DOI:10.52131/pjhss.2023.1103.0600

Pakistan Journal of Humanities and Social Sciences

Volume 11, Number 03, 2023, Pages 3117-3130
Journal Homepage:
https://journals.internationalrasd.org/index.php/pjhss

PAKISTAN JOURNAL OF HUMANITIES AND SOCIAL SCIENCES (PJHSS)
INTERNATIONAL RESEARCH ASSOCIATION FOR SUSTAINABLE DEVELOPMENT

Spatio-Temporal Analysis of Lahore's Resilience Against Heat Wave by Using Remote Sensing and GIS

Syed Javed Hussain Shah[1], Isma Younes[2]

[1] Ph. D Scholar, Department of Geography, University of The Punjab, Lahore, Pakistan.
Email: javedhussainnaqvi211@gmail.com
[2] Professor, Department of Geography, University of The Punjab, Lahore, Pakistan.

ARTICLE INFO

Article History:
Received: July 12, 2023
Revised: September 07, 2023
Accepted: September 08, 2023
Available Online: September 09, 2023

Keywords:
Urbanization
Resilience
Sustainability
Hazard
Heat Wave
Resilient City
Natural Disasters

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

This research work has been done with an objective to find out the resilience capacity of Lahore (study area) against the heat wave. Lahore, being the 2nd largest city of Pakistan with huge population, faces the disasters of various natures including urban flooding, smog and heat wave. Remote sensing data has been used in this research. Landsat images of the years 2002, 2012 and 2022 were acquired from the USGS website. These images were processed and analyzed by using ArcGis to find out the relationship among various indices causing heat wave. In this regard, NDVI, NDBI, LULC, LST and UHI maps were obtained. The extracted information was later re-arranged, over-layered and weighted to trace the zonal resilience of Lahore. The deduced findings reveal tremendous impact of decreasing vegetation cover and expansion in built-up area in creation of heat island and hindering the resilient capacity of Lahore. The eastern parts of the city are the most resilient followed by southern areas while central and western parts are least resilient against heat wave. Change detection analysis shows drastic change, the highest resilient areas of 2002 and 2012 are the least resilient in 2022. This research will further lead to new horizons of research pertinent to urban resilience and will be of great significance for developers and policy makers in making the cities resilient against disasters.

Corresponding Author's Email: javedhussainnaqvi211@gmail.com

1. Introduction

According to the United Nations (2014) it is estimated that due to rapid increase in urbanization and population, by the year 2050, about 2.5 million people will be residing in the urban areas and 90% of that will take place in Asia and Africa. Sadiq and Qureshi (2010), show through their research that the global climate change has immense impact on the regional temperatures as well. It is tragedy for Pakistan as being the low emitter of greenhouse gases and victim of severe climate change. About 90% of the natural disasters in Pakistan are due to climate change (Ali, Ahmad, Chaudhry, & Raza, 2015). In Pakistan all the main cities experience rise in temperature and heat waves too particularly in Karachi and Lahore since 2015. Due to rapid urbanization process, at large scale changes have occurred in Lahore including an increase in the number of households, commercial centers and industries related activities. All these factors contribute in raising surface temperature of the land (Adger, 2000). Due to remarkable urban expansion of Lahore, the vegetation is decreasing resulting in an increase in the temperature of the city. Zahid and Rasul (2012) are of the view that the temperature of Lahore is increasing due to anthropogenic activities making summers prolonged and hotter. The concentration of Aerosol Optical Depth (AOD) in the air of Lahore, making it no.1 polluted city in the world, plays a vital role in raising the temperature of the city (Shah, 2020). The sustained high temperature accompanied by high humidity may cause heat stroke or even death to humans and animals and this period stays from May to September.

In all such disastrous situations, a city must be resilient enough to cope with these problems. For a sustainable city, resilience is the key element which assures the survival of a city in one way or the other (Meerow, Newell, & Stults, 2016). The concept of resilient city is prevailing and flourishing rapidly across the globe as the impact of calamities and climate change is worsening the all systems of the cities. Urban resilience does not refer only to the capacity of resistance and recovery but also considers the long term strategies and adaptation processes related to mitigation and reduction of hazard's impact (Mehmood, 2016). Methodology for measuring urban sustainability and sustainable development varies from one discipline to other and same is with the selection of indicators and variables used to measure sustainability (Hardi & Pinter, 1995). Hoffmann (2008) had formulated the equation to describe the relationship among various components of resilience as

Resilience= Resistance +Coping Capacity + Recovery + Adaptation Capacity

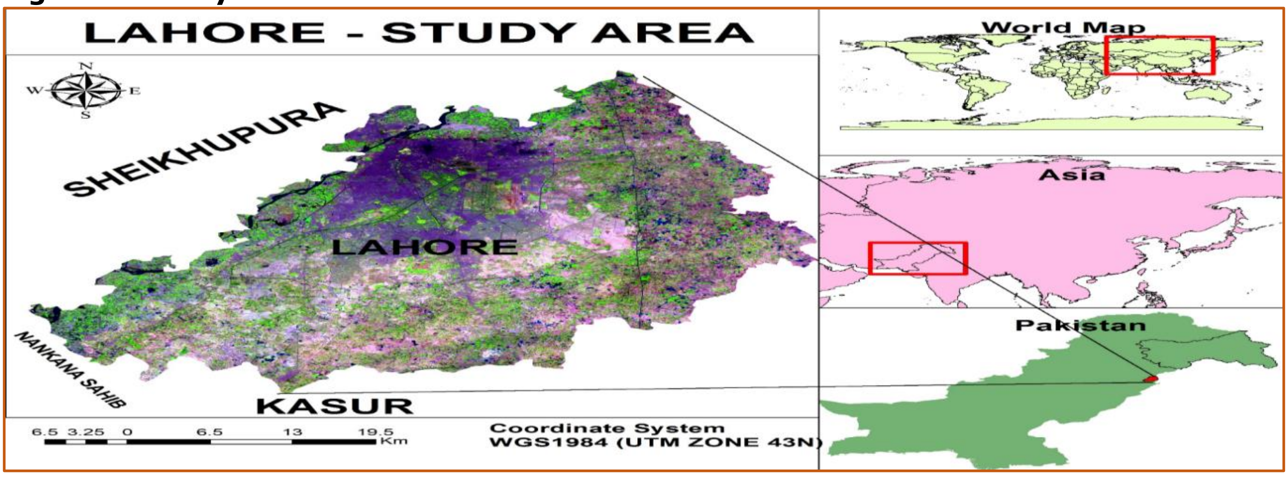
In this study, remote sensing techniques have been used to acquire the images from Landsat images-7 and Landsatn-8 from USGS website us. These images were processed by using ArcGis and NDVI, NDBI, LULC, LST and UHI maps were obtained. Later, supervised classification and then re-classification was done. Assessment accuracy was performed and at the end weighted overlay was done to have resilient characteristics of the study area against heat wave. The results reveal that the eastern parts of the city are the most resilient followed by southern areas while central and western parts are least resilient against heat wave.

Different approaches and mechanisms have been discussed which, if followed and adopted by developers and policy makers, will make Lahore a resilient and sustainable city. This research reveals the facts pertinent to the urban systems and connection among communities and their tangible and intangible resources. It unveils the secrets pertaining to the performance, efficiency and functions of the existing urban systems as well. It will provide a base for further research work to expand its vicinity and application.

Aimless research stands nowhere so when research on a specific content is done, many objectives emerge on the brain screen to be completed. But due the certain research limitations, these objectives are précised keeping in mind their relevancy. Main objectives of this research work include;

- To investigate how rapid urbanization is increasing the temperature of Lahore.
- To identify and evaluate the factors contributing in an increase in heat wave events and affected areas of Lahore.
- To evaluate the resilience capacity of Lahore against heat wave.
- To find out sustainability of Lahore if the on-going heat wave disaster continues to occur at the present rate.

