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Study on the Spatial-temporal Variation Characteristics of Drought in Henan Based on Enhanced Vegetation Condition Index from 2001 to 2023

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Abstract: To study the spatio-temporal variation of drought in Henan Province, the Enhanced Vegetation Condition Index (EVCI) was calculated using monthly MODIS EVI data with a 1 km resolution. Trend analysis, frequency analysis and Hurst index methods were applied to the spatio-temporal variation characteristics in Henan Province. The following results were attained. (1)The EVCI in Henan Province exhibited an upward trend from 2001 to 2023, with 92.4% of the area showing positive trend values, indicating that drought conditions in most of the study area have been alleviating year by year.(2)The drought occurrence frequency ranged from 0.14 to 0.87, with 81.9% of the area having a drought frequency below 0.6.Compared to 2001, and the proportion of drought-affected areas in 2023 decreased by 26.1%.(3)The Hurst index analysis indicates that in the future, EVCI would show weak anti-continuity changes in the northeastern region and weak continuity changes in the southern region. It suggests a weak ability to sustain drought alleviation, and ecological management should be emphasized.

1. Introduction

Drought is a destructive and frequently occurring natural disaster that can severely impact the socio-economic and ecological systems [1]. Drought leads to a decrease in soil moisture content, which subsequently affects plant growth and development, causing significant damage to ecosystems and the environment [2].Thus, investigating the temporal and spatial characteristics of drought in Henan Province is crucial for disaster prevention, mitigation, and ecological conservation.

Traditional drought monitoring is mainly based on meteorological station data[3].Drought indices based on meteorological station data can effectively monitor and quantitatively assess drought events driven mainly by precipitation [4].Due to the discrete distribution of meteorological stations, the spatial continuity of drought indices based on ground meteorological data is poor, making it difficult to analyze the spatial distribution of droughts. Furthermore, in regions with sparse meteorological station coverage, drought indices based on ground meteorological monitoring fail to meet the needs of drought studies. Compared to meteorological station data, remote sensing data has advantages such as ease of access and high spatial continuity, making it increasingly widely used in drought monitoring. Since vegetation growth conditions can indirectly reflect drought conditions in a region, remote sensing vegetation indices can be effectively used as indicators in drought monitoring. Common indicators for remote sensing vegetation drought monitoring include the Normalized Difference Vegetation Index (NDVI)[5], Temperature Vegetation Dryness Index (TVDI)[6], Vegetation Condition Index (VCI)[7] and Enhanced Vegetation Condition Index(EVCI)[8].EVCI, with its simplicity in calculation and sensitivity to vegetation conditions, is widely applied in spatiotemporally continuous drought monitoring.

This study calculated the EVCI using 1km resolution monthly MODIS EVI data and analyzed the spatial and temporal characteristics of drought in Henan Province based on EVCI, aiming to provide a scientific basis for disaster prevention, mitigation, and ecological protection in Henan.

2. Overview of the study area and data sources

2.1. Overview of the study area

Henan is located in central and eastern China, situated between 31°23′-36°22′ N and 110°21′-116°39′E, with a total area of 167,000 km^2.The terrain of Henan is characterized by higher elevations in the west and lower in the east, consisting of plains, basins, hills, and water bodies, with the highest elevation reaching 2414 m and the lowest at 23 m(see Figure 1).Most of Henan is located in the warm temperate zone, transitioning into the subtropical zone, with an average annual temperature of approximately 12-16℃ and average annual precipitation ranging from 513mm to 1129mm.Due to the influence of the monsoon climate, Henan Province is prone to frequent flood and drought disasters[9, 10].

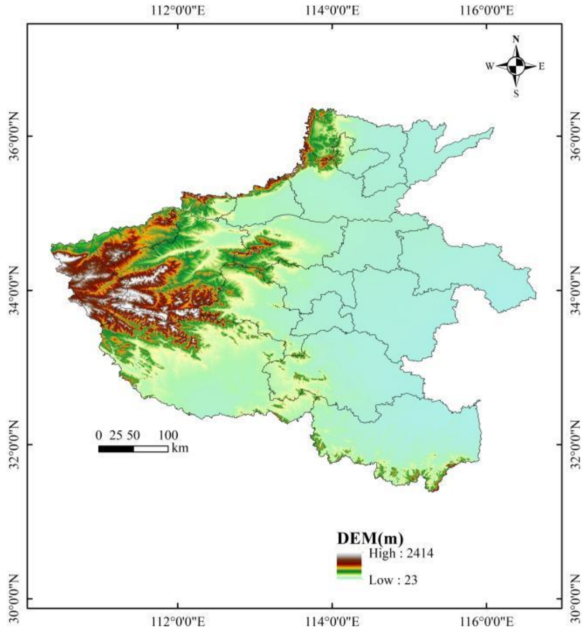

Figure 1: The digital elevation model of the study area

2.2. Data sources

MODIS is a remote sensing system developed by NASA that offers global dynamic observations through sensors carried by the Terra and Aqua satellites. MODIS offers multiple data products, including vegetation index products that are applicable for monitoring vegetation status and land use globally. The MODIS data used in this study is the 1000 m resolution monthly MOD13A3 EVI data from 2001 to 2023, with 12 phases per year, totaling 276 phases over 23 years. After time-based filtering, clipping, and removing outliers, it was downloaded for EVCI calculation from the GEE platform (https://earthengine.google.com).

