Journal of Applied and Advanced Research, 2018: 3(4) 96–104
http://dx.doi.org/10.21839/jaar.2018.v3i4.217
ISSN 2519-9412 / © 2018 Phoenix Research Publishers

Research Article – Atmospheric Sciences

Assessment of spatial distributions of some climate indices in Iraq

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(Received: 02-06-2018; Accepted 02-07-2018; Published Online 04-07-2018)
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Abstract

Aridity is one of the main factors which distinguish the climate of a region and has significant influence on human activities. This study investigated the spatial distribution of the aridity indices to determine the climate conditions in Iraq over the period (1981-2015), depending on the data of the air temperature and rainfall which obtained from 28 stations distributed through Iraq. The used aridity indices are: Lang, Erinc, Emberger, UNEP, De Martonne and Thornthwaite. The spatial distribution was determined using inverse distance weighting (IDW) interpolated method. The results of aridity indices analysis shows that the hyper-arid, arid, and semi-arid categories are predominant with almost (91%) to (100%) of the country's area. Dry sub-humid, moist sub-humid and humid categories occupies less than (10%) with most of indices at stations of (Arbil, Sulaymaniyah, and Salahaddin). To evaluate the seasonal spatial distributions, De Martonne was utilized. During winter, the climate types ranged from semi-arid to very-humid, while at spring season from arid to humid. Autumn season dominated by arid at (97%) of study area. The summer season was the driest compared with the other seasons. The change point for aridity indices was detected by using the cumulative sum charts (CUSUMs), it is found for the most stations in (1997). Consequently, the spatial distribution for the aridity indices were analyzed through two periods (1981-1997 and 1998-2015), this analysis showed that the arid and hyper-arid areas were increased in the second period compared with the first period with obvious extension toward the north of Iraq.

Keywords: climate change, aridity, aridity indices, spatial distribution.

Introduction

Under the global warming excess, the local temperatures and precipitation rates have changed in an unexpected way. Warming increases evaporation, and makes the wet regions turns out to be dry and arid areas to be drier (Ma *et al.,* 2005). Rising of air temperature and changing patterns of precipitation are aclualities that can not be denied, which may have different effects on human life, particularly on human settlements, food and energy exhaustion (Arghiuș, 2015). Intergovernmental Panel on Climate Change IPCC revealed that expanding recurrence of droughts and the dry spell can be deep concern of climate change. The arid and semi-arid areas involve right around 40% of the earth's property surface. These destinations suffers regression in the available water resources, and are accountable to be more sensitive to climate change. Evaluating the changing examples of aridity is a critical matter of anxiety with regards to worldwide climate change. Aridity is defined as the scarcity of moisture under average climate conditions (Barakat, 2009). It is a function of a continuum of environmental factors including temperature, precipitation, evaporation, and low vegetative cover (Oliver, 2008). Increase aridity, dryness, and desertification are real hazards, affect the conditions of livelihood of the world's population arid area like affecting on agriculture and water supply due to it may be constraining factors for growth the plant and dissemination (Moral *et al.,* 2016; Piri *et al.,* 2016).

Generally, aridity is basically resulted in large-scale, persistent atmospheric and oceanic circulation patterns, conditioned through regional orographic features. The cause of aridity is not confirmed by regional groundwater management and it can not be separate from water scarcity, since it is a hydrological, long-term and climatic feature. The cause of aridity is important within the state of global climate change, have an effect on global atmospheric and oceanic circulation patterns. So, estimating this condition would lead to a better understanding of the phenomenon (Andrade and Corte-Real, 2016).

Aridity index (AI) is a numerical indicator of the degree of dryness of the climate at a given location (Nastos *et al.,* 2013). Aridity indices are generally used to reveal the potential dangers of aridity changes and severity, and to study the spatial and temporal changes (Gao *et al.,* 2015). Aridity defines by various indicators, some of them uses air temperature and rainfall data, such as De Martonne, Lang, and Erinc aridity indices. However, Emberger index depends on the average annual rainfall and average temperature of the coldest and hottest months. The latter depends on the climatic data relevant to vegetation areas. Some other indicators rely on potential evaporation which calculated by different methods. Thornthwaite defined aridity index as the ratio between rainfall and potential evaporation (Hrnjak *et al.,* 2014). Aridity indices studies have been widely dealt with in the literature. The studies related to climatic indicators have proven to be very useful in predicting agricultural production (Deniz *et al.,* 2011).

Several studies have used aridity indices in different areas of the world. (Denize *et al.,* 2011) used Kerner oceanity index, Johansson continentality index, pinna combinative index, and De Martonne aridity index, to determine the climatic conditions at turkey's regions for the period (1960-2006) and for two separate periods (1960-1990 and 1991-2006). They found that the semi-dry area had been increasing in the second period compared with the first period (Deniz *et al.,* 2011). Iran is one of the most arid regions of the world, with 75% of its area having been classified as arid and semi-arid (Some'e *et al.*, 2013). Aridity indices variations in Iran were calculated in many studies. For example, (Tabari and aghajanloo 2013, Piri *et al.*, 2016, and Shifteh some'e *et al.*, 2013). Climate indices also used by Baltas (2007), who investigated the spatial variations at the northern parts of Greece by using (De Martonne index, Pinna combinative, Kerner oceanity, and Johansson indices). He found a significant correlation of (0.91) between De Martonne and Pinna combinative (Baltas, 2007). Also (Mohammed and Mohammed, 2010) determined climate classification system for Sudan using different aridity indices for the period (1971-2000) for 19 weather stations. They found that climate of Sudan can be classified as hyper-arid, arid, semi-arid, sub-humid and humid zones (Mohamed and Mohamed, 2017). In addition, Haider and Adnan (2014) assessed the aridity in Pakistan for 50 years. They found that the dryland with arid class at about (75 to 85%) of the region which is located at the south, while the humid class occupies less than 10% at the northern part of Pakistan (Haider and Adnan, 2014).