Figure 1: Study Area



Each research study enables the reader and the writer to give answers to certain questions which ensure the authenticity of that research work as well. This research work finds the answers of following questions;

1. What are the main disasters being faced by Lahore?
2. What are the main causes triggering the heat wave disaster in Lahore?
3. How long will Lahore be able to sustain itself against heat wave?
4. How far is Lahore resilient against heat wave?

Lahore (study area) is a provincial hub and capital of Punjab, Pakistan. Lahore is 2nd largest city of the country having an area of 1772 km^2 and 11.126 inhabitants. Lahore stretches from 74^0-01′ to 74^0-39; east longitudes and 31^0-15′ to 31^0-42′ north latitudes. On the eastern side of Lahore is Wahga, on the west lies the district of Sheikhupura, district Kasur lies on the southern side while from north it is bounded by River Ravi (GoP, 2018). In Koppen's classification, Lahore falls in semi-arid type of climate having mild winters and hot and rainy summers. Rainfall in the months of January to March is mild and low while July and August are the wettest months with maximum rainfall of the year (Zahid & Rasul, 2012).

2. Review of Literature

Urban expansion is highly important geographical phenomenon in today's world. Pakistan is one of those countries which are undergoing moderate level of urbanization. If compared with other SAARC countries, Pakistan has the highest number of inhabitants in urban areas as 39.2 percent of its population lives in the cities (GoP, 2015). This increasing urban population is not only creating alarming conditions for resources but also inviting and creating disastrous situations for urban systems (Mangi, Chandio, Shaikh, & Talpur, 2018). Though cities provide all the necessities of life and act as centre for human activities but at the same time they face many problems as well. The cities face disasters of various kinds and natures. There always exist two problems related to extreme events; first is the probability of occurring of an event and second is to determine the future behavior of these extreme events and their expected impact on the community (Jones, Fowler, Kilsby, & Blenkinsop, 2013). The disasters have complexity in nature as they are result of both, nature and human actions Sayers et al. (2013) as monsoon rains each year cause alluvial and pluvial flooding inundating a huge area of Pakistan, causing damage and loss to large infrastructure and population (Shah, 2020). These disasters are not only caused by the natural events but are also produced by the social, political and economic environments.

As each city of the world is facing disaster of one kind or the other, therefore, a city must be resilient enough against the disasters to have sustainability. There are different approaches to select indices and indicators to check the sustainability of a city (Anthopoulos, Janssen, & Weerakkody, 2015). Today there are widespread categories of metrics and indicators to be selected and applied to measure sustainability but consensus has not yet developed which are the most useful and which are of least significance (Armstrong, 2019).

The reviewed literature reveals that all over the world, tendency is inclining towards making the cities more resilient and sustainable in the face of hazards. The developed countries have shown great concern in this regard while in the developing countries, including Pakistan, very little has been done so far. Various aspects of urban growth, urban expansion, urban ecology and the environment of the study area (Lahore) have been highlighted so far but its resilient capacity and sustainability have not been portrayed yet in detail. So in this research work, effort has been made to fill this research gap by finding out the resilient capacity and sustainability of Lahore in the face of hazards particularly heat wave.

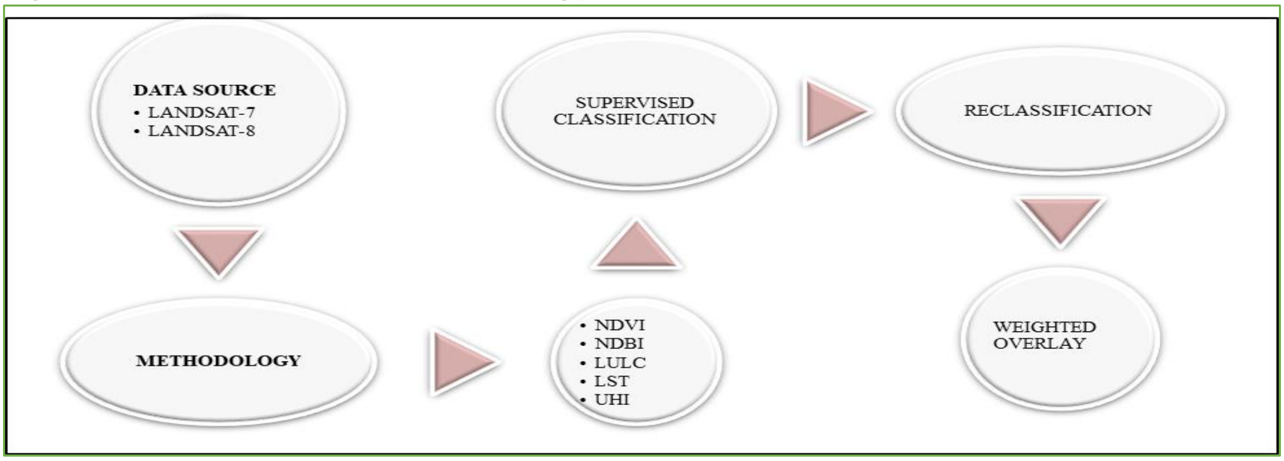
3. Data and Methods

3.1. Data Source

Remote sensing data for the Urban Heat Resilience of the study area was acquired from the United State Geological Survey website Earth Explorer (usgs.gov). The imageries of Landsat 7 and 8 of year 2002, 2012, and 2022 were acquired. The imageries contain multispectral data like Band 1, 2, 3, 4, 5, 6 ,7, and thermal data like band 6 and 10 of Landsat 7and 8 respectively.

The remote sensing data has limitations of one type or the other. In Landsat-7, images there appeared wedges like features denoted as scanline error. The same was removed by using Landsat toolbox before proceeding for further processes and analysis.

Figure 2: Data Source and Methodology



3. Methodology

3.1. Assessment of Urban Heat Resilience

Landsat-7 and 8 imageries of 2002, 2012, and 2022 were used to analyze Urban Heat Resilience. Multispectral data of Landsat-7 and 8 was used to calculate Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built up Index (NDBI) of study area. Thermal bands data of Landsat 7 and 8 were used to calculate Land Surface Temperature (LST). The LST so calculated then was used to calculate Urban Heat Island (UHI). After completing this process, Land Use and Land Cover (LULC) was calculated.

3.2. Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is an important parameter used in various research activities. For calculating NDVI, NIR and RED bands are used. Bands vary with reference to satellite as in Landsat -7, band 3 while in Landsat-8, band 4 are the Red Bands. Band 4 in Landsat-7 and band 5 in Landsat -8 are NIR (Bustos & Meza, 2015). The formula for NDVI is:

$$NDVI = (NIR - RED) / (NIR + RED) \tag{1}$$

3.2. Normalized Difference Built up Index (NDBI)

Normalized Difference Built up Index (NDBI) is an essential indice in remote sensing and GIs for many processes and analyses. In order to calculate NDBI, the NIR and SWIR band have been used. Band 4 in Landsat 7 and band 5 in Landsat 8 are the NIR Bands. On the other hand, band 4 in Landsat 7 and band 5 in Landsat 8 are the SWIR bands (Fu & Burgher, 2015). The formula of NDBI is:

$$NDBI = (SWIR - NIR) / (SWIR + NIR) \tag{2}$$

3.3. Land Surface Temperature Calculation

The Land Surface temperature is the key indicator in finding out the heat affected areas and heat islands. For calculating Land Surface Temperature, the thermal bands of Landsat-7 with ETM + sensor and Landsat-8 with OLI/TIR sensors have been used. So, the Landsat Surface Temperature was calculated from band 6 of the Landsat-7 thermal band of ETM+ sensor and band 10 of the Landsat-8 thermal band of TIR sensor (Guo, Ren, Zheng, Lu, & Dong, 2020).

