ABSTRACT
Southeast Anatolia Region, where Turkey’s summer-winter differences were experienced as a region, was preferred in this study. Daily precipitation and daily temperature data for the 1950–2019 period were provided for analysis. However, due to data deficiencies, Adiyaman, Batman and Kilis stations were worked in the 1959–2019 period and Sirnak station in the 2000–2019 period. All data have been tested for homogeneity.

According to the parameters used in this study, comparisons were made between the indices. It is divided into 4 according to the parameters used. Although the parameter used is the same, each index has drawn different results due to time differences. Dry results were obtained across the entire station from the methodology of the EDI (as used daily rainfall data). In addition, due to the low precipitation in the index, dry results were obtained in the RAI. Normal results were obtained with other precipitation-based drought indices.

According to EDDI results, the driest month is April. During the 12-month seasonal period, only 5 months have passed in the form of no drought.

According to SPEI and RDI values, normal results were achieved at all stations. Moderately and severely dry conditions sometimes occur, extremely dry have rarely been seen. RDI has been identified to have a more drought duration than SPEI.

According to PCI and HTC (based on precipitation and temperature), EDI and RAI results (precipitation-based), the region is dominated by drought. When viewed on a station-by-station basis, drought has been observed at stations in the borders.

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Although it is difficult to fully identify drought, it can be classified as a meteorological, agricultural, hydrological, and socioeconomic drought [4, 5]. 1) Meteorological drought occurs due to below-normal precipitation. 2) Agricultural drought occurs because of intense but less frequent precipitation or above-normal evaporation. All these harm plant production and plant development. 3) Then, hydrological drought occurs in aquifers, lakes, and reservoirs when river stream flow falls below long-term average levels. 4) Finally, socioeconomic drought occurs because of associating the supply and demand of some economic goods or services with meteorological, hydrological, and agricultural drought elements [6].

Drought indices provide comprehensive information for drought analysis. Drought indices are used to determine the beginning and end of the drought event, to monitor its change over time, to determine the severity of the drought, and to evaluate the drought.

Several drought indices have been developed to detect complex events such as droughts. Station-based drought models such as the Standardized Precipitation Index (SPI) [7], Aridity Drought Index (AI) [8], Percent of Normal Precipitation Index (PNPI) [9] and Reconnaissance Drought Index (RDI) [10] are among the most used models. Drought index deficiencies are markers that numerically and conceptually show information such as drought-related violence, duration, amplitude. These also categorize drought parameters.

Many research studies have conducted studies to compare drought indices. For example, there are many studies that compare index where only precipitation is used as parameters [11–13]. It is available in studies where indices with similar formulas are used [14]. There are also many studies comparing SPI and SPEI, where the same classification is used [15–18].

In this study, a drought study was conducted using meteorological data (precipitation, temperature and potential evapotranspiration). Southeast Anatolia Region, where the total annual rainfall in Turkey is low, the average annual evaporation is multi and the average annual temperature is high, has been selected. Meteorological data between 1950 and 2019 were used. The data were first tested for homogeneity. Meteorological droughts are important for monitoring drought and reducing its dangers because meteorological droughts occur first. For this purpose, China Z Index (CZI), Effective Drought Index (EDI), Percent of Normal Precipitation Index (PNPI), Rainfall Anomaly Index (RDI), Standardized Precipitation Index (SPI), Weighted Anomaly Standardized Precipitation (WASP), Z-Score Index (ZSI), Evaporative Demand Drought Index (EDDI), De Martonne Aridity Index (AI), Pinna Combinative Index (PCI), Hydro-Thermal Coefficient of Selyaninov (HTC), Standardized Precipitation Evapotranspiration Index (SPEI) and Reconnaissance Drought Index (RDI) in meteorological drought were used in the study. Comparisons were made between indices divided into four groups according to the parameters used.

**MATERIALS AND METHODS**

**Study Area and Data**

Southeastern Anatolia region, one of the 7 regions of Turkey, was selected as the field of study. The region is located within the 38° 6′ 22″ North and 41° 19′ 43″ East area. Southeast Anatolia Region is 8% of Turkey’s territory. It is equivalent to an area of 59.176 km². It is found from the Southern Taurus Mountains in the north to Iraq and Syria in the South. Fig 1 shows the map where the boundaries are set.

