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Drought Assessment based on Rainfall Anomaly Index (RAI) across Erbil-Iraq

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Data Availability Statement

The data supporting the findings of this study are publicly available and are included within this published article.

Ethics Information

Ethics approval was not required for this research.

Author Contributions

The author has contributed solely to all aspects of this research work.

AI Usage Declaration

The author declares that the content of this work was not generated using AI.

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ORIGINAL ARTICLE

Drought Assessment Based on Rainfall Anomaly Index (RAI) Across Erbil-Iraq

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Abstract

The prolonged occurrence of anomalies in rainfall is a significant hydro-meteorological event that has the potential to impact the hydrological imbalance, contribute to climate change, and affect the production of agriculture, which is mainly dependent on rainfall. This study analyzes the rainfall data of 12 stations for 20 years from 2001 to 2020 to indicate drought occurrence across Erbil-Iraq. Previous research used different methods for studying and analyzing droughts in the region but not RAI; the current study aims to evaluate the meteorological Rainfall Anomaly Index (RAI) in Erbil to evaluate the dry and wet years in the rainfall pattern in the study area. Results showed multi-successive drought years in all stations with different extents; the 2007 drought year was common in most stations and persisted for a long period (six years in some stations), with RAI ranging from −2.2 to −6.2 among all stations, also 2010 with RAI ranging from −2.6 to −6.6. Rainfall anomalies for Qushtapa station lasted 11 years, ranging from −0.3 to −4.6, from 2007 to 2017, the longest in the region and a rare case, another rare case of "Extremely dry" condition was found in Sidakan in 2010 with RAI = −6.6. Furthermore, RAI can assess wet events, and results also showed that 2018 and 2019 were the wettest in all stations in the study period of 20 years. Quastapa in particular, faced an "Extremely humid" year in 2018 with RAI = 13.3. In conclusion, the RAI index can accurately and easily indicate dry and wet years.

Keywords: Rainfall Anomaly Index, Drought, Wet, Kurdistan Region-Iraq (KRI), Erbil

1. Introduction

One of the most complicated hydrologic extremes is drought, which significantly affects several industries, including agriculture, water resources (water shortages), and ecosystems, and is the worst climate danger that can occur anywhere in the world [1]. Drought is typically accompanied by water shortage and is brought on by low average precipitation, high rates of evapotranspiration, a deficiency of natural water supplies, excessive use of water resources, or a combination of all factors [2]. There are large differences in precipitation within and between years in many places of the world. Total amounts of rainfall might vary significantly from year to year; thus, drought events are more common in such regions of the world [3]. Over the past century, many cases of prolonged droughts have lasted for years or even decades in various parts of the world. Abnormal tropical sea surface temperatures (SSTs) probably started recent droughts, and local feedback could intensify and prolong the drought [4]. In recent years and due to the recurrent drought events in all of Iraq, there has been a considerable number of research concerned with this issue [5,12] indicated that drought is a recurrent feature of the climate in Kurdistan Region of Iraq (KRI) and that the historical records (even recent records) indicate that drought occurs at least once in no more than six years, such region that has high variation in rainfall amounts has low reliability of rainfall and is most drought-prone also has more frequent and severe droughts. Geo-information technology was used by Fadhil [6] to map the 2007−2008 drought that badly affected the Kurdistan region. Results indicated that the vegetative cover and soil/vegetation wetness in the study area had significantly decreased, and the surface area of the water bodies was reduced considerably.

Aridity was studied in the Kurdistan region of Iraq using De Martone's aridity index (IDM). The index

