JOURNAL OF GEOSCIENCES INSIGHTS
Apr-Jun 2024, VOL. 2, ISSUE 2, pp. 9-14
https://doi.org/10.61577/jgi.2024.100007

REVIEW

OPEN ACCESS

Agricultural drought monitoring in maligavila GN division based on normalized difference moisture index (NDMI) and vegetation health index (VHI)

P.A.Manoja Lakmali Pinnawala Arachchi[1] and Supriya Mohanty[2]

[1]Department of Geography, University of Peradeniya, Sri Lanka
[2]Department of Agriculture, Agropolytechnic Centre - OUAT, Rourkela, Odisha, India

ABSTRACT

The agricultural sector is pivotal to the economic development of Sri Lanka, particularly in the dry zone where extensive agricultural lands are highly susceptible to drought. The "Yala" season, occurring annually, consistently experiences water deficits due to drought conditions. Drought is multifaceted and can be categorized into meteorological, hydrological, agricultural, and socio-economic droughts. Accurately assessing drought impacts requires multiple indices due to its complex nature. This study employs satellite-based Normalized Difference Moisture Index (NDMI) and Vegetation Health Index (VHI) to evaluate agricultural drought in the Maligavila GN division in Monaragala district, Sri Lanka. In 2015, the NDMI values for the region ranged from -0.103 to 0.311, reflecting variations in soil moisture content. By 2023, these values shifted significantly, ranging from -0.45 to 0.292, indicating a notable decrease in soil moisture. Similarly, VHI values, which assess vegetation health by combining the Vegetation Condition Index (VCI) and Temperature Condition Index (TCI), ranged from 12.33 to 91.82 in 2015 and from 11.442 to 86.966 in 2023. The decline in both NDMI and VHI values over this period suggests a marked increase in agricultural drought conditions. The analysis reveals that agricultural drought in Maligavila GN division has intensified from 2015 to 2023. The broader implications of these findings are significant for the agricultural sector in the dry zone of Sri Lanka. The increasing drought conditions necessitate the implementation of sustainable land management practices and efficient water resource management strategies. By enhancing soil moisture retention and supporting vegetation health, these measures can help mitigate the adverse impacts of drought and contribute to the resilience of the agricultural sector in the region.

KEYWORDS

Agricultural Drought; Vegetation Health Index (VHI); Normalized Difference Moisture Index (NDMI); Normalized Difference Vegetation Index (NDVI); Proportional Vegetation Index (PVI)

ARTICLE HISTORY

Received 13 May 2024;
Revised 27 May 2024;
Accepted 03 June 2024

Introduction

The agricultural sector is a cornerstone of national economies around the globe, including Sri Lanka, where it plays a crucial role in sustaining livelihoods and contributing to economic development. In Sri Lanka, over 30% of the population is employed in agriculture, making it a significant source of income and employment. However, the sector is increasingly vulnerable to various environmental challenges, with drought being one of the most critical threats. Agricultural drought, characterized by the detrimental impacts on agriculture due to factors such as insufficient rainfall, soil water deficits, and reduced groundwater or reservoir levels necessary for irrigation, poses severe risks to crop productivity and food security [1]. Agricultural drought differs from other types of drought, such as meteorological and hydrological drought, as it specifically relates to the effects on farming activities. Meteorological drought is defined by prolonged periods of below-average precipitation, while hydrological drought refers to deficiencies in surface and subsurface water supplies. In contrast, agricultural drought focuses on the impact on crop and soil moisture levels, which directly influence crop growth and yield [2]. The primary cause of agricultural drought is the lack of adequate rainfall, which leads to soil water deficits. These deficits affect the ability of crops to extract sufficient moisture from the soil, resulting in reduced growth, lower yields, and, in severe cases, crop failure.

In Sri Lanka, the dry zone, which includes the Monaragala district where the Maligavila GN division is located, is particularly prone to agricultural drought. This region relies heavily on seasonal rainfall, and any deviation from the expected rainfall patterns can lead to significant water shortages [3]. The "Yala" season, one of the two main agricultural seasons in Sri Lanka, frequently experiences water deficits due to erratic rainfall patterns and prolonged dry spells. The resulting agricultural drought has far-reaching consequences, affecting not only the productivity of crops but also the livelihoods of farmers and the overall food security of the country. Monitoring and managing agricultural drought is therefore essential for mitigating its adverse effects [4]. Traditional methods of drought monitoring, which often rely on ground-based observations and measurements, can be limited in scope and scale. These methods may not provide comprehensive coverage of large areas or timely information necessary for effective decision-making. In contrast, remote sensing technology offers a powerful tool for monitoring drought across extensive regions. By utilizing satellite imagery, remote sensing enables the continuous observation of environmental conditions, providing valuable data on various drought indicators [1].