In this study, 9 stations in Southeastern Anatolia region of Turkey were studied. Drought analysis was performed on stations from 1950–2019. Daily and monthly precipitation (mm) and monthly temperature (°C) data were used from meteorological data. This data was obtained from the General Directorate of Meteorology. Potential evapotranspiration (PET) was obtained using temperature data. Many methods are available to achieve potential evapotranspiration. In this study, Thornthwaite method (mm) was preferred. Due to their incomplete data at some stations, there are differences in the observation intervals at those stations. Adıyaman, Batman and Kilis stations 1959–2019 period and Sirnak station 2000–2019 period was worked. Diyarbakır, Gaziantep, Kilis, Mardin, Siirt and Sanlıurfa stations were worked in 1950–2019 period.

The type of climate that dominates the region is the terrestrial climate. When looking at Fig 2, the station with the most rainfall is Adıyaman, while the station with the least rainfall is Sanlıurfa. The highest annual temperature average station belongs to Sanlıurfa station. June, July, and August are very dry in the region. When examined monthly, it can be said that the months with the most precipitation are December and January, and the month with the least rainfall is August.

In addition, it can be said that the average annual rainfall values of the stations belonging to the provinces that make up the borders of the country are lower than the stations inland. This can be attributed to the position of the stations on the parallels.

**Homogeneity Test**

The concept of variance analysis used in statistics is the general name of a group of methods that contain many statistical methods. The simplest form of variance analysis
Figure 1. The location of Southeastern Anatolia Region in Turkey.

Figure 2. Average annual precipitation, average annual temperatures and average annual Thornthwaite distributions of stations.
The value is calculated as follows, the Standardized Precipitation Index [21]. The CZI Climate Center developed CZI in 1995 as an alternative to Pearson type III distribution. [11, 12]. China's National root transformation [22]. It has been observed that the pre-

There are several indices in the meteorological drought, Used Drought Indices Where Only Precipitation Data are

The ANOVA test results of stations.

| Station     | Type of Station | All | Eastern Region | West | Total |
|-------------|-----------------|-----|----------------|------|-------|
| DIYARBAKIR  | Metropolitan    | 423 | 17             | 439  |       |
| GAZIANTEP   | Metropolitan    | 435 | 18             | 453  |       |
| ADIYAMAN    | Metropolitan    | 425 | 17             | 442  |       |
| BATMAN      | Metropolitan    | 425 | 17             | 442  |       |
| DIYARBAKIR  | Metropolitan    | 425 | 17             | 442  |       |
| GAZIANTEP   | Metropolitan    | 425 | 17             | 442  |       |
| KILIS       | Metropolitan    | 425 | 17             | 442  |       |
| MARON       | Metropolitan    | 425 | 17             | 442  |       |
| Sivas       | Metropolitan    | 425 | 17             | 442  |       |
| SHIRAN      | Metropolitan    | 425 | 17             | 442  |       |
| Sivas       | Metropolitan    | 425 | 17             | 442  |       |

CZI is based on Wilson–Hilferty's cube root transformation [22]. It has been observed that the precipitation data to be used in the index complies with the Pearson type III distribution. [11, 12]. China's National Climate Center developed CZI in 1995 as an alternative to the Standardized Precipitation Index (SPI) [21]. The CZI value is calculated as follows,

$$CZ_I = \frac{6}{C_\sigma} \frac{C_\phi}{C_\sigma} + 1 = \left( \frac{6}{C_\sigma} \right) + \left( \frac{C_\phi}{6} \right)$$

(1)

$$C_\sigma = \sum_{i=1}^{n} (x_i - \bar{x}_i)^2$$

(2)

$$\phi_I = \frac{x_i - \bar{x}_I}{\sigma_I}$$

(3)

Where i is a time scale and can be equal to 1, 2, 3,...,72 months, and j is the current month. $C_\sigma$ = coefficient of skewness and $n$ = the total number of months in the record, $\phi_I$ = standardized variate, also called the Z-Score, and $x_i$ = precipitation of j month for period i, $\bar{x}_I$ = average of the precipitation of j month for period i, $\phi_I$ = Standard deviation of the precipitation of j month for period i.

