LOCAL CLIMATE ZONES AND ITS IMPLICATION FOR FUTURE GROWTH AND SUSTAINABILITY: A CASE STUDY OF LAHORE AND ISLAMABAD, PAKISTAN

Thesis submitted

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CERTIFICATE

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ABSTRACT

LOCAL CLIMATE ZONES AND ITS IMPLICATION FOR FUTURE GROWTH AND SUSTAINABILITY: A CASE STUDY OF LAHORE AND ISLAMABAD, PAKISTAN

By

Ayman Aslam

Rapid urbanization leads to unplanned growth and development in the cities and puts immense pressure on local administrations and energy demands. More energy consumption is a major contributor to greenhouse gas emissions, acting as a catalyst for the changing climate. As a consequence of rapid urbanization and climate change, many urban regions become hotspots for extreme weather events. From all of these, the most deadly are heatwaves, which are responsible for the death of millions of people worldwide. This study examines the urbanization trends across the years and observes the temporal land surface conditions as well. Apart from this, to study the urban temperatures in more detail and at a micro-scale, the concept of local climate zones has been used for mapping the cities and assessing the thermal conditions accordingly.This can help in shaping efficient urban forms and reduce thermal stresses. In the later stage, the risk perceptions and psychological distancing of the people are also examined in various LCZs. This study suggests working towards integrating disaster risk reduction and climate change adaptation philosophies. It can be helpful for urban planners, climatologists, architects, policymakers, public and relevant stakeholders to promote sustainable and climate-resilient development.

DECLARATION

I hereby declare that this research is purely the product of my own hard work and has not been published anywhere else before in any format. The findings from other papers used in the text is properly referred and acknowledged.

This thesis consists of 6 chapters, above 40,000 words, 28 figures and 25 tables. I hereby, allow copying of the findings and diagrams, or any part for research purposes only, if fully acknowledged/referenced in reproduction. No commercial use of this thesis is permitted in any form, or transformation.

Ayman Aslam

DEDICATION

This project is dedicated to my beloved parents, who have been a source of inspiration and support. I also dedicate this project to my siblings, who have always helped and encouraged me during this whole time. This project is also dedicated to the people of Pakistan for whom this initiative has been taken.

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I am thankful to ALLAH (SWT) firstly, whose blessings made it possible for me to complete this project successfully. Secondly, I am thankful to my supervisor Dr. Irfan Ahmad Rana, whose continuous support and guidance inspired and helped me to work in this domain incorporating urban planning and GIS.

I am also thankful to my GEC members and all the other people who helped and guided me during the project.

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List	Abbreviations
CDA	Capital Development Authority
DEM	Digital Elevation Model
LCZ	Local Climate Zones
LST	Land Surface Temperature
LULC	Land Use Land Cover
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
LCZ	Local Climate Zones
UTM	Universal Transverse Mercator
NIR	Near-Infrared
SWIR	Short wave Infrared
ROI	Region of Interest
TOA	Top of Atmosphere
UHI	Urban Heat Island

WUDAPT	World Urban Database Access Portal Tool
LDA	Lahore Development Authority
RP	Risk Perception
PD	Psychological Distancing
RPF	Risk Perception Fear
RPA	Risk Perception Attitude
RPT	Risk Perception Trust
PDS	Psychological Distancing Social
PDG	Psychological Distancing Geographic
PDT	Psychological Distancing Temporal
PDU	Psychological Distancing Uncertainty

CHAPTER 1

INTRODUCTION

1.1 Urbanization and climate change

Human activities, including both social and economic, are the drivers of land change (Grimm et al., 2008). With a greater number of people moving towards the urban regions, more of the land has been utilized for housing or business purposes. Many of the peri-urban areas are now transforming into dense urban areas(Reiner Jr et al., 2015). The Global Artificial Impervious Area (GAIA) found a total urban area to be 797,076 km^2, which is 1.5 times more than in 1990 (Gong et al., 2020). According to the mapped global urban dynamics from the year 1985 to 2015, the urban area has expanded by approximately 9,687 km^2 (Liu et al., 2020). The increased migration has reduced the green spaces and increased impervious surfaces in urban areas (Oke, 1982). Around 2.5 billion more people will be added to the population by 2050(United Nations, 2018). More migration to the cities leads to rapid urban and slum growth(He et al., 2019). Acting as a driving factor for land change exacerbates the impacts of climate change in the built environment(Grimm et al., 2008). If not planned and managed accordingly, this built environment will increase urban climate risks and frequency of extreme weather events (Ching et al., 2018), like urban heat islands, heat waves, extreme rainfalls, floods, storms, and droughts. The Fifth Assessment Report (AR5), published by the Intergovernmental Panel on Climate Change (IPCC), states that the global mean temperature has increased risk associated with extreme events and will likely continue in the future (Pachauri et al., 2014). To protect people and the earth's environment, United Nations Sustainable Development Goals focus on providing security to the people and planet (Griggs et al., 2013). SDG 11 and 13 are about sustainable cities and climate action, respectively, to make the cities and human settlements safe, sustainable, and resilient and take the necessary action to combat climate change and its impacts (Bebbington & Unerman, 2018). Urban areas are the main drivers of greenhouse gas emissions caused by transportation, industrial production, and energy generation, etc. Additional physical characteristics of an urban area like form and high density increases social, environmental, and health risks, making citizens vulnerable to climate change and extreme events, while low densities, on the other hand, result in increased energy consumption and sprawl (Habitat, 2011). Hence, it is imperative to focus on climate-resilient development through climate zone mapping for launching appropriate future urban development strategies to mitigate climate change and adapt accordingly.

The climate change phenomenon occurs in all regions around the world, but its severity has increased in the last two decades. Anthropogenic activities have caused a considerable impact on the climate. With an expected increase in temperature, living in highly dense areas will become more complex and life-threatening. There is a growing scientific consensus to map rapid urbanization and its effect on climate changes and vice versa (Villadiego & Velay-Dabat, 2014). Developing countries like Pakistan are likely to be more affected by this change because of the resources and infrastructure constraints (Farooqi et al., 2005). The Germanwatch Global Climate Risk Index published a report in the year 2020, representing the level of exposure and vulnerability to extreme events. According to this report, Pakistan is ranked 5th with the CRI score of 28.83 in the list of countries that are affected by climate change from the year 1999-2018 with 152 extreme weather events, out of the top 10 countries 7 are developing countries(Eckstein et al., 2019) Pakistan ranked 10th in the list in the report of Global Climate Index 1994-2013 based on the average results of the last 20 years. It was ranked 6th for the respective year 2013 (Kreft et al., 2013). This clearly shows the level of threat Pakistan is facing in terms of the extreme conditions linked to the changing climate. The ranking of Pakistan based upon the risk index is continuous in the long term and for the respective year in the countries that are most affected by climate change (Eckstein et al., 2019). One of the adverse effects of this changing climate is extreme weather events. Although floods are considered more severe and destructive, heat waves are termed as silent killers causing mortalities at a greater scale (Saeed & Qaiyum Suleri, 2015). With rapid urbanization, these events are increasing at a much faster rate than before.

1.2 Problem statement

The growing population has instigated demand for housing and infrastructural facilities, which has increased the built-up areas by devouring open spaces. With more and more people coming to the cities, it leads to unplanned development and slum growth, including changing local climate and environment (He et al., 2018). With an increase in temperature, living in highly dense areas will become harsh and life-threatening, difficult to live there, and this situation will worsen with every passing day if no proper planning has been done to deal with it. Urbanization is causing rapid changes in temperature and thermal stress. The effect of urban development on its social well-being and environmental conditions cannot be denied anymore. The urban heat island effect or air temperature difference studies have been done worldwide, but a wide range of land cover and urban structure/form needs to be classified, i.e., urban and rural. A local climate zone (LCZ) system was developed to identify the built environment's diverse climatic and physical conditions (I. D. Stewart & Oke, 2012). This is a standard system that can be used for cities worldwide for Urban Temperature studies. There has been a lot of work done on the LCZ scheme in different regions of the world, but developing countries like Pakistan still lack research in this field. This study aims to observe the local climate conditions in the two cities of Pakistan and the impact that urbanization has caused on their environments. Apart from that, the study has also observed the risk perceptions and psychological distancing to climate change of the people living in various LCZs of Islamabad city. The research aims to help the urban planners and climatologists for future urban development and policies and make them realize the importance that the development has on the local climate moreover work on the communication and awareness strategies to increase general public knowledge and perceptions.

1.3 Rationale of the study

Climate change is real, and the consequences linked to it can be denied. There has been a lot of work done on linking the rapidly urbanizing cities and the changing thermal conditions in the developed countries and somewhat in the developing countries. Local climate zone is a phenomenon developed by Steward and Oke (2012) to help in urban temperature studies, which can be used as a standard for countries worldwide. The developed regions/countries have done a lot of research work relating to LCZ's, but developing countries like Pakistan are still lagging behind. Apart from the use of LCZ for urban temperature studies in most parts of the world, urban climatology in urban planning is still limited and needs attention. This study analyzes the linkage between rapid urbanization and climate change. It helps understand the relationship between LST and LC indices and introduces the LCZ scheme to be incorporated in the master planning of the city to deal with the thermal stress conditions and UHI phenomenon, which is a matter of serious concern. The awareness level of the public and the perceptions of the people regarding climate change and psychological distancing have also been analyzed. The study also aims to monitor the behavior of the people living in different urban communities or built-up forms and analyzes them accordingly. tIn short, this study provides an integrated approach that is concerned with the integrated working of the planning departments and climate change ministries. To use this approach in future developments and plans, apart from just using the zoning regulations, the local climate zones can also be taken into consideration. Apart from that, measures are needed to increase the awareness level of the public as well. Thus, it can help link urban planning, urban climate, and public knowledge hence promoting climate-resilient/sustainable development.

1.4 Research questions

This study considers the issues of rapid urbanization and the effect this rapid urbanization has on the land cover conditions and the thermal environment of the area and the perceptions linked to the changing conditions. The research questions that are being addressed in the study are;

- What is the relationship between Land Surface Temperature, Normalized Difference Vegetation Index, and Normalized Difference Built-up Index?
- What are the types of built-up forms present in the two major cities of Pakistan?
- What is the awareness level of the public regarding climate change?
- What is needed to be done for sustainable development using local climate zones?

1.5 Research objectives

To deal with the issues and challenges of rapid urbanization and to observe the changing climate and its effect in the area, research was carried out. The Objectives of this study are;

1. To identify the relationship between Land Surface Temperature, Normalized Difference Vegetation Index, and Normalized Difference Built-up Index;
2. To identify the different built-up forms present in two major cities of Pakistan;
3. To measure the awareness level of the public regarding climate change;
4. To suggest measures for sustainable urban development using the local climate zoning approach.

1.6 Scope of the study

This study provides just an introductory approach towards the linkage between urban planning and urban climate. The phenomenon of climate change and rapid urbanization are studied together, and their effects are analyzed. The LCZ mapping that has been done is by the use of standard WUDAPT procedure, and hence its results are satisfactory. Still, they can be improved by considering detailed GIS data, maps, and aerial photographs, which are not used in this study due to data scarcity and lack of resources that can be incorporated in future works. This study is being carried out in only two of the major cities of Pakistan. One is the capital Islamabad which is a properly planned city. Another is a major city of Punjab, i.e., Lahore, whose master plan is developed, but the core of the city is unplanned; hence one is a perfectly planned city, and the other is partially planned. By taking this work as an example, similar work can be done for other cities as well with no proper master plan. Hence, their future plans can be developed by taking into consideration the recommendations and work from this study. The social aspect has also been taken into consideration, as the preparedness measures linked to the extreme events are directly proportional to the risk perception and psychological distancing to climate change, but only samples from five zones are collected as well the survey has been done only in the Islamabad city. This can be extended further to Lahore as well as other cities. The results obtained from this will help highlight the potential areas needing further assistance and prove useful in formulating plans for future communication strategies and awareness campaigns.

1.7 Conceptual framework

The conceptual framework of the study revolves around climate change, land cover change, rapid urbanization, urban heat island, the land surface temperature change, as well as the land cover indices. The social aspect linked to the phenomenon like the risk perceptions and psychological distancing to climate change of the people has also been taken into account. Thus, helping in climate-resilient or sustainable development using local climate zones concept. The linkages between all these are mentioned in figure 1. All of these phenomena are linked with one another. For example, climate change is linked to rapid urbanization and rapid land cover change, and both these phenomena are affecting the climate. Due to them, the land surface temperature and land cover conditions are changing, causing urban heat Island linking to the changing climate, the human activities is one major factor in all these problems. The anthropogenic activities are directly linked to their awareness level and knowledge, how they perceive things, how they think of climate change, how much far or distant this phenomenon is directly linked to the measures they will be taken in accordance to deal with the situation.

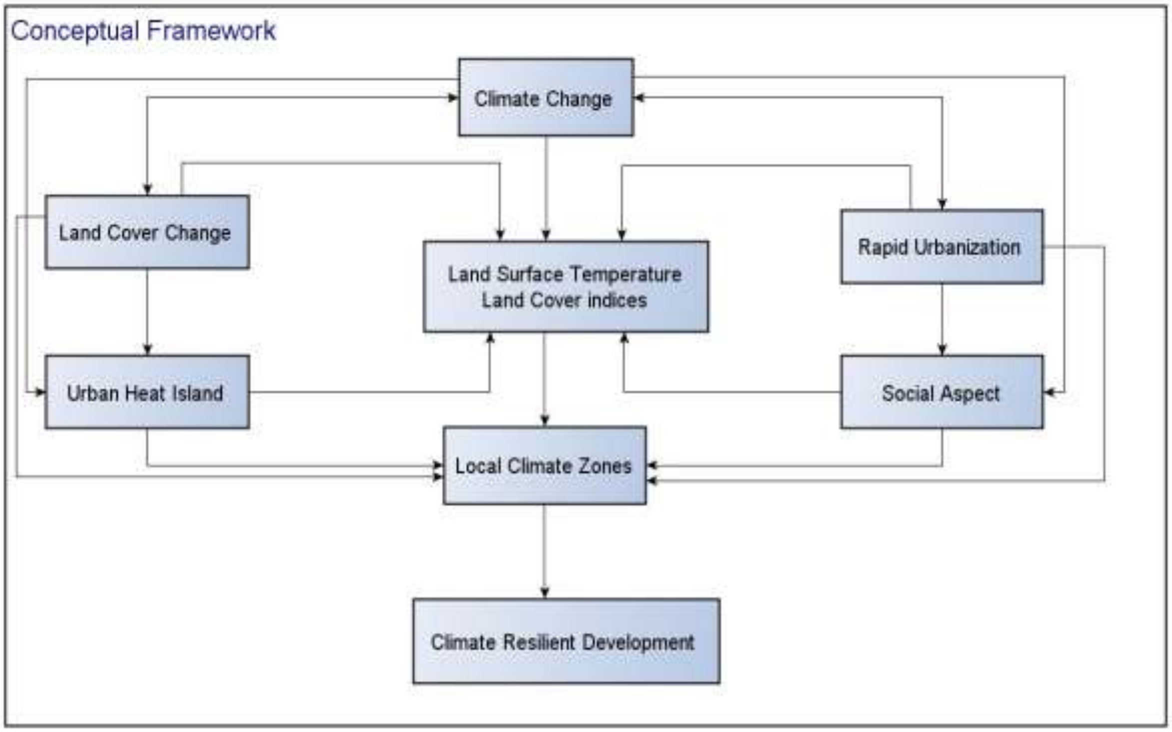


Figure 1 Conceptual framework of the study

By considering different phenomena of urbanization, climate change, the rapidly changing land cover, the land surface temperature, and the perceptions of the people. Linking all these to local climate zones classification. All of this will prove useful and thus contribute to helping us in achieving the goal of climate-resilient development.

1.8 Summary of the chapter

Urbanization and climate change are the two main issues; all the countries are facing worldwide. One of the major contributors to these processes is anthropogenic activities. The consistent migration is depleting the resources of the cities, apart from that uses the scarce resources of the land. Many of the greener areas have been converted to built-up lands. As a consequence of these, urban temperatures are continuously rising all around the world. This changing climate and extreme events linked to it is a major cause of fatality worldwide. Pakistan is the country that is ranked in the top countries, relating to its vulnerability to climate change. This research has been carried out in two major cities of Pakistan, Islamabad, and Lahore. It analyses the relationship between the land cover indices and the land surface temperature. Moreover, to observe the built-up types in two cities, local climate zones classification has been done using the standard WUDPAT procedure. The awareness level of the public regarding the changing climate has also been observed. The research being done provides just an introductory approach towards the linkage between urban planning and urban climate. Taking into consideration and revolving around climate change, land covers change, rapid urbanization, urban heat island, the land surface temperature, social aspect, resilience, and sustainability.

CHAPTER 2

LITERATURE REVIEW

2.1 Local climate zoning and sustainable urban development

Climate is defined as the long-time weather of an area, and urban climate is significantly different compared to its surrounding areas (Oke, 1982). The urban form of a city is closely related to urban climate (Eliasson, 1990). With increasing urbanization, the urban landscape is converted into built-up land like skyscrapers, pavements, and roads, increasing temperatures and influencing local climatic conditions (Oke, 1982). Due to this, UHI effect extreme weather events like heatwaves can be intensified (Tan et al., 2010). Generally, climate classifications are made for macro/meso scales, rendering them useless at the micro-scale. As a result, local climate zoning (LCZ) has emerged to cover this gap and resulted in numerous applications in the fields of urban planning, remote sensing, climate change adaptation, disaster risk management, meteorological and environmental sciences. Local climate zones are defined as regions that possess similar characteristics like surface cover, material, structure, and population activity, extending from several hundred meters to kilometers (I. D. Stewart & Oke, 2012). The basic purpose of the LCZ scheme was to help in urban temperature studies. Later a project was initiated to use local climate zones as a standard to collect detailed spatial information about the forms and function of cities globally, and a project named as World Urban and Access Portal tool was initiated (Benjamin Bechtel et al., 2015). The local climatic zones mapping approach includes information about urban morphologies, which can help in urban climatic research. Each Local climatic zone type has a set of variables linked to it. These variables include sky view factor, building height, albedo, pervious and impervious surface fraction, anthropogenic heat flux, building surface fraction, and terrain roughness class (I. D. Stewart & Oke, 2012). They can be referred to as urban canopy parameters (Hidalgo et al., 2019). From the local climatic zones maps, we can derive urban canopy parameters (UCP), which can improve the results of the urban climate models (Brousse et al., 2016). The output data from the LCZ will also prove to be useful for climatic responsive design (Benjamin Bechtel, 2011) and as an input for urban climate models (Benjamin Bechtel et al., 2019). Many studies have been done all around the world, incorporating the use of local climate zones. Some have used the basic WUDAPT procedure(Benjamin Bechtel et al., 2015), while others have introduced different techniques and methods. The availability of the data determines the methodology that is to be adopted for the classification purpose. The data-efficient regions or countries having proper access to data and resources have used the detailed GIS datasets to map Local climate zones (Agathangelidis et al., 2019). It is a standard method that can be used for cities worldwide to study the urban climates at the local scale (I. D. Stewart & Oke, 2012). Thus local climate zones can help in urban temperature studies and is considered important for the physical growth and layout for future development of the city through considerations of related concepts linked to LCZ.

2.2 Sustainable urban development

Sustainability is defined as the use of natural resources to meet the needs of the population without compromising or depleting them for future use. At present most of the work carried in the urban centers makes use of the resources, the resources utilized every year than the resources put back is 40% more, and this needs special attention (Lorek & Fuchs, 2013). Sustainability is not only about the resources and the environment but also about society. A summit on social development in the year 2005 defines three main pillars of sustainability, Economic Development, Social Development, and Environmental Protection. The first pillar is to give people what they want and not compromising their quality of life. The second is regarding raising awareness among the people. The third one is to protect the environment from the negative effects of technological innovation. In 2015, the United Nations presented 17 Sustainable development goals abbreviated as SDGs incorporating all the factors that will help protect and build the environment. To make cities and human settlements resilient and safe and take the necessary action needed to combat climate change (Gigliotti et al., 2019). All the 17 SDGs are mentioned in figure 2.

Figure 2 Sustainable Development Goals

Incorporating the SGD's in the development of the urban area is linked to sustainable urban development to build cities so that the required SDGS's are met. Two of the main SDGs linked to our study are goal 11 sustainable cities and communities, to make our cities and communities resilient, inclusive, safe and sustainable, and goal 13 climate action to take urgent action relating to the impacts of climate change.

2.3 Local climate zones

To incorporate the SGD's in the development of the urban area is linked to sustainability, to build cities in such a way that the required SDGS's are met. Two of the main SDG's linked to our study are goal 11 sustainable cities and communities, to make our cities and communities resilient, inclusive, safe and sustainable, and goal 13 climate actions to take urgent action relating to the impacts of climate change.

Local climate zones are the areas with uniform surface cover, structure, and human activities with a uniform temperature regime (1-2m) above the ground (I. D. Stewart & Oke, 2012). Instead of urban and rural, the areas are classified into 17 standard classes based upon the type of built-up and land cover. There are 10 classes for the built-up areas like compact high rise compact mid-rise compact low-rise, and so on as well as 7 vegetative classes like dense trees scattered trees, low plants(I. D. Stewart & Oke, 2012), with the unique air temperature at the height of 1-2m above ground and with the same structure and surface conditions. LCZ provides a generic framework for urban heat island studies, i.e., the difference of temperature between LCZ (ΔT LCZ 1 – LCZ D) (I. D. Stewart & Oke, 2012). Initially, the LCZ framework was not used on a larger scale; however, a study by Bechtel at al. 2015 initiated an international project, the WUDAPT (World Urban Database and Access Portal Tools), which led to the use of LCZs at a city level and beyond. In recent studies, the social and institutional aspects were added to the methodology to understand governance, processes, and perceptions relating to LCZs.

Nowadays, LCZ maps are prepared using different techniques as appropriate inputs in urban models for local weather, air quality, and energy-use applications (Benjamin Bechtel et al., 2019; Ching et al., 2018). Additionally, the local climatic zones maps can provide information about the urban morphology and heat conditions for proper urban renewal and planning (Stewart & Oke, 2012). The LCZ method has been proved useful for mapping temperature changes in a rapidly evolving urban environment for dense cities. It can be used for improving the built environment by providing green spaces, which will provide a cooling effect (J. Yang et al., 2017). The LCZ maps generated will help the urban planners make the new development policies by keeping in mind different factors like urban structure, texture, and configuration. The LCZ framework will also likely prove useful for climatic responsive designs (Benjamin Bechtel, 2011).

Resultantly, it has become an effective method for studying urban forms and climates at a local scale.

Empirically, many studies have used GIS-based analysis to map local climate zones for the urban environment. A GIS-based framework was proposed and applied to three French cities, i.e., Paris, Toulouse, and Nantes using data acquired as a part of the MApUCE project (Hidalgo et al., 2019). Similarly, another study developed LCZs for Toulouse city, France (Kwok et al., 2019). Numerous studies identified the urban climate of Chinese cities using GIS and remote-sensing methods (Benjamin Bechtel et al., 2015). Another study determined the thermal environment through LCZ maps for Taipei, Taiwan (Y.-C. Chen et al., 2019). These case studies have adopted various methodologies to create LCZs maps. In the light of diverse methodologies and datasets available, this study systematically reviews methods and data sources used in previous studies for developing local climate zones.

Generally, the areas are classified based upon the urban morphology, the type of built-up, and the natural cover. The local climatic zones maps of the city provide information about the urban morphology as well as the heat conditions, which is very useful information for urban renewal and planning (I. D. Stewart & Oke, 2012). For megacities where temperature changes are occurring rapidly due to urbanization, the LCZ method has been proved useful. For generating the local climatic zone maps of the city, different indices have been used, like urban structure, urban texture, surface cover, and anthropogenic heat sources (I. D. Stewart & Oke, 2012). The urban configuration has a close link with the thermal conditions of the city. The UHI effect can be mitigated by planning the city smartly. The important cooling effect is provided by the green spaces (J. Yang et al., 2017) so that it can be planned accordingly for a better living environment. The LCZ maps generated will be helpful for the urban planners to make the new development policies by keeping different factors like urban structure, texture, and configuration in mind. To understand the LCZ phenomenon and get familiar with the methodologies and data sources systematic review was done.

2.4 Systematic Review

Systematic reviews have emerged to synthesize previous research and findings. Systematic reviews were first done in medical science but have now been widely used for addressing other problems related to public policy and the environment (Bilotta et al., 2014; Oxman & Guyatt, 1993). These reviews have been used to identify the research gaps in a particular field of study and highlight future needs or trends for further research purposes. A systematic review synthesizes results from previous studies using explicit methods and provides meaningful information (Greenhalgh, 1997). A systematic review is conducted to find research work done on a particular problem and summarizes the results or the conclusions, qualitatively or quantitatively (Armstrong et al., 2011). The findings from the systematic review are not limited to a few articles, and detailed research is needed to understand a particular topic (Akobeng, 2005). Most systematic reviews include five necessary steps required to be followed; formulation of a research question and its scope, collecting the data and defining the sources, filtering the data and acquiring relevant data, and finally summarizing (Armstrong et al., 2011). This study uses a systematic review of the empirical research articles which exclusively focused on local climate zones development.

2.4.1 The PRISMA framework

Different frameworks have been used for the systematic review of the articles. In 1999, an international group developed guidelines for meta-analysis reporting called the QUOROM statement (Moher et al., 2000). It was updated in 2009 by 29 researchers to rename it as the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Liberati et al., 2009). PRISMA follows a checklist while doing systematic reviews or meta-analyses. This list should be followed while carrying out a systematic review. Some of the essential items of the checklist include title, abstract, introduction, methodology, results, and discussion. There are a total of 27 items in the PRISMA checklist (Moher et al., 2009). Using this framework, the strengths and weaknesses in current literature can be easily identified. It is structured and easy to understand. This study uses PRISMA for shortlisting relevant articles and conducts thematic analysis for the systematic review. This study has used the following PRISMA framework steps to systematically shortlist and review empirical published research on local climate zones (Figure 3).

2.4.1.1 Identification

Two databases, Scopus and Web of Science, were used to search for relevant papers using selected keywords. The keywords used for article extraction were 'local climat* zon*' and 'urban'—the asterisk (*) symbol includes all possible characters in the search query. The database was searched on 7th November 2020. Only articles that were in the English language were considered for review. A total of 482 articles were retrieved from both databases. Using the PRISMA methodology, all the records were downloaded and reviewed. The query and subsequent results have been shown in Table 1.

Table 1 Keyword search and results

Keyword Search	Database	Research Results	Date Searched
"local climat* zon*" AND urban	Web of Science Core Collection (including SCI-EXPANDED, SSCI, A&HCI, ESCI)	240 documents (193 research papers, 47 conference papers)	7th November 2020
	Scopus	242 documents (216 research papers, 26 conference papers)	

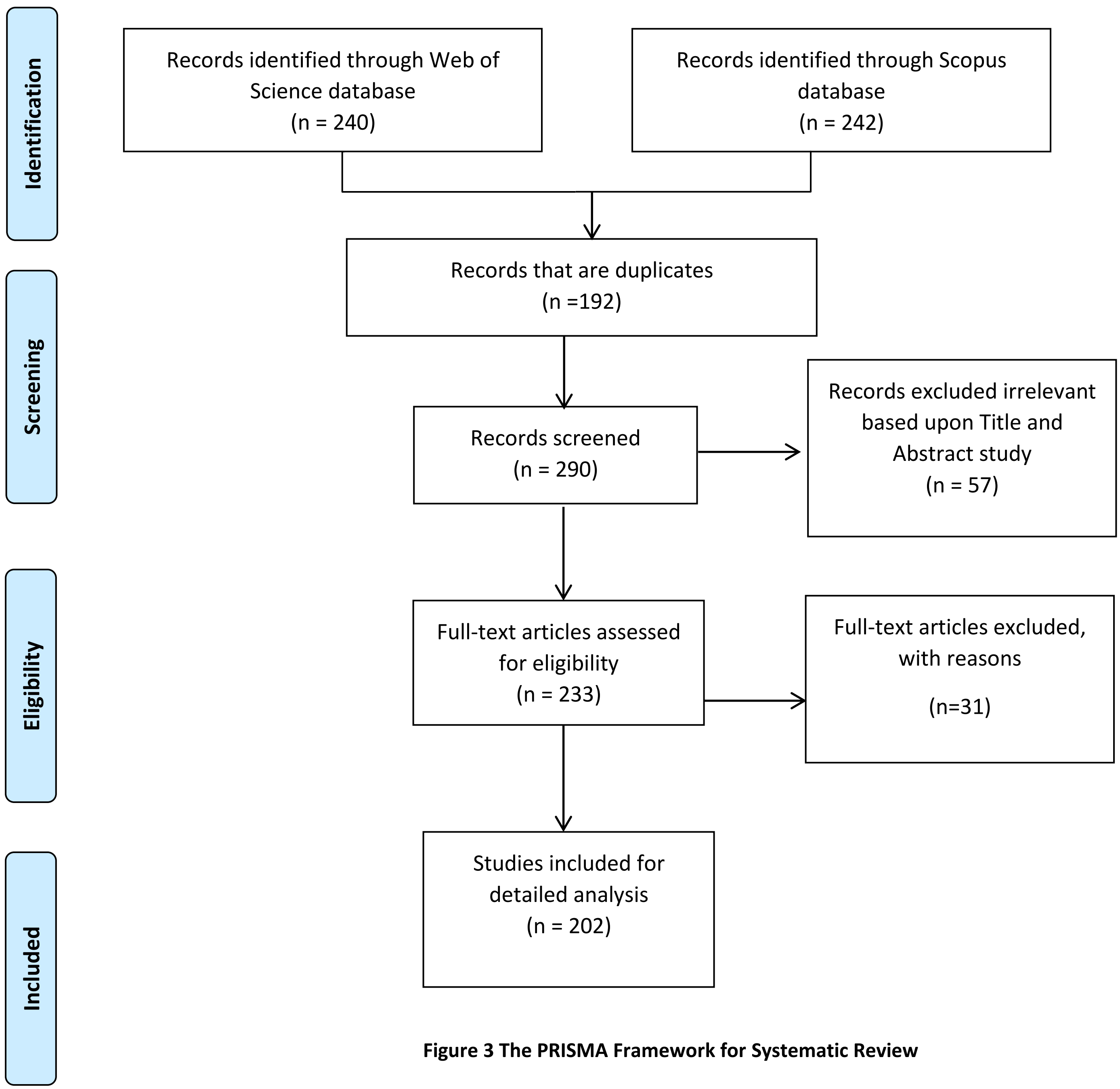


Figure 3 The PRISMA Framework for Systematic Review

2.4.1.2 Screening

In the screening process, duplicate articles were checked, extracted from both the databases, i.e., Web of Science and Scopus. A number of 192 duplicate articles were observed. In the next step, 290 articles retrieved were scrutinized. The articles' titles and abstracts were studied carefully, and the articles were included or excluded from the study accordingly. A total of 233 articles were shortlisted, which focused on the development and empirical use of LCZs. This study has conceptualized empirical research as a published study where conclusions are drawn strictly based on empirical evidence through direct or indirect observation from the real world.

2.4.1.3 Eligibility

After the screening of the records, all the remaining 233 articles were then accessed for full-text eligibility. However, nine articles were not accessible from the host institution. Therefore, this exclusion criterion resulted in 202 articles, including 57 conference papers, for further review.

2.4.1.4 Included

In the last step of the PRISMA framework, the total number of articles was determined using qualitative and quantitative synthesis. This study then reviewed, categorized, analyzed, and discussed a total of 202 shortlisted articles (Annexure 1).

2.4.2 Data analysis methods

A descriptive and thematic analysis was performed to get structured information from the data. Descriptive analysis included yearly and country-wise research publications on local climate zones, data collection methods, and data sources. A thematic analysis of the articles was done in the last phase to determine most key areas or themes linked to local climate zones. From this analysis, results were formulated, and recommendations for future studies were suggested.

2.4.3 Thematic analysis

Thematic analysis is mostly used for the analysis of qualitative data. It is defined as the method for identifying and analyzing different patterns in the data (Braun & Clarke, 2006). It is a simple and flexible yet robust method. It is not research-specific and can be used for any type of research. It gives the data transparent, rich, and detailed meaning, which can help formulate the results. The thematic analysis uses six stages for analysis, i.e., familiarization, codes formulation, generation of themes, themes review, defining and naming themes, and report formation (Braun & Clarke, 2006). While becoming familiar with the data and reviewing the articles, researchers can also note the ideas relating to the codes and can use them in later stages. These ideas can come directly from the source or by paraphrasing given information (Aronson, 1995). There is a broad category, and many codes can come under one theme. Themes are important that are extracted by bringing together segregated ideas or experiences which are meaningless when viewed separately (Leininger, 1998). Once themes are generated, they are reviewed again to represent an accurate and true representation of the data. If any theme appears unclear or vague, it can further split or merged with other themes. With the help of thematic analysis, the main features or important factors from large data can be identified and used for a systematic approach and help generate useful and clear results and reports (King, 2004). However, one disadvantage of thematic analysis is flexibility, which leads to inconsistency in generating themes (Holloway & Todres, 2003). This inconsistency might result from the subjective viewpoints of various researchers and analysts. Therefore, this study has used the occurrences of authors' keywords from bibliometric analysis to limit biasness and promote consistency.

This study, firstly, familiarized with the records and managed them on excel sheets. After that detailed and critical review for each article was conducted (see Annexure 1). The information was then summarized and grouped with respect to the ideas and results. A thorough study of the articles was conducted for code generation, and important words or phrases (that appear meaningful) were highlighted. However, this is a critical step, as while generating codes, clear boundaries have to be set so that they cannot be interchanged (Attride-Stirling, 2001). According to their main objectives, studies were assigned codes, key ideas (themes), data sources, and methods. Depending upon the multidisciplinary nature of research, some studies were given up to three codes. For example, if a study takes into account air temperature, land surface temperature, and the UHI effects, three different codes were assigned to it. Whereas similar phenomena such as urban configuration, urban morphology, and urban form, used in many of the studies, were assigned a single code.

After giving codes to all the articles, an excel file was made on which all the data was entered. After assigning themes, a detailed review of articles was done again to clear any ambiguity/missing codes for each paper. Each code was assigned thematic areas for categorization purposes, and a proper name was allotted for easier understanding for the readers. In the last stage, VOSviewer was used to visualize and identifying co-occurring keywords used in selected studies. This helped in cross-checking and naming thematic areas.

2.4.4 Descriptive statistics

A detailed analysis was performed for the articles that were included in this review. Temporal publications on local climate zones show an increase in local climate zoning (Figure 4). The published studies on LCZs began in 2012, and a sharp increase was seen, implying a growing scientific interest in LCZs.

The results show the most of the published research related to the local climate zones have been done on Chinese cities, about 22.27% (n= 45), followed by cities of India (n=10), the Czech Republic, Brazil, Hungary (n = 9), USA and Germany (n= 8), and France (n= 6).