This study tries to determine the climate conditions in Iraq by analyzing aridity indices based on monthly air temperature and precipitation data taken from 28 meteorological stations during (1981-2015). This investigation can be used to manage the water resources and agriculture in Iraq.

Materials and Methods

Study area and dataset

Iraq lies in the south-west of Asia, with an area of ($438320 km^2$). It is situated between (29°5' to 37° 22' N) latitudes and (38° 45' to 48° 45' E) longitudes. It is bounded to the north by Turkey, east by Iran, southeast by the Persian Gulf and the south by Kuwait and Saudi Arabia. Topographically, the shape of Iraq is like a basin, it is made up of the great Mesopotamian alluvial plain and basin of the Tigris and Euphrates rivers (Frenken, 2009). Iraq topography can be divided into four regions: the first one is Mesopotamian plain which is about a quarter of the total area of Iraq. The second one includes Desert plateau, which is lies to the west and occupies less than half of Iraq's total area. The third part is Mountainous region to the north and the northeast of Iraq. The last part is Undulating region which is a transition zone between the alluvial plain in the south and the high mountains in the far north and northeast (Robaa and AL-Barazanji, 2013).

The climate of Iraq is fundamentally of the continental, subtropical semi-arid type, with a Mediterranean climate in the north and northeastern region. Rainfall is very seasonal and starts from December to February in the winter, barring in the north and northeast of Iraq, where the rainy season starts in November and ends in April. The average annual precipitation was estimated to be (216mm) ranging from a maximum (1200mm) in the northeast to a minimum (100mm) in the south (Frenken, 2009). The average daily temperature during winter is usually 16°C and drops down at the night to 2°C. In summer, the temperature is usually over 43°C in daytime during July and August and dropping to 26°C at the night (Zakaria *et al.*, 2013). The meteorological data used are mean monthly precipitation and monthly air temperature (mean and maximum) of 28 stations all over Iraq during the period (1981-2015). The spatial distributions of the selected stations are shown in Figure (1). The data were obtained from the Iraq Meteorological Organization and Seismology (IMOS). The monthly values were averaged to obtain the annual values. Missing data of precipitation and air temperature were evaluated by using spline interpolation method in MATLAB programming language. Sunshine duration data were also used. The location of the stations, data of precipitation and air temperature, and missing data are listed in Table (1).

Figure 1. Geographical locations of meteorological stations

Table 1. Location of stations, data of precipitation and air temperature and missing data

Station	Station No.	Long.	Lat.	Elev. (m)	P (mm)	T_Mean(°C)	T_Max(°C)	Missing Data %
Taleafer	40603	42.48	36.37	373	302.17	20.94	26.93	12.03
Kirkuk	40621	44.35	35.74	331	344.21	22.80	28.89	1.66
Kerblaa	40656	44.05	32.57	29	92.388	24.25	31.12	2.53
Biji	40631	43.53	34.9	150	197.14	22.60	29.88	0.64
Nasiryah	40676	46.23	31.02	3	124.56	25.76	32.86	2.06
Mousl	40608	43.15	36.31	223	347.34	20.38	27.96	0.24
Rutba	40642	40.28	33.03	615	116.01	20.16	27.18	0.89
Hai	40665	46.03	32.13	15	127.79	25.38	32.33	0.55
Basara	40689	47.78	30.52	2	135.13	26.23	33.42	5.47
Amara	40680	47.17	31.83	9	172.86	25.22	32.52	2.77
Rabiah	40602	42.1	36.8	382	345.73	18.76	26.51	17.2
Ramadi	40645	43.32	33.45	48	108.82	22.24	29.81	9.72

Table 1 continued

Sinjar	40604	41.83	36.32	476	352.95	20.92	25.48	13.07
Baghdad	40650	44.4	33.3	34	120.09	23.15	30.87	2.85
khanaqin	40637	45.38	34.35	202	288.82	23.26	30.92	4.36
Haditha	40634	42.35	34.13	140	132.01	21.87	29.43	21.9
Najaf	40670	44.32	31.95	32	95.178	24.75	31.55	2.61
Hella	40657	44.45	32.45	27	100.16	23.25	30.99	8.88
Diwaniya	40672	44.95	31.95	20	105.31	24.70	31.91	2.14
Samawa	40674	45.27	31.27	6	102.34	24.94	32.27	8.17
Samara	40635	43.88	34.18	75	167.05	23.21	30.12	2.77
Anah	40629	41.95	34.37	150	140.59	20.87	28.70	16.3
Kut	40664	45.75	32.49	19	125.93	24.43	31.85	23
Tikrit	40633	43.7	34.57	107	170.07	23.08	29.83	0.63
Tuz	40632	44.65	34.88	220	266.65	22.93	29.22	1.02
Arbil	40616	44	36.15	420	425.51	20.93	26.89	0.27
Salahaddin	40611	44.2	36.38	1088	609.04	17.43	21.82	0
Sulaymaniyah	40623	45.45	35.53	853	728.88	19.23	24.55	0.27

Aridity Indices

Climate indices have widely used to describe and classify climatic conditions (Andrade and Corte-Real, 2016). The aridity index can be characterized as the numerical pointer to the grade of the drought of the atmosphere in the specified region and it characterizes the kind of climate with regard to water accessibility. The variability of water resources has a positive relationship with aridity indicators, as these fluctuations increases with increasing the values of aridity indicators. The increase in aridity indices correlated to the higher frequency of dry years across the region (Tabari *et al.*, 2014). Lang (L) defined the aridity index as the ratio factor between the mean annual Rainfall (mm) and mean annual air temperature (°C) (Neira, 2010), while Erinc (I_m) index is based on the precipitation (mm) and the annual maximum temperature(°C) that causes the water deficiency by evaporation (Alam and Iskander, 2013). Emberger (IE) index is depends on the climatic data relevant to vegetation areas. This index formula based on the mean annual rainfall (mm) and mean temperature (°C) of both the coldest and hottest month. UNEP (AI_u) defined as the ratio of precipitation to potential evapotranspiration (PET), UNEP was suggested the Thornthwaite method to calculate PET which is based in the relationship between mean monthly temperature with adjustment factor related to daylight hours per month (Neira, 2005). Thornthwaite (PE) provided the precipitation effectiveness index (PE) based on mean monthly precipitation (mm) and temperature (°C) (Mohamed and Mohamed, 2017). De Martonne index considered as one of the most important and most widely used indicators in applied climatology, it is based on the mean annual precipitation (mm) and mean annual temperature(°C), it is also can be computed on a less time scales (monthly and seasonally) (Hrnjak *et al.*, 2014; Moral *et al.*, 2016). The classifications of these six aridity indices are presented in Table 2.

Table 2. Climate classification of Aridity indices and their formulas.

Index	Classification
$L = \frac{P}{T}$	L<20 Arid; 20-40 Semi-Arid; 40-60 Humid; >160 Very Humid (Neira, 2010).
$I_m = \frac{P}{T_{max}}$	I_m<8 Hyper-Arid; 8-15 Arid; 15-23 Semi-Arid; 23-40 Dry Sub-humid; 40-55 Humid; >55 Very Humid (Alam and Iskander, 2013).
$PE = \sum_{1}^{n=12} 1.65\left(\frac{P}{T} + 12.2\right)^{10/9}$	PE<16 Arid; 16-31 Semi-Arid; 32-63 Sub-Humid; 64-127 Humid; >128 Very Humid (Mohamed and Mohammed, 2017).
$AI_u = \frac{P}{PET}$	AI_u<0.05 Hyper-Arid; 0.05-0.2 Arid; 0.2-0.5 Semi-Arid; 0.5-0.65 Sub Humid; >0.65 Humid (Andrade and Corte-Real, 2016).
$IE = 100 * \frac{P}{M^2 - m^2}$	IE<30 Arid; 30-50 Semi-Arid; 50-90 Sub-Humid; >90 Humid (Neira, 2010).
$AM = \frac{P}{T + 10}$	AM<5 Arid; 5-15 Semi-Arid; 15-20 Dry Sub-Humid; 20-30 moist sub humid; 30-60 Humid; >60 Very Humid (Haider and Adnan, 2014).

Change Point Analysis

Change point is a powerful and effective statistical tool used to decide a change in the data set and when this change happens. There are several ways to deal with change point analysis. The approach used in this study has been implemented by Taylor (2000) which is an iterative enforcement of cumulative sum charts (CUSUM) used to disclose a change in time series. It significantly distinguishes observed changes by providing levels of confidence and confidence intervals, controls the overall error rate, it is strong for extreme values, and also easy to use (Taylor, 2000).

Result and Discussion

Figure 2 illustrates the spatial distribution of Aridity indices (Lang, Erinc, Emberger, De Martonne, Thornthwaite and UNEP). The spatial distribution for aridity indices shows that the class of arid cover most of the stations in the country, particularly the stations in the south and middle parts. Semi-arid ranged from 6% to 28 % of the stations, the dry sub-humid, moist sub-humid and humid categories occupies less than 10% with most of indices in the north at stations of Arbil, Sulaymaniyah, and Salahaddin.

The northern part ranged from semi-arid to sub-humid with all indices except Lang index. The reason for that variability of the climate in the northern part is that the region received rainfall highest than the south. The highest

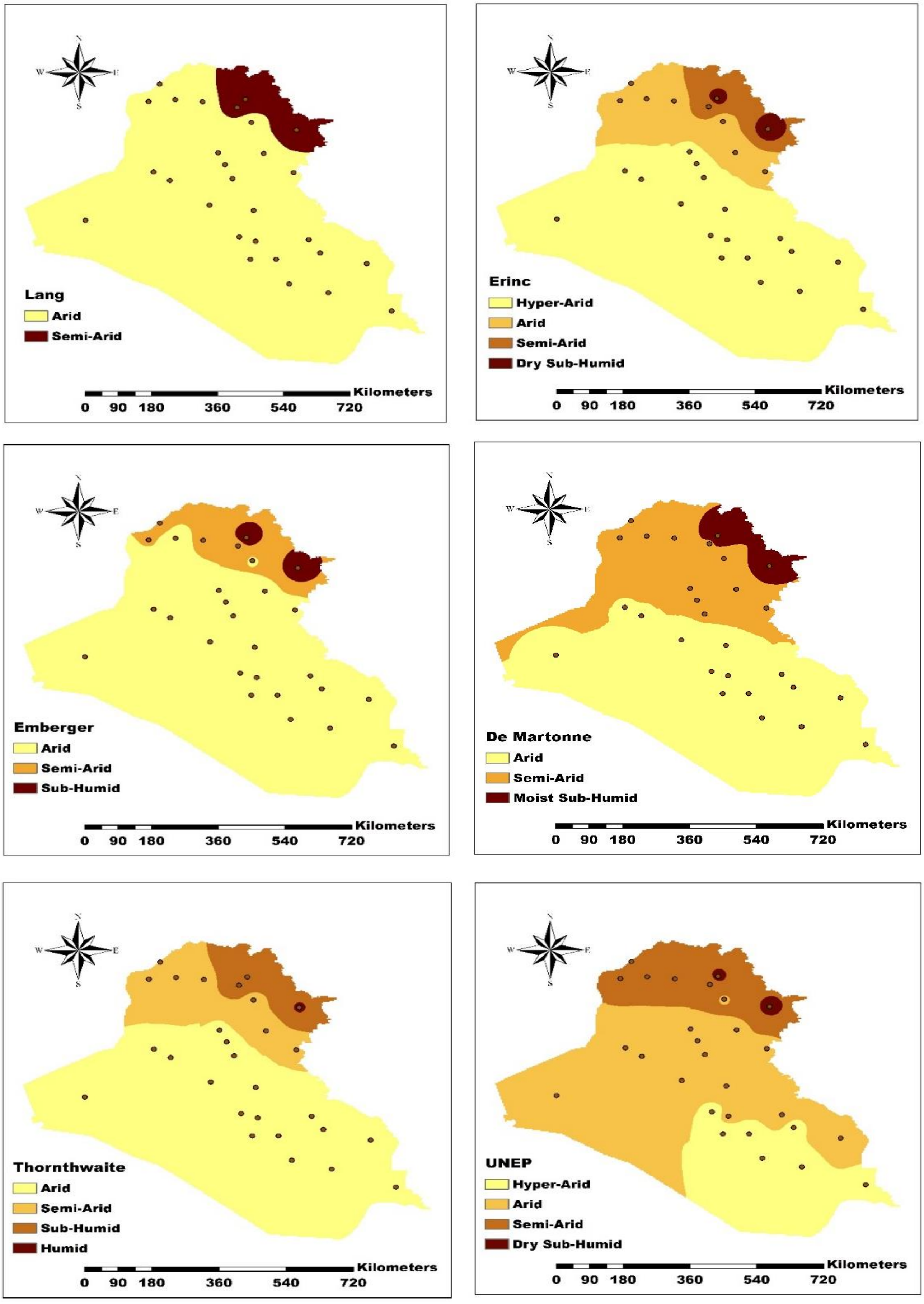


Fig. 2. The spatial distribution of aridity indices (1981-2015).

values of aridity were found at Karbala and Najaf stations with most of indices. Sulaymaniyah and Salahaddin stations classified as sub-humid in many classifications principally (Thornthwaite, De Martonne, Emberger and Erinc). This due to the highest rainfall and lowest amount of air temperature were recorded at these stations. Lang aridity index reveals that the arid climate dominates the region with 92.75% which represents the driest category for this index. The remaining part which lies in northeast was classified as semi-arid at stations of Arbil, Sulaymaniyah, and Salahaddin. As well, Emberger index classified the region as arid, except in the stations of Arbil, Mosul, Rabiah, and Sinjar in the north were characterized as semi-arid, sub-humid class only found at sulaymaniyah and salahaddin stations.

The percentage of classified areas presented in Table (3). At (7) out of (28) stations in the south, the value of UNEP was lower than (0.05) which refers to a hyper-arid climate. Both UNEP and Erinc classified the region as hyper-arid, arid, semi-arid, and dry sub-humid categories. In Thornthwaite classification, most of the region classified as arid and semi-arid in all regions except in Arbil and Salahaddin stations where they classified as sub humid and Sulaymaniyah as humid. The same areas in the south and central parts were classified as arid with Thornthwaite and hyper-arid with Erinc, also Kirkuk, Khanaqin, Mosul, Rabiah, Sinjar, Taleafer, and Tuz stations classified as semi-arid with Thornthwaite index and arid with Erinc index. According to De Martonne index, (15) out of (28) stations in the south part have values less than (5) which refer to arid climate, where it the lowest class in this index, the rest of stations classified as semi-arid. Only Salahaddin and Sulaymaniyah stations were characterized as sub-humid class.

Table 3. The percentage of classifications areas for the period (1981-2015), (1981-1997), and (1998-2015).

Period	Classification	Lang	Erinc	UNEP	Emberger	Thornthwaite	De Martonne
1981-2015	Hyper arid		76.61	26.82			
	Arid	92.68	15.59	55.11	86.96	76.15	66.63
	Semi-arid	7.31	6.38	17.3	10.73	15.54	28.03
	Dry sub humid		1.4	0.766	2.29	8.15	
	Moist sub humid						5.34
	Humid					0.146	
1981-1997	Hyper arid		73.597	2.36			
	Arid	88.33	14.061	76.72	80.51	73.17	57.0
	Semi-arid	11.52	9.88	19.39	14.82	12.44	35.3
	Dry sub humid		2.46	1.516	4.66	13.95	5.79
	Moist sub humid						1.90
	Humid	0.13				0.42	
1998-2015	Hyper arid		80.098	40.95			
	Arid	95.48	14.45	49.49	91.71	79.4	73.27
	Semi-arid	4.517	4.94	9.54	7.13	15.4	24.33
	Dry sub humid		0.506	0.005	1.154	5.16	2.07
	Moist sub humid						0.32
	Humid						

Referring to the seasonal spatial analysis for De Martonne index, the four seasons were presented in Fig.3. In winter season, the values of the index seemed to increase from south where it is semi-arid to the north with very humid climate type at stations of (Salahaddin and Sulaymaniyah). In this season, semi-arid class composes about (68%), dry sub-humid and moist sub-humid (14%), humid (16%), and very humid about (1%). This is in accordance with the spatial distribution of precipitation and temperature. In spring, semi-arid climate dominant with about (78%) of the area in south and middle parts except at stations of Samawa, Diwaniyah, and Najaf were characterized as arid. The northern part is varying from dry sub-humid to humid. In autumn season, as can be seen, the study area is mainly characterized by arid climate (97%) except for small areas in the north characterized as semi-arid climate conditions at stations Arbil, Salahaddin, and Sulaymaniyah. In summer, arid climate conditions prevailed all over Iraq. This season is the driest compared to the other seasons. That can be justified that there is very low precipitation or not available and high temperature.

Iraq region can be considered as a dry land and hence, all stations have been classified among the categories below the sub-humid class for all indices except a few areas in the north. The hype- arid, arid, and semi-arid categories may result from low rainfall and water evaporation due to factor including temperature, wind, vegetation, soil type, water storage capacity and sufficient groundwater supply.

To find out the change points of aridity indices, the cumulative sum chart (CUSUMs) test was used. The change points of stations were occurred in the years 1994, 1996, 1997, 1999, and 2000, but because of that the change points at (68%) of the stations were occurred in 1997, the spatial distribution of aridity indices was analyzed between two periods before and after 1997 (1981-1997 and 1998-2015). The difference before and after the change point is showed in figures (4 and 5). During the first period (1981-1997), the arid and hyper-arid climate conditions cover the stations in the southern and central parts of Iraq for each index, while the north part ranged from semi-arid to sub-humid. Humid class was only found at Sulaymaniyah station with indices of Lang (0.13%) and Thornthwaite (0.42%).

In the second period after 1997, the dry areas within arid and hyper-arid categories were increased from south to north with each index, while semi-arid conditions decreased where it was around 4.5% to 24.3% of the study area. Sub-humid class was found in small areas at stations of Salahaddin, and Sulaymaniyah. There was no humid climate

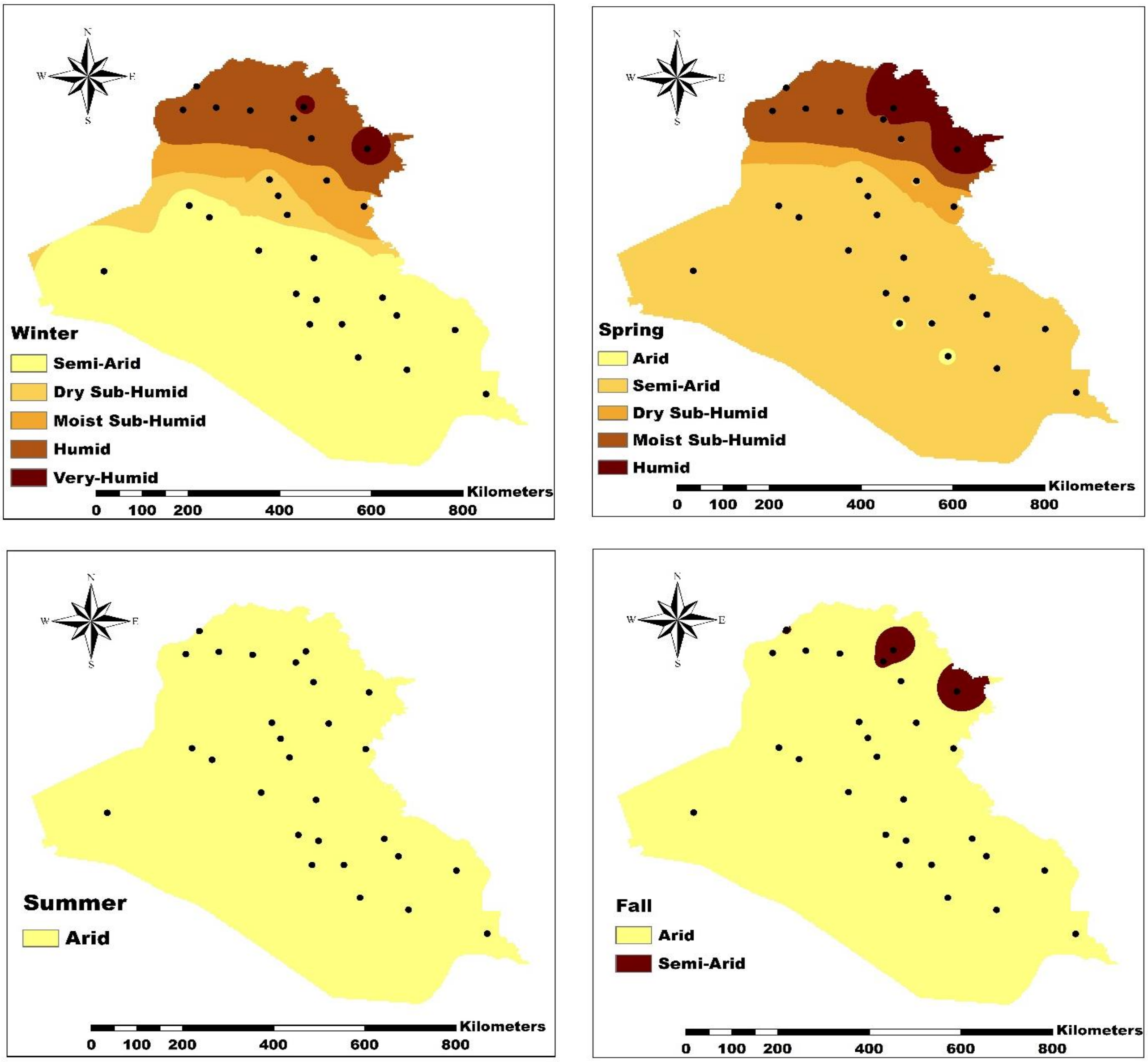
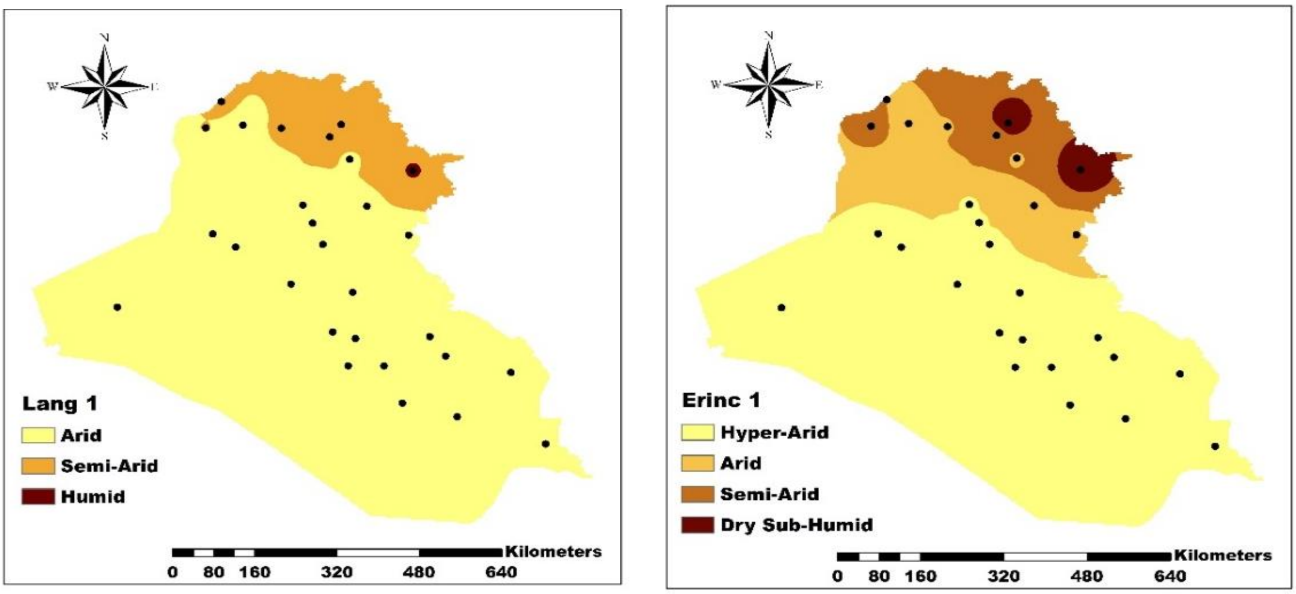


Fig. 3: The spatial analysis according to seasonal De Martonne index for the period (1981-2015).



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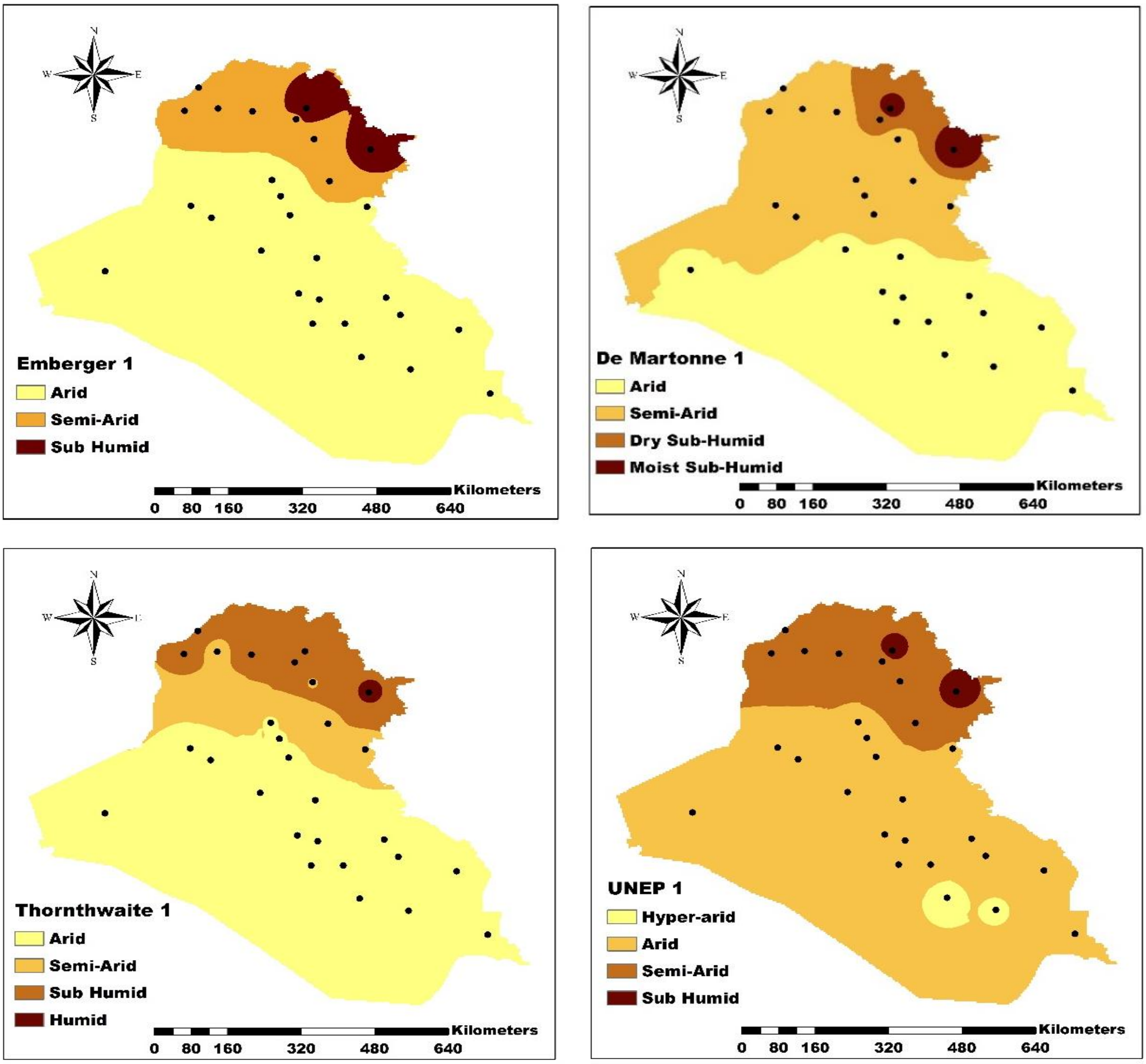
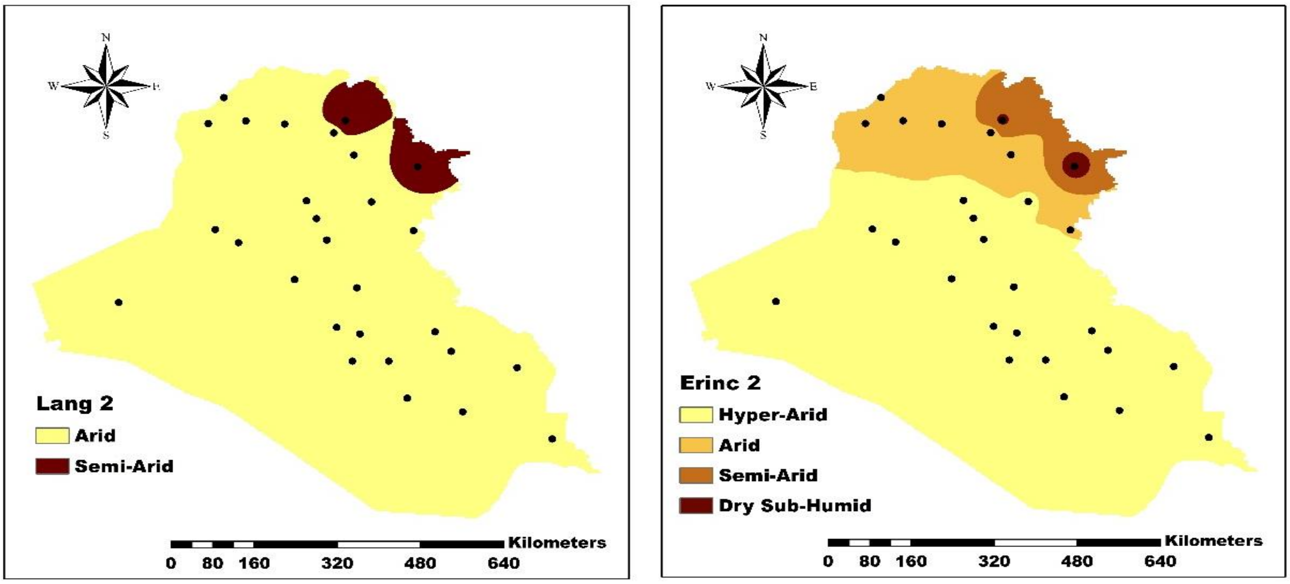


Fig 4: The spatial distribution of aridity indices for (1981-1997).



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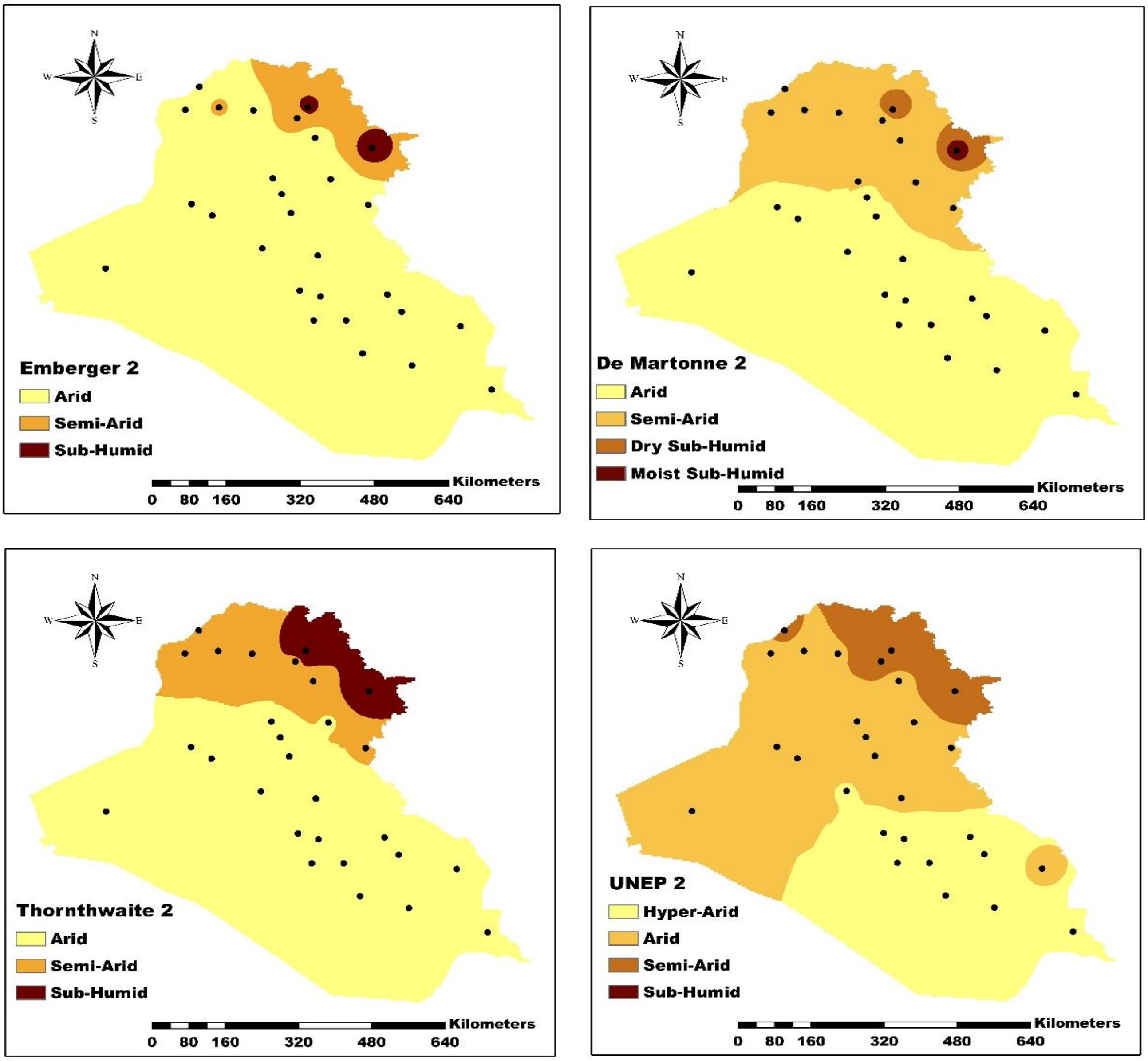

Fig 5: The spatial distribution of aridity indices for (1998-2015).

conditions at this period. Values of all indices are decreasing toward the north. Therefore, the north part of Iraq became drier through the second period. These outcomes were perfect compared with report of IPCC 2007, where it accentuated that the sea temperature altered uniquely toward finish of the 1990s of the most recent century. This outcome was consistent with other studies in neighboring countries (Deniz *et al.*, 2011; Tabari *et al.*, 2014).

Conclusions

This study gives an idea about the climate of Iraq. It focuses on the spatial analysis for six indices of aridity to determine aridity conditions during (1981-2015). For this purpose, the data of air temperature and rainfall were collected from 28 meteorological stations. According to results, arid and semi-arid dominate on the country, while the humid and sub-humid were very little in the northern part of Iraq. According to the two sub-periods (1981-1997 and 1998-2015), the results detected that the arid and semi-arid areas in the second period were increased. This result was similar to the results of middle east countries that have become more drier after (1997). The spatial analysis of De Martonne index was applied for annual and seasonally values. The spatial analysis according to seasonal De Martonne index shows that during summer and autumn seasons, arid type of climate was dominated.

Overall, the region of Iraq is clearly becoming drier. These conclusions confirms the importance of the assessing of the spatial variations of the climate of the region for better water resources management policies. It is evident that the decrease in precipitation and increase in temperature have an effect on both superficial and subterranean water.

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