UNDERGRADUATE RESEARCH PORTFOLIO REPORT

Spatio-Temporal Assessment of Vegetation Dynamics and Land Surface Temperature in Phoenix, Arizona (2001-2024)

A GIS and Remote Sensing Study Using Landsat Imagery and QGIS

Landsat 5 TM • Landsat 8 OLI/TIRS • NDVI • LST • QGIS

Prepared as an undergraduate GIS and remote-sensing research portfolio project for prospective graduate research and research-assistantship evaluation

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Abstract

This study presents a two-date spatio-temporal assessment of vegetation condition and land surface temperature (LST) in Phoenix, Arizona, using Landsat remote sensing imagery and QGIS-based raster analysis. Two Landsat Collection 2 Level-2 scenes were examined: Landsat 5 TM acquired on 26 June 2001 and Landsat 8 OLI/TIRS acquired on 25 June 2024. Vegetation was evaluated using the Normalized Difference Vegetation Index (NDVI), while thermal conditions were examined using the Landsat surface temperature product converted to degrees Celsius. Change rasters were produced by subtracting the 2001 surfaces from the 2024 surfaces. The mapped outputs indicate extensive low-vegetation and exposed surfaces in both observations, localized areas of higher NDVI in 2024, and strong spatial contrasts in surface temperature. The change maps reveal both vegetation gain and loss as well as localized warming and cooling. Spatial comparison of the NDVI and LST outputs is consistent with the well-established tendency for vegetated surfaces to remain cooler than sparsely vegetated or exposed land in hot urban environments. Because the design uses two selected acquisition dates rather than a continuous time series, the results are interpreted as an inter-date comparison rather than a definitive long-term trend. The project demonstrates an undergraduate-level workflow for integrating satellite data, raster processing, cartographic visualization, and critical environmental interpretation in an arid urban setting.

Keywords: Remote sensing, NDVI, land surface temperature, Landsat, Phoenix, change detection, GIS, QGIS, urban heat

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1. Introduction

Remote sensing provides a consistent framework for observing environmental conditions across large areas and for comparing spatial patterns through time. Two widely used indicators are the Normalized Difference Vegetation Index (NDVI), which summarizes the contrast between red and near-infrared reflectance associated with green vegetation, and Land Surface Temperature (LST), which represents the radiometric temperature of the land surface. NDVI is closely related to fractional vegetation cover and canopy condition, although its interpretation depends on vegetation density, soil background, and sensor characteristics (Carlson & Ripley, 1997). Thermal remote sensing, meanwhile, is widely used in urban climate research because surface temperature responds strongly to land cover, surface moisture, vegetation, and the surface energy balance (Voogt & Oke, 2003).

Phoenix, Arizona, provides a particularly relevant setting for examining these relationships. The metropolitan region is located in a hot, arid environment where irrigated vegetation, impervious surfaces, exposed soil, and developed land occur in close proximity. Previous research in Phoenix has shown that vegetation distribution and land-cover configuration are important components of spatial thermal variability (Jenerette et al., 2007; Buyantuyev & Wu, 2010; Li et al., 2016). Studies have also documented the cooling role of urban vegetation and the broader importance of landscape structure for understanding surface urban heat in the region (Jenerette et al., 2011; Fan et al., 2015; Wang et al., 2016).

The present project compares NDVI and LST for two closely matched late-June Landsat observations, one from 2001 and one from 2024. The purpose is to identify where vegetation condition and surface temperature differ between the selected dates and to assess whether the mapped spatial patterns are consistent with the expected inverse association between vegetation abundance and surface temperature. The study is designed as an undergraduate GIS and remote-sensing research exercise that emphasizes reproducible scene identification, index calculation, change mapping, and critical interpretation.

