. Most of the areas fall under open-low rise development (LCZ-6). The reduction in the vegetative land causes the transition of land into built-up types, thus affecting the agricultural land and the thermal conditions of the city. The level of thermal comfort is also one thing that is needed to be considered, as in many open low-rise developments in

14

Lahore, the vacant spaces are left as it is. Most of it belongs to the bare soil category, leading to more severe temperature conditions, so there is a need to do plantation in the open spaces to improve the thermal comfort level. The coolest zones belonged to LCZ G (water) and LCZ A (dense trees). Apart from the overall analysis of urbanization and land cover change, the administrative towns of Lahore have also been assessed. This detailed analysis helped us study and understand the land cover and urban morphology conditions at the micro-level. By analyzing these towns, the problems associated with each and every town can be highlighted, and future policies are formulated by keeping these in mind. As in most of the towns, most of the vacant land belonged to the LCZ D (low plants) or LCZ F (bare soil) category. They can be converted to LCZ B (scattered trees) to reduce thermal stress. By assessing the condition and problem of these towns individually, better future plans can be developed. These plans and policies can help make cities adaptive, climate-friendly, and resilient, protecting them from future intense heat events.

For Lahore, the initial draft for the integrated master plan of the city was presented in the year 1998. In the plans, the land use of the area has been incorporated along with building heights and housing structures. They have also considered the population densities (persons per hectare) and divided the areas into high, medium, and low-density zones (Lahore Development Authority, 2004). But did not incorporate thermal stress conditions or the UHI effect in future development planning. While developing the master plan of the city, there are specific zones designated for land use as commercial, residential, information regarding building height. However, the urban heat island effect due to built-up has not been considered. There is a need to incorporate the LCZs in the development plans for future growth and sustainable development that will help improve the city's thermal conditions. Apart from this, one major thing needed is coordination among the development authorities. It is not possible to resolve all the authorities, but laws should be made so that they are bound to follow the guidelines proposed in the master plan. One solution is to incorporate LCZs in development plans and policies at smaller levels, as carried out in this study. Due to many administrative authorities and the lack of implementation of the master plan, this approach can prove helpful as every development authority will take care of its jurisdiction following the standards provided by the city government.

6   Conclusions

Cities are becoming the center of attraction for the people living in rural areas; many people migrate from their towns or villages to the big metropolitan cities for better livelihood. Rampant housing

schemes development is trying to accommodate the large population in the city. This process leads to the cities' haphazard and unapproved growth; the scarce land has been utilized at a higher rate than before. This rapid urbanization trend depletes the land and resources and leads to increased climate risks, such as flash floods and heat waves events. There is a need to work on climate adaptation strategies and build climate-resilient and sustainable cities. This calls for a need to develop an integrated system between different authorities and experts of urban planning, climate change, architecture for future amendments in the master plan and policies. One important thing that needs to be considered to deal with heat-related events and urban temperature studies is LCZs; they will help the urban planner identify areas for greenspace allocation to mitigate the warming. They can be incorporated in future development plans for potential climate risk hotspots for remedial and corrective risk reduction measures. Planners suggest urban morphological parameters, ventilation corridors, and green spaces for effective climate-resilient development

Numerous planning and development organizations with different jurisdictions are present in Lahore. They try to provide and maintain the infrastructural services and housing demands of the people. These organizations have their own rules and regulations. A coordinated and integrated effort is needed for climate-resilient development at the city level. This study can provide baseline support for future urban temperature-related studies. LCZ maps provided to these organizations can better plan their areas, considering the thermal stress conditions. By identifying the hotspot areas, proper attention can be paid to that respective area that needs green spaces and trees. For new housing developments, areas with good thermal conditions can be replicated, and relevant standards can be updated. Urban morphology parameters such as sky view factor, building height, pervious/impervious surface fraction from the LCZ maps can also prove useful for local planners and developers. Hence by implementing the integration of LCZs with the future plans across different jurisdictions by cooperation among the organizations, sustainable and climate-resilient development can be achieved.

Some of the major limitations faced during the study are the availability of data and resources; the results can be made more accurate if more detailed datasets were present for the study area. Detailed maps and GIS-based urban planning data were missing, so limited resources were used to collect the training samples and mapping. In future studies, more high-resolution satellite images and aerial and site photographs can be used to identify better places to increase the training samples' accuracy. Moreover, advanced algorithms and techniques can also be used to provide more accurate LCZ maps. Along with mapping, real-time temperature data can also be collected from the potential regions to

understand the thermal conditions better and propose mitigating measures for sustainable planning and development.

