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Estimation of Intensity Patterns and Distribution of Aridity Indices over Selected Zones of Iraq Using Different Computational Methods

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Keywords:
Drought indices; Aridity index; Temperature; Rainfall; Food security; De Martonne aridity index; Palmer drought severity index.

Highlights:

- *The de Martonne index (DMAI) tends to classify stations as arid and semi-arid comparison to the other indices.*
- *The climate classification of the study area is dry climate.*
- *Using nine different drought indices.*

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Abstract: The purpose of the present study is to identify the prevailing climate classification in the area covered by the study using different drought indicators. The current study area included eight climate stations distributed in different regions of Iraq, including northern, central, and southern Iraq. The stations included (Basra, Sammawa, Hilla, Baghdad, Ramadi, Kirkuk, Mosul and Sinjar). Data related to the study were collected from rain and temperatures from 1980-2021. Nine types of drought indicators were used in the study, the most common and commonly used in hydrological studies related to drought classifications, despite the large variation in temperature and rainfall amounts recorded within the area covered by the study. Most indicators used in the study classified the prevailing climate in the study area as falling within the dry and moderate drought climate category, with some exceptional cases for some methods due to the progression of the climate classification table and the difference in temperatures. During the seasons of the year, the study showed that the Emberger Aridity Index (EAI) is not suitable to indicate the classification of Iraq's climate due to the large difference in temperatures between summer and winter, while the Minar's Moisture Content (J) index indicated that the desert climate is prevalent in all study areas and is the driest category for this index. Seasonal Aridity Index (SAI), which depends on rainfall and seasonal temperatures, classified the study area within the dry, moderate dry, and semi-humid climates. The Lange and the UNEP indices classified 62.5% of the study area as an arid region and 25% as semi-arid, while the remaining part was classified as dry semi-humid. The study showed that the dry climate was the reason for the scarcity of water resources available to implement the agricultural and food security plan.

تقدير أنماط الشدة وتوزيع مؤشرات الجفاف على مناطق مختارة من العراق باستخدام طرق حسابية مختلفة

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الخلاصة
الغرض من الدراسة الحالية هو التعرف على التصنيف المناخي السائد في المنطقة المشمولة بالدراسة باستخدام مؤشرات جفاف مختلفة. شملت منطقة الدراسة الحالية ثمانية محطات مناخية موزعة في مناطق مختلفة من العراق شملت شمال ووسط وجنوب العراق شملت محطات (البصرة، السماوة، الحلة، بغداد، الرمادي، كركوك، الموصل وسنجار) وتم جمع البيانات المتعلقة بالدراسة من امطار ودرجات حرارة للفترة من ١٩٨٠-٢٠٢١. استخدمت في الدراسة تسعة انواع من مؤشرات جفاف الاكثر شيوعا وتداولا في الدراسات الهيدرولوجية المتعلقة بتصنيفات الجفاف وبالرغم من التفاوت الكبير في درجات الحرارة وكميات الامطار المسجلة ضمن المنطقة المشمولة بالدراسة الا ان غالبية المؤشرات المستخدمة في الدراسة صنفت ان المناخ السائد في منطقة الدراسة يقع ضمن صنف المناخ الجاف والمتوسط الجفاف مع بعض الحالات الاستثنائية لبعض الطرق بسبب تدرج جدول التصنيف المناخي، واختلاف درجات الحرارة خلال فصول السنة حيث بينت الدراسة وفق موشر الجفاف إمبرجر (EAI)، انه لا يصلح للدلالة على تصنيف مناخ العراق بسبب التفاوت الكبير في درجات الحرارة بين الصيف والشتاء، فيما اشار المؤشر J ان المناخ الصحراوي هو السائد في جميع مناطق الدراسة وهو الفئة الأكثر جفافا لهذا المؤشر، أما المؤشر SAI الذي يعتمد على الأمطار ودرجات الحرارة الموسمية فقد صنف منطقة الدراسة ضمن المناخ الجاف والمعتدل الجاف وشبه الرطب. أما مؤشرلانج وبرنامج الأمم المتحدة للبيئة فقد صنف ان ٦٢,٥٪ من منطقة الدراسة على انها منطقة قاحلة، و٢٥٪ صنفت بأنها شبه قاحلة، فيما صنف الجزء المتبقي منها بأنه جاف شبه رطب. وأظهرت الدراسة أن المناخ الجاف كان السبب في شح توفر الموارد المائية المتاحة لتنفيذ خطة الأمن الزراعي والغذائي.

