

Detecting drought-prone regions through drought indices

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ABSTRACT

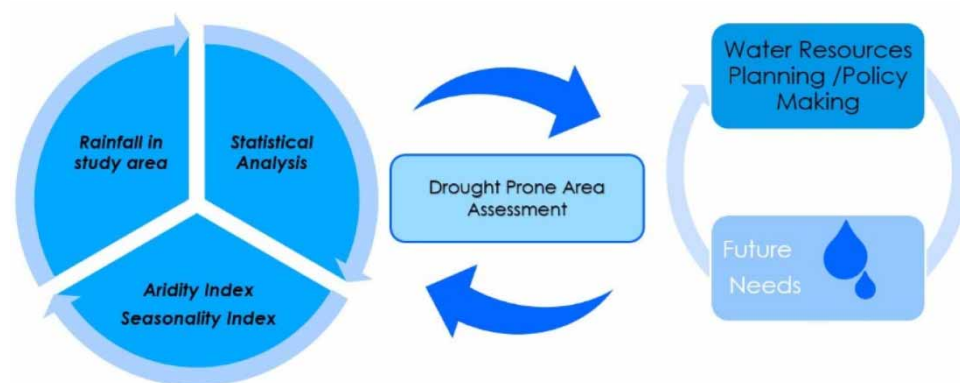
Climate change has led to heightened variability in global rainfall patterns, resulting in greater unpredictability and inconsistency, and it has led to the origin of meteorological drought situation. This has amplified the frequency of droughts or drought-like conditions worldwide. India, being primarily agrarian, faces significant challenges due to drought, affecting various regions intermittently. Given the urgency of addressing recurring drought issues, it is crucial to determine specific 'drought-prone' areas through the analysis of historical and current meteorological data. It is still a challenge to quantitatively understand where and to what extent the impact of rainfall patterns could lead the drought. Whether any region likely comes under drought-prone area or not? Can we help policy makers to apply their knowledge effectively? It will help to undertake the long-term mitigation measures for drought assessment and management which encompasses early warning, monitoring, and relief toward the good health of the society. The present study is a further step in the same direction in which Akola district in Maharashtra, India has been assessed for drought-prone declaration using two drought measuring indices; seasonality index (SI) and aridity index (AI). For this, the measured meteorological data precipitation, and potential evapotranspiration, from 1952 to 2002 is made available from India Water Portal.

Key words: Akola, aridity index (AI), drought assessment and management, seasonality index (SI)