7   References

dos Anjos, C.S., Lacerda, M.G., do Livramento Andrade, L. and Salles, R.N. (2017), "Classification of urban environments using feature extraction and random forest", *2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, IEEE, pp. 1205–1208.

Baker, H.S., Millar, R.J., Karoly, D.J., Beyerle, U., Guillod, B.P., Mitchell, D., Shiogama, H., *et al.* (2018), "Higher CO 2 concentrations increase extreme event risk in a 1.5° C world", *Nature Climate Change*, Vol. 8 No. 7, pp. 604–608.

BANDE, L., MANADHAR, P. and MARPU, P. (2019), "DEFINITION OF LOCAL CLIMATE ZONES IN RELATION TO ENVI-MET AND SITE DATA IN THE CITY OF ALAIN, UAE", *The Sustainable City XIII*, Vol. 238, p. 209.

Bechtel, B., Alexander, P.J., Bohner, J., Ching, J., Conrad, O., Feddema, J., Mills, G., *et al.* (2015), "Mapping Local Climate Zones for a Worldwide Database of the Form and Function of Cities", *Isprs International Journal of Geo-Information*, Vol. 4 No. 1, pp. 199–219.

Bertinelli, L. and Black, D. (2004), "Urbanization and growth", *Journal of Urban Economics*, Vol. 56 No. 1, pp. 80–96.

Bhatti, S.S., Tripathi, N.K., Nitivattananon, V., Rana, I.A. and Mozumder, C. (2015), "A multi-scale modeling approach for simulating urbanization in a metropolitan region", *Habitat International*, Elsevier Ltd, Vol. 50, pp. 354–365.

Bureau of Statistics, P. (2017), *LAHORE CITY , Pakistan*.

Cai, Z., Tang, Y., Chen, K. and Han, G. (2019), "Assessing the Heat Vulnerability of Different Local Climate Zones in the Old Areas of a Chinese Megacity", *Sustainability*, Vol. 11 No. 7, p. 2032.

Ching, J., Mills, G., Bechtel, B., See, L., Feddema, J., Wang, X., Ren, C., *et al.* (2018), "WUDAPT: An Urban Weather, Climate, and Environmental Modeling Infrastructure for the Anthropocene", *Bulletin of the American Meteorological Society*, Vol. 99 No. 9, pp. 1907–1924.

"City District Governments". (2009), *National Reconstruction Bureau,Government of Pakistan*, Lahore Development Authority. (2014). Lda.Gop.Pk. https://www.lda.gop.pk/page.php?p=TmpReg== Pakistan Bureau of Statistics. (2017). Population of major cities census - 2017 population top 10 cities. City District Governments. (2009). National Reconstructi.

Cui, X., Fang, C., Liu, H. and Liu, X. (2019), "Assessing sustainability of urbanization by a coordinated

development index for an Urbanization-Resources-Environment complex system: A case study of Jing-Jin-Ji region, China", *Ecological Indicators*, Vol. 96, pp. 383–391.

Danylo, O., See, L., Bechtel, B., Schepaschenko, D. and Fritz, S. (2016), "Contributing to WUDAPT: A local climate zone classification of two cities in Ukraine", *Ieee Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, Vol. 9 No. 5, pp. 1841–1853.

DAWN NEWS. (2019), "Why Lahore gets flooded every year — and how to stop it - Prism - DAWN.COM".

Deng, J.S., Wang, K., Hong, Y. and Qi, J.G. (2009), "Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization", *Landscape and Urban Planning*, Vol. 92 No. 3–4, pp. 187–198.

Emmanuel, R. and Loconsole, A. (2015), "Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK", *Landscape and Urban Planning*, Elsevier B.V., Vol. 138, pp. 71–86.

Fonte, C.C., Lopes, P., See, L. and Bechtel, B. (2019), "Using OpenStreetMap (OSM) to enhance the classification of local climate zones in the framework of WUDAPT", *Urban Climate*, Vol. 28, available at:https://doi.org/10.1016/j.uclim.2019.100456.

Geletič, J. and Lehnert, M. (2016), "GIS-based delineation of local climate zones: The case of medium-sized Central European cities", *Moravian Geographical Reports*, Vol. 24 No. 3, pp. 2–12.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M.C., Shyamsundar, P., Steffen, W., *et al.* (2013), "Sustainable development goals for people and planet", *Nature*, Vol. 495 No. 7441, pp. 305–307.

Groote, P., Jonge, R. De, Dekker, J. and Vries, J. De. (1989), *Urban Planning in Lahore A Confrontation with Real Development*, University of Groningen, Netherlands, Groningen.