الكلمات الدالة: مؤشرات الجفاف، مؤشر القحولة، درجة الحرارة، هطول الأمطار، الأمن الغذائي، مؤشر دي مارتون للقحل، مؤشر بالمر لشدة الجفاف.

1.INTRODUCTION

Due to the steady population growth and unprecedented competition in the uses of water for domestic and population purposes, agriculture, industry, and the energy sector with its various names, this has led to the availability and unequal distribution resulting from excessive use of water and climate change, which has caused an exacerbation of the problems of water scarcity, especially in recent decades, to include large parts of the world. Accordingly, monitoring the drought situation has become an important phenomenon due to the broad and strong interconnection between the various sectors affected by geographical and temporal distribution factors, thus causing cascading effects as a result of drought, which represents 50% of all-natural disasters; however, it affects more than 30% of the total people affected by it [1]. The severity and quantity of drought are described and represented using many drought indicators by integrating climate data, such as rainfall, temperature, and vegetation cover. The reason for this, especially during the last two decades, is due to the increase in computing resources, remote sensing data, and satellite images that depict these features at regular intervals, all of which contributed widely and effectively to monitoring the phenomenon of drought at different times. More than 150 drought indicators have been studied by many researchers in different parts of the world over successive decades [2, 3]. The most common and widely used of these indicators are the Palmer Drought Severity Index [4], the Standard Precipitation Index [5], and the percentage of rainfall abnormality [6], among many other indicators. In 2010, the Standard Precipitation Index [SPI], as described by the World Meteorological Organization [WMO], was considered the main indicator to describe the weather condition during operational periods In the past decade, several drought indices have been developed to monitor vegetation stress and drought scenarios, including indices [AVHRR, NDVI], Vegetation Condition Description Index [VCI], Percentage of Average Seasonal Green Areas [PASG], Temperature Condition Description Index [TCI], and Temperature vegetation dryness index [TVDI] [7-11]. A series of research on drought indicators continued, and researchers later developed a new drought index called the Integrated Drought Severity Index (IDSI). This index is based on a data fusion technique that resolved the multiple-resolution effect of the VCI, TCI, and PCI indicators [12]. Climatic indicators are considered one of the most appropriate methods for evaluating and identifying types of drought and describing their patterns for the large areas under study [13]). Aridity is defined as the degree to evaluate the effectiveness of climate on natural life [14]). Aridity means a shortage of precipitation over a long period. Aridity, in the worst cases, prevents development planning from growing rapidly. Global climate change occurs due to the natural processes caused by aridity large-scale changes in the hydrological cycle occur, such as increasing atmospheric water vapor content, plant growth, change in runoff, soil moisture content, and changes in the pattern of precipitation distribution. The lack of rainfall due to aridity depends on the region's climate, represented by temporary or seasonal conditions. This phenomenon may strike everywhere and at any time with levels of intensity and time of continuity [15]. Major environmental factors, represented by human and natural factors, are considered one of the main causes of global climate change during the twenty-first century (IPCC) [16]. The higher values of aridity indices over a large area in any region mean the greater variability of water resources [17]. De Martonne (DM) is one of the wide aridity parameters used for different time scales [18]. This indicator is used to determine dry and wet regions within the area under study and describe in detail the scientific change of climate regions [17, 19, 20]. Pinna combinative aridity index is used to detect the aridity and depends on both the mean annual amount surface temperature and precipitation, respectively [21-24]. The Emberger index is one of the oldest aridity indexes, which considers the mean temperature of the year and the months characterized by the coldest and highest temperatures [25]. Moreover, the Johansson Index and Kerner Index are used to classify continental and oceanic climates, respectively. Ref. [26] studied the characteristics of spatial and temporal drought in different regions of Iraq, including 18 climate stations from 1981 to 2021, using the SPT at different periods from 3 to 24 months. Ref. [27] studied the characteristics of climatic drought and its prediction in the Kurdistan region of Iraq using SPI and the reconnaissance drought index (RDI). The study formed nine climate stations. This study aimed to compare different climatic indices for evaluating aridity based on metrological data from eight weather stations distributed in the different zones of Iraq for 41 successive years from 1981 to 2021 to detect, on a regional basis, different drought characteristics decided by different climatic indices.