HIGHLIGHTS

- In the present study, Akola district in Maharashtra, India has been assessed for drought-prone declaration using the two drought measuring indices; seasonality index (SI) and aridity index (AI).
- For this, the measured meteorological data of precipitation, and potential evapotranspiration of 51 years was made available from India Water Portal.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Drought is a concept often grasped at a fundamental level but challenging to measure precisely. [Palmer \(1965\)](#) described it as a meteorological event marked by extended and abnormal moisture deficiency and more broadly as a recurring, temporary decrease in an area's precipitation. The term decrease signifies that water levels are below the norm, closely tied to the region's rainfall or precipitation. Consequently, rainfall is considered as the principal driver of meteorological drought. There are several indicators based on rainfall that are being used for drought monitoring ([Smakhtin & Schipper 2008](#)) which depend on rainfall deviation. But as these deviations vary in space and time relationship, it is always necessary to monitor a drought with more than one index ([Dixit & Shelke 2016](#)). Several conventional methods have been proposed by researchers from [Palmer \(1965\)](#) to [Shahabfar & Eitzinger \(2013\)](#) for drought analysis which basically rely on analysis of rainfall, radiation, temperature, water balance equation, vegetation cover, etc., but the most widely used are standardized precipitation index (SPI), normalized difference vegetation index (NDVI), aridity index (AI), and seasonality index (SI), which includes the temporal as well as spatial characteristics and gives a better preview for drought monitoring and assessment. [Faye \(2022\)](#) conducted an analysis of hydrological drought trends in two distinct regions of Senegal – the Senegal River valley and the Casamance Basin based on continental and tropical climatic characteristics, respectively. The key findings of his research showed that majority of the stations had a statistically significant increasing trend in both the SPI and standardized precipitation evapotranspiration index (SPEI). The study spanned the years 1981–2017. The key finding of the research is that, across the majority of monitoring stations in both areas (75% for SPI and 87.5% for SPEI), there exists a statistically significant increasing trend in both SPI and SPEI. However, the study also identified some exceptions, including negative trends such as a decreasing SPI in Bakel, declining SPI and SPEI in Matam, and a reduction in SPEI in Saint Louis. [Mann & Gupta \(2022\)](#) conducted an examination of the monthly, inter-seasonal, and inter-annual patterns in both rainfall and temperature within the Konkan Goa and Coastal Karnataka meteorological sub-divisions. The data utilized encompassed monthly rainfall records spanning from 1977 to 2016 and temperature data from 1980 to 2016. The findings indicate that the highest levels of rainfall are observed during the summer months, with the least precipitation occurring in the winter. Additionally, the research highlights a rising trend in rainfall for the Konkan Goa region, whereas Coastal Karnataka experiences a declining trend in rainfall. There is higher spatial variability of rainfall over districts of Maharashtra region ([Guhathakurta 2013](#)). It highlights the importance of the effective use of water and wastewater in the agriculture and industrial sectors. Many researchers worked on the use of wastewater for different purposes after an effective treatment ([Panagopoulos & Giannika 2022a, 2022b, 2023](#)). [Panagopoulos & Giannika \(2022a, 2022b\)](#) propose the incorporation of renewable energy sources like solar, wind, and geothermal energy. Beyond water recovery, valuable resources such as minerals, salts, metals, and energy can be extracted from brine. Notably, the utilization of salinity gradient power presents a promising avenue for power generation, as evidenced by successful bench-scale and pilot-scale applications of salinity gradient power technologies. [Panagopoulos & Giannika \(2022a, 2022b\)](#) conducted a techno-economic and environmental assessment of minimal liquid discharge (MLD) and zero liquid discharge (ZLD) systems in the Eastern Mediterranean. Their findings indicate that the suggested desalination brine treatment systems not only contribute to the circular economy but also hold substantial economic promise, not only in the Eastern Mediterranean but also in other regions. [Panagopoulos & Giannika \(2023\)](#) conducted an examination of the water conditions in Greece, situated in the Eastern Mediterranean. Their study delved into the formidable issue of water scarcity and explored the effectiveness of addressing this challenge through the implementation of desalination and MLD/ZLD practices. The findings disclosed an unequal distribution of water resources in Greece, highlighting that only 9 out of the total 14 river basin districts exhibited a surplus in water balance.

Consequently, the present study aims to identify the Akola district in Maharashtra as a 'drought-prone' area by assessing the meteorological parameters using the two drought indices, namely SI and AI.

To the authors' best knowledge, publications directly related to the analysis of the drought-prone region for the study area using different drought indices are very sparse and few. Mainly the rainfall pattern or only a single drought index has been used to study the area ([Guhathakurta 2013](#)). The present study is done for the analysis of rainfall patterns using two different indices (Seasonality and AI). Though there are many papers available on the study of drought using rainfall variations no work has been found to the authors' knowledge in which a study of rainfall patterns with two different indices (Seasonality and AI) was done for the study area. The present study may prove to be useful in the direction of policy-making for water resource planning for the study area.

2. STUDY AREA AND DATA

In the current research, Akola district in the Amravati division of Maharashtra state in western India is considered as a study area. Akola district, located in the Indian state of Maharashtra, has its administrative center in the city of Akola. This district is situated in the central region of the Amravati Division, which was previously part of the British Raj Berar Province. With an area covering 5,428 km², it shares its boundaries with Amravati district to the north and east, Washim district to the south, and Akola district to the west. Washim was a constituent of Akola until 1999. Akola District comprises seven talukas: Akola, Akot, Telhara, Balapur, Barshitakli, Murtijapur, and Patur.

Readers are directed to www.indiawaterportal.in for further details. For the present study, monthly values of precipitation and potential evapotranspiration (PET) data are made available from the India Water Portal and Indian Metrological department. Figure 1 along with Table 1 represent the location and data details of the Akola District, respectively.