Hameed, R. and Nadeem, O. (2008), "Challenges of Implementing Urban Master Plans: The Lahore Experience", *International Journal of Humanities and Social Sciences*, Vol. 2 No. 12, pp. 1297–1304.

Kaloustian, N., Tamminga, M. and Bechtel, B. (2017), "Local climate zones and annual surface thermal response in a Mediterranean city", *2017 Joint Urban Remote Sensing Event (JURSE)*, IEEE, pp. 1–4.

Kapadia, R. (2014), "Vagaries of the Weather ©".

Khan, M.A., Khan, J.A., Ali, Z., Ahmad, I. and Ahmad, M.N. (2016), "The challenge of climate change and policy response in Pakistan", *Environmental Earth Sciences*, Springer Berlin Heidelberg, Vol. 75 No. 5, pp. 1–16.

"Lahore Cantonment". (2020), *Globalsecurity.Org*, Lahore Development Authority. (2014). Lda.Gop.Pk. https://www.lda.gop.pk/page.php?p=TmpReg== Pakistan Bureau of Statistics. (2017). Population

of major cities census - 2017 population top 10 cities. City District Governments. (2009). National Reconstructi.

Lahore Development Authority. (2004), *Integrated Master Plan of Lahore 2021*.

"Lahore Development Authority". (2014), *Lda.Gop.Pk*, Lahore Development Authority. (2014). Lda.Gop.Pk. https://www.lda.gop.pk/page.php?p=TmpReg== Pakistan Bureau of Statistics. (2017). Population of major cities census - 2017 population top 10 cities. City District Governments. (2009). National Reconstructi.

Mahmood, S., Irshad, A., Nasir, J.M., Sharif, F. and Farooqi, S.H. (2019), "Spatiotemporal analysis of dengue outbreaks in Samanabad town, Lahore metropolitan area, using geospatial techniques", *Environmental Monitoring and Assessment*, Springer, Vol. 191 No. 2, p. 55.

Müller, N., Kuttler, W. and Barlag, A.-B. (2014), "Counteracting urban climate change: adaptation measures and their effect on thermal comfort", *Theoretical and Applied Climatology*, Vol. 115 No. 1–2, pp. 243–257.

"Pakistan: Provinces and Major Cities". (2018), *Citypopulation*, Lahore Development Authority. (2014). Lda.Gop.Pk. https://www.lda.gop.pk/page.php?p=TmpReg== Pakistan Bureau of Statistics. (2017). Population of major cities census - 2017 population top 10 cities. City District Governments. (2009). National Reconstructi.

Pakistan Bureau of Statistics. (2017), *Population of Major Cities Census - 2017 Population Top 10 Cities*, Lahore Development Authority. (2014). Lda.Gop.Pk. https://www.lda.gop.pk/page.php?p=TmpReg== Pakistan Bureau of Statistics. (2017). Population of major cities census - 2017 population top 10 cities. City District Governments. (2009). National Reconstructi.

Population Council. (2016), "Landscape analysis of the family planning situation in Pakistan", No. September.

Punjab Development Statistics. (2015), .

"Punjab Development Statistics | Bureau of Statistics, Punjab". (2015), .

Quan, J.L. (2019), "Enhanced geographic information system-based mapping of local climate zones in Beijing, China", *Science China Technological Sciences*, Vol. 62 No. 12, pp. 2243–2260.

Rajab, P.M. (2018), "Urban mapping Local Climate Zones based on morphology categorization", *Journal of Engeering and Applied Sciences*, available at:https://doi.org/10.3923/jeasci.2018.350.352.

Rana, I.A. and Bhatti, S.S. (2018), "Lahore, Pakistan – Urbanization challenges and opportunities", *Cities*, Elsevier, Vol. 72 No. October 2017, pp. 348–355.

Rana, I.A., Bhatti, S.S. and Arshad, H.S.H. (2017), "Assessing the socioeconomic and infrastructure development disparity – a case study of city districts of Punjab, Pakistan", *International Journal of Urban Sustainable Development*, Vol. 9 No. 3, pp. 346–358.

Rana, I.A., Routray, J.K. and Younas, Z.I. (2020), "Spatiotemporal dynamics of development inequalities in Lahore City Region, Pakistan", *Cities*, Elsevier, Vol. 96 No. July 2019, p. 102418.

Raza, A. (2017), "Lahore baking in hottest April since 1993", *The NEWS*.

Savić, S., Marković, V., Šećerov, I., Pavić, D., Arsenović, D., Milošević, D., Dolinaj, D., *et al.* (2018), "Heat wave risk assessment and mapping in urban areas: case study for a midsized Central European city, Novi Sad (Serbia)", *Natural Hazards*, Springer Netherlands, Vol. 91 No. 3, pp. 891–911.