2.DATA USED IN THE STUDY

Data from 8 meteorological stations from 1981 to 2021 were used (more information about the selected stations are listed in Table 1).

Table 1 Meteorological Information (IMOS).

No	Stations	Longitude E	Latitude N	Years	Average Precipitatin mm	Average Temperatue C°
1	Sammawa	45°16'	31°19'	1981-2021	98.3	26.47
2	Hilla	44°25'	32°29'	1981-2021	102.9	25.88
3	Ramadi	43°17'	33°25'	1981-2021	97.3	23.28
4	Baghdad	44°21'	34°21'	1981-2021	117.5	24.66
5	Basra	47°48'	30°30'	1981-2021	122.7	27.08
6	Kirkuk	44°18'	35°28'	1981-2021	335.8	22.04
7	Sinjar	41°51'	36°19'	1981-2021	328.5	20.78
8	Mosul	43°07'	36°20'	1981-2021	350.0	22.23

The monthly average values of the precipitation (P_m) and the surface air temperature (T_m) were obtained by processing and analyzing the data of meteorological stations under study and then using those time series in the detection and investigation of the indicators and indications of drought indices after analyzing the trend of these series. After that, homogeneity tests were performed for those time series, assuming that the proportion of consistent precipitation and air temperature of the station under test with the observed data was relatively constant over time and that the correlation coefficients were greater than 0.7 because the study area consists of relatively low terrain and sometimes tends to be flat. The results of the homogeneity tests showed that the time series for all the stations tested were homogeneous.

3.STUDY AREA

Iraq's climate is characterized as hot and dry in summer and cold and wet in winter compared to spring and autumn. The climatological data used in the analysis represent the monthly precipitation and air temperature values collected from (8) meteorological stations (Iraqi Meteorological Organization and Seismology) from 1981 to 2021, as shown in Fig. 1. Missing data were estimated using simple linear regression of the other years observed [28].

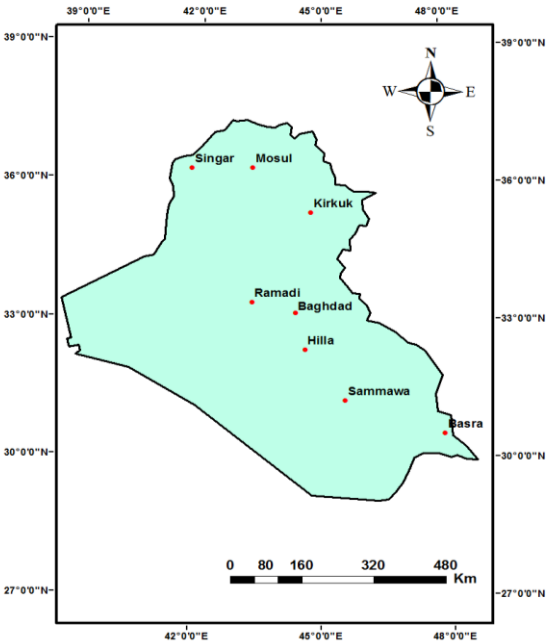

Fig. 1 Location of Meteorological Stations Used in this Study.

4.METHODOLOGY

The following methods for estimating aridity indices for different regions in this study depend on precipitation, air temperature, and evapotranspiration. De Martonn's aridity index (DMAI) is one of the oldest indices used to estimate the aridity of different regions at any location. Eq. (1) is given to calculate DMAT [29]:

$$\boldsymbol{DMAI} = \frac{\boldsymbol{P}}{\boldsymbol{T} + \boldsymbol{10}} \quad \textbf{(1)}$$

where P is the annual average rainfall in mm, and T is the annual air temperature in C°. DMAI ranges from DMAI<10 for the arid zone to DMAI>55 for an extremely humid zone, with other climate classifications between these two ranges. Eq. (2) was used to calculate the seasonal aridity index (SAI) [30]:

$$SAI = \frac{4P_s}{T_s + 10} \quad (2)$$

where P_s is the seasonal amount of precipitation in mm, and Ts is the mean seasonal air temperature in C°. Equation (3) is used to estimate the aridity index factor, i.e., Emberger Aridity Index (EAI), determined by the following formula [31].

$$EAI = \frac{100P}{H^2 - d^2} \quad (3)$$

where P is the mean annual precipitation (P), d is the mean coldest temperature in months, and H is the mean hottest temperature in months. The boundaries of EAI range from EAI<30 for the arid zone to EAI >90 for the humid zone. Lang compared the average rainfall (R in mm) and the average temperature (T). The Lang's rainfall factor (LRF) values are calculated by Eq. (4).

$$LRF = \frac{R}{T} \quad (4)$$

The Thonthwaite index, usually known as Precipitation Effectiveness (PE), was calculated using Eq. (5) [17].

$$PE = \sum_{i=1}^{n=12} 115\left(\frac{P}{T - 10}\right)^{2.25} \quad (5)$$

where P is the monthly precipitation in inches, and T is the mean monthly temperature in F°. PE ranges from PE<16 for the arid zone to PE>127 for the wet zone. UNEP is calculated using Eq. (6) [32] as follows:

$$UNEP = \frac{P}{PET} \quad (6)$$

Where

$$PET = 16N_m\left(\frac{10T_m}{I}\right)^a \quad (7)$$

$$I = \sum_{i=1}^{n=12} \left(\frac{T_m}{5}\right)^{1.514} \quad (8)$$

$a = 6.75\times10^{-7}\times I^3 - 7.1\times10^{-5}\times I^2 + 0.01792\times I + 0.49239$

where PET is potential evapotranspiration in mm, T_m is the mean monthly temperature in C°, N_m is the adjustment factor related to an hour of daylight, and I is the heat annual index. UNEP ranges from UNEP<0.05 for a hyper-arid zone to UNEP> 1.0 for humid zone. The ratio between the mean of the rainfall (R in mm) and the mean temperature (t) at the same time in the specific locations indicates the Minar's moisture content (J) at this location [33], as shown in the following expression:

$$J = \frac{R - 30(t + 7)}{t} \quad (9)$$

The value of J ranges from J< (-4-0) for the highly arid zone to J>35 for the humid zone. The mean values of precipitation (P), temperature (T), Pd and Td are the precipitation and temperature in the driest month, which are used to develop a new aridity index factor called Pinna Combinative Index (PCI) by [18, 26]. PCI is calculated by Eq. (10), as shown below:

$$PCI = \frac{1}{2}\left(\frac{P}{T + 10} + \frac{12Pd}{Td + 10}\right) \quad (10)$$

where PCI<10 for an arid zone and PCI>20 for a humid zone.

5.RESULTS AND DISCUSSION

Eight Meteorological stations (MS) are unevenly distributed in the entire region of North, East, West, Central, and Southern Iraq. Information related to rainfall and temperatures from 1981 to 2021 was provided by the General Authority for Weather Development in Iraq. The study aimed to identify the types of drought for those areas of Iraq using (7) types of drought indices. The values of the drought factor for all the methods used were fairly close, with some exceptions, indicating that the climate in those areas falls within the categories of dry, semi-arid, and moderate droughts. As it is clear from the results of Table 2 and Fig. 2, the DMAI classification showed that the regions of Samawa, Hilla, Baghdad, Basra, and Ramadi fall within the classification of dry areas. While the regions of Kirkuk, Sinjar, and Mosul fall under the semi-dry classification. The EAI classification indicated that most of the areas under study fall within the classification of dry regions except for the Sinjar region, which is classified as a semi-arid region because the temperature variation of all stations is very low. According to the J classification Fig. 3, the country has a "desert" climate in the entire area, which is the driest class for this index. In particular, the J classification indicated that the regions of Samawa, Hilla, Baghdad, Basra, and Ramadi fall within the extremely dry regions classification, while the areas of Kirkuk, Sinjar, and Mosul fall within the dry areas classification.

Table 2 The Values of Drought Indices for Selected Stations within the Study Area.

Stations	Drought Indices								
	PE	DMAI	LRF	EAI	PCI	J	SAIW	SAIS	SAIUT
SAMMAWA	3.97	2.73	3.78	5.37	2.31	-34.12	5.28	10.46	9.72
HILLA	6.16	2.90	4.04	5.79	2.79	-32.34	8.46	14.31	9.43
RAMADI	7.62	2.99	4.32	6.77	3.09	-31.86	10.43	15.47	8.26
BAGHDAD	5.99	3.56	5.11	6.51	3.37	-33.15	6.83	16.29	8.87
BASRA	5.85	3.32	4.54	7.22	2.55	-32.27	8.77	10.08	10.01
KIRKUK	14.98	11.01	16.38	26.44	7.85	-26.02	18.35	22.17	7.31
SINGAR	15.72	11.33	17.29	34.05	8.20	-25.75	20.59	22.02	5.68
MOSUL	18.35	11.29	16.67	20.21	8.4	-23.08	22.47	25.63	7.38

According to the J classification Fig. 3, the country has a "desert" climate in the entire area, which is the driest class for this index. In particular, the J classification indicated that the regions of Samawa, Hilla, Baghdad, Basra, and Ramadi fall within the classification of extremely dry regions, while the areas of Kirkuk, Sinjar, and Mosul fall within the classification of dry areas.

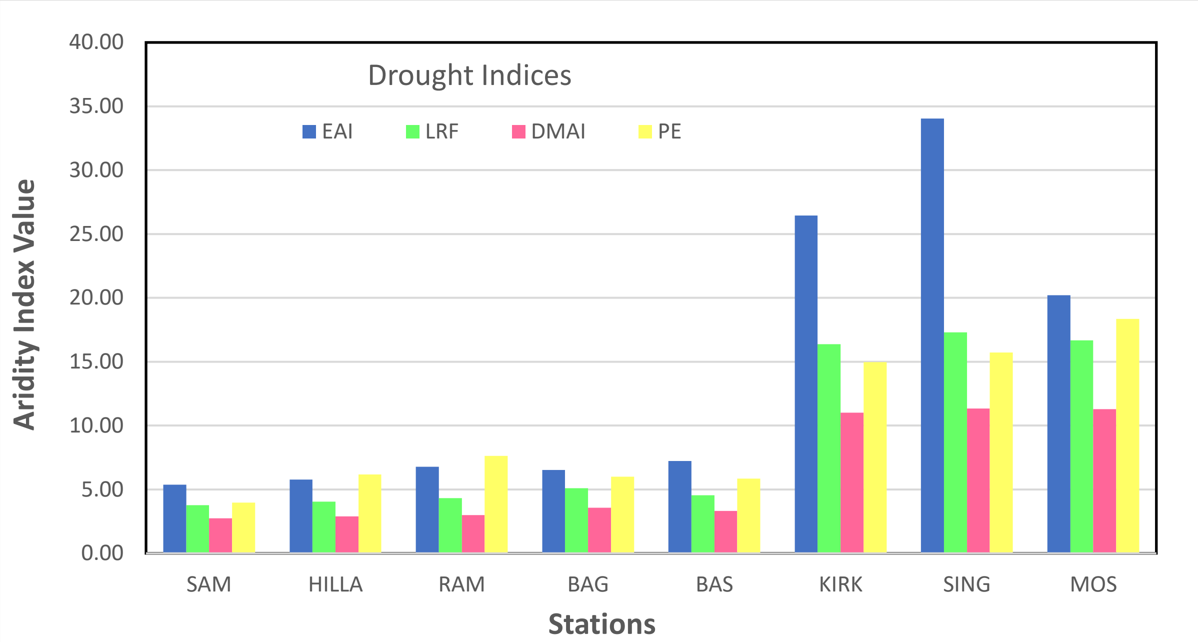

Fig. 2 Graphical Presentation of Station-Wise Results of Emberger Aridity Index, Lang's Rainfall Factor, De Marton's Aridity Index and Precipitation Effectiveness.

For the PCI classification, all study regions are classified as dry areas because the drought factor in all these stations is less than 10. The same applies to the LPF classification, as the drought factor is less than 40. For the PCI classification, all study regions are classified as dry areas because the drought factor in all these stations is less than 10. The same applies to the LPF classification, as the drought factor is less than 40. Using the SAI classification, which depends on seasonal rains and seasonal temperatures, the study area is classified under the dry climate classification in the autumn, dry, semi-dry, and moderate droughts during the winter. While for the spring season, the study areas fall under the semi-arid, moderate-dry, and semi-humid climate classifications, as shown in Fig. 4.

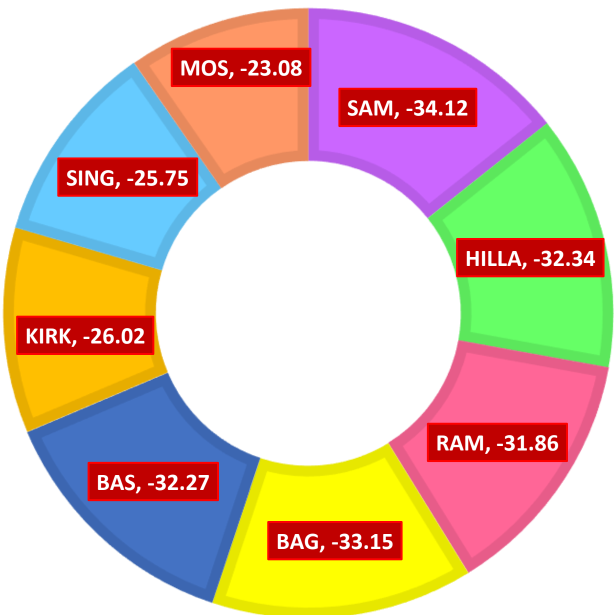

Fig. 3 Graphical Presentation of Station-Wise Results of Minar's Moisture Content (J).

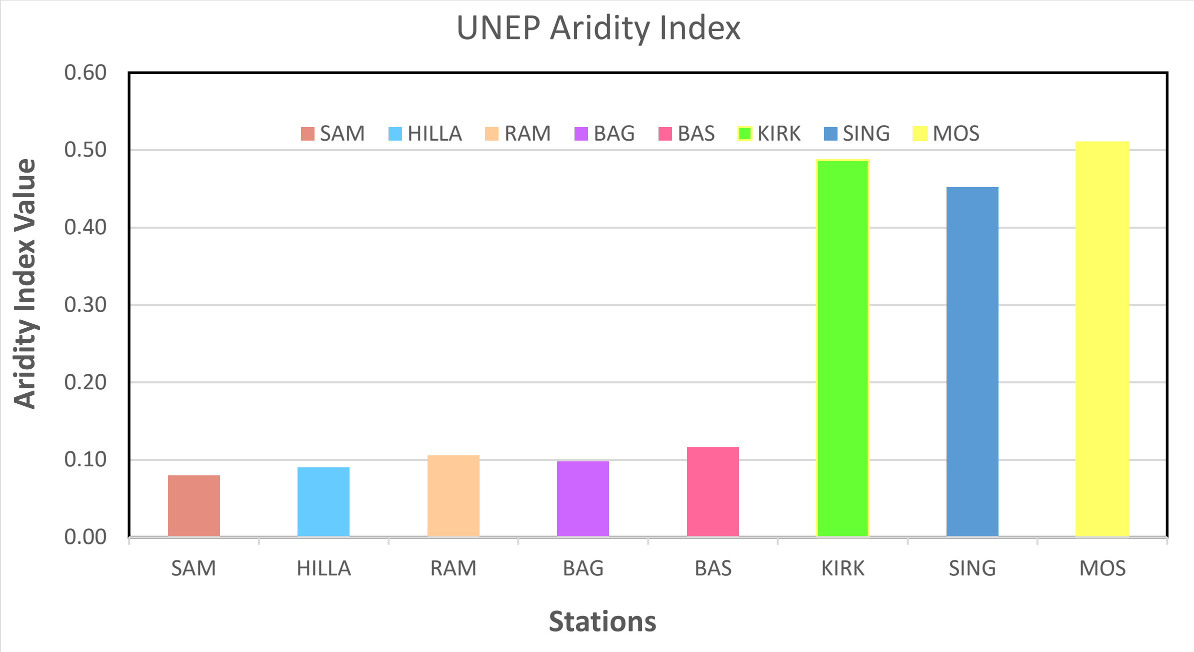

Fig. 4 Values of Aridity Index for Different Metrological Stations During Autumn, Spring, and Winter.

