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Seasonal Dynamics of Land Surface Temperature and Relative Humidity in Palakkad District, Kerala: A Geospatial Analysis

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Abstract
Studying local climatic anomalies is crucial for improving climate models and devising precautionary adaptation strategies. Such analyses also provide insights into land-use and land-cover dynamics and their interactions with regional climate variability. The current study aims to analyse seasonal and inter-annual changes in Land Surface Temperature (LST) and Relative Humidity (RH) in Palakkad District, Kerala. In order to evaluate these spatiotemporal fluctuations and heat stress, seasonal mean data were retrieved in Google Earth Engine and processed in QGIS for the periods of pre-monsoon, monsoon, and post-monsoon periods in the years of 2014, 2016, 2018, 2020, and 2022. The LST mean was obtained from MODIS Terra MOD11A2, and the RH mean was obtained from ERA5-Land reanalysis. The result of the study revealed the notable seasonal variations with lower LST and higher RH in monsoon periods. Moreover, LST is higher and RH is lower in the pre-monsoon months of the district. Throughout the district, spatial variation was noted, emphasising how topography, land cover, and urbanisation affect regional climate conditions. These results highlight the value of geospatial methods for tracking microclimatic variability and offer baseline knowledge for climate resilience and sustainable land-use planning in the Palakkad district.

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1. Introduction

To mitigate climate-induced hazards and disasters and develop climate models, it is vital to research climate in various years. Tropical humid type climate with enough both rainfall and sunlight mostly throughout the year is one of the most notable features of Kerala's climate (Nair *et al.*, 2021) [26]. The southwest monsoon season in Kerala starts from June and ends in September according to the Indian Meteorological Department (IMD). This seasons particularly affect surface temperature and atmospheric moisture levels during pre-monsoon, monsoon and post-monsoon periods (annual report, 2025) [2]. Climatic fluctuations cause the anomalies in LST and RH across these seasons. Thus, this can be recognised as one of the important indicators of large-scale climatic variations (Naga *et al.*, 2023) [24]. The climate of Kerala varies from humid coastal plains to the cold highlands of the Western Ghats. So, these changes in climate are ecologically sensitive which can alter even little seasonal patterns of weather. Over the last decades, shifting rainfall rates and distribution, late monsoon onset and rising temperature, particularly in the summer season have emphasized the urgency of monitoring changes in the climate (Preenu *et al.*, 2017) [27]. In this context, the role of remote sensing and GIS is important in climate studies because of the limited ground-based measurements. This offers spatially wider and temporally constant data which aids in parameter observation such as Land Surface Temperature (LST) and Relative Humidity (RH) (DeHennis & Wise, 2005) [9]. In fact, in order to study Kerala's changing climate, satellite observations are needed (Sha *et al.*, 2020) [33].

Relative Humidity and Land Surface Temperature are crucial parameters in assessing climate variability, particularly in sectors such as public health (Ibrahim *et al*., 2025) [18], agriculture (Hadria *et al*., 2018) [15], and hydrology(Dunn *et al*., 2017) [13], as they influence the incidence of heat-related illnesses (Heidari *et al*., 2020) [16] and vector-borne diseases (Zhang *et al*., 2024; Chabot-Couture *et al*., 2014) [41, 6], crop yields(Holzman *et al*., 2014) [17] and phenology (Walker *et al*., 2015) [38] under rising temperature and moisture stress (Lutsko, 2021) [23] and evapotranspiration (Li *et al*., 2022) [21] and drought risk assessment in water-scarce regions (Gampe *et al*., 2016) [14].

Kerala is located along the southwestern fringe of the Indian subcontinent, bordered by the Arabian Sea to the west and the Western Ghats to the east (Pullaiah, 2024) [28]. This narrow geographic strip is marked by considerable topographical diversity, transitioning from low-lying coastal plains to elevated highlands (Chattopadhyay, 2021) [7]. Palakkad district is one of the most topographically distinct regions in Kerala due to many reasons. Even though the 30-kilometre natural Palakkad Gap in the Western Ghats is important (Varada *et al*., 2022) [36] because the gap acts as a channel for the transition of air masses between the western Kerala and eastern Tamil Nadu plains (Sathiyamoorthy *et al*., 2024) [32]. Palakkad experiences a remarkably different climatic environment from the adjacent districts due to these special geographic characteristics (Sundaresan *et al*., 2023) [34]. During the pre-monsoon period, it usually accounts for lifted daytime temperatures and relatively less humidity (Nair, 2010) [25]. This fluctuation is primarily due to the inflow of dry and warm wind through the gap which normally influences both ecological patterns and local weather (Dhanya *et al*., 2023) [11]. Such climatic variations marked in recent years cause noteworthy challenges for agriculture, biodiversity, ecosystem functions and availability of water in the district (Punnoli & Jayarajan, 2024) [29]. Actually, Palakkad is a good place to study climate anomalies related to monsoon-driven conditions because of the aforementioned variables.

The importance of satellites and related databases in monitoring climate indicators like RH and LST has grown in recent studies. Dong *et al*.'s (2024) long-term vapour pressure deficit study (VPD) across China (from 1961 to 2020) reveals a significant increase in VPD along with a corresponding decrease in relative humidity (RH), which is particularly apparent in the spring and semi-arid regions, suggesting an increase in climate stress. Mainly, 1,740 stations provided ground-based observations of Tmin, TRH, Tmax, and other meteorological parameters (Dong *et al*., 2024) [12]. These findings align with broader worldwide trends of surface temperature increase and air drying. The relationship between Land Surface Temperature (LST) and drought severity investigated by Choudhury (2024) utilising MODIS-derived LST combined with the Standardised Precipitation Evapotranspiration Index (SPEI) across six drought-affected regions in India from 2001 to 2019 indicated notable negative correlations in critical areas such as NWI and CPR. This recommends that LST is a good indicator to determine the drought severity (Choudhury, 2024) [8]. Rani *et al*. used the MERRA-2, ERA5, MODIS, and AIRS Aqua datasets to examine daytime and nighttime LST of six climatic regions of India for the years 2003 to 2022. The significant result of the study is a widespread warming trend at night and a continuous cooling trend at daytime in these regions. There is a notable strong correlation between reanalysis sources and satellite data which emphasises the reliability of MODIS LST for climate analysis. In spite of these studies which employed robust statistical approaches viz. slope estimator of Sen and the trend test of Mann-Kendell. This can be varied in terms of temporal range, spatial resolution and data integration methodologies (Rani *et al*., 2024) [30].

The study of Liu *et al*. (2022) focused on MODIS, ERAS5 Land and AIRS datasets to compare the LST trend from 2003 to 2017. The findings revealed important evidence of warming and spatial correlation in their study area like Asian Russia and North America. These were caused by precipitation patterns, longwave radiation and incoming solar radiation (Li *et al*., 2022) [21]. In another study of Lin *et al*. in 2020 used MODIS Terra nighttime LST (MOD11A1) in their study area, China to estimate the surface temperature. The findings demonstrated that altitude, absolute humidity and NDVI increased model accuracy especially in mountainous regions. To assess drought sensitivity, Thanabalan *et al*. (2023) integrated TRMM rainfall data with MODIS LST and NDVI. The LST rate of May month might predict the health of the plants in September with two a two-to-three-month lead time (Thanabalan *et al*., 2023) [35] is the major finding of the study. Ruchi Bala *et al*. (2020) used thermal sharpening techniques to downscale MODIS LST in four cities in India. The RMSE values are below 1.3 °C. They successfully increased spatial resolution from 930m to 100m using spectral indices (Bala *et al*., 2020) [3].

In the case of relative humidity, Khadka *et al*. (2022) analysed the fluctuations across agro-climatic zones of India. They mainly used ERAS5 data to study and explore spatiotemporal variations for thermal comfort and agricultural practices (Khadka *et al*., 2022) [19]. Rejis *et al*. (2025) examined southwest monsoon dynamics in Kerala using rainfall data obtained from ERAS5 from 1990 to 2020. The downward tendency is the recent modification in the monsoon according to the paper. This is primarily due to the result of higher rainfall in August and September that was linked to alterations in large-scale circulation patterns (Reji *et al*., 2025) [31].

Remote sensing is becoming a vital tool to understand climate anomalies worldwide. In the case of Kerala, the role of remote sensing is needful it provides reliable ground-based results and datasets. For tracking LST trends, high temporal resolution datasets from MODIS and NASA's Terra are more helpful (Bhaga *et al*., 2020) [4]. The introduction of cloud-based geospatial platforms like Google Earth Engine (GEE) enhanced the ability to handle, interpret, and analyse large satellite time series (Wang *et al*., 2005) [39]. GEE facilitates effective spatial-temporal analysis of MODIS outputs without requiring local storage or processing resources (Vijayakumar *et al*., 2024) [37]. This means GEE is ideal for long-term anomaly detection and climate monitoring. There are numerous studies that assessed heatwaves, monsoon dynamics, urban heat islands and ecological changes due to land-induced induced both globally and domestically in India using MODIS LST through GEE (Wang *et al*., 2025) [40].

These results help to illustrate how crucial MODIS and ERAS5 or ERAS5-Land are for researching the climate indices we chose, such as LST and RH. This helps to monitor frequent climate changes and create necessary global, national, and regional modelling.

2. Study Area
Palghat or Palakkad is one of the fourteen revenue districts of Kerala. The district is one of the main granaries of Kerala and its economy is primarily dependent on agriculture. Agriculture engages more than 65% of the workers and 88.9% of the district's population is rural in nature. Palakkad derives its name from the Malayalam words 'pala' and 'kadu' which goes to prove that this place was once a beautiful stretch of forests covered with the sweet-scented flowers of the *Wrightia tinctoria* pala tree.

2.1. Location
Palakkad district is situated in the southwest coast of India, bounded on the North by Malappuram in the East by Coimbatore of Tamil Nadu, in the south by Thrissur and in the west by Thrissur and Malappuram districts. It lies between10° 21' and 11° 14' North latitude and 76° 02' and 76° 54' East longitude. The total geographical area of the district is 4480 sq.km, representing 11.53% of the state's geographical area.

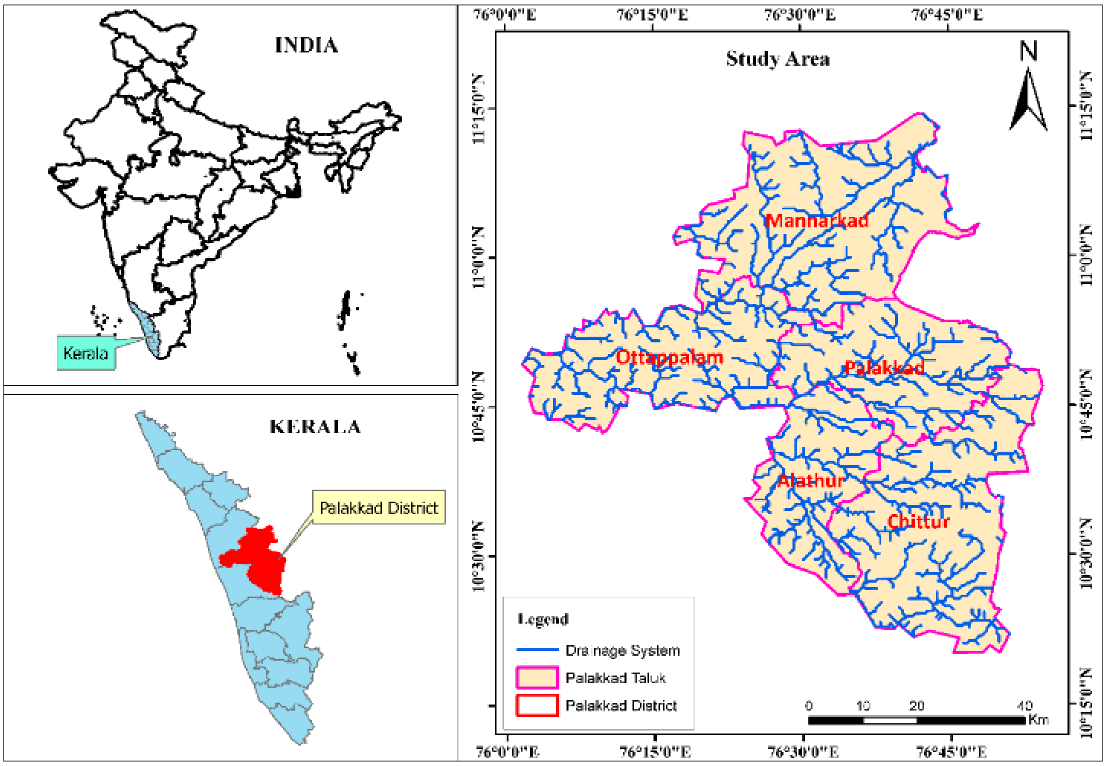

Fig 1: Location map of the Study area

2.2. Drainage
Bharathappuzha, with her tributaries, sprawls across the entire district. The river originates from the Anamalai Hills and flows through the districts of Palakkad, Malappuram, and Thrissur before emptying into the Arabian Sea at Ponnani. Its four main tributaries are Gayathrippuzha, Kannadipuzhz, Kalpathyppuzha and Thuthappuzha.

2.3. Climate
The district has a humid tropical climate with a very hot season extending from March to June in the western part of the district whereas it is less humid in the eastern sector. The most important rainy season is during south west monsoon which sets in the second week of June and extends up to September. About 75% of the annual rain is received. The temperature of the district ranges from 20 °C to 45 °C. The maximum temperature recorded at Palakkad was 43°C.

2.4. Soil
The soil of Palakkad district is mainly of four types, namely, peaty (kari), laterite, forest and black. Peaty soil is found only in the Thrithala firka of Ottappalam taluk (CGWB, 2019). Laterite is seen in the major portions of all taluks. Forest soil is confined to Mannarkkad and Ottappalam taluks, the narrow strip of land along the western boundaries of Palakkad and Alathur taluks and along the southern boundary of Chittur taluk. Black soil is seen mostly in the eastern sector of a small portion of Palakkad taluk.

2.5. Minerals
Low-grade iron ore (magnetite) is found at Kollengode, Mannarghat and Muthalamada. The Limestone deposits are found in the Chittur and Kozhinjampara firkas. Muscovita mica is reported to be present in the Sholayar villages. A large quantity of limestone deposits is found in the Walayar forest area where the government has started a cement factory (Department of Mining and Geology, 2016) [10].

3. Methodology
The present study intended to examine the seasonal changes of LST and RH in Palakkad district of Kerala. For this, we have focused on the pre-monsoon, monsoon and post-monsoon seasons in the years of 2014, 2016, 2018, 2020 and 2022. The study seeks to understand how temperature and humidity vary with the seasons and how these variations reflect the region's general climatic and environmental situations by analysing these two important parameters.
Due to the distinctive physiography and diversity in climate, Palakkad was selected as the study area. The current study tried to understand the impact of monsoon cycles on local moisture and temperature characteristics. A comparative assessment of seasonal changes is also carried out to stress

the relationships between regional environmental factors and climatic variability. The dataset of RH and LST for the years of 2014, 2016, 2018, 2020 and 2022 was retrieved from Google Earth Engine (GEE). LST mean data obtained from the MODIS Terra MOD11A2 Version 6 product. This provides an 8-day composite surface temperature at 1 km spatial resolution which reduces the effect of cloud contamination and allows uniform regional evaluations. Hourly relative humidity (RH) data were obtained from the ERA5-Land reanalysis dataset (~9 km spatial resolution) provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). Although this resolution is relatively coarse for a small and topographically varied area like Palakkad District, ERA5-Land was selected for its reliable temporal consistency, bias correction, and suitability for regional-scale humidity assessment in areas with limited ground observations.
The mean values of RH were computed using the standard psychrometric relationship between air temperature (T, °C) and dew point temperature (Td, °C), expressed as:

$$RH = 100 \times \frac{e(T_d)}{e(T)}$$

where the saturation vapour pressure $e(T)$(in hPa) is given by:

$$e(T) = 6.112 \times exp\left(\frac{17.67 \times T}{T + 243.5}\right)$$

This formulation is widely used in meteorological studies for estimating RH from temperature and dew point data (Alduchov *et al*., 1996; Lawrence, 2005) [1, 20].
These extracted means of years and variables extracted using GEE and saved in CSV and GeoTIFF formats.
The outcomes were then processed and shown using QGIS. Furthermore, a visual interpretation of land use and land cover was done to explain spatial variations in LST and RH in addition to quantitative analysis. The integrated approach not only stressed seasonal and temporal variability, but also clarified the ways in which land use patterns and environmental aspects affect the local temperature and moisture conditions in Palakkad.

4. Results and Discussion

4.1. 2014 Analysis

In 2014, the Land Surface Temperature (LST) during the pre-monsoon period was significantly high, especially in the central and eastern parts of Palakkad, including Palakkad and Chittur regions, with temperatures reaching close to 40°C. During the monsoon season, LST drops considerably across all regions, reflecting the cooling effect of rainfall, with values mostly below 30°C. In the post-monsoon season, the temperature remains relatively low but slightly higher than in the monsoon, especially in the south-eastern parts (Figure 2). The Relative Humidity (RH) in 2014 shows high values throughout all seasons, ranging between 92% and 97%. During the pre-monsoon, RH is relatively lower in the central regions compared to the northern and southern parts. During the monsoon, humidity increases across all areas, indicating heavy rainfall and saturated air. The post-monsoon season is characterised by high moisture, particularly in Mannarkad and Ottappalam (Figure 2).

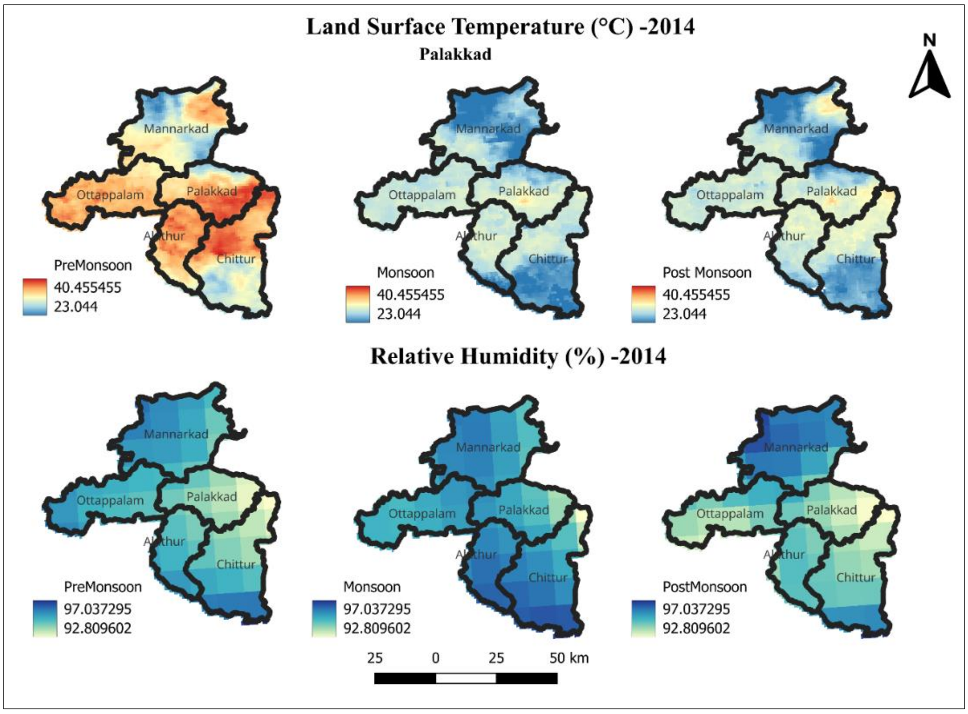

Fig 2: LST and RH of pre-monsoon, monsoon and post-monsoon seasons in 2014

4.2. 2016 Analysis

In 2016, the pre-monsoon LST was almost the same as in 2014, with the central and eastern areas showing values of over 35°C. The northern part of Mannarkad, however, is slightly cooler than in 2014. The monsoon period continues to experience a drop in temperatures across all regions, getting below 30°C, similar to 2014. Post-monsoon temperatures are still relatively low but indicate seasonal warming after the rains by showing a slight increase compared to monsoon levels (Figure 3). For Relative Humidity, the pre-monsoon season in 2016 is generally very humid, with RH values mostly ranging from 95% to 98%.

The monsoon season again records maximum RH values similar to 2014, while the post-monsoon period retains high humidity levels in the two spots of Mannarkad and Ottappalam, that is, in the districts of Thrissur and Palakkad, which is comparable to the previous years (Figure 3).

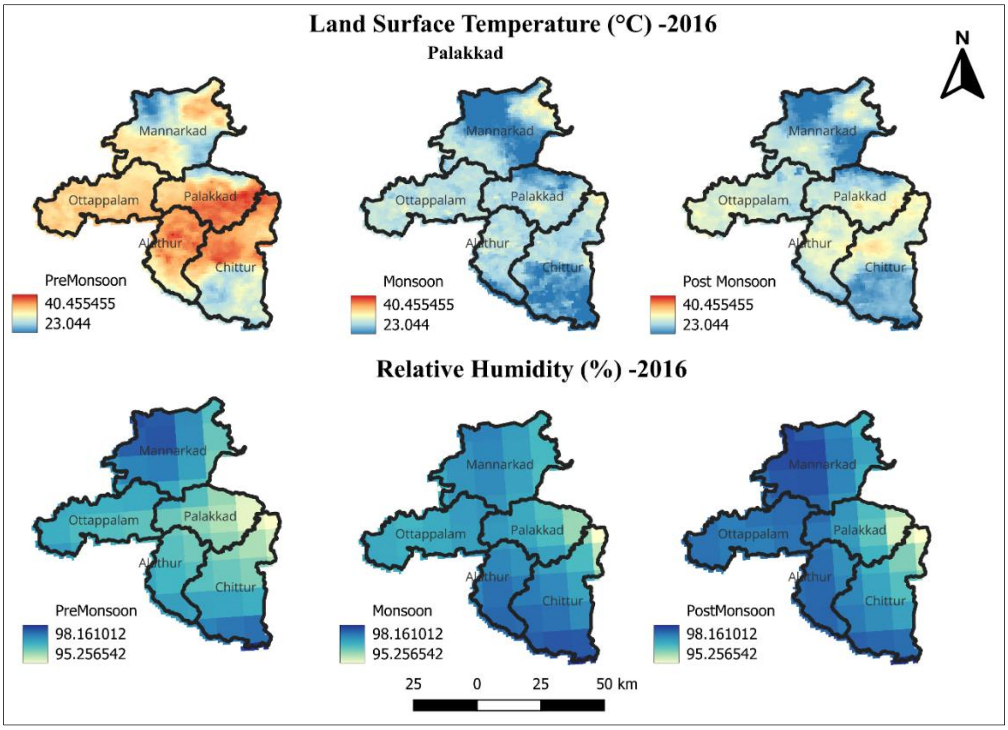

Fig 3: LST and RH of pre-monsoon, monsoon and post-monsoon seasons in 2016

4.3. 2018 Analysis

The 2018 LST during pre-monsoon is slightly higher in the east and the middle parts of the figure, which means warm conditions compared to previous years. 2018 is a year when the lowest LST continue during the monsoon, consistent with earlier years. The post-monsoon period still shows the pulmonar plethoric trend of 2017, with some areas getting warmer but others remaining cold or even getting colder; thus, the overall picture is that the season is at its cooler limits (Figure 4).Relative Humidity in 2018 increased compared to 2016, with a minimum of 97.6% and a maximum of 99.2%. This means the highest values recorded so far have been achieved during this period. It indicates a very wet year, and the likely reason for the high RH during the monsoon is the rainfall. The RH in these two places is also higher than in the south (Figure 4).

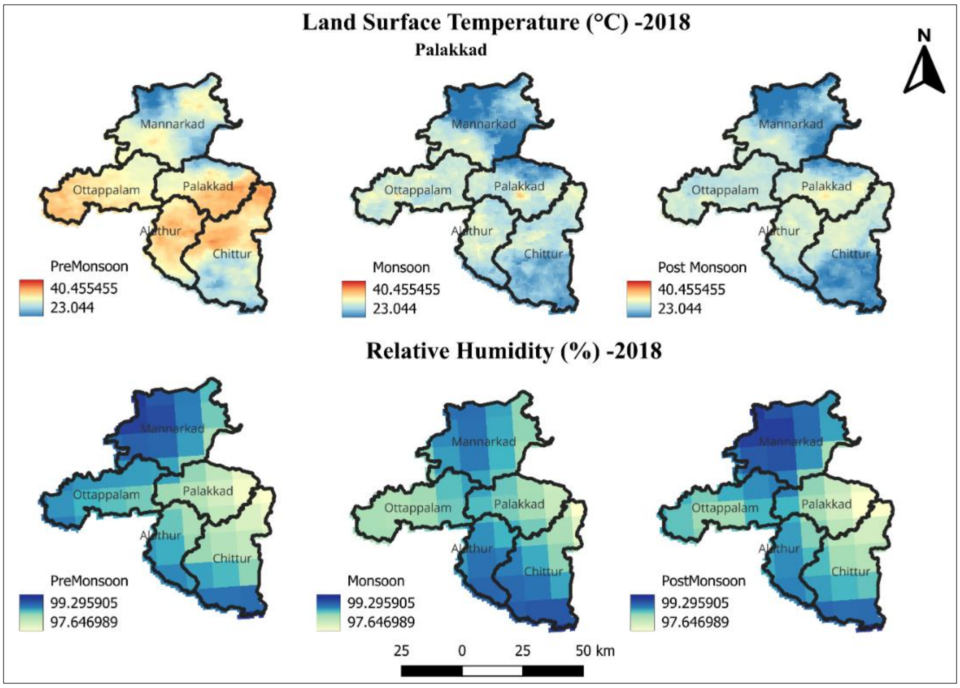

Fig 4: LST and RH of pre-monsoon, monsoon and post-monsoon seasons in 2018

4.4. 2020 Analysis

The pre-monsoon LST in 2020 has increased slightly compared to 2018 but is still lower than in 2014. The hottest areas remain the same, primarily the central and eastern parts of the district (Palakkad and Chittur). During the monsoon, temperatures remain cool, consistent with the past three years, and the post-monsoon temperature is marginally higher than during the monsoon but significantly lower than the pre-monsoon, following the usual trend (Figure 5).The Relative Humidity in 2020 depicts a downward trend from 2018, as the values lie in the range of 93.3% to 97.6%, showing that the atmosphere is relatively dry compared to the previous wet year. Though this decrease is seen, RH is high during the monsoon, and this is typical for the region from where we get the pre-monsoon and post-monsoon values, which are lower compared to 2018 (Figure 5).

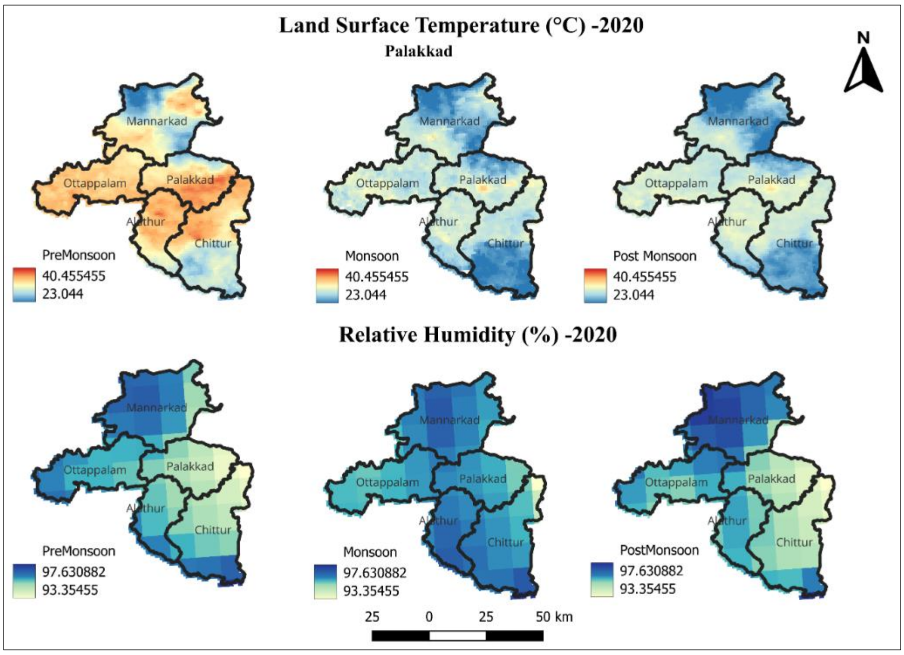

Fig 5: LST and RH of pre-monsoon, monsoon and post-monsoon seasons in 2020

4.5. 2022 Analysis

The pre-monsoon LST in 2022 has been slightly lower than that of 2020 in the northern parts (Mannarkad) and some central regions, thus indicating that the weather has been milder. Temperatures during the monsoon and post-monsoon stay on the lower side, retaining the pattern observed in the earlier years, and Mannarkad is cooler than the rest of the regions in all seasons (Figure 6).

The Relative Humidity in 2022 is more or less the same as that in 2020, with the values ranging from 93.3% to 97.6%, suggesting that the area has been a little drier than the peak year of 2018. The places where the humidity is high during the monsoon are Mannarkad and Ottappalam, while Palakkad and Chittur are the areas that show lower RH in pre- and post-monsoon seasons (Figure 6).

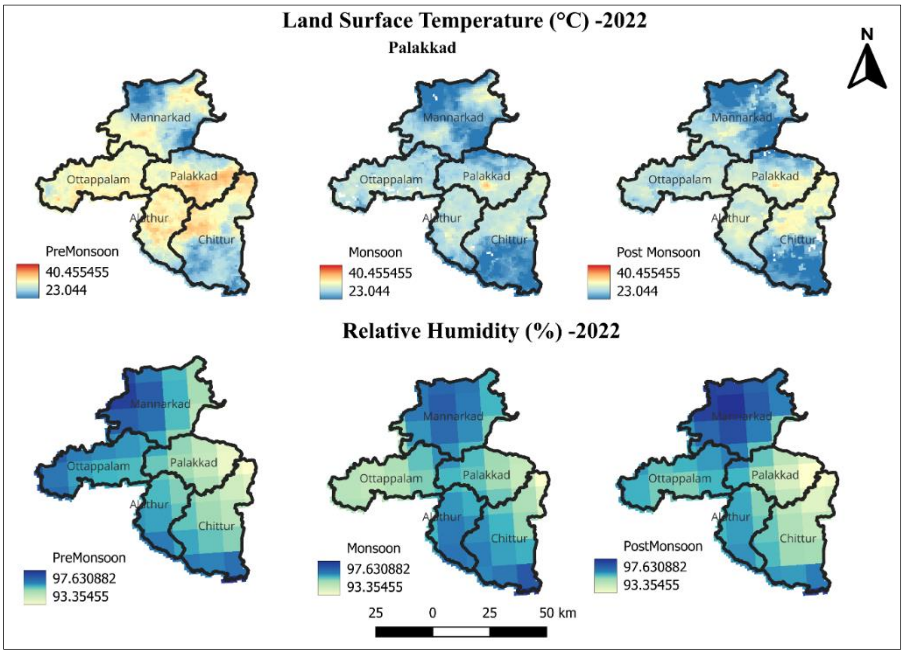

Fig 6: LST and RH of pre-monsoon, monsoon and post-monsoon seasons in 2022

4.6. Comparative Analysis of Land Surface Temperature (2014–2022)

Looking at the ten years, the pre-monsoon season has always been the highest LST value holder, whereas the monsoon and post-monsoon seasons have been significant in terms of their cooling effect. A peak in pre-monsoon LST was recorded in 2014, mainly in the Palakkad and Chittur areas, where the temperature went beyond 38°C in several spots, while Mannarkad was still at a relatively low level.

The year 2016 had a notably similar temperature pattern to 2014 but also presented a small decrease in the number of extreme hot areas in the northern region. It seems that 2018 was a transitional year, marking a slight cooling trend during pre-monsoon with temperatures even in central and eastern regions slightly lower than in previous years. The change of weather that can be linked to the considerable rainfall that year is quite apparent here.

Although pre-monsoon temperatures increased by a small margin in 2020 compared to 2018, they did not come near the extremes of 2014. Moreover, pre-monsoon LST in 2022 is slightly higher than that of 2020 in the areas of Mannarkad and Ottappalam; thus, these parts may be at risk of experiencing late hot spells if a trend is to be established. In all the years, monsoon temperatures were always on the lower side (mostly 23–28°C), and post-monsoon temperatures were only a little higher than monsoon but much lower than pre-monsoon.

4.7. Comparative Analysis of Relative Humidity (2014–2022)

Relative humidity initially increased from 2014 to 2018, dipped in 2020, and then stayed stable in 2022. The change of RH from 92-97% in pre-monsoon 2014 indicated very little difference in atmospheric moisture content across the regions with Mannarkad showing slightly higher values than the central and southern regions. It was found in 2016 that the RH had risen to 95–98%, which means that there was more moisture in the air prior to the monsoon onset. The year 2018 saw the highest relative humidity, especially during the monsoon and post-monsoon seasons, with values going as high as 99% indicating it was one of the wettest years of the decade. Nevertheless, a decrease in RH from 93-97% was observed in 2020, indicating relatively drier conditions compared to 2018. This was the case again in 2022, as the levels of humidity were very close to those recorded in 2020. It can be seen from the figures of all the years that the period of monsoon is the one during which the atmosphere receives the highest amount of water vapor and pre-monsoon and post-monsoon are the seasons with the greatest fluctuations in the area while the two localities of Mannarkad and Ottappalam are the ones with the most elevated values lying both on the plateau and in the valley of the river.

4.8. Decadal Trend Summary

In general, data shows that pre-monsoon periods compared to the extremes of 2014 tend to be a bit cooler in the last few years, but still, heat stress should not be neglected in places like Palakkad and Chittur. The cooling effect of the monsoon is going on with little change from year to year. The highest level of humidity occurred in 2018 when the rainfall was also very high and thus, an extreme weather event could be the reason. Meanwhile, 2020–2022 show a gentle decline that may point to changes in local rainfall patterns or that the region might be experiencing some dry spells. On the other hand, Mannarkad is the coolest and the most humid place during all the years, and Palakkad and Chittur are the hottest with relatively low humidity. So, these two places are at a greater risk of heat stress.

5. Conclusion

The LST of pre-monsoon was very high from March to May in almost all years. This ranges from 35°C to 40°C, especially in Alathur, Chittur, and parts of Palakkad. The high range areas near Silent Valley (altitude above 1200 m) in Mannarkkad taluk retain comparatively cooler temperatures. The heat stress is mainly notable in the southeastern plains. There was a slight less intense hot in 2018 and 2022 compared to earlier years. This may be due to climatic variations like the flood in 2018. The relative humidity was comparatively lower than monsoon season. Ottappalam and Mannarkkad taluks have higher humidity than Palakkad, Alathur and Chittur. Over the years, the RH increased to 93% in 2014 and 97–99% in 2018-2022.

There was a significant drop in LST around 23–30 °C in the monsoon period (from June to September) across most of the regions. The areas in Mannarkkad and other elevated areas were considerably cooler than the plain areas of Chittur and Palakkad. The cooling effect of the monsoon season is visible throughout the years, while 2020 and 2022 show relatively excessive heating. The RH of all taluks considerably increased up to 96-99%. There was a trend of high humidity across the district, whereas 2018 and 2022 showed near-saturation humidity. This is consistent with heavy rainfall.

LST remains moderate during post post-monsoon season in October and November.

This ranges from approximately 25 to 32 °C. Heat dissipation is more uniform, though plain regions, like Chittur and Palakkad, remain marginally higher LST compared to Mannarkkad. This season was cooler than pre-monsoon but slightly warmer than monsoon. The RH of all taluks is still high, which was up to 94-98%. This was moderately decreased from the monsoon period, and a higher proportion can be seen in the elevated or western areas. There was a slight decrease in RH noticed after 2020 in some portions.

The RH and LST show an inverse relationship throughout all years. That means, if the LST is high, the RH will be low and vice versa. In fact, the map shows that the pre-monsoon season has the highest stress is highest in Chittur & Alathur, causing a hot and dry climate, monsoon provides low temperatures and high humidity, and post-monsoon exhibits a variation, warming begins again, but with moderate RH. Palakkad and Chittur taluks maintain warm, steady hotspots, which demonstrate pronounced urban heat and arid plain influences. Homogeneous cooling was the major effect of the monsoon season; on the other hand, Palakkad and Chittur regions lag in temperature decrease relative to Mannarkkad. The relative humidity reveals an upward trend mainly during the monsoon.

In 2018, there was an ascending trend and a comparatively dropped pre-monsoon dryness due to the flood in Kerala. 2022 shows a decline in LST than earlier pre-monsoon seasons. Even though it still implies heating pockets due to climate variability.

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Authors Contribution: All authors have contributed equally to this work.

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