*Correspondence: Ms. P.A.Manoja Lakmali Pinnawala Arachchi, Department of Geography, University of Peradeniya, Sri Lanka, e-mail: pamlparachchi111@gmail.com

One of the key advantages of remote sensing is its ability to cover large areas simultaneously. This capability is particularly important for regions like the Maligavila GN division, where agricultural activities are spread over vast tracts of land. Remote sensing provides high-resolution data, such as 30-meter multispectral resolution and 15-meter panchromatic resolution, which allows for detailed analysis of the spatial and temporal variations in drought conditions [5]. By capturing data on vegetation health and soil moisture levels, remote sensing can help identify areas that are most affected by drought and monitor changes over time. In this study, we aimed to monitor agricultural drought in the Maligavila GN division using satellite-derived indices. Specifically, we utilized data from the Landsat-8 satellite to calculate the Normalized Difference Moisture Index (NDMI) and the Vegetation Health Index (VHI) [6]. The NDMI is a widely used index for assessing soil moisture content. It is derived from the near-infrared and shortwave infrared bands of satellite imagery and provides a measure of the moisture content in vegetation and soil. Higher NDMI values indicate higher moisture content, while lower values indicate drier conditions. The VHI, on the other hand, is a composite index that combines the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). The VCI is derived from the Normalized Difference Vegetation Index (NDVI), which measures the greenness of vegetation and is an indicator of vegetation health and vigor [7]. The TCI is based on land surface temperature data and provides information on thermal stress in vegetation. By combining these two indices, the VHI offers a comprehensive measure of vegetation health and drought stress.

For this study, we calculated the NDMI and VHI for the years 2015 and 2023 to examine the temporal variations in agricultural drought conditions in the Maligavila GN division. The NDMI values in 2015 ranged from -0.103 to 0.311, indicating varying levels of soil moisture across the region. In 2023, the NDMI values ranged from -0.45 to 0.292, reflecting a significant decrease in soil moisture over the eight-year period. This decrease suggests an intensification of drought conditions, with more areas experiencing severe soil moisture deficits. Similarly, the VHI values in 2015 ranged from 12.33 to 91.82, while in 2023, the values ranged from 11.442 to 86.966. The lower VHI values in 2023 indicate a decline in vegetation health and an increase in drought stress [6]. These findings suggest that the agricultural drought conditions in the Maligavila GN division have worsened over the years, with more areas being affected by water deficits and reduced vegetation health. The implications of these findings are significant for the agricultural sector in the Maligavila GN division and the broader Monaragala district. The increasing severity of agricultural drought necessitates the implementation of effective drought management strategies. These strategies may include adopting water-efficient irrigation practices, improving soil moisture retention through conservation techniques, and diversifying crops to enhance resilience to drought conditions [8].

Materials and Methodology

Study area

Maligavila GN division, located in the Monaragala district of Sri Lanka was chosen as the study area for this project. It is geographically located between 6°40′30″ - 6°45′N (as shown in the figure 1) and 81°20′30″-81°25'30"E and total area covers 31.726366km². There are about 80% of the Eastern and Southern parts of Maligavila GN division is covering with barren lands and chena cultivation. This area belongs to the dry zone and it is mainly influenced by the North-East monsoon. This area is experiencing an annual precipitation of <1800mm and an average temperature around 27°C-30°C [9].