**Effective Drought Index (EDI)**

Unlike other drought indices, Effective Drought Index (EDI) uses data in the daily time period [23]. Initially, EDI was developed to monitor drought status in the daily time step [12, 24, 25]. It is suitable for the study of both meteorological and agricultural droughts, as the calculations include daily data. Calculate the EDI value:

$$EP_i = \sum_{n=1}^{N} \sum_{m=1}^{M} \frac{P_m}{n}$$

(4)

$$DEP = EP - MEP$$

(5)
Standardized Precipitation Index (SPI)
The Standardized Precipitation Index (SPI) method, which converts the precipitation parameter into a single numerical value to describe the drought of regions with different climates, was first developed by [7]. SPI is obtained by dividing the difference between precipitation and the average in a selected time frame into standard deviation.

\[
SPI = \frac{x - \overline{X}}{\sigma_x}
\]  

(10)

Where \( x \) is the observed precipitation value, the average of the \( x \) precipitation series, and the standard deviation of series \( \sigma_x \) (Eq. 10). The resulting SPI values show a trend that increases and decreases linearly with the lack of precipitation [30]. To consider, the impact of precipitation deficiency on different water sources, different time periods such as 1, 3, 6, 12 months are determined in which changes in indices will be observed. SPI is one of the most studied drought indices among drought indices [31].

Weighted Anomaly Standardized Precipitation (WASP)
Weighted Anomaly Standardized Precipitation (WASP) was developed by [20] to monitor rainfall in the tropics within 30 degrees from the equator. Grilled uses monthly precipitation data at a resolution of 0.5° × 0.5°. It is based on 12-month overlapping totals of standardized monthly precipitation anomalies.

\[
WASP = \frac{1}{\sigma_{WASP_x}} \sum_{i=1}^{N} \left( \frac{P_i - \overline{P}}{\overline{P}} \right) \sum_{j=1}^{M} \left( \frac{P_j - \overline{P}}{\overline{P}} \right)
\]  

(11)

Where \( P \) is the precipitation in time increment \( i \) for in each year (mm), and \( P \) is average precipitation for the study period (mm) (Eq. 7) [27].

Rainfall Anomaly Index (RAI)
Rainfall Anomaly Index (RAI) was started by Van Rooy in the early 1960s [28]. This index is based on monthly or annual precipitation data.

\[
\text{RAI} = \begin{cases} 
\frac{P - \overline{P}}{m - P} & \text{if } P > \overline{P} \\
-\frac{P - \overline{P}}{x - P} & \text{if } P < \overline{P}
\end{cases}
\]  

(8)

In Eq. 8 and 9, \( P \) is annual precipitation, \( \overline{P} \) is average of 30 years of precipitation, the average of \( \overline{P} \) 10 precipitation values occurring in \( \overline{P} \) average of at least 10 precipitation values occurring during the period [29].

Percent of Normal Precipitation (PNPI)
Percent of Normal Precipitation (PNPI) was defined by [9] as a normal percentage of precipitation. It can be calculated in daily, weekly, monthly, seasonal, and annual time series. Precipitation data must be in accordance with the time series to be calculated. It is required to have at least 30 years of data to calculate the normal period. PNPI is calculated as following.

\[
PNPI = \frac{P}{\overline{P}} \times 100
\]  

(7)

Where \( P \) is the precipitation in time increment \( i \) for in each year (mm), and \( \overline{P} \) is average precipitation for the study period (mm) (Eq. 7) [27].
**Z-Score Index**

Z-Score Index is compared to Standardized Precipitation Index (SPI). However, it is more similar to China Z Index (CZI). Precipitation data is not required to match gamma distribution or Pearson Type III distribution. It has been involved in many studies [12, 32].

\[
ZSI = \frac{P - \overline{P}}{SD} \quad (12)
\]

Here \( \overline{P} \) average monthly precipitation (mm); \( P \) precipitation (mm) in the specific month and the SD shows the standard deviation at any time (Eq. 12) [33].