2. Literature Review and Research Context

2.1 NDVI and the vegetation–temperature relationship

NDVI has long been used as a practical indicator of vegetation greenness and fractional cover in optical remote sensing. Its usefulness for urban thermal studies arises from the role of vegetation in modifying surface energy exchange through shading and evapotranspiration. Weng, Lu, and Schubring (2004) demonstrated that remotely sensed surface temperature and vegetation abundance can be analyzed together to investigate urban heat patterns. Yuan and Bauer (2007) likewise showed that NDVI provides useful information about surface urban heat island conditions, while also noting that impervious surface metrics can add explanatory power. These studies support the use of NDVI–LST comparison as a first-order framework for examining thermal contrasts across heterogeneous urban landscapes.

2.2 Urban heat and vegetation in Phoenix

Phoenix has been a major case study for urban heat research because rapid urbanization occurs within a water-limited desert environment. Jenerette et al. (2007) identified regional relationships among surface temperature, vegetation, and human settlement in metropolitan Phoenix. Buyantuyev and Wu (2010) further showed that surface-temperature patterns vary with land cover and that vegetation plays an important daytime role in explaining spatial temperature differences. Jenerette et al. (2011) quantified substantial cooling associated with vegetation relative to bare soil under hot, dry summer conditions, while also emphasizing the water and social trade-offs involved in producing that cooling service.

More detailed spatial studies have shown that not only the amount of vegetation but also its arrangement matters. Fan, Myint, and Zheng (2015) examined how the spatial configuration of vegetation influences seasonal surface temperatures in central Phoenix. Li et al. (2016) found that both land-cover composition and configuration contribute to neighborhood LST patterns, and Wang et al. (2016) linked spatio-temporal surface urban heat patterns with land-use and land-cover change across the Phoenix metropolitan area. Together, this literature provides a strong regional basis for interpreting the NDVI and LST contrasts mapped in the present study.

2.3 Research gap and undergraduate contribution

The present report does not attempt to reproduce the full statistical and multi-temporal complexity of the Phoenix urban heat literature. Instead, it contributes a transparent two-date workflow that links publicly available Landsat data to NDVI, LST, and change-detection outputs in QGIS. Its value for undergraduate research lies in demonstrating the complete analytical chain—from scene selection and band identification to raster calculation, standardized visualization, spatial interpretation, and explicit recognition of limitations. This provides a foundation that can be extended with zonal statistics, correlation analysis, additional dates, and land-use/land-cover data in future research.

3. Research Questions and Objectives

3.1 Research questions

1. How does the spatial distribution of NDVI differ between the selected June 2001 and June 2024 Landsat observations?
2. How does the spatial distribution of LST differ between the same two observations?
3. Where do the NDVI and LST change maps indicate vegetation gain/loss and localized warming/cooling?
4. Are the mapped spatial patterns consistent with the expected inverse association between vegetation condition and land surface temperature?

3.2 Objectives

- Derive NDVI maps for Phoenix, Arizona, for 2001 and 2024.
- Derive LST maps for the same study area and acquisition dates.
- Produce NDVI-change and LST-change maps using a 2024-minus-2001 differencing framework.
- Interpret spatial correspondence between vegetation condition and land surface temperature.
- Document the workflow and its limitations in a form suitable for undergraduate research and future extension.

4. Study Area

The study area covers Phoenix, Arizona, USA, and surrounding metropolitan terrain within the selected Landsat scene. The area of interest was defined in USGS EarthExplorer by locating Phoenix and drawing a polygon around the metropolitan area and adjacent terrain used in the completed workflow. The mapped extent contains a heterogeneous mixture of developed and exposed surfaces, localized vegetation, and water features. This mixture is appropriate for comparative NDVI and LST analysis because strong surface contrasts occur within the same regional climate setting.

> For strict reproducibility in a future journal-oriented version, the manually defined polygon should be replaced or supplemented with a formally archived boundary file and reported area/coordinate reference system. The present report retains the exact project extent used to generate the submitted maps and clearly identifies the satellite scenes from which that extent was processed.

5. Data and Materials

Year	Sensor / Product	Scene ID	Acquisition date
2001	Landsat 5 TM, Collection 2 Level-2	LT05_L2SP_036037_20010626_20200906_02_T1	26 June 2001
2024	Landsat 8 OLI/TIRS, Collection 2 Level-2	LC08_L2SP_036037_20240625_20240709_02_T1	25 June 2024

Table 1. Landsat scenes used in the analysis.