The spectral radiance of thermal bands of Landsat-8 with TIR sensor is retrieve from digital number (Alves, 2016). Consequently, Land Surface Temperature was calculated by using the brightness temperature of thermal infrared bands, mean and difference in land surface emissivity of the study area (Cheng, Nnadi, & Liou, 2015).

$$L\lambda = (ML * Q_{Cal}) + AL - 0.5 \tag{3}$$

Where:

$L\lambda$= TOA spectral radiance, ML= RADIANCE_MULT_BAND 10, AL= Radiance_ Add_ Band_10, Q_{Cal}=Quantized and calibrated DN values, and -0.5 = the inaccuracy of radiance.

$$BT = (k2 / (\ln (K1/L\lambda) +1)) -273.15 \quad (4)$$

BT= Brightness Temperature, K2=is Calibration constant 2, K1=is Calibration constant 1, $L\lambda$: TOA, Ln: is natural logarithm, and the value 273.15 is used to convert the temperature kelvin to Celsius.

$$NDVI= (NIR-RED)/(NIR+RED \quad (5)$$
$$PV= \text{Square } (NDVI-NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \quad (6)$$
$$E = 0.004 * PV + 0.986 \quad (7)$$
$$LST = (BT/(1+(\lambda * BT/P) *In(E) \quad (8)$$

Where:

LST = Land Surface Temperature, BT = Brightness Temperature, λ = 10.8 μm, ρ = 1.438 × 10−2 mK, and E = Land Surface Emissivity.

3.4. Urban Heat Island (UHI)

In order to calculate Urban Heat Island, the Land Surface Temperature Current Value, Land Surface Temperature Mean Value, Standard Deviation value of the Land Surface Temperature are required. The Urban Heat Island is calculated by the following equation;

$$UHI = (LST - LST_{Mean}) / \text{Standard Deviation} \quad (9)$$

Where: LST = Land Surface Temperature, LST_{Mean} = Mean value of Land Surface Temperature, and Standard Deviation = Standard Deviation value of Land Surface Temperature.

3.5. Land Use and Land Cover (LULC)

There are numerous steps to be followed to make LULC map. First, a signature file for supervised classification was created and to make signature file of the different land uses. Training site was created to get the training points of different land types like Built- up Land, Agricultural Land, Open Spaces, and Water Bodies. Then labels were given the names (Built up Land, Agricultural Land, Open Spaces, and Water Bodies) and the color (Red, Green, Yellow, and Blue) respectively. After the signature file was saved and the tool supervised classification was opened, the composite band file of the study area was given to assign the signature file to it. Thus the suitable output for Supervised Classified image was provided.

3.6. Weighted Overlay

For performing weighted overlay process, there is a need to reclassify all maps like Normalized Difference Vegetation Index, Normalized Build up Index, Land Surface Temperature, Urban Heat Island, and Land Use and Land Cover. To reclassify the maps, Spatial Analyst Tool in Arc Toolbox was used. After opening Spatial Analyst Tool, process of Re-class was done by using Reclassify tool. Then the raster file was given as the input file and adjusted the class frequency as 4 classes then suitable output was provided. After that, Arc Toolbox was reopened and again Spatial Analyst Tool was opened, overlay was selected and opened weighted overlay tool.

Table 1: Weighted Overlay

Weighted Overlay	Influence
UHI	35
NDBI	25
LULC	15
LST	15
NDVI	10

Source: *(Author)*

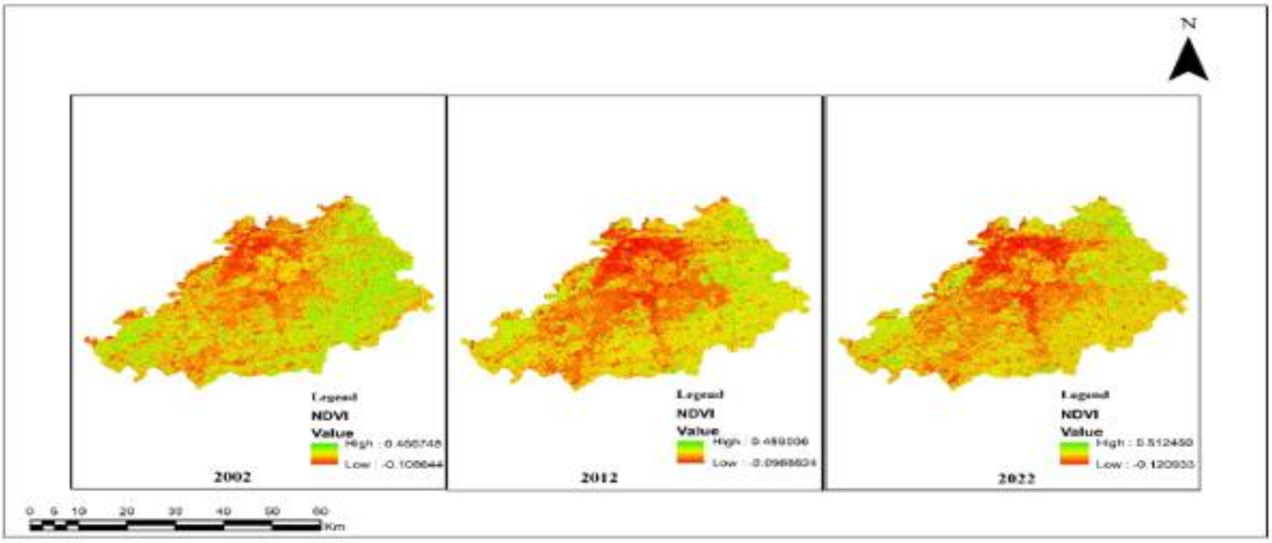
At the end all the reclassified maps were given as the input file and set the influence to give output to it. The accuracy assessment was done as well. A reference data set was created to determine the accuracy that matched well with the schema. The produced map showed accuracy very well.

4. Results and Discussion

4.1. Normalized Difference Vegetation Index (NDVI)

There is widespread use of Normalized Difference Vegetation Index (NDVI) by researchers to find out the pattern of land use and kind of the area. According to Zha et al., (2003) NDVI is of great use and significance in investigating the correlational aspects of changes in land use pattern Land Surface Temperature (LST). In this research study, as per requirement, NDVI has been used to analyze relational aspects of vegetation cover and land surface temperature.

Figure 3: Comparison of NDVI (2002, 2012, 2022)

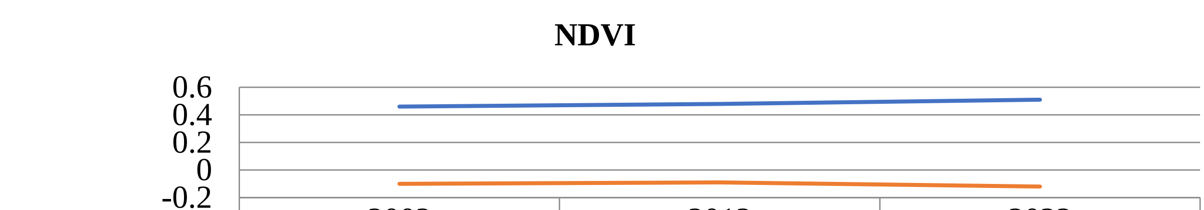


In this study NDVI was calculated by using NIR and RED bands by applying the below mentioned equation

$$NDVI= (NIR- RED)/ (NIR+RED)$$

Figure 3 clearly depicts the trend and pattern of temporal vegetational change change. For the year 2002, the highest vegetation value is 0.17 while the lowest value is -0.35. In that year, eastern parts comprising major areas of Wahga Town are witnessing thick vegetaion cover anlong eastern parts of Nishtar Town and western parts of Iqbal town having maximum value of 0.17. On the other hand, the central areas and the north-western parts including most parts of the "old city" , Shalimar Town, Ravi Town and Data Gunj Baksh Town had least vegetation cover and is described as having the lowest value -0.35. Right after a decade, in 2012, the situation worsened, as shown in the figure above, when a large part of the city which was once thickly vegetated, had lost its greenery resulting tremendous increase in built up area and temperature as well. Maximum value soared to 0.48 while the lowest value was -0.096. The vegetation in the southern and south- eastern parts has been replaced by cemented, paved and impervious surfaces by the anthropogenic activities. Later in the year 2022, there was drastic and disasterous removal of vegetation engulfing almost the whole city except few parts in the north-east (Wahga Town) and south-west (Iqbal Town) where the maximum value was 0.51 as shown above in satellite image of 2022