**Drought Indices Where Only PET Data are Used**

**Evaporative Demand Drought Index (EDDI)**

Since it is done via \( E_0 \) index results can be obtained by more than one method (Thornthwaite, Blaney-Criddle, Penman-Monteith, Hargreaves-Samani etc.) [14]. The calculation steps are similar to Standardized Evapotranspiration Index (SPEI) [34].

\[
P(E_o) = \frac{i - 0.33}{n + 0.33} \quad (13)
\]

\[
EDDI = W - \frac{C_0 + C_1W + C_2W^2}{1 + d_1W + d_2W^2 + d_3W^3} \quad (14)
\]

Values of constants; \( C_0 = 2.515517 \), \( C_1 = 0.802853 \), \( C_2 = 0.010328 \), \( d_1 = 1.432788 \), \( d_2 = 0.189269 \), \( d_3 = 0.001308 \) (Eq. 14). If \( P(E_o) \leq 0.5 \) then \( W = \sqrt{-2\ln[P(E_o)]} \); \( P(E_o) > 0.5 \) then \( W = \sqrt{-2\ln[1 - P(E_o)]} \) [34]. EDDI within our climatology period (1950–2019), \( n = 70 \) (Eq. 13). The EDDI results obtained require a classification (Table 2).

**Drought Indices Where Temperature and Precipitation Data are Used**

**De Martonne Aridity Index (AI)**

De Martonne Aridity Index (AI) was found by [36]. Aridity is effective in climate and has emerged from

| Climate classification | Values of IDM | PCI | HTC |
|------------------------|---------------|-----|-----|
| Dry                    | <10           | <10 | <0.3|
| Semidry                | 10 to 20      | 10 to 20 | 0.30 to 0.6 |
| Mediterranean          | 20 to 24      | 20 to 24 | 0.6 to 0.8 |
| Semi-humid            | 24 to 28      | 24 to 28 | 0.8 to 1.0 |

Drought indices where only PET data are used based on the index value [34].

**USDM drought category**

| Description       | EDDI percentiles |
|-------------------|------------------|
| Abnormally dry    | 70–79            |
| Moderate dry      | 80–89            |
| Severe dry        | 90–94            |
| Extreme dry       | 95–97            |
| Exceptional dry   | 98–100           |

**Table 2.** Dry and wet categories of various drought indices where only PET data are used based on the index value [34].

**Table 3.** Dry and wet categories of various drought indices where temperature and precipitation data are used based on the index value [35].

a lack of humidity. It can also be calculated monthly or on an annual period. However, there are two different calculations.

\[
I_{DM} = \frac{P}{T + 10} \quad (15)
\]

\[
I_M = \frac{12P'}{T'^2 + 10} \quad (16)
\]

Eq. 15 performs annual calculations, while eq. 16 performs monthly calculations. The drought values obtained because of these formulas are classified according to Table 3. \( P \) expresses the annual precipitation value (mm), \( T \) expresses the annual temperature value. \( P' \) and \( T' \) represent the average monthly precipitation and temperature [35, 37].

**Pinna Combinative Index (PCI)**

The Pinna combinative index \( (Ip) \) was developed by Pinna [35].

\[
I_p = \left( \frac{P}{2} \right) \left( \frac{T}{10} + 10 \right) \quad (17)
\]

\( P \) and \( T \) represent the annual mean precipitation and temperature. \( P' \) and \( T' \) are the mean values of precipitation and air temperature of the driest month (Eq. 17). Many studies have been carried out on this index [35, 38].

**Hydro-Thermal Coefficient of Selyaninov**

The Selyaninov’s hydrothermal coefficient (HTC), developed by [39]. Calculated using the following formula,

\[
HTC = \frac{P}{\sum_{i=0}^{10} T_i} \quad (18)
\]

where \( P \) is the sum of precipitation amounts (mm) and \( T \) is the sum of temperatures (°C) for the months (Eq. 18).
Table 4. Dry and wet categories of various drought indices where PET and precipitation data are used based on the index value \([10, 40]\)

| Class           | SPEI       | RDI          |
|-----------------|------------|--------------|
| Normal          | -1 to +1   | -1 to +1     |
| Moderately Dry  | -1 to -1.5 | -1 to -1.5   |
| Severely Dry    | -1.5 to -2 | -1.5 to -2   |
| Extremely Dry   | ≤ -2.0     | ≤ -2.0       |

