JOURNAL OF INFORMATION AND COMMUNICATION TECHNOLOGY
https://e-journal.uum.edu.my/index.php/jict

How to cite this article:
Mansor, N. S., Awang, H., Min, C. K., Bluszcz, A., Candra, A., & Khamis, S. (2025). Monitoring land surface temperature on urban expansion using normalised difference vegetation index and google earth engine. *Journal of Information and Communication Technology*, *24*(3), 22-43. https://doi.org/10.32890/jict2025.24.3.2

Monitoring Land Surface Temperature on Urban Expansion using Normalised Difference Vegetation Index and Google Earth Engine

[1]Nur Suhaili Mansor, [2]Hapini Awang, [3]Chong Kar Min, [4]Anna Bluszcz, [5]Ade Candra & [6]Shakiroh Khamis
[1,2&3]Institute for Advanced and Smart Digital Opportunities, School of Computing, Universiti Utara Malaysia, Malaysia
[4]Faculty of Mining, Safety Engineering and Industrial Automation, Silesian University of Technology, Poland
[5]Faculty of Computer Science and Information Technology, Universitas Sumatera Utara, Indonesia
[6]Kulliyyah of Information and Communication Technology, International Islamic University Malaysia, Malaysia

[*1]nursuhaili@uum.edu.my
[2]hapini.awang@uum.edu.my
[3]karminchong88@gmail.com
[4]Anna.Bluszcz@polsl.pl
[5]ade_candra@usu.ac.id
[6]shakirohk@gmail.com
*Corresponding author

Received: 15/1/2025 Revised: 1/4/2025 Accepted: 13/4/2025 Published: 31/7/2025

ABSTRACT

Urban expansion and the corresponding increase in land surface temperature (LST) are significant environmental concerns worldwide. In Malaysia, the urbanisation rate has increased dramatically from 1970 to 2020, according to the Statistics Department. This rapid development, particularly in states such as Selangor, Johor, and Penang, has intensified surface heating and reduced ecological resilience, exacerbating the effects of climate change. Despite growing recognition of these impacts, many existing studies rely on static or predictive models that lack spatial precision and real-time monitoring. Malaysia has recorded an average LST increase since 2000, highlighting the urgent need for systematic, ICTenabled frameworks to monitor and respond to thermal and environmental changes. This study aims to develop a scalable and replicable framework for monitoring LST changes linked to urbanisation by integrating vegetation-based indices and remote sensing technologies. The framework is demonstrated through a case study of Perak, Malaysia, which is an area experiencing accelerated urban growth and ecological stress. The study was conducted in four structured phases. First, satellite imagery from Landsat 8 and Moderate Resolution Imaging Spectroradiometer (MODIS) was collected using Google Earth Engine (GEE). Second, data preprocessing was performed to derive NDVI, Vegetation Cover Proportion (Pv), and surface Emissivity (Em). Third, spatial and temporal patterns were visualised. Finally, analysis was conducted to examine correlations between LST variation and land cover changes from 2019 to 2023. Findings reveal a consistent rise in LST and a decline in vegetation health in urbanising and deforested zones, confirming a reinforcing feedback loop of surface heat accumulation and ecological degradation. This ICT-driven framework provides a practical model for real-time environmental monitoring, supporting data-informed strategies in urban planning, reforestation, and climate adaptation, particularly in rapidly developing, climate-vulnerable contexts such as Malaysia.

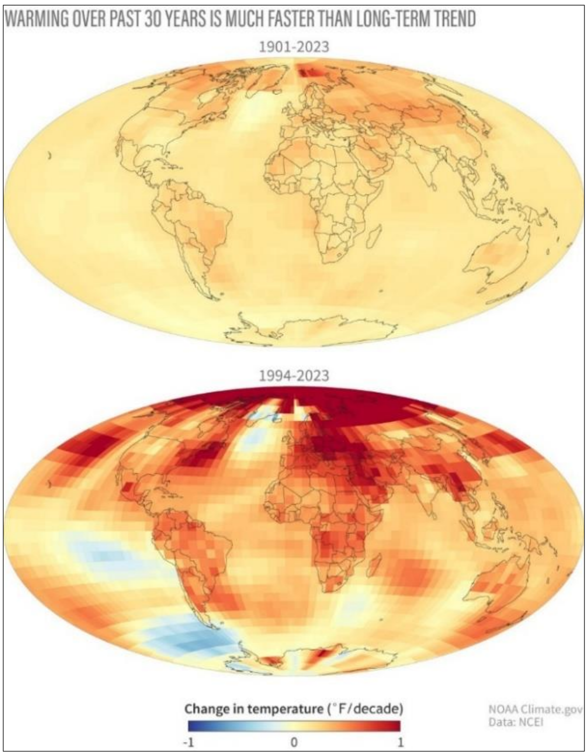
Keywords: Land Surface Temperature (LST), Google Earth Engine (GEE), Normalised Difference Vegetation Index (NDVI), Vegetation Cover Proportion (Pv), Emissivity (Em).

INTRODUCTION

With the continuously increasing intensity of global warming, the Earth's climate system has undergone significant development, with the primary contributor being the growth of greenhouse gases in the atmosphere over time (Intergovernmental Panel on Climate Change (IPCC), 2023). This event has had a profound influence on the general climate change, which affects the frequency and severity of rain, floods, storms, droughts, and prolonged heatwaves (Tang, 2019). Although the concepts of climate change and global warming are often used interchangeably, the former term implies a more comprehensive set of climatic fluctuations, encompassing temperature changes, sea level fluctuations, and ecological imbalances (Riedy, 2016). The United Nations Framework Convention on Climate Change (UNFCCC) reiterates that climate change is caused by both natural variability and human activities that alter the global atmospheric composition (Yadav, 2021). According to recent observations, the surface temperature has increased more rapidly between 1994 and 2023 than the long-term average temperature recorded during the 20th century (1901-2023), as presented in Figure 1 (Rebecca & LuAnn, 2024). The latter warming is especially pronounced in polar regions, such as the Arctic, where the lack of reflective ice cover has further increased heating (Lindsey & Dahlman, 2020).

Figure 1

Annual Land Surface Temperature Trends over the Last Few Decades Compared to the 20th Century (Rebecca & LuAnn, 2024)



Land Surface Temperature (LST) is one of the key parameters that has become central to geophysical activities, serving as a crucial instrument for measuring climate dynamics (Li et al., 2023). LST is vital to determining heat distribution, vegetation stress, and the effects of urban heat islands, the latter reflecting the thermal infrared radiation emitted by the Earth's surface (Jaafar et al., 2020; Abu El-Magd et al., 2024). Monitoring LST changes over a specific period can provide researchers with valuable data regarding the scope and effects of global warming in various locations, contributing to the development of measures to combat climate change (Abbass et al., 2022; Liu et al., 2020).

Malaysia, characterised by an equatorial climate, is becoming increasingly vulnerable to temperature changes. The rapid course of urbanisation has altered the natural cover with impervious surfaces, decreasing vegetation density and altering microclimates. In 2019, 20 districts in Malaysia were under the red alert category, as classified by the Malaysian Meteorological Department (MET), with registered maximum temperatures of 37 °C and 40 °C. The conditions are similar to those observed during the 1998 El Niño event, resulting in temperatures of approximately 40 °C in the peninsula (Azuar & Mardhiah, 2024). These are the states that are most affected: Perlis, Kedah, Perak, Pahang, and Selangor. Specifically, Perak registered extreme surface warming, with the New Straits Times ranking the city of Ipoh in the first place on the upward trend of temperature between 1998 and 2019, 6.75, citing urbanisation, deforestation due to development, and the urban heat island phenomenon as the leading causes of surface warming (Solhi, 2021).

Despite rising concerns, there is no study with detailed and spatially resolved investigations that systematically evaluates the LST trends in Perak based on multi-source satellite imagery. The literature tends to use single indices alone, such as the Normalised Difference Vegetation Index (NDVI), without the use of supplementary parameters that would increase the thermal accuracy. Moreover, when commercial analytical platforms are used, the scalability of such research is frequently low, making it challenging to reproduce the results. In situations where timely and deterministic outputs are required, this limitation is particularly problematic. Thus, a gap has been highlighted in the use of multi-parametric and open-access methods of observing surface temperatures more realistically and inexpensively. This gap is necessary to improve the knowledge about localised heat patterns and aids adaptive land-use and climate resilience plans.