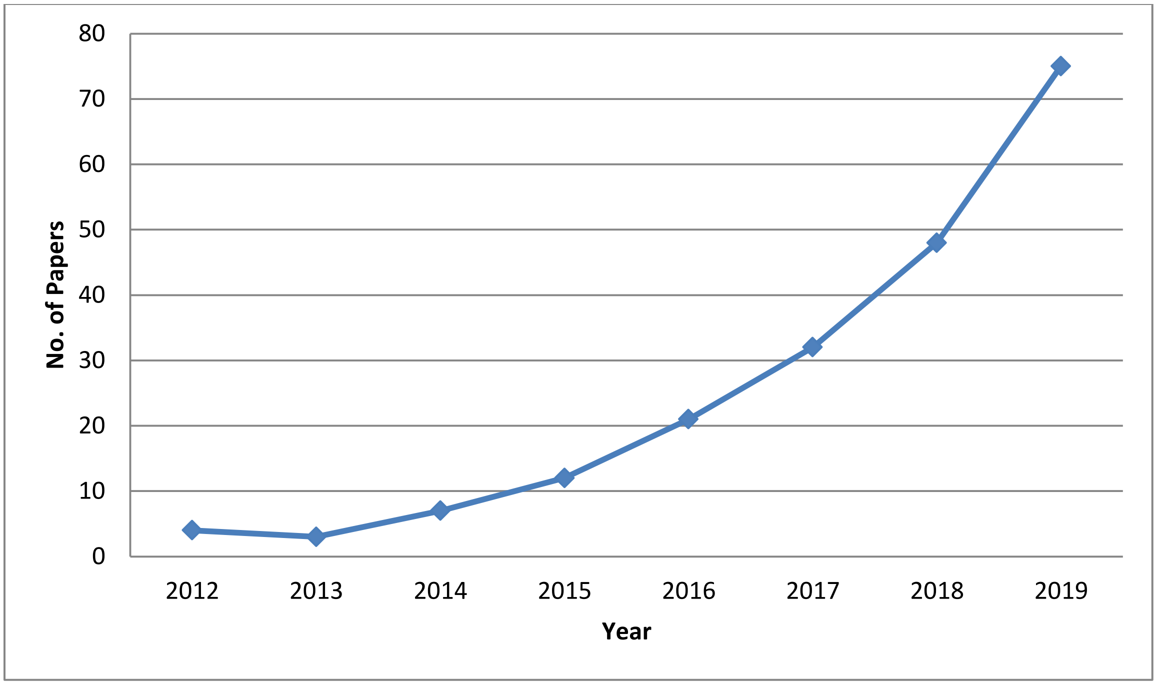


Figure 4 Number of annual research and conference papers on local climate zones

Around 19.8% of the published research has been done in multiple countries/cities (Table 2). Overall, most of the research is being done on the Asian and European regions. Similarly, around 14 individual studies were conducted on various world cities (see Annexure 1 for details).

The top-ten most cited papers were determined from the review papers included in the study. It was found that the scientific article by Stewart and Oke (2012) entitled "Local climate zones for urban temperature studies" is the most cited paper (table 3) on local climate zoning, with 999 citations in WoS and 1110 in Scopus. This paper has served as the basis for local climate zones in many empirical research articles.

Table 2 City-wise empirical research (categorized by country)

Sr. No.	Case studies from countries	Number of studies
1	China	45
2	India	10
3	Czech Republic, Brazil, Hungary	9
4	USA, Germany	8
5	France	6
6	Serbia	5
7	UK, Belgium, Indonesia	4
8	Ireland, Australia, Switzerland	3
9	Portugal, Malaysia, Canada, Taiwan, Greece, Sri Lanka, Spain, Zimbabwe, UAE	2
10	Studies on multiple cities/countries at the same time	40
11	Studies on individual cities/countries	14
	Total	202

Similarly, the second most cited paper is "Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones" by Middel et al. 2014, with 227 and 252 citations, respectively (Table 3).

Apart from the top-cited papers, this review also highlights some of the important journals published on local climate zone studies. The top journal with the greatest number of publications was Urban climate, with 32 publications, with 17 publications in just 2019. Some other journals with a higher number of publications included Building and environment, Remote sensing, and Landscape and urban planning (Table 4). Some of the major conferences held that published on the topic of LCZ and helped in advancing the LCZ methodologies (Table 5).

Table 3 Topmost cited from selected papers

S.no	Title	Authors	Citations*	
			(WoS)	(Scopus)
1	Local climate zones for urban temperature studies	(I. D. Stewart & Oke, 2012)	999	1110
2	Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones	(Middel et al., 2014)	227	252
3	Mapping local climate zones for a worldwide database of the form and function of cities	(Benjamin Bechtel et al., 2015)	180	211
4	Evaluation of the 'local climate zone' scheme using temperature observations and model simulations	(Iain D. Stewart et al., 2014)	180	201
5	Classification of local climate zones based on multiple earth observation	(Benjamin Bechtel & Daneke, 2012)	108	119
6	Counteracting urban climate change: adaptation measures and their effect on thermal comfort	(Müller et al., 2014)	94	105
7	Using local climate zone scheme for UHI assessment: Evaluation of the method using mobile measurements	(Leconte et al., 2015)	90	93
8	Urban heat island and its impact on climate change resilience in a shrinking city: The case of Glasgow, UK	(Emmanuel & Krüger, 2012)	81	88
9	Local climate classification and Dublin's urban heat island	(P. Alexander & Mills, 2014)	71	79
10	Design of an urban monitoring network based on Local Climate Zone mapping and temperature pattern modelling	(Lelovics et al., 2014)	65	81

* Note: As of 8th December 2020

Table 4 Top ten journals of the selected published articles

Sr No.	Journal Name	2019	2018	2017	2016	2015	2014	2012	Total*
1	Urban climate	17	12	-	2	1	-	-	32
2	Building and environment	3	2	-		1	1	1	8
3	Remote sensing	5	1	-	1	-	-	-	7
4	Landscape and urban planning	2	2	-	1	1	1		7
5	IEEE Journal of selected topics in applied earth observations and remote sensing	2	1	1	2	-	-	1	7
6	Hungarian Geographical Bulletin	-	-	-	5	-	1	-	6
7	Theoretical and applied climatology	2	-	1	-	1	1	-	5
8	International journal of climatology	1	1	1	-	-	1	-	4
9	Climate	1	3	-	-	-	-	-	4
10	ISPRS international journal of geo-information	-	3	-	-	1	-	-	4

* Note: In 2013, no paper in the top-ten journals

Table 5 Top-five conferences with published papers

Sr. No.	Conferences	No. of Papers
1	2017 Joint Urban Remote Sensing Event (JURSE)	11
2	2019 IEEE International Geoscience And Remote Sensing Symposium (IGRASS 2019)	3
3	2017 IEEE International Geoscience And Remote Sensing Symposium (IGRASS)	3
4	PLEA 2018 - Smart And Healthy Within The Two-Degree Limit: Proceedings Of The 34th International Conference On Passive And Low Energy Architecture	3
5	Proceedings Of 33rd PLEA International Conference: Design To Thrive, PLEA 2017	3

2.4.5 Data sources used for local climate zoning

Results have revealed numerous types of data have been adopted for the local climate zones mapping. The review on LCZs clearly shows that for mapping the LCZ, secondary datasets like Landsat or Sentinel images are used. In contrast, some published research has also used primary data like field surveys, site/aerial photographs for further validation, and ground-truthing. The review shows that most published work has used both primary and secondary sources for LCZ mapping. The data sources were categorized into remote sensing-based, GIS-based, and in-situ measurement and government datasets (Table 6).

Table 6 Major Data sources used in studies

Datasets	Number of Studies	Source	Purpose
Remote sensing-based datasets			
Landsat (8,7,5) images	98	USGS Earth Explorer	For mapping of local climate zones/LST determination
Photographs/ Photogrammetric mapping	19	Site photographs aerial view/Sky view	For more area details and height information for local climate zones mapping
Sentinel 1,2	24	Sentinels Scientific Data Hub https://scihub.copernicus.eu/	For information about the urban structure for local climate zones, height information by generating DEM, a potential source for global mapping/ Land cover classification
Google Street View/Google Earth Images	18	Google Earth	For detailed area view for better identification of local climate zones
MODIS products	14	Earth Data Search by NASA (https://search.earthdata.nasa.gov/search)	For determination of LST
GIS-based datasets			

Training areas/Data from WUDAPT	85	Google Earth/WUDAPT portal	For the identification of different class to generate local climate zones
LCZ maps	19	Already available maps	Used as an input in different models like SOLWEIG/ENVI-met
Land cover	18	Government departments, Corine land cover, Global land cover maps	For local climate zones mapping and to be used as an input in models like SUEWS
Open Street Map	16	Open database (ODbl) licence (https://www.openstreetmap.org/ Geofabrik portal (http://www.geofabrik.de)	This data can be used for improving the classification accuracy, i.e., roads and water bodies can be accurately classified
In-situ measurements and government datasets			
Meteorological stations data	56	Meteorological departments /weather stations/ personal equipment	Mostly the data has been used to determine the air temperature. Some studies have also used for humidity and wind conditions in the respective local climate zones. This has also been used as an input in different models
Statistical, planning, and GIS data	35	Government departments	Used for statistical comparisons and GIS-based detailed LCZ mapping
Field surveys	16	Primary data source	Used for ground-truthing, better identification of training areas, and temperature readings
Mobile measurements	10	Personal survey/instrument mounted on a vehicle	Temperature measurements to determine the thermal differences between local climate zones

2.4.5.1 Remote sensing-based datasets

Various datasets have been used in developing LCZs for urban areas. The most frequently used satellite imagery data was Landsat, a free-to-use data source, explaining its recurrent use in LCZ studies. Researchers have also used Sentinel (1-2) data for LCZ baseline input, which is preferred for larger spatial scales. One of the advantages of Sentinel data was its compatibility with many other datasets, thus ensuring the quality of LCZ output maps (Demuzere et al., 2019). Many of the conference papers have also emphasized using Sentinel data for multi-seasonal imagery (Chunping et al., 2018), training set configuration (Qiu, Schmitt, Mou, et al., 2018), and feature importance analysis (Qiu, Schmitt, Ghamisi, et al., 2018). Some studies have used Landsat and Sentinel images (Sukhanov et al., 2017) to analyze classification accuracy (Kaloustian et al., 2017). MODIS data has also been used to determine the land surface temperature in some LCZs studies, e.g., Dubai (UAE) (Nassar et al., 2016). In some instances, ASTER images have also been used to determine temperature (Jason Wai Po Tse et al., 2018). Some studies have also used LiDAR data to get detailed urban morphology information for generating LCZ maps (Bartesaghi Koc et al., 2018).

Photography can be used for proper identification; some studies have also used photogrammetric mapping to ascertain the height of infrastructure. In a study on Vancouver (Canada), site photographs with aerial and sky views have been used to better represent and identify LCZs (Aminipouri et al., 2019). Small format aerial photography has also been used for Hungarian cities (Skarbit et al., 2015). Similarly, already available photogrammetric data was used to determine the building heights in the areas of Brno and Hradec Kralove, Czech Republic (Geletič & Lehnert, 2016).

2.4.5.2 GIS-based datasets

Several studies have used GIS data or available maps for further use in LCZ mapping. The most common dataset was used World Urban Access Portal Tool (WUDAPT) for training data samples. The second-most commonly used data is training areas or samples created and extracted using the Google Earth platform. These training areas help in the identification of different LCZs classes. Training areas via Google Earth data have been used for local climate zones mapping in Madrid (Spain), Hamburg (Germany), Hong Kong (China), and Greater Tunis (Tunisia).

Similarly, some studies use the training samples directly from the WUDAPT portal for the construction of LCZs for Khartoum (Sudan), Chicago (USA), Sao Paulo (Brazil), Vancouver (Canada), Hong Kong and Shenyang (China), Matsuyama (Japan), Singapore (Singapore), Melbourne and Sydney (Australia), London (UK), Madrid (Spain), Paris (France) and Warsaw (Poland). Some of the conference papers also discussed the improved methodology linking to the transferability of the training samples from one city to the other (Kaloustian et al., 2017). Similarly, some studies have used pre-existing LCZs map/data for comparison and validation purposes. For example, a study on Sao Paulo, Brazil, used LCZ maps already validated by WUDAPT for determining urban canopy parameters (Pellegatti Franco et al., 2019).

Google Street View and Google Earth images have been used to identify the different classes and obtain more detailed information about the area under classification. Google Earth images have been used in a study conducted in Glasgow (UK) to determine the land cover classes in the area (Emmanuel & Krüger, 2012). Similarly, a study has been conducted on Paris, Hong Kong, Sao Paulo, and Rome that used Google Street view for LCZ classification (G. Xu et al., 2019). Land cover can be used potential data source of information for LCZs mapping and as an input for different climate models. Corine land cover map was used for London (UK) to identify training areas (Mouzourides et al., 2019). Open Street Maps (OSM) have been incorporated in some studies to improve classification accuracy. For example, a study in Hamburg (Germany) used open street map data to improve classification accuracy by combining proper key/value to corresponding LCZ classes (Fonte et al., 2019). Similarly, researchers have used OSM data for generating 3D urban models for Kowloon (Hongkong), Dublin (Ireland), and Toulouse (France) (Benjamin Bechtel et al., 2019). Studies have also used OSM data combined with Sentinel and Landsat images for more accurate feature extraction and classifications (Y. Xu et al., 2017).

2.4.5.3 In-situ measurements and government datasets

Several studies have also used additional data via in-situ measurements and government departments. The most common datasets used by 56 studies were obtained from meteorological stations. It was mainly used to incorporate air temperature, humidity, and wind conditions in the respective climate zones. Data loggers have also been used for taking supplementary temperature readings, usually placed at the height of 1.5m above the ground. The readings obtained from the equipment were then compared with the respective weather stations for validity purposes. Data from meteorological stations and data loggers were later used in the LCZ map to determine the urban heat island effect (Chieppa et al., 2018). Some of the studies also installed their stations for data collection for LCZ mapping of Kochi, India (Thomas et al., 2014), Belgian cities like Brussels, Antwerp, and Ghent (Verdonck et al., 2017), and Nanjing, China (X. Yang et al., 2019). Temporal data from meteorological stations has also been effectively used for calibrating spatial models for calculating climate indices (Geletič et al., 2019). In other cases, detailed administrative data have been used for generating the LCZ maps. In Dallas-Fort Worth, Austin, and San Antonio, Texas (USA), government data was used for determining the population concentration and land use and subsequent use in processing LCZ maps (Zhao et al., 2019). A field survey was conducted in Harare, Zimbabwe, for collecting GPS points, which was later used to classify the LCZ and perform an accuracy assessment (Terence Darlington Mushore et al., 2019). Some studies have used mobile measurements to get the air temperature readings in different zones and develop an understanding of temperature conditions. A study on Nancy, France, used mobile measurements to determine the air temperature at 2m height for urban heat island assessment (Leconte et al., 2015).

Overall, various data sources used in the studies have been discussed here. It can be concluded LCZ related research prefers using satellite images, especially Landsat 8, 7, or 5. Along with Sentinel 1-2 images, training samples have been collectively used to determine different classes. These training samples are usually digitized on Google Earth or directly obtained from the WUDAPT portal (if the city is included in C40 cities, i.e., the cities whose samples are available on the portal). With limited efforts, Landsat images and Google Earth training areas can be freely obtained for any country or region. On the other hand, some studies have also moved from traditional mapping using WUDAPT protocol to GIS-based mapping, using detailed urban planning or OSM data for feature extraction and identification, which provides better mapping accuracies. However, this data method cannot be applied in data-scarce countries. For detailed urban morphology, photogrammetric data has also been used to get the height information. The studies presented in conferences have focused on using multiple data sources like OSM, Sentinel, and Landsat data simultaneously to better map and transfer the training areas. Most studies have incorporated the use of air temperature data from meteorological stations or personally installed weather stations to understand the temperature differences in different classes and to assess the thermal conditions of the city. Primary data are an important source of information. Although many studies predominantly use secondary data for LCZ mapping, field surveys have emerged as an additional source for information gathering and ground-truthing. Recently, mobile measurements and field surveys have also emerged as potential data sources for better accuracies and assessments. However, this method is time-consuming and labour-intensive and depends upon the availability of resources and the purpose of LCZs.

2.4.6 Methods used for local climate zoning

2.4.6.1 WUDAPT method

The initial LCZ method was introduced by Stewart and Oke (2012) to classify the cities. It classifies different areas and land covers based upon the influence on the air temperature. The method identified the relationship between urban morphology and urban heat island phenomena (Stewart & Oke, 2012). The study classified 17 classes, ten classes for the built-up area like compact high-rise, mid-rise, and low rise; and seven for vegetation classes like dense, scattered trees, low plants, and bare soil. These zones were classified based on the value ranges of the urban canopy parameters associated with LCZs. Later, the World Urban Database and Access Portal Tools (WUDAPT) was developed to create local climate zone maps of the cities, providing information on urban form and functionality (Mills et al., 2015). To define the urban canopy parameters (building height, buildings surface fraction, impervious surface fraction) associated with local climate zones, more precisely, high-level data is required. Different data levels referred to as Level 0, Level 1, and Level 2 gathered through the WUDAPT approach have been mentioned in Table 7.

Table 7 WUDAPT data gathering approach

WUDAPT hierarchical approach	
Level 0	Cities are mapped into LCZ, having ten built-up and seven vegetative classes
Level 1	LCZ maps used to sample urban landscape to provide information about the functions (office, industrial, residential) and forms (building height, street length) for the whole city level
Level 2	The highest level at which data is gathered at a scale of (250 m) with intra-city spatial variability

Source: (Hidalgo et al., 2019)

Results have revealed numerous methodologies have been adopted for the local climate zones mapping (Table 8). The most commonly used method for mapping the local climate zones is the WUDAPT procedure. Around 68 studies (33.6%) have incorporated this method in their LCZ empirical research. The methodology proposed by WUDAPT can be used to generate the LCZ maps of the city; wherever data is available. The common and free-to-use datasets used in WUDAPT were Landsat imagery and Google Earth, along with open-source SAGA GIS software. The method uses Landsat images and Google Earth-based training samples for generating the LCZ maps of the city using SAGA-GIS software. Research acknowledges that this method does not require detailed datasets and exceptional skills to prepare local climate zone maps. However, this undermines quality and may require further calibrations using accuracy methods. Studies have used the WUDAPT procedure for mapping LCZs in Alabama, USA (Chieppa et al., 2018), Harare, Zimbabwe (T. D. Mushore, 2019), and Yogyakarta, Indonesia (Pradhesta et al., 2019).

Table 8 Major analytical methods used in empirical studies

Methods	Number of studies
WUDAPT procedure	68
GIS-based LCZs	21
Different classifiers/algorithms for LCZs	15
GIS-based LCZ focused on urban indicators/parameters	9
LCZs using Google Earth engine	2

2.4.6.2 GIS-based methods local climate zoning

GIS-based methods and frameworks can utilize both vector-data and raster-data for mapping LCZs, thus giving more precise, accurate, and reliable results. Raster-based methods can be used to identify urban features and building information (Zheng et al., 2018). Moreover, remote sensing-based can also be incorporated for image-based analysis, using supervised and unsupervised classifications (Benjamin Bechtel et al., 2016). On the other hand, Vector-based methods capture the boundaries and generate more precise LCZ maps (Perera & Emmanuel, 2018; Unger et al., 2018). Many new techniques have also been developed for local climate zoning; these techniques include the use of remote sensing technologies to obtain information for cities that are not available otherwise (Benjamin Bechtel et al., 2015).

Similarly, GIS methods have been effectively used for investigating the relationship between different phenomena, e.g., land surface temperatures and local climate zoning (Jason Wai Po Tse et al., 2018). The MApUCE project uses detailed vector data like topographic data, cadastral parcels, roads, and buildings provided by the institutes within the GIS framework. It computes morphological indicators like features, area, volume, compactness, distance, etc. Another study used GIS-based methods for developing LCZs for three cities of the Czech Republic (Geletič & Lehnert, 2016). Similarly, a study conducted in Quezon City (Philippines) also utilized GIS-based methods to map LCZs (Estacio et al., 2019).

2.4.6.3 Classifiers and algorithms for local climate zoning

Apart from the basic WUDAPT procedure and GIS frameworks, different classifiers and classification algorithms have also been used for generating the local climate zone maps. Residual convolutional neural Network (ResNet) is a classifier that has been used for LCZ classification to feature importance analysis for nine cities of Europe. Some studies have used auxiliary data like Open street map (OSM), Global Urban Footprint (GUF), and Nighttime light (NTL) (Qiu, Schmitt, Mou, et al., 2018). Another study used four different classifiers, Naïve Bayes (NB), Random Forest (RF), Support Vector Machine (SVM), and multilayer perceptron (MLP) neural network for classifying the LCZ (Benjamin Bechtel et al., 2016). A research study conducted on Chicago (USA), Amsterdam (Netherlands), Xi'an (China), and Madrid (Spain) used SVM, MLP, and XGboost classifiers (Y. Xu et al., 2017). Similarly, another study conducted in Hamburg, Germany, used six different classifiers to map the LCZ (B. Bechtel et al., 2012). Some studies have also used different algorithms like multi-resolution segmentation (dos Anjos et al., 2017).

2.4.6.4 Urban canopy parameters and indicators

Various studies have exclusively focused on using the defined urban canopy parameters to classify the area into different zones. These parameters help in developing LCZs using established value ranges. A study on Dubai, UAE, used nine different parameters for the classification of local climate zones. The study area was divided into 250m*250m grid cells, and urban geometry and land cover parameters were determined for each cell. According to the value, each cell was assigned a respective LCZ (Nassar et al., 2016). A study has been conducted in Schillerkiez, Germany, the value of the parameters (sky view factor, building/vegetation height, pervious/impervious surface fraction was determined (Quanz et al., 2018). Similarly, a study has been conducted in Heraklion, Greece, which used Earth observation data and remote sensing science to derive urban canopy parameters (sky view factor, building density and height, impervious/pervious surface fractions, and surface albedo) for characterizing LCZ (Mitraka et al., 2015). Some studies have used the Google Earth Engine platform for refining the WUDAPT methodology. A study used Google Earth to determine the information transferability of LCZs from one city to another, applied for various cities of the world (Demuzere et al., 2019).

2.4.7 Urban climate models for local climate zoning

Many studies have also used advanced weather and climate models in their studies (Table 9). Weather Research and Forecasting (WRF) model was developed at the University of Oklahoma by the collaboration of many organizations and universities, notably the joint development of the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the Forecast Systems Laboratory (FSL), the Naval Research Laboratory (NRL) and the Center for Analysis and Prediction of Storms (CAPS). This model was to ascertain the effect of urbanization on weather conditions (Skamarock et al., 2005) and link LCZs with weather forecasting models (Brousse et al., 2016). WRF was the model that has been incorporated in around 13 studies. A study on Sao Paulo, Brazil, used WRF-chem (Weather and Research Forecasting with chemistry) model by considering both the physical and chemical parameterizations to study the impact of different urban land covers on pollution. WRF model was also used in a study on Vienna, Austria, coupled with building effect parameterization and building energy models using both WUDAPT and GIS-based methodologies (Hammerberg et al., 2018).

Apart from WRF, ENVI-met, Surface Urban Energy and Water Balance Scheme, and MUKLIMO have also been used in some studies. A study conducted on North Desert Village Phoenix (USA) utilized Envi-met model for simulating near-ground air temperatures (Middel et al., 2014). Surface Urban Energy and Water Balance model (SUEWS) was used to derive the required land cover parameters for the model for various cities (P. J. Alexander et al., 2016). A study conducted in the Czech Republic used the MUKLIMO_3 model for the spatio-temporal modeling of the air temperature (Geletič et al., 2016).

Table 9 Different models frequently used in empirical studies

Models	Number of studies
Weather Research and Forecasting Model (WRF)	13
Envi-met	8
Surface Urban Energy and Water Balance Scheme (SUEWS)	4
MUKLIMO	4
Urbanclim	2
Rayman	2
SOLWEIG	2

A review of selected articles has revealed numerous methods and models used. It has emerged that the WUDAPT procedure is predominantly used for generating local climate zone maps. Using this method, LCZs can be easily developed with little expertise and freely available data. This method can be easily used in data-scarce regions for temperature studies, where detailed urban data is missing. However, for developed countries with GIS data availability, advanced GIS methods and models should prepare more precise maps. Some studies have also incorporated different classifiers and algorithms for LCZ mapping to further improve the results and classification accuracy. Moreover, the review has revealed that LCZ maps can be used as input for many urban climate models.

2.4.8 Thematic analysis

VOSviewer has been used for this visualization, which is a software tool for analyzing scientific literature. The visualization map has been prepared for the co-occurrence of 4 keywords. The size of the circles determines the frequency of occurrences, i.e., the larger the size of the circles, the higher the frequency. The distance between the terms determines the relatedness; the closer they are, the higher the relatedness. A total of 34 authors' keywords (co-occurring together at least four times) were found and shown in Figure 5. The keyword analysis reveals that urban heat island is consistently used within LCZ literature, followed by land surface temperature, urban climate, and WUDAPT. This implies that most of the studies have concurrently used these keywords/themes in their papers.

Thematic analysis was used to identify key factors and dimensions considered in previous research studies. Each study was scrutinized, and the main features have been identified (Table 6, 8). Analysis has revealed that the most consistent and recurring theme was urban heat island followed by air temperature, land surface temperature, and urban morphology (including urban configuration and form) in Figure 6.

2.4.8.1 *Urban heat island*

Urban heat island (UHI) is defined as higher temperature in the urban areas as compared to the surroundings; this difference of temperature is mostly greater at night as compared to the day (Arnfield, 2003), and numerous cities are affected by it (Zhou et al., 2014). UHI phenomena can be defined as a longer duration of high temperature and higher maximum air temperature of the urban regions than the outer suburbs. UHI is a closely related term in assessing thermal temperatures in urban settings (Li et al., 2017; Peng et al., 2012). Local urban heat island intensities are also an alternative term to determine the heat intensities of the regions and help in determining the effects of local urbanization. UHI is one of the main concerns for local administrations and urban planners for the physical development of the city. Consequently, it is one of the most recurrent phenomena studied in LCZ research. The LCZ of a city depends upon the urban configuration or the types of built-up area. With more urban development, the temperature differences between the urban and rural areas also increase the urban heat island. It has been demonstrated in the research that LCZ can effectively help in a better understanding of the urban heat island effect and its impacts.

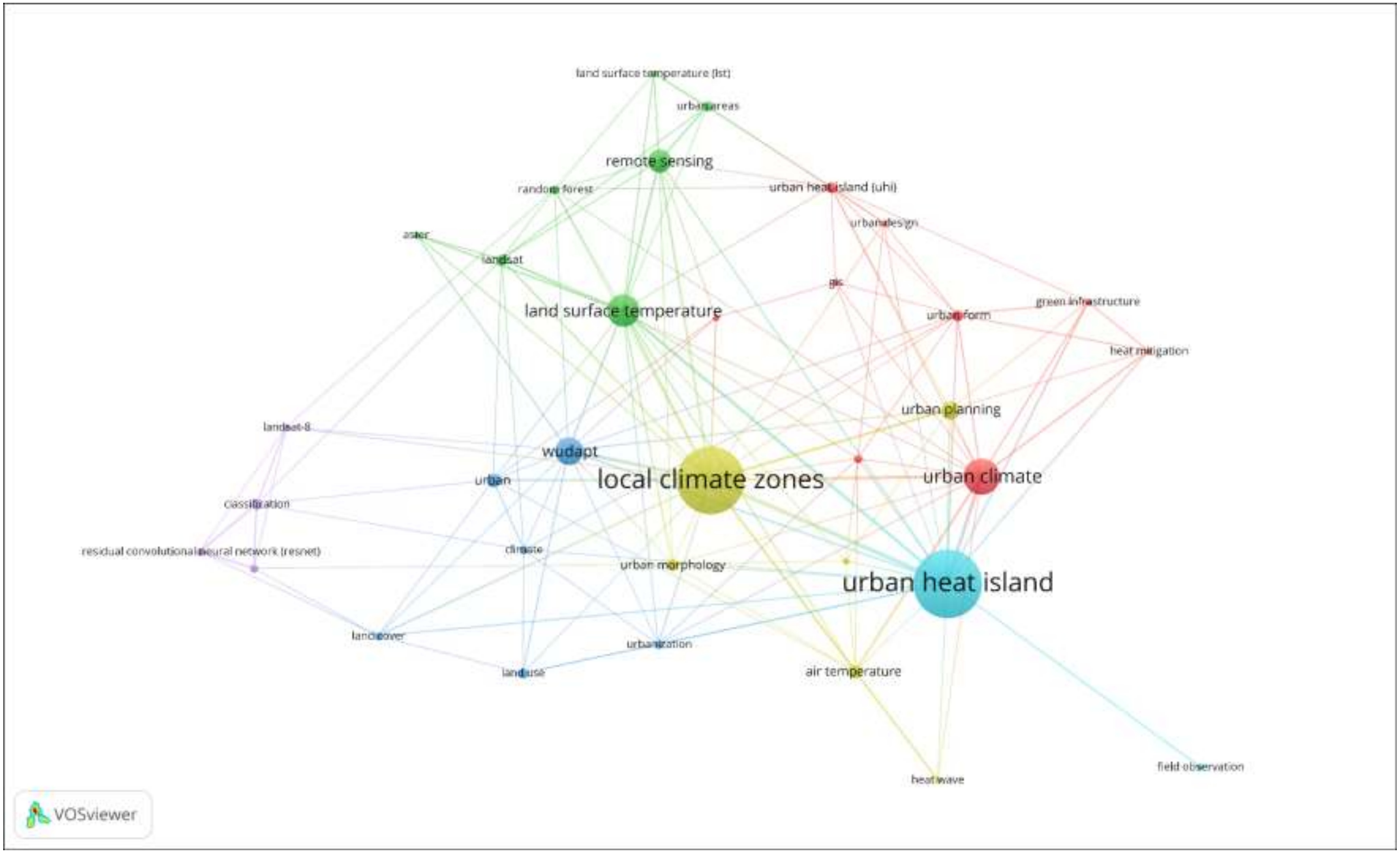


Figure 5 Co-occurrence of four authors' keywords in the local climate zoning literature (Visualized in VOSviewer 1.6.14)

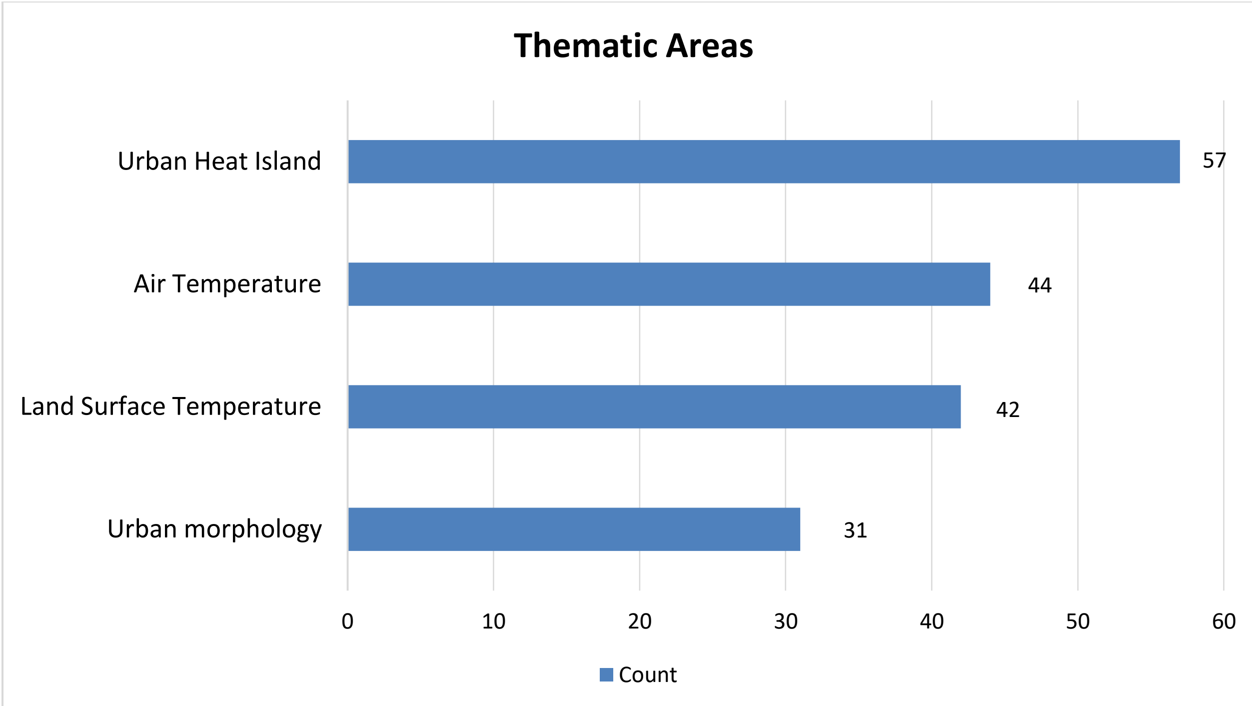


Figure 6 Thematic Areas

Some research focused on the UHI phenomena includes a study carried out in Szeged, Hungary (Gál et al., 2016), Fuzhou, China (Lin Zhongli & Xu Hanqiu, 2016), and Bogor, Indonesia (Nurwanda & Honjo, 2018). There is also a need to work on the temporal local climatic zones maps to observe the UHI effect through the years and how it has increased with time and the areas significantly affected by it.

2.4.8.2 Air temperature

Air temperature is considered an important factor in developing LCZs. It helps to classify the LCZ and supporting studies on the urban heat island effect. One of the Czech Republic studies used meteorological station data from Metropolitan Station System in Olomouc (MESSO) for observing the air temperature and compared it with LCZ classes of the respective sites to understand the heat island effect (Lehnert et al., 2015). An integrated method has also been proposed using air temperature data from mobile measurements and spatial interpolation to determine the local urban heat island intensities. The air temperature data has also been obtained through mobile measurements for temporal correction and UHI values. The air temperature at 2m is an important factor, as most human activities occur there. With the changing human activities, the air temperature also changes. Many studies observed the relationship and concluded that areas with more compact and dense developments have higher air temperatures than the surroundings. The studies focused on air temperature conditions using meteorological stations and mobile data to classify and model the urban climate (B. Bechtel et al., 2012). Another study modeled the spatio-temporal variability using meteorological station data (Geletič et al., 2016). Therefore, air temperature can be seen as an important factor for LCZs mapping to analyse the thermal stresses and identify the urban hotspot maps. Ultimately, this can be used for developing necessary urban risk reduction measures and climate change adaptation strategies.