Raster processing and cartographic layouts were completed in QGIS 3.44.8. For NDVI, the red and near-infrared bands were used: Landsat 5 Band 3 (red) and Band 4 (NIR), and Landsat 8 Band 4 (red) and Band 5 (NIR). For thermal analysis, the Collection 2 Level-2 surface-temperature products ST_B6 (Landsat 5) and ST_B10 (Landsat 8) were used. The selected acquisition dates differ by only one calendar day within late June, which reduces—but does not eliminate—seasonal differences between the two observations.

6. Methodology

6.1 Data acquisition and project organization

The Landsat scenes were downloaded from USGS EarthExplorer after defining the Phoenix area of interest and selecting low-cloud summer imagery. The downloaded archives were extracted into separate 2001 and 2024 directories. Relevant spectral and thermal bands were loaded into QGIS, and processed outputs were stored separately from the original data. Scene identifiers and acquisition dates are reported in Table 1 so the source imagery can be independently located.

6.2 NDVI derivation

NDVI was calculated using the standard expression:

$$\mathbf{NDVI = (NIR - Red) / (NIR + Red)}$$

For 2001, the Landsat 5 NIR and red channels correspond to Bands 4 and 3; for 2024, the Landsat 8 NIR and red channels correspond to Bands 5 and 4. Landsat Collection 2 Level-2 surface-reflectance data are distributed as scaled integer values; USGS documents a multiplicative factor of 0.0000275 and an additive offset of −0.2 for converting surface reflectance digital numbers to reflectance. For a publication-oriented replication, this scaling step should be explicitly verified before NDVI computation and documented in the processing log (U.S. Geological Survey, n.d.-a).

The completed maps use the same NDVI class limits in both years to support direct visual comparison:

Class	NDVI range	Interpretation
1	≤ 0.0208	Water / very low vegetation
2	0.0208–0.0842	Bare or sparsely vegetated land
3	0.0842–0.1477	Low vegetation
4	0.1477–0.2112	Moderate vegetation
5	> 0.2112	Relatively denser vegetation

Table 2. NDVI classification used consistently for the 2001 and 2024 maps.

The thresholds above are retained from the completed project workflow. Because the original draft did not record a formal rule or published source for these exact break values, they should be treated as project-specific visualization classes rather than universal ecological thresholds.

6.3 LST derivation

Landsat Collection 2 Level-2 surface-temperature products were used for thermal analysis. USGS specifies a scale factor of 0.00341802 and an additive offset of 149.0 for the Collection 2 surface-temperature product. The scaled value is in Kelvin and was converted to degrees Celsius by subtracting 273.15 (U.S. Geological Survey, n.d.-b):

$$\mathbf{LST\ (°C) = [(DN \times 0.00341802) + 149.0] - 273.15}$$

The resulting LST rasters were classified into seven temperature classes. A consistent cool-to-hot color progression was used for interpretation, with blue representing relatively cool surfaces and red representing relatively hot surfaces.

6.4 Change detection

Change rasters were generated by subtracting the 2001 surface from the 2024 surface:

$$\mathbf{NDVI_change = NDVI_2024 - NDVI_2001}$$

$$\mathbf{LST_change = LST_2024 - LST_2001}$$

Positive NDVI-change values represent higher NDVI in the 2024 observation, whereas negative values represent lower NDVI. Positive LST-change values represent higher surface temperature in the 2024 observation, whereas negative values represent lower surface temperature. These differences are interpreted as inter-date changes; they should not be treated as a continuous 23-year trend without additional observations.

6.5 Cartographic standardization and interpretive approach

Final maps were prepared in QGIS Print Layout with a title, legend, scale bar, north arrow, and explanatory caption. Consistent class limits were applied across the annual NDVI maps, and a consistent temperature-class scheme was used for the LST maps. Results were interpreted through direct spatial comparison of vegetation, temperature, and change patterns. No inferential regression or pixel-level correlation was included in the completed workflow; accordingly, the discussion uses cautious language such as “spatially consistent with” rather than presenting a statistically estimated causal relationship.