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trend was found using the nonparametric Mann–Kendal test by Mustafa et al. [7], who showed the variety of climates in the region, with semi-arid zone being the major type. The seasonal aridity results revealed a humid winter climate and a dry summer climate. Iraq has suffered from severe droughts, especially in Erbil Province in the Kurdistan Region, in recent decades; over the last years, a severe agricultural drought that affected Erbil province resulted in a notable decrease in crop productivity, using geoinformation technology to assess the severity of the farm drought, it is discovered a direct correlation between the decline in crop yield and the reduction in rainfall [13]. Using remote sensing (RS) and geographic information systems (GIS), the effects of drought on the land surface temperature and vegetation cover in the Kurdistan Region of Iraq (KRI) over 20 years, from 1998 to 2017 was studied, showing that there was an increase in the frequency and severity of droughts across the study period. These droughts were characterized by higher land surface temperatures, less vegetation cover, and less precipitation [8]. Also Alee et al. [9] used satellite products and remote sensing to evaluate agricultural and meteorological droughts in the Iraqi province of Erbil; results show that there were other factors outside short-term climatic droughts contributing to the farming droughts, indicating that the province saw two to nine extreme drought occurrences. The rainfall record of 30 years since 1980 for the northern region of Iraq governorates (Sulaymaniyah, Erbil, Dohuk, Mosul, and Kirkuk) was examined using the standardized precipitation index "SPI", and the pattern, severity, and length of the drought was determined, results show severe droughts events in all governorate which affects agriculture and overburden the surface water [14].

There are different meteorological indices that indicate drought conditions, Dafouf et al. [10] in his paper used four meteorological indices: Rainfall Anomaly Index (RAI), percentage of normal index (PNI), standardized precipitation index (SPI), z-score index (ZSI), to the assessment of drought in the Ziz watershed located in south-eastern Morocco. His assessment of drought by these metrological indices indicated that the Ziz River basin experienced alternating dry and wet periods, and the results highlight a strong correlation between the four indices ($r \geq 0.967$). Baez-Villanueva et al. [11] used the Standardized Precipitation Index (SPI), Standardized Precipitation and Evapotranspiration Index (SPEI), Empirical Standardized Soil Moisture Index (ESSMI), and standardized Snow Water Equivalent Index (SWEI) to assess streamflow drought over catchments, and demonstrated the effectiveness of using individual drought indices to characterize streamflow drought. Khalaf and Hummadi, [16] studied drought indices and their impact on desertification, implementing precipitation-based drought indices SPI (Standardized Precipitation Index), RDI (Reconnaissance Drought Index), PNI (Percent of Normal Index), RAI (Rainfall Anomaly Index), and ZSI (Z-Score Index) and PPA (Percentage of Precipitation Anomaly), results show that all indices point to a severe drought for the periods, and positive linear regression relationship between all indices. Natarajan et al. [17] studied and evaluated the performance of six popular drought indices, namely, Standardized Precipitation Index (SPI), China Z Index (CZI), Modified China Z Index (MCZI), Deciles Index (DI), Rainfall Anomaly Index (RAI), and Z-Score Index (ZSI) for four districts in Tamil Nadu based on 120 years of precipitation records. Results showed that the SPI and CZI provided similar quantification of drought events irrespective of their climatic considerations, while ZSI and RAI resulted in overestimating drought severity.

Previous researches used different methods for studying and analyzing droughts in Kurdistan Region-Iraq (KRI), but not RAI. The Rainfall Anomaly Index (RAI) can accurately and easily indicate drought and wet events. The current study aims to evaluate the meteorological (RAI) in the Erbil governorate in KRI to asses drought/wet events, patterns, and intensity.

2. Material and method

2.1. Study area

The study area Erbil is one of the governorates of the Kurdistan region in the north of Iraq. The Geographical location shown in Fig. 1 is between latitudes (35° 25′N - 37° 18′N) and longitudes (43° 19′E - 45° 08′E). The governorate consists of three regions starting from south to northeast (a wide plane, low mountains and a high mountain) that affect the amount of rainfall that increases as it moves northeastward in the region as altitude increases.

The climate of the Kurdistan region has been identified according to the Koppen classification as arid and semi-arid (steppe - BSh and Mediterranean – Csa). It is hot and dry in summer and cold and wet in winter, with short spring and autumn seasons compared to summer and winter [12].