Figure 4: NDVI Trend Line



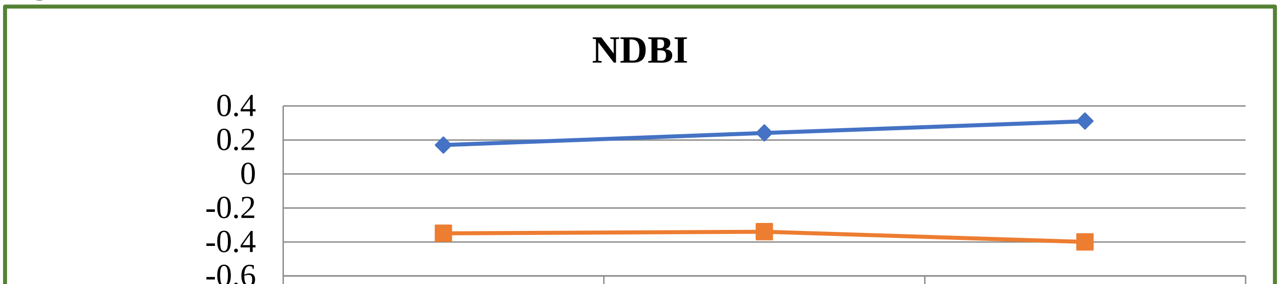
	2002	2012	2022
High Values	0.46	0.48	0.51
Low Values	-0.1	-0.09	-0.12

Rest of the study area had minimum value of -0.12 particularly in inner city and the north-western parts.This catastrophic change in land use pattern and type has triggered the most tragic and horrible disaster-heat wave. This line graph (above) shows the trend of increase or decrease in the values of NDVI. Both the values, high and low, are shoing a temporal increase. High values reached 0.46 to 0.51 and the low values increase from -0.1 in the year 2002 to -0.12.

4.2. Normalize Difference Built up Index (NDBI)

Mapping of the built up area is a vital indicator to monitor the urban growth, urban expansion and urban sprawl Shah (2020) as the built-up, being an important type of land use, is closely related and linked with urbanization.There are various indices and indicators used by researchers for mapping and classifying built-up lands such as Index Based Built-up Index (IBI), Urban Index (UI) Normalized Difference Bareness Index (NDBaI) and Bare Soil Index (BI) (Xu, 2008; Kawamura et al., 1996; Zhao and Chen, 2005; Rikimaru,1997). In present research study, Normalized Difference Built up Index (NDBI) has been applied to assess buiult-up area of study area.

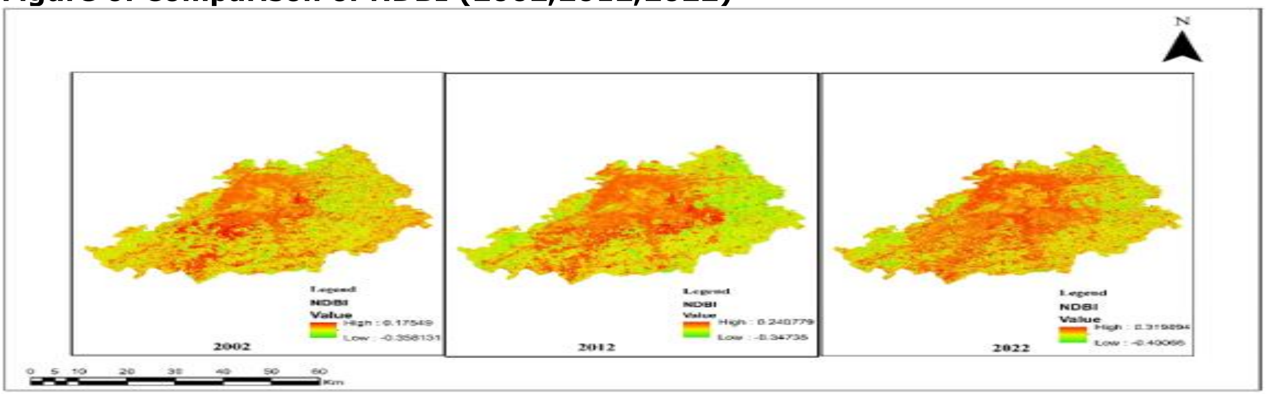
Figure 5: NDBI Trend Line



	2002	2012	2022
High Values	0.17	0.24	0.31
Low Values	-0.35	-0.34	-0.4

The figure above depicts an increase in values of Normalized Difference Built up Index of the study area.

Figure 6: Comparison of NDBI (2002,2012,2022)



Multispectral data of Landsat-7 and 8 was adopted to calculate the Normalized Difference Built up Index (NDBI). The formula applied to calculate NDBI for this research study is:

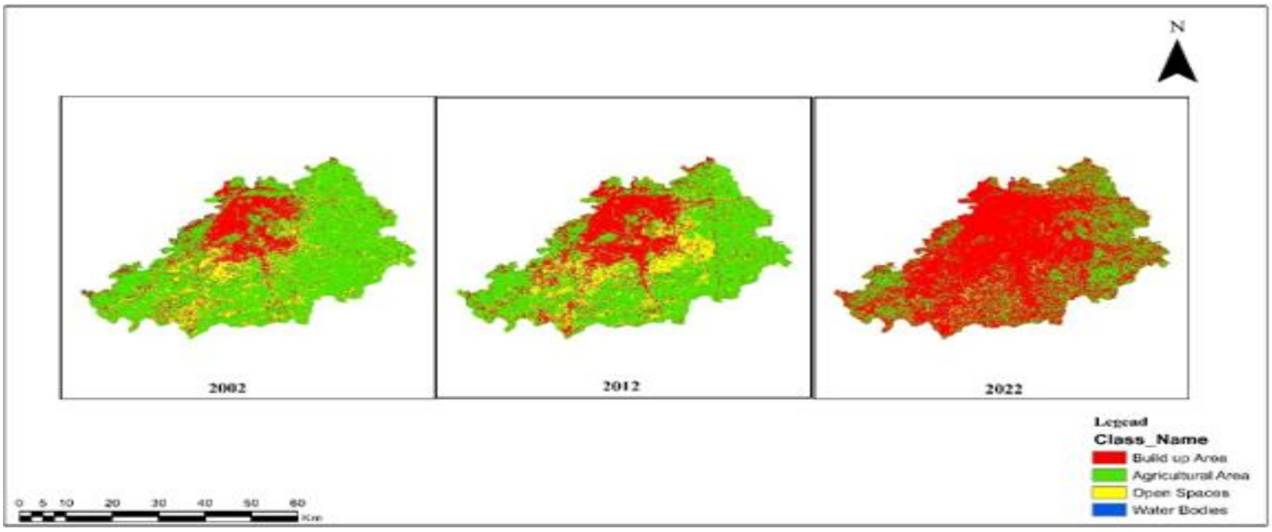
$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