Schell, L.M. and Ulijaszek, S.J. (1999), *Urbanism, Health and Human Biology in Industrialised Countries*, Cambridge University Press.

Skarbit, N. and Gál, T. (2016), "Projection of intra-urban modification of night-time climate indices during the 21st century", *Hungarian Geographical Bulletin*, Vol. 65 No. 2, pp. 181–193.

Smith, A.B. and Matthews, J.L. (2015), "Quantifying uncertainty and variable sensitivity within the US billion-dollar weather and climate disaster cost estimates", *Natural Hazards*, Vol. 77 No. 3, pp. 1829–1851.

Stewart, I.D. and Oke, T.R. (2012), "Local Climate Zones for Urban Temperature Studies", *Bulletin of the American Meteorological Society*, Vol. 93 No. 12, pp. 1879–1900.

The NEWS. (2019), "Heatwave intensifies as Lahore sizzles at 46°C", *The NEWS*.

The NEWS. (2021), "Heatwave grips Lahore as mercury reaches 44.1°C", *The NEWS*.

Tse, J.W.P., Yeung, P.S., Fung, J.C.H., Ren, C., Wang, R., Wong, M.M.F. and Cai, M. (2018), "Investigation of the meteorological effects of urbanization in recent decades: A case study of major cities in Pearl River Delta", *Urban Climate*, Vol. 26, pp. 174–187.

Unger, J., Lelovics, E. and Gál, T. (2014), "Local Climate Zone mapping using GIS methods in Szeged", *Hungarian Geographical Bulletin*, Vol. 63 No. 1, pp. 29–41.

Verdonck, M.L., Demuzere, M., Hooyberghs, H., Beck, C., Cyrys, J., Schneider, A., Dewulf, R., *et al.* (2018), "The potential of local climate zones maps as a heat stress assessment tool, supported by simulated air temperature data", *Landscape and Urban Planning*, Elsevier, Vol. 178 No. July 2017, pp. 183–197.

Verdonck, M.L., Okujeni, A., van der Linden, S., Demuzere, M., De Wulf, R. and Van Coillie, F. (2017), "Influence of neighbourhood information on 'Local Climate Zone' mapping in heterogeneous cities", *International Journal of Applied Earth Observation and Geoinformation*, Elsevier, Vol. 62 No.

May, pp. 102–113.

Yuan, F. and Bauer, M.E. (2007), "Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery", *Remote Sensing of Environment*, Vol. 106 No. 3, pp. 375–386.

Zhou, X. and Wang, Y.-C. (2011), "Spatial–temporal dynamics of urban green space in response to rapid urbanization and greening policies", *Landscape and Urban Planning*, Vol. 100 No. 3, pp. 268–277.