2.2. Data and software

In this study, the monthly rainfall data of 12 stations for 20 years from 2001 to 2021 were obtained

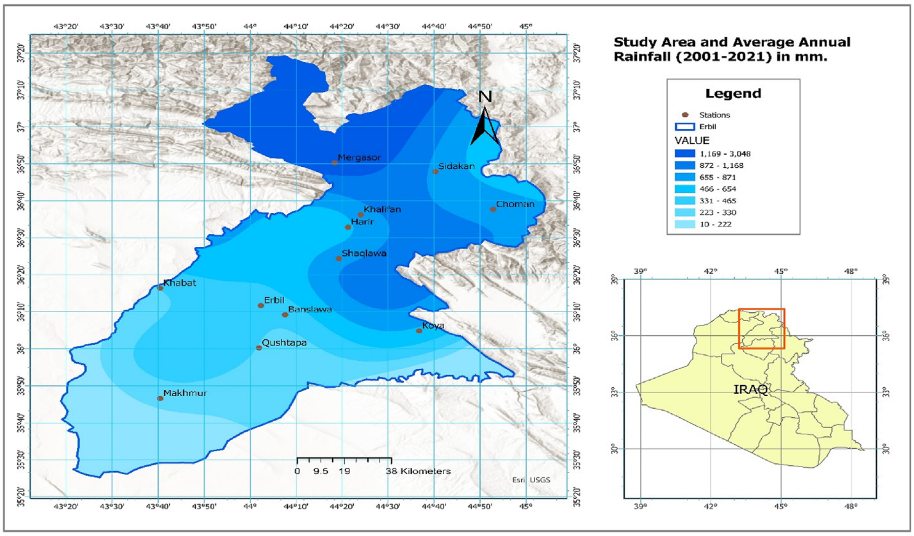

Fig. 1. Study area (Erbil-Iraq) and mean annual rainfall (2001–2020).

from the Directorate of Agriculture in Erbil. Microsoft Excel was used to process the rainfall data, calculate RAI, and graph the 2D plots. ArcGIS Pro was used to plot the spatial map of RAI in the study area.

2.3. Rainfall Anomaly Index (RAI)

The Rainfall Anomaly Index (RAI) was calculated from the precipitation data to analyze the frequency and intensity of the dry and rainy years in the study area. The positive and negative RAI indices are computed by using the following equations [15]:

$$RAI = 3\left[\frac{N - \overline{N}}{\overline{M} - \overline{N}}\right] \text{For positive anomalies} \quad (1)$$

$$RAI = -3\left[\frac{N - \overline{N}}{\overline{X} - \overline{N}}\right] \text{For negative anomalies} \quad (2)$$

where:

N = current monthly/yearly rainfall (mm).
$\overline{N}$ = monthly/yearly historical series' rainfall average (mm).
$\overline{M}$ = the historical series' 10 highest monthly/yearly rainfall average (mm).
$\overline{X}$ = the historical series' 10 lowest monthly/yearly rainfall average (mm).

Throughout the rainfall research period, positive anomalies will have values above average, and negative anomalies will be below average. Table 1 shows the classification of the RAI index from wet to dry conditions.

Table 1. Classification of Rainfall Anomaly Index (RAI) intensity.

Index (RAI)	Classification
Above 4	Extremely humid
2 to 4	Very humid
0 to 2	Humid
−2 to 0	Dry
−4 to −2	Very dry
Below −4	Extremely dry

The procedure of finding the parameters of the RAI equation and thus calculating RAI for any locations using Excel is simple:

1. Prepare the yearly rainfall data record for the study period in one column, each value is (N) or the yearly rainfall, then find the average; to get ($\overline{N}$) or the yearly historical series' average rainfall.
2. Copy the yearly rainfall data record to another column and sort them in descending order; keep the first ten values and delete the rest of this column, then find the average; to get ($\overline{M}$) or the ten highest yearly precipitation average.
3. Copy the yearly rainfall data record to another column and sort them in ascending order; keep the first ten values and delete the rest of this column, then find the average; to get ($\overline{X}$) or the ten lowest yearly precipitation average.
4. To find an anomaly, subtract ($N - \overline{N}$) for each value of the yearly rainfall data and sort the result in descending order. Some of the resulting values will be positive (called positive anomaly), and others will be negative (called negative anomaly).
5. Put positive anomalies in Eq. 1 to find RAI and get the wet year RAI results. If you put negative

anomalies in Eq. 2 to find RAI, you get results of drought year RAI.