The figure 3 indicates comparative increase in built-up area of Lahore for the years 2002,2012 and 2022. The city saw tremendous expansion in size and population with the passage of time. Maximum and minimum values have been assigned to these maps for better comprehension and analysis. NDBI values of the image for the year 2002 range from 0.17 to -0.35 indicating the highest and the lowest built-up area of Lahore. Maximum value represents the densely built-up areas comprising of the central areas and the north-western parts including most parts of the "old city" , Shalimar Town, Ravi Town and Data Gunj Baksh Town. On the other hand, the lowest value of the same image indicates the sparsely built-up areas situated in the north, north-east and west including Wahga Town, south-western parts of Iqbal Town and western areas of Ravi Town along the banks of River Ravi. A decade later,in 2012, the maximum and minimum values change a lot. the landsat imagery of 2012 reflects the maximum value of 0.24 which is observed again in the central parts " Inner Lahore" of the study area and the lowest value for the same image is -0.34 found in the vegetaed and cropped areas. In 2022 image, the highest value is 0.31 representing the central, the southern and the northern segmented areas of Lahore.While comparing these images, the findings clrealy revealing tremendous increase of built up area of Lahore.

4.3. Land Use Land Cover (LULC)

Through LULC quantitative changes pertinent to LULC can be acquired (Lieu, et al.,2009) and for future land use changes and their implications, LULC and modeling is of great significance (Nandy, et al., 2006).

Figure 7: Comparison of LULC (2012,2002, 2022)



When remote sensing is integrated with GIS, the best tools are produced to perform analysis of LULC changes (Halefom, Sisay, Khare, Singh, & Worku, 2017). In this research study, for evaluating change detection analysis the satellite image has been assigned classes named built-up area, agricultural area, open spaces and water bodies and these classes were given colours as red, green, yellow and blue respectively.

The figure 4 describes the spatio-temporal change in various classes of Lahore. In 2002 image, agricultural land is dominating followed by open spaces. Only central parts of the "old city" including Data Gunj Baksh Town, Gulberg Town, Saman Abad Town, Ravi town and Shalimar Town are witnessing built up area and that is not so densely built up as well. Next to built-up area is open spaces class scattered in Iqbal Town, Contonment area and Nishtar Town. Northern and eastern areas are dominated by vegetation in the form of cropped land. The image of 2012 is showing the urban expansion as built up areas in the image have stretched southwards and eastwards. Beside the old walled city, now in 2012, not only the built up areas have increased but open spaces class has also shown extension in the same direction as that of built-up area indicating the removal of vegetation for new settlements. The agricultural area is showing a sharp decline as well. This decline in agricultural area is being indicated at the northern parts of the Wahga Town and southern most parts of Iqbal Town. Exactly after a decade in 2022, an abrupt and drastic change has happened. The image of 2022 is very accurately describing the agricultural areas and open spaces swallowed by the built-up areas. This decade, 2012-2022 was years of very rapid urbanization, urban expansion and urban sprawl in the history of Lahore. The comparative change analysis for these two decades, 2002-2022, can easily be comprehended by putting a single glance at the images collectively. In 2002, agricultural land was dominating which was later in 2022 replaced by the built-up area.

4.4. Land Surface Temperature (LST)

Land Surface Temperature(LST) gives the most accurate indicator to investigate the balance of energy exchange between the atmosphere and the earth (Fabrizi, 2010). There are numerous satellites and methods for monitoring and observing Land Surface Temperature (LST)Jiménez-Muñoz, Sobrino, Skoković, Mattar, and Cristobal (2014); Sekertekin, Kutoglu, and Kaya (2016); Wang et al. (2015); Yu, Guo, and Wu (2014) and is the most commonly and widely used data for studies. Among all the methods, the extracted information from thermal infrared (TIR) is the best to be used for monitoring the temperature distribution over an area (Adinna, Christian, & Okolie, 2009; He, Liu, Zhuang, Zhang, & Liu, 2007; Imhoff, Zhang, Wolfe, & Bounoua, 2010; Lin, Moore, Messina, DeVisser, & Wu, 2012; Weng, 2009). In this study TIR has been used too.

$$LST= (BT/1+ (\lambda*BT/P) *In(E)$$

In this equation;
LST = Land Surface Temperature
BT= Brightness Temperature
λ= 10.8μm, ρ=1.438×10-2mK
E= Land Surface Emissivity

Figure 8: Comparison of LST (2002, 2012, 2022)

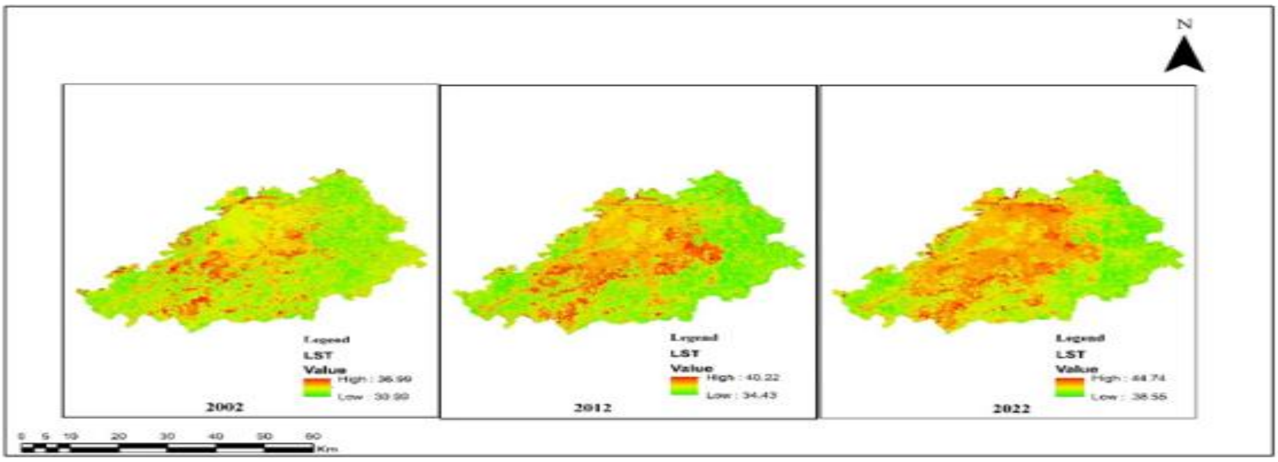
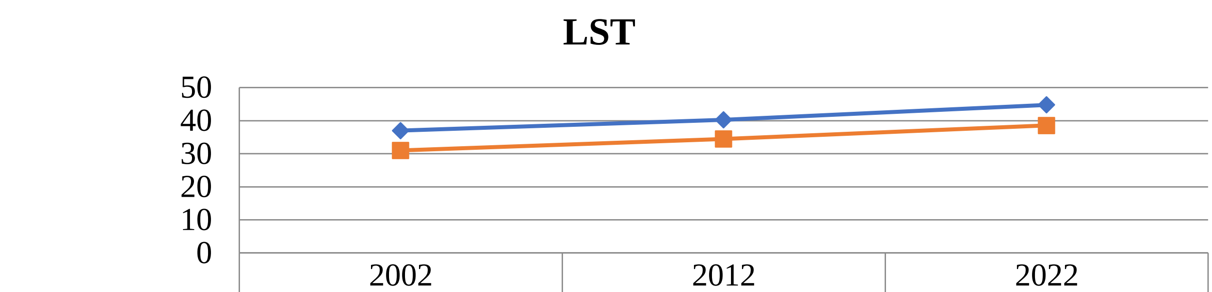


Figure 5 explains comparative analysis of LST of Lahore for the past two decades, 2002 -2022. All the images have been assigned values both maximum and minimum. In the image of 2002, maximum value is 36.99 which is prevailing over most of the core parts of the study area Lahore. The areas having maximum values include southern and north western parts of Iqbal Town, southern areas of Gulberg Town and Samanabad Town, eastern parts of Data Gunj BakshTown and scatted patches in Ravi and Shalimar Towns. On the other hand, Wahga Town and Aziz Bhatti Town have the minimum values along with south western parts of Iqbal Town, western areas of Ravi Town and southern Nishtar Town. The image of 2012 is showing an increase in values, both maximum and minimum.