Drought Indices Where PET and Precipitation Data are Used

Standardized Precipitation Evapotranspiration Index (SPEI)

SPEI was originally developed by \([40]\) to assess agricultural drought severity, considering plant evaporation and meteorological drought. SPEI is expressed as the difference \((D_i)\) between monthly or weekly potential evapotranspiration \((PET)\) and precipitation \((P)\). This difference \((D_i)\) is the surplus or lack of water for the analyzed month \((i)\).

\[
D_i^k = \sum_{j=1}^{\kappa_k} (P_{ij} - PET_{ij}), \quad n \geq k \tag{19}
\]

\[
SPEI = W - \frac{C_2 + C_1 W + C_0 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{20}
\]

P and PET are calculated for \(i\) month. In different \(D_k\) series, \(k\) is the timescale for the month and \(n\) is the calculation number. \(D\) cannot be calculated in the case of \(k > n\) (Eq. 19). Values of constants; \(C_2 = 2.515517, C_1 = 0.802853, C_0 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308\) (Eq. 20). If \(P \leq 0.5\) then \(W = \sqrt{-2 \ln(P)}\); \(P > 0.5\) then \(W = \sqrt{-2 \ln(1 - P)}\). \(P\) is the probability of higher values of \(D\). Many studies have been carried out on this index \([41]\).

Reconnaissance Drought Index (RDI)

Reconnaissance Drought Index (RDI) was found by Tsakiris and Vangelis of the National Technical University of Athens / Greece \([10]\). There are two new expressions in the form of Normalized RDI and Standardized RDI.

\[
\alpha_k^{(i)} = \frac{\sum_{j=1}^{\kappa_k} P_{ij}}{\sum_{j=1}^{\kappa_k} PET_{ij}} \tag{21}
\]

\[
RDI_k^{(i)} = \frac{\alpha_k^{(i)}}{\alpha_1} - 1 \tag{22}
\]

\[
RDI^{(i)}_n = \frac{\chi_k^{(i)} - \chi_k}{\sigma_k^{(i)}} \tag{23}
\]

Here, \(P\) and \(PET\) provide precipitation and potential evapotranspiration of the \(y\)-pearl month of the \(x\)-pearl year (Eq. 21). In the formula, \(\alpha_k^{(i)}\) value was found to be satisfactory able to track both lognormal and gamma distributions at different timescales and over a wide range of locations \([42, 43]\). The \(\chi_k\) parameter is the average of \(\alpha_k^{(i)}\) values calculated for \(n\) years of data. In eq. 23; \(\chi\), arithmetic means and \(\sigma\), standard deviation.

The SPEI and RDI results obtained are divided into the same classification (Table 4). The results provide information about the region.

RESULT AND DISCUSSIONS

There are many drought indices in meteorological drought. However, many parameters such as precipitation and temperature vary from the location of each station. In addition, drought indices use different classifications due to the parameters used. As a result of the analysis, the obtained index values are divided according to drought categories. It has been tried to show which category the region is in.

Drought Indices Where Only Precipitation Data are Used

The result of frequency analyses of the CZI, EDI, PNPI, RAI, SPI, WASP, and Z-Score indices using the same drought classification are shown in Fig 4. Only classification by dry category was made. First, it can be said that similar results have been achieved in 9 stations. This shows that there is not much difference between the precipitation at the stations.

The index with extremely dry results is the EDI. This result may be due to the index’s use of daily precipitation value, unlike other indices. RAI is the index where the severe dry category is maximum at each station. This result is due to the lack of precipitation in stations most of the time. Moderately dry, all stations have a certain percentage of drought. However, it belongs to Adiyaman and Gaziantep stations with a maximum value of 21%. At both stations, this value belongs to the RAI index. The slightly dry class contains only values for the PNPI index. This classification is available in Table 2.

The indices where normal results are lowest at all stations are EDI and RAI. From here, according to the RAI and EDI indices, it is the conclusion that the Southeast Anatolia Region is dry. According to these indices, the region can be said to be severely drought.

Drought Indices Where Only PET Data are Used

The EDDI values obtained monthly are averaged for each month and the value for that month was obtained. Fig 5 shows the mapping of the monthly averages of the EDDI at
Drought Indices Where PET and Precipitation Data are Used

The AI drought index showed lower results in drought across the region than the other two indices.