Zuhra, S.S., Tabinda, A.B. and Yasar, A. (2019), "Appraisal of the heat vulnerability index in Punjab: a case study of spatial pattern for exposure, sensitivity, and adaptive capacity in megacity Lahore, Pakistan", *International Journal of Biometeorology*, Springer, Vol. 63 No. 12, pp. 1669–1682.
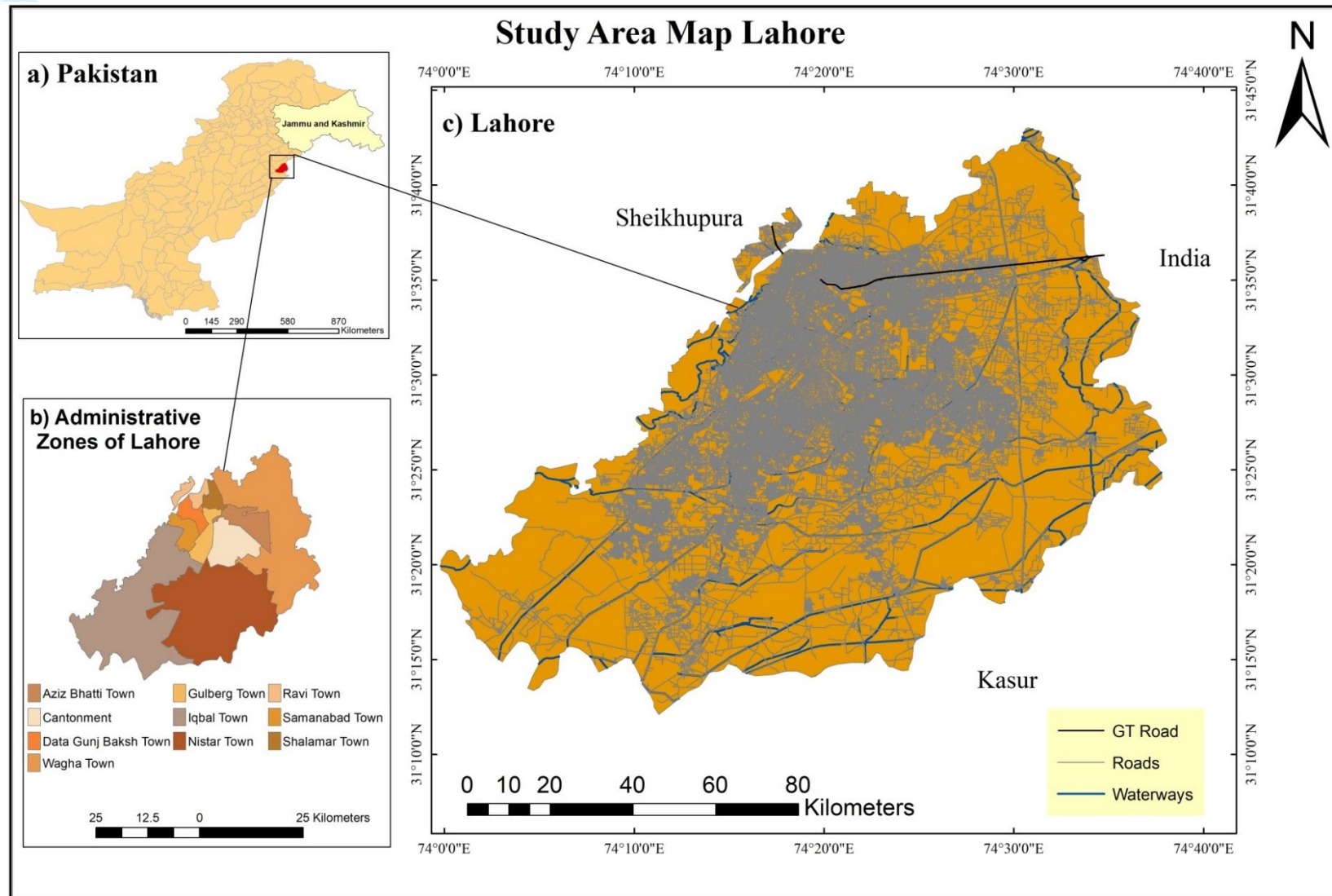
Figure 1 Study area map a) The administrative boundaries map of Pakistan, b) The map of the administrative