2.4.8.3 Urban morphology

The urban form of a city is closely related to urban climate (Eliasson, 1990). Urban morphology can be defined as the study of physical forms of human settlements, i.e., how the cities, towns, or villages used to be and how it has physically transformed over the years. Detailed urban morphological data is generally required for the LCZs mapping. Each urban block may possess different patterns that can be used in identifying the morphology, i.e., building density, the height of buildings, and ecological space coverage ratio. Each LCZ type can have a set of variables linked to it. These variables include sky view factor, building height, albedo, pervious and impervious surface fraction, anthropogenic heat flux, building surface fraction, and terrain roughness class (Stewart & Oke, 2012). They can be referred to as urban canopy parameters (Hidalgo et al., 2019). A study conducted on Chongqing, China, and Dubai UAE, divided the study area into a grid of 250*250 m and determined the values of urban indicators for each grid (Z. Cai et al., 2019; Nassar et al., 2016). The study by Cai et al. 2019 also compared the grid values with the standard value ranges. Some studies have used urban morphology as an urban climate landscape depending upon the LCZ classification (Wang et al., 2017). Thus, the LCZ mapping approach can include this additional information for potential use in urban climatic research.

Urban morphology gives information about the urban surface; its characteristics can help classify the city. However, due to data limitations in most regions, the WUDAPT methodology has been adopted to derive the information relating to the city forms and functionalities (Jason Wai Po Tse et al., 2018). An urban database developed by the French named MApUCE provides detailed morphological information by using topographic data and cadastral information. The types of morphological indicators being used are the number of features, building area, number of floors, volume, etc. (Hidalgo et al., 2019). The area's build-up pattern determines the type of climate zones it will fall in. More compact development and high-rise will fall in the category LCZ 1 similarly midrise and compact in LCZ 2 and so on. The building type and functionalities affect climatic conditions. The temporal mapping of the LCZ can also be done and can be used for determining the change in urban morphology with time and the LCZ maps and hence can give knowledge about their relationship.

With increasing urbanization, the urban landscape is converted into built-up land like skyscrapers, pavements, roads, rising temperatures, and influencing local climatic conditions (Oke, 1982). Temperatures in the city are closely linked to surface morphology. A study conducted in Wuhan, China, focused on the urban morphology for observing the thermal environment of the city (Yue et al., 2017). Land surface temperature is closely linked to the distribution of the building in the area (Yang et al., 2019). Due to this, UHI can intensify extreme weather events like heat waves (Tan et al., 2010). Thus, LCZs and urban morphological parameters can help in adjusting urban heat island models.

2.4.8.4 Land surface temperature

Land surface temperature (LST), defined as the earth's surface temperature, is considered one of the important factors while developing local climatic zones mapping. Many studies have been done to incorporate the knowledge of land surface temperature with the local climate zoning. A study on the Deltaic regions of China examined the relationship between LST and local climatic zones. It was observed that the LST values were higher in LCZ of built-up areas with the highest in LCZ 1 while less LST was observed in the LCZ of vegetative cover (Jason Wai Po Tse et al., 2018). The land surface temperature of the area depends on several factors like surface radiation, altitude, topographical morphology, land cover, and general climatic conditions (Yang et al., 2019). The land surface temperature divides the urban climate landscapes into two the action and compensation landscapes, depending upon their LST. Land surface temperature is also an important factor for analyzing the thermal conditions of compactly developed areas. While some empirical studies focused on determining LST's relationship with LCZs and urban form (M. Cai et al., 2017). The land surface conditions can be analyzed with the temporal land use and land cover maps. It can provide meaningful knowledge for the LCZs and potential risk mapping. Using LST maps, hotspots can be generated and used to work out mitigation measures for bringing thermal comfort in the urban environment.

2.5 Risk perception and psychological distancing to climate change

Risk perception is used to understand people's judgments and reactions towards events (Renn, 2008). To deal with extreme events and mitigate risk, it is important how people perceive the risks so that adequate risk reduction plans and policies may be designed and implemented successfully (Rana & Routray, 2016). The scientific literature has identified a positive association between preparedness and risk perception (Miceli et al., 2008; Peacock et al., 2005). The perceived risk is considered more important than the actual risk because it influences the ability to deal with the risks (Peacock et al., 2005)

. To determine the risk perception, some of the factors play a key role, like fear or worry. People will take appropriate measures to mitigate risk if they feel threatened (Rana & Routray, 2016). Similarly, attitude and behavior suggest whether people will modify their responses and adaptation measures against a potential threat (Ho et al., 2008). The level of trust also plays a vital role in risk perception. The response to the events will improve if the individual trusts the information received by the governmental sources (Slovic, 1999). Knowledge of personal experience can also affect risk perception, as people who have experienced an event or their family is affected by it will perceive it higher (Lorenzoni & Pidgeon, 2006). Apart from these components, some studies have also considered the socioeconomic factors like income, age, gender, education and related them to the attitude of people towards the perceived risk (Besel et al., 2017; Hoffmann & Muttarak, 2017). According to the literature, women's risk perception tends to be higher than men (Khan et al., 2020; Van der Linden, 2015). Similarly, married (Stedman, 2004) and young individuals tend to perceive high risk (Weber, 2016). However, these factors vary considerably due to cognitive abilities, socio-political and cultural factors (Renn, 2008).

Psychological distance has emerged as a phenomenon to understand public pre-disposition to accept risks. Some people may think that climate change is happening, while others believe it to be a distant phenomenon and its effects will be seen in the future (Spence et al., 2012). The events that are distant and are not directly experienced by humans and how they act upon them are explained by the construal level theory (Trope & Liberman, 2010). The two main components of the theory are construal level, and psychological distancing, how an object or event can be interpreted represents its construal level, and psychological distancing is highly related to the construal level. With the increase in distance, the object becomes more abstract and generalized, while closer objects are perceived in a more detailed and specified manner (Bar-Anan et al., 2006, 2007). The psychological distance can be observed through various dimensions, namely, geography, social, temporal, and uncertainty (Spence et al., 2012), referring to the questions like where an event occurs, to whom, when, and whether it occurs or not (Trope & Liberman, 2010). The general public is less involved in the changing climate issues and concerns due to the psychological distancing. It affects public perception and attitude towards risk. The situation can be made better by reducing the psychological distance (Jones et al., 2017).

Several studies have tried to establish a link between the built environment and risk perception. A study conducted in Delhi, India, suggested traffic risk perceptions are influenced by the built environment (Rankavat & Tiwari, 2016). Similarly, another study conducted in some villages of China affected by the Wenchuan earthquake has considered the role of the built environment in earthquake evacuation; risk perception and the built environment positively affected their response (Ao et al., 2020). Open spaces are also known to affect public risk perceptions (Shrestha et al., 2018). To assess the thermal comfort of the public spaces, a study in three Dutch urban squares concluded that the openness of the influences climate responsive designs (Lenzholzer & van der Wulp, 2010). Similarly, a significant association between perceptions of the built environment and physical activity has been observed in Portugal (Santos et al., 2009). The outdoor places, parks, and recreational facilities are directly related to the high level of physical activity (Norman et al., 2006). Another study linked the role of the built environment on criminal activities in neighborhoods (Cozens, 2008). However, limited studies have linked climate change risk perception and psychological distancing in the built environment. Therefore, this study classifies built-up forms using the local climate zoning framework given by Stewart and Oke (2012) and quantifies climate change risk perceptions and psychological distance.

2.6 Summary of the chapter

Migration towards the urban centers is not only putting immense pressure on the resources but is one of the major causes of resource depletion. To deal with these consequences, sustainable development is needed. United Nations has presented 17 SDG's to protect people, the planet, and the environment. To incorporate the SGD's in the development and built resilient and safe cities. Two main SDG's linked to this study is SDG 11 and 13.

To build sustainable cities and combat the changing climate, the conditions of the urban areas should be studies at a micro-scale. For this purpose, the local climate zones scheme introduced by Stewart and Oke (2012) has been adopted. To get familiar with the materials, methods and data sources, a detailed systematic review has been done using Prisma Framework. The analysis revealed that the annual number of studies linked to LCZs is increasing temporally. The highest number of research studies regarding LCZ's has been done by China. The most cited paper is “Local climate zones for urban temperature studies” by Stewart and Oke (2012), while urban climate is the journal in which the majority of the work linked to LCZs has been published. Different types of data have been used, while the most common methodology adopted is WUDAPT. The most common thematic area is the urban heat island. The review has also highlighted case studies being done all around the world as well as the conference proceedings.

To measure the public awareness and perceptions, at the last stage review of the studies linked to risk perception and psychological distancing to climate change was done. There was observed a positive association between preparedness and risk perception, and the most important factors identified were fear, worry, trust and past experiences to measure perception. In the case of psychological distancing to climate change, the distance increases the level of abstraction and is associated negatively with the preparedness measures. It can be observed through various dimensions, namely, geography, social, temporal and uncertainty. After the detailed literature review was done, the methodology of the research was finalized.

CHAPTER 3

METHODOLOGY

3.1 Data Collection and Sources

The study analyzes the relationship between Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and Land Surface Temperature (LST). All of these are determined using the Landsat images. To observe the built-up forms or types, the local climate zones classification of the two cities Islamabad and Lahore, has been done; one is planned while the other is unplanned. Apart from the LCZ classification, the land cover classification has also been done in ArcMap using Maximum Likelihood classification. Landsat 8 images of different time periods (2013 and 2019) have been used to prepare maps (Table 11, 12). The USGS Earth Explorer platform was extracted freely available satellite data (http://earthexplorer.usgs.gov/). Detailed information on different used datasets used has been given in table 10, while information regarding individual cities in table 11 and table 12 for Islamabad and Lahore, respectively. The training samples were collected for representation from Google Earth for all the classes like compact low rise, low plants, and water, etc. Image processing techniques were applied using the Landsat 8 image bands, and from it, and Land Use Land Cover LULC maps were prepared in ArcMap. Apart from these, the Landsat images were also imported in SAGA GIS for LCZ classification.

Table 10 Data sources and its description

Analysis	Data	Source	Resolution
Land use land cover change classification	Landsat 8	USGS Earth Explorer	30 m
Land surface temperature	Landsat 8 Thermal bands	USGS Earth Explorer	100 m
Local climate zone classification	Landsat 8 Training areas	USGS Earth Explorer Google Earth	100 m (resampled)

Table 11 Landsat data Information for Islamabad

Analysis	Landsat 8 images
Land use land cover change classification	LC08_L1TP_150037_20130610_20170504_01_T1
	LC08_L1TP_150037_20190627_20190705_01_T1
Land surface temperature	LC08_L1TP_150037_20130610_20170504_01_T1 (band 10)
	LC08_L1TP_150037_20190627_20190705_01_T1 (band 10)
	LC08_L1TP_150037_20130330_20170505_01_T1 (band 10)
	LC08_L1TP_150037_20190408_20190422_01_T1 (band 10)
Local climate zone classification	LC08_L1TP_150037_20130330_20170505_01_T1
	LC08_L1TP_150037_20130610_20170504_01_T1
	LC08_L1TP_150037_20131016_20170429_01_T1
	LC08_L1TP_150037_20190408_20190422_01_T1
	LC08_L1TP_150037_20190627_20190705_01_T1

Source: Landsat 8 imagery USGS Earth explorer

Table 12 Landsat data Information for Lahore

Analysis	Landsat 8 images
Land use land cover change classification	LC08_L1TP_149038_20130502_20170504_01_T1
	LC08_L1TP_149038_20190519_20190522_01_T1
Land surface temperature	LC08_L1TP_149038_20130502_20170504_01_T1 (band 10)
	LC08_L1TP_149038_20190519_20190522_01_T1 (band 10)
	LC08_L1TP_149038_20131025_20170429_01_T1 (band 10)
	LC08_L1TP_149038_20191026_20191030_01_T1 (band 10)
Local climate zone classification	LC08_L1TP_150037_20130330_20170505_01_T1
	LC08_L1TP_150037_20130610_20170504_01_T1
	LC08_L1TP_150037_20131016_20170429_01_T1
	LC08_L1TP_150037_20190408_20190422_01_T1
	LC08_L1TP_150037_20190627_20190705_01_T1

After mapping the LCZs and identifying the relationship between land cover indices and LST. In the next step for the determination of risk perceptions and psychological distancing to climate change, a public survey was being done from 5 different built-up zones or LCZs. For this purpose, a questionnaire was developed, and sampling was done from different LCZs. The sampling technique that has been used is discussed below.

3.2 Sampling

After mapping the LCZs, the primary data used for the analysis was collected from different LCZs of Islamabad city. Each questionnaire was given an area code relating to the type of the LCZ. A convenience sampling technique was used, as no population data could be attributed to varying densities and forms. Five built-up zones were identified using the LCZ method (see Section 4.2). Thereafter, for comparative analysis, seventy samples were randomly collected from each zone. A total of 350 questionnaires were collected. After the data was obtained, the questionnaires were re-checked, and incomplete questionnaires were discarded. Therefore, a final of 297 questionnaires were further used for data analysis.

3.3 Methodology Flowchart

The detailed flowchart of the methodology that has been adopted for the research study has been provided in figure 7 below. The software that were used in the study includes Google Earth, SPSS, ArcMap, and SAGA GIS. During the first stage, data was collected, then land covers indices were calculated, and land surface temperature conditions were observed temporally. The relationships between them were analyzed. The spatio-temporal assessment of the land use and land cover was also done to calculate the percentage of area converted from open/ green areas to built-up. At the next stage, to analyze the built-up forms and to study the urban temperatures, local climate zones classification has been done using the WUDAPT methodology. After mapping, the areas were identified for the survey purposes, and data was collected with the help of questionnaires. Statistical analyses were performed, and results were formulated. At the last stage, policies for sustainable and resilient development have been proposed.

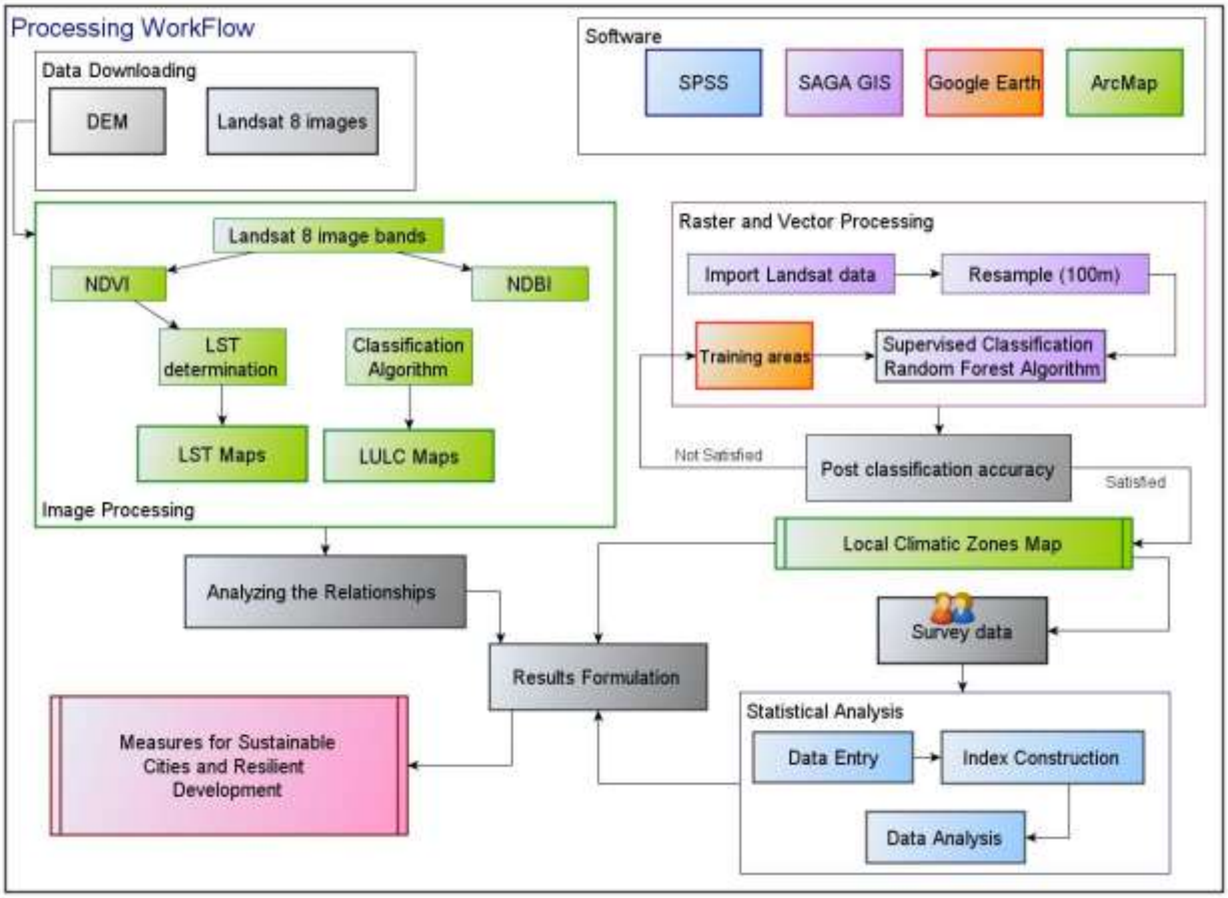


Figure 7 Flowchart of the research study

*Color of the boxes represents the software used in the process.

3.4 Data analytical methods

After the successful downloading of the required data, various methods were adopted to extract the required results. Landsat 8 images were used for the mapping of the local climate zones, land surface temperature, and land cover mapping. Three software were used in the analyses, i.e., SAGA GIS, ArcMap, and Google Earth. For mapping land surface temperature (LST) and land use land cover change (LULC), ArcMap was used. For the land cover classification map, composite bands were prepared, and different band combinations were used to better identify the vegetative and built-up area. False-color image was used for collecting the signatures of the built-up area and vegetative cover. The Maximum Likelihood method of supervised classification was used. In the end, the land cover map of Islamabad was prepared, and the relationship between them is analyzed. The Normalized Difference Vegetation Index (NDVI) and Normalized Difference built-up index (NDBI) were prepared to represent the vegetative and built-up area better. For NDVI, band 4 (red band) and band 5 (Near-infrared band) were used, and for the determination of NDBI band, 5 (the Near-Infrared band) and 6 (Short-wave infrared band) were used.

Landsat 8 Thermal Infrared Sensor (TIRS) has two bands, 10 and 11, from January 2014, the United Nations Geological Survey (USGS) recommended not to use band 11 due to larger calibration uncertainty (Avdan & Jovanovska, 2016) so for the extraction of the land surface temperature, the thermal band, i.e., band 10 (Qcal) of Landsat 8, was used. From band 10, the top of the atmosphere spectral radiance (L) and brightness temperature (T_b) from radiance were calculated. Then by using the emissivity and brightness temperature (T_b), the land surface temperature was determined. All these calculations were performed using the raster calculator in the ArcMap software. Top of atmosphere Spectral radiance was determined using the required multiplicative rescaling (ML) factor and the additive rescaling factor (AL). Both are band-specific and can be obtained from the metadata file. For the brightness temperature, K1 and K2 are the thermal conversion constants of band 10. All variables used in the equation are obtained from the metadata file present in the images folder that is automatically downloaded with the image. From the NDVI prepared in the previous step, the Proportion of Vegetation (Pv) was calculated through the min and max value of NDVI (see table 13), from the Pv value, the surface emissivity (ε) was calculated. The relationship between LST and the land cover indices has also been determined using correlation and regressions analysis.

Lastly, to map local climate zones, Landsat 8 data was imported into the SAGA GIS software. The imported data was then cropped according to the region of interest (ROI) and then resampled to 100 m resolution; the scale may vary depending upon the classes and cities, but this is the default value used for mapping LCZ (Benjamin Bechtel et al., 2015). After that, training areas were prepared through the Google Earth Engine, and the required sample areas were digitized. For the preparation of the training samples, a sample file was downloaded from the WUDAPT site in which the names of all the classes were mentioned. Changes were made to it according to the needs, like the name of the user, and data was then uploaded to Google Earth for the collection of the respective training areas. Depending upon the knowledge, training samples of each class were digitized under their respective names and were then saved as a KML file, which was then imported into the SAGA GIS and used for LCZ classification and mapping. The coordinate project transformation (shapes) was done so that the projection system of both the datasets remained the same; the projection of Landsat was used as a reference, i.e., Universal Transverse Mercator (UTM). In the last step, supervised classification was done using the Random Forest algorithm, and the final local climate zone maps of Islamabad and Lahore were prepared. The final output was saved as KML and then uploaded to Google Earth to check post-classification accuracy. More training samples were taken for the areas that were not classified correctly, and the process was repeated until results were obtained.

Table 13 Image Processing Techniques

Name	Formulae	Equations for Landsat 8
NDVI	(NIR-Red)/(NIR + Red)	$\frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4)}$
NDBI	(SWIR – NIR)/ (SWIR + NIR)	$\frac{(Band\ 6 - Band\ 5)}{(Band\ 6 + Band\ 5)}$
TOA Spectral Radiance (L)	ML * Qcal + AL	0.0003342*"band10"+0.1
Brightness Temperature (T_b)	(K2 / (ln (K1 / L) + 1)) − 273.15	(1321.0789/Ln(774.8853/"L" + 1)) - 273.15
Proportion of Vegetation (Pv)	((NDVI-NDVImin)/(NDVImax-NDVImin))2	Square(("NDVI" + 1)/(1 + 1))
Surface Emissivity (ε)	0.004 * Pv + 0.986	0.004 * Pv + 0.986
Land Surface Temperature	Tb/[1+(*Tb/c2)*ln(ε)]	"Tb" / (1 + (10.8 * "Tb" / 14388) * Ln("ε "))

3.5 Index construction and statistical analysis

The data collected from the survey were entered into SPSS for further analysis. The socioeconomic characteristics of the respondents were assessed through frequency analysis. The climate change risk perception and psychological distance to climate change were analyzed using the data of each indicator were used. Descriptive statistics (mean and standard deviation) and the Chi-square test was used to observe differences between the five LCZs. The difference between dimensions of climate change risk perception and psychological distance to climate change was observed using ANOVA-test. The weighted average technique was used to ascertain overall risk perception and psychological distance to climate change. As a consistent 1-5 Likert was used for all indicators, no data standardization was needed. Therefore, all indicators were averaged to find out overall risk perception (Eq 1) and psychological distance to climate change (Eq. 2). To understand relationships among dimensions of risk perception and psychological distance, Pearson's correlation test was employed. The value of 1 shows a perfect correlation between the two variables. The values between 0.5 to 1 define that the correlation between the variables is strong, values between 0.30 to 0.49 represent a medium, while the values less than it represents a very small correlation. In the case of a negative sign, an inverse relationship between the two variables exists and vice versa.

$$Overall\ climate\ change\ risk\ perception = \frac{Fear + Behavior + Trust}{3} \qquad \text{(Eq. 1)}$$

$$Overall\ psychological\ distance\ to\ climate\ change = \frac{Social + Geographic + Temporal + Uncertainty}{4} \qquad \text{(Eq. 2)}$$

3.6 Summary of the chapter

In this chapter, the data collection sources and the methods that will be followed during the research are discussed in detail. For mapping, the NDVI, NDBI, LST and LCZs freely available remote sensing data of Landsat 8, for different time periods, have been used obtained from the USGS Earth Explorer site. For the collection of data in the form of questionnaires from respective LCZs, a convenience sampling technique was used. The public survey was carried out only in Islamabad, and only 5 LCZ zones were considered.

The software used for mapping NDVI, NDBI, and LST, ArcMap has been used. For mapping, the LULC Maximum Likelihood classification algorithm has been adopted. In the case of LCZ mapping, training areas were obtained from Google Earth, and a random forest classification algorithm has been used in SAGA GIS, as recommended by the standard WUDAPT methodology.

The statistical analysis of the questionnaire data has been carried out in SPSS. The indexes of the variables were constructed. After that Chi-square test and One Way, ANOVA has been applied to the risk perception and psychological distancing indicators. The correlations of the variables have also been observed.

CHAPTER 4

LOCAL CLIMATE ZONES CLASSIFICATION

4.1 Introduction (LCZ)

Local climate zones are particularly developed for the temperature studies of the urban areas (I. D. Stewart & Oke, 2012) For the purpose of urban temperature studies, many factors have been considered, like air temperature, urban morphology (Y. C. Chen et al., 2019) and land surface temperature (J W P Tse et al., 2018). Rapid Urbanization is also one of the main causes of the increasing urban temperatures (Ongoma et al., 2016). Urban development impacts the urban temperature, like the areas with dense development have mostly higher LST while others with more vegetative cover have low LST (J W P Tse et al., 2018). The relationship between the built-up and vegetative area land surface temperature can be determined by the Normalized difference vegetation Index and Normalized difference built-up index (Guha et al., 2018). With rapid urbanization, there is also a rapid change in the land cover, affecting the urban temperature and resulting in uncomfortable thermal conditions in the city.

Many studies have been done all around the world, incorporating have developed local climate zones, depending on data availability, using different techniques and methods. The data-efficient regions or countries having proper access to data and resources have used the detailed GIS datasets to map Local climate zones (Agathangelidis et al., 2019). Some empirical studies were done on various cities or regions in Germany, Ireland, Spain, and the USA following the standard WUDAPT procedure, i.e., using the Landsat 8 images and training samples for mapping the local climate zones (Benjamin Bechtel et al., 2015)Whereas, some of the studies have used detailed GIS datasets for creating LCZs, e.g., cities in Greece, (Agathangelidis et al., 2019), Czech Republic (Geletič et al., 2019), Australia (Koc et al., 2018), and Nagpur (Kotharkar & Bagade, 2018). Hence, many studies with varying methodologies have been conducted for mapping local climate zones, but mostly in developed countries. There are limited studies on LCZ mapping for planned capital cities as well as unplanned cities in developing countries. Therefore, this study focuses on developing LCZs for Islamabad, a planned city in Pakistan, and Lahore, a traditional city.

4.2 Detailed methodology flowchart for LCZs

To perform the local climate zones classification of both the cities, data was downloaded, training samples were collected, and the classification and LST maps were prepared, a complete description of the methodology has been provided in the flowchart below (figure 8), the major steps involve data downloading, then raster and vector processing three of the software used in the analysis are ArcMap, SAGA GIS, and Google Earth.

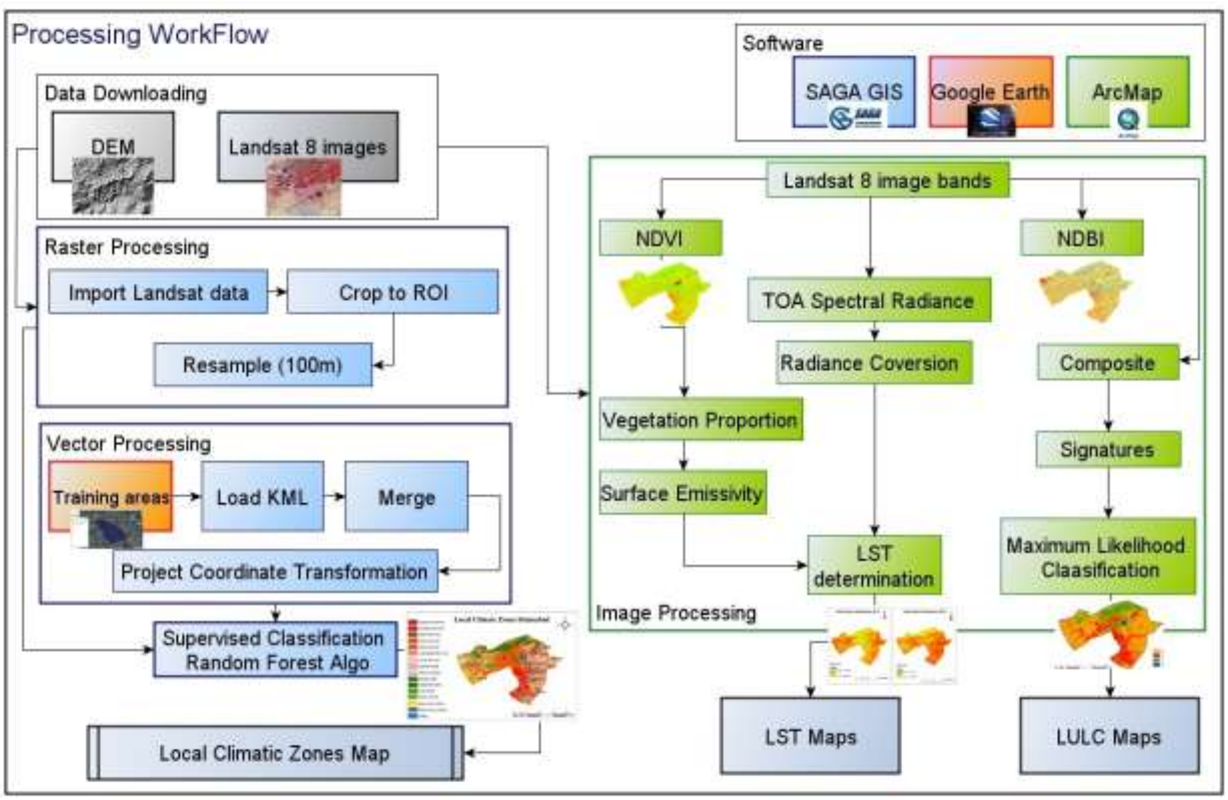


Figure 8 Methodological flowchart

Note: The color of the boxes represents the software used, green for ArcMap, blue for SAGA GIS, and red for Google Earth.

4.3 New capitals: An era for planned cities in developing countries

Cities built by keeping in mind the need and purpose, with proper planning, can be termed as planned cities. The capital city of the country is a symbol of unity, economic power, and development. The functions carried out by the capital are determined by the country's size and organization; it must be the centre of gravity (Doxiadis, 1965). The capital must be planned in such a way that it satisfies the needs of the whole nation. From the 1950s to the 1980s, many developing countries moved their capital cities from one part of the country to a new location (Table 14) to boost economic growth and fair distribution of wealth and power (Hardoy, 1964). Older and congested cities could not house an increasing number of institutions in the globalization era. Another argument linked to the creation of new capitals included the cost of land acquisition, streets widening, and improving the existing facilities to meet new needs. The overall expenditure would be double the investment needed for a new undeveloped city, where the government could benefit from the increasing land value of the surrounding areas (Doxiadis, 1965). Another reason for these planned capital cities was the accumulation of power in one city. Therefore, a compromise among the citizens/regional governments instigated the national government to establish a new capital city. This capital should be the representation of a nation as a whole, having inhabitants belonging to all the social groups (economic, ethnic, political). Hence it is needed from a social point of view, and existing cities do not serve the purpose mostly (Doxiadis, 1965). Most of the country’s capitals were coastal cities, a mark of a colonized rule, and recent independence incentivized to make a new capital. Pakistan is one of those countries, which moved its national capital to Islamabad from Karachi in the year 1959.

Table 14 New capital cities of the developing countries

Sr. No	Country	New Capital	Former Capital	Year
1.	Brazil	Brasilia	Rio de Janeiro	1956
2.	Mauritania	Nouakchott	Saint Louis	1957
3.	Pakistan	Islamabad	Karachi	1959
4.	Botswana	Gaborone	Mafeking	1961
5.	Libya*	Beida	Tripoli/Benghazi	1963
6.	Malawi	Lilongwe	Zomba	1965
7.	Belize	Belmopan	Belize City	1970
8.	Tanzania	Dodoma	Dar es Salaam	1973
9.	Nigeria	Abuja	Lagos	1975
10.	Liberia*	TBA	Monrovia	1982
11.	Ivory Coast	Yamoussoukro	Abidjan	1983
12.	Argentina*	Viedma/Carmen de Patagones	Buenos Aires	1987

Source: (Gilbert, 1989)

* None of these plans came to fruition

4.4 Islamabad, Pakistan - the dynapolis

Islamabad is the capital of Pakistan; the name represents the Islamic ideology. The city is generally known for its higher standard of living and natural green areas (relative to the rest of the cities of similar size in the country). It is located on the Potohar Plateau between Margalla hills and Rawalpindi district, lying at an elevation of 457.2 to 609.6 meters (see Figure 8). It is also the ninth-largest city of Pakistan in terms of population. It was built in the year 1961 to replace the old capital Karachi, which was a congested urban area with a high cost of living, challenging climate (Botka, 1995), and limited space for future urban expansion (Associates, 1960). One of the factors considered while proposing the new capital in the Northern part and corner of the country was its geographical proximity to one of the major roads in the country, the Grand Trunk (G.T.) Road (Maria & Imran, 2006). The area of Islamabad was selected in the year 1959 by a group of planning experts (Doxiadis, 1965). It included areas of Islamabad, Rawalpindi, and a national park from the year 1959 to 1963 (Maria & Imran, 2006). Strategic location, climate, logistics, defense requirements, aesthetics, and natural beauty were considered as the primary criteria for site selection. The commission recommended the current location of Islamabad after an extensive review of various sites – after the approval from the concerned Government authorities, the strategy for its planning and development was put into practice.

The urban planning and design of Islamabad city are attributed to Constantinos Apostolou Doxiadis, a Greek architect and town planner. He gave the principle of dynametropolis, i.e., a dynamic metropolis.). Doxiadis envisioned an ideal city growth to be concentric with a city center. Following the concepts of dynapolis and ekistics, in 1960, Islamabad was designed as a dynamic settlement with incremental linear growth. It was envisioned to grow unidirectional, towards the southwest side for development purposes (Doxiadis, 1965), whereas it was restricted towards the North, East, and Southeast. The city centre, termed as a “blue area” was placed on the expanding axis with the living spaces alongside the axis (Daechsel, 2013). The length of the city and its centers would stretch along the Margalla hills (Prentice, 1966).