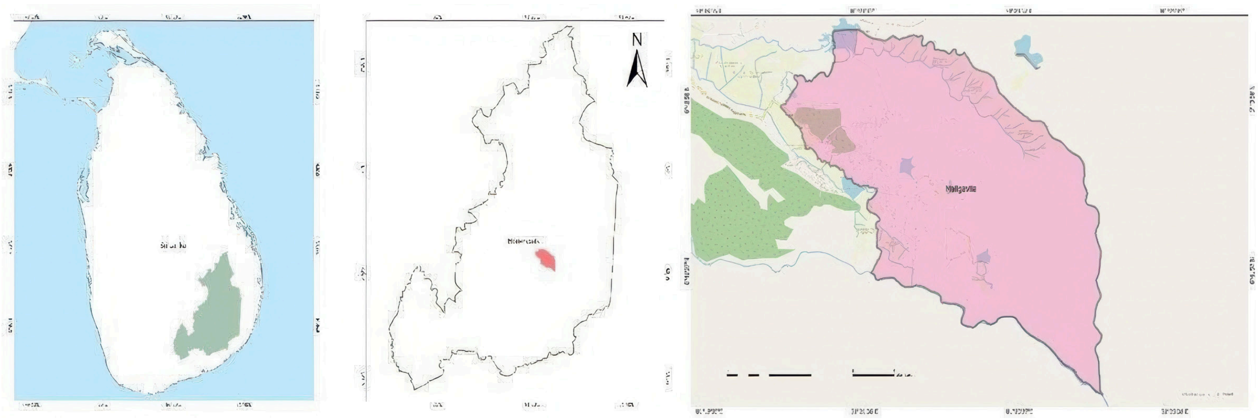

Figure 1. Study area map.

Data collection & methods

In the study, LANDSAT-8 satellite datasets were to calculate the remote sensing-based agricultural drought indices because of their fine spatiotemporal resolution for drought monitoring. LANDSAT-8 satellite datasets were obtained from USGS Earth Explorer. band 3, Band 4, band 5, band 6 and band 10 were used to calculate drought [10]. Chart 01 shows the methodology flow chart of the project.

Band 3 and band 5 were used to calculate Normalized Difference Water Index (NDWI). band 5 and band 6 were used to calculate NDMI. Band 4 and band 5 were used to calculate NDVI. Proportional Vegetation Index (PVI) was calculated using the minimum and maximum values of NDVI. Band 10 was used to calculate the Land Surface Temperature (LST). Vegetation Health Index (VHI) was calculated using Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). The algorithm was created by using ArcGIS pro software [11].

https://doi.org/10.61577/jgi.2024.100007

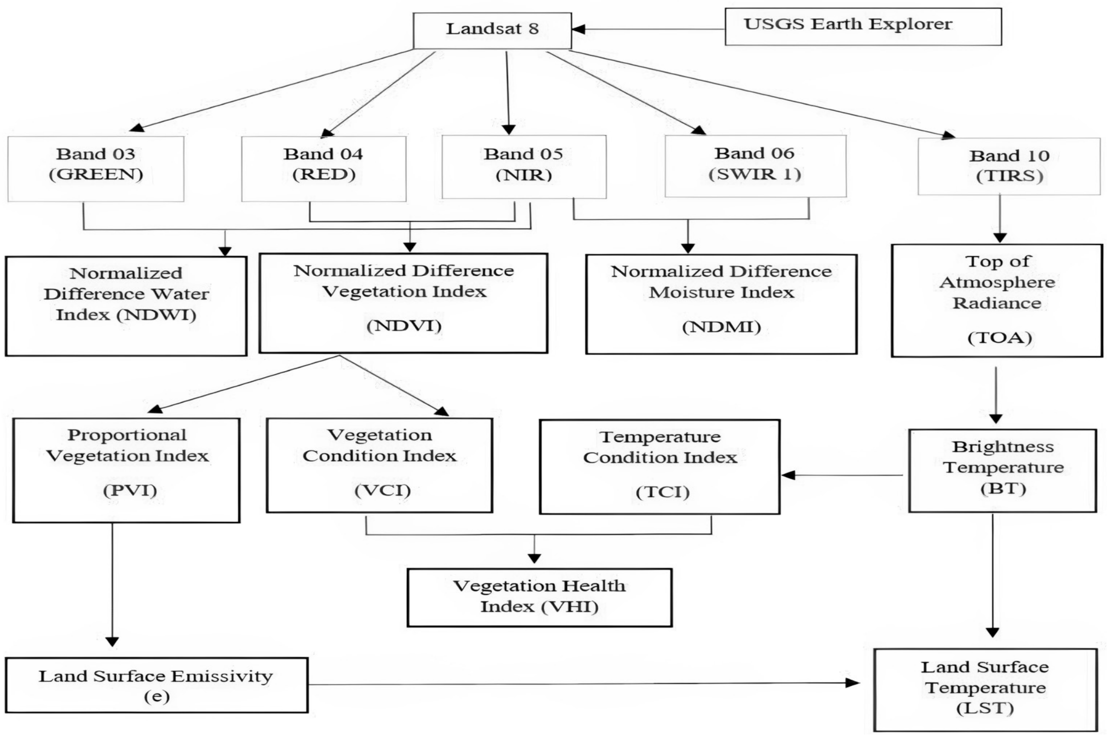

Chart 1. Methodology Flow flowchart.