7. Results

7.1 NDVI in 2001

The 2001 NDVI map indicates that much of the selected study area falls within low-NDVI or sparsely vegetated classes. Red and orange categories occupy broad zones, while higher-NDVI green classes occur more locally. Blue areas correspond to water or very low NDVI values. The map therefore establishes a baseline in which exposed and low-vegetation surfaces are spatially extensive.

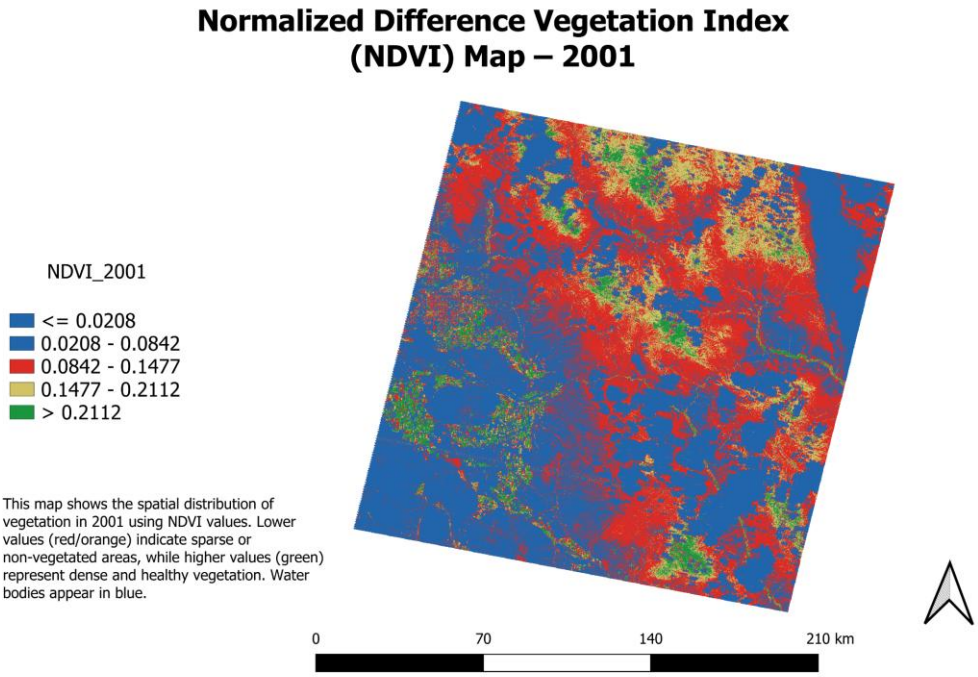


Figure 1. Normalized Difference Vegetation Index (NDVI) map for Phoenix, Arizona, 2001.

7.2 NDVI in 2024

The 2024 NDVI map shows a broader visual presence of moderate and relatively higher NDVI classes in several sectors compared with the 2001 map. Low-vegetation surfaces remain extensive, but the spatial distribution of green classes suggests localized increases in vegetation greenness or cover on the selected 2024 observation date.