Figure 9: LST Trend Line



	2002	2012	2022
High Values	36.99	40.22	44.74
Low Values	30.99	34.43	38.55

The areas having maximum values have spread over their adjacent areas as well. Reducing the areas of minimum values. The maximum value is 40.22 while the minimum value is 34.43. in Landsat image of 2022, the maximum value has reached to 44.74 and minimum 38.55. Stretch trending of areas with maximum value is southward and eastward. South eastern parts of the Iqbal Town and Nishtar Town come under this category of maximum values while areas of Wahga Town in the north and south and eastern and south eastern areas of Nishtar Town are least affected.

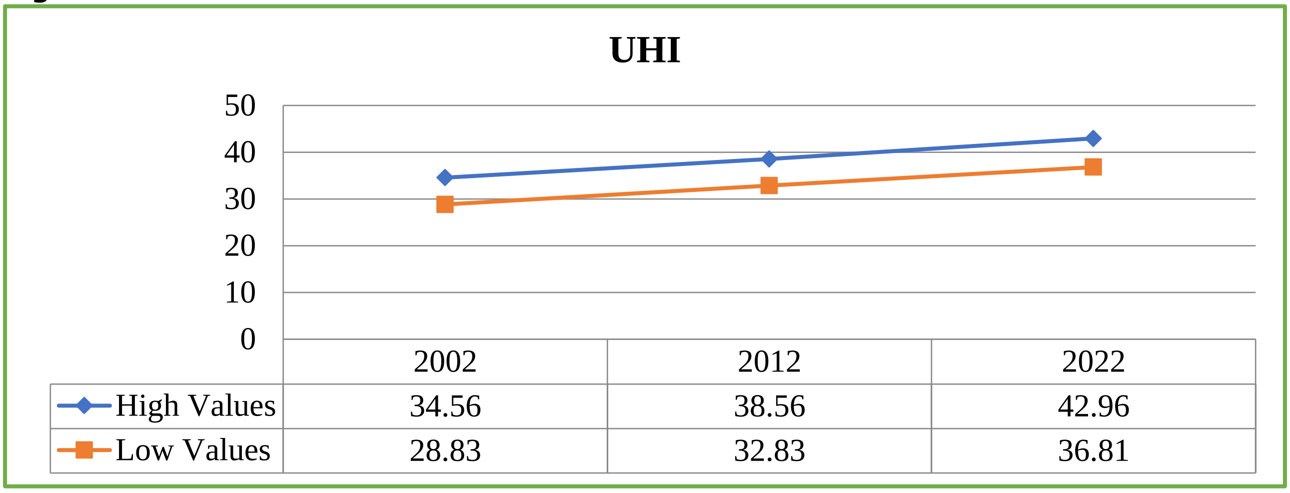
It is very clear from the figure 9 that the Land Surface Temperature of study area has increased. The highest value in 2002 was 36.99 which soared to 44.74 in 2022. On the other hand, the low value also increased a lot, from 30.99 in 2002 to 38.55 in 2022.

4.5. Urban Heat Island (UHI)

When atmospheric and surface temperature of surrounding area is lower than the urban areas, the phenomena is denoted as Urban Heat Island(UHI) (Lillesand, Kiefer, & Chipman, 2015). Due to rapid urbanization conversion of vegetated areas into built-up areas is taking place Yang, Qian, Song, and Zheng (2016) as well which, in return, is harming the urban environment. This conversion of land use is casting significant impact on LST of any area and resultant product is Urban Heat Island (UHI) (Achmad, Fadhly, Deli, & Ramli, 2022; Roy et al., 2020; Voogt & Oke, 2003). As shown in the equation, three indices are required to measure UHI of any place those include current value of land surface temperature(LST) mean value of LST and standard deviation value of LST

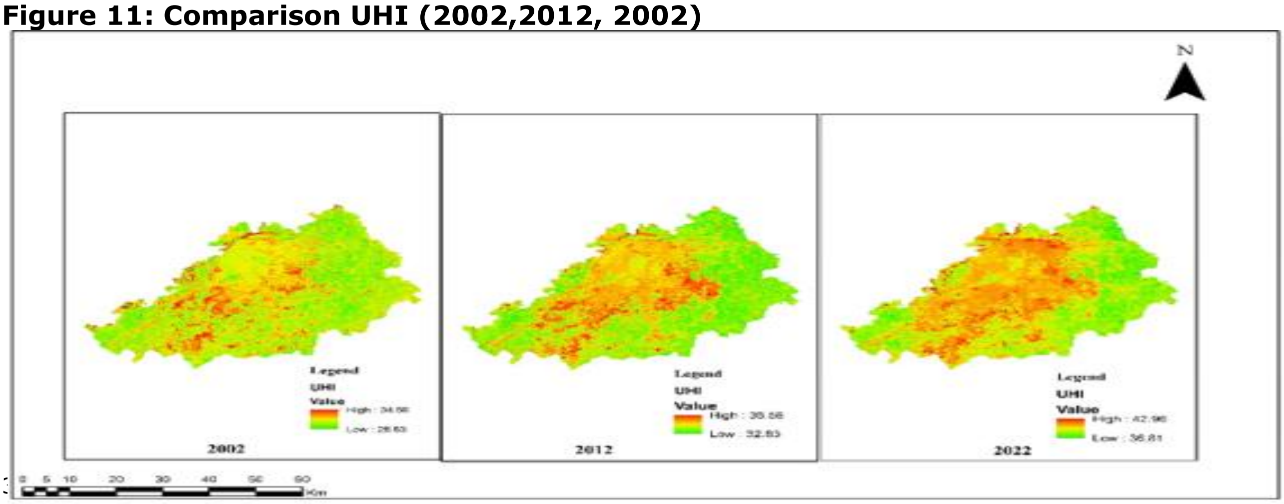
$$UHI = (LST - LST_{Mean}) / \text{Standard Deviation}$$

Figure 10: UHI Trend Line



The figure 10 shows tremendous increase in both values, high and low. High values saw rapid increase and from 34.56 in 2002 to 38.54 in 2012 and reached 42.96 in 2022. Low values also followed the same pattern of increase and reached 36.81 in 2022 which was as 28.83 in 2002.

Figure 11: Comparison UHI (2002,2012, 2002)



Impact of vegetation cover on LST, which in return gives birth to urban heat island, is very obvious from the above figure. In 2002 image the presence of vegetation is hindering the creation of urban heat island and UHI phenomena is confined to few parts of the study area. The maximum value, 34.56, is being experienced in Samanabad Town and northern Iqbal Town. In most of the other parts of the study area temperature is not enough to create UHI as they fall in the lowest value category of 28.83. the image of 2012 shows an increase, both in value and area. Extension in UHI affected area is eastward encompassing Aziz Bhatti Town, Gulberg Town and cantonment. Hence in these areas, the maximum values reach to 38.56 and minimum 32.83. in 2022 image, extensive area falls under influence of maximum value, that is 42.96. most of the study area has been dominated by the highest value category clearly conveying the message of high temperature. The eastern and northern areas of Lahore seem to be in the domain of lowest values, 36.81. the inclining stretch of UHI developing area is westward. Within two decades, the areas having UHI has extended many folds in terms of areas and values, 34.56 in 2002 to 42.96 in 2022.