First, converted digital number to radiance by using the radiometric calibration coefficients in Metadata file. It was calculated by using below equation.

$L\lambda = ML*QCAL+AL$ (1)

After that, it converted to brightness temperature using following formula:

$BT= (K2 / Ln ((K1 / L\lambda) +1)) -273.15$ (2)
Where,
K1 & K2 are senser-specific calibration constants. Ln is the natural algorithm and it can be given from raster calculator in ArcGIS pro.

In the next step, NDVI was calculated using band 4 & band 5. NDVI is an important index in environmental analysis. It can be used to monitor the health and density of vegetation cover in an area. The following formula can be used to calculate NDVI [12].

NDVI = Float (band 5 – band 4) / (band 5 + band 4)

The minimum and maximum NDVI values were used to calculate the proportional Vegetation Index (PVI). Computation of PVI is given by,

PVI = (NDVI - NDVImin) / (NDVImax - NDVImin)2

The PVI values used to calculate the land surface emissivity. The formula for emissivity can be identified as follows.

E= (0.004 * PV + 0.986)

In present study, NDWI as calculated for the indentity of the waterbodies of the study area. Green and NIR bands of landsat-8 satellite image used to calculate NDWI.

NDWI = (band 3 – band 5) / (band 3 + band 5)

NDMI is a remote sensing index used to assess moisture content or water availability in vegetation and soil cover over a particular area [13]. Normally, this value ranges from -1 to +1. The following equation shows the procedure for calculation of NDMI.

NDMI= (band 5 -band 6) / (band 5 -band 6)

In present study, drought was categorized according to NDMI values. Table 1 indicate the drought classification based on NDMI. If the value is higher than 0 is identified as no drought condition.

Table 1. Agricultural drought classification based on NDMI.

Values	Severity Class
≤-0.6	Severe drought
-0.6 - -0.4	Moderate drought
-0.4 - -0.2	Mild drought
-0.2 - 0	Relatively wet
>0	Very wet

The VHI is calculated by using VCI and TCI indices. The values of VCI, TCI & VHI normally range between 0-100. Higher VHI values indicating healthier vegetation and lower values indicating stress or decline. It can be calculated by using the following equation (Table 2).

Table 2. Agricultural drought classification based on VHI.

Values	Severity Class
<10	Extreme Drought
<20	Severe Drought
<30	Moderate Drought
<40	Mild Drought
>40	No Drought

https://doi.org/10.61577/jgi.2024.100007

$$VHI=\alpha VCI+(1-\alpha)\,TCI \quad (3)$$

Table 2 indicate the drought classification based on VHI. If the value is higher than 40 is identified as no drought condition and the values under the 40 is consider as drought condition.

Results

The following maps shows the NDMI, NDWI, LST, NDVI, VCI and TCI maps of Maligavila GN division in 2015 & 2023. These are important to get an idea about the study area and final output was calculated using these data (Figures 2 and 3).