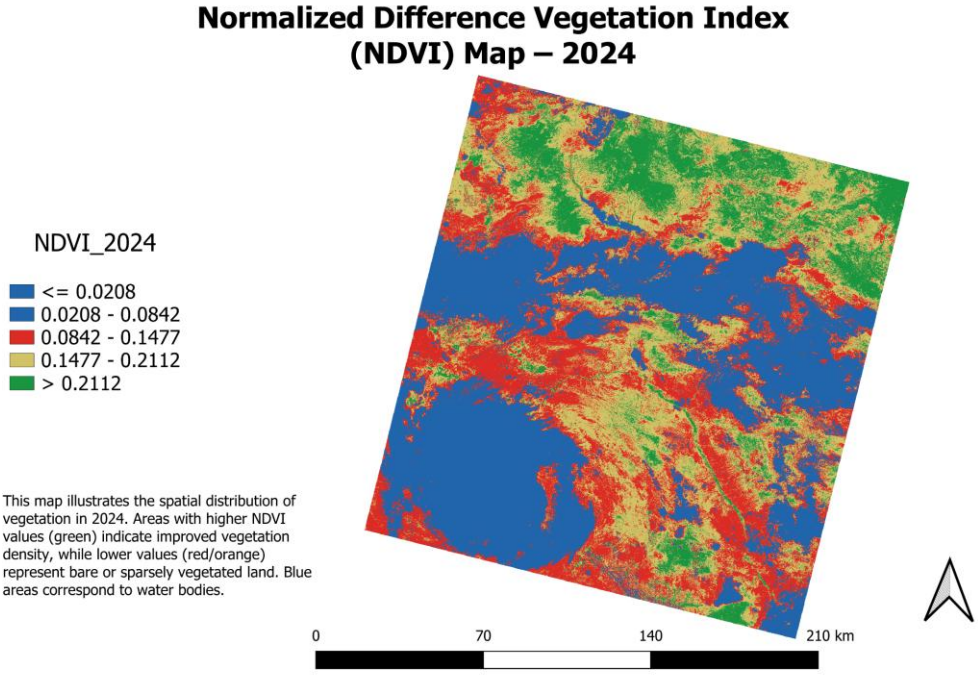


Figure 2. Normalized Difference Vegetation Index (NDVI) map for Phoenix, Arizona, 2024.

7.3 NDVI change (2001–2024)

The NDVI change map reveals a spatially heterogeneous pattern. Negative classes shown in red identify locations where NDVI is lower in 2024 than in 2001; near-neutral classes indicate limited difference; and green classes identify locations with higher NDVI in 2024. The coexistence of positive and negative values demonstrates that change across the selected dates is not spatially uniform.

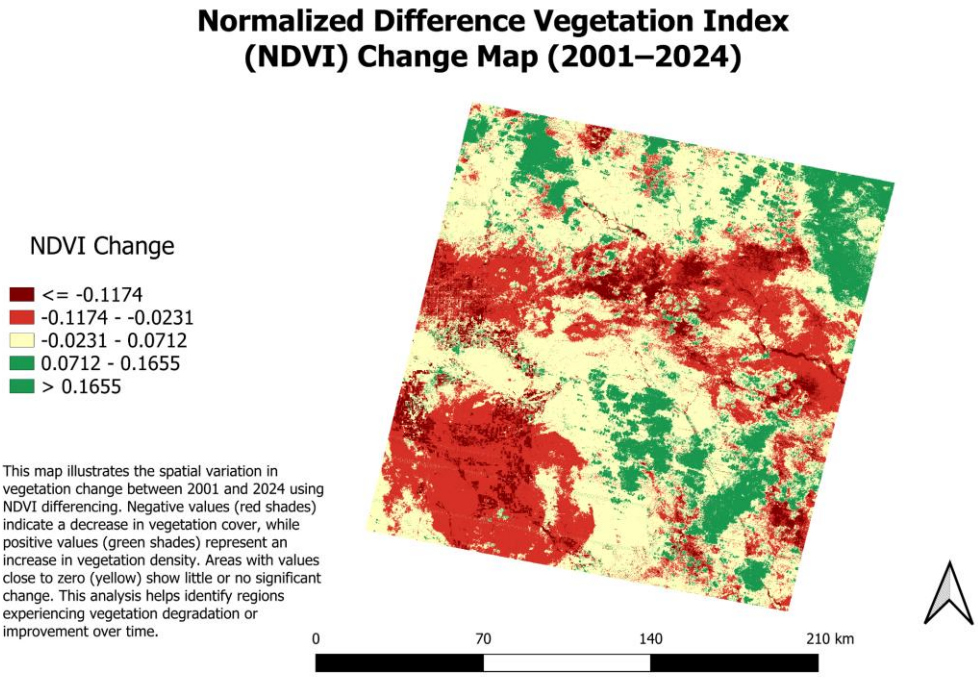


Figure 3. NDVI change map showing areas of lower and higher NDVI between the selected 2001 and 2024 observations.