This study visualise and map the LST across Perak in each year between the period of 2019 and 2023 based on satellite; analyse how LST has changed with time and the distribution for five years; and how NDVI, Vegetation Cover Proportion (Pv), and Emissivity (Em) have been combined in Google Earth Engine (GEE) to improve LST estimation using open-access tools. By addressing these objectives, the study aims to provide a robust and cost-effective framework for environmental monitoring, as well as support data-driven decision-making for climate adaptation and sustainable urban development in rapidly changing regions.

LITERATURE REVIEW

Remote Sensing for Environmental Monitoring

Remote sensing (RS) has become a cornerstone technology for observing, monitoring, and analysing Earth's surface phenomena, particularly within the context of environmental and climate studies. It enables the systematic collection of geospatial data over large areas and extended periods, facilitating the assessment of changes in land use, vegetation cover, and thermal properties of the Earth's surface. Satellite RS platforms have significantly enhanced spatial, temporal, and spectral resolution over the past few decades, making them an effective tool for both researchers and policymakers to monitor environmental change in near real-time.

Nevertheless, the increasing amounts and challenges of remotely sensed data have challenged the conventional methods of data analysis. Geographic information system (GIS) solutions that run on desktop computers are usually not very efficient at handling large-scale time-series data, especially when incorporating the use of multiple sensors and high-resolution images. According to Amani et al. (2020), the shift to cloud computing environments is now a necessity to handle the growing pressure to provide fast and scalable analysis. Unlike on-site systems, cloud-based systems like GEE are now preferred for performing environmental applications due to their computational efficiency, ease of use, and integration with multiple satellite archives.

Some of the most popular RS satellite missions are the Landsat Series and Moderate Resolution Imaging Spectroradiometer (MODIS). The Landsat series of satellites have orbited since 1972 and provide almost 50 years continuous observation of the Earth under the joint management of NASA and the USGS Landsat 8, however, introduced in 2013, has optical sensors and thermal infrared, and the tools can capture photos at 30 m (reflective bands) and 100 m (thermal band) A scaling. Specifically, the Thermal Infrared Sensor (TIRS) enables the precise measurement of LST and helps detect urban heat abnormalities (Anandababu et al., 2018). With this good temporal and spatial performance, the satellite can be effectively used to track the natural dynamics in the environment, including urban sprawl, deforestation, and crop conditions, among others.

MODIS is implemented on the Terra and Aqua satellites of NASA and would provide less spatial resolution but a greater frequency of captures. For example, the 8-day composite LST product MOD11A2 provides LST and surface emissivity with a spatial resolution of 1 km. This kind of temporal depth allows for the study of seasonal and interannual thermal processes and vegetation changes within climatic regions. In addition, multi-year trend studies of regional-to-global-scale land environments using long-term time series data from MODIS can be invaluable instruments. Such data are consistent over time, which can help with investigations of climate variability, the occurrence of extreme heat, and indicators of ecological stress (Bartkowiak et al., 2019; Adeyeri et al., 2024).

There is a great application of both Landsat 8 and MODIS data in research on land-atmosphere interactions, including surface energy balance, evapotranspiration estimation, and urban heat island analysis. Their joint application enables scientists to leverage the spatial resolution of Landsat and enhance the coverage of MODIS, providing a comprehensive view of landscape change and heat behaviour. In this regard, RS is an imperative tool for facilitating land management, disaster risk reduction, and climate adaptation planning by providing operational and evidence-based information.

GEE and Multi-Parameter LST Estimation

The progress of cloud-based geospatial systems has become a turning point in the processing and utilisation of satellite imagery in the environmental monitoring sector. GEE is one of the most powerful tools in this field, introduced by Google in 2010. GEE is an open-source and cloud-based framework for managing and analysing massive sets of geospatial data across planetary dimensions. The site provides direct access to a large cloud-based collection of long-term archives and active observation of Earth data in the forms of optical, radar, and thermal data collected by various satellite programs, including Landsat, MODIS, Sentinel, and NOAA-AVHRR (Ermida et al., 2020). Such data is available via a set of advanced libraries in JavaScript and Python combined with an extensive range of performance visualisation functions promoted by the GEE Code Editor and Application Programming Interface (API).

Unlike other RS software at the desktop level (such as that used in our laboratory), GEE does not require the storage of local data or specialised high-performance computing infrastructure. The server-side implementation of geospatial algorithms exhibits better computational performance because it can be run at a higher speed than client-side applications, allowing users to carry out large-scale tasks with a level of technical effect that appears to be comparably lightweight. These features make the method especially beneficial for temporal analysis, such as the long-term tracking of LST, which can potentially produce huge image files within a few-year period, ranging from gigabytes to terabytes in size (Tamiminia et al., 2020). The fact that GEE is reproducible and accessible is of great value in developing nations and in universities where costly commercial software is not readily available.

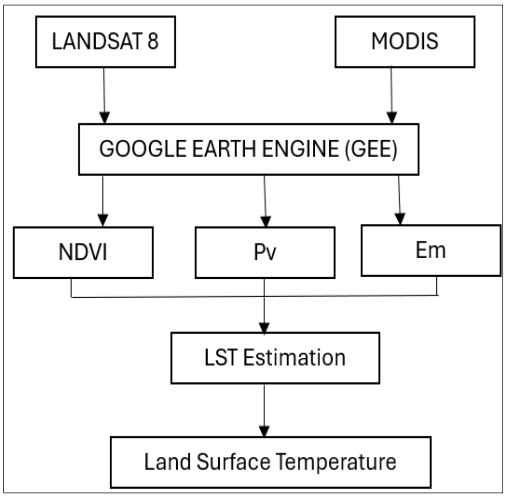
In the current research work, LST values were calculated using the GEE compute platform, which integrates several input parameters from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) as well as MODIS MOD11A2 products. Nonetheless, rather than employing thermal bands alone, the research adopts a multi-parametric approach to enhance the accuracy of the findings and make them more interpretable. In particular, the NDVI, Pv, and Em were combined to determine the surface temperature values.

NDVI is computed as a ratio of red and near-infrared (NIR) bands and is one of the commonly used proxies for representing vegetation health and density. It assists in realising the role of vegetation as an urban heat buffer. Nonetheless, the variations in surface emissivity cannot be explained by NDVI, but it is essential in the case of thermal infrared applications. In an effort to overcome this pitfall, the study employed Pv, a derivative calculated using NDVI values that estimate geometric ratios of vegetation on the ground, based on known equations. The value is used to calculate Em, which serves as an estimate that quantifies how the Earth's surface radiates infrared radiation.

Em-incorporation is essential since various types of surface materials (e.g., concrete, asphalt, vegetation) emit different amounts of thermal energy, and without considering this factor, profound errors can occur in LST retrieval. The integration of NDVI, PV, and Em ensures the methodology complies with state-of-the-art practices in computing LST based on satellite-retrieved data, as results in both spectral correction and normalisation of surface properties (Kumar & Mutanga, 2018; Abbass et al., 2022), as depicted in Figure 2.

Figure 2

LST Trends using GEE



The calculations were performed only in the GEE, where it is possible to conduct a consistent calculation across years (2019-2023) and the scope of spatial areas. Notably, it does not attempt to forecast future temperatures, but instead aims to observe real temperature trends on the surface based on satellite evidence. This emphasis is significant in urban planning and climate resilience practices, where understanding past and present conditions is crucial for creating adaptive strategies.

A Case Study of Perak, Malaysia

Peninsular Malaysia is an excellent place to study the effect of urban expansion on LST, given the geographical details of Perak in the northwest corridor of the area. This location fills the gap between Ghana, in the West African region, and Malaysia as a comparison. In physical terms, it is a large, geographically diverse state located at the centre of the Malaysian peninsula; it encompasses a vast geography of heterogeneous land, including urban areas, agricultural plains, lowland rainforests, hill slopes, and river networks. The varied land cover pattern creates a comprehensive picture of the environment in terms of the terrain's aspects and land cover types, as well as their impact on various surface temperature differences. Its natural and built environments provide an opportunity to make Perak a representative microcosm to study regional thermal anomalies in the context of rapid development.