3. Methods

3.1. Data preprocessing

The MODIS data used in this study needs preprocessing, which includes time-based filtering, vector clipping of the study area, and outlier removal.

On the GEE platform, MODIS data is stored in the form of ImageCollection, with multiple images corresponding to different time periods, so time-based filtering and separate downloads are needed. The GEE platform offers multiple application programming interfaces (APIs) for image processing. The Filter. Calendar Range interface is applied to filter all images within a start and end date. In this study, monthly images from 276 months between 2001 and 2023 were filtered with a one-month interval. Vector data for the study area was uploaded to the GEE platform, and a function for clipping images was programmed using the clip and Map interfaces to batch generate the clipped EVI images for Henan. Due to factors such as cloud cover, some pixels may have poor image quality and contain outliers.MOD13 data contains a quality control band called Detailed QA, which uses 16-bit binary numbers. Filtering bits 0-5 of Detailed QA (see Table1) can remove EVI data outliers. On the GEE platform, code was developed to extract the values of the 0-1 and 2-5 bits from Detailed QA. Using the update Mask interface, pixels where 0-1 bits are not 00 and 2-5 bits are not 000 can be masked, thereby removing outliers.

Table 1: Descriptions of the VI Quality Assessment Science Data Sets (DetailedQA)

Bits	Parameter Name	Value	Description
0-1	VI Quality	00	VI produced with good quality
		01	VI produced, but check other QA
		10	Pixel produced, but most probably cloudy
		11	Pixel not produced due to other reasons than clouds
2-5	VI Usefulness	0000	Highest quality
		0001	Lower quality
		0010	Decreasing quality
		0100	Decreasing quality
		1000	Decreasing quality
		1001	Decreasing quality
		1010	Decreasing quality
		1100	Lowest quality
		1101	Quality so low that it is not useful
		1110	L1B data faulty
		1111	Not useful for any other reason/not processed

3.2. Calculation of EVCI

The growth status of vegetation can indirectly reflect drought conditions, making the Enhanced Vegetation Condition Index (EVCI) widely used in drought monitoring. The calculation formula for EVCI is follow:

$$EVCI = \frac{EVI_i - EVI_{min}}{EVI_{max} - EVI_{min}} \tag{1}$$

Where EVI_i is the EVI value for the i-th month of a specific year, and EVI_{max} and EVI_{min} are the maximum and minimum EVI values for the i-th month over multiple years, respectively.The EVCI ranges from 0 to 1, with higher values indicating milder drought conditions.

3.3. Trend analysis of EVCI

To study the overall drought situation from 2001 to 2023, the average of all EVCI data can be calculated annually, and a linear regression analysis of the annual mean EVCI can be performed. The anomaly index of EVCI, AEVCI, can also be calculated, and the formula for AEVCI is:

$$AEVCI = \frac{EVCI_j - \overline{EVCI}}{\overline{EVCI}} \tag{2}$$

Where $EVCI_j$ is the average EVCI of j-th year, and $\overline{EVCI}$ is the mean EVCI of all years.

3.4. Calculation of drought frequency

In this study, the EVCI values are divided into two levels: when EVCI ≤ 0.5, it suggests poor vegetation conditions with drought; when EVCI > 0.5, it suggests good vegetation conditions without drought. The frequency of drought occurrence is recorded and the frequency is calculated:

$$f = \frac{k}{N} \tag{3}$$

Where k represents the frequency counts of drought occurrences, N is the total number of months in the study period (N=276), and f is the drought frequency.

3.5. Hurst index

The Hurst index is utilized to investigate the continuity of EVCI trend variations. The Hurst index is an effective method for quantitatively describing the long-term dependence of time series information[11].In this paper, the R/S(rescaled range analysis) method was employed to determine the Hurst index (H).When H >0.5, future trends are continuous compared to the past; when H < 0.5, future trends differ from the past. When H = 0.5, the future trend is uncertain. To explore the continuity of drought trends, this study calculated the Hurst index (H) and classified it into five levels: strong anti-continuity ($H \leq 0.25$), weak anti-continuity ($0.25 < H < 0.5$), indeterminable ($H = 0.5$), weak continuity ($0.5 < H < 0.75$), and strong continuity ($H \geq 0.75$).

