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Relation of land surface temperature with different vegetation indices using multi-temporal remote sensing data in Sahiwal region, Pakistan

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Abstract

At the global and regional scales, green vegetation cover has the ability to affect the climate and land surface fluxes. Climate is an important factor which plays an important role in vegetation cover. This research aimed to study the changes in land cover and relation of different vegetation indices with temperature using multi-temporal satellite data in Sahiwal region, Pakistan. Supervised classification method (maximum likelihood algorithm) was used to achieve the land cover classification based on ground-truthing. Our research denoted that during the last 24 years, almost 24,773.1 ha (2.43%) of vegetation area has been converted to roads and built-up areas. The built-up area increased in coverage from 43,255.54 ha (4.24%) from 1998 to 2022 in study area. Average land surface temperature (LST) values were calculated at 16.6 °C and 35.15 °C for winter and summer season, respectively. In Sahiwal region, the average RVI, DVI, TVI, EVI, NDVI and SAVI values were noted as 0.19, 0.21, 0.26, 0.28, 0.30 and 0.25 respectively. For vegetation indices and LST relation, statistical linear regression analysis indicated that kappa coefficient values were $R^2=0.79$ for RVI, 0.75 for DVI, 0.78 for DVI, 0.81 for EVI, 0.83 for NDVI and 0.80 for SAVI related with LST. The remote sensing (RS) technology can be used to monitor changes in vegetation indices values over time, providing valuable information for sustainable land use management. Even though the findings on land cover provide significant references for reasoned and optimal use of land resources through policy implications.

Keywords Vegetation cover, Land surface temperature, Land use/land cover, Climate change, Remote sensing, GIS

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Introduction

Environmental and climate changes have in a harmful way affected crops' health in the following ways: variations in land surface temperature (LST) and land cover changes (Ali and Malik 2011; Nasir et al. 2022; Mokhtar et al. 2022; Rendana et al. 2023), variations in the precipitation and disease vectors, severe heat stress and relocation of the people from rural to urban areas (Ali et al. 2018; Amin et al. 2018; Alsafadi et al. 2023). The recent research trends showed that the environmental changes are responsible for 3.2% decrease in the per-head food security (Akram et al. 2018; Ali et al. 2019; Din et al. 2022). At the global and regional scales, green vegetation cover has the ability to affect the climate and land surface fluxes (Amin et al. 2017; Baqa et al. 2022). The terrestrial vegetation and ecosystem is changing due to climate change (Hateffard et al. 2021; Fahad et al. 2017). Vegetation is directly or indirectly connected with the energy cycle, hydrology, soil and climate because vegetation cover is an important segment of terrestrial ecosystem (Hussain et al. 2020a; Masood et al. 2022; Chandra et al. 2023). Global warming increased the LST after industrial revolution (Hussain et al. 2020b, 2022a). The vegetation cover plays significant role in the characterising of human activities, variations in the terrestrial ecosystem, soil ecosystems, hydrology and regional and global climate change process (Nasim et al. 2018; Islam et al. 2021; Akram et al. 2022a, b). In 2013, intergovernmental panel on climate change (IPCC) described that the rapid warming of climate system negatively influences the agricultural practices as well as the vegetation cover (Hussain et al. 2021a, b; Mubeen et al. 2021). The plant growth in the arid regions is highly dependent on the water availability due to high rate of evapotranspiration and low precipitation (Fahad et al. 2018; Khan et al. 2020b; Sabagh et al. 2020; Reddy et al. 2023). To study the plant phenology, vegetation coverages and biomass are necessary to identify the vegetation signal correctly (Feizizadeh et al. 2013; Sabr et al. 2016; Hassan et al. 2021; Karuppasamy et al. 2022; Naz et al. 2022; Hussain et al. 2023a; Yang et al. 2023).

Normalised difference vegetation index (NDVI) has great capability to signal across the seasonal and annual changes in the activity of the vegetation in response to climate change (Rahman et al. 2017). The NDVI is related to the chlorophyll content as well as leaf area index and has been broadly used in various means (Rani et al. 2018), like for detecting the crop types and land use/land use (LULC) change as well as assessing crop yield and production (Sultana et al. 2014; Tariq et al. 2020). The NDVI values are connected to the biological activities of the plant. Changes in active surface temperature can be well characterised easily through NDVI which shows vegetated cover condition (Zahoor et al. 2019; Aslam et al. 2021). The NDVI also helps identify various cycles of vegetation phenology at regional as well as global scales (Zaidi et al. 2017; Kazmiet al. 2023). The NDVI is additional receptive to chlorophyll activity, but enhanced vegetation index (EVI) is connected by plants' structural difference and hence helpful in drawing tropical forests (Waleed and Sajjad 2022). Information about vegetation using remote sensing (RS) images is mostly interpreted by changes and differences of the green leaves of plants as well as canopy spectral characteristics (Abdullah et al. 2022). Ratio vegetation index (RVI) was one of the first vegetation indices (VIs), and it was proposed in 1969. It is based on the principle that leaves absorb relatively more red than infrared light. Difference vegetation index (DVI) and transformed vegetation index (TVI) are very responsive to variation in soil background. It can be used to assess the vegetation biological environment (Mahmood and Jia 2016; Dewan et al. 2021). Soil adjusted vegetation index (SAVI) is used to correct NDVI for the influence of soil brightness in areas where vegetative cover is low. Landsat data presently deliver numerous vegetation index products that are broadly used in environmental changes (Liu et al. 2016; Majeed et al. 2021; Hussain et al. 2020c; Ali et al. 2023).