In the state of Perak, urbanisation has gained significant momentum over the last twenty years, with rapidly increasing population centres and changes in land-use and infrastructure development in cities such as Ipoh, Taiping, and Manjung. The transformations have resulted in significant alterations in surface albedo, thermal conductivity, and vegetation cover, which have a direct impact on surface temperature dynamics. According to statistics provided by the Malaysian Meteorological Department (MET, 2019), the state has reported critical heat levels on numerous occasions, as daytime surface temperatures exceed 37 °C in several districts during the dry season. Such an increase in thermal trend is not only representative of climate variations but is also highly associated with human activities, including deforestation, urban sprawl, and reduced green cover areas.

It is complemented by historical analysis. To illustrate the point, Solhi (2021) drew attention to the fact that the state capital, Ipoh, recorded a 6.75 °C rise in temperature since 1998 through the year 2019, which was largely explained by climate change caused by a combination of the urban heat island (UHI) effect and growth of impervious cover, and decreasing vegetation cover. The consequences of this type of thermal stress are significant, as they are not only associated with environmental sustainability but also with human health, energy use, and ecological integrity. Drew attention to the fact that the state capital, Ipoh, recorded a 6.75 °C rise in temperature since 1998 through the year 2019, which was primarily explained by climate change caused by a combination of the UHI effect and the growth of impervious cover, and decreasing vegetation cover. The consequences of this type of thermal stress are significant, as they are not only associated with environmental sustainability but also with human health, energy use, and ecological integrity (2019-2023).

The second strong argument is that Perak was chosen because of its transitional nature, lying between the highly urbanised west coast states, such as Selangor, and the more forested and less developed eastern parts of the country. Such geographical positioning enables comparative evaluations between peri-urban and urban core areas, allowing for the identification of LST gradients associated with different degrees of land transformation. There is also the availability of relatively accessible historical data on land use in the state, as well as the support provided by regional governance structures that are receptive to data-driven policy formulation, enabling the creation of effective environmental policies.

To put it briefly, Perak offers a moderate environment for studying the interrelationship between land use dynamics and thermal behaviour. Its high level of development, ecological vulnerability, and exposure to climate make it especially convenient for geospatial studies of LST. The knowledge gained from this study will be used to implement specific interventions, such as greening cities, re-establishing forests, and climate-adaptable planning, not only in Perak but also in other locations with similar settings within Southeast Asia.

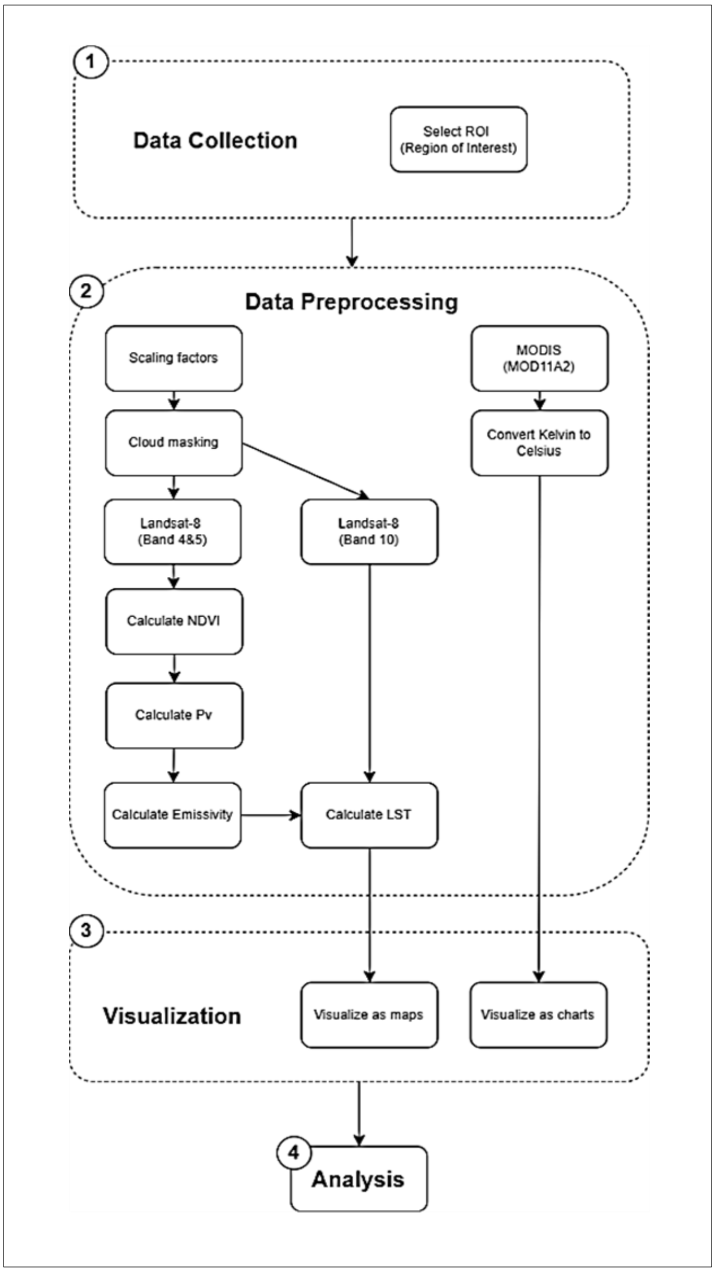
METHODOLOGY

This section describes the well-developed approach used to track and examine trends in LST utilising multi-source satellite data processed through GEE. Based on the theoretical insights gained from the literature review and the problem statement defined in the introduction, the proposed methodology of the study combines open-access satellite data, established RS indices, and cloud-based geospatial analytics. The primary goal is to establish a repeatable, time-coherent, and spatially persistent LST surveillance structure to enhance climatic resilience and inform city planning.

The general plan of this research (shown in Figure 3) comprises four interdependent phases that form the framework for monitoring and analysing LST using satellite imagery and GEE. Data collection is the preparatory step and requires the Region of Interest (ROI) and suitable pieces of satellite data from Landsat 8 and MODIS, spanning the years 2019 to 2023. Thereafter, the imagery (in the Data Preprocessing phase) is processed to mask clouds, scale, and calculate the necessary vegetation indices for accurate LST estimation, namely NDVI, Pv, and Em. Visualisation then becomes the third phase, in which the processed data is transformed into spatial maps and time-series charts that illuminate the patterns of temperature and trends in vegetation over various years. Lastly, the analysis phase combines the results to explain the spatial and temporal dynamics of LST in relation to land-use change, providing insights into aspects of resilience and sustainable city planning related to climate.

Figure 3

The Workflow of the Study



Data Collection

The first stage of the research process involved a purposeful search and selection of the ROI, guided by specific research goals aimed at monitoring LST and studying trends in vegetation issues. The study's time frame was considered to be up to five years, between 2019 and 2023, which is sufficient in terms of time granularity to observe climate and land-use-induced changes in surface temperature. The three major criteria on which the datasets were chosen were spatial resolution, temporal coverage, and the trustworthiness of thermal and vegetation indices. In this regard, two major satellite information sources were utilised, i.e. Landsat 8 and MODIS (MOD11A2).

NASA and the United States Geological Survey (USGS) jointly launched Landsat 8, which offers medium-resolution imagery with Earth observation data having a spatial resolution of 30 metres in the reflective bands and 100 metres (resampled to 30 metres) in the thermal infrared bands. The study utilised Bands 4 (Red), 5 (Near-Infrared, NIR), and 10 (Thermal Infrared Sensor, TIRS), which help calculate vital indices such as NDVI, Pv, and Em. Such bands play a vital role in assessing the health of vegetation as well as the thermal properties of ground surfaces. Table 1 provides an overview of the spectral and spatial characteristics of Landsat 8 bands used in this research, which serves as the technical basis for the precise estimation of LST and mapping of vegetation.