zones of Lahore, c) The map of Lahore showing the roads, waterways, and GT-Road within Lahore boundary
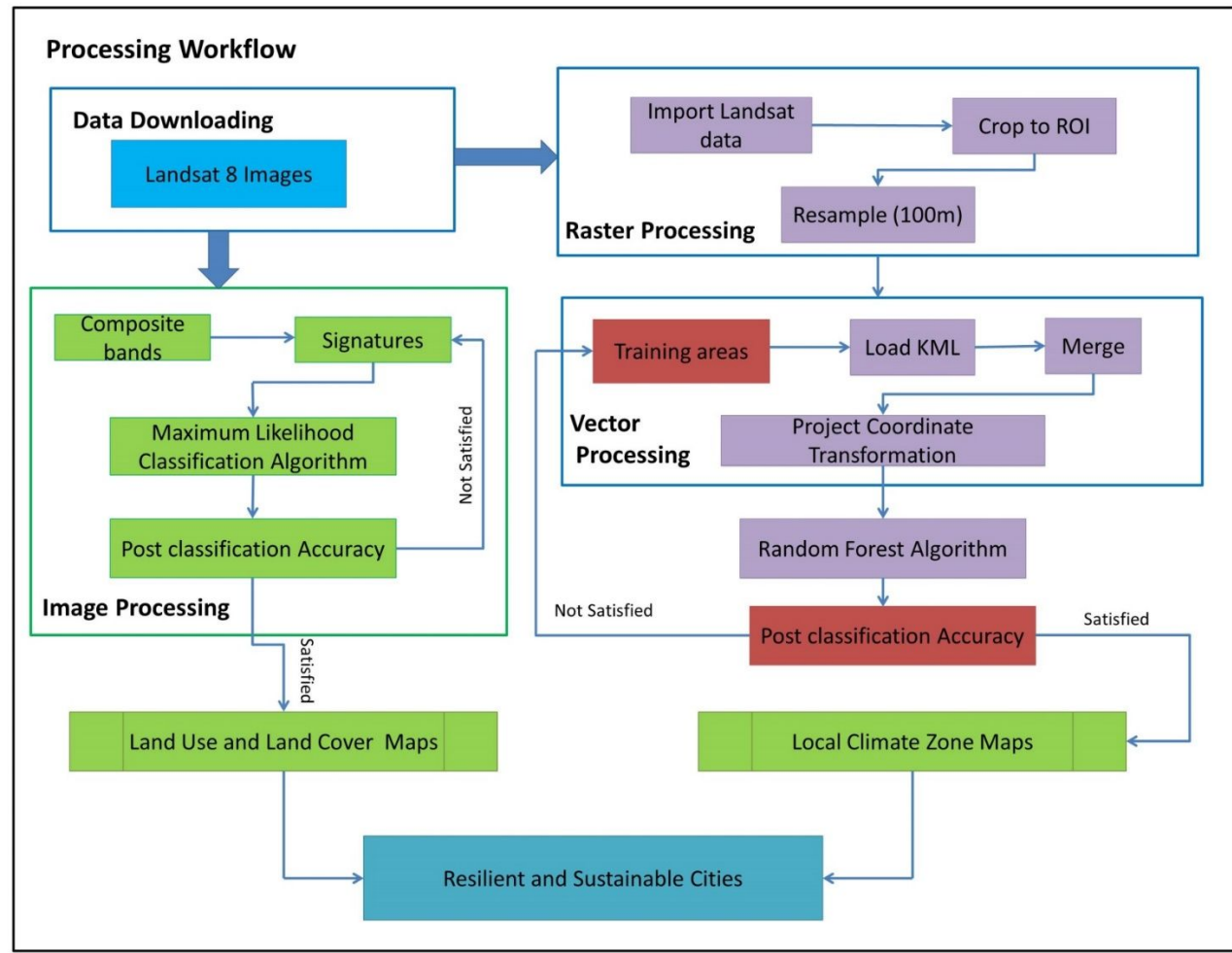
Figure 2 Methodological Flowchart of the study
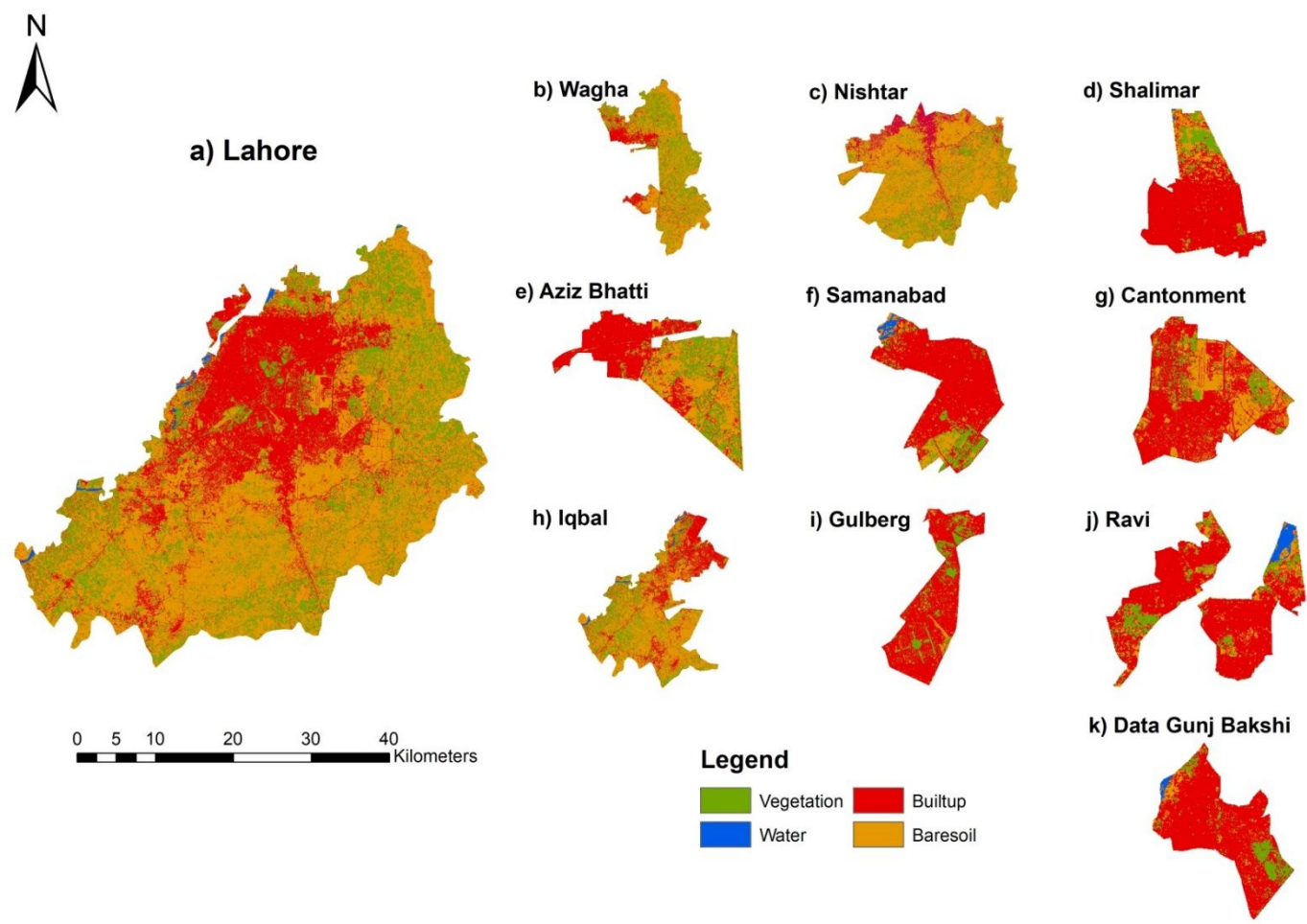
Figure 3 Land cover map of Lahore and its administrative zones for the year 2019
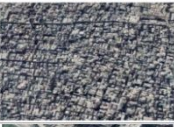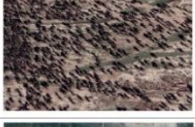
Google Earth View of the Local Climate Zones