4. Result and discussion

4.1. Temporal variation characteristics of drought

The annual drought variation characteristics are analyzed through the trend of the annual mean

EVCI (see Figure 2) the anomaly index AEVCI (see Figure 3) and Proportion of drought-affected area (see Figure 3) .From the annual mean EVCI trend, the EVCI index in Henan showed an upward trend from 2001 to 2023, increasing by 0.01303 each year, indicating an improvement in vegetation condition and some alleviation of drought during this period. From the AEVCI values, 2011 is a clear dividing year: before 2010, most AEVCI values were negative, indicating poor vegetation conditions and severe drought; after 2010, most AEVCI values were positive, reflecting better vegetation conditions and milder drought. The annual mean EVCI and AEVCI values from 2001 to 2004 were at a noticeable low, indicating severe drought in these years. From the perspective of the proportion of drought-affected area (see Figure 4), the drought area in Henan Province shows a declining trend year by year. From 2001 to 2023, the average annual drought area proportion in Henan Province was 42.5%. Compared to 2001, the drought area proportion in 2023 decreased by 26.1%, which corresponds to the annual trends of EVCI and AEVCI. The decreasing trend in drought area also corresponds to the trends in annual EVCI and AEVCI. Overall, from 2001 to 2023, the annual drought in Henan Province has undergone a mitigating process, and the EVCI based on MODIS data effectively reflects this trend.

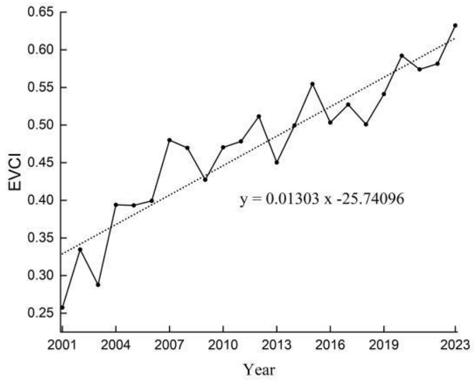

Figure 2: Trend of the annual mean EVCI

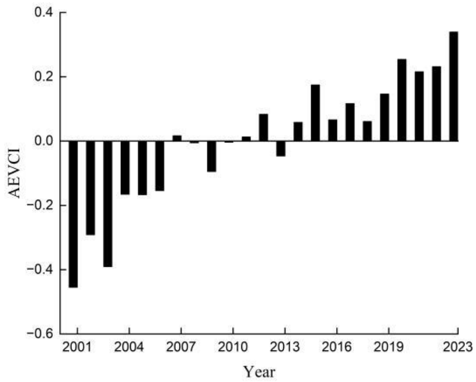

Figure 3: AEVCI values for each year

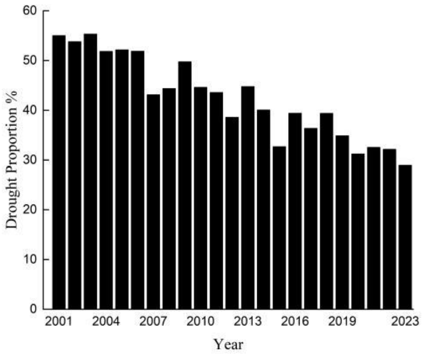

Figure 4: The proportion of drought affected area in Guangdong from 2003 to 2017

4.2. Spatial variation characteristics of drought

To study the spatial variation characteristics of drought in Henan, this study calculated the linear regression trend values of EVCI in the study area (see Figure 5) and statistically analyzed the frequency of drought occurrence based on EVCI (see Figure 6). From 2001 to 2023, the EVCI trend values in Henan ranged from -0.04 to 0.039, with most areas showing positive trend values, accounting for 92.4% of the study area, indicating that drought conditions in 92.4% of the region have alleviated during this period; 7.6% of the regions experienced worsening drought, mainly located in the central region. From the perspective of drought occurrence frequency, the frequency of drought in Henan from 2001 to 2023 ranged from 0.14 to 0.87. In most areas, the drought occurrence frequency was below 0.6, accounting for 81.9% of the study area. The high-frequency drought zones with frequencies above 0.6 were mainly concentrated in the central region.