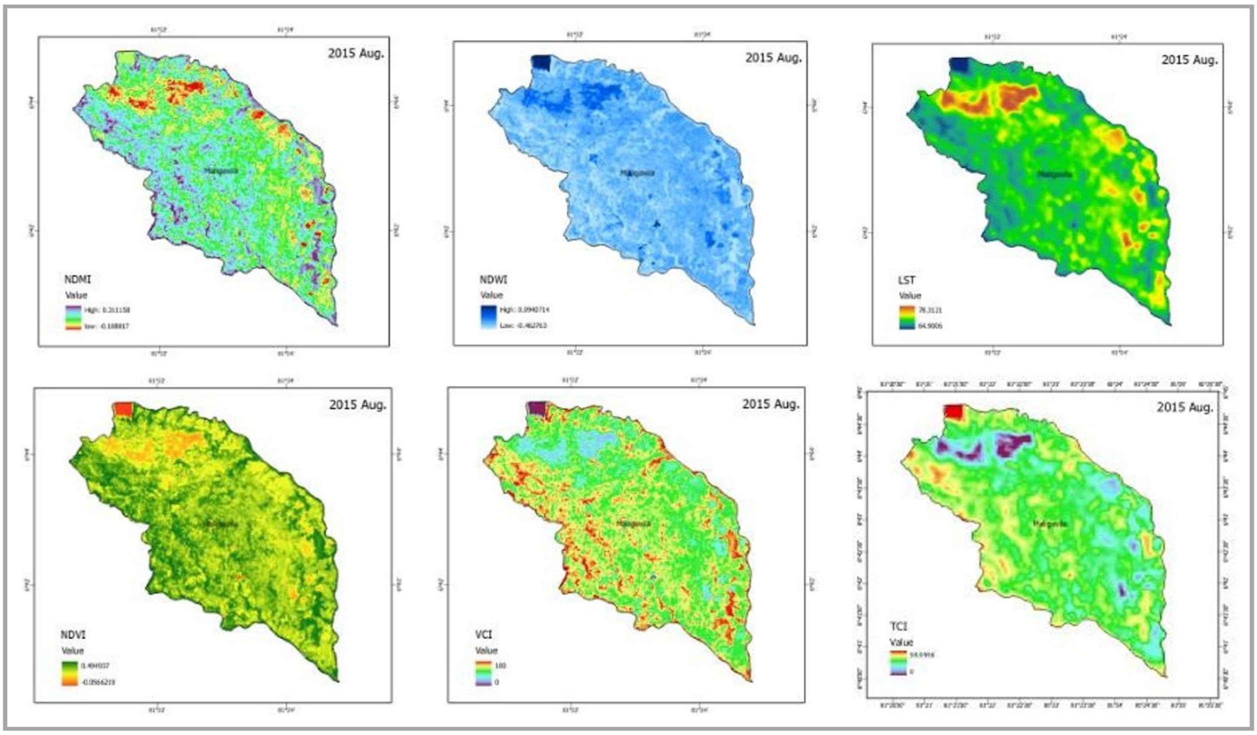

Figure 2. NDMI, NDWI, LST, NDVI, VCI and TCI maps of Maligavila GN division in 2015