3. Results and discussion

The annual Rainfall Anomaly Index (RAI) for the 12 selected stations across Erbil-Iraq was calculated and analyzed using the MS Excel program. Fig. 1 shows the map of the study area with the chosen stations as the spatial distribution of average annual rainfall, which ranges from 260 mm in Makhmur to 1368 mm in Mergasor. Fig. 2 shows the annual rainfall 2001−2020 (the blue columns), the average annual rainfall (the green line), and the results of RAI for each station (the yellow columns).

The graphs of Fig. 2 show multi-successive drought years in all stations; the long drought period of six years from (2007−2012) is obvious in most stations with different extents with RAI ranging from −0.1 to −6.8. Also, the two (three in most stations) successive extreme wet years of 2018−2019 are evident in all regions, which led to disaster and floods, with RAI reaching an unprecedented value of 13.3.

Erbil station is in Erbil city and faced a six-year drought condition from 2007 to 2012, a distinctive drought period that extended all across the Erbil governorate and led to crop failure in all rainfed regions in the area. Erbil also faced an “Extremely dry” event in 2017 and an “Extremely humid” event in 2018 with RAI = −6 to 9.9. Such extreme conditions are rare in the all-recorded history of the rainfall data record Fig. 2a.

Banslawa station Fig. 2b is very close to Erbil station and shows a similar pattern of dry and wet years, and the same remarks could be said about it, the RAI values in the study period range from −6 to 9.

Qushtapa station Fig. 2c is also close to Erbil station (about 21 km away) and suffered from the same