The city was divided into 2 km x 2 km sectors following a gridiron pattern with a road network comprising a width of 91.4, 182.8, and 365.76 m. At the start of the master planning, four major highways or routes were planned to connect the whole Metropolitan area of Rawalpindi/Islamabad. However, Rawalpindi got excluded from the master plan. Only two of the highways named Kashmir (now Srinagar) and Islamabad could be constructed (Maria & Imran, 2006). The city was then divided into residential, commercial, industrial, educational, administrative, diplomatic enclave, national park, and green areas. The Islamabad city administrative boundaries were termed as Islamabad capital territory (ICT), with autonomous bodies such as the ICT administration and federal government control (Malik & Rajaram, 2017). Currently, ICT is divided into urban and rural areas, with 133 villages coming in rural areas

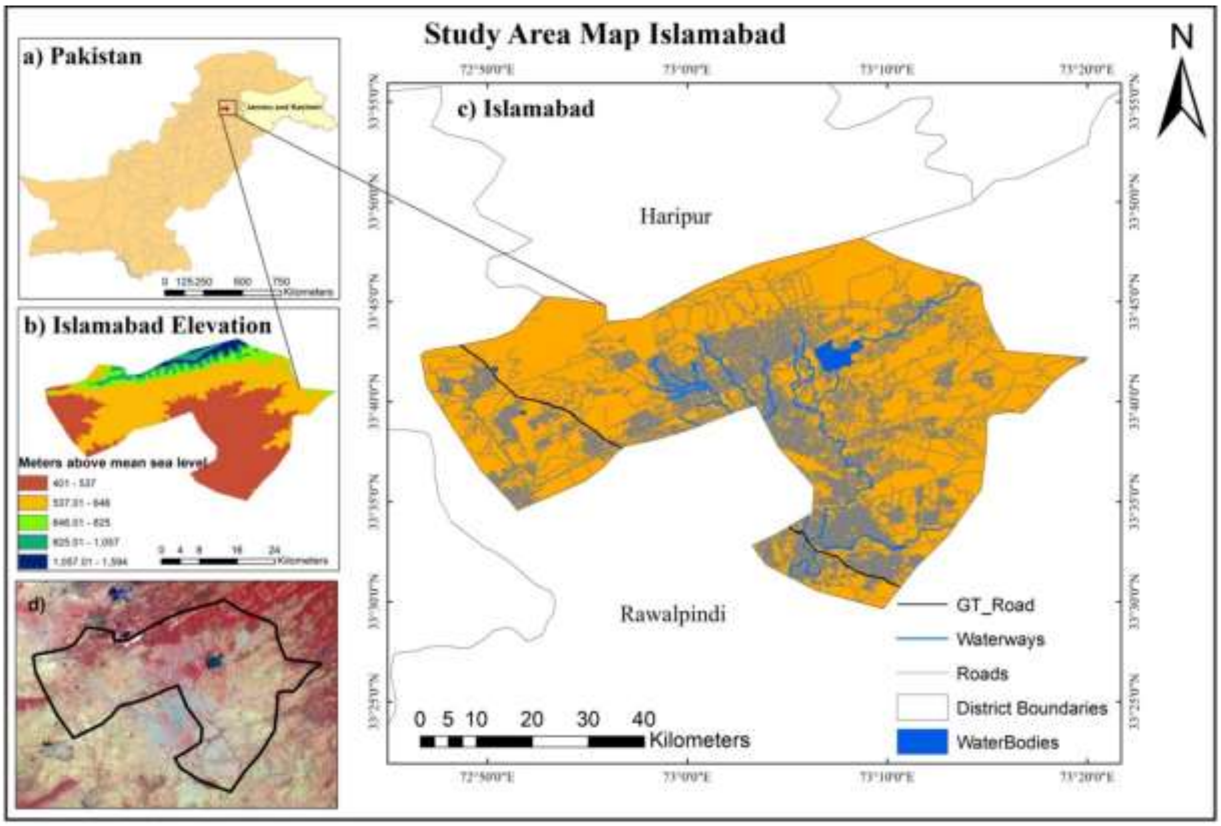


Figure 9 Figure 1 Study area map. a) The administrative boundaries map of Pakistan. b) Elevation map of Islamabad. c) The map of Islamabad showing the roads, waterways, and water bodies, GT-Road within Islamabad boundary and the boundaries of the surrounding districts d) The satellite imagery of the Islamabad region.

Since then, the Islamabad Master Plan, conceived by Doxiadis, has undergone several drastic amendments. To implement the first Master Plan, the Capital Development Authority (CDA) was formed in the year 1960 by the CDA ordinance on June 27, overtaking charge from the National Capital Commission. The initial Master Plan included the areas of Rawalpindi, but it was never integrated and implemented (see

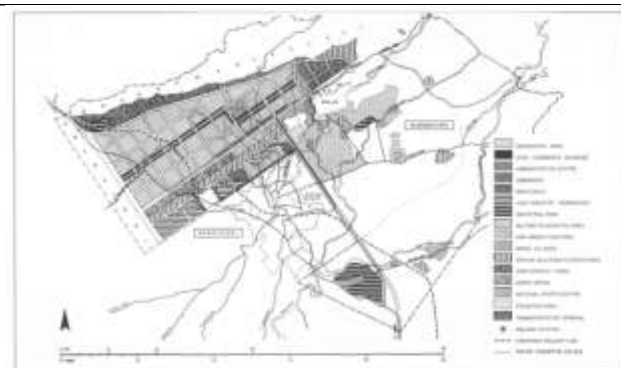
Table 15A), but Islamabad somehow managed to implement a larger part of it (Botka, 1995). Rawalpindi was a provincial metropolitan of Punjab, which cannot be included in the federal territory. Therefore, the master plan excluded the Rawalpindi region and was revised in 1978 (see Table 15B). Later, another revision was made to the master plan by CDA with the help of UNDP experts in the year 1991 (see Table 15C). According to the new zoning regulations, Islamabad was divided into five zones. Zone 1 is designed for housing commercial and administrative land use, Zone 2 for the private sector, Zone 3 included Margalla Hills National Park, Zone 4 for rural areas, and Zone 5 for private sector development (Maria & Imran, 2006). Another major revision was done in 2005 (Table 15D), which allowed the private sector to invest in housing and related facilities. According to this amendment, the private sector began rampant development in the once restricted rural lands. In short, these amendments failed to implement the initial master plan and the concept of dynapolis. Currently, a new commission is formulated to develop master plan of the city.

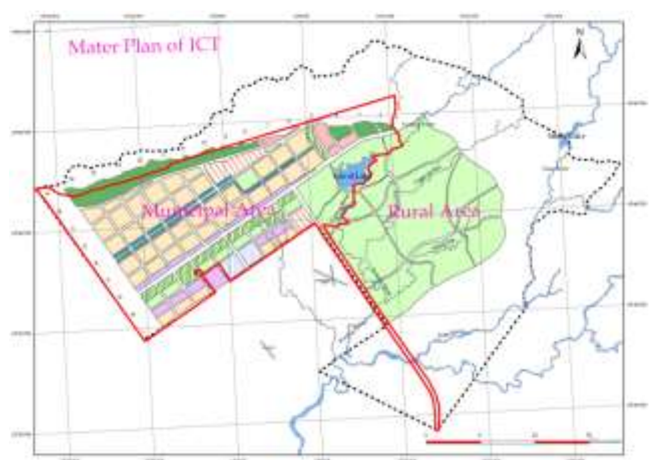
Table 15 Amendments in Islamabad Master Plan

Amendments in the Master Plan	**Master Plan Layout**
A)The first Master Plan of Islamabad Metropolitan Area was given in the year 1960 in which there were three zones; Islamabad (the capital with administrative and residential functions), Rawalpindi (the regional center and cantonment), and Park Area (preservation of landscape and institutional zone) (*Capital Development Authority Islamabad*, 1960)	

B) The implementation of the revised plan started in the year 1960 up to 1979, and various amendments were made, like relocation of national university exemption of E-11 sector, F-9 sector converted into a city park, blue area core split into half, Rawalpindi was excluded from the plan, a revised Master plan was given in the year 1978.

(Botka, 1995)

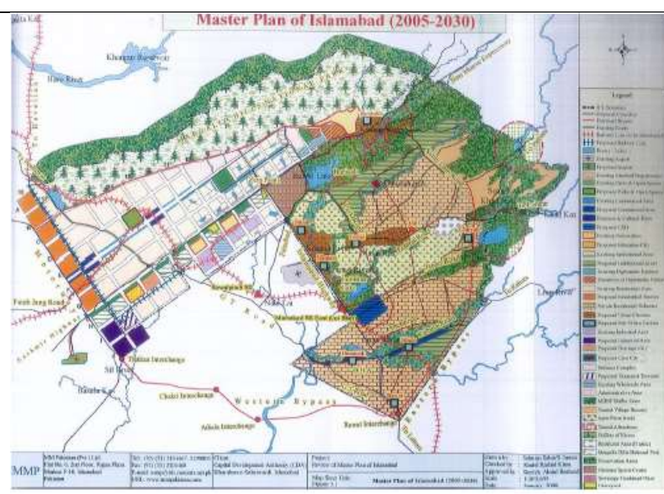




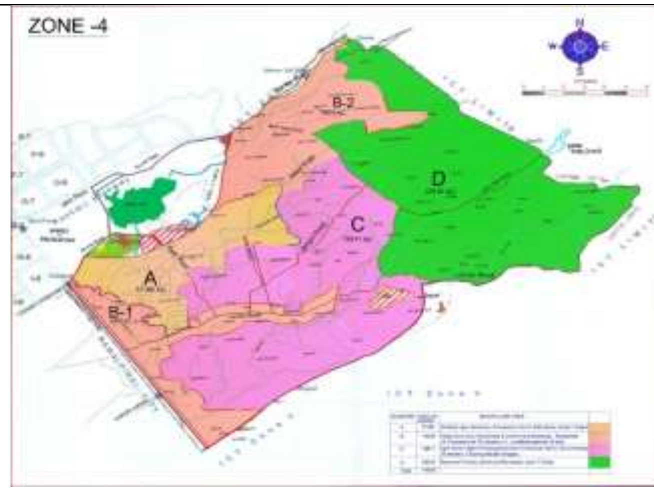
C) A review committee was formed by CDA for reexamining the concept of growth and change in 1985. Another revision was made to the master plan by CDA, with experts from the United Nations Development Programme (UNDP), a comprehensive review in the year 1991. According to the new regulations, Islamabad was divided into five zones where zone 1 was designed for residential, commercial, and administrative land use for future extension; zone 2 existing designed municipal area; zone 3 included Margalla Hills National Park and Rawal Lake; zone 4 for National institutes and rural areas; and zone 5 for private sector development

(*Capital Development Authority Islamabad*, 1991)

D) Another review was done in 2004-2005 with three main components, i.e., reviewing the existing rural as well as urban areas to develop an action plan for "unplanned growth", "housing", and "water supply". Zone 4 was then sub-divided into A, B (B-1 and B-2), C and D. Each sub-zone was allowed permissible land uses, ranging from agro-farming schemes to private sector-led residential development.



<table>
<tr>
<td>The private sector began development in the once restricted rural lands. In short, these amendments failed to implement the initial master plan and the concept of dynapolis.

(Peerzada & Naeem, 2019)</td>
<td>
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<td>E) Currently, a new commission is formed to update the master plan. A dialogue was conducted between members of different departments to participate in the revision of the master plan in May 2019 and give suggestions. In the new master plan, zoning regulations are expected to be enhanced, and focus will be given to water, sanitation, and sewerage requirements and the preservation and enhancement of green areas, which is also under consideration

(Tribune, 2020)</td>
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4.4.1 Land cover

The land cover determines how much of the land has been covered with water, forest, vegetation, or other natural features – satellite images of different time periods can be used to determine the land cover change. Satellite imageries of the years 2013 and 2019 were analyzed to determine the land cover change of Islamabad. Land cover from the year 2013 shows that there were more green areas and less built-up land compared to that in the year 2019 (see Table 16 and Figure 10). The temporal gap of 6 years shows that now the green areas have been dramatically reduced, and a significant increase in the built-up area can be seen. The table shows the change in land cover properties from the year 2013 to 2019. It was found that 10% of the total land cover was built-up in the year 2013, which increased to 22% (Table 5). The percentage change in the built-up area was 113.46%, clearly depicting rapid physical development in the city.

Similarly, there was a percentage decrease of 33.39% in the vegetation of the city. The bare soil in the area has also been decreased, which shows the continuously changing land cover with the increasing built-up land at a rapid rate and the decrease in the vegetative cover. Land cover analysis has shown that urban development growing mostly in the south and southwest direction. The master plan also envisioned future development in this direction. However, the reduction of vegetative cover, especially in Zone 3 (conservation/protected zone) Margalla hills national park and Rawal Lake, is a gross violation of the master plan. Therefore, a planned and controlled physical expansion is needed to conserve the green areas of the city.

Table 16 Land cover change of Islamabad city (2013-2019)

	Area (km^2)		**Percentage (%)**		**Percentage change**
	2013	*2019*	*2013*	*2019*	
Built Up Area	87.66	187.11	10.36	22.12	113.46% increase
Vegetation	204.17	135.98	24.14	16.08	33.39% decrease
Bare Soil	548.32	517.18	64.85	61.17	5.67% decrease
Water Body	5.31	5.17	0.62	0.61	2.57% decrease
Total	845.46	845.46	100	100	

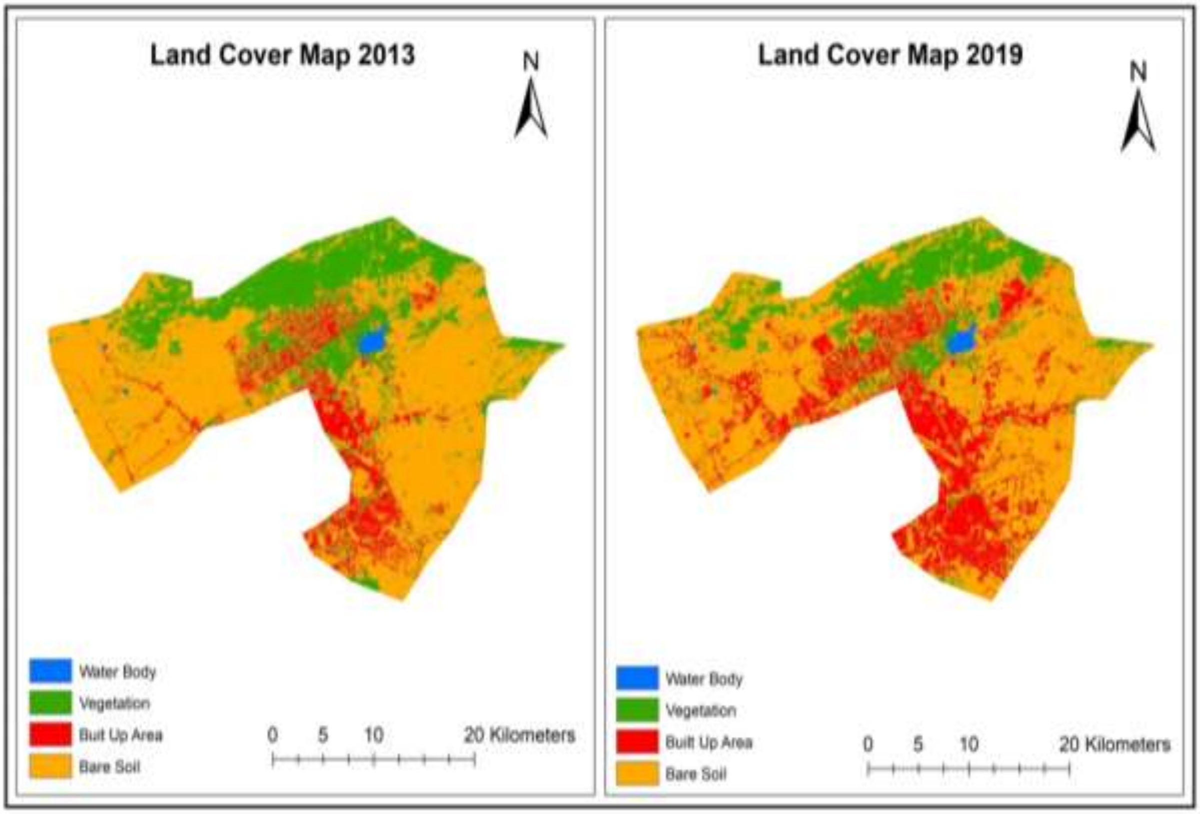

Figure 10 Land cover map of Islamabad of the year 2013 and 2019

4.4.2 Normalized difference vegetation and built-up index

The NDVI analysis has been done to confirm the land cover changes and to observe their relationship with LST. To observe the seasonal and temporal vegetation changes in the city, the changes in the NDVI values were observed for two months of each respective year 2013 (March, June) and 2019 (April, June). Overall, the mean NDVI value decreased from 0.25 (2013) to 0.23 (2019). The maximum value of NDVI in the year 2013 was 0.55, while in 2019, it was 0.59. An increase in the maximum value was also observed for June.

Figure 11 shows the spatial variations in the NDVI values for selected years – vegetation cover decreased (shown in colour tones of green), while non-vegetative areas increased (shown in colour tones from yellow to red). Zones 2 and 4 clearly exhibited a decrease in vegetation cover. According to the master plan, Zone 4 was designated for rural areas, while zone 2 for private sector development. However, a dramatic decrease in the vegetative cover and increasing built-up land was observed, which can be attributed to the physical development of new private housing schemes in these zones. The values of NDVI were high and fairly consistent in Margalla hills for both years, indicating a somewhat stable vegetation condition in this area.

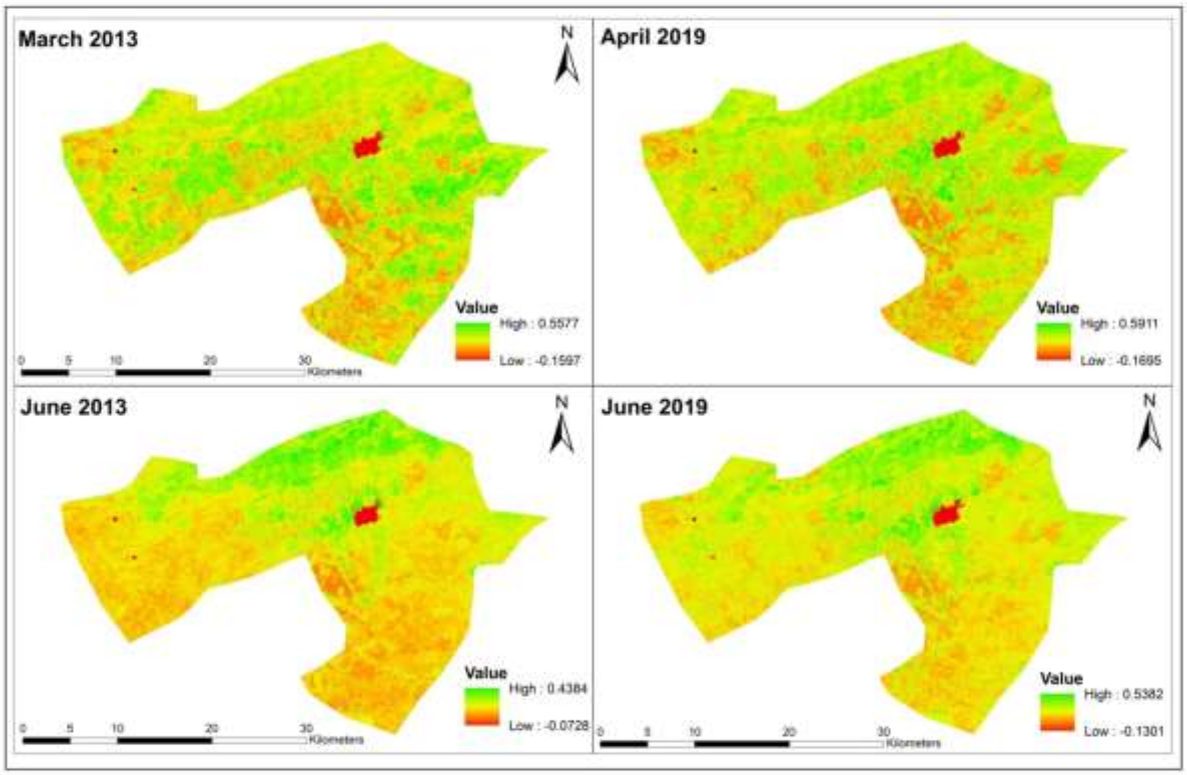

Figure 11 Normalized difference vegetation index (NDVI) map of Islamabad of the year 2013 and 2019

The NDBI was used to compare the non-built-up areas such as vegetation, water bodies, and bare land. This was done to counter-check the findings of the LULC and NDVI change analysis. It was calculated for four time periods (March 2013, June 2013, April 2019, and June 2019). The lowest value of NDBI was observed in the region of Margalla hills for all four time periods. Figure 12 shows the spatiotemporal changes in the NDBI values for Islamabad. The green shaded area (non-built-up) was quite high in 2013 in zone 4, which reduced significantly by April 2019 – this shows a dramatic change in the land cover in this region, which is supported by the results of the LULC and NDVI maps which indicate a reduction in vegetation cover in this area.

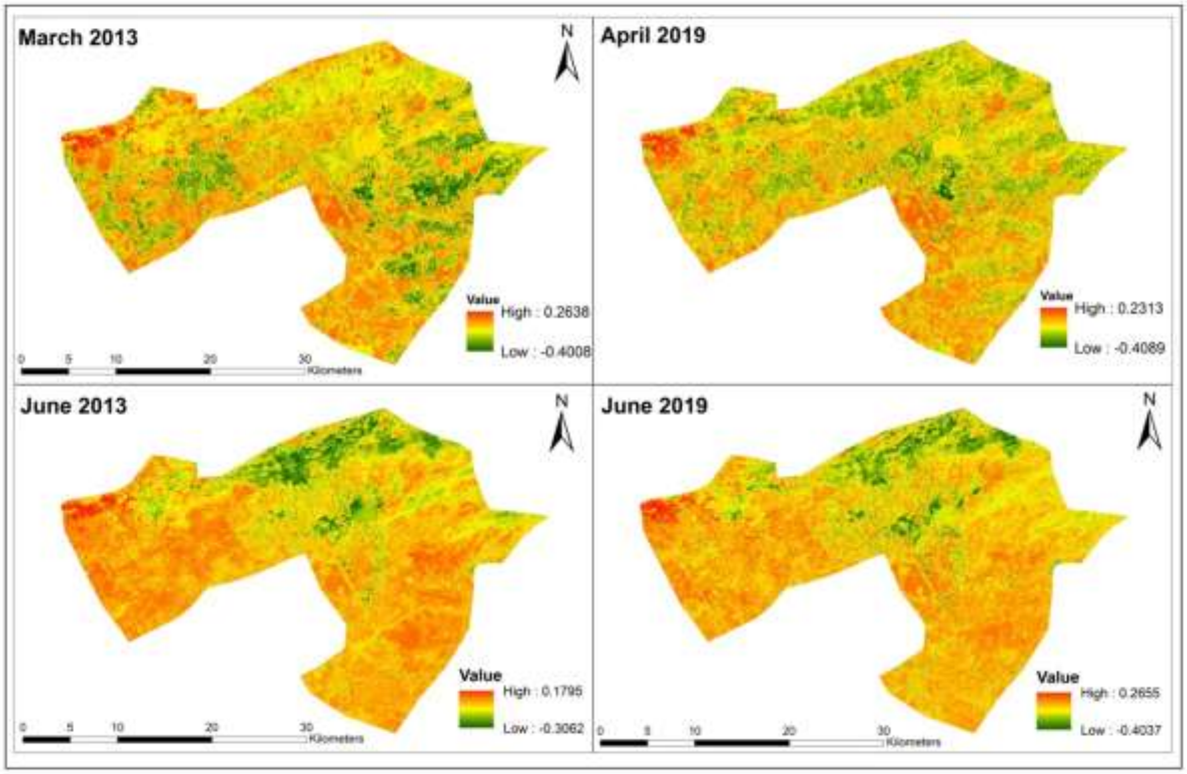

Figure 12 Normalized difference built-up index map (NDBI) of Islamabad of the year 2013 and 2019

4.4.3 Land surface temperature

Rapid urbanization and built environment are some of the leading causes of increasing urban temperatures (Ongoma et al., 2016). Urban development impacts the urban temperature, like the areas with dense development have mostly higher land surface temperature (LST). In contrast, others with more vegetative cover have low LST (J W P Tse et al., 2018). Thus, urbanization and the rapid land cover change affect the urban temperature and resulting in thermal stresses in the city.

LST maps show the minimum and maximum temperature of two years (2013 and 2019). In March 2013, the maximum temperature was 33°C, while in April 2019, it is reached up to 41°C. The imagery of April was not available for 2013, so the imagery of the end of March has been used for the year 2013 (Figure 13). A large proportion of city areas fall in a higher temperature range. The temperature ranges of most of the areas, which were 20-26 range, have converted into a temperature range of 26 to 30°C, primarily due to the rapid urban built-up area.

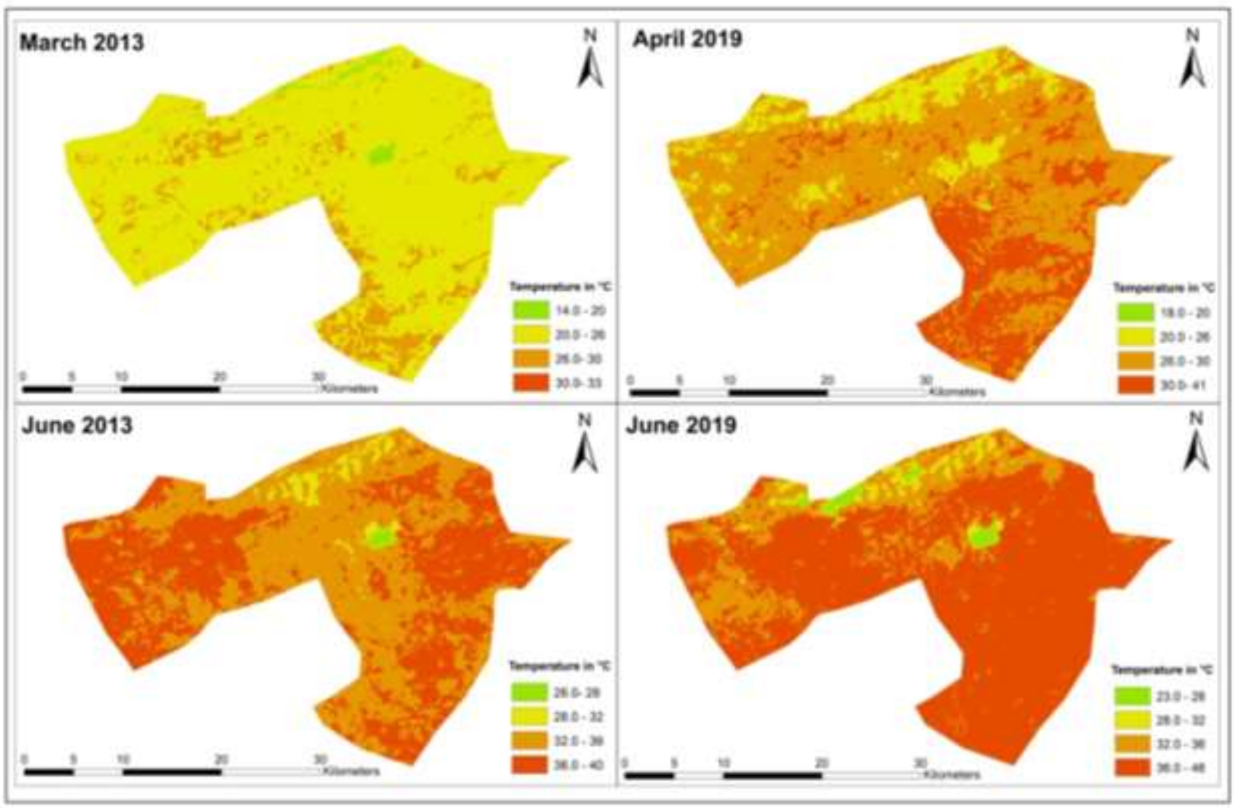

Figure 13 Land surface temperature map of Islamabad of the year 2013 and 2019

To cross-check, the land surface temperature was also determined for another month, i.e., June. Back in 2013, the maximum temperature attained in June was around 39 to 40°C, which reached around 46 °C in 2019. The temperature ranges in June 2013 placed most of the areas in 32 to 36 °C, while in the year 2019, the majority of city areas fell in the range of 36 ^{o}C to 46^{o}C. The maps clearly show previous areas belonging to the average temperature range are now included in the hotspots.

4.4.4 Relationship between LST, NDVI, and NDBI

The reduction in the vegetative cover and increase in the built-up areas is evident from the land cover maps (Figure 10). The built-up area increased by 113.46% from 2013 to 2019, while the vegetative cover decreased by 33.39% during the same period. The bare land, as well as the area occupied by water bodies, also decreased. These changes can also be observed in the NDVI and NDBI maps (Figures 11 and 12). In terms of temperature variations, the mean in June 2013 was 33.71 ^{o}C, while it was 35.23 ^{o}C in 2019. Thus, it can be hypothesized that LST increases with the increase in built-up and bare land, and decreases with the increase in vegetative cover and water bodies. To further confirm the hypothesis, a correlation analysis was performed between NDVI/LST and NDBI/LST.

NDVI alone can be used to identify the increase or decrease in the vegetative cover, while its use with the LST can help to determine if the temperature changes are linked to the changing land cover conditions. The correlation and regression analysis revealed that LST had a negative relationship with NDVI (Figure 14). The R^2 is defined as the regression coefficient. The scatterplot between NDVI and LST has been plotted for four timespans (i.e., March 2013, April 2019, June 2013, and June 2019); the regression coefficients have also been displayed on the graphs calculated from the linear regression trendline. The R^2 values were 0.280, 0.202, 0.084, 0.0006 for March 2013, April 2019, June 2013 and June 2019, respectively. The Pearson's correlation was also calculated between the two variables for all time frames, March 2013, April 2019, June 2013, June 2019), and it came out to be -0.529, - 0.450, -0.290, and -0.0244, respectively (the negative sign indicates an inverse relationship between NDVI and LST).

To further confirm the relationship between NDVI and LST, NDBI values were plotted against the LST and correlation was calculated.

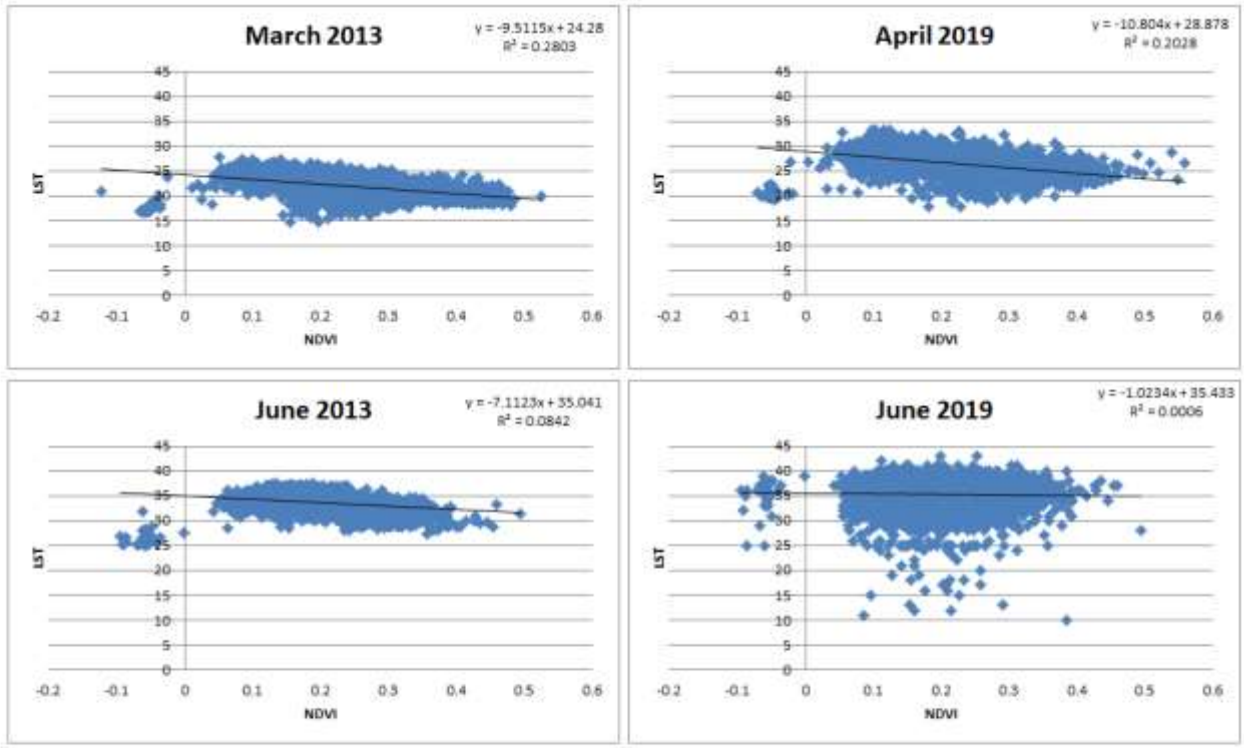

Figure 14 Relationships between NDVI and LST (2013 and 2019)

The results indicated R^2 values of 0.421, 0.279, 0.521, 0.242 and the Pearson's correlation values of 0.648, 0.528, 0.721, 0.492 for March 2013, April 2019, June 2013 and June 2019, respectively.The higher correlation values show that LST has a strong positive correlation with NDBI (Figure 15). From the above findings, it can be seen that LST increases with an increase in the built-up area and bare land, while it decreases with an increase in vegetative cover. The relationship observed between NDBI and LST is stronger as compared to LST and NDVI.

Overall, the results clearly show that the overall temperature of the city has increased. A large portion of the city now belongs to the high-temperature range, implying high climate/heatwave hazardous areas. These results call for incorporating climate-resilient development and planning strategies in master plan revisions to avert the serious impacts of climate change and rapid urbanization on humans and the environment in the future.

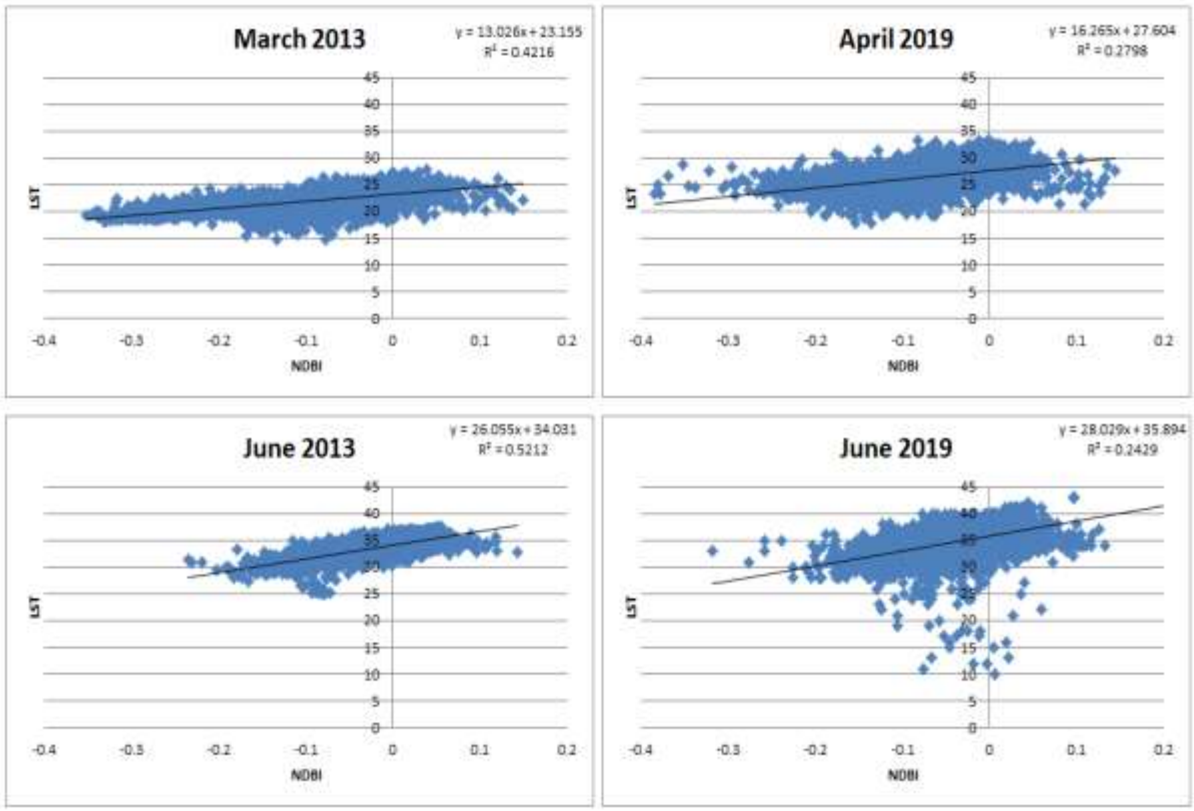

Figure 15 Relationships between NDBI and LST (2013 and 2019)

4.4.5 Local climate zones

Islamabad was classified in local climate zones to analyze the type of built-up; open or compact and high-rise or low-rise that affects the thermal conditions of an area. Local climate zones (LCZs)Z was classified into various zones based on their densities and built-up types. The satellite view of these zones in the study area has been provided in Figure 16 using Google Earth to better understand and represent the classified regions. From the LCZ map of Islamabad, the type of built-up or development can be identified easily (Figure 15). There were a total of 17 classes on the LCZ maps, but this study area found only 16 classes in the study area. The first class (LCZ 1), i.e., compact high-rise, was not found.