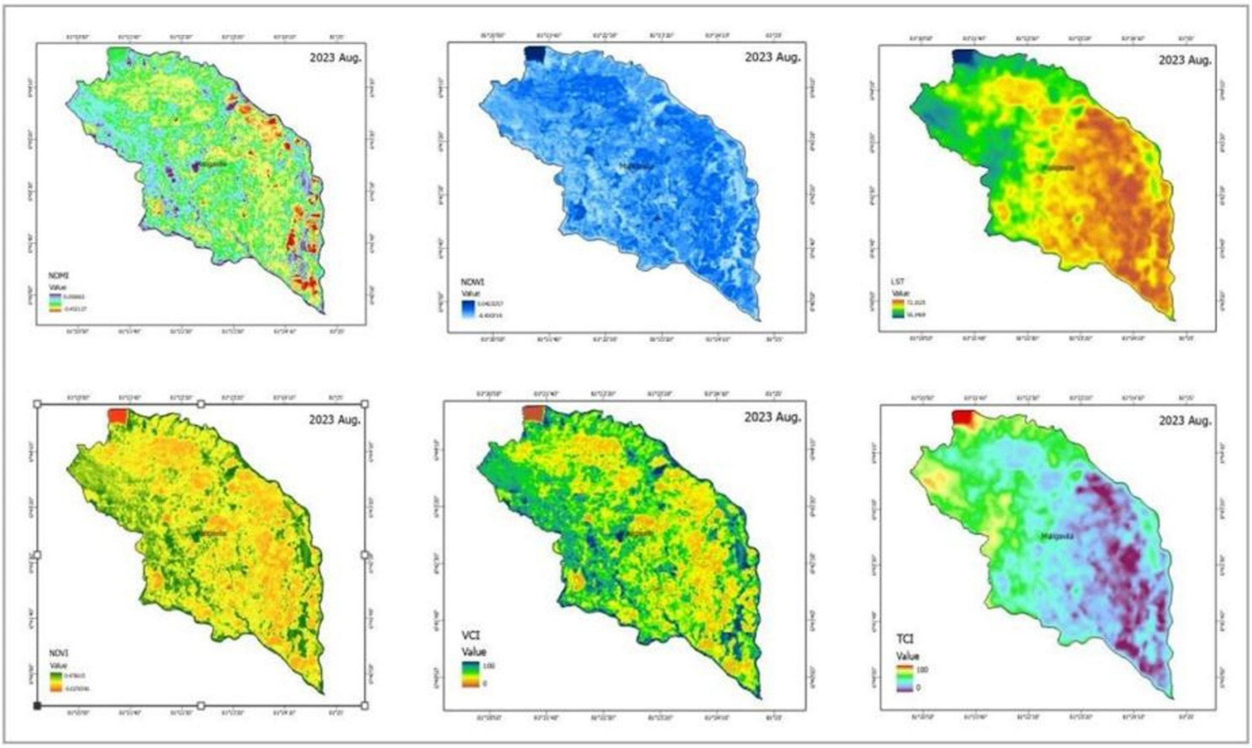

Figure 3. NDMI, NDWI, LST, NDVI, VCI and TCI maps of Maligavila GN division in 2023.

https://doi.org/10.61577/jgi.2024.100007

Agricultural drought assessment through Normalized Difference Moisture Index (NDMI)

In 2015, NDMI values ranged from -0.103 to 0.311 and in 2023, it ranged from -0.45 to 0.292. Figure 4 shows the distribution of soil moisture in Maligavila GN division.

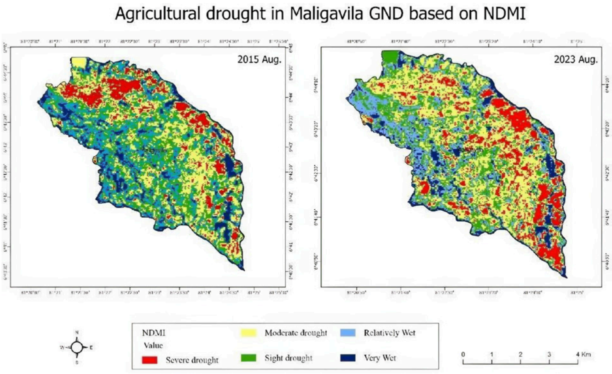

Figure 4. Spatio-temporal pattern of Normalized Difference Moisture Index (NDMI) in Maligavila GN division.

According to the map results, North-East parts of the study area is suffering from high water stressed in 2015 but it is totally changed in 2023. In 2023, drought was spread in whole area specially in Eastern and Southern parts can be identified high water stress areas. As mentioned earlier, there is about 80% of the Eastern and Southern parts of the Maligavila GN didivsion covered from barren lands and chena cultivation. It can be affected on the low soil moisture content of this area [14].

Agricultural drought assessment through vegetation health index (VHI)

In 2015, highest VHI value is 91.8213 and lowest value is 12.3383. In 2023, highest VHI value is 86.9664 and lowest value is 11.442. Figure 5 shows the distribution of agricultural drought in the study area in both 2015 & 2023 years.

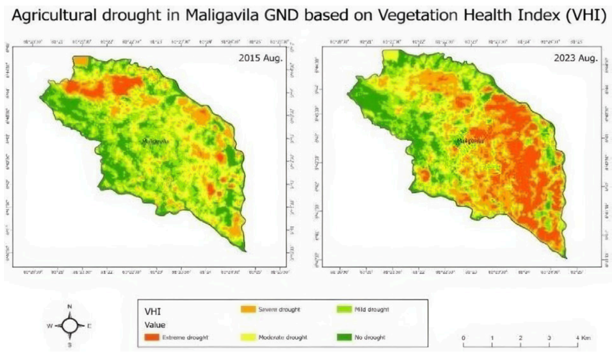

Figure 5. Spatio-temporal pattern of Vegetation Health Index (VHI) in Maligavila GN division.

According to both these indices, vegetation health and soil moisture content was rapidly decreased in the study area and it affected to the rise of agricultural drought in 2023 than 2015. The south and East parts of Maligavila GN division are mostly suffering from agricultural drought.

Discussion

The presented maps and data indicated significant changes in soil moisture and vegetation health in the Maligavila GN division between 2015 and 2023. The NDMI values showed a considerable shift, with 2015 values ranging from -0.103 to 0.311, while 2023 values ranged from -0.45 to 0.292. This data highlighted a significant decrease in soil moisture over the eight-year period. Figure 4, illustrating soil moisture distribution, reinforced the conclusion that the North-East parts of Maligavila experienced high water stress in 2015, whereas in 2023, drought conditions spread across the entire area, particularly affecting the Eastern and Southern regions.