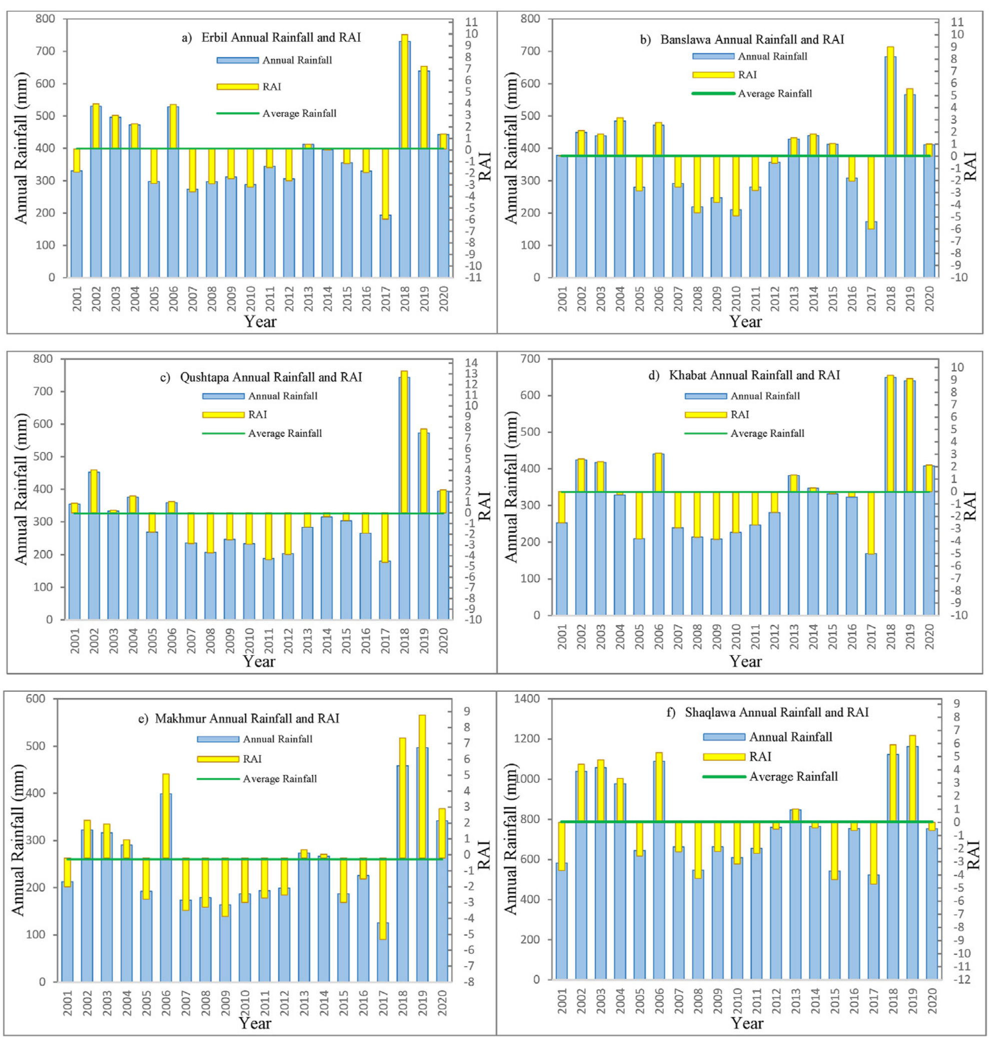

Fig. 2 Annual rainfall and RAI of selected stations from 2001 to 2020.

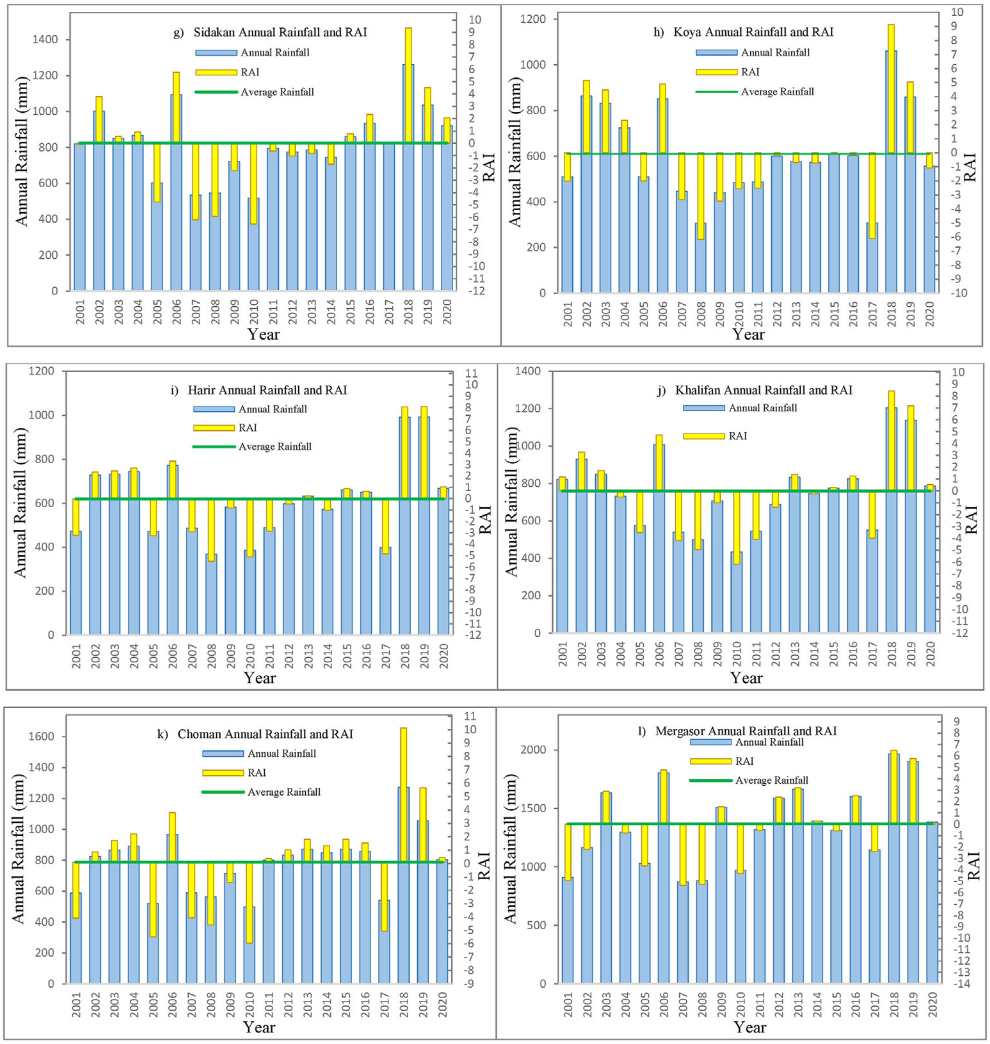

Fig. 2 (Continued)

drought conditions (2007−2012). However, the negative rainfall anomaly in this station extended for 11 years to 2017, with RAI ranging from −0.3 to −4.6, and recovered from the longest drought years to an "Extreme humid" year of 2018 with RAI = 13.3, a disastrous flood within the entire region.