The Thornthwaite (PE) classification also shows that the arid area and aridity increase in the study area, mainly in the northwestern, enteral, and southern regions. As shown in Table 2 and Fig. 5, the UNEP index is less marginal and considers 62.5% of the zone as arid, 25% as semi-arid and the remaining as dry sub-humid. From Table 2 and Fig. (2, 3, 4, and 5), it has been found that the driest area of the country is located in the central and south regions of the study area. Aridity is a very common phenomenon, mainly in Samawa, Hilla, Baghdad, and Basra in Iraq, indicating that the aridity is characterized by scatter patterns with different values, where the pattern of aridity is increased when the lower values of all aridity indices are increased. All methods used showed that the country experienced a period of droughts with varying levels during the past two decades. The most drought years were 2007, 2008, 2009, 2012, and 2017. Drought was most affected in the central and southern regions of the country.

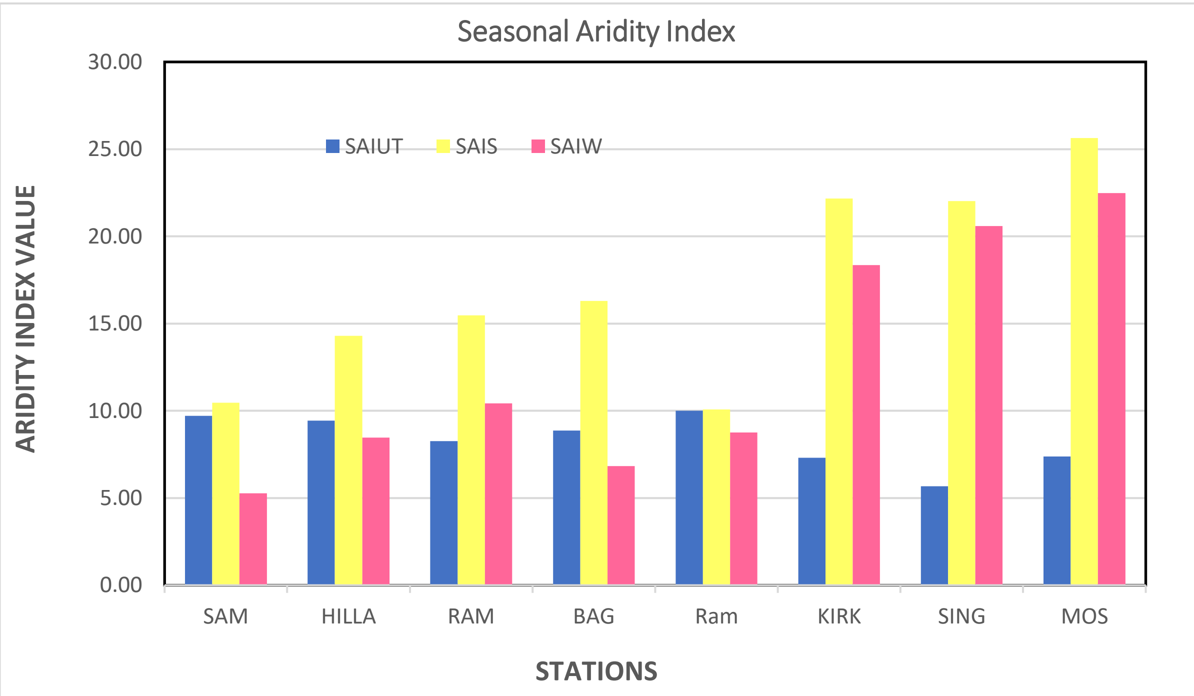

Fig. 5 Graphical Presentation of Station-Wise Results of United Nations Evapotranspiration AridityIndex.

6.CONCLUSIONS

The eight climate indices are evaluated to delineate dry lands in selected stations. The following conclusion can be addressed from this study:

1- Compared to the other indices, the de Martonne index (DMAI) tends to classify stations as arid or semi-arid.
2- The Emberger index (EAI) classifies all the stations of selected zones as dry, which is the lower climate class. However, this index is unsuitable for implying it in the classification of Iraq's climate because the temperature difference between summer and winter is very high.
3- According to the J classification, the country has a "desert" climate in all the areas, which is the driest class for this index.
4- For the PCI classification, all study regions are classified as dry areas because the drought factor in all these stations is less than 10.
5- For the SAI classification, which depends on seasonal rains and seasonal temperatures, the study area is classified under the dry, semi-dry, moderate-dry, and semi-humid climate classifications, depending on the seasonal type.
6- The Lang and UNEP indices define a low class of aridity named arid for LRF and consider 62.5% of the zone arid, 25% semi-arid, and the remaining part dry sub-humid.

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