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 16 Visual representation of the local climate zones of Islamabad from Google Earth

LCZ 2, the compact mid-rise, was present mostly in Zone 5 of the city that is for the private sector development. There has been a lot of compact low-rise development, i.e., LCZ 3 in the south direction in Zone 4 of Islamabad that is assigned for rural areas. A few open high-rise buildings, LCZ 4, were present in the blue area (commercial zone of

Islamabad). LCZ 5, i.e., open mid-rise development, was present in sector G-9 (area of Karachi company) Islamabad that comes in Zone 2. The most dominant class was LCZ 6, i.e., open-low rise followed by compact low-rise, i.e., LCZ 3 on the map. In the peripheries, many sparsely built settlements, i.e., LCZ 8 and 9. Relatively, the heavy industrial zone was minimally represented. LCZ A, i.e., dense trees, enveloped the region of Margalla Hills. There was also compact low-rise development in some of the parts of Zone 3 that are conserved for the National Park; the vegetative cover in the area has been reduced. Bare soil or sand was mostly present on the outskirts of the city. LCZ G, i.e., water, belonged in the centre shows the Rawal Lake. LCZ F (bare soil or sand) was observed in the West direction.

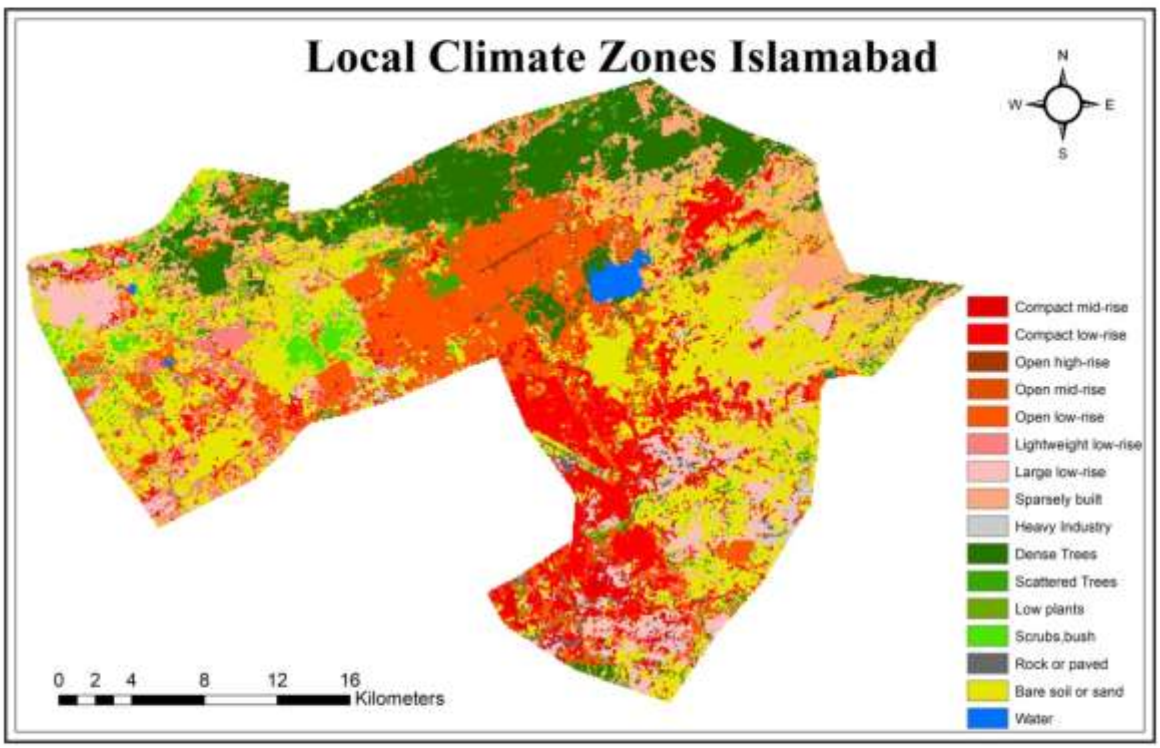

Figure 17 Local climate zones map of Islamabad

Overall, it can be seen clearly that the compact and open low-rise, i.e., LCZ 3 and LCZ 6 were the two most dominant classes in the area (figure 17). The buildings were more compact, and the open high-rise was present in the hub. A further increase in high-rise may damage the city's environment. The higher temperatures in the outskirts can be linked to the topographic differences and the presence of bare soil. The city centre belongs in the high-temperature risk hotspots, as the temperatures have already touched 46^{o}C. The National Park area needs to be preserved, and strict action is required against any kind of development in Zone 3. The dense trees in the National Park can help in reducing the overall temperatures in the city. Due to the rapid compact-low rise development, the temperatures have also increased in the south direction. Any further increase will lead to severe thermal discomfort in the city, so for maintaining the city environment, all these factors are needed to be considered for future developments and extensions.

4.4.6 Implications for Islamabad

Islamabad's population, which was around 0.4 million in 1990, has now crossed over 1.2 million. It has the highest literacy rate of 85% (*Pakistan Social And Living Standards Measurement Survey (2014-15)*, 2016) and the highest human development index of 0.8 in the country (*Pakistan Human Development Index Report*, 2017). The rural population from the nearby peripheries is migrating towards the city in search of better livelihoods and quality of life. With more people coming to the city, more land has been occupied for providing shelter to the rapidly increasing population. The population of the city is increasing exponentially, instigating infrastructural and service provision pressures on the city administration. Consequently, this has spurred several physical development projects and urban expansions in its neighboring areas.

The current growth of Islamabad metropolitan is very much different from the vision of Doxiadis concept of dynapolis. The core and its centrality have decreased with the growing city. The city is bound by G.T. road, which limits its planned growth on the west side. In the North, Margalla hills are present, so the growth of the city is in the west and south direction. Due to its slow development of new sectors, huge chunks of unplanned, haphazard, and leapfrog growth has started happening outside the city, showing an example where the core is planned, and the exterior of the city is unplanned.

Local climate zones (LCZs) have been proposed to study thermal conditions, urban heat island effect, and air temperature difference studies effectively and accurately. The study further argues that LCZ is more robust and useful than using land cover indices for developing future physical development strategies. The LCZ map of the city provides a base to work and study on the urban temperatures by incorporating different parameters of urban morphology, surface cover, and structure. For this purpose, Islamabad, a prime example of a planned capital city of a developing country, was chosen. Landsat 8 images were used to determine built-up areas, vegetation, land surface temperature, and LCZs. LCZ mapping was done using the standard procedure of WUDAPT, and training samples were acquired from Google earth. It has been found that continuous amendments and revisions of the master plan have been unable to keep up with initial visions of the city, i.e., following the concept of Doxiadis' dynametropolis. The results of the study show a rapid change in the land cover conditions of Islamabad city. There was a strong and positive correlation between LST and NDBI and a negative association between LST and NDVI. From the LCZ map, it can be clearly seen that most of the areas of Zone 4 were initially proposed as a rural areas. In different sections, forests and agro-farming have not been developed as planned. Most of the area is bare soil or land with mixed development patterns, which is affecting the thermal and environmental conditions of the zone.

LCZ can serve as the basis for the urban temperature studies of Islamabad; the rising temperature in the capital is a growing concern for climatologists and urban planners. Reducing green spaces is considered the main factor for increasing temperature. But, in Pakistan, the type of built-up is not considered while making urban expansion policies relating to climate change. The open spaces or the green areas need to be planned to contain the climate-friendly nature of the city, which can be measured via the coolest zones, i.e., LCZ G (water) and LCZ A (dense trees). Further high-rise construction should be done with proper planning and mitigation strategies, and the unplanned compact-low rise development needs to be adequately monitored (LCZ 6). The bare soil or sand areas, i.e., LCZ E, can be easily converted to LCZ B (scattered trees) and can significantly reduce heat and urban climate risks in the capital city.

The population in Islamabad has increased rapidly, and the capital city is leading to unplanned development and deviating from its original dynapolis planning concept. Urban sprawl in Zone 2 and 4 is utilizing the scarce land and affecting the climatic conditions of the city. The LULC map depicts a percentage increase of 113% in the built-up land and a 33 % decrease in the vegetative cover. The LCZ map reveals that the most dominant classes in the area were LCZ 3 and LCZ 6, followed by LCZ F and LCZ A. The most rapid built-up was the LCZ 3 class in Zone 4 of Islamabad that was initially designed for agriculture use. Due to scarce land for future extensions, open low-rise might be unsuitable for providing compact development. Apart from zone 4, the areas of zone 3 (designated conservation zone) also need proper attention. The study reveals that Margalla hills national park but now, as clearly seen, there has been a lot of compact/open low-rise (LCZ 3/LCZ 6) development in some areas; dense tree cover has considerably reduced. A dominant class of LCZ F (bare soil) was observed in the outskirts of the city, which can be transformed into greener areas to reduce thermal stresses in the built environment.

4.5 Lahore

Lahore is the capital of Punjab province and the 2nd largest city of Pakistan (*Pakistan: Provinces and Major Cities*, 2018). It is located between the districts of Sheikhupura and Kasur, touching the Wagah border at one end and lying at an elevation of 217m (figure 18). 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, as it exhibits a number of mosques, temples, tombs, parks, and gardens, including some prominent places like Badshahi Mosque, Lahore Fort, Shalimar Garden, Minar-e-Pakistan, and 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).

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 1265km2 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 within the city 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 also present in Lahore. It is also considered as the most developed city of the province Punjab, in case of socioeconomic as well as infrastructure development (Rana, Bhatti, & Arshad, 2017). Due to greater density and population size, the accessibility to the educational institutes is higher than some other major districts of the province but is still quite manageable (Rana, Bhatti, & E Saqib, 2017).

There are different organizations in Lahore to manage the city. In the beginning, to manage the housing demands and needs, an authority named Lahore Improvement Trust was set up in 1936(Groote et al., 1989). Later on, a principal agency named Lahore Development Authority (LDA) was created under the LDA Act 1975 and took over the Lahore Improvement Trust (*Lahore Development Authority*, 2014). Along with LDA, some other organizations governing the housing and development projects in Lahore include Defence Housing Authority, Cantonment Board, Model Town Society, Lahore Metropolitan Corporation, and Walled City Development Authority. Moreover, many private housing schemes/organizations are also working in Lahore to meet the continuously growing housing demands. Among all these authorities, LDA is the one that develops master plans of the entire city, but 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 & Nadeem, 2008).

Up till now, many efforts have been made in terms of developing the master plan of the city. The first time the preparation of the Master plan for the 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 & Nadeem, 2008). Another plan, named Structure Plan, proposed for a 20 year time period (1981-2000), also failed in its execution due to lesser citizens participation and following the same out 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 between the departments to benefit from the plan to its fullest.

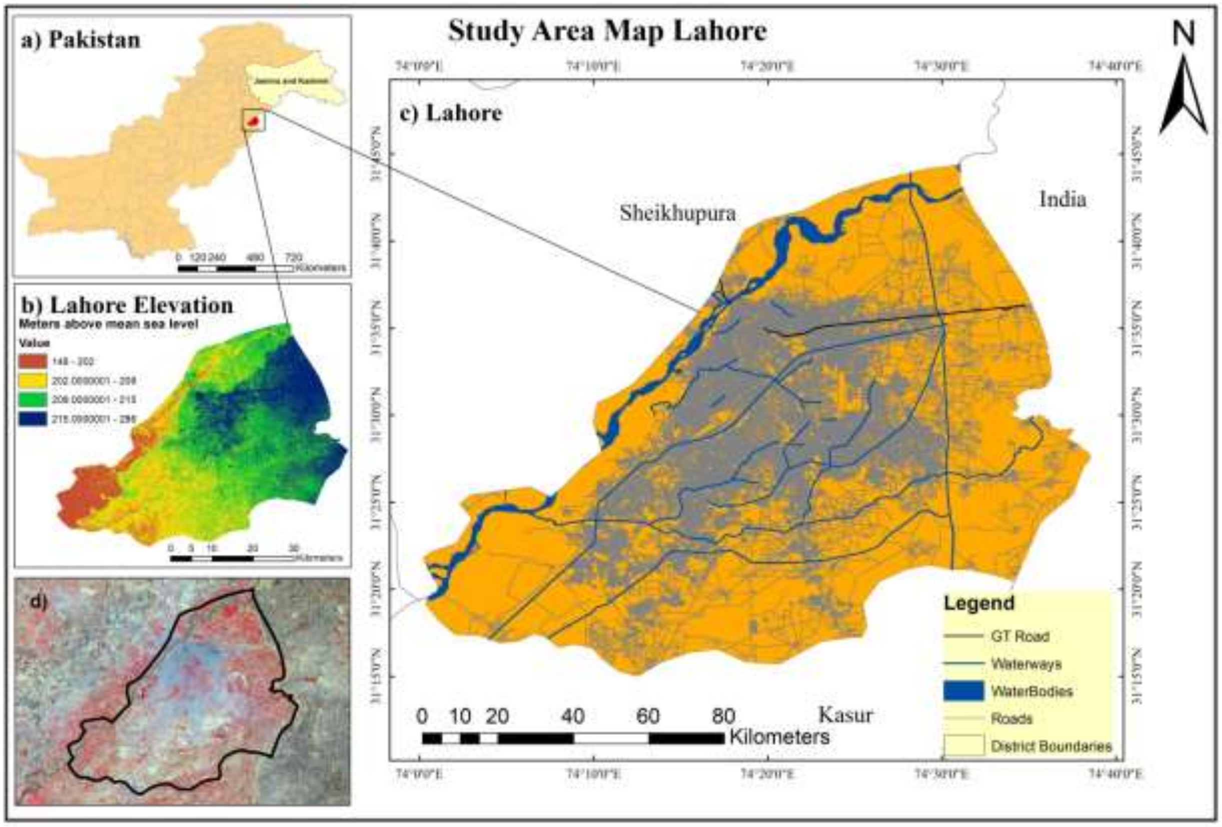

Figure 18 Study Area Map of Lahore. a) The administrative boundaries map of Pakistan. b) Elevation map of Lahore. c) The map of Lahore showing the roads, waterways, and water bodies, GT-Road within Lahore boundary, and the boundaries of the surrounding districts d) The satellite imagery of the Lahore region.

4.5.1 Land cover

The land cover determines the cover of land like vegetation, built-up, soil or water, to determine the change that has occurred in the land cover with time The land cover determines the cover of lands like vegetation, built-up, soil or water, to determine the change that has occurred in the land cover with time like how much land that was previously used for vegetative purposes have been converted to built-up and so on, satellite images of Landsat 8 have been used for the month of May, with a time gap of 6 years one is of 2013, and the other is of 2019. The Land cover maps of both years have been produced in ArcMap using the Maximum likelihood classification.

The map of the year 2013 shows that more of the land has been occupied with green areas and bare soil than the built-up land. While the map of 2019 clearly shows the transition from more greener and vacant areas to built-up land (see Figure 19). The temporal classification of the city shows the dramatic increase in the built-up land and the reduction in the vegetative cover. Below (Table 17) represents the change in the area in sq km. In 2013, 238 km^2 area was under built-up land it has now reached to 489 km^2 showing 105.369% increase, out of total 1842 km^2 area only about 12% was under built-up in the year 2013, it has now crossed 26 % and is reaching almost 27% in 2019. Similarly, the vegetation has decreased due to the city's rapid development and growth, showing a decrease of 41.02%. The barren land increased a little due to the decrease in the vegetative cover with an increase of 3%. Both the land cover types, i.e., vegetation and bare soil, occupied almost 85% of the total area in the year 2013, but now it has been reduced to almost 70% due to the decrease in vegetative cover and conversion of land to built-up.

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 and to improve the life quality in the city, and preserve the greener areas.

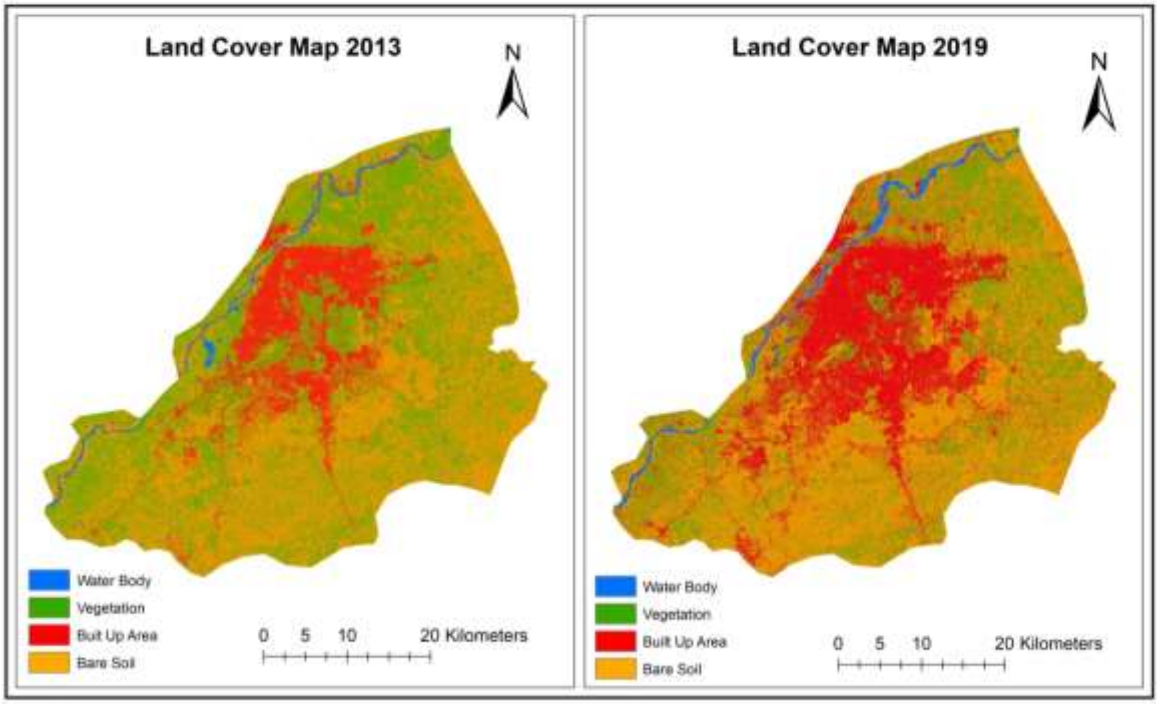

Figure 19 Land cover map of Lahore of the year 2013 and 2019

Table 17 Land cover change of Lahore city (2013-2019)

	Area(km2)		**Percentage %**		**Percentage Change**
	2013	2019	2013	2019	
Built-up	238.2165	489.2292	12.92987	26.55399	105.369% increase
Vegetation	696.7305	410.8257	37.81702	22.29847	41.0359% decrease
Bare Soil	884.34	915.678	48.00005	49.70043	3.54245% increase
Water Body	23.0859	26.6616	1.253053	1.447117	15.4873% increase
Total	1842.3	1842.3	100	100	

4.5.2 Normalized Difference Vegetation and Built-up Index

The Normalized Difference Vegetation Index (NDVI) used to identify the patterns of green surface cover or vegetative land has been calculated. The plants absorb blue and red spectrum while reflecting green, this reflection is highest in the NIR band, and it has been used widely for identifying the vegetative cover changes; this study has also used the NIR band to determine the values of NDVI. The value ranges from -1 to 1. The different value ranges represent different features. Values less than 0 are normally for water bodies and built up-area. The vegetation is above 0.2, between water bodies and vegetative cover. The value range represents barren rock or sand. Above 0.4 is sparse vegetation, while when the value of NDVI goes above 0.6, it represents dense vegetation. These indices have been used to determine the land cover changes and to determine its relationship with Land Surface Temperature. Figure 20 shows that the darker shade of green has been increased in the outskirts, showing an increase in the dense vegetative cover. The mean for both the images is 0.17, showing that although the dense cover has increased at some places, the overall mean has not changed due to the decrease in the vegetative cover around the city boundaries caused by the increase in the built-up land.

Along with NDVI, Normalized Difference Built-up Index (NDBI) has been calculated to analyze the built-up area patterns. Vegetation reflects NIR, while the built-up area reflects SWIR the most. Its value ranges are also between -1 to 1, just like NDVI. Negative values are for the features other than the built-up like water, vegetation while values above 0 represent the built-up area. Figure 21 shows the NDBI index for Lahore. The higher values that represent the built-up proportion goes up to 0.62 in the year 2019, which was around 0.45 in the year 2013, showing the increase in the built-up area with time.

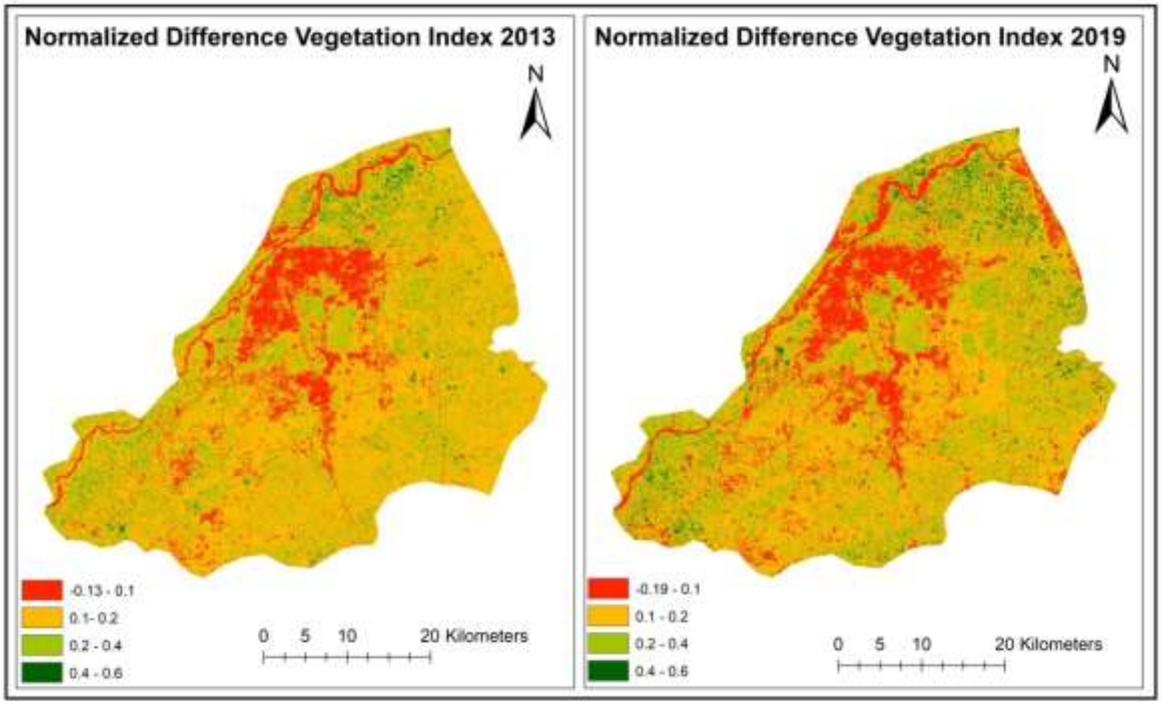

Figure 20 Normalized difference vegetation index (NDVI) map of Lahore of the year 2013 and 2019

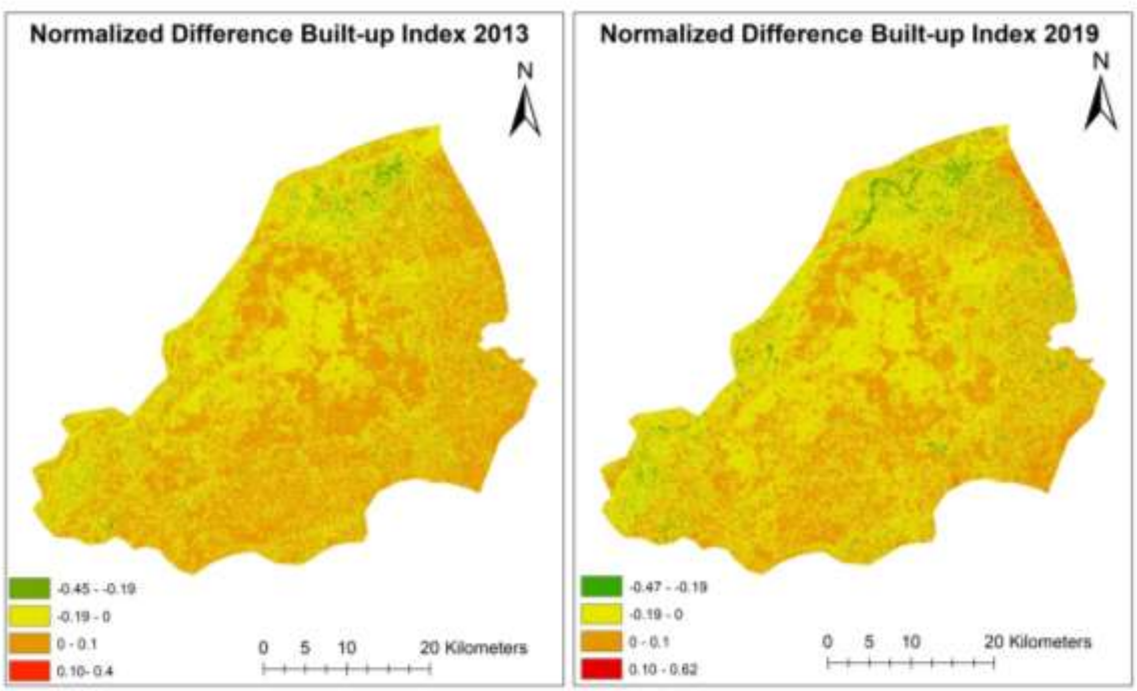

Figure 21 Normalized difference built-up index (NDBI) map of Lahore of the year 2013 and 2019

4.5.3 Land Surface Temperature

With the increasing trend of migration and settling of people from the peripheral areas to the main city, the population of the city is increasing and causing pressure on the resources apart from these consequences. One main contribution of this rapid urbanization is the utilization of scarce land as well as disturbing the environment of the city, causing conditions of thermal discomfort. One way to determine the surface temperature conditions in the city is by making Land surface temperature maps.

LST maps of Lahore city have been used to analyze the minimum and maximum temperature trends of two years (2013 and 2019). The two months used for temperature analysis were April and May. The temperature has been determined for the month of April and May for the year 2013, as well as 2019, to cross-check and validate the findings (Figure 22). In April 2013 and 2019, the maximum temperature was not much different, but the lowest temperature in April 2019 was around 15^{o}C, which was 23^{o}C in 2013. For the month of May, the maximum temperature was around 46-47^{O}C in 2013 while it was up to 55^{o}C in the year 2019, which is very high and is a matter of serious concern if this trend continues, it will become impossible to live in the city, the areas that are in the hotspot range are mostly built-up areas while some of them belong to bare soil land. In the past, the hotspot regions were mostly concentrated in the center.

With the passing time due to increased migration and development, the city is now expanding at a higher rate, and more of the vegetative cover has been converted to the built-up land. This has led to the increase in the hotspot regions, now covering almost the whole of the city.

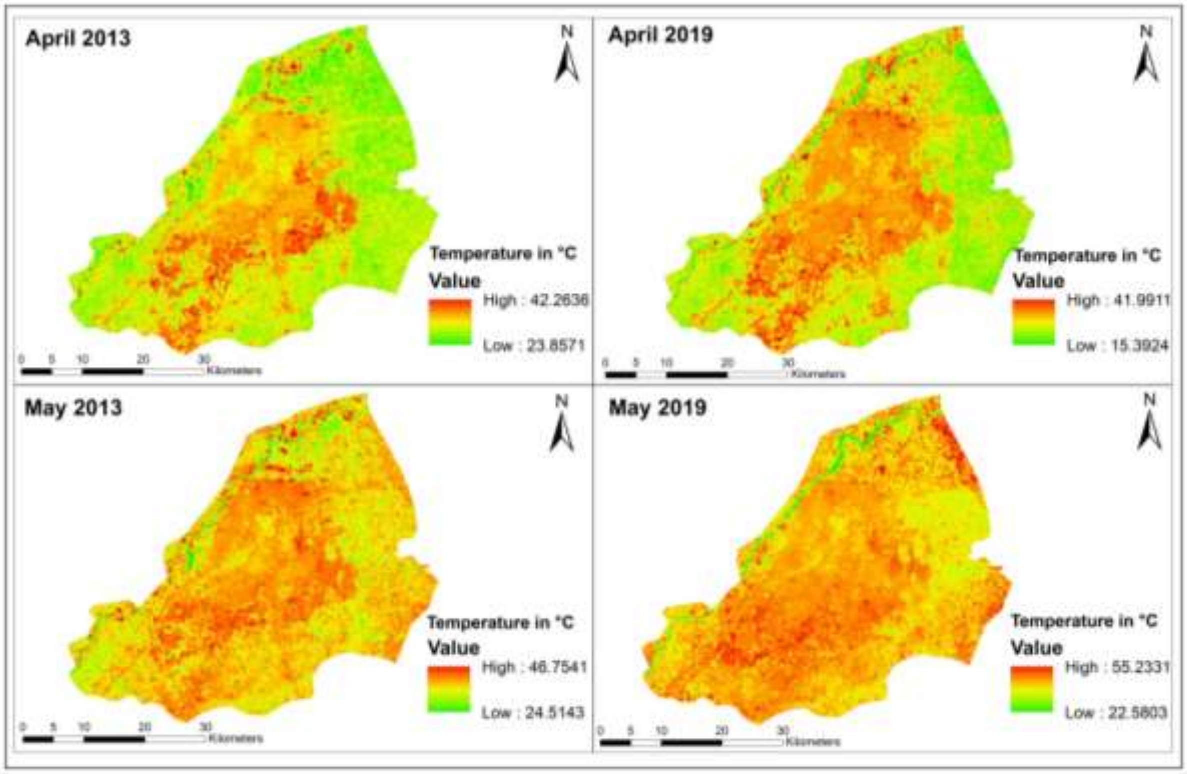

Figure 22 Land surface temperature map of Lahore of the year 2013 and 2019

4.5.4 Relationships between NDBI, NDVI, and LST

The Land cover maps clearly show the change in the built-up land and the vegetative cover. Many of the vegetative lands have been converted into built-up land for housing and development to accommodate more people. The land cover indices and LST maps have also been prepared to determine the change. The value of NDBI, which was 0.36 in the year 2013, has now reached 0.6 in 2019, showing an increase in the built-up land. The maximum temperature limit has also been increased; hence, it indicates that LST directly relates to built-up land while it has an indirect or inverse relationship with vegetation. It grows with the increase in built-up and bare land, decreasing with the increase in vegetative cover and water bodies. The maps of NDVI, NDBI, and LST demonstrate their relationship. From the maps of LST, it can be interpreted that the city's overall temperature and living conditions have been changed now most of the city lies in the hotspot range, becoming vulnerable to hazardous events. This needs proper planning and attention so that climate-resilient and adaptive development plans can be made in the future to promote sustainability.

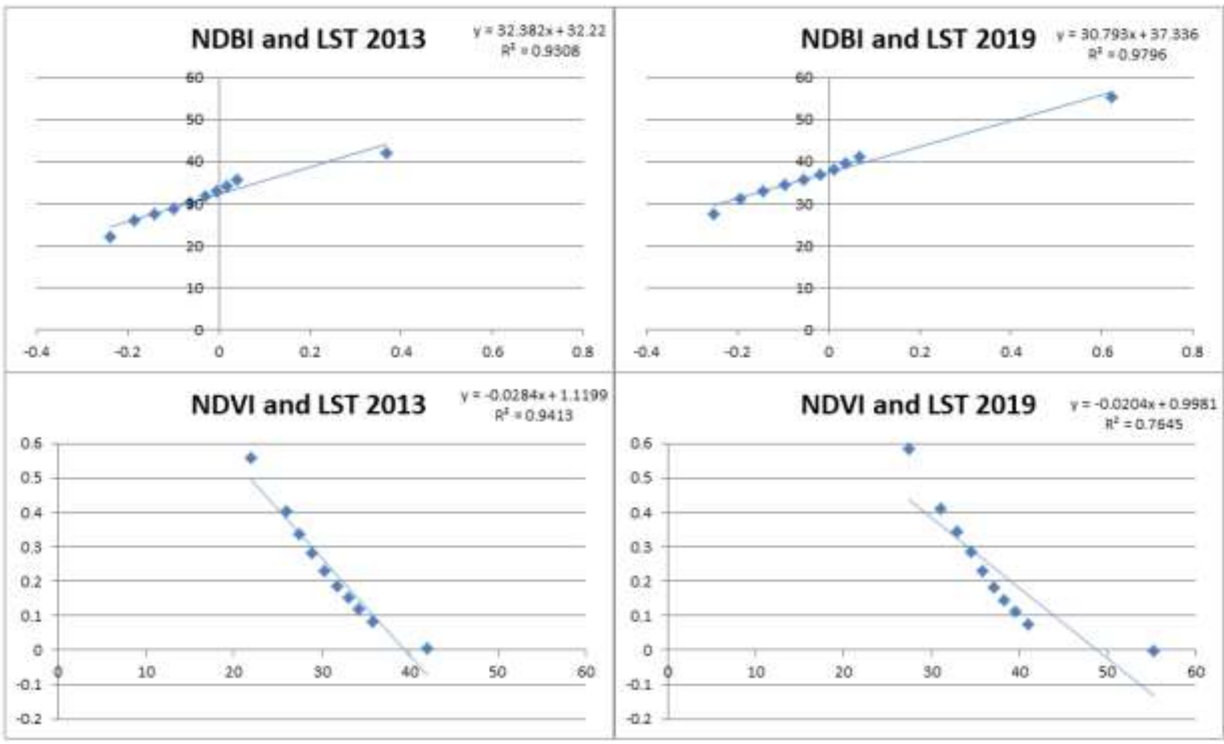

Figure 23 Relationship between NDBI, NDVI, and LST for the year 2013 and 2019

The relationship between land surface temperature, NDVI, and NDBI has been determined by a scatter plot (Figure 23). The graph shows that LST exhibits a strong positive relationship with NDBI having a correlation value of 0.93 and 0.97 for the years 2013 and 2019. It increases with the increase in the built-up land while LST has an inverse relationship with NDVI having a correlation value of 0.94 and 0.76 for the years 2013 and 2019, respectively. As the vegetative cover in the area decreases, so is the NDVI value, and hence LST increases. LST has a strong correlation with both NDVI and NDBI. The LST increases or decreases depending upon the built-up land or vegetative cover change with the changing land cover indices.