Khabat and Makhmur stations Fig. 2d,e have similar patterns of wet and dry years as Erbil station with very few differences, these stations lay in the same plane and near each other; therefore, the similarity is expected. The RAI values in the study period range from −5 to 9.4 for Khabat, and for Makhmur, they range from −5.1 to 9.

The rest of the stations lie in the mountainous area and feature a similar oscillation pattern between dry and wet conditions. The only station somewhat different is Mergasor station Fig. 2l, which lies deep in the mountainous region with the highest mean annual rainfall of (1368 mm) its RAI ranges between −5.4 and 6.5. So, the big difference is in the extent of dry wet events, except for the year (2009) which was a wet year in this station RAI = 1.5, and dry in all others.

Only two extremes were chosen to show the spatial distribution of dry and wet events: the years (dry 2017 and wet 2018). Fig. 3b shows the study area RAI of the harsh 2017 drought year with minimum RAI = −6.1. The light color is the most affected by drought conditions (the lower part of the figure). Notice that as we move to the northeast, the effect of the drought is less severe (in those areas with higher rates of mean annual rainfall). Fig. 3a shows the 2018 wettest year with a maximum RAI = 13.3, the maximum value in all records in the region; the low rainfall areas have a higher wet RAI index.

Finally, Fig. 4, which is a stacked column chart of all station's RAI from 2001 to 2020 that shows the collective RAI properties of all stations each year (the y-axis is the Collective RAI or sum of all RAI

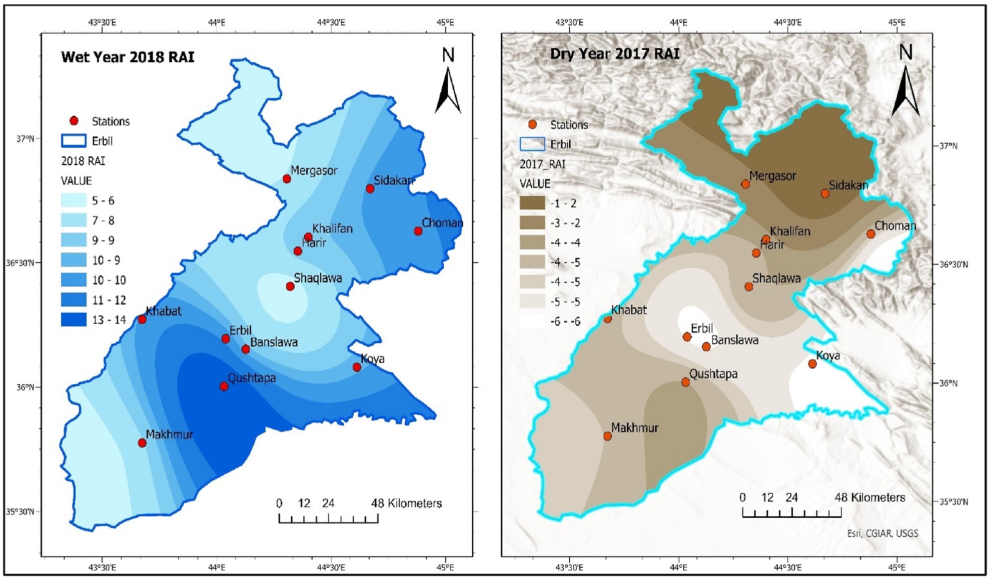

Fig. 3. Study area RAI of the driest 2017 year and the 2018 wettest year.