3. METHODOLOGY USED

Maharashtra, situated in the northwest of peninsular India, is significantly impacted by the southwest monsoon, resulting in frequent water scarcity issues. Historical monsoon rainfall patterns suggest a continued risk of rainfall scarcity in the future. To assess past rainfall trends, a comprehensive understanding of the region's climatology is essential. Akola, located in western Maharashtra, consistently grapples with water scarcity challenges each year. The annual rainfall in this area is significantly lower compared to the Konkan region and is also influenced by Vidarbha. Akola, part of the lower rainfall regions, consistently grapples with severe water scarcity issues. Given its substantial impact on the economy and human well-being, it's imperative to thoroughly examine the region's historical rainfall patterns to determine if it qualifies as a drought-prone area. This analysis is crucial for the district administration as it provides essential information about district-level rainfall patterns and temporal rainfall variations. Such data is invaluable for effective disaster management, as well as planning and managing water resources. Over the past 51 years, meteorological data on precipitation and PET have been sourced from the India Water Portal and IMD, as mentioned earlier. PET, as described by [Thornthwaite \(1948\)](#), represents the maximum water transfer to the atmosphere achievable under ideal circumstances of soil moisture

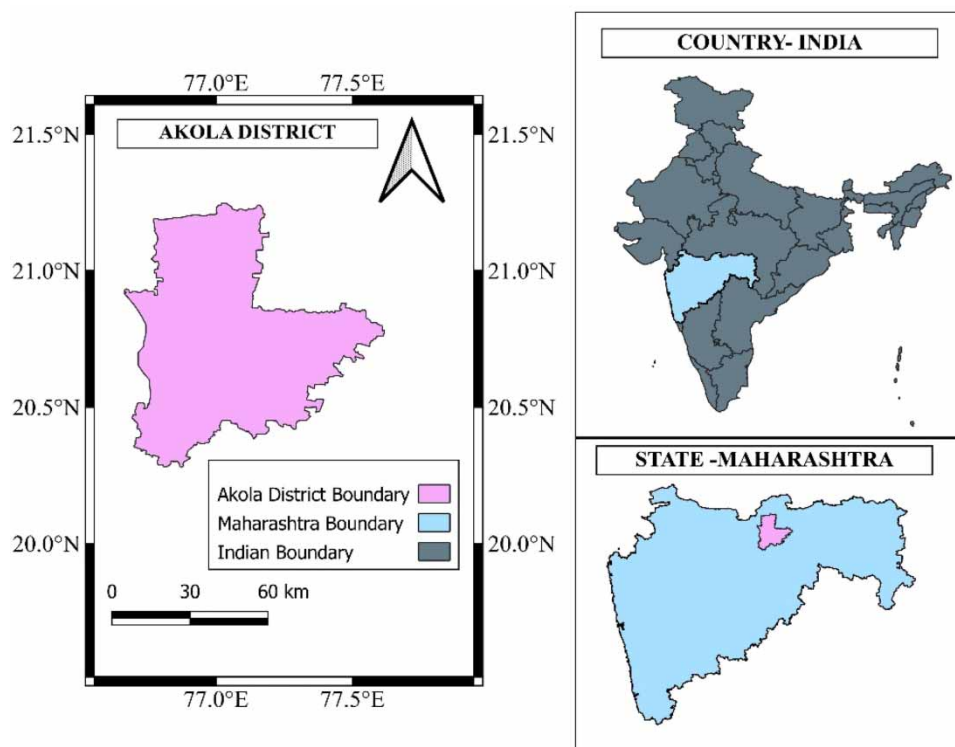


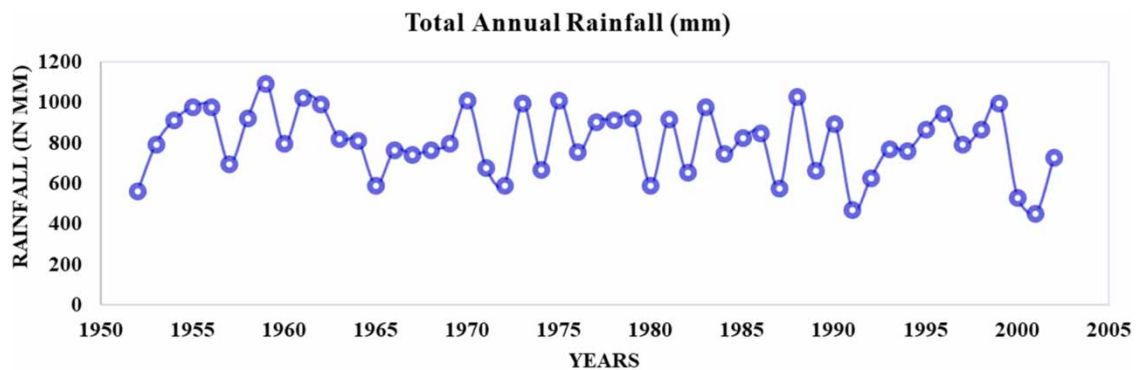
Figure 1 | Index Map of Akola district, Maharashtra, India.