The increase in drought conditions and water stress could be attributed to the extensive presence of barren lands and chena cultivation in these parts. The dominance of these land uses, covering approximately 80% of the Eastern and Southern parts, likely contributed to the reduced soil moisture content. Barren lands typically exhibited low water retention, and chena cultivation, which involved slash-and-burn agricultural practices, could further exacerbate soil degradation and reduce its ability to retain moisture [15,16].

In terms of vegetation health, the VCI and the TCI provided insight into the stress experienced by vegetation in the study area. The highest VHI value in 2015 was 91.8213, with the lowest at 12.3383. By 2023, these values had slightly declined, with the highest VHI at 86.9664 and the lowest at 11.442. Figure 5, which depicted the distribution of agricultural drought, demonstrated that both vegetation health and soil moisture content had rapidly decreased. This decline led to a significant rise in agricultural drought conditions by 2023, particularly affecting the South and East parts of Maligavila GN division.

The observed decrease in both NDMI and VHI values suggested a correlation between reduced soil moisture and deteriorating vegetation health. As soil moisture content diminished, plants struggled to obtain the necessary water for growth, leading to decreased vegetation health and increased susceptibility to drought. The spread of drought conditions throughout the area further exacerbated these effects, creating a feedback loop where declining soil moisture and vegetation health reinforced each other [17,18].

The changes between 2015 and 2023 could also be linked to broader climatic patterns and land management practices. Prolonged periods of low rainfall or irregular precipitation patterns might have contributed to the worsening drought conditions. Additionally, land management practices, such as the extensive use of chena cultivation, could have long-term impacts on soil structure and fertility, further reducing the land's capacity to support healthy vegetation.

Addressing these challenges required a multifaceted approach. Implementing sustainable land management practices could help mitigate soil degradation and improve water retention. Techniques such as agroforestry, cover cropping, and conservation tillage could enhance soil health and moisture retention, thereby supporting healthier vegetation. Additionally, efforts to restore degraded lands, particularly in areas dominated by barren lands, could help alleviate the stress on soil and vegetation [19].

Similar studies also identified the efficacy of NDMI and VHI in detecting drought conditions. Patel et al. demonstrated that NDMI accurately reflected soil moisture deficits, correlating with decreased crop yields. Wong et al. found that VHI was effective in assessing vegetation stress during prolonged dry

https://doi.org/10.61577/jgi.2024.100007

periods. Both indices proved valuable for early drought detection, allowing for timely interventions. Implementing water conservation strategies and sustainable land management practices, as suggested by these findings, is crucial for mitigating the adverse effects of agricultural drought in Maligavila GN Division [20,21].

Conclusions

This project attempted to identify the Spatio-temporal variations of agricultural drought in Maligavila GN division in Monaragala district, Sri Lanka using remote sensing-based NDMI and VHI. It was found that remote sensing is a good technology to apply in real world phenomena. ArcGIS pro software was used to create the algorithm and it also helped to get a better outcome. Based on the results, land surface temperature was increased in 2023 when it compares with 2015 as well as the vegetation health Index values were rapidly decreased in my study area. Based on these results, August 2023 can be identified as a drought month when it compares with August 2015. The findings of this project can be used in decision making processes related to precision agriculture, Forestry and environmental conservation.

Author Contribution

The provided data is contributed by the corresponding author, P.A. Manoja Lakmali Pinnawala Arachchi, with the writing completed by the first author, Supriya Mohanty.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