4.6. Urban Resilience against Heat Wave

In this study urban resilience of Lahore (study area) has been calculated. For performing weighted overlay, there is a need to reclassify all maps like Normalized Difference Vegetation Index, Normalized Build up Index, Land Surface Temperature, Urban Heat Island, and Land Use and Land Cover. After reclassification weight was assigned to each class which rendered role in formation of classes based on the resilience capacity. According to the number of classes five colours are assigned to them; pink, blue, green, yellow and brown. These colours are bi-dimensional by characteristic in this research study. They not only describe the resilience capacity of the relevant area but also show the temporal change detection.

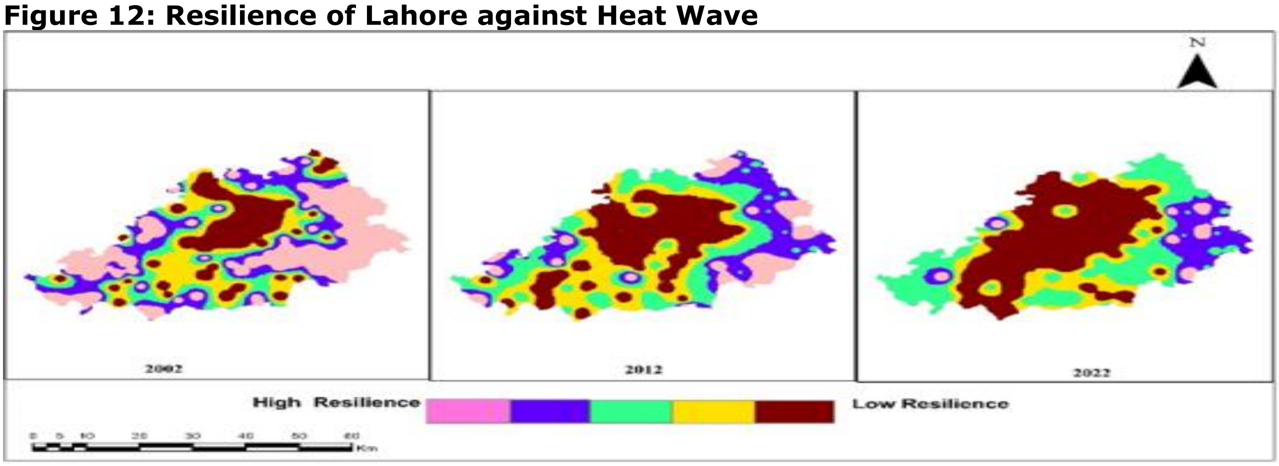
Table 2: Resilience and Colours

Colour	Resilience Characteristic
Pink	Highest Resilient
Blue	High Resilient
Green	Moderate Resilient
Yellow	Low Resilient
Brown	Least Resilient

Source: (Author)

Pink colour represents the highest resilient areas, blue shows high resilient areas, green reflects moderate resilient parts, yellow depicts less resilient areas and the brown explains the least resilient areas against the heat wave disaster. In the image 2002, pink color is present mostly in the eastern areas and few areas in south and west of the city also have the same characteristics of highest resilience. These areas include; Wahga Town and north western areas of Iqbal Town.

Figure 12: Resilience of Lahore against Heat Wave



Blue color representing high resilient areas include fringing and adjacent parts of the highest resilience areas. Green color showing areas of moderate resilience are also present in stripes and patches along the high resilient areas in all parts of the study area except Gulberg and Data Gunj Baksh Towns. Yellow color is presenting less resilient class and areas having this characteristic are found encircling the least resilient areas (brown) in northern Samanabad, Data Gunj Baksh Town and west Gulberg. In the image of 2012, it is very clear that the highest resilient area has decreased and the least resilient has increased. High resilient areas having blue color expanded and overlaid pink color areas particularly in Wahga Town in north- south direction. Green color also expanded and bordering areas between Wahga Town and Aziz Bhatti Town are now dominated by blue color. The Shalimar Town, western cantonment, and Data Gunj Baksh areas are now under great stress of UHI and heat wave. In the image of 2022, highest resilient areas are disappearing and now are in patches instead of clusters. Areas with less and least resilient capacity has increased many folds and have captured the whole inner city including Data Gunj Baksh Town, Shalimar Town, cantonment, Gulberg Town, Ravi Town and Samanabad Town.

The class having different colors are showing the change direction pattern of the resilient capacity of the relevant areas as well. In the year 2002, eastern and south western areas of Lahore were in the highest resilience zone. In 2012, the highest resilience zone shrinked in area and in 2022 the same west through drastic change and now is present in patches. Only the eastern Wahga Town is standing in its highest resilience capacity. On the other hand, the less and the least resilient class included small central and inner parts of the city in 2002, which expanded in 2012 and in 2022 about half of the study area has fallen in this least resilient class.

5. Conclusion

The process of urbanization has been creating numerous disasters, , in one way or the other, since the industrial revolution. Natural as well as anthropogenic disasters are threatening the urban systems and the urbanites. Cities are meant to meet the needs of the population and this function by the cities can only be performed if the cities are resilient against disasters. In this regard, it is need of the hour to assess resilience capacity of a city. This study uses remote sensing data for evaluating the Urban Heat Resilience of the study area acquired from the United State Geological Survey website EarthExplorer (usgs.gov). The imageries contain multispectral data like Band 1, 2, 3, 4, 5, 6 ,7, and thermal data like band 6 and 10 of Landsat 7and 8 respectively. Landsat-7 and 8 imageries of 2002, 2012, and 2022 were used to analyze NDVI and NDBI of area under study. In order to calculate LST, thermal bands data of Landsat-7 and 8 were used. The LST has been used to calculate UHI. After that the Land Use and Land Cover (LULC) was calculated. The extracted information was later rearranged, over-layered and weighted to trace the zonal resilience of Lahore. NDVI images showed great temporal variation in maximum and minimum values. In 2002 maximum value was 0.46 and minimum was -0.08 which soared to 0.51 and -0.21 respectively in 2022 and same is the case with NDBI. The built up area in the year 2002 was confined to central (inner walled city) which spread in all directions irrespective of confinement and the whole city is now witnessing the scenario of UHI and heat wave. After over laying and applying weight, five classes were created characterized as high resilient to low resilient. The deduced findings reveal tremendous impact of decreasing vegetation cover and expansion in built-up area in creation of heat island and hindering the resilient capacity of Lahore. Overall, the eastern parts of the city are the most resilient followed by southern areas while central and western parts are least resilient against heat wave. In 2012, the highest resilience zone reduced in area and in 2022 the same went through drastic change and now is present in patches. On the other hand, the less and the least resilient class included small central and inner parts of the city in 2002, which expanded in 2012 and in 2022 about half of the study area has fallen in this least resilient class. As a city acts like a pivot around which economic, cultural and social cycle of millions urbanites revolves, so the city must be resilient enough to cope with disasters. Heat wave can be avoided if conversion of green cover to grey cover is stopped. The process of haphazard urban expansion and urban sprawl if checked properly can change the hellish hot life in Lahore into heavenly cool breezes.