Table 1 | Data details of Akola district

Data period	Meteorological parameters	Source
1952–2002	Precipitation	India Water Portal http://www.indiawaterportal.org/
1952–2002	Potential evapotranspiration	India Water Portal- http://www.indiawaterportal.org/

and vegetation. Penman (1948, 1956) provided a more precise definition, specifying it as the quantity of water transpired over a specified duration by a short green crop that entirely shades the ground, maintains uniform height, and possesses sufficient soil moisture. Whether a region has a moist or dry climate depends on two key factors: the quantity of precipitation it receives and whether this precipitation exceeds or falls short of the water required to counterbalance evaporation and plant transpiration, collectively known as Evapotranspiration (ET). In essence, aridity is determined by both precipitation levels and PET. Since temperature is inherently factored into the PET, it is not treated as a separate parameter in this study. The data used for two distinct drought indices, SI and AI, for Akola district are sourced from the Indian Water Portal. These indices are employed to determine whether Akola qualifies as a drought-prone area or not. Prior to conducting any calculations for drought indices, a comprehensive statistical analysis of rainfall data spanning 51 years, from 1952 to 2002, for the Akola region was carried out. Figure 2 and Table 2 provide detailed information regarding the precipitation data in the study area.

Table 2(b) highlights a noticeable trend: the average rainfall over each 10-year period has consistently declined over the past five decades, up until 2002. This decline in average rainfall is a significant factor contributing to the water scarcity issue. Figure 2 reinforces this observation, illustrating that out of the 51 years analyzed, only 18 years (which is one-third of the total data years) exceeded the threshold of 850 mm of rainfall. This threshold represents 80% of the highest recorded rainfall value of 1,059 mm, which occurred in 1959. The standard deviation of the existing dataset shows that the data are consistent and can be helpful in using further methodology of drought indices (154.71). Skewness and Kurtosis, both are

**Figure 2** | Annual rainfall at Akola from 1952 to 2002.**Table 2** | Statistical analysis of rainfall at Akola

(a)					
Data Period	Max. rainfall (mm) with year	Min. rainfall (mm) with year	Sth. deviation	Kurtosis	Skewness coefficient
1952–2002	1,059 (1959)	449.221(2001)	154.71	−0.56	−0.29
(b)					
Data Period	Average annual rainfall	Data Period	Average annual rainfall		
1952–1962	886.36	1985–1995	757.67		
1963–1973	778.23	1996–2002	758.41		
1974–1984	823.57				

below zero and provide more insides into the dataset. So, the statistical analysis of the rainfall data has proven effective for further calculation of drought indices.

In this particular analysis, both the skewness coefficient (-0.29) and kurtosis (-0.56) have negative values, implying low variability in the rainfall data. This suggests that the rainfall data exhibit a relatively symmetrical distribution. Indeed, the standard deviation being not too large suggests a reasonably even distribution in the rainfall pattern. However, it's worth noting that while there is less variability in rainfall, the actual values of rainfall in this region are considerably lower when compared to the western part of Maharashtra. This highlights the significant disparity in rainfall levels. Moreover, over the course of these 51 years, the maximum temperature recorded remains relatively constant at 34°C , while the minimum temperature remains at 32°C . This indicates a consistent temperature trend in the area.

Hence, solely relying on the statistical analysis of the 51-year rainfall data may not be sufficient to determine the aridity of the region. This underscores the importance of calculating drought indices for Akola. Furthermore, the declining trend in rainfall, as indicated in Table 2(a), introduces an element of uncertainty regarding future rainfall patterns. In the present era, it becomes increasingly crucial to gain insights into the likelihood of reduced rainfall, as this provides valuable indicators for anticipating and preparing for potential drought conditions in the future. Therefore, conducting an analysis of Akola using SI and AI will serve the primary goal of this paper, which is to determine whether Akola qualifies as a 'drought-prone area.' Such a determination is essential for effective mitigation planning and ensuring the well-being of the community.