Table 1

Landsat 8 Images' Bands Information

Band Name	Wavelength (μm)	Resolution (m)
SR_B1 (Coastal Aerosol)	0.435-0.451	30
SR_B2 (Blue)	0.452-0.512	30
SR_B3 (Green)	0.533-0.590	30
SR_B4 (Red)	0.636-0.673	30
SR_B5 (Infrared)	0.851-0.879	30
SR_B6 (Short wave infrared)	1.566-1.651	30
SR_B7 (Short wave infrared)	2.107-2.294	30
ST_B10 (Thermal infrared)	10.60-11.19	100

In light of the high spatial resolution of Landsat 8, the study has also used the MODIS product MOD11A2. This dataset contains information about the 8-day mean of LST and Emissivity (LST&E) with a spatial resolution of 1 kilometre. Although it is coarser in spatial granularity than Landsat, MODIS data is superior in terms of consistency, particularly in temporal constancy and frequency of observations, which enhances the strength of trend analysis over time. MODIS was used in two ways: first, to complement the Landsat-based LST with high-frequency thermal measurements, and second, to assist in cross-validating temperature values over the analysis period. The combination of Landsat 8 and MODIS, with the docking of each, provides high-resolution visualisation of both LST patterns and the broad temporal continuity required to study the spatiotemporal dynamics involved in urban heat and vegetation health under changing environments.

Data Preprocessing

To achieve the accuracy, consistency, and reliability of the LST analysis process, all datasets obtained from satellite sources were subjected to multiple preprocessing procedures within the GEE environment. These are necessary preliminaries before the raw imagery can be ready for downstream calculations. The steps are as follows: radiometric scaling, cloud masking, index calculation, emissivity correction, and temperature estimation. The actions aim to maximise the quality of data, eliminating the typical artefacts of cloud contamination and radiometric noise. Landsat 8 imagery was initially radiometrically scaled using predetermined scaling factors that were specified in the dataset's metadata. The process transforms digital numbers into reflectance values, allowing similar interpretation over time and location. Figure 4 represents the Gee script that implements these scaling factors to standardise the reflectance in Bands 4 (Red), 5 (NIR), and 10 (Thermal Infrared).

To further enhance the dataset's accuracy, cloud masking was implemented using the pixel quality assessment (QA_PIXEL) band in conjunction with built-in GEE cloud filtering algorithms. This action helps eliminate the analysis of pixels contaminated by clouds, leading to distortion in NDVI and LST estimation. Figure 5 illustrates the source code snippet of the implementation of this cloud masking procedure, which is necessary to reduce outliers in the temporal trend results.

Figure 4

Source Code for Scaling Factors

```
// Function to Apply Scaling Factors
function applyScaleFactors(image) {
  var opticalBands = image.select('SR_B.').multiply(0.0000275).add(-0.2);
  var thermalBands = image.select('ST_B.*').multiply(0.00341802).add(149.0);
  return image.addBands(opticalBands, null, true)
              .addBands(thermalBands, null, true);
}
```

Figure 5

Source Code for Cloud Masking

```
// Function to Mask Clouds and Cloud Shadows
function cloudMask(image) {
  var cloudShadowBitmask = (1 << 3);
  var cloudBitmask = (1 << 5);
  var qa = image.select('QA_PIXEL');
  var mask = qa.bitwiseAnd(cloudShadowBitmask).eq(0)
                 .and(qa.bitwiseAnd(cloudBitmask).eq(0));
  return image.updateMask(mask);
}
```

Vegetation and Emissivity Derivation

Before preprocessing, the NDVI has been calculated according to Equation 1:

$$NDVI = \frac{NIR + Red}{NIR - Red} \tag{1}$$

where:

- NIR = Reflectance from Band 5 (Near-Infrared)
- RED = Reflectance from Band 4 (Red)

NDVI is an indicator of vegetation health and density, allowing one to determine the level of green cover through proxy values. The Pv was calculated based on NDVI values using Equation 2.

$$Pv = (\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}})^2 \quad (2)$$

where:

- $NDVI_{min}$ and $NDVI_{max}$ are the minimum and maximum NDVI values in the dataset
- Pv represents the fractional vegetation cover, which is a crucial input for emissivity estimation

The surface emissivity (Em) was then estimated using Equation 3, which incorporates Pv to adjust for material-specific thermal emission properties:

$$Em = 0.004 * Pv + 0.986 \quad (3)$$

where:

- Em = Emissivity
- Pv = Vegetation cover proportion (from Equation 2)

This correction is necessary because different land covers (e.g., urban infrastructure vs. vegetation) emit thermal radiation at different efficiencies.

LST Estimation

Once emissivity values were obtained, the LST was calculated from the thermal Band 10 of Landsat 8 using Equation 4:

$$LST = \frac{BT}{1 + (\lambda * (BT / 1.438)) * \ln(Em))} - 273.15 \quad (4)$$

where:

- BT = Brightness temperature derived from Band 10 (in Kelvin)
- λ = Central wavelength of Band 10 (10.895 μm)
- Em = Surface emissivity from Equation 3

This equation provides a corrected surface temperature by accounting for emissivity effects, ensuring more precise LST retrieval across mixed land cover types.

MODIS LST Conversion

In parallel, LST data from the MODIS MOD11A2 product were used to complement and validate the Landsat-derived temperature estimates. Since MODIS LST values are initially in Kelvin, they were converted to degrees Celsius using a simple transformation as depicted in Figure 6. This conversion enables direct comparison between MODIS and Landsat outputs, supporting the validation of temporal trends.

Figure 6

Source Code to Convert Kelvin to Celsius

```
// Preprocessing: Convert from Kelvin to Celsius
var LSTDay = collection.map(function(img) {
  return img.multiply(0.02).subtract(273.15).copyProperties(img, ['system:time_start', 'system:time_end']);
});
```

Visualisation

Visualisation is a great mediator between crude geospatial data and interpretable analysis, enabling users to intuitively recognise spatial and structural changes in environmental variables over time. Processed outputs in this study were visualised under two principal formats, namely spatial maps and temporal charts. All these visual depictions were created entirely within the GEE environment, which includes plotting capabilities and export tools, ensuring consistency in terms of colour scale, resolution, and classification structure across study years. The spatial visualisation was used to display annual maps from 2019 to 2023 of the NDVI and LST. The NDVI maps represent vegetation health in a clear manner, where higher values indicate dense vegetation cover and lower values indicate bare soil (or built-up spaces). The LST maps, however, display the surface temperature distribution, including thermal hotspots associated with urban growth, deforestation, or a decline in vegetation cover. Such maps play a crucial role in detecting environmental stress in key locations and inter-annual variations in land surface conditions.

To complement the spatial outputs, a temporal visualisation was performed using a time-series line graph, which indicates the annual patterns of the mean values of the NDVI and LST. Such plots facilitate the longitudinal evaluation of vegetation degradation and temperature rise, providing a high-level overview of ecological patterns during the five-year study period. The visualisation of the result on a graphical model is not only used to prove everything that is already hypothesised; it is also easy to read and explain to stakeholders, as it presents complicated data in a simple, graphical format. Interestingly, standard visual encodings, such as standardised colour ramps in the case of NDVI and LST, are used to provide clarity and comparability between time steps.

Analysis Phase

The last stage of the methodological workflow involves a systematic analysis of the spatially and temporally derived outputs to draw valuable conclusions regarding land surface dynamics and environmental health. This step is based on comparative reasoning, according to which annually produced maps and charts of NDVI and LST will be compared to identify correlations and trends that can be linked to anthropogenic alterations in land use, including urbanisation, agrarian intensification, and forest degradation. The spatial analysis part has prioritised the location of geographical areas with significant thermal anomalies and stresses to vegetation. Regions that exhibited a consistently high LST value, as well as low NDVI values, were also listed as areas of environmental concern. These areas were typically newly developed urban areas or other green spaces that had been impacted by deforestation or land conversion. Regions with consistent or increasing NDVI values were, on the other hand, marked as retaining or regaining vegetative health, as a result of reforestation efforts or conservation efforts.

In the time series, the objective of the analysis was to capture changes between annual, inter-annual, and cyclical variations in surface temperature and green cover. The longitudinal measure will be used to collect data and determine whether there are changes in line with the general trend, or if it is due to seasonal or weather disturbances that alter the data. Notably, the coinciding phenomenon of increased LST and decreased NDVI within various geographic regions highlights the presence of a feedback mechanism in which vegetation loss continues to compound surface heating, leading to additional stress on the remnant vegetated surface. The present work combines spatial pattern analysis and temporal trend to provide a thorough diagnosis of heat and ecological stress on the surface. The knowledge gained from this step is not only of research interest but can also be directly adopted into urban design, climate adaptation planning, and environmental policy, especially in cases where rapid land conversion is underway.

RESULTS AND DISCUSSIONS

This section presents a detailed spatiotemporal analysis of land cover changes and vegetation health in Perak, Malaysia, over five years from 2019 to 2023. The study captures both the visual and quantitative dimensions of environmental transformation by integrating true-colour satellite imagery with NDVI data. The analysis aims to identify patterns of urban expansion, vegetation degradation, and their ecological implications. Emphasis is placed on year-to-year variations to highlight the progressive impact of anthropogenic activities—such as deforestation, infrastructure development, and agricultural encroachment—on the region's vegetative landscape. The analysis intends to understand the extent of ecological stress in Perak and inform subsequent discussions on land surface temperature dynamics.

The combined analysis of the true-colour map and NDVI map for Perak from 2019 to 2023 provides a comprehensive understanding of the region's land cover changes and vegetation health dynamics. The true colour and NDVI maps visually represent land cover and reveal notable shifts in land use patterns over the five years. 2019 Perak displayed extensive greenery, indicating healthy vegetation across most parts of the state. This observation is corroborated by the NDVI map, which displays high NDVI values, indicating robust vegetation health. As we can see in true colour and NDVI maps from 2020, there is a drop in vegetation cover and health to some extent. The true colour map shows a decrease in the number of green lands, especially in low-altitude areas and those near urban centres, such as Ipoh, and on the western coast. This observation is supported by the NDVI map, which shows reduced NDVI values in these locations. It suggests that climatic conditions, farming patterns, or preliminary indicators of climatic pressures may have an impact on vegetation fitness. The differences became even greater in 2021. An increase in deforestation and urban growth is evident in the true-colour map, especially in the central areas. It is evident in the NDVI map, where it can be observed that certain areas have experienced a significant reduction in vegetation health. These shifts are consistent with the rising changes in land use and its stress on the environment, borne by human actions such as deforestation, urbanisation, and the expansion of agriculture.

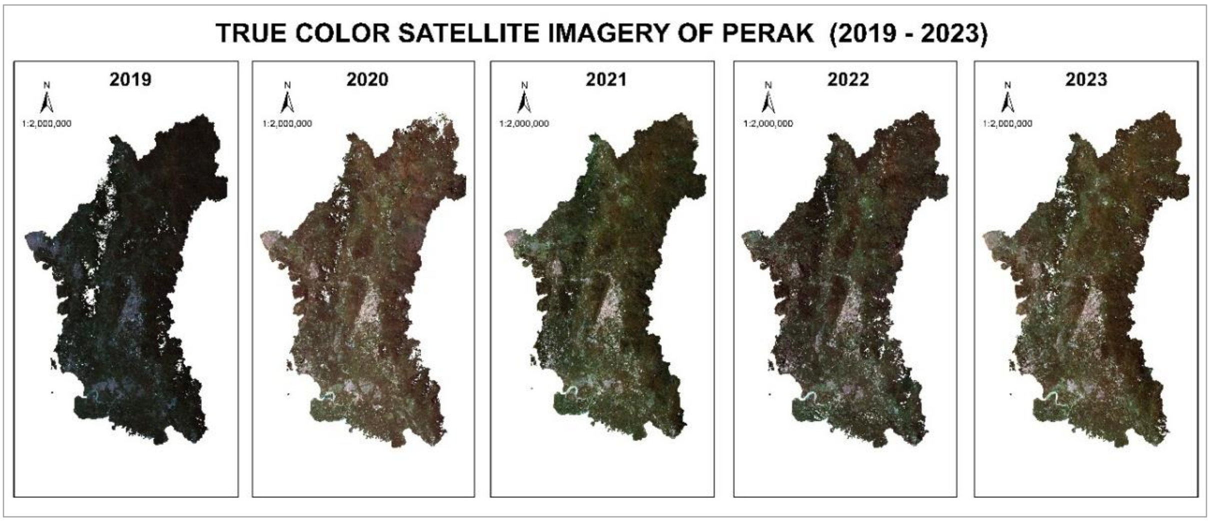
The situation presented in the 2022 maps is mixed. Although areas with less vegetation can still be observed on the true colour map, a minor improvement is visible in certain regions on the NDVI map. Such recovery can be attributed to reforestation processes, modifications in agricultural practices, or the return of natural vegetation. Nevertheless, the continued low NDVI values in other regions demonstrate that difficulties persist, indicating that although some regions are being restored, others are being overwhelmed with stress due to deforestation or urban sprawl. The visible farms and brightlands are replaced in the true-colour map by 2023, and notable deforestation and urban sprawl land use changes can be seen. Such changes are reflected in the NDVI map, which has yielded mixed results, as some areas show an improvement in vegetation health, while others still lag behind. This is an indication that, irrespective of the measures taken to enhance and sustain vegetation cover, some difficulties still exist regarding the sustainability of the land. It is noted that NDVI values fluctuated during these years, portraying the dynamic aspect of vegetation health in Perak, which is influenced by both natural and artificial processes.

True Colour and NDVI Maps of Perak from 2019 to 2023

The overall assessment of vegetation state and land-cover change in Perak from 2019 to 2023 can be achieved through a comparative study of true-colour images (Figure 7) and NDVI (Figure 8). The visual appearance of maps in true colours and NDVI demonstrates the land cover area and shows evident changes in land-use patterns during the five years. In the true-colour image from 2019, the cover of vegetation and its saturation are significant, which indicates healthy vegetation in the majority of the state's regions. The trend is partly corroborated by the accompanying NDVI image, which shows higher NDVI values, indicating strong vegetation health.

Figure 7

True Colour Maps of Perak in 2019, 2020, 2021, 2022, and 2023

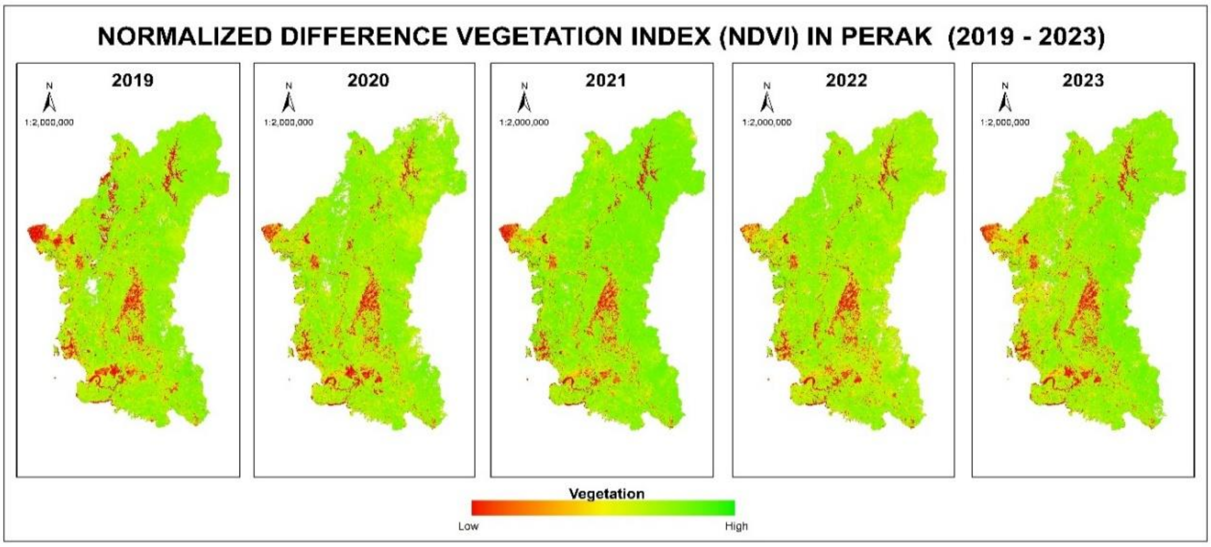


Another study in 2020 shows a slight decrease in the vegetation coverage and vigour. The true-colour image shows a decline in greenness, especially at low altitudes and in areas close to major towns like Ipoh and along the western coast. The observation is confirmed by the NDVI map, which documents lower NDVI in these places, suggesting that climatic conditions, agricultural activities, or a precursor to climate stress may have impacted the vegetation status. The tendency becomes more evident in 2021: the true-colour image reveals greater deforestation and urbanisation, especially in central areas, whereas the NDVI map indicates significant decreases in vegetation health in specific patches. Such trends are in line with the increasing land-use and environmental pressure related to anthropogenic activities, such as deforestation, urbanisation, and agricultural encroachment.

Perak in 2022 presents a complex image in terms of spatio-temporal analysis. True-colour images, on the one hand, still capture the areas of reduced vegetation growth. Conversely, the NDVI images display smaller, local changes, presumably caused by reforestation campaigns, changes in agricultural activity, and natural vegetation regeneration with a cyclical period. Nevertheless, the low NDVI readings recorded in other regions reflect that the problems of deforestation and encroachments on urban areas are still present. As of 2023, deforestation and urban sprawl exhibit distinct patterns, which are reflected in the true-colour landscape, with similar, albeit not identical, patterns also evident in the NDVI data. Taken together, the time series supports the hypothesis that, despite temporary improvements obtained through rehabilitation activities, the general management of vegetation and terrain remains fragile. The dynamic nature of Perak's vegetation cover, which is subject to natural or anthropogenic forces, is evident as the NDVI values shifted drastically over time.

Figure 8

NDVI Maps of Perak in 2019, 2020, 2021, 2022 and 2023



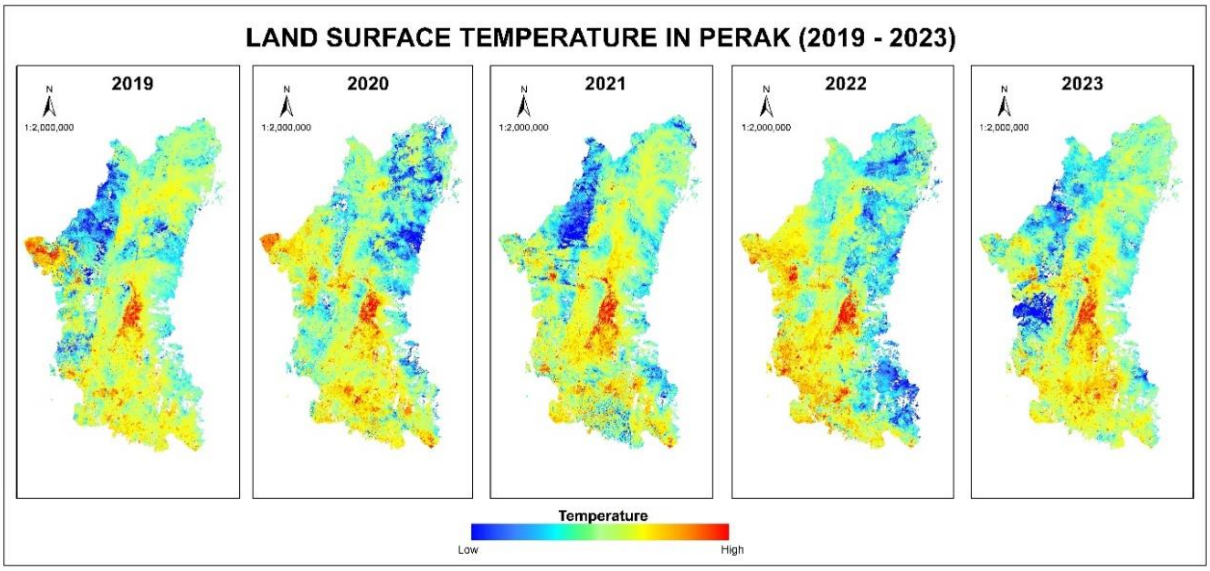
LST Changes of Perak from 2019 to 2023

The LST maps provided in Figure 9, between 2019 and 2023, in Perak, help provide essential details regarding intra-regional temperature variations. The 2019 LST map depicts a comparatively small temperature variation that covers most of Perak; specifically, a cooler temperature can be distinguished, especially in highland areas such as the Cameron Highlands. A measurable warming of LST is reported in central and western areas of the state, although such trends may be explained by changes in land use and climatic conditions. The areas covered by orange and red on the map are significantly warmer than in 2019, indicating stronger heat absorption, which could be linked to an increase in urbanisation and deforestation.

Continuing along this trend, the LST map of 2021 continues to record further increments in surface temperatures in central and western Perak. The wide spatial area of thermal hotspots is also aligned with the build-up influences of environmental stressors, such as the reduction in vegetation cover and the persistence of urban growth. According to the LST map from 2022, there is still a reduction in the rise of temperatures; however, a group of sites continues to exhibit high temperatures. This trend of increasing and then levelling off is attributed to conflicting data on land management interventions and variable climate.

Figure 9

LST Maps of Perak from 2019 to 2023



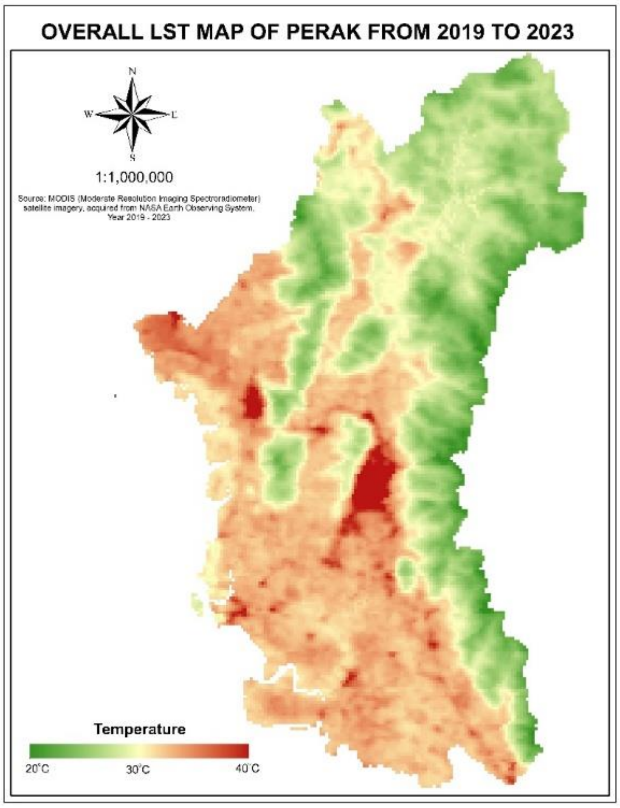
The LST map of 2023 reveals that high thermal hotspots exist in many locations, indicating consistent areas that absorb high temperatures. The broad spread of high mean annual LST over the map highlights the factor of long-term urbanisation and the related decrease in green cover. In the spatiotemporal analysis, it was indicated that the most thermally based areas were mainly associated with regions that had experienced the sharpest land-use changes, particularly deforestation and urban sprawl. The gradual increase in LST, recorded by the end of each year over recent decades, gives us an idea of the need to implement certain environmental policies to mitigate the effects of heat.

Compositing of 2023 LST maps with simultaneous NDVI and true-colour data enables an in-depth analysis of the predominant vegetation cover and thermal activity. By comparing the true-colour sequences and the NDVI series, it is possible to identify not only the temporal changes in vegetation extent but also the changes in vegetation vigour. Areas with adverse NDVI are associated with those places where magnifications in LST occur concurrently, hence depicting the interconnection between heat absorption and vegetative cover. Regions experiencing severe deforestation and urbanisation reveal high LST anomalies, which denote the loss of thermoregulatory capabilities in the landscape.

Figure 10 shows the long-term LST map of Perak covering the time range from 2019 to 2023. It can be seen that, although a small portion of the area under consideration remains comparatively unchanged, the majority of the spatial units have experienced relatively high temperature levels over the five years. Generally, the highland regions, such as the Cameron Highlands, have relatively lower values, but their geographical area is relatively small. Contrarily, LSTs in the western and central parts of Perak are high, with the dominance of red and orange colours, indicating that the area is experiencing strong heat stress. This spatial pattern is indicative of current urbanisation and deforestation that have compromised the vegetation cover and increased surface albedo, thus adding to the absorption of heat in the area.

Figure 10

Overall LST Map of Perak from 2019 to 2023



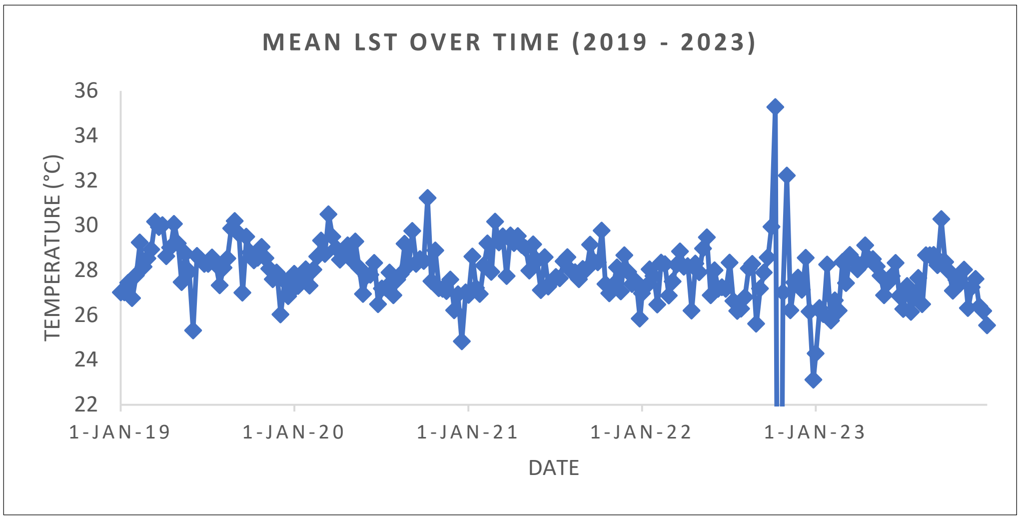
The continued rise in the average annual temperatures in most parts of Perak in the last five years is an indication of a significant environmental crisis. The persistence of thermal stress, typical of most areas, also highlights the impact of human-related activities and underscores the need for strong land-based management and massive reforestation projects. This prolonged weather trend makes it clearer why it is high time to implement a culture of sustainability to alleviate the effects of the heat-stress challenge and maintain the ecological integrity and robustness of Perak's landscapes. Continuous monitoring of the environment, combined with the application of adaptive management measures, is essential to address these challenges and ensure the long-term sustainability of the area.

Time Series Analysis of LST in Perak from 2019 to 2023

Figure 11 illustrates the change in average LST of Perak over the years from 2019 to 2023. The fluctuation in the plot is strong, and a trend on the plot highlights the temporal variability of thermal conditions.

Figure 11

Over Time in Perak (2019-2023)

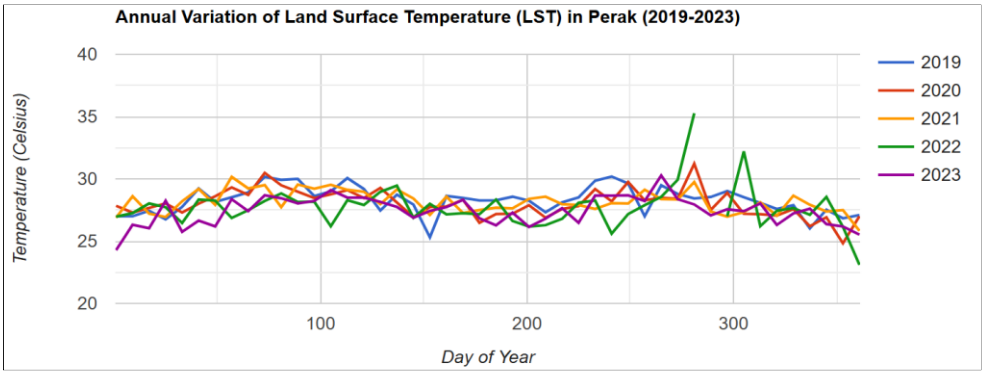


The average LST shifted in the observation period between 26 °C and 30 °C with the interjection of spikes and valleys. In 2019, the initial value was approximately 28 °C, and small-scale yearly changes were observed, which is comparable to the average seasonal change. In 2020, there was a trend of a positive increase in the mean LST, and the measurements were often close to 30 °C, especially in the months that fell in the middle of the year, although there existed intra-annual variance. Despite the unchanged oscillatory trend, the rate of fluctuations elevated in comparison with that of 2019.

The climate data for 2021 indicate overall stability at the same level as previous years, but with an increased number of temperature anomalies at the beginning of the year, which can probably be attributed to the influence of the season or the occurrence of seasonal meteorological anomalies. The overall trend in mean LST of 2022 is similar, as it carries over continuity with 2021 but with slightly diminished dips. It is observed in the LST time series that in 2023, there were sharp fluctuations in the short term, particularly a sharp increase in late June and early July, which reached approximately 35 °C. An anomalous increase in this value can suggest either an extraordinary weather condition or the beginning of a severe heatwave. Once this stage is reached, the average LST returns to the seasonally accepted range of values with minimal variations until the end of the year.

Figure 12

Annual Variation of LST in Perak (2019-2023)



Here, the study evaluates the annual changes in LST (in the Sultanate of Perak) from 2019 to 2023—the time-series plots (Figure 12) evidence sharp variations and perceptible trends in the five-year data. The average temperatures in the base year of 2019 were mostly between 26 °C and 30 °C, with intermittent falls and stagnation corresponding to seasonal changes. In 2020, the same trend was observed, with a slightly higher average and a definite increase at the time of year, indicating extended durations of above-average heat due to climatic processes at that time. In 2021, the series exhibits obvious surges, with the strongest ones occurring around days 100 and 300, indicating a large-scale short-term heat or anomaly. These outings indicate that 2021 has recorded temperatures higher than those of the previous years. 2022 follows a similar pattern, with a sharp spike at day 250, surpassing 32 °C, indicating a potential heat wave or other weather anomaly that may be prevalent in the area during this time. The 2023 dataset is characterised by substantial variability and extreme excursions, especially on days 200 and 250, where the temperatures were over 34 °C. These peaks highlight the existence of severe heat events and also the effects caused by climatic anomalies in the Perak province.

Comparison of the mean LST calculated on the entire data lake to the annual disaggregated series provides an overall view of temperature dynamics in Perak. So, although it can be seen from the long-term mean that there is a relative stability with spikes here and there, yet on year to year variation graph, particular daily maximums are singled out and this makes the picture clearer in regard to the complex interactions between longer-term, climatically-induced trends and sudden extreme hot events. The results also suggest that long-term monitoring and dynamic control measures are necessary to mitigate the environmental impact in Perak.

CONCLUSION

Urban expansion and increasing LST are pressing environmental challenges faced by many developing countries, particularly those in tropical regions. Malaysia is no exception, as rapid urban growth has led to widespread vegetation loss and altered thermal conditions nationwide. These changes have intensified urban heat island effects, stressed ecological systems, and heightened the need for climate-resilient planning. Within this national context, the state of Perak exemplifies the localised impacts of these trends. The study's findings reveal a persistent rise in LST, especially in densely populated and non-forested areas of Perak, underscoring the significant role of human-driven land cover changes. These insights reinforce the need for state and local authorities to adopt data-driven policies that integrate land use planning, environmental monitoring, and climate adaptation to mitigate the compounded stresses of urbanisation and warming in the region.

The persistent increase in LST, particularly in densely populated and non-forested areas, highlights the significant impact of human activities on the state's thermal regime (Shen et al., 2023). As one strives to adapt to increasing populations and mitigate urban heat island intensification, there is a need to integrate sustainable land-use practices reinforce reforestation processes and expand the scale of green infrastructure in urban planning (Wang et al., 2024). Constant environmental monitoring and the use of adaptive management measures are unavoidable for ensuring the long-term sustainability and resilience of ecosystems in Perak.

Despite its contributions, the current study has several limitations. Although the conclusion based on the 2019-2023 period serves as a good point of reference, this time frame is not long enough to establish long-term trends in climate trajectories on a regional level. Furthermore, the available data is considerably uneven in some respects, especially regarding the year 2022, which reduces the accuracy and the range of data analysed. These gaps highlight the need to undertake more comprehensive and long-term data collection that will explain the changing climate conditions in Perak.

Future studies can thus widen coverage in time and utilise other climatic variables to strengthen the findings. Using the new modelling methods to model future LST trends may provide more accurate, as well as actionable information (Suthar et al., 2024). Such models are intended to be compared with historical observations to fine-tune their ability to predict. Collaboration of socioeconomic data with climate would also enable the design of more comprehensive policies that could harmonise urban growth and environmental sustainability (Adom, 2024). To this extent, the local Perak government will be able to develop more constructive plans that will minimise the adverse effects of climate change and encourage economic development (Raihan & Tuspekova, 2022).

ACKNOWLEDGMENT

This research is supported by Universiti Utara Malaysia (UUM) Matching Grant Scheme: S/O Code: 21529.

REFERENCES

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the impact of global climate change, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research 2022 29:28*, *29*(28), 42539–42559. https://doi.org/10.1007/S11356-022-19718-6

Abu El-Magd, S. A., Masoud, A. M., Hassan, H. S., Nguyen, N. M., Pham, Q. B., Haneklaus, N. H., Hlawitschka, M. W., & Maged, A. (2024). Towards understanding climate change: Impact of land use indices and drainage on land surface temperature for valley drainage and non-drainage areas. *Journal of Environmental Management*, *350*, 119636. https://doi.org/10.1016/J.JENVMAN.2023.119636

Adeyeri, O. E., Folorunsho, A. H., Ayegbusi, K. I., Bobde, V., Adeliyi, T. E., Ndehedehe, C. E., & Akinsanola, A. A. (2024). Land surface dynamics and meteorological forcings modulate land surface temperature characteristics. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2023.105072

Adom, P. K. (2024). The socioeconomic impact of climate change in developing countries over the next decades: A literature survey. *Heliyon*, *10*(15), e35134. https://doi.org/10.1016/J.HELIYON.2024.E35134

Amani, M., Ghorbanian, A., Ahmadi, S. A., Kakooei, M., Moghimi, A., Mirmazloumi, S. M., Moghaddam, S. H. A., Mahdavi, S., Ghahremanloo, M., Parsian, S., Wu, Q., & Brisco, B. (2020). Google Earth Engine cloud computing platform for remote sensing big data applications: A comprehensive review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. https://doi.org/10.1109/JSTARS.2020.3021052

Anandababu, D., Purushothaman, B. M., & Suresh Babu, S. (2018). Estimation of land surface temperature using LANDSAT 8 data. *International Journal of Advanced Research*, *4*(2), 177–186. www.IJARIIT.com

Azuar, A., & Mardhiah, A. (2024, July 24). How climate change intensifies Malaysia's weather extremes. https://themalaysianreserve.com/2024/07/24/how-climate-change-intensifies-malaysias- weather-extremes/

Bartkowiak, P., Castelli, M., & Notarnicola, C. (2019). Downscaling land surface temperature from the MODIS dataset with a random forest approach over alpine vegetated areas. *Remote Sensing 2019, Vol. 11, Page 1319*, *11*(11), 1319. https://doi.org/10.3390/RS11111319

Ermida, S. L., Soares, P., Mantas, V., Göttsche, F. M., & Trigo, I. F. (2020). Google Earth Engine open-source code for land surface temperature estimation from the Landsat series. *Remote Sensing 2020, Vol. 12, Page 1471*, *12*(9), 1471. https://doi.org/10.3390/RS12091471

Intergovernmental Panel on Climate Change (IPCC). (2023). Climate change 2022 – Impacts, adaptation and vulnerability. In *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. https://doi.org/10.1017/9781009325844

Kumar, L., & Mutanga, O. (2018). Google Earth Engine Applications Since Inception: Usage, trends, and potential. *Remote Sensing 2018*, *10*(10), 1509. https://doi.org/10.3390/RS10101509

Li, Z. L., Wu, H., Duan, S. B., Zhao, W., Ren, H., Liu, X., Leng, P., Tang, R., Ye, X., Zhu, J., Sun, Y., Si, M., Liu, M., Li, J., Zhang, X., Shang, G., Tang, B. H., Yan, G., & Zhou, C. (2023). Satellite remote sensing of global land surface temperature: Definition, methods, products, and applications. In *Reviews of Geophysics*. https://doi.org/10.1029/2022RG000777

Lindsey, R., & Dahlman, L. (2020). Climate change: Global temperature | NOAA Climate.gov. *ClimateWatch Magazine*.

Liu, J., Fiifi, D., Hagan, T., Liu, Y., Liu, J.; Hagan, D. F. T.; & Liu, Y. (2020). Global land surface temperature change (2003–2017) and its relationship with climate drivers: AIRS, MODIS, and ERA5-Land based analysis. *Remote Sensing 2021, Vol. 13, Page 44*, *13*(1), 44. https://doi.org/10.3390/RS13010044

Mohd Jaafar, W. S. W., Maulud, K. N. A., Muhmad Kamarulzaman, A. M., Raihan, A., Sah, S. M., Ahmad, A., Maizah Saad, S. N., Mohd Azmi, A. T., Syukri, N. K. A. J., & Khan, W. R. (2020). The influence of deforestation on land surface temperature—A case study of Perak and Kedah, Malaysia. *Forests 2020, Vol. 11, Page 670*, *11*(6), 670. https://doi.org/10.3390/F11060670

Phan, T. N., & Kappas, M. (2018). Application of MODIS land surface temperature data: A systematic literature review and analysis. *Journal of Applied Remote Sensing*, *12*(04), 1. https://doi.org/10.1117/1.jrs.12.041501

Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. *Resources, Conservation & Recycling Advances*, *15*, 200096. https://doi.org/10.1016/J.RCRADV.2022.200096

Rebecca, L., & LuAnn, D. (2024, January 18). *Climate change: Global temperature | NOAA Climate.gov*. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Riedy, C. (2016). Climate change. In *The Blackwell Encyclopedia of Sociology*. https://doi.org/10.1002/9781405165518.wbeos0737

Shen, W., Liu, Q., Ji, M., He, J., He, T., & Huang, C. (2023). Impacts of urban forests and landscape characteristics on land surface temperature in two urban agglomeration areas of China. *Sustainable Cities and Society*, *99*. https://doi.org/10.1016/J.SCS.2023.104909

Solhi, F. (2021, March 6). Malaysian cities are getting hotter. *New Starits Time Newspaper*, 1–5. https://www.nst.com.my/news/nation/2021/03/671506/malaysian-cities-are-getting-hotter-study

Suthar, G., Singh, S., Kaul, N., & Khandelwal, S. (2024). Prediction of land surface temperature using spectral indices, air pollutants, and urbanisation parameters for Hyderabad city of India using six machine learning approaches. *Remote Sensing Applications: Society and Environment*, *35*. https://doi.org/10.1016/J.RSASE.2024.101265

Tamiminia, H., Salehi, B., Mahdianpari, M., Quackenbush, L., Adeli, S., & Brisco, B. (2020). Google Earth Engine for geo-big data applications: A meta-analysis and systematic review. *ISPRS Journal of Photogrammetry and Remote Sensing*, *164*, 152–170. https://doi.org/10.1016/J.ISPRSJPRS.2020.04.001

Tang, K. H. D. (2019). Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. In *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2018.09.316

Wang, D., Xu, P. Y., An, B. W., & Guo, Q. P. (2024). Urban green infrastructure: Bridging biodiversity conservation and sustainable urban development through an adaptive management approach. *Frontiers in Ecology and Evolution*, *12*, 1440477. https://doi.org/10.3389/FEVO.2024.1440477/ BIBTEX

Yadav, S. (2021). United Nations Framework Convention on Climate Change (UNFCCC) and the role of the United States of America. *International Journal of Advanced Research*, *9*(09), 148–155. https://doi.org/10.21474/IJAR01/13388