Compact midrise (Dense mix of mid-rise buildings) LCZ 2		Heavy Industry (low-rise or mid-rise Industrial structures) LCZ 10	
Compact low-rise (Dense mix of low-rise buildings) LCZ 3		Dense Trees (Heavily wooded landscape of deciduous or evergreen plants/trees) LCZ A	
Open High-rise (Open arrangements of tall buildings with tens of stories) LCZ 4		Scattered Trees (Lightly wooded landscape of deciduous or evergreen plants/trees) LCZ B	
Open mid-rise (Open arrangement of mid-rise buildings) LCZ 5		Bush, scrubs (Open arrangements of bushes, scrubs) LCZ C	
Open low-rise (Open arrangements of low-rise buildings) LCZ 6		Low plants (Landscape of grass or planes/crops) LCZ D	
Lightweight low-rise (Dense mix of single-story buildings) LCZ 7		Bare rock or paved (Landscape of rock or paved cover) LCZ E	
Large low-rise (Open arrangements of large low-rise buildings) LCZ 8		Bare soil or sand (Landscape of soil or sand cover) LCZ F	
Sparsely built (small or medium buildings arrangements in the natural setting) LCZ 9		Water (Open water bodies) LCZ G	

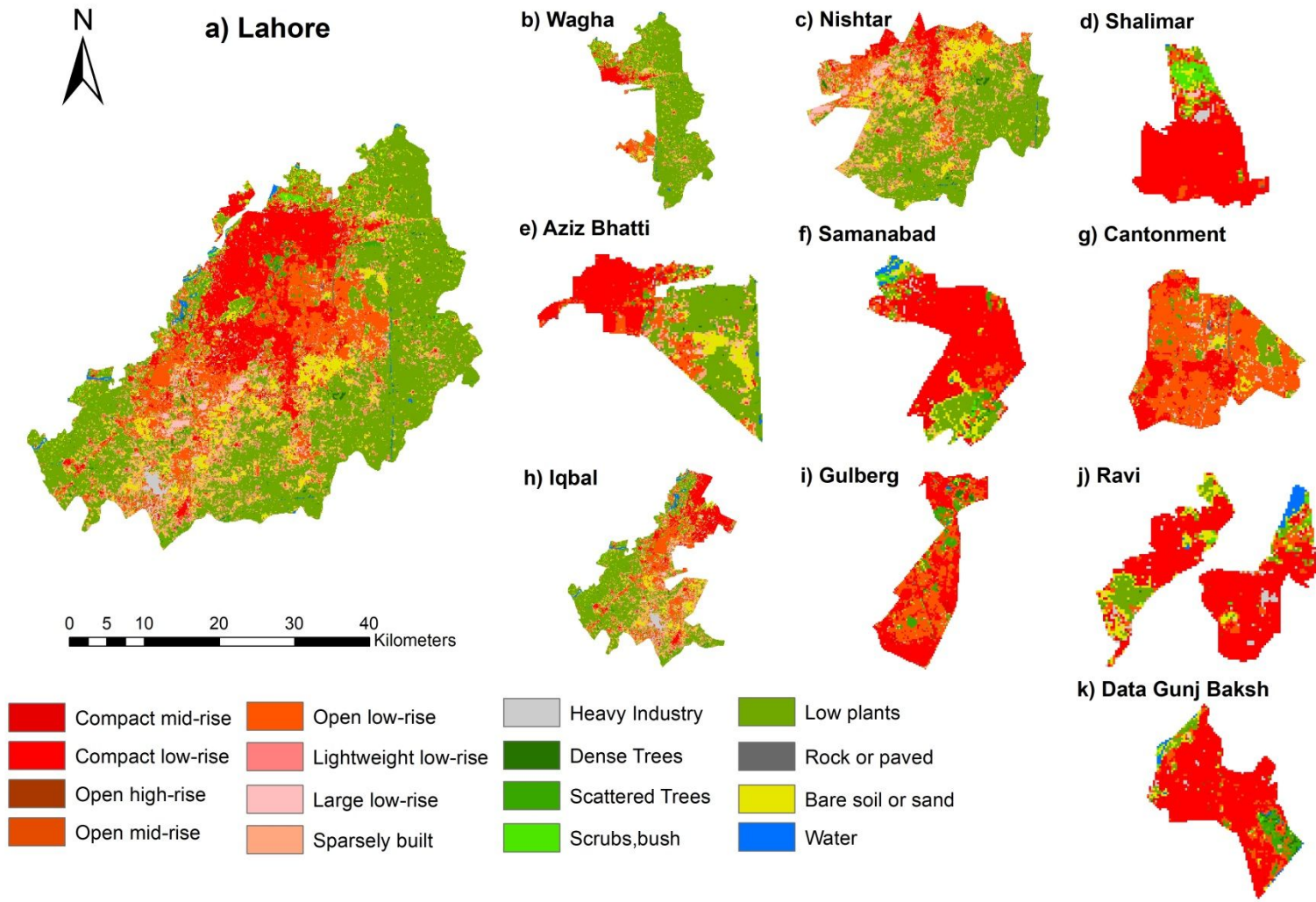**Figure 4 Google Earth Views of Local Climate Zones**