4. DROUGHT INDICES AND RESULTS

As mentioned above, SI and AI are calculated from the observed meteorological data of 51 years from 1952 to 2002 at Akola station.

4.1. Seasonality index

SI serves the purpose of categorizing rainfall patterns based on the monthly distribution of rainfall data. It offers a comprehensive analysis of precipitation on a monthly and yearly basis within a particular region. While SI provides a basic numerical representation of precipitation seasonality, its simplicity in calculation makes it a valuable tool for examining spatial and temporal variations in seasonality. However, for a more comprehensive assessment, it is essential to complement SI with information on the actual amount of precipitation.

The computation of SI follows a specific methodology. SI was computed using the following formula:

$$SI = \frac{1}{R} \sum_{n=1}^{12} X_n - \frac{R}{12} \quad (1)$$

X_n represents the monthly mean rainfall, while R signifies the mean annual rainfall, as described by Dixit & Shelke (2016). This index assesses variations in rainfall patterns and aids in categorizing rainfall regimes based on monthly rainfall distribution. Theoretically, SI can range from 0 (when all months have equal rainfall) to 1.83 (when all rainfall occurs in a single month). Table 3 displays SI class limits and representative rainfall regimes according to Janowiak & Arkin (1991).

4.1.1. Calculation of SI for Akola

Table 4 calculates SI for each year in Akola based on monthly precipitation data. Initially, the yearly SI is computed for each year using the monthly precipitation values. This results in 51 SI values corresponding to 51 years of data. The final SI for Akola over 51 years is determined by taking the average of all these SI values.

Table 3 | Seasonality Index (SI) classes and associated different rainfall regimes

Rainfall regime	SI	Rainfall regime	SI
Very equable	≤ 0.19	Seasonal	0.60–0.70
Equable but with a definite wetter season	0.20–0.39	Markedly seasonal with a long drier season	0.80–0.99
Rather seasonal with a short drier season	0.40–0.59	Most rain in 3 months or less or most dried season	1.0–1.19

Ref: Janowiak & Arkin (1991).

Table 4 | Seasonality index at Akola

Years	SI	Year	SI	Years	SI	Years	SI	Years	SI
1952	1.17	1963	1.99	1974	2.88	1985	3.82	1996	4.85
1953	1.29	1964	2.22	1975	3.03	1986	4.08	1997	4.61
1954	1.44	1965	2.16	1976	3.08	1987	3.68	1998	4.88
1955	1.33	1966	2.12	1977	3.10	1988	4.10	1999	4.92
1956	1.22	1967	2.33	1978	3.23	1989	4.21	2000	5.23
1957	1.53	1968	2.52	1979	3.19	1990	4.20	2001	5.25
1958	1.59	1969	2.59	1980	3.61	1991	4.57	2002	5.35
1959	1.69	1970	2.75	1981	3.39	1992	4.44		
1960	1.67	1971	2.61	1982	3.40	1993	4.50		
1961	1.80	1972	2.91	1983	3.72	1994	4.58		
1962	1.82	1973	2.95	1984	3.69	1995	4.71		

Average seasonality index of 51 years (from 1952 to 2002) = 3.18

The calculated average SI for Akola is 3.18, significantly exceeding the limits provided in Table 3. This suggests that Akola experiences a highly pronounced dry season with limited rainfall, leading to water scarcity in the region.

4.2. Aridity index

Like SI, AI is also computed for the Akola region, and you can find the specifics in this section. AI is a numerical measure of a location's climate dryness. These indices help identify and delineate regions facing water scarcity due to insufficient available water. Numerous researchers, including Dregne (1986), Paltasingh *et al.* (2012), and Deulkar & Dixit (2015), have demonstrated the utility of AI for monitoring and detecting drought situations. In this study, 51 years of precipitation and PET data from a meteorological station in the Akola region are utilized to estimate AI. While there are multiple methods for calculating AI, the 'Holdridge method,' as outlined by Sun *et al.* (2007), is the most straightforward and widely adopted by researchers. This method is favored for its ability to provide a comprehensive representation of vegetation types across large areas. Its formulation can be expressed as,

$$AI = PET/P' \quad (2)$$

where AI is the aridity index, PET is the potential evapotranspiration (mm), and P is the average annual precipitation (mm).