4.5.5 Local Climate Zones

After conducting temporal analysis and analyzing the change, the area of Lahore was classified in local climate zones using the WUDAPT procedure to analyze the urban morphology, and surface covers characteristics and observes the city's thermal conditions. To get an idea about the classes, the Google earth view has been provided in figure 8. 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 24). 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.

The central part of the city, mostly 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 as 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 areas of large-low rise, lightweight low-rise, and sparsely built settlements, i.e., LCZ 7, 8, 9, also exist in the outskirts (figure 25). 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, some of the areas around the LCZ G belonged to LCZ C (scrubs and bushes) as well as LCZ F, i.e., bare soil or sand, that was also present on the outskirts of the city in the south and east direction.

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 24 Google Earth Views of Local Climate Zones of Lahore

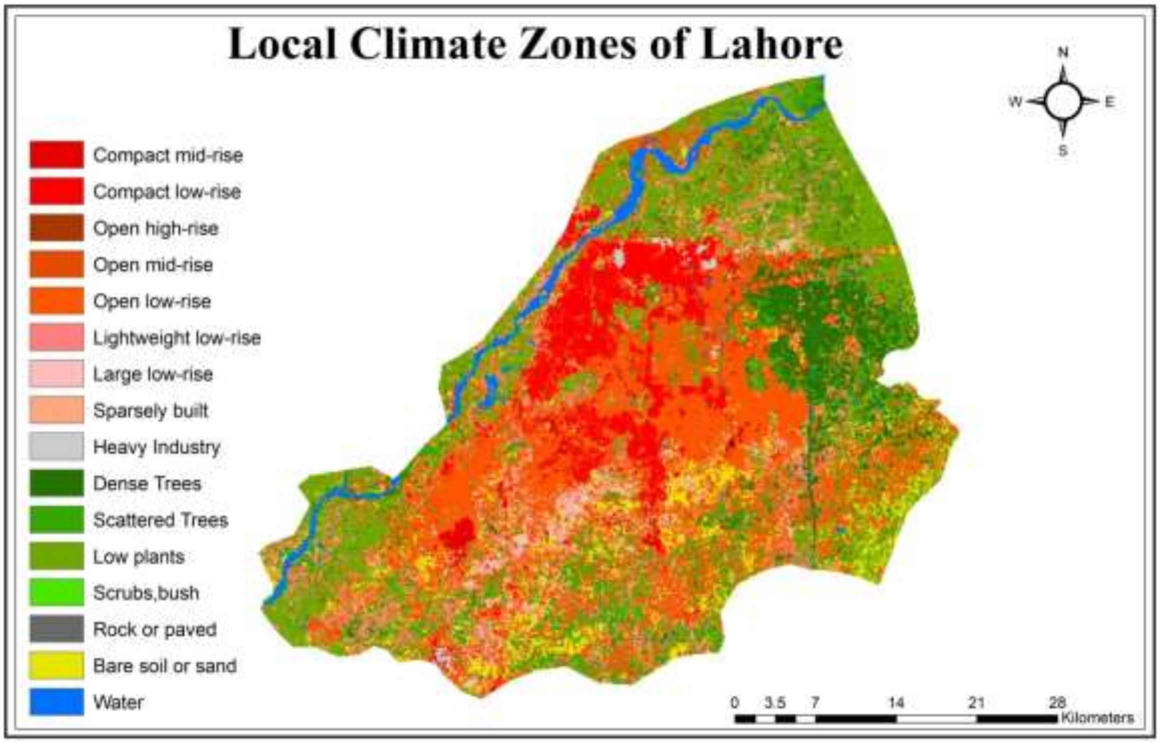

Figure 25 Local climate zones of Lahore

4.5.6 Implications for Lahore

Due to the rapid urbanization and the migration of people from nearby villages, the population of the city 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 5 Million, so in the first phase in the time gap of 18 to 20 years the population increased by 2 Million, but in the next phase, from the year 1998-2017, there has been a rapid increase in the population as it has now crossed 11, showing that in the last 18 years the population has increased to around 6 Million that is almost the thrice as compared to the initial phase. This increased migration, along with increasing the population of the city, is also putting immense pressure on the available resources like housing demands, jobs, educational facilities, recreational spots, and so on. Consequently, not only leading to unplanned and haphazard growth, causing sprawl, but it is also utilizing the scarce resource of land, moreover affecting the area's environment as well. Many new societies have been made to meet the housing demand of the city, leading to rapid expansion and increased built-up area.

This rapid change has been analyzed through land cover maps, land surface temperature, LC indices, and local climate zones in this study. By incorporating all of these factors, a better understanding of the thermal and surface cover conditions can be collected, and hence better planning can be done. The land cover maps helped in analyzing the change over the time period of 6 years. It shows that the built-up land has expanded from 238 km^2 to 489 km^2 from 2013 to 2019, and the vegetative cover was reduced. The LST map shows the changing thermal conditions of the city over time. The relationship between land cover indices like NDVI and NDBI were analyzed with LST; results showed a close association between them with a strong positive correlation between LST and NDBI and a strong negative correlation between LST and NDVI. 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. These Landsat images were also used in Land cover mapping and LST determination. Apart from analyzing the change and thermal conditions, these maps can also help formulate future climate-resilient and sustainable development plans.

The LCZ map of the city depicts that most of the old areas of the city 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), but the thermal conditions in these areas are also intense, as seen from the LST map. The major reason is that although the construction has been done in the open low-rise pattern, the vacant spaces are left as it is. Most of it belongs to the bare soil category hence 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). The initial draft for the integrated master plan of the city was presented in the year 1998. Until then, many amendments have been made in the planning strategies, but neither of these incorporated the built environment and structure. The type of built-up has not been incorporated from the urban heat perspective. There is a need to incorporate the LCZs in the development plans for future growth and sustainable development that will help in improving the thermal conditions of the city. 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.

4.6 Summary of the chapter

The urbanization trend, spatio-temporal land cover change, and land surface temperature conditions of the two cities of Pakistan, one is the capital of Islamabad, and the other is the capital of Punjab Province, Lahore, has been done. The relationship between the land cover indices and the land surface temperature conditions has also been observed. The graph constructed showed a positive relationship between LST and NDBI while a negative relationship between LST and NDVI. With the increase in greener areas, the LST decreases while it increases with the built-up land.

The land use land cover maps have also been prepared for both cities for the years 2013 and 2019. The area statistics have also been calculated. The results showed that the built-up land in Islamabad increased to 113.46%, while vegetative cover decreased to 33.39%. The maximum temperature that was 40^{o}C in the year 2013 June reached around 46^{o}C in 2019 June. Many of the areas that were in the normal range became hotspots. To observe the thermal conditions in detail, the standard WUDAPT methodology has been adopted for mapping the LCZs. The map of Islamabad showed that the most dominant classes were LCZ 3 and LCZ 6. The main sectors are planned, but the constant construction on the open land/ reserved areas and the conversion of land to built-up has been damaging the area's environment. Future developments are a dire need to follow the master plan strictly and to maintain the thermal conditions. The vacant areas should be planned accordingly.

In case of Land cover maps of Lahore. The statistics showed that the built-up land increased to 105.36% while the vegetative cover decreased to 41.03%. The maximum temperature also increased; in May 2013, it was around 46^{o}C while it reached around 55^{o}C in May 2019. The LCZ map of Lahore showed that the inner city falls under the LCZ 3 category; these areas are old and unplanned. As moving outwards, mostly the development falls in the LCZ 6 category, with a mix of other built-up types like LCZ 2, LCZ 4 and LCZ 5. The thermal conditions in the LCZ 6 category are also intense in Lahore due to negligence regarding tree plantation. Many implications have been proposed, with the highlight is to plan vegetative classes accordingly with the type of built-up and convert the bare soil or sand (LCZ F) to scattered plants/trees (LCZ B). Integrated authorities for the implementation and coordination are also needed in the case of Lahore.

In short, it is recommended to strictly follow the master plans for future development plans and suggest policies by incorporating the LCZ concept so that the thermal conditions of the city are kept in mind while proposing future extension plans.

CHAPTER 5

PUBLIC AWARENESS OF CLIMATE CHANGE

5.1 Introduction

With rapid urbanization and development, the climate change consequences and the extreme events related to it are increasing. The ability to deal with these events depends upon the level of awareness and perceptions. Many studies have been done worldwide to determine the perceptions and assess the heat stress resilience of the people. A similar study has been conducted in South Africa, proposing an integrating urban design, infrastructure, and planning framework assisting the decision-makers for efficient urban heat management (Hatvani-Kovacs et al., 2016). Similarly, another study has been conducted in Lodz city, which examines the perception of the people regarding the informal green spaces and focuses on their need for urban adaptation and sustainable development (Włodarczyk-Marciniak et al., 2020). A study conducted in Taiwan assessed the perceptions and preferences of the people regarding smart city services and, at a later stage, provided suggestions for smart city development (Ji et al., 2021). Similarly, another similar work has been done in Singapore, which observes the perception of people regarding sustainable building designs and recommends work on the awareness and adaptation practices for sustainable development(Yin et al., 2018). In this research work, after local climate zones (LCZs) maps of the two cities based on different built-up forms and densities have been finalized, the risk perceptions and psychological distance to climate change were examined in different LCZs. It was hypothesized that climate change risk perception and psychological distance to climate change will vary depending upon the built-up density across different built-up zones. A public survey was conducted, responses were collected in the form of questionnaires and statistical tests were been performed to check the null hypothesis.

5.2 Indicators and questionnaire development

For the questionnaire development, the first step, a rigorous literature review, was done to identify the indicators for measuring public risk perceptions (Table 1) and the psychological distance to climate change (Table 2). The dimensions were filtered through a detailed review, and recurrent indicators were identified and classified under each dimension. Three dimensions of risk perception were identified, namely, fear (4 indicators), attitude (4 indicators), and trust (3 indicators). Similarly, four dimensions of psychological distance were identified, namely, social distance (3 indicators), geographical/spatial (3 indicators), temporal distance (2 indicators), and uncertainty (3 indicators). All these indicators were measured on the 1-5 Likert scale. The scale was based on a very low, low, moderate, high, and very high. In some instances, it was measured as strongly disagree, disagree, neutral, agree, and strongly agree.

After the finalization of indicators, the questionnaire was developed. The first section of the questionnaire included basic socio-economic factors like age, income, gender, and education. Section two and three included the indicators relating to climate change risk perception and psychological distance to climate change, respectively.

Table 18 Indicators used to assess climate change risk perception

Codes	Indicators and questions	Empirical References
	Fear, Dread, or Worry	
RPF1	<u>Perceived fear</u> How much are you afraid of the changing climate?	(Rana & Routray, 2016; Sjöberg, 2000; Slovic et al., 1980)
RPF2	<u>Affect life quality</u> How much do you think that your quality of life will be affected by climate change?	(Ho et al., 2008)
RPF3	<u>Human Intervention</u>	(Wachinger et al., 2010)

	How much do you feel that the changing climate is due to human activities?	
RPF4	<u>Increased occurrence</u> How much do you think that the severity of climate-related hazards will increase in the future?	(Ho et al., 2008; Sullivan-Wiley & Gianotti, 2017)
	Behavior and Attitude	
RPA1	<u>Capacity to deal/cope or able to control</u> How much do you think you can deal with the consequences of changing climate? *	(Ho et al., 2008; Rana & Routray, 2016)
RPA2	<u>Knows mitigation actions to adopt</u> How much do you think you can adapt well from the known adaptation measures to deal with the changing climate?	(Alshehri et al., 2013; Ho et al., 2008)
	<u>Concern about climate change</u>	(Leiserowitz et al., 2010)
RPA3	How much are you concerned about climate change?	
RPA4	How much is this issue of climate change important to you personally?	
	Trust	
	<u>Reliability of the information</u>	(Siegrist & Cvetkovich, 2000; Slovic, 1987)
RPT1	How much do you trust the information you receive linked to climate change from different sources? *	
	<u>Trust on policies and agencies</u>	(Diakakis et al., 2018; Slovic, 1999)
RPT2	How much do you trust the ministry of climate change measures to combat climate change?	
RPT3	How much do you trust the disaster management authority's capability to deal with the hazards caused by climate change?	

*reversed in scale

Table 19 Indicators used to assess psychological distancing to climate change

Codes	Indicators and questions	Empirical References
	Social Distance	
	Worry that your close ones might be hurt	(McDonald et al., 2015; Miceli et al., 2008)
PDS1	How much do you think that climate change will affect/harm you and your family?*	
PDS2	How much do you think that climate change will affect/harm people of the developing countries?*	
PDS3	How much do you think that climate change will affect/harm people like you?*	
	Geographic Distance	
	Concerns that it will affect people like you	(McDonald et al., 2015; Spence et al., 2012)
PDG1	How much do you think that climate change will affect/harm people in your community?*	
PDG2	How much do you think that climate change will affect/ harm people in Pakistan?*	
PDG3	How much do you think that climate change will affect/harm people all around the world?*	
	Temporal Distance	
	Concerns regarding future generations	(McDonald et al., 2015; Spence et al., 2012)
PDT1	How much do you think that climate change will affect/harm future generations?*	
PDT2	When, according to you, will Pakistan start feeling the effect of climate change?	
	Uncertainty	
PDU1	I am uncertain that climate change is happening	(McDonald et al., 2015; Spence et al., 2012)
PDU2	The seriousness of climate change is often exaggerated	
PDU3	Most scientists agree that humans are causing climate change*	

*reversed in scale

5.3 Socioeconomic profile of respondents

The sample included a total of 72.4% of respondents who were male, while 27.6% were females (Table 3). Almost 84% sample population was in the age group of 45. 13.8% were between 46 -65, while only 1.7 were above 65+. The mean age was around 31. Details are provided in table 3 below. The respondents' income was mostly in the range of 20,000 to 50,000, i.e., around 44 %. A greater percentage of the sample population was educated with around 15 to 18 years of education (around 45%). The house ownership percentage was almost equal, around 50.5%.

Table 20 Socioeconomic characteristics of the respondents (n = 297)

Socioeconomic Characteristics	Classes	Freq	%
Age	<=25	125	42.1
	26-45	126	42.4
	46-65	41	13.8
	65+	5	1.7
Gender	Male	215	72.4
	Female	82	27.6
Income	<=20,000	25	8.4
	20001-50,000	130	43.8
	50,001-80,000	85	28.6
	80,001+	57	19.2
Education in years	<=10	53	17.8
	11-14	104	35.0
	15-18	135	45.5

	18+	5	1.7
Household size	<=2	12	4.0
	3-6	210	70.7
	7-10	64	21.5
	10+	11	3.7
House ownership	Yes	150	50.5
	No	147	49.5
Past experiences with climate extreme events	Yes	100	33.7
	No	197	66.3

5.4 Local climate zones of Islamabad

After the mapping of the LCZs, out of 17 classes, 16 were found in the study area. LCZ 1, i.e., compact high-rise, was not present. However, for this study, only 5 built-up areas from LCZ 2 to LCZ 6 were selected, namely, compact mid-rise, compact low-rise, open high-rise, open mid-rise, and open low-rise. The detailed location of the areas coming under the specific LCZ type and the places that were surveyed for the required purpose is mentioned in Figure 26

.

Google Earth view of the selected local climate zones

LCZ 2 *Compact midrise (dense mix of mid-rise buildings)*
DHA-II sector c, G-11/3, F-10 Markaz, E-9/1

LCZ 3 *Compact low-rise (dense mix of low-rise buildings)*
Bhara Kahu, Muslim Town, Gulzar-e- Quaid

LCZ 4 *Open high-rise (open arrangements of tall buildings with tens of stories)*
Blue Area

LCZ 5 *Open mid-rise (Open arrangement of mid-rise buildings*
G-9/2 Karachi Company

LCZ6 *Open low-rise (open arrangements of low-rise buildings)*
Naval Anchorage

Figure 26 Google Earth Views of the Surveyed LCZs

5.5 Climate change risk perception

For the determination of the risk perceptions of people living in different built-up zones or the LCZ types, descriptive analysis was performed. Firstly the individual values of the risk perception indexes were calculated for each question of the respective LCZ type, and then the mean of that index was calculated. The detailed values of the mean and standard deviation of the individual indexes have been mentioned in table 4. A chi-square test was applied to determine the difference in terms of an indicator concerning the LCZ type. The chi-square test showed that there is a significant difference in terms of fear components, the value of risk perception fear components are given; risk perception component one of fear that shows how much people are concerned regarding the climate change ($\chi2$ =45.271, p-value =0.000), risk perception component two of fear ($\chi2$ =24.742, p-value =0.071), risk perception fear component regarding human intervention ($\chi2$ =49.928, p-value =0.000), and risk perception fear component regarding increased occurrences ($\chi2$ =31.500, p-value =0.012). So, in different LCZ types, the risk perception 1 and 3 component of fear have p-value = 0.000 showing the significant difference, while for risk perception fear component 3 and 4 it is 0.071 and 0.012, respectively. Similarly, there was a significant difference in different LCZ types in terms of Attitude and Trust. Below table 4 shows the values for the Chi-square test from LCZ 2 to LCZ 6.

Table 21 Descriptive statistics of climate change risk perception indicators

Indicators*	**Descriptive statistics**	**LCZ 2**	**LCZ 3**	**LCZ 4**	**LCZ 5**	**LCZ 6**	**Chi square test**
Fear							
RPF1	Mean	3.71	3.65	3.75	3.02	4.02	$\chi2$ =45.271
	Std. Deviation	1.211	1.092	1.040	1.489	1.142	p-value =0.000
RPF2	Mean	3.86	3.84	3.98	3.35	4.02	$\chi2$ =24.742

	Std. Deviation	1.120	0.977	1.110	1.282	1.127	p-value =0.071
RPF3	Mean	4.06	4.31	4.28	3.53	4.48	χ2 =49.928
	Std. Deviation	1.256	0.767	0.861	1.352	0.701	p value =0.000
RPF4	Mean	4.03	4.18	4.26	3.79	4.48	χ2 =31.500
	Std. Deviation	1.062	1.002	1.009	1.133	0.567	p-value =0.012
Attitude							
RPA1	Mean	3.22	2.67	2.71	2.83	2.68	χ2 =22.382
	Std. Deviation	1.156	1.055	1.145	1.176	0.982	p-value =0.131
RPA2	Mean	3.32	3.45	3.42	3.40	3.62	χ2 =38.691
	Std. Deviation	1.075	0.997	0.963	1.211	0.804	p-value =0.001
RPA3	Mean	3.75	3.82	3.74	3.35	3.47	χ2 =54.725
	Std. Deviation	1.231	0.905	0.835	1.392	0.700	p-value =0.000
RPA4	Mean	3.71	4.16	4.02	3.52	4.27	χ2 =31.736
	Std. Deviation	1.156	0.958	1.126	1.184	0.918	p-value =0.011
Trust							
RPT1	Mean	2.74	2.94	2.40	2.98	2.43	χ2 =37.446
	Std. Deviation	1.015	1.161	1.015	1.180	0.851	p-value =0.002
RPT2	Mean	2.46	2.64	2.96	2.53	3.17	χ2 =40.888
	Std. Deviation	1.162	1.161	1.224	1.197	0.942	p-value =0.001
RPT3	Mean	2.46	2.78	2.89	2.79	3.12	χ2 =41.359
	Std. Deviation	1.175	1.166	1.205	1.269	0.922	p-value =0.000

* Refer to table 1 for indicator details

The average values of each dimension and overall risk perception were made for LCZ 2 to LCZ 6 calculated, namely, fear, attitude, and trust (Figure 27). It shows that people living in the LCZ 6, i.e., open low-rise have the highest risk perception index with a value of 3.55. In individual dimensions, the highest values of fear and trust were 4.25 and

2.91 in the same LCZ, i.e., LCZ 6, respectively. The least risk perception was from the people living in open mid-rise areas with an average value of 3.16. There was not much difference in the perceptions of people of the LCZ 3 and LCZ 4 with a value around 3.4.

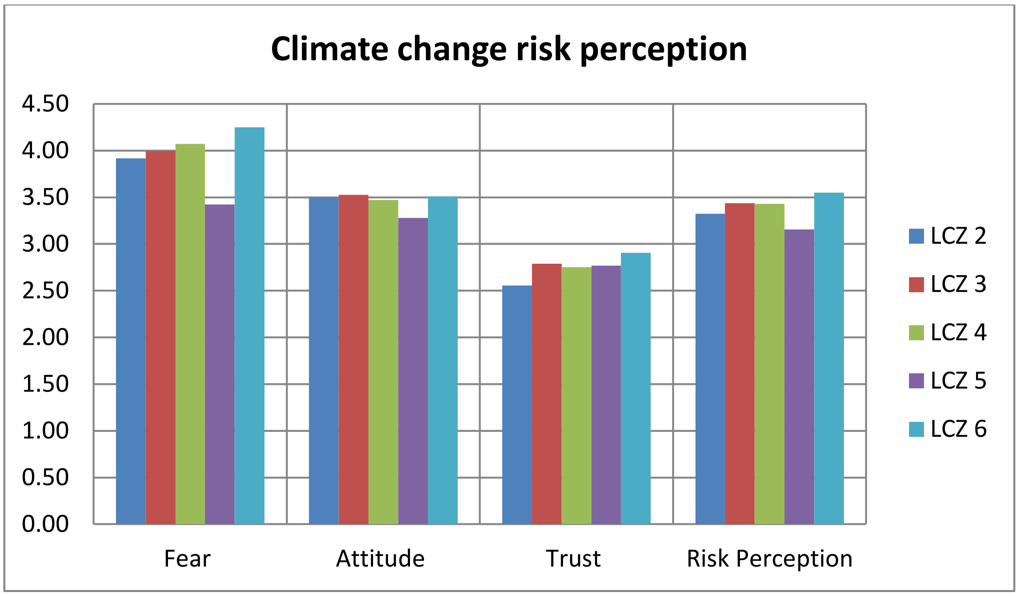

Figure 27 Mean values of climate change risk perception and its dimensions

Risk perception is an important parameter. The value of the risk that has been perceived affects how the citizens will respond in case of any calamity. ANOVA test, also known as the F-test, was performed to check the significant difference in perceptions and the LCZs. This test showed that there was a significant difference in terms of fear among the respondents (F-value = 8.602, p-value of 0.000), while in the case of attitude and trust, the difference was found significant at 10% (p-value= 0.071). In terms of overall risk perception, a significant difference was observed with an F-value = 7.544 and a p-value = 0.000.

Table 22 ANOVA test for climate change risk perception and its dimensions

Dimensions	Descriptive statistics	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	ANOVA test (F test)
Fear	Mean Std. Deviation	3.92 0.896	4.00 0.586	4.07 0.854	3.42 0.962	4.25 0.748	F=8.602 p-value=0.000
Attitude	Mean Std. Deviation	3.50 0.647	3.53 0.492	3.47 0.467	3.28 0.582	3.51 0.474	F=2.179 p-value=0.071
Trust	Mean Std. Deviation	2.56 0.743	2.79 0.715	2.75 0.656	2.77 0.713	2.91 0.499	F=2.181 p-value=0.071
Risk perception	Mean Std. Deviation	3.32 0.473	3.44 0.306	3.43 0.456	3.16 0.450	3.55 0.408	F=7.544 p-value=0.000

The results obtained from different analysis being done on the risk perception indicators and their dimensions. It has been observed that there is a significant difference between them in respective LCZs. Chi-square test proved that there is a significant difference in most of the dimensions of risk perception, i.e., fear, attitude, and trust, in different LCZ types. Similarly, the highest climate change risk perception index value was from LCZ 6 (open-low rise category), while the lowest belongs to the LCZ 5 (open midrise category). ANOVA test also proved that there was a significant difference in terms of fear and overall risk perception.

5.6 Psychological distance to climate change

The psychological distance to climate change was calculated among the LCZs using similar tests. Firstly, the individual values of the psychological distance indexes were calculated for each indicator (Table 6). After the indexes were calculated, a chi-square test was applied to determine differences in indicators of the psychological distance of the selected LCZs. The chi-square test showed that there was a significant difference in social distancing indicators relating to the worry that the close ones might be hurt; for affecting your family ($\chi2$ =36.250, p-value =0.003), affecting your fellow country-people ($\chi2$ =57.611, p-value =0.000), and affecting you ($\chi2$ =105.387, p-value =0.000) in different LCZ types. The concern for affecting your close ones because of climate change varied significantly across all the LCZs. Similarly, a significant difference was observed for spatial distancing indicators. Significant difference existed between all LCZs relating to the concern that climate change will affect their community ($\chi2$ =49.159, p-value =0.000), their country ($\chi2$ =42.104, p-value =0.000), and the world ($\chi2$ =37.837, p-value =0.002). Temporal distancing indicators showed a significant difference concerning LCZs regarding the impact of climate change on future generations ($\chi2$ =72.566, p-value =0.000) and impacts of climate change in the country ($\chi2$ =70.895, p-value =0.000). In terms of uncertainty, a significant difference was again observed among the selected LCZs, i.e., uncertainty regarding climate change is happening ($\chi2$ =63.686, p-value =0.000), the seriousness of climate is exaggerated ($\chi2$ =128.446, p-value =0.000), and anthropogenic climate change ($\chi2$ =61.567, p-value =0.000). Table 6 shows the chi-square test among LCZs.

Table 23 Descriptive statistics for psychological distancing to climate change indicators

Indicators	Descriptive statistics	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	Chi-square test
Social							
PDS1	Mean	2.33	2.05	2.07	2.46	1.65	$\chi2$ = 36.250
	Std. Deviation	1.204	1.112	1.099	1.250	0.860	p-value =0.003
PDS2	Mean	1.79	1.63	1.36	2.58	1.37	$\chi2$ = 57.611
	Std. Deviation	1.138	0.969	0.770	1.443	0.758	p-value =0.000
PDS3	Mean	2.19	2.10	2.26	3.25	1.55	$\chi2$ = 105.387
	Std. Deviation	0.930	1.165	0.973	1.292	0.769	p-value =0.000
Geographic							

PDG1	Mean	2.14	2.00	1.89	2.16	1.40	χ2 = 49.159
	Std. Deviation	1.013	1.036	1.012	0.926	0.741	p-value =0.000
PDG2	Mean	1.96	1.62	1.47	2.25	1.43	χ2 = 42.104
	Std. Deviation	1.077	0.937	0.734	1.329	0.767	p-value =0.000
PDG3	Mean	1.96	1.72	1.49	2.25	1.45	χ2 = 37.873
	Std. Deviation	1.092	0.970	0.758	1.144	0.832	p-value =0.002
Temporal							
PDT1	Mean	1.61	1.50	1.45	2.32	1.27	χ2 = 72.566
	Std. Deviation	0.869	0.766	0.683	1.156	0.446	p-value =0.000
PDT2	Mean	3.84	3.25	3.84	2.81	4.07	χ2 = 70.895
	Std. Deviation	1.505	1.745	1.449	1.458	1.645	p-value =0.000
Uncertainty							
PDU1	Mean	3.16	2.76	2.26	2.84	1.63	χ2 = 63.686
	Std. Deviation	1.568	1.503	1.506	1.308	1.193	p-value =0.000
PDU2	Mean	2.83	3.53	3.25	2.71	4.48	χ2 = 128.446
	Std. Deviation	1.199	1.303	1.229	0.965	0.77	p-value =0.000
PDU3	Mean	1.76	1.74	1.77	2.54	1.43	χ2 = 61.567
	Std. Deviation	1.027	1.004	1.018	1.250	0.722	p-value =0.000

* Refer to table 2 for indicator details

After observing significant differences in the psychological distance among the LCZs, average values for dimensions like social, geographic, temporal, uncertainty, and overall psychological distance index were calculated (Figure 28). It was observed that people living in LCZ 5, i.e., open mid-rise showed a high value of 2.77 for social distancing to climate change and 2.23 for geographic distance to climate change. Moreover, the highest overall psychological distance of 2.56 was also observed in the same LCZ. However, no difference was observed for temporal and uncertainty dimensions of psychological distancing to climate change in various LCZ types. The least psychological distancing index value was 1.51 for social distancing, while in the case of the overall psychological distancing index was 2.03. Both were from the respondents living in open low-rise areas.

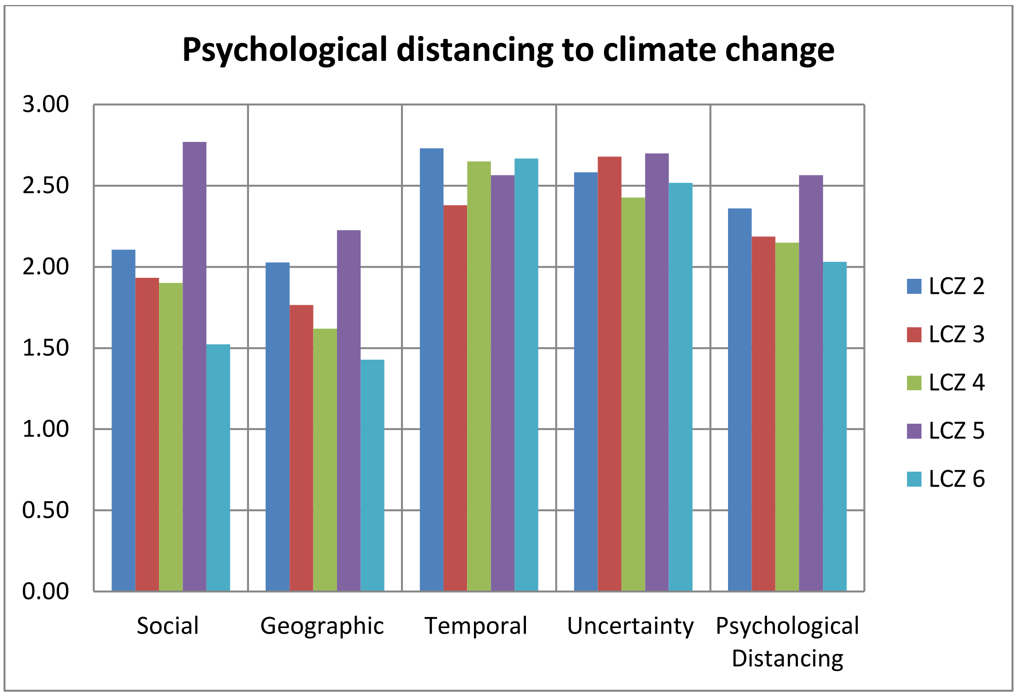

Figure 28 Mean values of psychological distancing to climate change and its dimensions

The ANOVA test was also applied to ascertain the difference between dimensions of psychological distancing and LCZs. The results from the f-test showed a significant difference in terms of social and geographic distancing, while no significance was observed for temporal and uncertainty. The overall psychological distance varied among the selected LCZs (F= 11.383, P value= 0.000).

Table 24 ANOVA test for psychological distancing dimensions

Dimensions	Descriptive statistics	LCZ2	LCZ3	LCZ4	LCZ5	LCZ6	ANOVA test (F test)
Social distance	Mean	2.11	1.93	1.90	2.77	1.52	F=18.722
	Std. Deviation	0.813	0.852	0.753	1.01	0.632	p-value=0.000
Geographic distance	Mean	2.03	1.77	1.62	2.23	1.43	F=8.798
	Std. Deviation	0.952	0.848	0.716	0.870	0.756	p-value=0.000
Temporal distance	Mean	2.73	2.38	2.65	2.56	2.67	F=1.695
	Std. Deviation	0.761	0.922	0.667	0.796	0.757	p-value=0.151
Uncertainty	Mean	2.58	2.68	2.43	2.70	2.52	F=1.480
	Std. Deviation	0.822	0.790	0.744	0.713	0.404	p-value=0.208
Psychological distance	Mean	2.36	2.19	2.15	2.56	2.03	F= 11.467
	Std. Deviation	0.50	0.509	0.435	0.568	0.337	p-value= 0.000

The results show a significant difference exists between the indicators and dimensions of psychological distance to climate change in the LCZs. As suggested by the chi-square test, there was a significant difference in psychological distancing to climate change in terms of social, geographic, temporal, and uncertainty. Similarly, the highest value of psychological distancing to the climate change index was observed for the respondents of the LCZ 5 category, while the lowest belonged to the LCZ 6. The ANOVA test also proved a significant difference in terms of social, geographic, and overall psychological distancing. It can be summarized that the people living in open mid-rise had a higher psychological distancing to climate change than other LCZs where the people living in open low-rise had the lowest psychological distancing to climate change.

5.7 Relationship between climate risk perception and psychological distance

The relationship between risk perception, psychological distance, and their dimensions were established using Pearson's correlation test. A correlation matrix was constructed between the dimensions of risk perception and psychological distancing (Table 8). The matrix shows a moderate relationship between the fear component and attitude dimension of climate change risk perception (0.491) at a significance level of 1%. In the case of risk perception and psychological distancing dimensions, a strong negative correlation existed between them. Fear component of risk perception exhibited a strong negative relationship with psychological distancing social and geographic dimension; for social and fear component correlation value is (-0.672) and in case of geographic (-0.625), and the correlation is significant at 1%. This strong inverse correlation can be due to how much people fear climate change and how much they think it will affect their lives. If a person perceives greater fear, he/she will have a lower value of psychological distancing to the climate change dimension, as the person will think climate change phenomenon is near to them. The correlation of risk perception fear component was also significant with psychological distancing temporal and uncertainty indicators with the significance level of 0.01. In the case of attitude, it possesses a strong negative relationship with social distancing (-0.505) and geographic distancing (-0.505). This implies that people having a serious or concerned attitude towards climate risks will have higher concerns that their close ones might be hurt, or the changing climate will affect people. Thus, the lower social and geographic dimension values imply a lesser psychological distance to climate change, perceiving it as real and not a distant phenomenon. Similarly, a small positive correlation with temporal distancing -0.210) and a small negative correlation with uncertainty dimension (-0.261) were observed. There was a strong correlation between geographic and social distancing dimensions with a value of 0.77 and a p-value =0.000. This implies that people worry more if their close ones might get hurt.