7.4 LST in 2001

The 2001 LST map shows clear thermal differentiation across the study area. Cooler classes occur in spatial clusters that include water features and relatively vegetated sectors, whereas warmer classes occur across exposed or low-vegetation surfaces. The pattern is consistent with expected differences in surface energy balance across contrasting land-cover types.

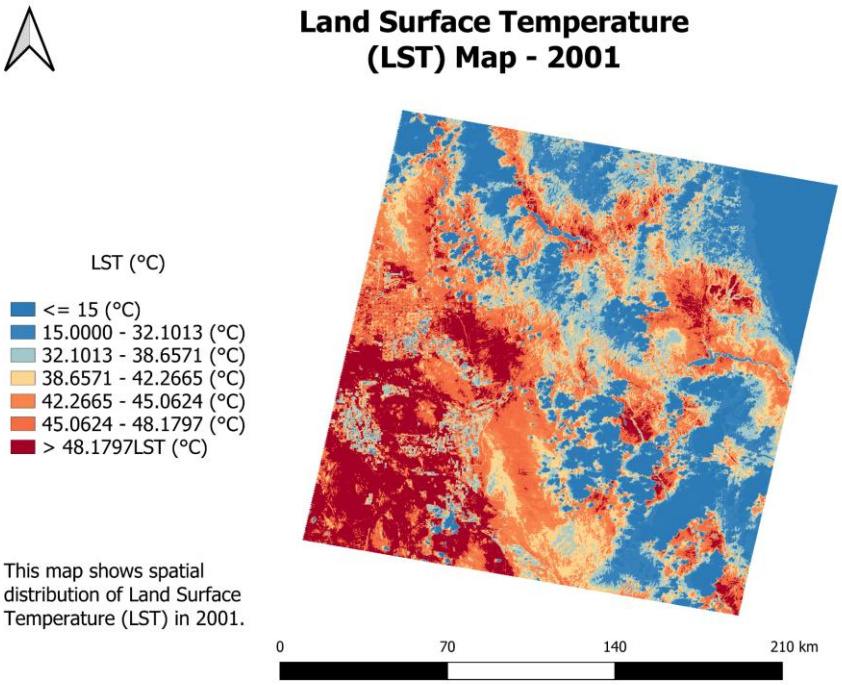


Figure 4. Land Surface Temperature (LST) map for Phoenix, Arizona, 2001.

7.5 LST in 2024

The 2024 LST map also displays strong spatial contrasts between relatively cool and hot surfaces. High-temperature classes remain extensive, while cooler zones are associated visually with selected water and vegetated areas. The distribution differs from the 2001 observation in several sectors, motivating direct examination of the change surface.