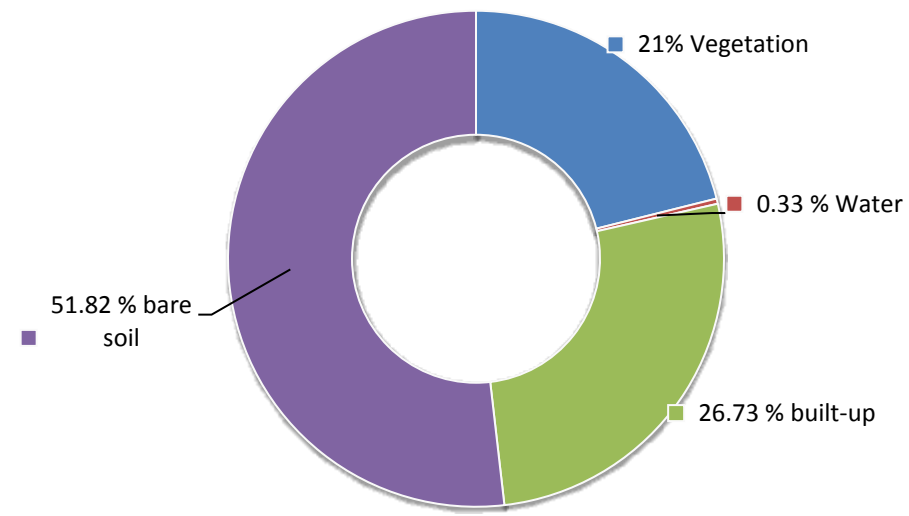**Figure 4 Local Climate zones of Lahore and its administrative town for the year 2019**

Figure 5 Percentages of the land cover types present in Lahore

Local climate zones and its potential for building urban resilience:

A case study of Lahore, Pakistan

Ayman Aslam[1], Irfan Ahmad Rana[2], Saad Saleem Bhatti[3]

[1.2] Department of Urban and Regional Planning, School of Civil and Environmental Engineering,

National University of Sciences and Technology (NUST), 44000, H-12 Sector, Islamabad, Pakistan

[1] ayman.aslam96@gmail.com

[2] Corresponding Author, irfanrana90@hotmail.com; iarana@nit.nust.edu.pk

ORCID 0000-0002-3157-1186

[3] School of Geography and Environmental Sciences, Ulster University, Coleraine, United Kingdom

[3] s.bhatti@uslter.ac.uk   ORCID 0000-0002-1472-3731