Table 25 Correlation matrix between dimensions of climate change risk perception and psychological distancing

Dimensions	Fear	Attitude	Trust	Social	Geographic	Temporal	Uncertainty
Fear	1	.491**	-0.092	-.672**	-.625**	.279**	-.277**
Attitude	.491**	1	-.124*	-.505**	-.505**	.210**	-.261**
Trust	-0.092	-.124*	1	-0.052	0.044	0.024	0.066
Social	-.672**	-.505**	-0.052	1	.772**	-.164**	.270**
Geographic	-.625**	-.505**	0.044	.772**	1	-.155**	.281**
Temporal	.279**	.210**	0.024	-.164**	-.155**	1	-0.078
Uncertainty	-.277**	-.261**	0.066	.270**	.281**	-0.078	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Overall, the value of correlation was -0.537 (p-value 0.000), showing a strong negative correlation between risk perception and psychological distance. This implies that the higher the climate change risk perception, the lower will be the psychological distance to climate change. This empirical finding supports the conceptual and theoretical debate that higher climate risk perception and lower psychological distance will motivate people to undertake climate change adaptation and mitigation measures. To summarize, it can be concluded that there is a strong negative correlation between risk perception and psychological distancing to climate change. If one increases, the other will decrease. Similarly, a strong negative correlation exists between the different dimensions of risk perception and psychological distancing. Among these dimensions, the association between the fear dimension of risk perception and the social and geographic distancing dimensions was found strong. Therefore, it can be concluded as the risk perception of the people living in open mid-rise was low, and their psychological distance to climate change was high, as they think it a phenomenon that is far from them and it will not cause any damage to them.

5.8 Summary of the chapter

Detailed information regarding the indicators for the risk perception and psychological distancing to climate change and their questions have been provided. The socioeconomic profile of the respondents showed that most of the respondents were male and belonged to the age group of 26 to 45. Most people were educated. A detailed aerial view of the 5 LCZs that were surveyed has also been provided.

Different analyses have been done on the data. The Chi-square test revealed that there is a significant difference between the risk perception components. ANOVA test performed also proved the significant difference for overall risk perception and for the fear components as well. The mean values showed that the highest risk perception was of people living in LCZ6.

Similarly, both test ANOVA and Chi-square tests also proved the significant difference in psychological distancing dimensions. The highest value was for LCZ 5 category people showing greater distancing to climate change. The correlation matrix constructed showed a strong negative association between risk and psychological distancing dimensions.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of findings

The systematic review of local climate zoning using bibliometric and thematic analysis revealed some important findings. The number of research studies related to the local climate zones has been increased with time, showing the importance and growing use in urban climate studies. Due to a close relationship with the urban heat island effect, local climate zoning is an effective tool for earmarking potential hotspots of climate risks in cities. Most of the published research works on local climate zones have been done in Chinese cities. The systematic review has revealed numerous sources of data, methodologies, and analysis to generate local climate zone maps. Many studies consistently advocated the use of the WUDAPT methodology. The most recurrent theme linked with local climate zoning is the urban heat island. The other concepts/terminologies appearing in LCZ literature included; air temperature, urban morphology, land surface temperature, and thermal comfort.

The urbanization trends showed that the population of both cities, i.e., Islamabad and Lahore, has been increasing rapidly and is a major cause of rapid and unplanned growth. The LCZ maps of both the cities clearly depict that the compact and open low-rise, i.e., LCZ 3 and LCZ 6 were the two most dominant classes in the area. In the case of Islamabad, the sectors fall in the LCZ 6 category, while the areas in the southeast direction came under LCZ 3 category. While most of the old areas of Lahore city fall under the category of compact-low rise (LCZ-3) that are present in the core of the city that is unplanned. Moving outwards, most of the areas fall under open-low rise (LCZ-6) category. The higher temperatures in the outskirts of Islamabad can be linked to the topographic differences and the presence of bare soil, while in the case of Lahore, temperatures are also higher in LCZ 6 category development that is due to the fact that vacant spaces are left as it mostly consists of bare soil (LCZ E) and no plantation has been done. Together with urbanization and rapid growth, one major effect that is leading to the increasing temperatures is reducing the green spaces. The planning should be done so that open spaces are present around every community/built-up area to promote climate-friendly development and increase the thermal comfort of the residents.

By using the LCZ map, it can serve as the basis for the urban temperature studies; the rising temperatures in the cities are a matter of serious concern. Up till then, many amendments have been made in the planning policies and development plans, but neither of these incorporated the role of built environment and structure. Generally, in Pakistan, the type of built-up is not considered while making urban expansion policies. There is a dire need to incorporate the LCZs in the development plans for future growth and sustainable development that will help in improving the thermal conditions of the city. In case of compact high rise (LCZ 1) development, the coolest zones, i.e., LCZ G (water) and LCZ A (dense trees) should be planned accordingly nearby as well the bare land, i.e., LCZ E, should be converted to LCZ B (scattered trees) and the unplanned and haphazard growth should be clearly monitored for maintaining the thermal comfort of the city.

To deal with extreme events, the awareness and the preparedness level of the public play an important role. Many studies have been conducted to determine the risk perception of people regarding disasters and extreme weather events. However, this study has observed the role of the built environment climate change perceptions. The findings suggest a significant difference between climate risk perceptions and psychological distance to climate change for people living in different built-up forms/densities or simply LCZs. Statistical tests have shown that there was a significant difference in indicators of fear and attitude. The risk perception of people living in LCZ 6 was higher as compared to the other LCZs. ANOVA test further confirmed that there is a significant difference in climate change risk perception among LCZs. Apart from the risk perception, psychological distance to climate change was also analyzed. The results showed a significant difference in terms of psychological distancing to climate change indicators, i.e., geographic, social, temporal, and uncertainty among LCZs. There is a dire need to increase climate change risk perception and reduce psychological distance through adequate risk communication strategies.

6.2 Main recommendations

Some of the major recommendations from the study are discussed below;

1. LCZ is an emerging concept and framework with potential uses for increasing urban resilience, climate change adaptation, and sustainability. However, current research and development are still being done for accurate LCZ mapping due to its novelty and recent use. Despite numerous accuracy assessments, there is still a need to improve accuracy and develop a uniform/standard methodology for creating LCZ maps. One of the recurrent suggestions in studies was the use of uniform and detailed input data for better comparisons and consistency. Efforts have been on the way to incorporate Level 1; detailed data on shapes (building heights) and functions (residential, commercial) for the whole city, and level 2 data, i.e., intra-city spatial variability. The majority of the studies have stressed the generation and standardizing of level 1 and level 2 data for precise urban canopy parameters for various models.
2. The multidimensional application of LCZs is increasingly utilized in the fields of urban planning, climatology, GIS, remote sensing, and broadly, sustainable urban development. Therefore, more data sources can be used for making more accurate classifications and mapping. It is recommended to use both simultaneously for better analysis and modeling of the urban built environment. The datasets of satellite, aerial, and ground-level images and buildings information can be combined to form holistic and integrated local climate zones. It is also suggested for developing a more standardized and refined process classification of LCZs for easier synchronized/overlay mapping and replication, especially for high-density areas and data-scarce regions. Moreover, LCZs linking climate change adaptation, disaster risk

reduction, and urban planning under the sustainable urban development framework are needed, especially from a policy viewpoint.

3. It is also recommended to incorporate energy demand/performance of the buildings for better modeling urban climate. The wind is also an important factor to be considered in future research. More research is needed to link the usage of wind environments for improving ventilation in dense urban corridors and heat maps. There is also a need to study these effects seasonal and temporal trends for generating more understanding regarding local climate zoning. Moreover, new technologies and algorithms can be developed using deep learning and neural networking methods.
4. Many conference papers have highlighted major improvements in the methodological processes of the local climate zones, like using multi-seasonal imageries, Landsat and Sentinel, and OSM data for extracting different features for better feature representation and extraction. Currently, the transferability of training areas from one city to another is a lengthy and time-consuming process. New models and algorithms need to be developed, which can harness the powers of machine learning and artificial intelligence techniques for smoother and efficient transfer.
5. Institutional aspects involving local urban development and planning departments, local administrations, and meteorological/climate agencies are limited, especially in developing countries. For effective use of LCZs, it is important to include all relevant stakeholders and departments for effective climate-sensitive planning. This can help in achieving the goals of sustainability and resilience in the urban environment. Using LCZs can identify potential climate risks in the local environment to reduce risks by preparing mitigation strategies. Thus, incorporating LCZs in future plans can help in climate change adaptation, disaster risk reduction, and sustainable urban development.
6. Rising temperatures in the cities due to rapid urbanization and development are a matter of serious concern worldwide, but the developing countries that are ranked

in the list of top countries in their vulnerability to climate change need proper attention. Generally, in Pakistan, the type of built-up is not considered while making master plans of the city. Many amendments have been made in the planning policies and development plans, but neither of these incorporated the role of built environment and structure. There is a dire need to incorporate the LCZs in the development plans for future urban expansion policies, city growth, and sustainable development to build climate-friendly and resilient cities.

7. One important thing needed to be considered for a country like Pakistan is an integrated authority for plan implementation as most of the plans fail due to a lack of coordination between different governing authorities and jurisdiction problems.
8. The statistical analysis related to the risk perceptions and psychological distancing to climate change revealed a significant difference among the risk perception and psychological distancing indicators in various LCZs. So, it is needful to work on communication strategies. It is recommended to improve awareness campaigns that can help people understand climate change and its impacts, adopt precautionary measures, and reduce climate risks.

6.3 Conclusions

With the increasing threat of climate change-induced extreme events and rapid urban growth in the capital city, climate and disaster risks will increase significantly. There is an urgent need for collaboration among urban planners and climatologists for relieving thermal stresses through climate-resilient development. It is recommended that future development plans should simultaneously focus on land use and local climate zoning for mitigating potential hotspots of climate risks in the city. It is further advocated that the city administration can integrate LCZs for working out better sustainable and climate-resilient development solutions. In the current revision of the master plan, there is no reference to the LCZs or urban heat island effects. Without incorporating LCZs, the master plan could create urban risks in the future. LCZs can effectively help the authorities identify such potential high-risk areas and maintain thermal comfort in the city.

Along with the LCZs integration in the future development plans, the perceptions of the people regarding the awareness linked to climate change has also been observed. It was found that a strong negative correlation exists between the concept of climate change risk perception and psychological distance to climate change. This finding has implications for disaster managers, climate change and social scientists, urban planners, and policymakers for designing climate change adaptation and mitigation strategies. By perceiving the risks of the public associated with the heat waves or other climate change-induced disasters, governments can understand better how people think about these events and how they will react. Furthermore, the climate change risk perceptions and psychological distance can partially predict community willingness to undertake adaptation and preparedness measures. Thus, it has direct impacts on climate change vulnerability and risks in the built environment. This study advocate increasing climate change risk perception and reducing the psychological distance to climate change. This study can provide a nexus for integrating the philosophies of disaster risk reduction and climate change adaptation.

6.4 Limitation and future directions

As the scientific studies involving bibliometric and thematic analysis have methodological limitations, the systematic review has certain constraints. The bibliometric information may be updated, as some reviewed articles may be assigned to the next year's issues. Similarly, only two databases were used, which may have resulted in a limited review of more methodologies, data sources, and themes. The systematic review methodology is supplemented by qualitative analysis, which might vary among researchers. The thematic analysis has identified key areas using a standard methodology from a qualitative perspective, which may have influenced potential biases in coding and naming themes.

One of the limitations linked to the mapping process of LCZs faced by developing countries like Pakistan is data scarcity; the detailed and disaggregated urban planning data is missing. There were no detailed maps available, so limited resources were used to collect the training samples. The LCZ model can be better and accurately represented using detailed urban planning data or maps, advanced/high-resolution and aerial satellite imageries, and ground-level data. More advanced techniques and physical parameters of geometric and surface cover properties can also be used to reflect better ground realities. In the future, more factors like air temperature, wind conditions, and morphological parameters can be included for a better understanding of the effect of different LCZ types. In short, this study can act as a foundation for research on advanced urban temperature studies for developing countries like Pakistan as well the LCZ scheme can be integrated into future master plans.

One other limitation linked to the perceptions is that this research work has been conducted in only 5 built-up zones, which had a large population available for survey. It can be further expanded in other built-up zones like lightweight low-rise (LCZ 7), large low rise (LCZ 8), sparsely built (LCZ 9), and heavy industries (LCZ 10) to get a better idea about the perceptions of people. It can also be regressed with socioeconomic factors like gender, education, income, marital status, and past experiences in future studies. Moreover, it is suggested to link heatwaves risk perception, or similar climate change-induced disasters, with psychological distancing and the built environment.

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Annexure 1 Journal and conference papers reviewed

Author, Year and DOI (where available)	Study area	Data	Methods and analysis	Software
(Agathangelidis, Cartalis, & Santamouris, 2019) 10.3390/cli7060075	Athens (Greece)	Meteorological stations data, Landsat, Sentinel-2, MODIS products, Detailed maps and data	GIS based LCZ, Urban Heat Exposure determination, comparisons, Statistical analysis	not mentioned
(Alexander & Mills, 2014) 10.3390/atmos5040755	Dublin (Ireland)	Meteorological stations data, mobile measurements, Corine LULC, Bing maps	Grid-based sampling approach, Comparisons	Google Earth
(Alexander, Bechtel, Chow, Fealy, & Mills, 2016) 10.1016/j.uclim.2016.08.003	Dublin (Ireland) Hamburg (Germany) Melbourne, (Australia) Phoenix (USA)	Meteorological stations data, land cover data, LCZ data	urban energy budget and water budget model (SUEWS), Accuracy assessment, Statistical analysis	Google Earth

(Alexander, Fealy, & Mills, 2016) 10.1016/j.landurbplan.2016.02.006	Dublin (Ireland)	Meteorological stations data, Land cover parameters, statistical data from governmental departments	LCZ from MOLAND LULC, analysis of the SUEWS, Impact indices	not mentioned
(Alexander, Mills, & Fealy, 2015) 10.1016/j.uclim.2015.05.001	Dublin (Ireland)	Meteorological data from the instruments placed (weather station); socio-economic-demographic data and; surface cover and urban structure data.	Urban Energy Budget Models, Surface Urban Energy and Water Balance model (SUEWS), Accuracy assessment, Sensitivity analysis,	not mentioned
(Aminipouri et al., 2019) 10.1016/j.buildenv.2019.05.022	Vancouver (Canada)	Meteorological stations data, photographs	SOLWEIG model, comparisons	not mentioned
(Aminipouri, Knudby, Krayenhoff, Zickfeld, & Middel, 2019) 10.1016/j.ufug.2019.01.016	Vancouver (Canada)	Meteorological stations data, photographs	SOLWEIG model, evaluation	not mentioned
(BANDE, MANADHAR, & MARPU, 2019), 10.2495/SC190191	Al Ain (UAE)	training areas, Landsat 8 images , site measurements	WUDAPT procedure, WRF model, ENVI-met simulations	ENVI-met, Google Earth , SAGA GIS

(Bechtel & Daneke, 2012) 10.1109/JSTARS.2012.2189873	Hamburg (Germany)	NEXTMap®,IFSAR data (DSM, DTM), Landsat 7 and 5 images, training areas	ZeroR and Naive Bayes as baseline, Maximum Likelihood, Neural Networks (NN), and Support Vector Machines (SVM), Accuracy assessment	SAGA GIS, Weka
(Bechtel et al., 2015) 10.3390/ijgi4010199	Hamburg, Germany, Dublin, Ireland, and Houston, USA	Landsat 8 images, training areas	WUDAPT procedure, accuracy assessment	Google Earth, SAGA GIS
(Bechtel et al., 2016) 10.1109/JSTARS.2016.2531420	Khartoum (Sudan)	Landsat 8 images, Sentinel 1 data, Georef images, Bing maps, training areas	Improved WUDAPT procedure four classifiers Naïve Bayes (NB), RF, Support Vector Machines, Multilayer perceptron, Neural network, Accuracy assessment	Google Earth, SAGA GIS, Weka
(Bechtel et al., 2019) 10.1016/j.uclim.2019.01.005	50 cities	Landsat 8 , MODIS for LST, data from WUDAPT	LST from MODIS and Landsat, spatial filtering, comparisons, statistical analysis	Google Earth Engine

(Bechtel et al., 2019) 10.1016/j.uclim.2018.10.001	Brazil, Belgium, Dublin and many others	Landsat 8, Open Street Map, training areas	WUDAPT PROCEDURE, Accuracy assessment	Google Earth, SAGA GIS, ArcMap
(Beck et al., 2018) 10.1016/j.uclim.2018.04.007	Augsburg (Germany)	Landsat 8 images, Meteorological stations data, training areas	WUDAPT procedure, Quality control, Statistical analysis	Google Earth, SAGA GIS
(Bernard, Bocher, Petit, & Palominos, 2018) 10.3390/cli6030060	Paris (France)	Urban block maps, Buildings data from governmental source	SVF calculation, accuracy assessment, Statistical analysis	SAGA GIS, OrbisGIS
(Bokwa et al., 2019) 10.1016/j.enbuild.2019.07.023	Bratislava (Slovakia), Brno (Czech Republic), Kraków (Poland), Szeged (Hungary) and Vienna (Austria),	LCZ maps, Meteorological Stations data	MUKLIMO_3 for temp patterns, ALARO-ALADIN numerical weather prediction model, Statistical Analysis	not mentioned
(Brousse et al., 2016) 10.1016/j.uclim.2016.04.001	Madrid (Spain)	Landsat 8, Training areas Google earth, measurements from 24 meteorological stations	Random Forest Classifier for LCZ (WUDAPT PROCEDURE). RMSE error	SAGA GIS, Google Earth

(Brousse et al., 2019) 10.1016/j.uclim.2018.12.004	Kampala (Uganda) and Dakar (Senegal).	Landsat 8, Sentinel-1, NDVI, NDUI, training areas	LCZ on EE by 4 methods, comparisons, accuracy assessment, TERRA-URB model	Google Earth Engine, GRASS GIS
(Budhiraja, Gawuc, & Agrawal, 2019) 10.1109/JSTARS.2019.2955133	Delhi (India)	training areas, Landsat 8 images , MODIS LST	WUDAPT procedure, SUHI indicators, statistical tests	Google Earth, SAGA GIS
(Cai, Tang, Chen, & Han, 2019) 10.3390/su11072032	Chongqing (China)	Landsat 8 images, detailed GIS data from governmental departments	LCZ by using parameters, GIS and Statistical analysis	SPSS, QGIS, ENVI
(Chen et al., 2019) 10.1007/s00704-018-02764-x	Taipei (China)	Spot-6, Landsat 8 images, Total Floor Area (TFA) and Building coverage Ratio (BCR) from digital building model, Land use. Mobile measurements	Statistical analysis, Comparisons	QGIS, SAGA GIS
(Chieppa, Bush, & Mitra, 2018) 10.1175/EI-D-17-0020.1	Auburn and Opelika (Alabama), (USA)	Meteorological stations data, Landsat 8, Google Earth images, training areas	WUDAPT procedure, statistical analyses	SAGA GIS Google Earth
(Ching et al., 2018)	Generic study	Landsat 8, training areas	WUDAPT procedure, Surface	SAGA GIS,

10.1175/BAMS-D-16-0236.1	showing the status and potential of WUDAPT		Urban Energy and water balance scheme (SUEWS), WRF models	Google Earth
(Ching et al., 2019) 10.1016/j.uclim.2019.100459	Kowloon (Hong Kong), Dublin (Ireland), Toulouse (France)	Satellite image, Elevation and population data, OSM data, LCZ map	Digital synthetic city tool for level 1, 2 data, UCP generation, Envi-met model,	Google Earth
(Collins & Dronova, 2019) 10.3390/rs11131615	Salt Lake Valley (USA)	Landsat 5, 8 images (1993, 2017), training areas	Object based Classification following WUDAPT PROCEDURE, accuracy assessment, Change detection	Google Earth, ArcGIS, Weka
(Colunga, Cambron-Sandoval, Suzan-Azpiri, Guevara-Escobar, & Luna-Soria, 2015) 10.20937/ATM.2015.28.03.05	Querétaro (Mexico)	Meteorological stations, databases of the SMN (CNA-SMN, 2014) for climate stations, Landsat 8 imagery, training areas	WUDAPT PROCEDURE, statistical analysis,	RClimDex software, ENVI 5
(Danylo, See, Bechtel, Schepaschenko, & Fritz, 2016)	Kyiv and Lviv (Ukraine)	4 Landsat 8 images, training areas, Globeland30 land cover , Open Street Map data	WUDAPT procedure, accuracy assessment/validations, comparisons	Google Earth, SAGA GIS, R

10.1109/JSTARS.2016.2539977				
(Daramola & Balogun, 2019) 10.1016/j.uclim.2019.100504	Akure (Nigeria)	Meteorological stations data, Landsat images	RS based LCZ, Surface Energy Balance Algorithm for Land (SEBAL) model	not mentioned
(Demuzere, Bechtel, & Mills, 2019) 10.1016/j.uclim.2018.11.001	Khartoum, Chicago, Mexico, Sao Paulo, and many others	Training areas from WUDAPT, Landsat 8 and Sentinel 1	LCZ on EE based on WUDAPT PROCEDURE, accuracy assessment, comparisons	Google Earth Engine, SAGA GIS
(Demuzere, Bechtel, Middel, & Mills, 2019) 10.1371/journal.pone.0214474	Various European cities	WUDAPT training areas, Sentinel 1 and Landsat 8 images, DEM	WUDAPT procedure up scaling using EE, accuracy assessment, continental scale LCZ map	Google Earth Engine
(dos Santos Cardoso & Amorim, 2018) 10.14198/INGEO2018.69.07	Presidente Prudente (Brazil)	Mobile measurements, Meteorological stations data, LCZ map	Thermal comparisons	Google Earth
(Droste et al., 2017) 10.1175/JTECH-D-16-0150.1	São Paulo (Brazil)	Meteorological stations data, data from smartphone battery, LCZ	Calibration and validation, Air temp modeling, Accuracy assessment	Google Earth

(Droste, Steeneveld, & Holtslag, 2018) 10.1088/1748-9326/aad8ef	Basel (Switzerland)	LCZ, Wind data	Mixed-layer model, Validation, Sensitivity analysis	not mentioned
(Emmanuel & Krüger, 2012) 10.1016/j.buildenv.2012.01.020	Glasgow (UK)	UK Met Office historical data Government data sources, Google Earth images and street camera views	Accuracy assessment, Statistical analysis	not mentioned
(Feng, Cai, & Chapman, 2019) 10.1002/qj.3619	Birmingham (UK)	MODIS data, LCZ map, Meteorological stations data	Statistical analysis	not mentioned
(Fenner, Meier, Bechtel, Otto, & Scherer, 2017) 10.1127/metz/2017/0861	Berlin (Germany)	Meteorological stations data, Landsat 8 images, training areas	WUDAPT procedure, statistical analysis, comparisons	Google Earth, SAGA GIS
(Ferreira & Duarte, 2019) 10.1016/j.uclim.2018.11.002	São Paulo metropolitan region (Brazil)	MODIS LST and NDVI EVI data, LCZ and LULC maps	Maps comparison, Statistical analysis	not mentioned
(Fonte, Lopes, See, & Bechtel, 2019) 10.1016/j.uclim.2019.100456	Hamburg (Germany)	Landsat 8, Open Street Map data, training areas	WUDAPT procedure, OSM integration, Accuracy assessment	Google Earth, SAGA GIS

(Franco, Andrade, Ynoue, & Ching, 2019) 10.1016/j.uclim.2018.12.007	Sao Paulo (Brazil)	LCZ map, Meteorological stations data	WRF-Chem model, comparisons, statistical analysis	R, ArcGIS
(Gál, Skarbit, & Unger, 2016) 10.15201/hungeobull.65.2.2	Szeged (Hungary),	Meteorological stations/Installed stations data	GIS based LCZ, comparisons	not mentioned
(Geletič & Lehnert, 2016) 10.1515/mgr-2016-0012	Czech Republic (Brno, Hradec Králové, Olomouc)	ZABAGED geodatabase, Open Street Map, LULC databases, Local land registry, Photogrammetric mapping, Landsat 8 (5 images), training areas	Statistical analysis, Accuracy assessment, Majority filter	ArcMap
(Geletic, Lehnert, & Dobrovolny, 2016) 10.3390/rs8100788	Prague and Brno (Czech Republic)	Landsat 8 and ASTER data	GIS based LCZ, split-window and multispectral algorithm for LST, comparisons, statistical analysis	not mentioned
(Geletič, Lehnert, & Dobrovolný, 2016) 10.15201/hungeobull.65.2.7	Brno (Czech Republic)	ZABAGED vector geo-database, photogrammetric data,Meteorological stations data	GIS based LCZ,MUKLIMO_3 model, statistical tests	not mentioned
(Geletic, Lehnert, Dobrovolny, &	Brno (Czech Republic)	Meteorological stations data	GIS based LCZ, MUKLIMO_3 for climate modeling,	not

Zuvela-Aloise, 2019) 10.1007/s10584-018-2353-5			comparisons	mentioned
(Geletic, Lehnert, Savic, & Milosevic, 2018) 10.1016/j.scitotenv.2017.12.076	Brno (Czech Republic)	Meteorological stations data, LCZ	MUKLIMO_3 model, human heat exposure maps, statistical analysis	not mentioned
(Geletic, Lehnert, Savic, & Milosevic, 2019) 10.1016/j.buildenv.2019.04.011	Prague, Brno (Czech Republic) and Novi Sad (Serbia)	Detailed data from the Statistical offices, Landsat 8 images	GIS based LST, statistical analysis, comparisons of LST and SUHI with LCZ	not mentioned
(Gholami & Beck, 2019) 10.5937/gp23-24238	Los Angelos, Mexico City, Lisbin, London and many other /25 cities all around the world	Training areas from WUDAPT, Landsat 8 Images	WUDAPT procedure, LST retrieval, statistical analysis	SAGA GIS
(Goncalves et al., 2018) 10.3390/cli6030070	Bragança (Portugal)	Meteorological stations data, LCZ	Statistical analysis, comparisons	ArcGIS,
(Hammerberg, Brousse, Martilli, & Mahdavi, 2018) 10.1002/joc.5447	Vienna (Austria)	Meteorological stations data, Landsat images, detailed GIS data, training areas	WUDAPT procedure, GIS based LCZ, comparisons, WRF model	Google Earth, SAGA GIS, QGIS

(He et al., 2018) 10.1177/1420326X18796545	Xi'an (China)	Field surveys, Aerial photos, Land cover and Land use maps, Satellite images (Google earth), Landsat 8 (3 images 2016), Government data sources, training areas	WUDAPT PROCEDURE, Accuracy assessment	SAGA-GIS, Google Earth, ArcGIS
(Herbel, Croitoru, Rus, Harpa, & Ciupertea, 2016) 10.15201/hungeobull.65.2.3	Cluj-Napoca (Romania)	Meteorological stations, mobile measurements	comparisons	not mentioned
(Hidalgo et al., 2019) 10.1016/j.uclim.2018.10.004	Toulouse, Paris and Nantes (France)	MApUCE datasets like topographic data cadastral parcels population data, (ESRI World Imagery) , training areas	WUDAPT PROCEDURE, Voronoi tessellation algorithm, Statistical analysis, Accuracy assessment,	GIS software mentioned
(Hu et al., 2019) 10.1109/JSTARS.2019.2926502	Nanjing (China)	Landsat 8, Gaofen-1 (GF-1), and three-dimensional (3-D) building data, Google Earth images , training areas	Random Forest algorithm for LCZ, accuracy assessment, LCZ and LST comparison	not mentioned
(Hu, Ghamisi, & Zhu, 2018) 10.3390/ijgi7090379	Melbourne, Sydney, Beijing, Nanjing and many others	Landsat 8 images, Sentinel-1 dual-Pol data, training areas	WUDAPT procedure, LCZ classification using canonical correlation forest (CCF), Statistical analysis, Accuracy	SAGA GIS Google Earth

			assessment	
(Jacobs et al., 2019) 10.1016/j.scitotenv.2019.04.087	Delhi, Dhaka (India), Faisalabad (Pakistan)	Landsat images, Traverse and Meteorological stations data, training areas	WUDAPT procedure	Google Earth
(Johnson & Jozdani, 2019) 10.3390/rs11202420	Generic	Nine physical parameters	Accuracy assessment, LCZ dissimilarity metric, Traditional error metric	not mentioned
(Khamchiangta & Dhakal, 2019) 10.1016/j.jenvman.2019.109285	Bangkok (Thailand)	Landsat images, Data from governmental departments, training areas	WUDAPT procedure, Statistical analysis, Accuracy assessment, LST derivation	Google Earth, ArcMap
(Koc, Osmond, Peters, & Irger, 2018) 10.1109/JSTARS.2018.2815004	Sydney (Australia)	LIDAR data	GIS based LCZ, statistical analysis	Relief Visualization Toolbox v16.0., ArcGIS
(Kotharkar & Bagade, 2018a) 10.1016/j.landurbplan.2017.08.009	Nagpur (India)	Meteorological stations data, field surveys, training areas	WUDAPT procedure, Buffer and outlier analysis, Statistical analysis	ArcGIS, MS Excel, Minitab,

				Hoboware and Holux GPS logger utility
(Kotharkar & Bagade, 2018b) 10.1016/j.uclim.2017.03.003	Nagpur (India)	Detailed urban data from Governmental departments, Landsat 7, Satellite images from Bhavun and Google Earth	GIS based LCZ, verification of LCZ map	ArcGIS, Google Earth Pro and AutoCAD
(Kotharkar, Bagade, & Agrawal, 2019) 10.5937/gp23-24251	Nagpur (India)	Meteorological stations data	Thermal discomfort Indices,Statistical analysis	not mentioned
(Kotharkar, Bagade, & Ramesh, 2019) 10.1016/j.landurbplan.2019.05.017	Nagpur (India)	Meteorological stations data, traverse survey	Regression/ statistical analysis, Quality assessment	R
(Kwok et al., 2019) 10.1002/joc.6140	Toulouse (France)	Government data sources, Meteorological stations	Statistical analysis, Meso Atmospheric Model (Meso-NH)	ArcGIS
(Lau, Chung, & Ren, 2019)	Hongkong (China)	Meteorological stations data, Questionnaire	WUDAPT procedure,	not

10.1016/j.buildenv.2019.03.005		survey, training areas	Statistical analysis, subjective perceptions	mentioned
(Leconte, Bouyer, Claverie, & Petrissans, 2015) 10.1016/j.buildenv.2014.05.005	Nancy (France)	Satellite image, detailed GIS data and DSM, mobile measurements data	LCZ based upon parameters, cold spots and hotspots, comparisons	SAGA GIS
(Leconte, Bouyer, Claverie, & Petrissans, 2017) 10.1007/s00704-016-1886-7	Nancy (France)	Mobile measurements, Meteorological stations data, DEM	LCZ based on parameters, cooling rate, comparisons	SAGA GIS
(Lehnert, Geletic, Husak, & Vysoudil, 2015) 10.1007/s00704-014-1309-6	Olomouc (Czech Republic)	Temperature and other measurements from the MESSO stations, CORINE Land Cover 2006 Czech Republic Database, satellite images	Different methods for LCZ, Accuracy assessment, GIS analysis	not mentioned
(LehnertA, Kubeček, Geletič, Jurek, & Frajer, 2018) 10.5937/gp22-19750	Olomouc(Czech Republic)	Mobile measurements, LCZ map	Statistical analysis, comparisons	not mentioned
(Lelovics et al., 2016),	Szeged (Hungary),	Data from online urban monitoring networks, Meteorological Stations data	Statistical analysis,	not

	Novi Sad (Serbia)	,aerial photographs	comparisons	mentioned
(Liu et al., 2018) 10.1016/j.buildenv.2018.07.019	Shenzhen (China)	Field survey Meteorological measurements and questionnaire	Fuzzy-AHP, Thermal comfort Indicator values, Statistical analysis	RayMan Pro
(Liu, Qi, Li, & Yeh, 2019) 10.3390/rs11060690	Guangzhou (China)	3 datasets, LCZ dataset, Sentinel 2A- optical image, Sentinel 1A SAR data	LULC Classification based on Machine learning algorithms, accuracy assessment	eCognition, Google Earth
(Lyu, Buccolieri, & Gao, 2019) 10.3390/atmos10080438	Nanjing (China)	Physical parameters datasets, Meteorological stations data, training areas	WUDAPT procedure, statistical analysis,	ENVI-met
(Mhedhbi, Masson, Hidalgo, & Haoues-Jouve, 2019) 10.1016/j.uclim.2019.100499	Greater Tunis (Tunisia)	Sentinel 2 data, training areas	WUDAPT procedure, questionnaire, validation with LCZ	SAGA GIS, Google Earth
(Middel, Hab, Brazel, Martin, & Guhathakurta, 2014) 10.1016/j.landurbplan.2013.11.004	North Desert Village Phoenix (USA)	Meteorological stations data, soil vegetation and buildings data, Bing maps	ENVI- met model, validation, statistical analysis	ArcGIS
(Middel, Lukasczyk, Maciejewski,	Phoenix, Las Vegas,	Google Street View imagery, (2015–2016-	WUDAPT PROCEDURE, Flood	SAGA GIS,

Demuzere, & Roth, 2018) 10.1016/j.uclim.2018.05.004	Dubai, and many others	2017 image data), Landsat 8 images, training areas, Sentinel 1 composite, training areas	fill algorithm, Sobel filter	Google Earth
(Milošević, Savić, Marković, Arsenović, & Šećerov, 2016) 10.15201/hungeobull.65.2.4	Novi Sad (Serbia)	LCZ map, aerial photographs,site stations	Rayman Model, comparisons	not mentioned
(Mirzaee, Ozgun, Ruth, & Binita, 2018) 10.1016/j.uclim.2018.08.012	Boston (US)	LCZ parameters ranges, Field survey, photographs	Simulation algorithm for Sky View factor, validation, statistical analysis, comparison with LCZ ranges	R, Adobe Photoshop CS5
(Molnar, Gyongyosi, & Gal, 2019) 10.1007/s00704-019-02881-1	Szeged (Hungary)	Meteorological stations data, Corine LULC data, aerial photographs, Google earth images, detailed data from governmental departments	WRF-SLUCM modeling	not mentioned
(Morris et al., 2015) 10.1016/j.scs.2015.04.010	Putrajaya (Malaysia)	LCZ, Meteorological stations data, in situ data, MODIS data	WRF model coupled to Noah LSM and UCM, statistical analysis	Google Earth