The RS data are the most important sources widely used for change analysis in the present years (Kumar et al. 2016; Abdo et al. 2022). Since benefits of repetitive data acquirement, its synoptic view and digital format suitable for handling by computer, remotely sensed data, for example, thematic mapper (TM) and operational land imager (OLI) have become the main data causes for various change analysis applications throughout the previous year's (Huyen et al. 2016; Rizvi et al. 2021; Thakur et al. 2021). However, in semi-arid and arid environment, like various satellite imagery have been applied for development, monitoring, and LULC change analysis (Chaudhuri and Mishra 2016; Yohannes et al. 2021; Zhou et al. 2021; Tariq et al. 2023). As a matter of fact, geographic information system (GIS) methods are proficiently used to examine the effects of several reasons on LULC changes: those reasons contain population density, terrain slope, proximity to roads and contiguous land use (Roy et al. 2017; Chen et al. 2020; Fashae et al. 2020). RS data, in combination with (GIS), have been supposedly used as a compelling apparatus in quantitatively assessing urban range and signifying urban development at a usually high spatial scale (Fu et al. 2020; Govind and Ramesh 2020). Benefit of multi-measuring an extensive spatial territory, satellite remote detection sufficiently associated to improved comprehension and screen scene advancement and procedures, and appraised biophysical qualities of land surfaces (Pal and Ziaul 2017; Olorunfemi et al. 2020;

Morshed et al. 2020). The GIS revolution gives a reliable domain to organising, imagining and dissecting computerised data to encourage change detection and database advancement (Govind and Ramesh 2019; Liaqut et al. 2019; Hussain et al. 2023b).

Long-period observations of RS vegetation dynamics have got an increasingly noticeable role in the study of global ecology (Bashir and, Ahmad 2017; Chen et al. 2017; Abdo 2018). Remote sensing is also frequently used for identifying periodic changes in vegetation (Ige et al. 2017; Mia et al. 2017). With the passage of time, applied RS is becoming predictable tool for supporting humans in progress on resolving ecological-related tasks on worldwide, and local and regional scales (Orimoloye et al. 2018; Şen et al. 2018). Significant change amongst vegetation indices as well as physically significant agronomic variables is an important task in RS (Nayak and Fulekar 2017; Onamuti et al. 2017; Afzal et al. 2023). The RS is considered as a suitable tool that permits monitoring and records the vegetative condition and quantity by a comparatively less cost and possible different measurements of field (Fatima et al. 2018; Kumar et al. 2018). Currently, observing vegetation detection and dynamics, their related driving forces have turned into an important problem in studies of worldwide change in climate. Various studies rely on satellite data which have been documented in vegetation growth changes with relevance to change in climate diverse biomes and regions (Hussain 2018; Malik et al. 2019). Sahiwal is the main city of Pakistan and is the major cultural and economic centre in Central Punjab (Pakistan). The key objectives of this research were to:

a. Estimation of land cover changes in the region of Sahiwal, Pakistan from 1982 to 2022.
b. Calculate the temperature and different vegetation indices in study area using Landsat data with 30 spatial resolution for the years 1998, 2010 and 2022.
c. Identify the relation of different vegetation indices with temperature using Landsat data.

Materials and methods

Study area

Research site is bound by Sahiwal, Pakpattan and Okara districts of Punjab, Pakistan. This area lies between latitude 29° 25′ 12″ N to 31 °28 ′16″ N and longitude 71° 58′ 34″ E to 74° 43′ 25″ E approximately (Fig. 1). Sahiwal district comprises 2 tehsils: Sahiwal and Chichawatni. Pakpattan district has also two tehsils: Arifwala and Pakpattan. The Okara district comprises three tehsils: Depalpur, Renala Khurd and Okara. Climate of the division of Sahiwal is very hot and dry. Area of Sahiwal is very plain and productive with River of Sutlej passing on the southern side and River of Chenab passing on the western side. Summer season starts in April and continues till October. May, June and July are the hottest

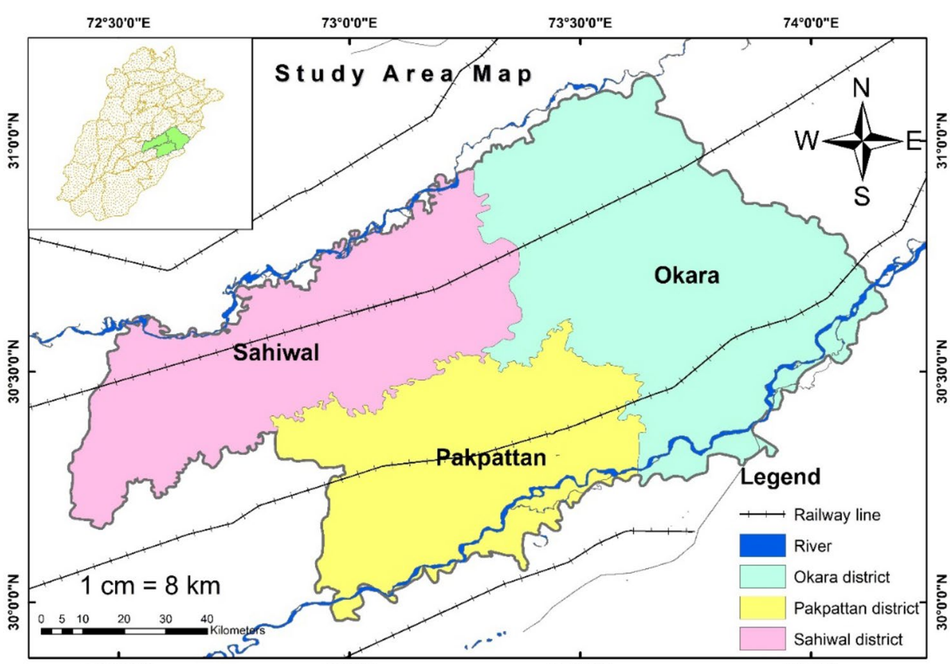

Fig. 1 Study area map of Sahiwal division

months. Total area of Sahiwal division with mild winters and very hot summers features an arid climate.

Data collection and classification

Landsat satellite images with 30 m * 30 m spatial resolution were downloaded from the website (earthexplorer.usgs.gov) of the USGS (United States of Geological Survey) with vegetation area, bare soil, built-up area and water bodies as mapped LULC types. For this study, images of Landsat 4/5 (TM) and Landsat 8 (OLI) were used (Table 1).

Landsat images consist of 8 discrete bands. For this study, only 1–5 and 7 bands were used as band 6 is a thermal band and band 8, so it was not used for further analysis to confirm the bands. Landsat images were pre-processed in ERDAS image 15 for geo-referencing, layer stacking (stacking the method used to produce multiband image from discrete bands), mosaicking (to combine the two stacked images) and sub-setting (after stacking study area was extracted) of the image on the basis of area of interest (Xu et al. 2016). All satellite data studied by assigning per-pixel signatures (Adefisan et al. 2015). The LULC maps were prepared using supervised classification technique (maximum likelihood algorithm) and training site selections. Supervised classifications applied on Landsat images for the year 1998, 2010 and 2022 were carried out to generate classified LULC maps. For each of the predetermined LULC types, training samples were selected by delimiting polygons around representative sites (Usman et al. 2015). Spectral signatures for the respective land cover types derived from the satellite imagery were recorded using the pixels enclosed by these polygons. The changes in LST and all LULC categories for the whole

Table 1 Properties of landsat satellite images

No	Satellite/ sensor	Pixel size	Spectral resolution	Band used	Path/row	Acquisition date
1	LANDSAT 5	30 m	Multispectral (11 bands)	1,2,3,4,5,6,7,9	150/039, 149/039	March 1998
2	LANDSAT 5	30 m	Multispectral (11 bands)	1,2,3,4,5,6,7,9	150/039, 149/039	March 2010
3	LANDSAT 8	30 m	Multispectral (11 bands)	1,2,3,4,5,6,7,9	150/039, 149/039	March 2022

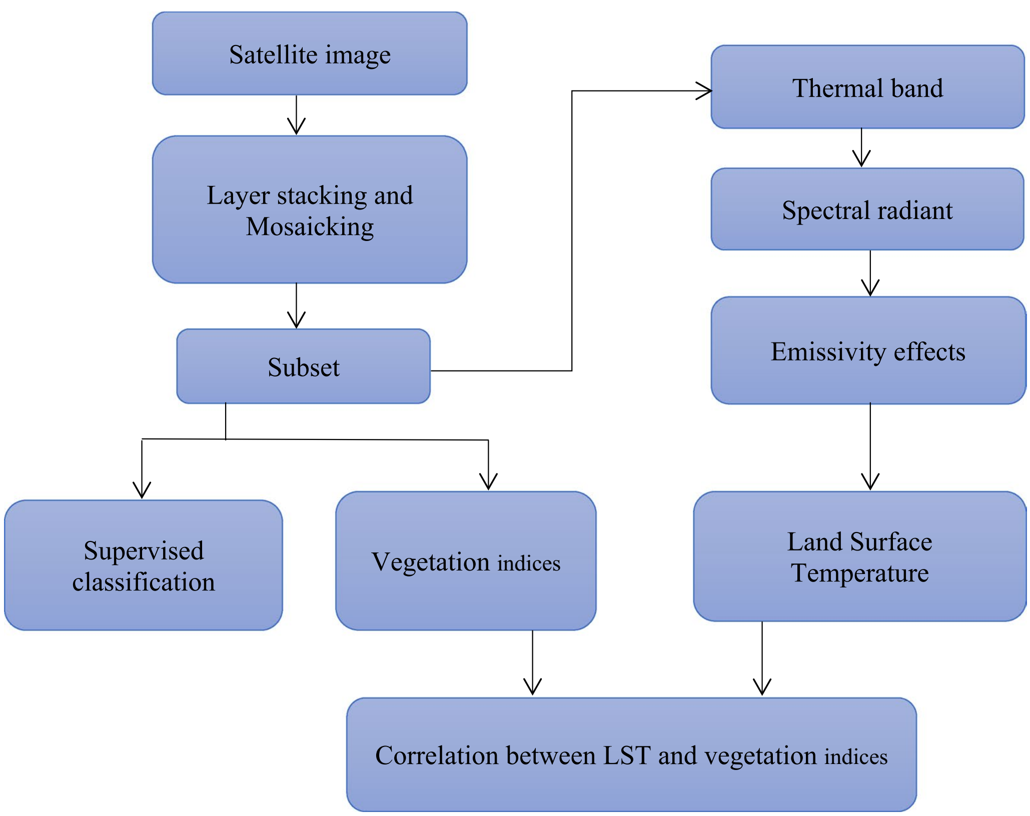

Fig. 2 Flow chart for methodology

region through 1998 to 2022 are aggregated to form a model of the relationships. All steps are shown in Fig. 2.

Vegetation indices

Vegetation index is one of the greatest and useful indices to rapidly detect vegetated lands with the use of multispectral RS data (Jia et al. 2014). Vegetation indices are linked to the leaf area index and chlorophyll content and been broadly used in many ways, such as assessing crop yield and net primary production, detecting crop types and detecting LULC change. Vegetation indices are also used to rapidly detect vegetation regions using RS data Ahmed (2012). Table 2 shows the various vegetation indices which are used in climate.

Estimation of surface temperature

The LST is a universal term relating to joint temperature of intact objects existing on the desert land. Numerous scientists used well-defined measurements on Landsat images to calculate the LST. The LST was calculated from the Landsat images with 30 m spatial resolutions (Hussain and Karuppannan 2023). Initially, Lλ values were calculated to spectral radiance using Eq. 1.

$$L\lambda = gain \times QCAL + offset \quad (1)$$

Lλ denotes spectral radiance. QCAL is a quantized calibrated pixel value in digital number (DN). In the 2nd step, the spectral radiance was converted to temperature using this Eq. 2.

$$T = \frac{K_2}{ln\left(\frac{K_1}{L\lambda} + 1\right)} \quad (2)$$

where K1 and K2 values are 607.76 and 1260.56 for Landsat 4/5 (TM) and Landsat 7 (ETM+), and 772.88 and 1321.07 for Landsat 8 (OLI), respectively, and ln shows natural logarithm [72–75]. In the last step, temperature in Kelvin was converted to Celsius (C°) through this Eq. 3.

$$T(C^\circ) = T(K) - 273.15 \quad (3)$$

Results

LULC changes

Supervised classifications for the years 1998, 2010 and 2022 and study area were covered with various LULC classes (Fig. 3). In the year 1998, water bodies were 13134.52 ha (1.29%) followed by bare soil 45051.47 ha (4.42%). The area covered by vegetation area was 924108.7 ha (90.65%) whilst the built-up area was 37126.8 ha (3.64%). In 2010, the image analysis of the study area showed that the vegetation area accounts for 917106.9 ha (89.96%), whilst the built-up area, water bodies and bare soil covered 57014.85 ha (5.59%), 10264.72 ha (1.01%), and 35034.96 ha (3.44%), respectively (Table 3). Similarly, in the year 2022, water bodies were covered by 9048.414 ha (0.89%) followed by bare soil 30655.12 ha (3.01%); vegetation area was covered 899335.6 ha (88.22%). However, built-up area was 80382.34 ha (7.88%) as shown in Fig. 2. Vegetation area and water bodies decreased slightly to 2.43% and 0.40% from 1998 to 2022, respectively. Finally, the built-up area increased in coverage from 4.24% from 1998 to 2022 in study area. It is denoted that during the last 14 years, almost 2.43% of vegetation area has been converted to roads and built-up areas. It was noted that there had been fast changes in LULC, mainly in forest and vegetation area. The vegetated area decreased by 2.43% during 1998–2022 as vegetation area converted to roads and built-up area. The decrease in water resources has also been one of the major reasons for the reduction of vegetation areas.

LST changes

Climate change can have both direct and indirect impacts on vegetation productivity and health, which can be reflected in changes in NDVI values. Direct impacts of climate change on vegetation include

Table 2 List of various vegetation indices

No	Name	Formula	References
1	Ratio vegetation index (RVI)	$\frac{RED}{NIR}$	Omran 2012
2	Difference vegetation index (DVI)	$NIR - RED$	Bendib et al. 2017
3	Transformed vegetation index (TVI)	$\frac{NIR - RED}{NIR + RED} + L$	Dewan and, Yamaguchi 2009
4	Enhanced vegetation index (EVI)	$G * \frac{NIR - RED}{NIR + C1 \times RED - C2 \times B + L}$ C1 = 6, C2 = 7.5,	Weng 2009
5	Normalised difference vegetation index (NDVI)	$\frac{NIR - RED}{NIR + RED}$	Hussain et al. 2022a
6	Soil adjusted vegetation index (SAVI)	$\frac{(NIR - RED)}{(NIR + RED + L)} \times (1 + L)$ L = 0.5	Khan et al. 2020b

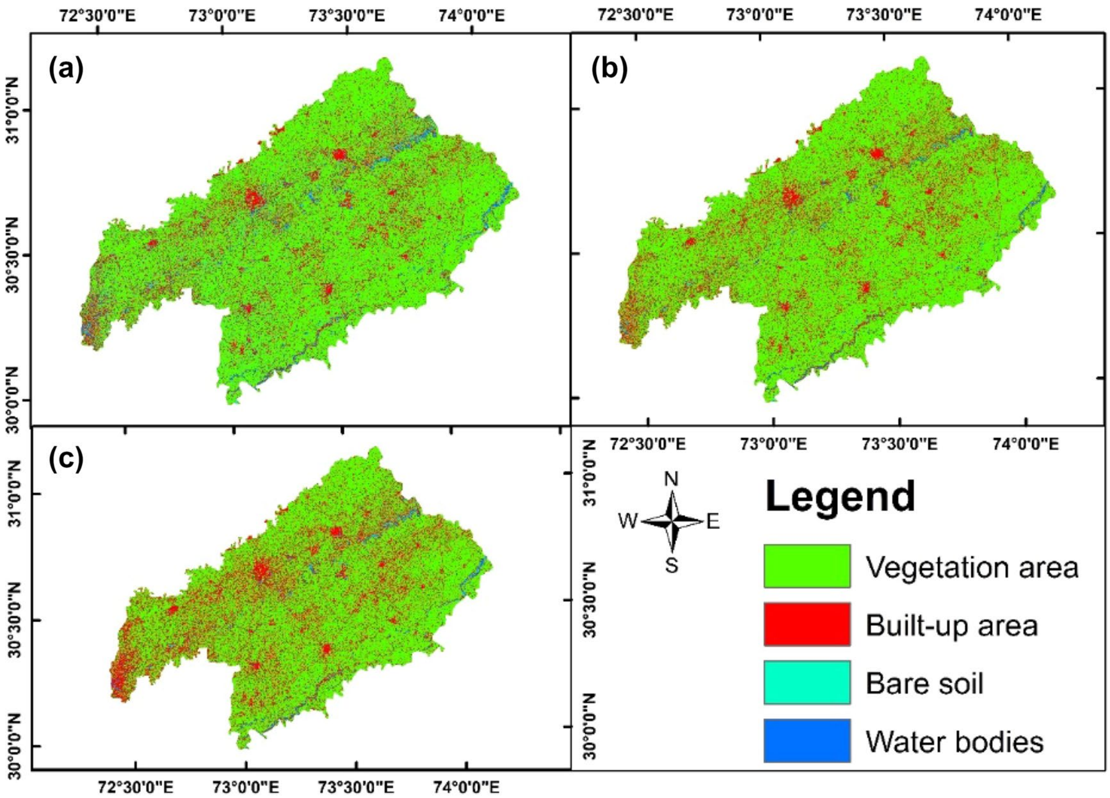

Fig. 3 Maps of LULC in Sahiwal region from **a** 1998, **b** 2010 and **c** 2022

Table 3 Changes in LULC in Sahiwal region from 1998 to 2022

LULC	1998		2010		2022		Changes 1998–2022	
	Ha	%	Ha	%	Ha	%	Ha	%
Vegetation	924,108.7	90.65	917,106.9	89.96	899,335.6	88.22	− 24,773.1	− 2.43
Build-up area	37,126.8	3.64	57,014.85	5.59	80,382.34	7.88	43,255.54	4.24
Bare Soil	45,051.47	4.42	35,034.96	3.44	30,655.12	3.01	− 14,396.4	− 1.41
Water bodies	13,134.52	1.29	10,264.72	1.01	9048.414	0.89	− 4086.11	− 0.40
Total	1,019,421	100	1,019,421	100	1,019,421	100		

changes in temperature, precipitation and CO_2 concentration, which can affect plant growth and development. For example, an increase in temperature can increase the rate of plant growth, whilst a decrease in precipitation can reduce the amount of available water for plant growth. Generally, in winter season, LST varies from 6.7 °C to 26.5 °C during 2022 in the study area (Fig. 4). Generally, in summer season, LST values were calculated in the range of 23.3 °C during 2022 (Table 4) in the study area. Average LST values were calculated at 16.6 °C and 35.15 °C for winter and summer season, respectively. In the north-eastern part displays higher LST values in the study area due to the fast urban expansion and decreased vegetation cover. In contrast, south-western part shows less in LST values due to maximum agricultural and vegetated region.

Vegetation indices

The vegetation indices are commonly used remote sensing index to monitor vegetation health and productivity. The NDVI is based on the difference in reflectance between near-infrared and red light, which is used to estimate the amount and health of vegetation cover in a given area. Changes in NDVI values can reflect changes in vegetation productivity and health, which can be related to climate change. Landsat images have been used

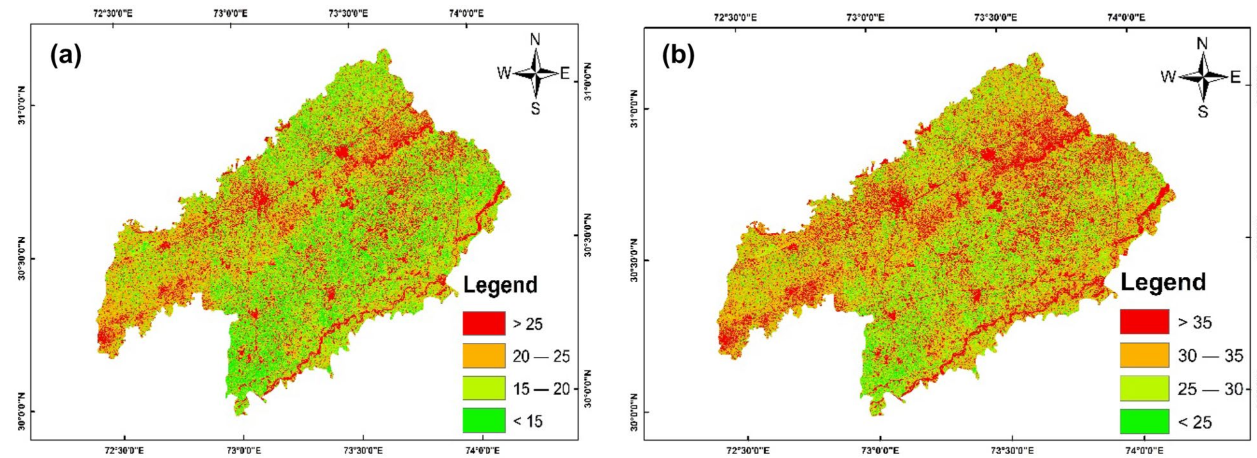

Fig. 4 Map of land surface temperature during **a** winter and **b** summer season

Table 4 Maximum and minimum values of LST during winter and summer season in Celsius

LST	Min	Max	Average
Winter	6.7	26.5	16.6
Summer	23.3	47	35.15

for the assessment of the vegetation indices like (RVI, DVI, TVI, EVI, NDVI and SAVI). These indices models were derived through Landsat images of the year 2022 (Fig. 5). The RVI values ranged from − 0.14 to + 0.53 in the study area, whilst DVI values (minimum − 0.18 and maximum + 0.59). The TVI values ranged from − 0.15 to + 0.67 in the study area, whilst EVI values (minimum − 0.09 and maximum + 0.65) in Sahiwal region (Table 5). The NDVI values were noted as − 0.1 and + 0.70, whilst SAVI values were calculated (− 0.12 and + 0.62) in study area. In Sahiwal region, the average RVI, DVI, TVI, EVI, NDVI and SAVI values were noted as 0.19, 0.21, 0.26, 0.28, 0.30 and 0.25 respectively. The LULC can have a significant impact on the NDVI, which is an important indicator of vegetation health and productivity. The NDVI is a measure of the difference in reflectance between near-infrared and red light, which is used to estimate the amount and health of vegetation cover in a given area. Changes in land use and land cover can affect both amount and quality of vegetation in an area, which can be reflected in changes in NDVI values.

Relationship between temperature and vegetation indices

The regression line produced a definitive explanation, showing a strong negative relationship between vegetation indices and LST in such areas. Regression analysis showed that where LST values were less, NDVI and EVI values were the most significant, but where LST values were maximum, NDVI and EVI values were also less. The change in surface temperature has a direct impact on NDVI and LULC types. For vegetation indices and LST relation, statistical linear regression analysis indicated that kappa coefficient values were $R^2 = 0.79$ for RVI, 0.75 for DVI, 0.78 for DVI, 0.81 for EVI, 0.83 for NDVI and 0.80 for SAVI related with LST in the region of Sahiwal (Fig. 6). The kappa values for three years' analysis indicated that LST and vegetation indices are correlated negatively in the linear regression analysis.

Changes in NDVI values can be used to monitor the impacts of climate change on vegetation productivity and health over time. Studies have shown that NDVI values can be used to identify areas of vegetation productivity and health that are sensitive to changes in climate variables, such as temperature and precipitation. In addition, changes in NDVI values can be used to monitor changes in land use and land cover, which can affect the amount and health of vegetation cover in an area. For example, deforestation or conversion of natural vegetation to agricultural land can lead to a decrease in vegetation cover and a corresponding decrease in NDVI values.

Discussion

This study applied the RS and GIS methods to estimate the surface temperature and LULC amongst farmer's opinion and map the LULC in overall study area. Since LULC shifts have a large impact on local climate, studying their correlation with LST with vegetation index is important for making well-informed decisions when designing new cities. Consequently, we select the most recent era (i.e. 1998, 2010 and 2022) and aggregated the annual mean LST in Sahiwal division of Punjab to assess the correlation between LULC and LST.