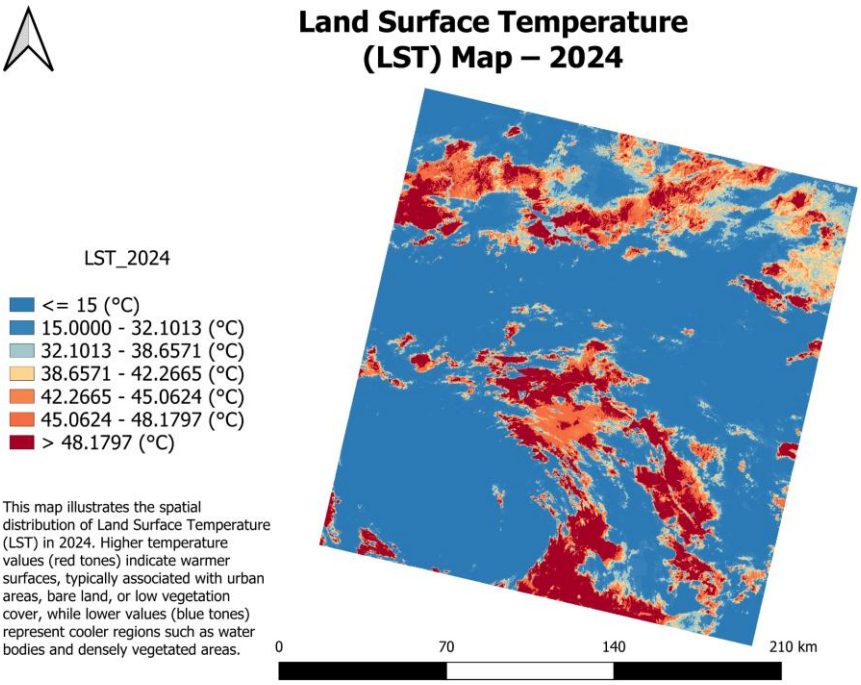


Figure 5. Land Surface Temperature (LST) map for Phoenix, Arizona, 2024.

7.6 LST change (2001–2024)

The LST change map identifies both positive and negative differences across the study area. Red classes indicate locations where the selected 2024 observation is warmer than the 2001 observation, while blue classes indicate locations where it is cooler. The patchwork of warming and cooling emphasizes that the two observations differ spatially rather than by a single uniform temperature shift.

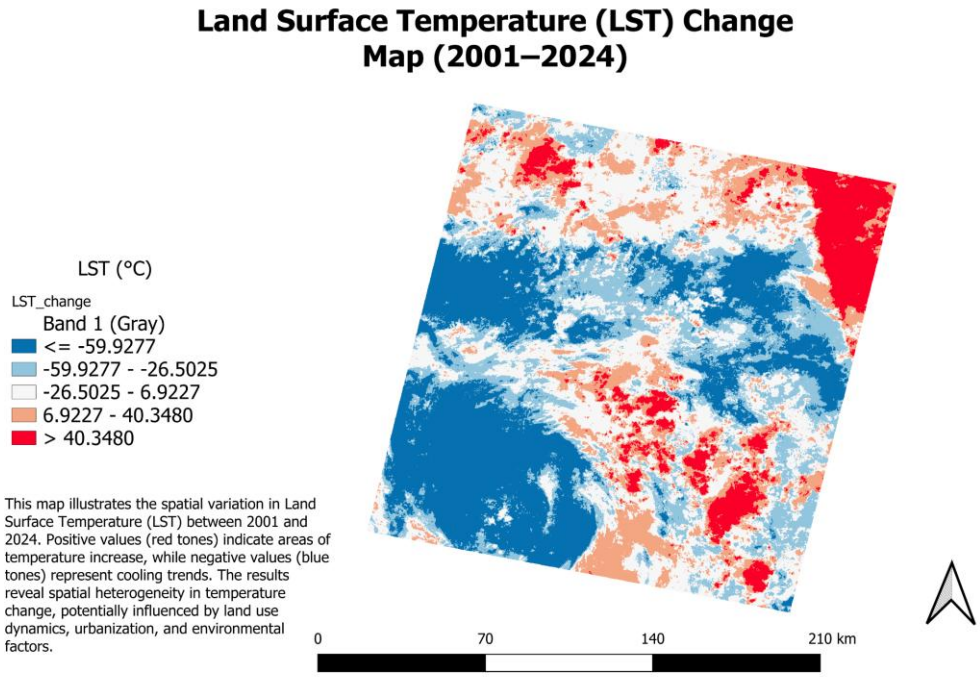


Figure 6. LST change map showing spatially heterogeneous warming and cooling between the selected 2001 and 2024 observations.

8. Discussion

8.1 Spatial relationship between vegetation and surface temperature

Across the completed maps, relatively vegetated areas generally coincide with cooler surface-temperature classes, while low-NDVI and exposed surfaces more often coincide with warmer classes. This visual relationship is consistent with a large body of remote-sensing research showing that vegetation can reduce surface heating through shading and evapotranspiration (Weng et al., 2004; Yuan & Bauer, 2007). It is also consistent with Phoenix-specific research in which vegetation abundance and arrangement have been linked to surface-temperature variation (Jenerette et al., 2007; Buyantuyev & Wu, 2010; Fan et al., 2015).