The AI drought index has more semi-humid values. According to the PCI and HTC indices, the region is a drought zone.

Drought Indices Where Temperature and Precipitation Data are Used

The percentage results of the AI, PCI and HTC drought indices using the two parameters are seen in Fig 6. The results are based on annual formulas. According to the results, the Sanliurfa station is dry with a value of close to 90% in the maintenance of PCI and HTC indices. On a drought basis, it can be said that Batman came after Sanliurfa. The AI drought index showed lower results in drought across the region than the other two indices.

Stations by Spline method (ARGCIS). Drought is observed from April to October, according to the results. Between December and February, minor variations were observed between the stations. It can be said that there are many seasonal differences on the border of the region.

November and March include a pass. The month dominated by Level 0 is January, while the month dominated by Level 4 is July.

**Figure 4.** Frequency analysis of drought indices using only precipitation.
Figure 5. Monthly map of drought indices using only PET value by Spline method.
Figure 6. Frequency analysis of drought indices using precipitation and temperature.
Figure 7. SPEI and RDI at different timescales in Diyarbakir.

2019 between 1983 and 1986 in the chart. According to the results, the frequentness of 1-month values and the frequentness of 12-month values vary.

CONCLUSION

Drought cannot be fully defined due to its mixed structure and effects. That is why it has been suffered for a long time. From simple approaches to mixed approaches, this has contributed to the development of the progressively evolving drought indices.

In this study, it covers a long period of 70 years between 1950 and 2019 for the Southeast Anatolia Region. Drought analysis was tried using meteorological drought indices. Given the drought indices, it can be concluded that there are differences between both seasonal variations and the parameters used. The objective is to sort the indices by separating the indices according to the parameters in which they are used. Thus, comparing the indices with each other gives more accurate results. In addition, the role of each method in drought detection will be determined. It is also intended to determine the most appropriate drought index for the region.

It is seen that the methods partially detect the drought that occurred in the period 2006 – 2009, which occurred throughout the country and caused large agricultural crop
and economic loss, especially in the Southeastern Anatolia Region.

- Drought indices where only precipitation is used have high dry values on a percentage basis compared to normal values. According to the drought results applied for 70 years, normal values are currently prevailing in the region. However, it is observed that the dry values are increasing. RAI is the largest number of dry results between the indices. PNPI is also classified as 5 droughts, unlike other indices. As a result of these analyses, it was determined that SPI-originated indices (CZI, Z-Score and others) are reliable and accurate indices for drought analysis, and it was concluded that other indices may not yield very reliable results.

- In drought indices where only PET is used, it has been determined that dry months are more than normal months. Drought has an impact in most months. The months of April and July can be said in the months of the dry.

- Different results occur in drought instances where both precipitation and temperature are used. According to the PCI and HTC drought index, drought has been experienced, while AI says the drought may be just starting. In the indices in this drought classification, weak results were achieved more dryly than others.

- Firstly, 5 different reference periods of 1, 3, 6, 9 and 12 months were determined for the total amount of rain per month. Potential evapotranspiration amounts were then obtained by Thornthwaite method by using monthly average temperatures, and these potential evapotranspiration amounts were divided into 5 different reference periods: 1, 3, 6, 9 and 12-month periods. In drought indices where both precipitation and PET are used, drought has generally been observed in both indices for at least 1 month. In SPEI, maximum drought was observed at all stations with a 3-month frequency. In RDI, maximum drought was observed at all stations with a 3-month frequency.

Differences are observed when looking at the drought rates obtained from the stations' annual and monthly drought indices. These differences are because the stations experience summer droughts, with rainfall falling mostly during the winter and spring months.

With this study, the approach created for the Southeast Anatolia Region is based on the meteorological drought index. Researchers tried to conduct spatial analysis of drought and determine the stations affected by drought in the study area, which is important for water resources and agriculture.

As a result, this study can be further expanded by including climate elements such as humidity, temperature, precipitation type, evaporation, wind, sunbathing intensity, etc. Relations between drought and these variables can be revealed. The effects of all climate elements on drought should be investigated and methods should be developed to foretell the drought.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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