(Mouzourides, Eleftheriou, Kyprianou, Ching, & Neophytou, 2019) 10.1016/j.uclim.2019.100505	London (England)	Landsat 8 images, Corine land cover map, training areas	WUDAPT procedure, Accuracy assessment, Urban Canopy Parameter Values from LCZ and then Multi resolution analysis (MRA)	SAGA GIS, Google Earth
(Mughal et al., 2019) 10.1029/2018JD029796	Singapore (Malaysia)	Landsat 8 images, detailed data from governmental departments, Meteorological stations data, training areas	WUDAPT procedure, WRF/MLUCM model Multilayer Urban Canopy Model, Statistical analysis	Google Earth, SAGA GIS
(Muller et al., 2014) 10.1007/s00704-013-0890-4	city of Oberhausen (Germany)	Meteorological stations data, digital ortho photos	ENVI- met model, physiologically equivalent temperature, model evaluation	RayMan Pro version 2.1
(Mushore et al., 2019) 10.1016/j.uclim.2018.12.006	Harare (Zimbabwe)	Landsat 8, Meteorological stations data, field survey, training areas	classification by WUDAPT procedure and SVM, accuracy assessment, LST retrieval and distribution	Google Earth, ENVI, SAGA GIS
(Nassar, Blackburn, & Whyatt, 2016)	Dubai (UAE)	Detailed GIS data, Landsat 8 and MODIS	LCZ based upon parameters,	not

10.1016/j.jag.2016.05.004		data	LST determination, statistical analysis	mentioned
(Nurwanda & Honjo, 2018) 10.3390/ijgi7050165	Bogor (Indonesia)	Landsat 5 and 8 images, training areas	Maximum Likelihood classification algorithm for LCZ, accuracy assessment, LST derivation, statistical analysis	QGIS, Google Earth
(Oxoli et al., 2018) 10.3390/ijgi7110421	Milan (Italy)	Landsat 8, sentinel-2, Rapid Eye, detailed vector data, training areas	LCZ in QGIS, Accuracy assessment, Statistical analysis	QGIS
(Pacifici, Rama, & Marins, 2019) 10.1016/j.uclim.2018.11.003	São Paulo (Brazil)	LCZ map, Meteorological stations data	Comparisons, Temporal analysis	not mentioned
(Perera & Emmanuel, 2018) 10.1016/j.uclim.2016.11.006	Colombo (Srilanka)	Field surveys, Google Earth, LCZ data sheets, Photogrammetric data, training areas	WUDAPT PROCEDURE, sub-classification	Google Earth, SAGA GIS
(Pokhrel, Ramirez-Beltran, & Gonzalez, 2019)	San Juan Metropolitan Area	Meteorological stations data, Landsat 8 images, urban parameters, training areas	WUDAPT procedure, WRF model, validation,	MATLAB, SAGA GIS,

10.1016/j.enbuild.2018.10.023	(SJMA) of Puerto Rico		comparisons	Google Earth, ArcGIS
(Pour, Mirijovsky, & Purket, 2019) 10.1080/22797254.2018.1564888	Olomouc (Czech Republic)	Meteorological stations data, ground and air-borne data	Image processing and validation, LCZ for evaluation, Comparisons	INPHO
(Qiu, Mou, Schmitt, & Zhu, 2019) 10.1016/j.isprsjprs.2019.05.004	Paris, Amsterdam, Cologne, Munich, Milan, London, and Berlin.	Sentinel 2 images, LCZ maps	Novel recurrent residual network architecture, called Re-ResNet used, Statistical analysis, Accuracy assessment, Land cover classification	Google Earth
(Qiu, Schmitt, Mou, Ghamisi, & Zhu, 2018) 10.3390/rs10101572	Amsterdam, Berlin, Cologne, London, Milan, Munich, Paris, Rome, Zurich	Sentinel 2 and Landsat 8 images, data from OSM and Google Earth Engine, training areas	LCZ from ResNet classifier, accuracy assessment, comparisons, Majority voting	not mentioned
(Quan, 2019a)	Beijing (China)	Detailed GIS data from governmental sources, WUDAPT based LCZ map, Landsat 8	GIS based LCZ	not mentioned

10.1007/s11431-018-9417-6		images, Global land cover map, industries list, field surveys, Google Earth images		
(Quan, 2019b) 10.3390/ijerph16122140	Beijing (China)	City street map, Landsat 8, land cover map, MODIS	GIS based LCZ, LST fusion, Statistical analysis	not mentioned
(Quanz, Ulrich, Fenner, Holtmann, & Eimermacher, 2018) 10.3390/cli6010005	Berlin (Germany)	Building and vegetation digital surface models, Aerial photographs, Meteorological stations data	LCZ based upon parameters, comparisons, Statistical analysis	SOLWEIG 2015a
(R. Emmanuel & Loconsole, 2015) 10.1016/j.landurbplan.2015.02.012	Glasgow Clyde Valley Region, (UK)	Detailed GIS, climate and land cover data from governmental departments, LiDAR data, field survey	LCZ based upon parameters, ENVI-met model, Predicted Mean Vote for perception, comparisons	ArcGIS, Google Earth,
(Ren et al., 2019) 10.1038/s41598-019-55444-9	20 cities of China	Landsat 8 level 1 images from 2014 to 2015, sentinel 1 for DEM, training areas	WUDAPT procedure, Accuracy assessment (confusion matrix), TCPInSAR processor(DEM accuracy)	SAGA GIS, Google Earth
(Richard et al., 2018)	Dijon (France)	Meteorological stations data, Landsat 8 images, detailed vector data, data from CLC	WDAPT procedure, urban climate zone maps, WRF	Google Earth, SAGA

10.1016/j.uclim.2018.10.002		database, training areas	model and validation, Statistical analysis,	GIS, QGIS
(Rodler & Leduc, 2019) 10.1016/j.uclim.2019.100457	Brooklyn (USA), Nantes (France),	Detailed GIS data from governmental sources, Topographic data from IGN	parameters determination, LCZ match making, statistical analysis	not mentioned
(Savić et al., 2013) 10.5937/geopan1303060s	Novi Sad (Serbia)	Field surveys, satellite images, topographic maps, aerial photographs	Installation of Meteorological stations based upon LCZ,	Google Earth
(Savic et al., 2018) 10.1007/s11069-017-3160-4	Novi Sad (Serbia)	Meteorological stations data, Satellite image, aerial photographs, detailed urban data, LULC and topographic maps	SEERISK methodology for risk assessment, Lelovics-Gál methodology for LCZ, analysis and risk maps	not mentioned
(Secerov et al., 2019) 10.1007/s10661-019-7210-0	Novi Sad (Serbia)	Meteorological stations data, LCZ map	Statistical analysis	MySQL
(Šećerov, Savić, Milošević, Marković, & Bajšanski, 2015) 10.5937/GeoPan1504174S	Novi Sad (Serbia)	Detailed urban data, Corine Land cover maps Photographs, satellite images, topographis maps	installation of the monitoring network,GIS based LCZ, Online Portal for climate data	MySQL, Java software
(Shi et al., 2019)	Hongkong (China)	Meteorological Stations data	Building energy estimation	DeST,

10.1016/j.energy.2019.116208			model	AutoCAD
(Shi, Lau, Ren, & Ng, 2018) 10.1016/j.uclim.2018.07.001	Hong Kong (China)	Land use, Landsat 8, Mobile measurement platform, training areas	WUDAPT PROCEDURE, Statistical analysis	SAGA GIS, Google Earth
(Shi, Ren, Lau, & Ng, 2019) 10.1016/j.landurbplan.2019.04.004	Hong Kong (China)	Meteorological stations data, mobile measurements, LCZ map, USGS LULC classification	Landscape matrices, statistical analysis	not mentioned
(Shi, Xiang, & Zhang, 2019) 10.3390/s19163459	Guangzhou (China)	Landsat 8 images, training areas	WUDAPT procedure, LST and urban design factors retrieval, statistical analysis	Google Earth, SAGA GIS
(Simanjuntak, Kuffer, & Reckien, 2019) 10.1016/j.apgeog.2019.04.001	Bandung (Indonesia)	Landsat 8, Spot-6, Pleiades images, data from governmental departments, OSM data, training areas	WUDAPT procedure and Object based classification, accuracy assessment, comparison, statistical analysis	Google Earth, R, e-Cognition

(Siu & Hart, 2013) 10.1007/s10661-012-2876-6	Hong Kong (China)	Meteorological stations data, field surveys, photographs	classifying weather stations using LCZ, comparisons	not mentioned
(Skarbit & Gál, 2016) 10.15201/hungeobull.65.2.8	Szeged (Hungary)	Satellite images, training areas, EURO-CORDEX datasets, Meteorological stations data	WUDAPT procedure,MUKLIMO_3 model, comparisons	Google Earth, SAGA GIS
(Skarbit, Stewart, Unger, & Gal, 2017) 10.1002/joc.5023	Szeged (Hungary)	Detailed GIS data, Rapid Eye image, CORINE land cover database	GIS based LCZ, temperature-based indices, comparisons	not mentioned
(Smoliak, Snyder, Twine, Mykleby, & Hertel, 2015) 10.1175/JAMC-D-14-0239.1	Minneapolis–St. Paul, Minnesota (USA)	Meteorological stations data, LCZ	Spatial Interpolation, validation	not mentioned
(Stewart & Oke, 2012) 10.1175/BAMS-D-11-00019.1	Vancouver, Uppsala, , Toronto and many others	Mobile measurements, Literature data	Thermal source, Parametric properties, LCZ	not mentioned
(Stewart, 2013) 10.1002/ad.1625	Toronto, London, São Paulo, Onitsha	Photographs, Field measurements	Parametric properties, UCZ to LCZ	not mentioned
(Stewart, Oke, & Krayenhoff, 2014)	Nagano (Japan),	Google Earth images, Heat Island reports,	TEB (urban Model), OSU-	not

10.1002/joc.3746	Vancouver (Canada) and Uppsala (Sweden)	Meteorological stations, Historical maps and photographs, Field surveys	CAPS (soil-vegetation model)	mentioned
(Theeuwes, Steeneveld, Ronda, Rotach, & Holtslag, 2015) 10.1088/1748-9326/10/11/114022	Basel (Switzerland)	Meteorological stations data, LCZ	mixed-layer model, validation, sensitivity analysis	not mentioned
(Tse et al., 2018) 10.1016/j.uclim.2018.08.007	Pearl River Delta (China)	Land use products by WUDAPT (Landsat 5), Meteorological Stations, training areas	WUDAPT procedure, Weather Research and Model (WRF), The Noah Land Surface Model (Noah-LSM), Accuracy assessment	not mentioned
(Tse et al., 2018) 10.1016/j.uclim.2017.05.010	Yangtze River Delta (China)	Landsat 8 (10 images) (2013-2014-2015), Night-time Aster (2) (2015, Meteorological stations data, training areas	WUDAPT procedure, Accuracy assessment	ArcGIS, SAGA GIS, Google Earth
(Unger, Gál, Csépe, Lelovics, & Gulyás, 2015)	Szeged (Hungary)	Meteorological stations and monitoring network data, LCZ map	Human comfort monitoring network,Development of Information System	WEKA, MySQL, Java software
(Unger, Lelovics, & Gál, 2014)	Szeged (Hungary)	aerial photographs,Rapid Eye satellite image, topographic map, Corine Land cover	GIS based LCZ	QGIS

10.15201/hungeobull.63.1.3		dataset, detailed urban data		
(Unger, Skarbit, & Gal, 2018) 10.1007/s00484-017-1440-z	Szeged (Hungary)	Meteorological stations data, LCZ map	Physiologically equivalent temperature for thermal sensation, Evaluation of thermal sensation	RayMan
(Vandamme, Demuzere, Verdonck, Zhang, & Van Coillie, 2019) 10.3390/rs11141731	Kunming (China)	Landsat 7, 8 images (2005, 2011, 2017), training areas	WUDAPT procedure, accuracy assessment, comparisons	SAGA GIS, Google Earth
(Verdonck et al., 2017) 10.1016/j.jag.2017.05.017	Antwerp, Brussels and Ghent (Belgium)	Landsat 8 images, training areas	WUDAPT PROCEDURE improved Procedure, quantitative assessment, comparisons	EnMAP-Box, Google Earth, SAGA GIS
(Verdonck et al., 2018) 10.1016/j.landurbplan.2018.06.004	Antwerp, Brussels, and Ghent (Belgium)	European Centre for Medium-Range Weather Forecasts (ECMWF), CORINE land cover data for Europe (EEA, 1994), Imperviousness Degree (IMD) data set of the EEA, global GMTED 2010 Dataset, training areas	WUDAPT PROCEDURE, Statistical analysis, Urbanclim model, Thermal stress analysis	not mentioned

(Verdonck, Demuzere, Hooyberghs, Priem, & Van Coillie, 2019) 10.1016/j.jenvman.2019.06.111	Brussels (Belgium)	Census data, Meteorological stations data	UrbanClim Model, hazard Maps	not mentioned
(Villadiego & Velay-Dabat, 2014b) 10.1016/j.buildenv.2014.01.017	Barranquilla (Colombia)	Government data sources, Satellites images from Google Earth and Bing maps, Field survey, Meteorological stations data, training areas	WUDAPT PROCEDURE, statistical analysis	Quantum GIS
(Wang et al., 2018) 10.1016/j.isprsjprs.2018.04.009	Phoenix, Arizona and Las Vegas, Nevada (USA)	Landsat 8 images, ASTER, Google street view, OrbView 5, NAIP, training areas	WDAPT procedure, accuracy assessment, LULC classification, evaluation	Google Earth, SAGA GIA
(Wang et al., 2018) 10.1016/j.uclim.2017.10.001	Hong Kong (China)	Landsat 5 2 images, Building data, Land use data (vector form) from land and survey department, Boundary shapefile from planning department, training areas	WUDAPT PROCEDURE, Accuracy assessment	ArcGIS, SAGA GIS, Google Earth
(Wang et al., 2019) 10.1016/j.uclim.2019.100455	Pearl River Delta (China)	Landsat 5, 8 images (1999, 2009,2014) MODIS LST, training areas	WUDAPT procedure, accuracy assessment, change detection and analysis	Google Earth, SAGA GIS

(Wang, Xing, Huang, & Xie, 2016) 10.15244/pjoes/63672	Chongqing (China)	Mobile measurements, site photographs	LCZ based upon parameters, comparisons	Not mentioned
(Wang, Zhan, & Ouyang, 2017) 10.3390/su9101700	Wuhan (China)	Landsat 8 (4 images), Land Surface Temperature , training areas	WUDAPT PROCEDURE, Majority filter, Statistical analysis	Google Earth, SAGA GIS, ENVI 5.2 SPI
(Wicki & Parlow, 2017) 10.1117/1.JRS.11.026001	Basel (Switzerland)	Landsat 8 images, detailed GIS data from governmental departments	LULC classification using Maximum Likelihood algorithm, Morphological parameters determination, relation and accuracy assessment	QGIS
(Wong et al., 2019) 10.1016/j.uclim.2019.100460	Hong Kong (China)	WUDAPT, NUDAPT data	Evaluation of uWRF, Comparisons	GIS software
(Xu, Ren, Cai, Edward, & Wu, 2017) 10.1109/JSTARS.2017.2683484	Guangzhou and Wuhan (China)	Landsat 8 and ASTER data, training areas	Improved WUDAPT procedure, 3 classification algorithms, Accuracy	Google Earth, ENVI

			assessment	
(Xu, Zhu, Tapper, & Bechtel, 2019) 10.1177/0309133319837711	Paris, Hong Kong, San Paulo, Rome	Google street view images, WUDAPT data	LCZ by using logistical regression model, accuracy assessment, comparisons	not mentioned
(Yang et al., 2018) 10.1016/j.buildenv.2018.04.009	Nanjing (China)	Meteorological stations data, Land use map, satellite image, photographs	LCZ site selection, ENVI-met model, Comparisons	Google Earth
(Yang et al., 2019) 10.1016/j.enbuild.2019.04.001	Nanjing (China)	Field measurements, Meteorological stations data, LCZ map	Diagnostic equation, Evaluation, comparisons	not mentioned
(Yang et al., 2019) 10.1016/j.scs.2019.101487	Shanghai (China)	Landsat 8, Classified Land use, Building information, Meteorological stations	Single window algorithm, Statistical analysis	ArcGIS
(Yoo, Han, Im, & Bechtel, 2019) 10.1016/j.isprsjprs.2019.09.009	Rome (Italy), Hong Kong (China), Madrid (Spain), and Chicago (US)	Landsat 8 images, reference data from IEEE GRSS data fusion	Random Forest algorithm 3 schemes, Convolutional neural networks (CNN) classifier 2 schemes, accuracy assessment	R
(Yue, Zhan, Wang, & Xiao, 2017)	Wuhan (China)	Landsat 7, MODIS LST, detailed urban planning data	LCZ based upon parameters, comparisons	not mentioned

10.2495/SDP-V12-N8-1312-1325				
(Yunwei Zhang et al., 2018) 10.1177/1420326X18804103	Xi’an (China)	Stationary reference station (SRS), portable/mobile stations (PMSs), training areas	WUDAPT PROCEDURE, Statistical analysis	not mentioned
(Zhao et al., 2019) 10.1016/j.compenvurbsys.2018.11.002	Dallas-Fort Worth (DFW), Austin, and San Antonio, Texas (US)	Lidar data, Statistical data, land cover and planning data from government departments	GIS based LCZ, comparative analysis and validation	ArcGIS, Google Earth, ERDAS
(Zhao, Ma, Zhong, Zhao, & Cao, 2019) 10.3390/rs11232828	Berlin (Germany), Sao Paulo (Brazil), Paris (France)	Landsat 8 images, training areas	Conditional random fields-based classification, accuracy assessment	SAGA GIS, Google Earth
(Zheng et al., 2018) 10.1016/j.uclim.2017.05.008	Hong Kong (China)	Satellite images, detailed vector data from the planning departments, Topology and Land use data	GIS Analysis, GIS based LCZ, Statistical analysis	ArcGIS, SAGA GIS
(Ziaul & Pal, 2018) 10.1016/j.uclim.2018.01.006	Malda (India)	Government data sources, Landsat 5(2004), Landsat 8(2016), Field surveys, training areas	WUDAPT PROCEDURE, Accuracy assessment, Statistical analysis	ArcGIS, SAGA GIS, Google

				Earth
(Rajab, 2018) 10.3923/jeasci.2018.350.352	Sydney (Australia)	airborne remote sensing data, LiDAR data and cadastral information	GIS Based LCZ	not mentioned

Conference papers reviewed

Author and Year	Study Area	Data sources	Methodology	Software
(Bechtel et al., 2012)	Hamburg (Germany)	mobile measurements, DTM, DSM, NEXTMap, Landsat images, Metrological stations data	Six supervised classifiers for LCZ, accuracy assessment, Empirical UHI models for spatiotemporal modeling	SAGA GIS, PostgreSQL, WEKA
(Bechtel et al., 2016)	Sao Paulo (Brazil), Beijing, Hongkong (China), Chicago (USA),Lisboa(Portugal), Khartoum (Sudan), Madrid (Spain) , Milano (Italy)	LCZ maps and GHSL products	comparisons, accuracy assessment	not mentioned
(Bechtel et al., 2017)	Multiple cities	Landsat 8 images, training areas, ASTER , SRTM data	Different approaches for LCZ, quality assessment, cross comparisons	SAGA GIS, Google Earth, Google Earth Engine
(Budhiraja, Pathak, & Agrawal, 2017)	Delhi (India)	Landsat 8 images, training areas	WUDAPT procedure, radiative transfer equation-based method for LST, Zonal statistics, comparisons	SAGA GIS, Google Earth
(Cai, Ren, & Xu, 2017)	Shanghai(China)	Aster and Landsat 8 images, training areas	WUDAPT procedure, accuracy assessment, Single Channel Algorithm for LST, comparisons	SAGA GIS, ArcGIS, Google Earth

(Cai, Ren, Xu, Dai, & Wang, 2016)	Guangzhou (China)	Landsat 8 images, training areas,	WUDAPT procedure, Improved WUDAPT procedure, accuracy assessment, comparisons	Google Earth, SAGA GIS
(Chen, Lin, & Shih, 2017)	Taipei (Taiwan)	Landsat 8 images, training areas	WUDAPT procedure, LST determination, comparisons	SAGA GIS, Google Earth, QGIS
(Chunping Qiu, Schmitt, & Zhu, 2019)	Amsterdam (Netherlands),London (England), Berlin , Cologne, Munich (Germany), Paris (France) and Milan (Italy)	Sentinel-2 imagery, Field survey,	ResNet classifier, sentinel imagery fusion, accuracy assessment	Google Earth, Google Earth Engine
(Chunping Qiu, Schmitt, Ghamisi, Mou, & Zhu, 2018)	Amsterdam (Netherlands),London (England), Berlin , Cologne, Munich (Germany), Paris (France) and Milan (Italy)	Sentinel-2 imagery, Open Street Map data, TanDEM-X data, Google street view	residual convolutional neural network (ResNet) classifier, cross validation	Google Earth
(Chunping, Schmitt, Lichao, & Xiaoxiang, 2018)	Amsterdam (Netherlands),London (England), Berlin , Cologne, Munich (Germany), Paris (France) and Milan (Italy)	Sentinel-2 images	ResNet classifier, accuracy assessment, comparisons	not mentioned
(CP Qiu, Schmitt, Ghamisi, & Zhu, 2018)	Amsterdam (Netherlands),London (England), Berlin , Cologne, Munich (Germany), Paris	Sentinel-2 imagery, Open Street Map data, TanDEM-X data	Canonical Correlation Forest classifier, accuracy assessment, majority voting for improvement	not mentioned

	(France) and Milan (Italy)			
(dos Anjos, Lacerda, do Livramento Andrade, & Salles, 2017)	Chicago (US), Amsterdam (Netherlands), X'ian (China), Madrid (Spain)	Landsat 8, sentinel-2, Google street view	Multiresolution segmentation algorithm, Random forest classifier, accuracy assessment	eCognition 8.7, WEKA 3.7 , QGIS, Google Earth
(Dung, Jacobs, Motoasca, Versele, & Breesch, 2019)	Ha Tinh (Viet Nam)	Field survey, LCZ photographs	modified adaptive model, psychometric analysis	not mentioned
(Estacio et al., 2019)	Quezon City (Philippines)	Detailed urban data, DSM, DTM, Landsat image	GIS based LCZ, cross validation and evaluation	Google Earth, ArcGIS, SAGA GIS
(FERREIRA & DUARTE, 2018)	Sao Paulo (Brazil)	Landsat 7 and 8 images, IKONOS images, Google historic imagery	WUDAPT procedure, change detection	QGIS, Google Earth
(Ferreira, Shimomura, Ferreira, & Duarte, 2017)	Sao Paulo (Brazil)	Landsat 8 images, training areas, EMPLASA LULC map, QUAPA maps	WUDAPT procedure, accuracy assessment, comparisons	Google Earth, SAGA GIS, QGIS 2.18
(Geletic, Dobrovolný, & Lehnert, 2017)	Brno and Prague (Czech Republic)	Landsat 8 and Aster images,	GIS based LCZ, split window and multispectral algorithm for LST, statistical analysis,	not mentioned
(Gupta, Pushplata, Nekkla, Kumar, & Kumar)	Chandigarh (India)	Landsat 5 and 8 images, training areas	WUDAPT procedure, Split and single window algorithm for LST, comparisons	SAGA GIS, Google Earth
(He, Zhang, & Zhang, 2018)	Xi'an (China)	Landsat 8 images, training areas	classification standard, WUDAPT procedure, LCZ map with land parcels	SAGA GIS, Google Earth
(J. Quan, 2019)	Beijing (China)	Landsat, MODIS	GIS based LCZ, spatiotemporal fusion model , statistical analysis	not mentioned

(Jing et al., 2019)	Generic	Sentinel-1, Sentinel-2 imagery	training data preprocessing, ResNeXt model for LCZ, accuracy assessment	not mentioned
(Koc, Osmond, Peters, & Irger, 2017)	Sydney (Australia)	cadastral data, hyper spectral and lidar data	Automated LCZ classification	ATCOR 4, PARGE, ENVI 5.3, LP360, ArcGIS, Relief Visualization Toolbox v16.0,Feature Analyst
(Lopes, Fonte, See, & Bechtel, 2017)	Coimbra (Portugal)	OSM data, Landsat 8 images, WUDAPT LCZ map	Improved methodology using OSM data, adaptive buffering, spatial analysis	not mentioned
(Mitraka et al., 2015)	Chicago (US), Amsterdam (Netherlands), X'ian (China), Madrid (Spain)	Sentinel-1 data, Open Street Map data, Landsat 8 imagery, Training data, GRSSDASE website data	Conical correlation forest for LCZ, accuracy assessment,	not mentioned
(Mitraka, Del Frate, Chrysoulakis, & Gastellu-Etchegorry, 2015)	Heraklion (Greece)	Landsat 8 images, DSM, DTM, urban data from governmental departments, Google street view, Bing Images	LCZ based upon parameters	Google Earth
(Mu, Liu, Zhang, Han, & Yang, 2019)	Xi'an (China)	Landsat 8 images, detailed urban data,	GIS and RS based LCZ, statistical analysis	Google Earth, ENVI 5.3, Gis 10.2
(Mushore, 2019)	Harare (Zimbabwe)	Landsat 8 images, training areas	WUDAPT procedure, SVM classifier, accuracy assessment, comparisons	SAGA GIS, Google Earth
(N Kaloustian, Tamminga, & Bechtel, 2017)	Beirut (Lebanon), Damascus (Syria)	Landsat 8, sentinel-1, sentinel 2 images, training areas, MODIS LST	WUDAPT procedure using different inputs, training areas transferability, accuracy assessment,	Google Earth, SAGA GIS

			comparisons	
(Noushig Kaloustian & Bechtel, 2016)	Beirut (Lebanon)	Landsat 8 and sentinel-2 data, training areas	WUDAPT procedure, accuracy assessment, comparisons	Google Earth, SAGA GIS
(Nurwanda & Honjo, 2018)	Bogor (Indonesia)	Landsat 5 and 8 images,	LCZ using Maximum Likelihood classification, accuracy assessment, statistical analysis, comparisons	QGIS
(Perera & Emmanuel)	Colombo (Srilanka)	LCZ map, data from installed stations	ENVI-met model, comparisons	SPSS
(Pradhesta, Nurjani, & Arijuddin, 2019)	Yogyakarta (Indonesia)	Landsat 8 images, training areas	WUDAPT procedure, accuracy assessment, comparisons	Google Earth, SAGA GIS
(Prata Shimomura & Ferreira, 2018)	Sao Paulo (Brazil)	Landsat 8 images, training areas, MODIS LST product	WUDAPTT procedure, accuracy assessment, comparisons	SAGA GIS, Google Earth, ArcGIS 10.1
(Ribeiro, Martilli, Falls, Zonato, & Villalba)	Barcelona (Spain)	Corine land cover, Metrological stations data, Landsat 8 images, training areas	WUDPAT procedure, WRF model, statistical analysis	Google Earth
(S. J. Quan, Dutt, Woodworth, Yamagata, & Yang, 2017)	Manhattan (USA), Atlanta (Georgia) and Tokyo (Japan)	detailed urban data, land use and land cover data, Landsat 8 images	LCZ classification using level 2 data	not mentioned
(Semenova, Konstantinov, Varentsov, & Samsonov, 2019)	Naryan-Mar, Arkhangelsk, Nadym, Salehard, Kandalaksha, Murmansk, Anadyr(Russia)	Landsat 7 images, training areas, detailed urban data, Metrological stations data	WUDAPT procedure, Rayman Model, comparisons	QGIS, Google Earth, SAGA GIS
(Sharifi, Wu, Khamchiangta, Yoshida, & Yamagata, 2018)	Tokyo (Japan) , Bangkok (Thailand)	LCZ maps, detailed urban data, Landsat images	classifying LEZ	not mentioned

(Sharma, Hooyberghs, Lauwaet, & De Ridder, 2016)	Delhi (India)	Landsat 8 images, MODIS NDVI and LST, SRTM data, European Centre for Medium-range Weather Forecasts ERA-Interim data	WUDAPT procedure, UrbClim Model, statistical analysis	SAGA GIS
(Shih, 2017)	Taipei (Taiwan)	Landsat 8 images, training areas	WUDAPT procedure, LST determination, statistical analysis, comparisons	QGIS, Google Earth, SAGA GIS
(Skarbit, Gal, & Unger, 2015)	Szeged (Hungary)	Metrological stations data, Small format Aerial photography data,	GIS based LCZ, comparisons	not mentioned
(Sukhanov et al., 2017)	Amsterdam, Chicago, Madrid, Xi'An	Landsat 8 and Sentinel-2 images, Open Street Map data, training data	Convolutional Neural Networks , Random forest and Gradient boosting Machines for LCZ classification, accuracy assessment	not mentioned
(Thomas, Sherin, Ansar, & Zachariah, 2014)	Kochi (India)	Data from installed stations, Mobile measurements, Google Images, Field survey	LCZ based upon parameters, comparisons	not mentioned
(Tim Sinsel et al., 2018)	Sao Paulo (Brazil)	Open Street Map data, WUDAPT data	Standard and site specific LCZ tiles for simulation, accuracy assessment	ENVI-met
(Tuia, Moser, Wurm, & Taubenböck, 2017)	NorthRhine-Westfalia (Germany),	OSM data, Rapid Eye, stereo images, land cover maps	LCZ via a Markov random field, accuracy assessment	not mentioned
(Verdonck et al., 2017)	Brussels, Antwerp and Ghent (Belgium)	LCZ map, data from installed stations	UrbClim model, comparisons	not mentioned
(Verdonck, Demuzere, Hooyberghs, Priem, & Van Coillie, 2019)	Brussels (Belgium)	LCZ map	LCZ map translation using statistical sectors, Heat risk maps	not mentioned
(Wang, Dong, Xu, & Tong, 2018)	Shanghai, Nanjing, and Hefei (China)	Landsat 8 images, training data,	WUDAPT procedure, Index of Distribution, statistical analysis	Google Earth, SAGA GIS

(Wei & Blaschke, 2016)	Guangzhou (China)	HJ-1B imagery, AVHRR data	LCZ using Self organizing Map algorithm, validation, statistical analysis	ENVI
(Wu et al., 2018)	Shanghai (China)	detailed urban data, Landsat images, Open Street Map data	Building use classification using random forest, LCZ classification using level 2 data, comparisons	SAGA GIS
(Xiang & Ren, 2017)	Beijing (China)	LCZ map	ENVI-met model, BioMet tool, comparisons	ENVI-met
(Xu, Ma, Meng, Ren, & Leung, 2017)	Chicago (US), Amsterdam (Netherlands), X'ian (China), Madrid (Spain)	OSM data, training data provided by GRSS, Landsat 8 and sentinel-2 images	Improved methodology for LCZ (SVM, MLP and XGboost classifiers), accuracy assessment	not mentioned
(Xu, Ren, Cai, & Wang, 2017)	Guangzhou (China)	Landsat 8 images, training areas, Baidu 3D street map	WUDAPT procedure, accuracy assessment	Google Earth
(Yang, Jin, Yao, Zhu, & Peng, 2017)	Nanjing (China)	Field surveys, Metrological and installed stations data, satellite images, indicators calculation, aerial photographs	building models, comparisons	EnergyPlus
(Yang, Yao, Zhu, Jin, & Peng, 2017)	Nanjing (China)	Google Earth and satellite images, field surveys, LCZ photographs	comparisons	Google Earth, ENVI-met
(Yao et al., 2017)	Nanjing (China)	satellite images, aerial photographs, urban indicators, Metrological and installed stations data	comparisons, accuracy assessment	ENVI-met, ArcGIS
(Zhao, 2018)	San Antonio , Texas (U.S)	Lidar data, detailed urban data , NLCD data, Landsat 8 images	GIS based LCZ, Plank function for LST, statistical analysis	Google Earth
(Zhongli & Hanqiu, 2016)	Fuzhou (China)	Landsat 8 images, training areas	Improved methodology for LCZ(hierarchical classification), accuracy assessment, single window algorithm for LST	Google Earth

Annexure 2 Research Questionnaire

Sr. No: _______________ Area Code: _______________

This study is being conducted in National University of Science and Technology (NUST) Islamabad. The survey will take only 5-10 minutes .All the data collected during the survey will be kept confidential and will only be used for the purpose of this study.

- Age: ___________ Gender: ___________ (Male=0, female =1) Income: ___________
- Education: ___________ (in years) Household size: __________ House Ownership: ____________
- No. of Children: ___________ No. of elderly: ___________
- Type of occupation? Self-employed ☐ Service ☐ Student ☐ At home ☐
- Do you have any past experience of heat waves or floods? Yes ☐ No ☐
- Do you have access to the following?
- Radio? Yes ☐ No ☐ Newspaper? Yes ☐ No ☐ TV? Yes ☐ No ☐ Internet? Yes ☐ No ☐
- According to you what are the causes of climate change? ________________________________

Please answer the below questions from the scale of 1-5.

1. Very low **2. Low** **3. Neutral** **4. High** **5. Very high.**

Sr. No	**Questions**	**1**	**2**	**3**	**4**	**5**
1.	How much are you afraid of the changing climate?					
2.	How much do you think that your quality of life will be affected from the climate change?					
3.	How much do you feel that the changing climate is due to the human activities?					
4.	How much do you think that the severity of climate related hazards will increase in future?					
5.	How much do you think you can deal with the consequences of changing climate?					

6.	How much do you think you can adopt well from the known adaptation measures to deal with the changing climate?					
7.	How much are you concerned about the climate change?					
8.	How much this issue of climate change is important to you personally?					
9.	How much do you think that the disasters related to climate change can be reduced?					
10	How much do you trust the information you receive linked to climate change from different sources?					
11	How much do you trust the ministry of climate change measures to combat with climate change?					
12	How much do you trust the disaster management authority capability to deal with the hazards caused by the climate change?					
13	How much do you think that the climate change will affect/harm you and your family?					
14	How much do you think that the climate change will affect/harm people in your community?					
15	How much do you think that the climate change will affect/ harm people in Pakistan?					
16	How much do you think that the climate change will affect/harm people all around the world?					
17	How much do you think that the climate change will affect/harm people of the developing countries?					
18	How much do you think that the climate change will affect/harm people like you?					
19	How much do you think that the climate change will affect/harm future generations?					

Mark on the scale of 1 to 5.

1. **Don't know** **2. Never** **3. In the next 100 years** **4. In the next 10 years** **5. Is Already Experiencing**

Sr. No.	Question	1	2	3	4	5
20.	When according to you Pakistan will start feeling the effect of climate change?					

How much do you agree with the given statements? Mark on the scale of 1 to 5.

2. **Strongly Disagree** **2. Disagree** **3. Neutral** **4. Agree** **5. Strongly Agree**

Sr. No.	Statements	1	2	3	4	5
21.	I am uncertain that climate change is happening					
22.	The seriousness of climate change is often exaggerated					
23.	Most scientists agree that humans are causing climate change					

If any comments or Suggestions you'd like to add: