Spatiotemporal agricultural drought analysis in Sivaganga district using Remote sensing indices and Google Earth Engine

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Abstract

Agricultural drought poses a significant threat to crop productivity and rural livelihoods, particularly in semi-arid regions such as Sivaganga district in Tamil Nadu, India. This study leverages the capabilities of Google Earth Engine (GEE) to assess agricultural drought vulnerability using Landsat 8 satellite data spanning from 2018 to 2024. Key remote sensing indices including the Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), Land Surface Temperature (LST), Temperature Condition Index (TCI) and Vegetation Health Index (VHI), were analyzed within the GEE platform to evaluate spatial and temporal drought patterns. The results indicate that the northeastern and central regions of Sivaganga district experienced severe to very severe drought during 2018, 2020 and 2021, primarily due to low precipitation, elevated thermal stress and prolonged dry spells. Conversely, the southern regions demonstrated greater resilience, with moderate to no drought conditions observed in 2019 and 2023. Emerging moderate drought conditions in 2024 in the eastern part of the district signal a potential trend toward increased aridity. The integration of NDVI, VCI, LST, TCI and VHI within GEE provided a robust framework for comprehensive drought assessment, revealing strong correlations between thermal stress and vegetation health.

This study underscores the importance of adaptive water management strategies, reforestation efforts and climate-resilient agricultural practices to mitigate drought risks. The findings offer actionable insights for targeted agricultural planning and sustainable resource management, highlighting the critical role of remote sensing and cloud-based platforms like GEE in supporting informed decision-making in drought-prone regions.

Keywords: NDVI, VCI, LST, TCI, VHI, Google Earth Engine.

Introduction

Drought is one of the most pervasive natural hazards with profound implications for ecosystems, economies and human societies. It disrupts water availability, reduces agricultural productivity and exacerbates food insecurity, particularly in semi-arid regions[9]. Among its various forms, agricultural drought is especially critical as it directly impacts crop yields, vegetation health and rural livelihoods[14]. This type of drought arises when soil moisture deficits or insufficient rainfall impair plant growth, posing significant challenges to regions reliant on rain-fed agriculture. Sivaganga district in Tamil Nadu, India, exemplifies such vulnerability due to its dependence on seasonal monsoons and limited irrigation infrastructure. Erratic rainfall patterns and prolonged dry spells have made this region highly susceptible to drought-induced crop failures and economic losses.

The assessment of agricultural drought has traditionally relied on ground-based observations and meteorological data, which are often spatially limited and resource-intensive[16]. However, advancements in remote sensing technologies have revolutionized drought monitoring by providing scalable, cost-effective and near-real-time insights into environmental conditions[11]. Satellite-derived indices, such as the Normalized Difference Vegetation Index (NDVI), have been widely used to evaluate vegetation health and detect anomalies indicative of drought[4]. Similarly, the Vegetation Condition Index (VCI) offers a normalized measure of vegetation stress by comparing current conditions to long-term trends, making it particularly valuable for identifying drought-affected areas[6].

Thermal indices, such as Land Surface Temperature (LST) and the Temperature Condition Index (TCI), complement vegetation-based metrics by capturing thermal stress on crops and ecosystems[13]. Elevated surface temperatures can exacerbate water stress and reduce plant productivity, making LST a critical parameter for drought assessment[15]. TCI further refines this analysis by quantifying deviations in temperature from historical averages, thereby highlighting regions experiencing extreme heat or cold[5]. The integration of these indices into composite metrics, such as the Vegetation Health Index (VHI), provides a holistic perspective on drought severity by combining information on both vegetation condition and thermal anomalies[6].

Despite the global adoption of remote sensing tools for drought monitoring, region-specific studies in Sivaganga district remain limited. This gap underscores the need for targeted research to evaluate drought dynamics and their implications for local agriculture and water resources. Recent advancements in cloud-based platforms like Google Earth Engine (GEE) have further enhanced the accessibility and efficiency of remote sensing analyses[2]. GEE enables researchers to process large-scale satellite datasets, perform complex computations and visualize results in a user-friendly environment, making it an ideal tool for assessing drought in data-scarce regions like Sivaganga.

This study aims to address the existing research gap by conducting a spatiotemporal analysis of agricultural drought in Sivaganga district using Landsat 8 satellite data from 2018 to 2024. Key indices including NDVI, VCI, LST, TCI and VHI, were analyzed within the GEE platform to identify drought patterns and assess their impact on vegetation health. By leveraging these advanced tools, the study seeks to provide actionable insights for policymakers, stakeholders and agrarian communities. The findings are expected to support the development of sustainable water management practices, climate-resilient agricultural systems and targeted interventions to mitigate drought risks in the region.

In summary, this work highlights the importance of integrating remote sensing technologies and cloud-based platforms for comprehensive drought assessment. The principal conclusions underscore the value of such approaches in informing adaptive management strategies and improving agricultural resilience in drought-prone regions.

Study area

The research focuses on Sivaganga district, situated in the southern region of Tamil Nadu, India. Geographically, it is positioned between 9°30′N and 10°15′N latitude and 78°10′E and 78°50′E longitude. The district is predominantly rural, with agriculture serving as the primary source of livelihood for its population. Characterized by a semi-arid climate, the region experiences limited water availability and is highly susceptible to recurring droughts. Rainfall in Sivaganga is heavily reliant on the southwest and northeast monsoons, which are often unpredictable and unevenly distributed. This variability leads to significant fluctuations in precipitation both spatially and temporally.

The average annual rainfall ranges from 850 mm to 1,200 mm, but the inconsistency in its distribution exacerbates water scarcity issues, particularly during dry spells. These climatic conditions make the district highly vulnerable to drought, posing challenges to agricultural productivity and the overall resilience of local communities.

Material and Methods

This study evaluates agricultural drought vulnerability in Sivaganga district, Tamil Nadu, India, using remote sensing indices derived from Landsat 8 satellite data. The analysis spans from 2018 to 2024 and leverages the computational capabilities of Google Earth Engine (GEE), a cloud-based platform designed for large-scale geospatial data processing[2]. Landsat 8's multispectral imagery, with a spatial resolution of 30 meters, was utilized to compute key drought indices, ensuring detailed spatial and temporal assessments.

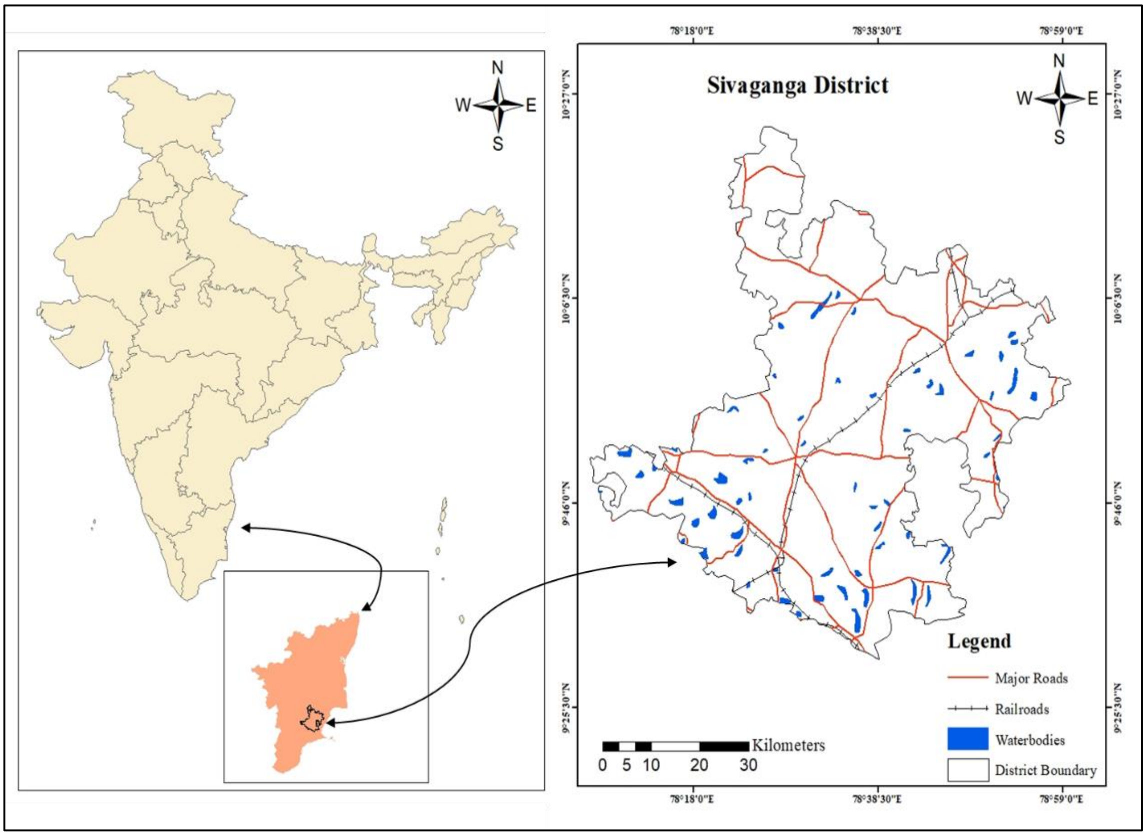

Figure 1: Location Map of Sivaganga District

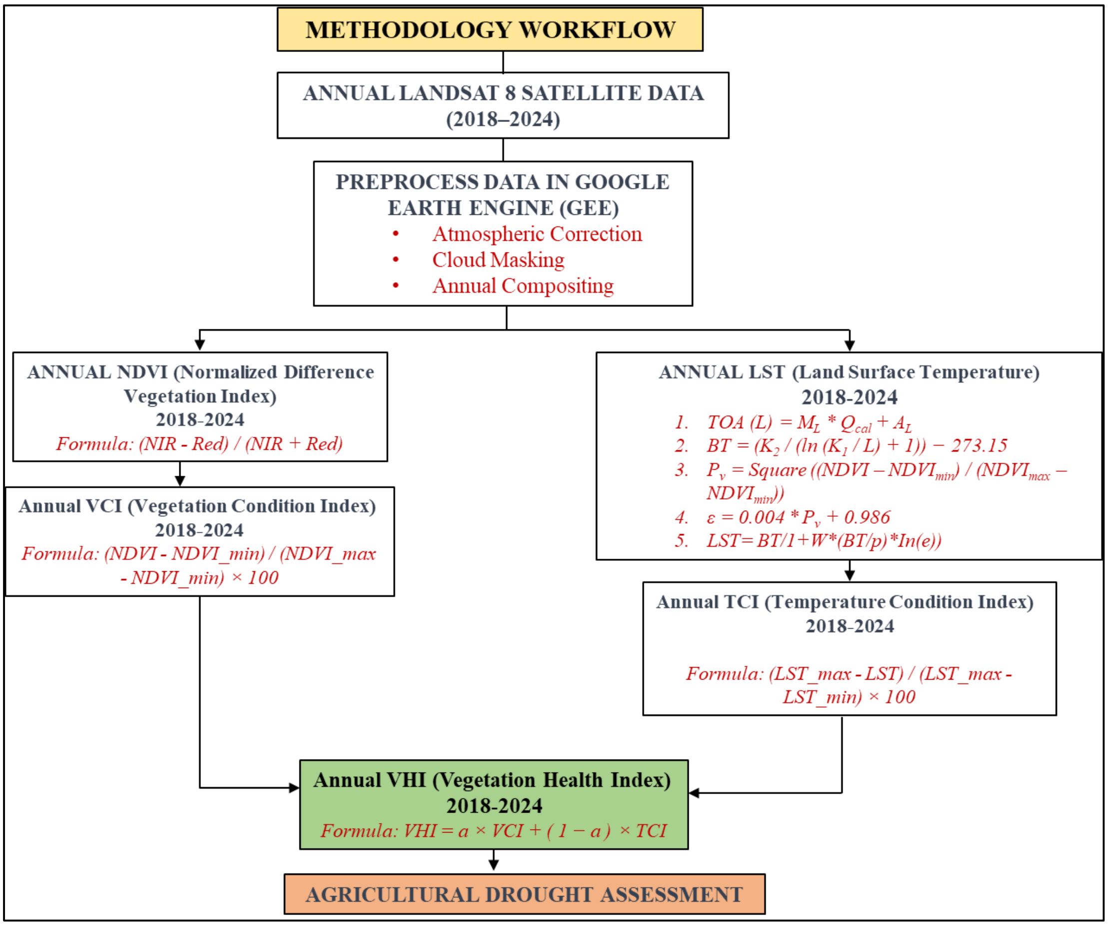

Figure 2: Methodology Flow Chart

The methodology involved calculating five widely recognized remote sensing indices to assess vegetation health and thermal stress. The Normalized Difference Vegetation Index (NDVI) was used to quantify vegetation vigor by analyzing the difference between near-infrared (NIR) and red reflectance bands[11]. NDVI values range from -1 to 1, with higher values indicating healthier vegetation. To account for deviations from historical trends, the Vegetation Condition Index (VCI) was computed, normalizing NDVI values relative to long-term maximum and minimum NDVI[4]. VCI provides a percentage-based measure of vegetation stress where lower values signify severe drought conditions.

Thermal stress on crops was evaluated using Land Surface Temperature (LST), derived from Landsat 8's Thermal Infrared Sensor (TIRS) bands through radiative transfer equations[13]. LST was further analyzed using the Temperature Condition Index (TCI), which quantifies temperature anomalies relative to historical extremes[15]. TCI values range from 0 to 100, with lower values indicating higher thermal stress. Finally, the Vegetation Health Index (VHI) was calculated by integrating VCI and TCI, offering a comprehensive assessment of drought severity[6]. VHI balances contributions from vegetation health and thermal conditions, providing a holistic perspective on drought impacts. All data processing and analysis were conducted within the GEE platform, which enabled efficient handling of large datasets and ensured reproducibility. Preprocessing steps included atmospheric correction using the Landsat Surface Reflectance Tier 1 product and cloud masking to enhance data quality. Monthly composites of NDVI, LST, VCI, TCI and VHI were generated to analyze temporal trends while spatial analysis was performed at the district level.

Results

The agricultural drought vulnerability in Sivaganga district from 2018 to 2024 was assessed using remote sensing indices derived from Landsat 8 satellite data, processed within the Google Earth Engine (GEE) platform. The analysis focused on five key indices: Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI). These indices were classified into five drought severity categories such as Very Severe, Severe, Moderate, Slight and No Drought to evaluate spatial and temporal patterns of drought across the district.

The Normalized Difference Vegetation Index (NDVI) was used to assess vegetation health and vigor over the study period. NDVI values range from -1 to 1, with higher values indicating healthier vegetation. Regions with low NDVI values were categorized as experiencing very severe drought conditions, while higher NDVI values corresponded to slight or no drought. Spatial analysis revealed that the northeastern and central regions of Sivaganga district were most affected by drought during 2018, 2020 and 2021, with predominantly severe to very severe drought classifications. In contrast, 2019 and 2023 exhibited improved vegetation health, particularly in the southern regions, where moderate to no drought conditions were observed. This variability highlights the interannual fluctuations in vegetation vigor and underscores the vulnerability of specific regions to prolonged dry spells.

Land Surface Temperature (LST) was analyzed to evaluate thermal stress on vegetation and ecosystems. Elevated LST values were consistently observed during 2020 and 2021, coinciding with widespread drought conditions. These elevated temperatures exacerbated water stress and reduced plant productivity, particularly in the northeastern and central regions.

Conversely, 2019 and 2023 showed reduced LST anomalies, indicating periodic relief from thermal stress. The findings emphasize the critical role of surface temperature in influencing drought severity and its direct impact on vegetation health.

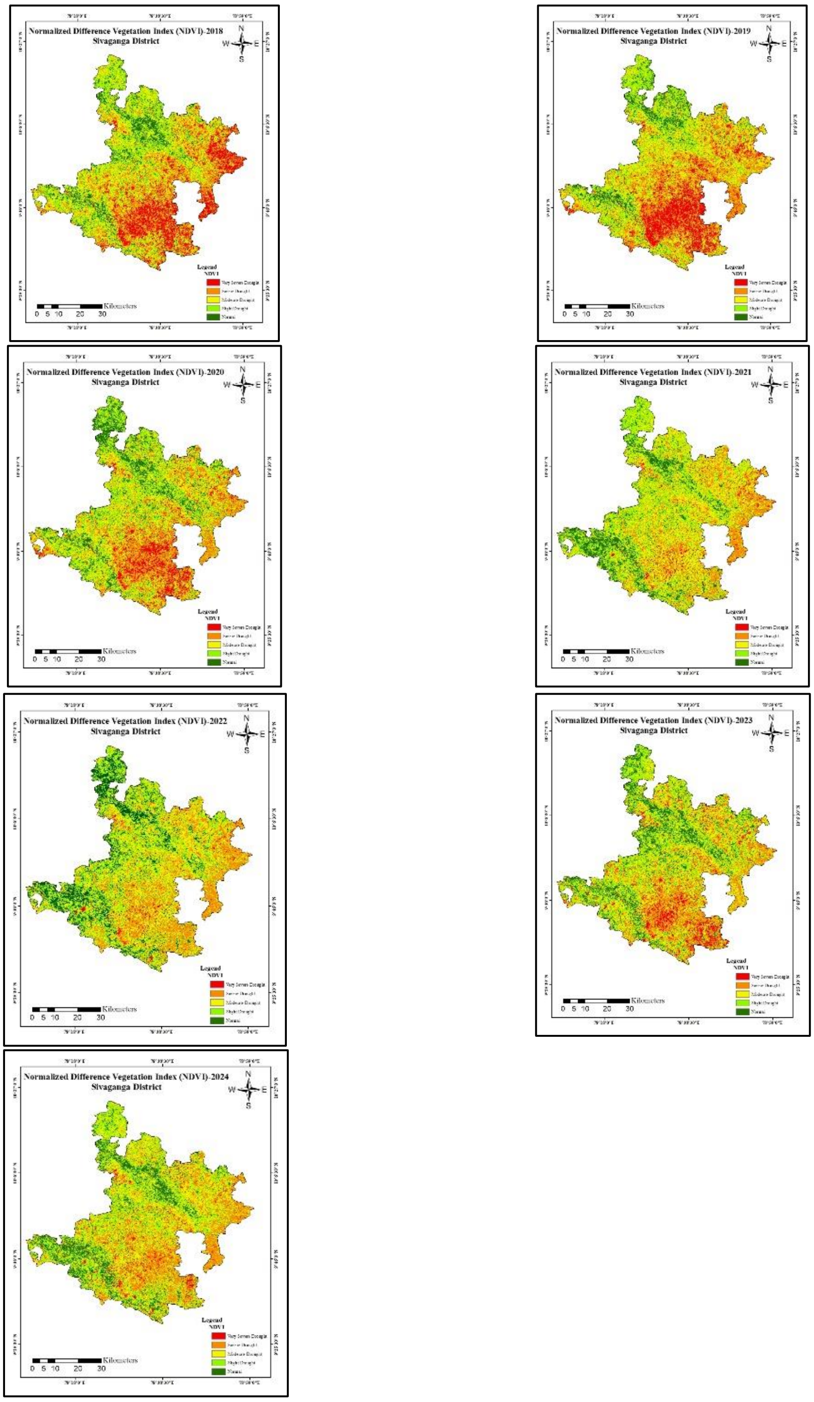

Figure 3: NDVI Map (a)2018; (b)2019; (c)2020; (d)2021; (e)2022); (f)2023; (g)2024

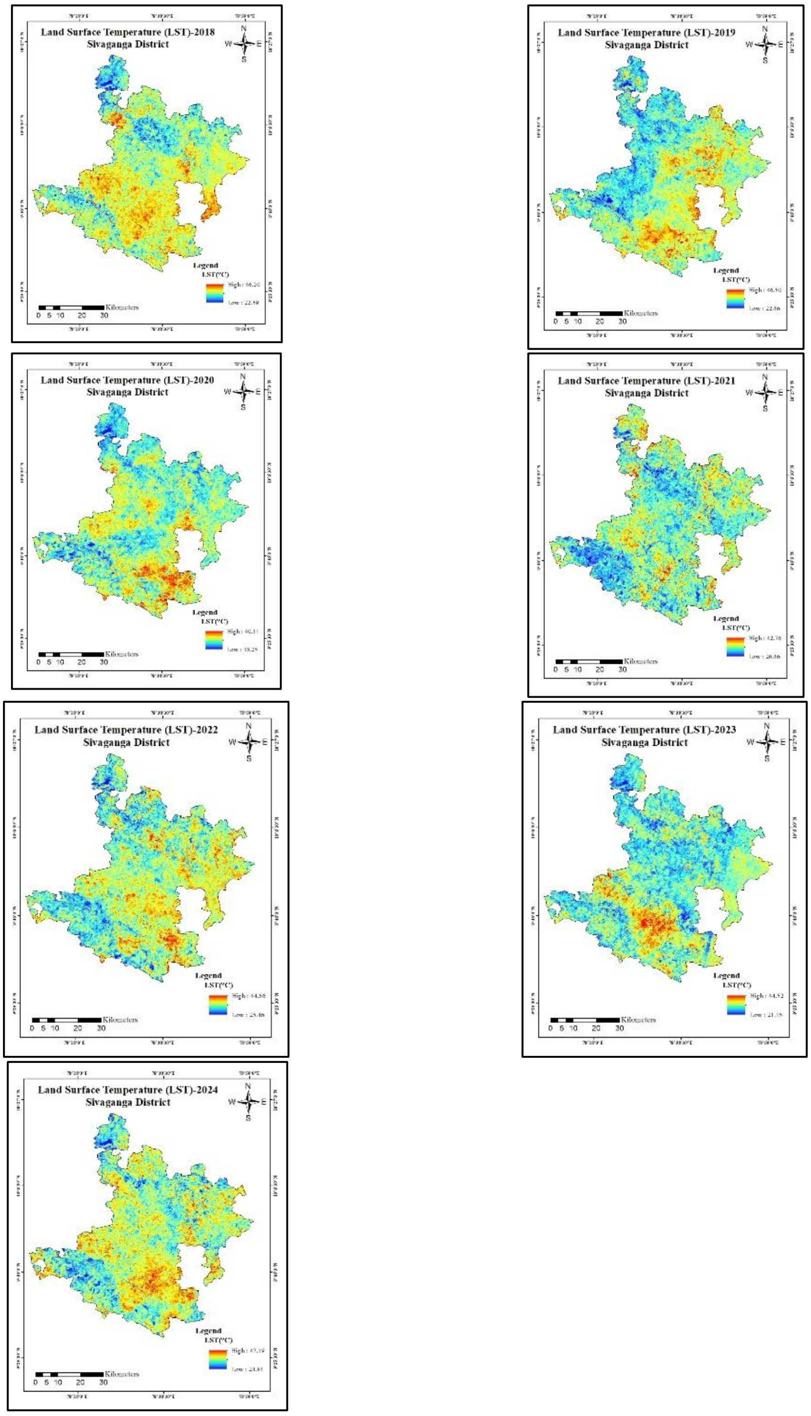

Figure 4: LST Map (a)2018; (b)2019; (c)2020; (d)2021; (e)2022); (f)2023; (g)2024

The Vegetation Condition Index (VCI) provided a normalized measure of vegetation stress by comparing current NDVI values to long-term historical trends. VCI values range from 0 to 100, with lower values indicating severe drought conditions. The analysis confirmed that 2020 and 2021 were marked by extensive very severe drought conditions, particularly in the northeastern and central regions. In contrast, 2018, 2019 and 2023 demonstrated relatively stable conditions, with predominant classifications of slight drought to no drought. The VCI findings corroborated the NDVI results, highlighting the persistence of vegetation stress during drought years and the importance of monitoring long-term trends for effective drought assessment.

The Temperature Condition Index (TCI) quantified deviations in land surface temperature from historical averages, providing insights into thermal anomalies. TCI values range from 0 to 100, with lower values indicating higher thermal stress. The analysis revealed that 2020 and 2021 experienced widespread severe and very severe drought conditions, driven by elevated thermal anomalies and reduced precipitation. Conversely, 2019 and 2023 showed moderate to slight drought conditions, with some areas classified as no drought, suggesting periodic climatic relief. The TCI findings underscore the critical role of temperature anomalies in exacerbating drought severity and their impact on vegetation health.

The Vegetation Health Index (VHI) integrated VCI and TCI to provide a holistic assessment of drought severity by combining information on both vegetation condition and thermal anomalies. VHI values range from 0 to 100, with lower values indicating more severe drought conditions. The analysis confirmed that 2020 and 2021 were characterized by extensive very severe drought conditions across most of the district, particularly affecting the northeastern and central regions. In contrast, 2018, 2019 and 2023 demonstrated relatively stable conditions, with predominant classifications of slight drought to no drought. The VHI findings corroborated the results from NDVI, LST, VCI and TCI, emphasizing the persistence of drought conditions during specific years and the need for comprehensive monitoring frameworks.

Preliminary assessments for 2024 indicated emerging moderate drought conditions, particularly in the eastern part of the district. This trend suggests a potential shift toward increased aridity, underscoring the need for proactive measures to mitigate drought risks in the coming years. The findings highlight the importance of continuous monitoring and adaptive management strategies to address evolving drought dynamics.

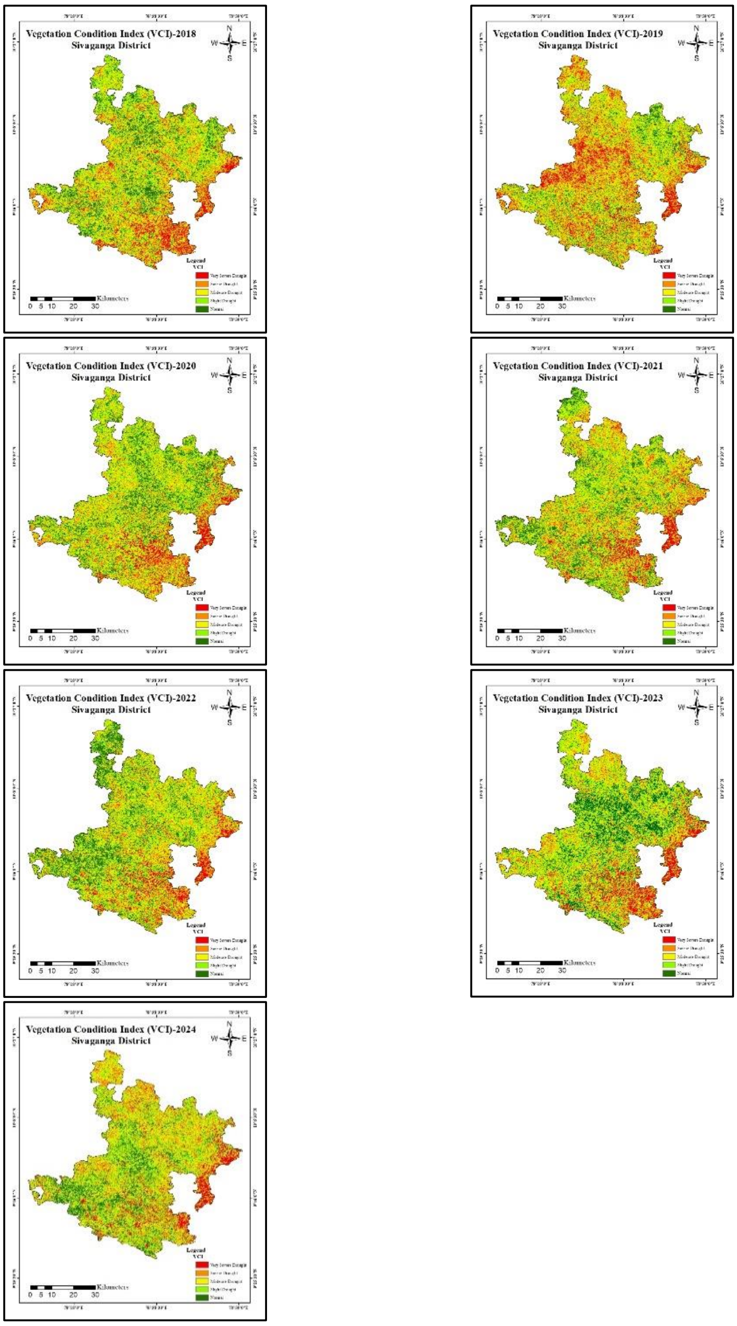

Figure 5: VCI Map (a)2018; (b)2019; (c)2020; (d)2021; (e)2022); (f)2023; (g)2024

The spatio-temporal analysis highlighted persistent vulnerabilities in the northeastern and central regions, which experienced prolonged periods of vegetation stress and thermal anomalies during 2018, 2020 and 2021. These areas are highly susceptible to climatic fluctuations, making them prone to extreme drought events.

In contrast, the southern regions demonstrated greater resilience, with lower drought severity throughout the study period. This regional disparity underscores the importance of targeted interventions to address localized vulnerabilities and to enhance agricultural resilience in drought-prone regions.

Discussion

The findings of this study provide a comprehensive understanding of agricultural drought dynamics in Sivaganga district from 2018 to 2024, leveraging advanced remote sensing indices and cloud-based platforms like Google Earth Engine (GEE). The integration of NDVI, LST, VCI, TCI and VHI has revealed critical insights into the spatial and temporal patterns of drought severity, emphasizing the interplay between vegetation health and thermal stress. The northeastern and central regions of Sivaganga district emerged as hotspots of drought vulnerability, consistently experiencing severe to very severe drought conditions during 2018, 2020 and 2021.

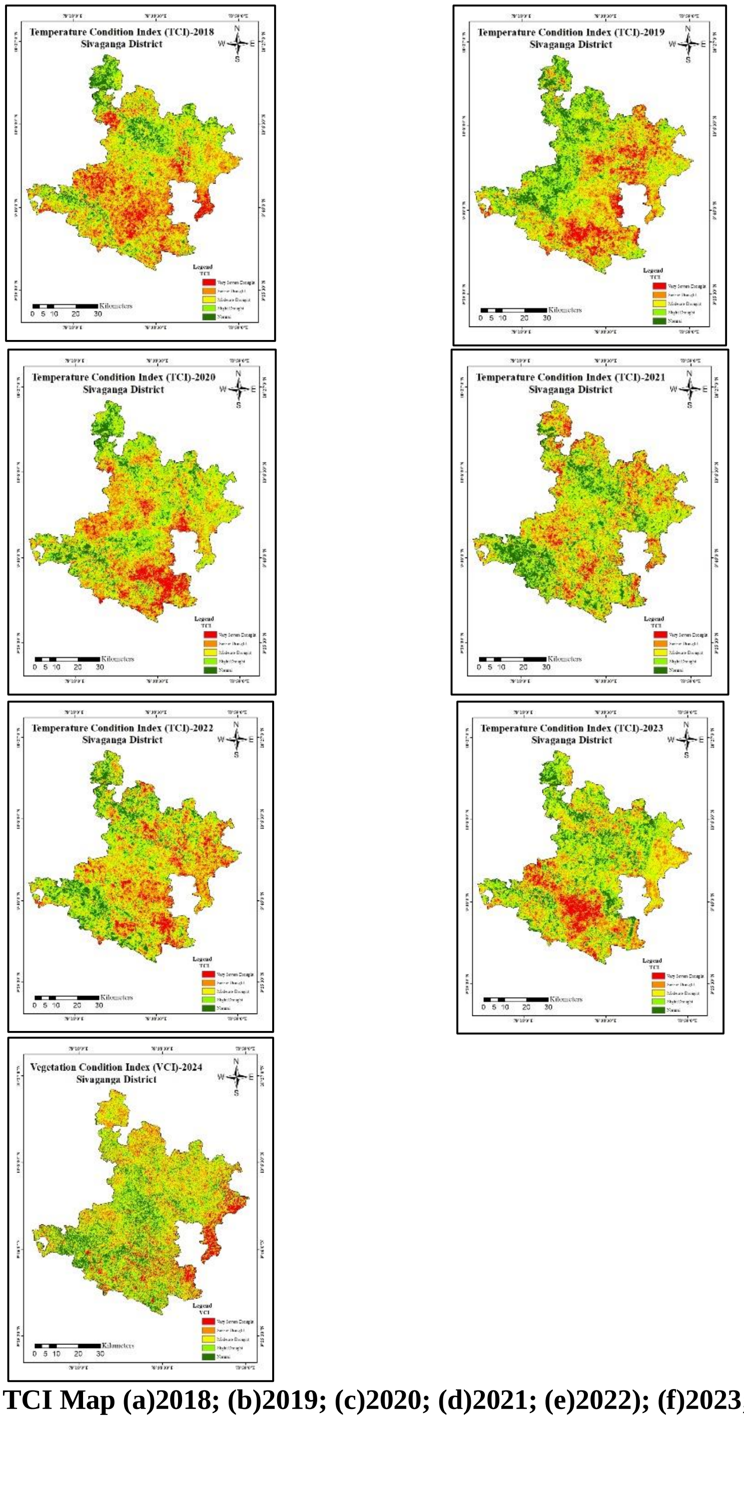

Figure 6: TCI Map (a)2018; (b)2019; (c)2020; (d)2021; (e)2022); (f)2023; (g)2024

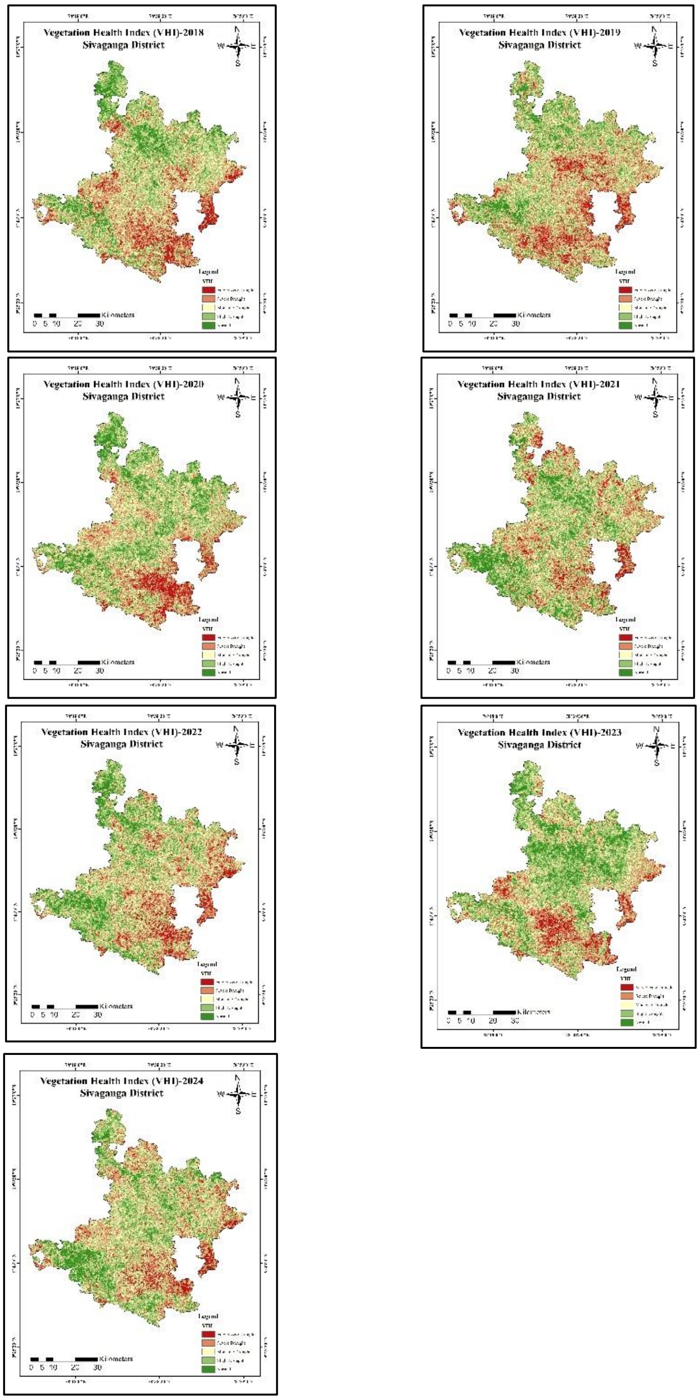

Figure 7: VHI Map (a)2018; (b)2019; (c)2020; (d)2021; (e)2022); (f)2023; (g)2024

These areas are characterized by prolonged dry spells, erratic rainfall patterns and elevated land surface temperatures, which collectively exacerbate water stress and reduce agricultural productivity. The persistence of drought in these regions underscores their susceptibility to climatic fluctuations and highlights the urgent need for targeted interventions.

In contrast, the southern regions demonstrated greater resilience, with lower drought severity throughout the study period. This regional disparity can be attributed to variations in topography, soil characteristics and microclimatic conditions, which influence moisture retention and vegetation health. The analysis of NDVI and VCI revealed significant interannual variability in vegetation vigor, with periods of recovery observed in 2019 and 2023. These findings align with previous studies that emphasize the role of seasonal rainfall and temperature anomalies in modulating drought severity[5].

For instance, Kogan[4,5] highlighted how deviations in vegetation health, as captured by NDVI and VCI, are closely linked to fluctuations in precipitation and temperature, underscoring the importance of monitoring these parameters for effective drought assessment. The integration of LST and TCI further highlighted the critical role of thermal stress in exacerbating drought conditions, particularly during 2020 and 2021. Elevated land surface temperatures not only increase evapotranspiration rates but also reduce soil moisture availability, creating a feedback loop that intensifies drought impacts. The VHI, by combining vegetation and thermal data, provided a holistic perspective on drought severity, confirming the persistence of Very Severe Drought conditions during specific years.

Emerging moderate drought conditions in 2024, particularly in the eastern part of the district, signal a potential trend toward increased aridity. This shift underscores the importance of proactive measures to mitigate drought risks, such as the adoption of climate-resilient agricultural practices, improved water management strategies and reforestation efforts.

The findings also highlight the value of remote sensing technologies and cloud-based platforms like GEE in providing scalable, cost-effective and near-real-time insights into drought dynamics. By enabling large-scale data processing and visualization, GEE facilitates informed decision-making and supports the development of adaptive management strategies.

Conclusion

This study demonstrates the effectiveness of integrating remote sensing indices and cloud-based platforms like Google Earth Engine (GEE) for assessing agricultural drought vulnerability in Sivaganga district. The analysis of NDVI, LST, VCI, TCI and VHI revealed significant spatio-temporal variability in drought severity, with the northeastern and central regions being the most vulnerable to extreme drought events. Persistent drought conditions during 2018, 2020 and 2021 underscore the critical need for region-specific interventions to enhance agricultural resilience and mitigate drought risks.

The findings emphasize the importance of adopting adaptive water management strategies, promoting climate-resilient agricultural practices and implementing reforestation efforts to address the challenges posed by recurring droughts. Emerging moderate drought conditions in 2024 highlight the need for continuous monitoring and proactive measures to address evolving drought dynamics. By leveraging advanced remote sensing tools and cloud-based platforms, this study provides actionable insights for policymakers, stakeholders and agrarian communities to enhance agricultural resilience in drought-prone regions.

In conclusion, the integration of NDVI, LST, VCI, TCI and VHI within GEE offers a robust framework for comprehensive drought assessment, underscoring the critical role of remote sensing technologies in supporting informed decision-making. Future research should focus on expanding the scope of analysis to include socio-economic factors, groundwater availability and crop-specific vulnerabilities to develop more holistic drought mitigation strategies. The lessons learned from this study can serve as a foundation for building sustainable and resilient agricultural systems in semi-arid regions like Sivaganga district.

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