The present study, however, does not estimate the strength of that relationship statistically. Therefore, the maps support a spatial interpretation rather than a numerical claim about correlation magnitude. A future extension should sample or aggregate co-located NDVI and LST pixels and calculate Pearson or Spearman correlation, ideally with spatial diagnostics because neighboring pixels are not statistically independent.

8.2 Inter-date vegetation change

The NDVI comparison indicates a mixed pattern rather than a uniform increase or decline. Localized higher NDVI in 2024 may reflect changes in vegetation cover, irrigated landscaping, land use, antecedent moisture, or other environmental conditions. Because only one scene is analyzed for each year, “vegetation gain” in

this report should be interpreted as higher NDVI on the selected 2024 date rather than definitive long-term ecological improvement.

8.3 Inter-date thermal change

The LST change surface also contains both positive and negative differences. Phoenix research has shown that urban thermal patterns are shaped by vegetation, impervious surfaces, land-cover configuration, and broader land-use change (Li et al., 2016; Wang et al., 2016). The heterogeneous pattern in the present results is therefore plausible, but attribution of a specific warm or cool patch to a particular cause would require additional land-cover, meteorological, or neighborhood data.

8.4 Implications for GIS and remote-sensing research

At the undergraduate level, the study demonstrates how a relatively compact Landsat workflow can reveal meaningful environmental structure that is not obvious from a single map. Combining NDVI, LST, and change detection provides a framework for formulating stronger follow-up questions about urban greening, heat exposure, land-cover transitions, and the effectiveness of vegetation as a cooling strategy. The explicit limitations identified here also define a logical research pathway from descriptive GIS analysis toward more advanced quantitative remote sensing.

9. Limitations and Future Research

- Two-date design: the study compares two selected late-June observations and cannot establish a continuous 2001–2024 trend.
- Quantitative validation: the completed workflow does not yet include class-area summaries, zonal statistics, or pixel-level NDVI–LST correlation/regression.
- Cross-sensor comparison: Landsat 5 TM and Landsat 8 OLI/TIRS have different sensor characteristics; a publication-grade extension should document any harmonization and uncertainty treatment.
- Preprocessing documentation: a reproducible extension should preserve a processing log for surface-reflectance scaling, QA/cloud masking, raster alignment, resampling, projection, and no-data handling.
- Classification thresholds: the exact NDVI class breaks were retained from the original workflow but were not tied to a published ecological classification; future analysis should justify or replace them with a documented method.
- Causal interpretation: vegetation, surface moisture, impervious cover, irrigation, terrain, and weather can all influence LST; the present study does not isolate their individual effects.
- Future expansion: additional comparable dates, land-use/land-cover classification, zonal statistics, and spatial correlation/regression would convert the current two-date assessment into a stronger longitudinal research design.

10. Reproducibility and Data Availability

The source scenes are identified by sensor, acquisition date, and USGS scene ID in Table 1 and can be obtained through USGS EarthExplorer. The core processing environment used in the completed project was QGIS 3.44.8. The equations, band designations, class limits, and differencing convention used in the report are documented above so that the workflow can be independently reconstructed. For a future research release, the QGIS project file, area-of-interest boundary, processing log, and derived raster statistics should be archived alongside the report.

11. Conclusion

This study produced an undergraduate-level spatio-temporal remote-sensing assessment of vegetation condition and land surface temperature in Phoenix, Arizona, using Landsat observations from 2001 and 2024. Annual NDVI and LST maps, together with corresponding change surfaces, show that both vegetation and thermal conditions vary substantially across space and that differences between the two selected dates are spatially heterogeneous. The mapped outputs are consistent with the widely reported tendency for greener urban surfaces to be cooler than sparsely vegetated or exposed surfaces.

The principal contribution of the project is the integration of public satellite data, QGIS raster analysis, change detection, cartographic communication, and literature-based interpretation within a transparent workflow. The study also demonstrates appropriate caution by distinguishing a two-date comparison from a continuous long-term trend and by identifying the statistical and preprocessing steps required for a stronger publication-oriented extension. These features make the project a suitable research sample for demonstrating undergraduate readiness for further GIS, remote sensing, and environmental-data work.

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