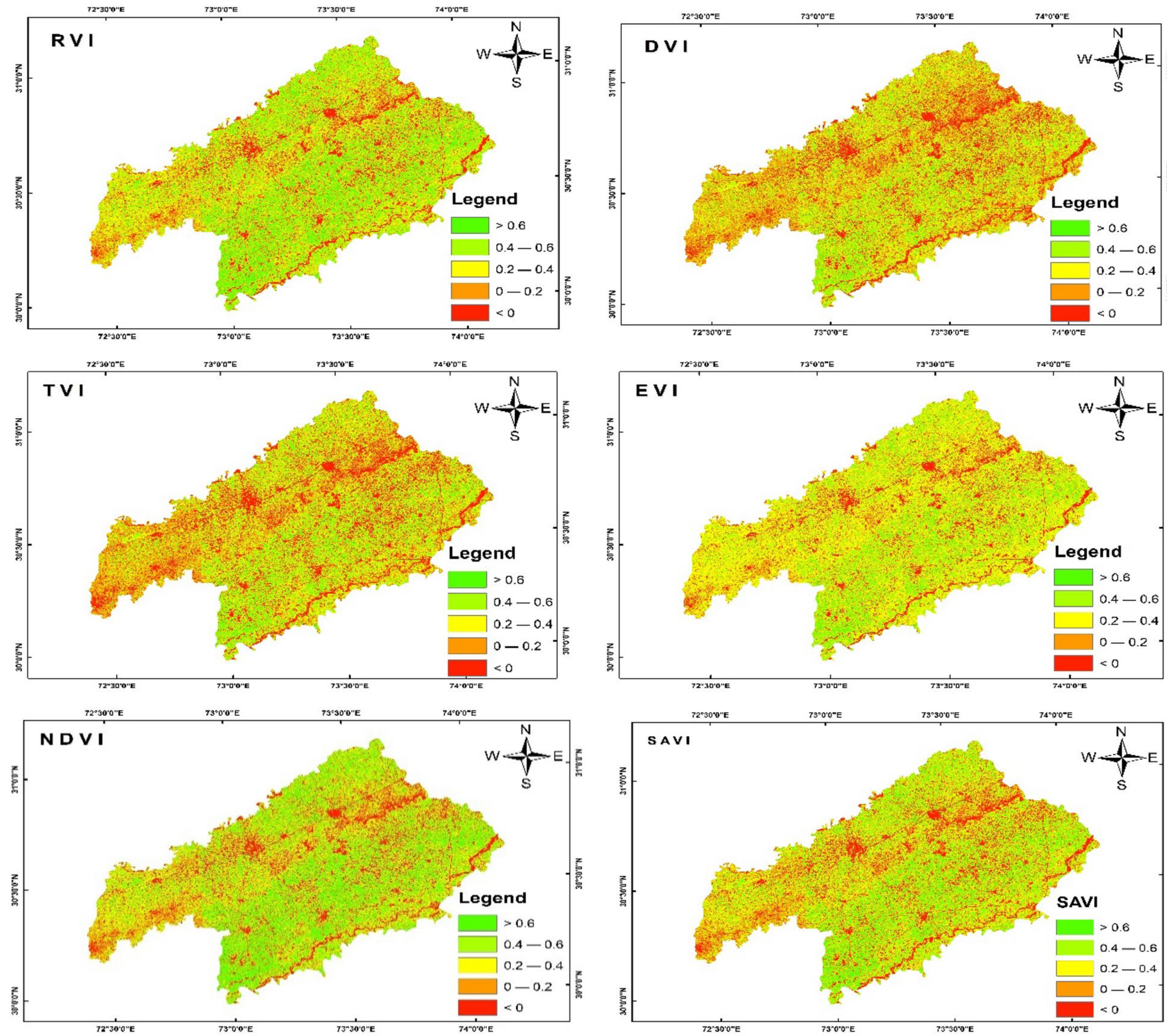

Fig. 5 Maps of all vegetation indices of Sahiwal division

Table 5 Summary of the measured vegetation indices in Sahiwal region

Indices	Min	Max	Average
RVI	− 0.14	0.53	0.19
DVI	− 0.18	0.59	0.21
TVI	− 0.15	0.67	0.26
EVI	− 0.09	0.65	0.28
NDVI	− 0.1	0.7	0.3
SAVI	− 0.12	0.62	0.25

Similarly, LULC data are compiled inside these administrative regions. We then fit the models to examine the capacity of every explained variable to explain the geographical variance in the LST using the per cent LST change (1998–2022) as the predictor variables and the LULC types as the explanatory variables. The last step is to train a multivariate model to learn more about the intertwined relationship between LULC categories and also the LST.

According to our results, vegetation area and water bodies decreased slightly to 2.43% and 0.40% from 1998

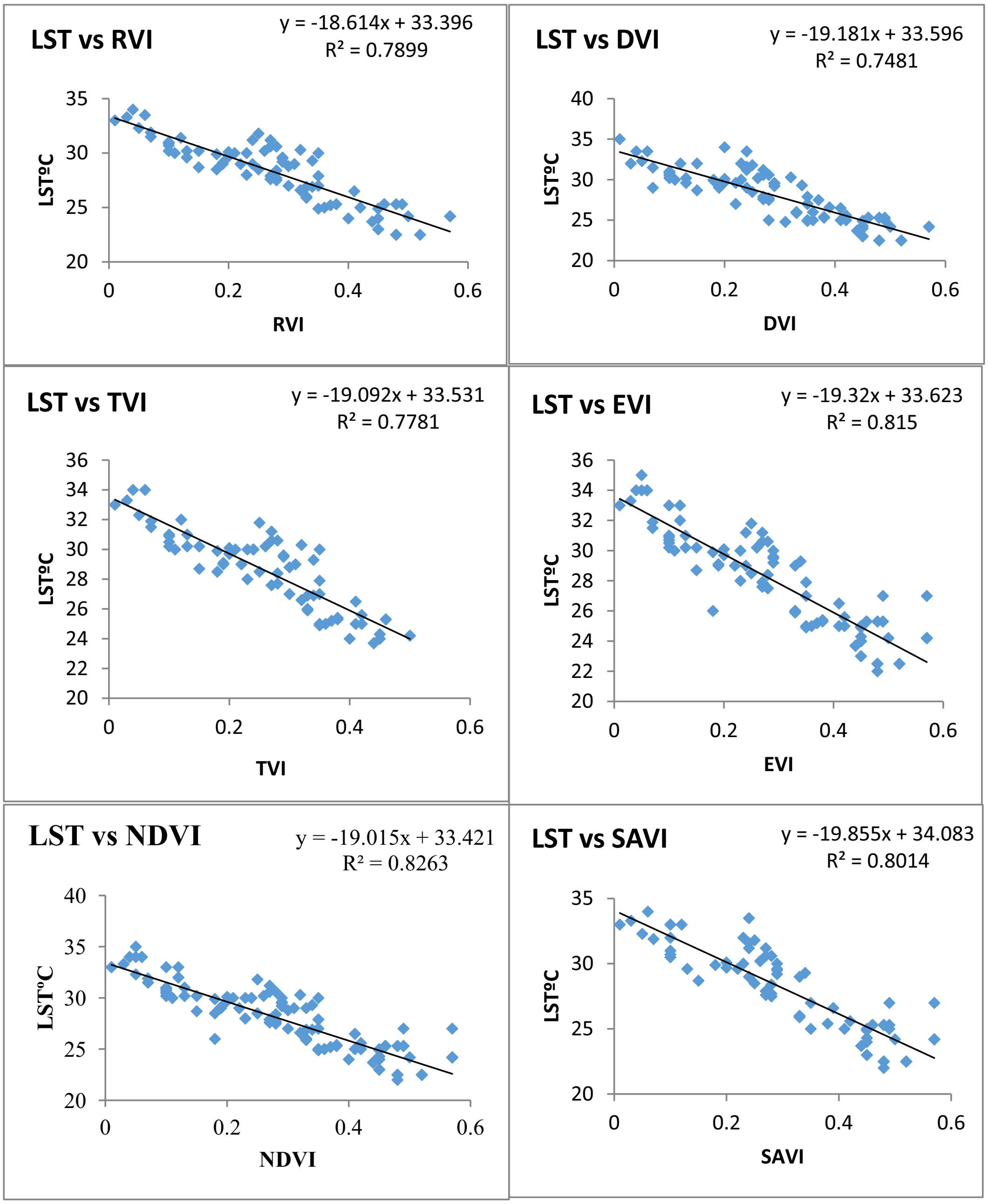

Fig. 6 Linear regression model between vegetation indices and LST of Sahiwal division