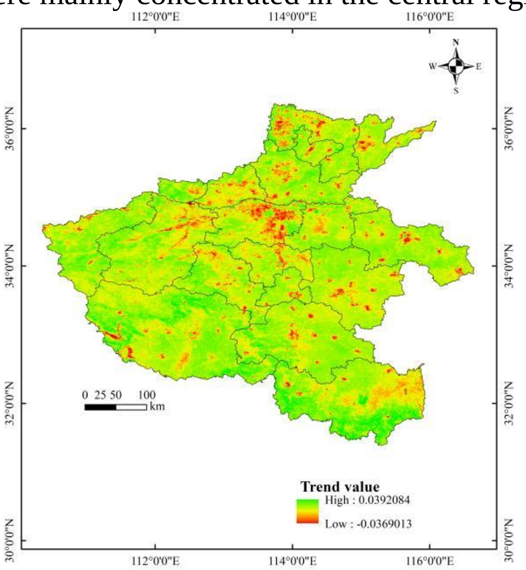

Figure 5: Spatial distribution of the trends in EVCI changes

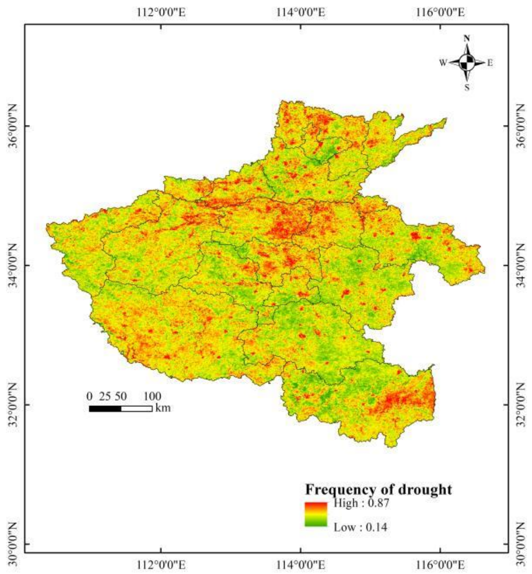

Figure 6: Frequency of drought occurrence

The Hurst index of EVCI in Henan Province ranges between 0.11 and 0.95(see Figure 7).The strong anti-continuity area accounts for 0.2% of the study area; the weak anti-continuity area accounts for 58.6%; the weak continuity area accounts for 40.5%; and the strong continuity area accounts for 0.7% of the study area. Compared to past trends, the areas where future EVCI trends are likely to shift are primarily located in the northeastern part of the province, while the regions where trends are expected to persist are mainly in the south. In general, the ability of these areas to sustain drought alleviation is relatively weak. Therefore, regional ecological management should remain a focus in the future.

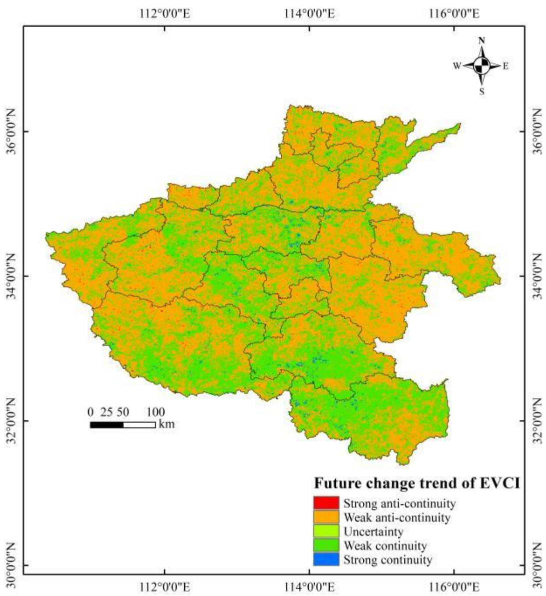

Figure 7: Future trends of EVCI

5. Conclusions

Henan is located in the transition zone between the warm temperate and subtropical zones, where precipitation varies significantly between years. This study indicates that droughts frequently occur in Henan, consistent with previous studies on droughts in Henan and the transitional regions between northern and southern China [12, 13].From the perspective of the trend of drought changes, the overall severity of drought in Henan Province has gradually decreased from 2001 to 2023.

This study focused on Henan Province, using MODIS EVI data to calculate EVCI. EVCI was used as a drought monitoring indicator to analyze the spatio-temporal variations of drought in Henan from 2001 to 2023, leading to the following conclusions:

(1) From the perspective of temporal trends, the EVCI in Henan Province exhibits an upward trend, with an annual increase of 0.01303, suggesting that drought has generally mitigated over time.

(2) From the perspective of spatial distribution, 92.4% of the area experienced drought alleviation, with the regions experiencing increased drought mainly distributed in the central part.

(3) From the perspective of drought occurrence frequency, 81.9% of the regions had a drought frequency below 0.6, while high-frequency areas with a frequency above 0.6 were mainly concentrated in the central region.

(4) From the perspective of future change trends, the Hurst index indicates that drought in the northeastern region would show a weak anti-continuity change, so ecological management in this area should be emphasized in the future.

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