1. Nairizi S. Drought and Water Scarcity. International Commission on Irrigation and Drainage: New Delhi, India. 2017.
2. Vergopolan N, Xiong S, Estes L, Wanders N, Chaney NW, Wood EF, et al. Field-scale soil moisture bridges the spatial-scale gap between drought monitoring and agricultural yields. Hydrol Earth Syst Sci. 2021;25(4):1827-1847. https://doi.org/10.5194/hess-25-1827-2021
3. Konapala G, Mishra AK, Wada Y, Mann ME. Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. Nat Commun. 2020;11(1):3044. https://doi.org/10.1038/s41467-020-16757-w
4. Das HP. Agricultural drought mitigation and management of sustained agricultural development in India. InNatural Disasters and Extreme Events in Agriculture: Impacts and Mitigation. Berlin, Heidelberg: Springer Berlin Heidelberg; 2005;277-303.
5. Alahacoon N, Amarnath G. Agricultural drought monitoring in Sri Lanka using multisource satellite data. Adv Space Res. 2022;69(11):4078-4097. https://doi.org/10.1016/j.asr.2022.03.009
6. Ghazaryan G, Dubovyk O, Graw V, Kussul N, Schellberg J. Local-scale agricultural drought monitoring with satellite-based multi-sensor time-series. GISci Remote Sens. 2020;57(5):704-718. https://doi.org/10.1080/15481603.2020.1778332
7. Pei F, Wu C, Liu X, Li X, Yang K, Zhou Y, et al. Monitoring the vegetation activity in China using vegetation health indices. Agric For Meteorol. 2018;248:215-227. https://doi.org/10.1016/j.agrformet.2017.10.001
8. Brempong MB, Amankwaa-Yeboah P, Yeboah S, Owusu Danquah E, Agyeman K, Keteku AK, et al. Soil and water conservation measures to adapt cropping systems to climate change facilitated water stresses in Africa. Front sustain food syst. 2023;6:1091665. https://doi.org/10.3389/fsufs.2022.1091665
9. Karunakalage A, Sharma R, Daqiq MT, Kannaujiya S. Assessment of Climatic and Vegetation Influence on Spatial Distribution of Groundwater Recharge in Humid Subtropical Central Gangetic Plain. Authorea Preprints. 2023.
10. Benzougagh B, Meshram SG, El Fellah B, Mastere M, Dridri A, Sadkaoui D, et al. Combined use of Sentinel-2 and Landsat-8 to monitor water surface area and evaluated drought risk severity using Google Earth Engine. Earth Sci Inform. 2022;15(2):929-940. https://doi.org/10.1007/s12145-021-00761-9
11. van Duynhoven A, Dragićević S. The Geographic Automata Tool: A New General-Purpose Geosimulation Extension for ArcGIS Pro. Appl Sci. 2024;14(15):6530. https://doi.org/10.3390/app14156530
12. Ozyavuz M, Bilgili BC, Salici A. Determination of vegetation changes with NDVI method. J Environ Prot Eco. 2015;16(1): 264-273.
13. Taloor AK, Manhas DS, Kothyari GC. Retrieval of land surface temperature, normalized difference moisture index, normalized difference water index of the Ravi basin using Landsat data. Appl Comput Geosci. 2021;9:100051. https://doi.org/10.1016/j.acags.2020.100051
14. Denmead OT, Shaw RH. Availability of soil water to plants as affected by soil moisture content and meteorological conditions 1. J Agron. 1962;54(5):385-390. https://doi.org/10.2134/agronj1962.00021962005400050005x
15. Dela JD. Fourth Country Report from Sri Lanka to the United Nations. 2009.
16. Pramod CW, Jeyavanan K, Sivananthawerl T. Socioeconomic Sustainability of Chena Cultivation in the Forested Land of Hambantota District, Sri Lanka. InProceedings of International Forestry and Environment Symposium. 2023. https://doi.org/10.31357/fesympo.v27.7139
17. Elias E. Characteristics of Nitisol profiles as affected by land use type and slope class in some Ethiopian highlands. Environ Syst Res. 2017;6:1-5. https://doi.org/10.1186/s40068-017-0097-2
18. van Hateren TC, Chini M, Matgen P, Teuling AJ. Spatio-temporal analysis of remotely sensed soil moisture and vegetation patterns during recent European droughts. Copernicus Meetings. 2020. https://doi.org/10.5194/egusphere-egu2020-7094
19. Haregeweyn N, Tsunekawa A, Tsubo M, Fenta AA, Ebabu K, Vanmaercke M, et al. Progress and challenges in sustainable land management initiatives: A Global Review. Sci Total Environ. 2023;858:160027. https://doi.org/10.1016/j.scitotenv.2022.160027
20. Diop M, Chirinda N, Beniaich A, El Gharous M, El Mejahed K. Soil and water conservation in Africa: State of play and potential role in tackling soil degradation and building soil health in agricultural lands. Sustainability. 2022;14(20):13425. https://doi.org/10.3390/su142013425
21. Mistry P, Suryanarayana TM. Assessment & Monitoring of Agricultural Drought Indices Using Remote Sensing Techniques and their Inter-Comparison. Ecological Perspective. 2023;3(1):1-8. https://doi.org/10.53463/ecopers.20230171

https://doi.org/10.61577/jgi.2024.100007