to 2022, respectively. Finally, the built-up area increased in coverage from 4.24% in 1998 to 2022 in study area. These results are to be anticipated, considering the substantial importance that each of these LULC determines the LST in any particular location. Initially, all possible LULC categories are chosen as explanatory variables in the multivariate model (Khaliq et al. 2022). The findings survey showed that the agricultural production is highly influenced by climate change. Whilst temperature is also increasing in overall the study area, the survey also mentioned their concerns and notice about rise in temperature, variations in the rainfall patterns. It is necessary to increase the adaptation programmes at maximum levels to meet the basic needs of the people of the area regarding climatic change, which is quite visible in the form of rising temperature (Hussain et al. 2022b, 2023c; Hu et al. 2023).

According to Hussain et al. (2022c; d), several multidimensional models are examined, with goodness-of-fit and values compared to determining the best approach to resolving this problem by reducing the number of response variables. In winter season, LST varies from 6.7 °C to 26.5 °C during 2022. In summer season, LST values were calculated in the range of 23.3 °C during 2022 in the study area. This finding demonstrates that multivariate model can account for 70% of the observed variation of the dependent variable (LST) throughout the investigated region. The geographic performance evaluation of this model is shown by mapping the local R^2 values for every municipality. The substantially poorer goodness-of-fit is found, for example, since most of the study area's metropolitan areas are located in the eastern and northern regions, making the LULC more complicated (Rahman et al. 2017). Alternatively, the LULC is comparatively less complicated in the areas where the model performs best. The need to model these correlations at higher levels and scale down to large metropolitan areas suggests further research is required here. Indirect impacts of climate change on vegetation include changes in extreme weather events, such as floods, droughts and wildfires, which can affect vegetation productivity and health. For example, a drought can lead to reduced vegetation cover and productivity, whilst a wildfire can lead to the loss of vegetation cover (Hussain et al. 2022e; Waleed et al. 2022).

The finding by one of the greatest effective methods, is based on following the temporal variation in vegetation cover, for example, NDVI in Multan and Faisalabad districts of Pakistan. In conclusion, NDVI values can be used to monitor the impacts of climate change on vegetation productivity and health over time (Gillespie et al. 2018; Rani et al. 2018). Changes in NDVI values can reflect both direct and indirect impacts of climate change on vegetation, as well as changes in land use and land cover. The RS technology can be used to monitor changes in NDVI values over time, providing valuable information for sustainable land use management and natural resource management in the context of climate change. The satellite is a significant device that acquires data related to object remotely. Lasting examinations of RS vegetation dynamics held a progressively noticeable part in the study of global ecosystem. Each object from RS images can be recognised due to distinctive spectral landscapes it holds. The RS is quite used for identifying periodic vegetation variations. With the passage of time, functional RS is becoming expected tool to help humans develop in resolving atmosphere allied responsibilities on global, regional and local scales.

Conclusion

This research makes use of satellite imagery to examine changes in LULC and relation of vegetation indices with LST in Sahiwal region of Punjab. The built-up area increased in coverage from 43,255.54 ha (4.24%) from 1998 to 2022 in study area. It is noted that during the last 24 years, almost 24,773.1 ha (2.43%) of vegetation area has been converted to roads and built-up areas. Average LST values were calculated at 16.6 °C and 35.15 °C for winter and summer season, respectively. In the region of Sahiwal, the average RVI, DVI, TVI, EVI, NDVI and SAVI values were noted as 0.19, 0.21, 0.26, 0.28, 0.30 and 0.25, respectively. The findings strengthen our knowledge of LULC dynamics in the research region, which will aid in the development of sustainable development strategies. In addition, the LST assessment and its link to LULC change contribute to gradually influencing adaptation-related choices and policies in Pakistan. Despite the exhaustive nature of the topic matter covered, the authors of this study recognise that it has several significant caveats. In conclusion, changes in LULC can have a significant impact on NDVI values, which is an important indicator of vegetation health and productivity. Understanding the relationship between LULC and vegetation indices can help identify areas of high productivity and areas that are at risk of degradation, which can inform land use planning and natural resource management. The GIS offers the advantage of producing and integrating new data rapidly and cheaply over a wide range of regions and changes resulting from management practices, therefore, aiding the ease in decision-making process. We can predict vegetation situations on the earth's surface concerning to future climate based on examination by previous RS satellite statistics. Outcomes of this research will also help the decision-makers take any measures or decisions for future development.

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Author contributions
Conceptualization, SH and AR; data curation, WJ and MM; formal analysis, SH, HGA, AR and WJ; investigation, MM and AR; methodology, SH, MM and AT; software, AT and MM; supervision, AR; Validation, MM; visualisation, AR and AT; writing—original draft, SH and AR; writing—review and editing, HA, AAAD and HGA.

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Availability of data and materials
The data that support the findings of this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate
This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent
Not applicable.

Competing interests
The authors have no competing interests to declare. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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