References

Achmad, A., Fadhly, N., Deli, A., & Ramli, I. (2022). Urban growth and its impact on land surface temperature in an industrial city in Aceh, Indonesia. *Letters in Spatial and Resource Sciences, 15*(1), 39-58. doi:https://doi.org/10.1007/s12076-021-00292-3

Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in human geography, 24*(3), 347-364. doi:https://doi.org/10.1191/030913200701540465

Adinna, E., Christian, E. I., & Okolie, A. T. (2009). Assessment of urban heat island and possible adaptations in Enugu urban using landsat-ETM. *Journal of Geography and Regional Planning, 2*(2), 30.
Ali, N., Ahmad, I., Chaudhry, A., & Raza, M. (2015). Trend analysis of precipitation data in Pakistan. *Sci. Int, 27*, 803-808.
Alves, E. D. L. (2016). Seasonal and spatial variation of surface urban heat island intensity in a small urban agglomerate in Brazil. *Climate, 4*(4), 61.
Anthopoulos, L. G., Janssen, M., & Weerakkody, V. (2015). *Comparing Smart Cities with different modeling approaches.* Paper presented at the Proceedings of the 24th International Conference on World Wide Web.
Armstrong, N. E. (2019). *Resilience and sustainability: analyzing urban resilience and sustainability planning on the upper Texas Gulf Coast.*
Bustos, E., & Meza, F. J. (2015). A method to estimate maximum and minimum air temperature using MODIS surface temperature and vegetation data: application to the Maipo Basin, Chile. *Theoretical and Applied Climatology, 120*, 211-226. doi:https://doi.org/10.1007/s00704-014-1167-2
Cheng, C.-H., Nnadi, F., & Liou, Y.-A. (2015). A regional land use drought index for Florida. *Remote Sensing, 7*(12), 17149-17167. doi:https://doi.org/10.3390/rs71215879
Fu, B., & Burgher, I. (2015). Riparian vegetation NDVI dynamics and its relationship with climate, surface water and groundwater. *Journal of Arid Environments, 113*, 59-68. doi:https://doi.org/10.1016/j.jaridenv.2014.09.010
GoP. (2015). *Pakistan Economic Survey, 2014-2015*. Retrieved from Finance Division, Islamabad: Pakistan.:
GoP. (2018). *Pakistan Economic Survey, 2017-2018*. Retrieved from Finance Division, Islamabad: Pakistan:
Guo, J., Ren, H., Zheng, Y., Lu, S., & Dong, J. (2020). Evaluation of land surface temperature retrieval from Landsat 8/TIRS images before and after stray light correction using the SURFRAD dataset. *Remote Sensing, 12*(6), 1023. doi:https://doi.org/10.3390/rs12061023
Halefom, A., Sisay, E., Khare, D., Singh, L., & Worku, T. (2017). Hydrological modeling of urban catchment using semi-distributed model. *Modeling Earth Systems and Environment, 3*, 683-692. doi:https://doi.org/10.1007/s40808-017-0327-7
Hardi, P., & Pinter, L. (1995). *Models and methods of measuring sustainable development performance*: International Institute for Sustainable Development Winniped, MB, Canada.
He, J., Liu, J., Zhuang, D., Zhang, W., & Liu, M. (2007). Assessing the effect of land use/land cover change on the change of urban heat island intensity. *Theoretical and Applied Climatology, 90*, 217-226. doi:https://doi.org/10.1007/s00704-006-0273-1
Hoffmann, S. L. (2008). *Application of resiliency theory and adaptive cycles as a framework for evaluating change in amenity-transition communities*: Utah State University.
Imhoff, M. L., Zhang, P., Wolfe, R. E., & Bounoua, L. (2010). Remote sensing of the urban heat island effect across biomes in the continental USA. *Remote sensing of environment, 114*(3), 504-513. doi:https://doi.org/10.1016/j.rse.2009.10.008
Jiménez-Muñoz, J. C., Sobrino, J. A., Skoković, D., Mattar, C., & Cristobal, J. (2014). Land surface temperature retrieval methods from Landsat-8 thermal infrared sensor data. *IEEE Geoscience and remote sensing letters, 11*(10), 1840-1843.
Jones, M. R., Fowler, H. J., Kilsby, C. G., & Blenkinsop, S. (2013). An assessment of changes in seasonal and annual extreme rainfall in the UK between 1961 and 2009. *International Journal of Climatology, 33*(5), 1178-1194. doi:https://doi.org/10.1002/joc.3503
Lillesand, T., Kiefer, R. W., & Chipman, J. (2015). *Remote sensing and image interpretation*: John Wiley & Sons.
Lin, S., Moore, N. J., Messina, J. P., DeVisser, M. H., & Wu, J. (2012). Evaluation of estimating daily maximum and minimum air temperature with MODIS data in east Africa. *International Journal of Applied Earth Observation and Geoinformation, 18*, 128-140. doi:https://doi.org/10.1016/j.jag.2012.01.004
Mangi, M. Y., Chandio, I. A., Shaikh, F. A., & Talpur, M. A. h. (2018). Urban land use planning trend and sustainable challenges in socio-economic development. *Mehran University Research Journal of Engineering & Technology, 37*(2), 397-404.

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and urban planning, 147*, 38-49. doi:https://doi.org/10.1016/j.landurbplan.2015.11.011
Mehmood, A. (2016). Of resilient places: planning for urban resilience. *European planning studies, 24*(2), 407-419. doi:https://doi.org/10.1080/09654313.2015.1082980
Roy, S., Pandit, S., Eva, E. A., Bagmar, M. S. H., Papia, M., Banik, L., . . . Razi, M. A. (2020). Examining the nexus between land surface temperature and urban growth in Chattogram Metropolitan Area of Bangladesh using long term Landsat series data. *Urban Climate, 32*, 100593. doi:https://doi.org/10.1016/j.uclim.2020.100593
Sadiq, N., & Qureshi, M. S. (2010). Climatic variability and linear trend models for the five major cities of Pakistan. *Journal of Geography and Geology, 2*(1), 83-92.
Sayers, P., Yuanyuan, L., Galloway, G., Penning-Rowsell, E., Fuxin, S., Kang, W., . . . Le Quesne, T. (2013). Flood risk management: A strategic approach. In: Asian Development Bank, GIWP, UNESCO and WWF-UK.
Sekertekin, A., Kutoglu, S. H., & Kaya, S. (2016). Evaluation of spatio-temporal variability in Land Surface Temperature: A case study of Zonguldak, Turkey. *Environmental monitoring and assessment, 188*, 1-15. doi:https://doi.org/10.1007/s10661-015-5032-2
Shah, S. J. H. (2020). Arts and Social Sciences. *Journal reference: Arts and Social Sciences, 1*(1), 31-41. doi:https://doi.org/10.34154/2020-ASSJ-0202-33-43/euraass
United Nations, u. (2014). World urbanization prospects. *United Nations: San Francisco, CA, USA*.
Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. *Remote sensing of environment, 86*(3), 370-384. doi:https://doi.org/10.1016/S0034-4257(03)00079-8
Wang, F., Qin, Z., Song, C., Tu, L., Karnieli, A., & Zhao, S. (2015). An improved mono-window algorithm for land surface temperature retrieval from Landsat 8 thermal infrared sensor data. *Remote Sensing, 7*(4), 4268-4289. doi:https://doi.org/10.3390/rs70404268
Weng, Q. (2009). Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. *ISPRS Journal of photogrammetry and remote sensing, 64*(4), 335-344.
Yang, L., Qian, F., Song, D.-X., & Zheng, K.-J. (2016). Research on urban heat-island effect. *Procedia engineering, 169*, 11-18.
Yu, X., Guo, X., & Wu, Z. (2014). Land surface temperature retrieval from Landsat 8 TIRS—Comparison between radiative transfer equation-based method, split window algorithm and single channel method. *Remote Sensing, 6*(10), 9829-9852. doi:https://doi.org/10.3390/rs6109829
Zahid, M., & Rasul, G. (2012). Changing trends of thermal extremes in Pakistan. *Climatic change, 113*(3-4), 883-896. doi:https://doi.org/10.1007/s10584-011-0390-4