Table 5 represents the standardized values of AI given by UNESCO (1979).

4.2.1. Calculation of AI

Similar to the calculation of SI, AI is computed for each year in Akola using monthly PET values, as shown in Table 6. Initially, the yearly AI is determined from monthly PET values for each year, resulting in 51 AI values corresponding to 51 years of data. The final AI for Akola over 51 years is determined by averaging all these AI values.

Table 5 | Aridity indices table

Classification	Aridity index	Global land area
Hyper arid	$AI < 0.05$	7.5%
Arid	$0.05 < AI < 0.20$	12.1%
Semi-arid	$0.20 < AI < 0.50$	17.7%
Dry sub humid	$0.50 < AI < 0.65$	9.9%

Ref: UNESCO (1979) Aridity classification.

Table 6 | Aridity indices at Akola

Years	AI	Year	AI	Years	AI	Years	AI	Years	AI
1952	0.15	1963	0.10	1974	0.12	1985	0.10	1996	0.09
1953	0.10	1964	0.10	1975	0.08	1986	0.10	1997	0.10
1954	0.09	1965	0.14	1976	0.11	1987	0.14	1998	0.09
1955	0.08	1966	0.11	1977	0.09	1988	0.08	1999	0.08
1956	0.08	1967	0.11	1978	0.09	1989	0.12	2000	0.15
1957	0.12	1968	0.11	1979	0.09	1990	0.09	2001	0.18
1958	0.09	1969	0.10	1980	0.14	1991	0.17	2002	0.11
1959	0.07	1970	0.08	1981	0.09	1992	0.13		
1960	0.10	1971	0.12	1982	0.12	1993	0.11		
1961	0.08	1972	0.14	1983	0.08	1994	0.11		
1962	0.08	1973	0.08	1984	0.11	1995	0.09		
Average AI for 51 years (1952–2002) = 0.11									

The average AI calculated for Akola is 0.11, falling within the range of ' $0.05 < AI < 0.20$ ' according to Table 5. This classification designates the Akola region as 'Arid.' Hence, the primary objective of this study to determine if Akola is 'drought-prone' is achieved, confirming that Akola is indeed an arid region with limited rainfall and recurrent water scarcity.

5. RESULTS AND CONCLUSION

SI and AI have been computed for the Akola district of Maharashtra using 50 years of dataset. This will help to find the changes (if any) in SI in the last 50 years. The spatial distribution of SI is slightly increased from the year 1980 onwards but the average of all 50 years dataset categorized Akola district as dry season with limited rainfall, leading to water scarcity in the region. A high value indicates most of the rain occurs within a few months (2–3 months). An increasing trend in SI is thus an indicator of an alarming situation for the agriculture and industrial sectors. We have analyzed the rainfall data of 50 years over Akola, a major district of Maharashtra which plays a significant role in the industrial and agricultural contribution in the overall region. The analysis includes variability of rainfall, trends in rainfall patterns and changes in spatial and temporal patterns of seasonality and AI. The study highlights the impact of rainfall changes on temporal and spatial patterns over smaller spatial scales. Analysis of seasonality (3.18) and AI (0.11) helps to have an idea about the distribution of the rainfall among the months within Akola district.

It is still a challenge to quantitatively understand where and to what extent the impact of rainfall patterns could lead to drought and ultimately the impacts on the livelihood of the people. The use of two drought indices and statistical analysis of rainfall values shows the quantitative results that the Akola district region lies under the arid drought-prone region which clarifies the level of attention required in the sectors of interest (Agriculture and Industry), one could avoid the mismanagement of these sectors due to future drought by applying proper water resources planning policy. Our study highlighted the applicability of these indices in planning the different schemes for water management within a study area. The authors want to highlight that the physical and engineering studies on droughts can reduce the severe impacts on the livelihood of the society. Moreover, the authors want to enhance their methodologies using more different drought indices and meteorological parameters so as to capture the intensity of anthropogenic transformations of drought hazard and their impacts in the Akola district for future study.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 16 October 2023; accepted in revised form 28 November 2023. Available online 27 December 2023