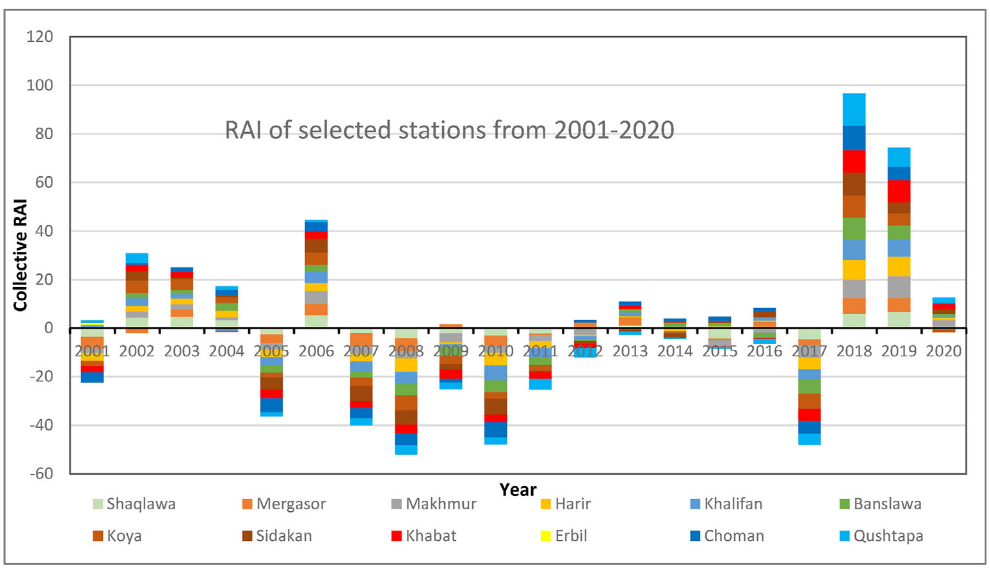

Fig. 4. A stacked column chart of all stations RAI from 2001 to 2020.

indexes of all stations), clarifies the situation; when the study area is at drought event (where RAI < −1) almost all stations suffer obvious example are years (2005, 2007, 2008, 2010, and 2017). On the other hand, when the study area is a wet event (where RAI>1), almost all stations are wet. Obvious examples are years (2003, 2006, 2018 and 2019). But when the study area faces mild dry or humid conditions, some stations have positive RAI, and others have negative values of RAI, with small values of the index (note the height of each part of the column represents the value of RAI index).

Table 2 shows a summary of RAI events for the period 2001−2020. It displays the minimum and maximum value of RAI for each station during the study period and the number of each event class; for example, the “Extremely humid” event class in Erbil station is (2), and this class is important to indicate certain flood occurrences in the region, at the same time, it had (1) an “Extremely dry” event, which means certain drought occurrence and consequently crop failure, and in the low rate annual rainfall of “Very dry” event (6) is also a crop failure year, that means in the 20 years of study period

Table 2. RAI events for the period 2001−2020.

Station	Min. RAI	Max. RAI	E. humid	V. humid	Humid	Dry	V. dry	E. dry	Driest year	Wettest year
Makhmur	−5.1	9.0	3	3	3	2	8	1	2017	2019
Qushtapa	−4.6	13.3	3	1	4	5	5	2	2017	2018
Khabat	−5.0	9.4	2	4	2	4	7	1	2017	2018
Banslawa	−6.0	9.0	2	3	6	2	4	3	2017	2018
Erbil	−6.0	9.9	2	4	2	5	6	1	2017	2018
Koya	−6.2	9.1	2	3	6	2	4	3	2017	2018
Harir	−5.5	8.1	2	4	4	3	4	3	2008	2019
Khalifan	−6.2	8.4	3	1	6	4	1	5	2010	2018
Shaqlawa	−4.7	6.6	5	1	1	4	6	3	2017	2019
Choman	−6.0	10.0	2	2	9	1	0	6	2010	2018
Sidakan	−6.6	9.4	2	3	6	2	4	3	2010	2018
Mergasor	−5.4	6.5	2	3	6	2	4	3	2007	2018

there was a total of (9) years in which agriculture had very harsh conditions of droughts.

4. Conclusion

The analysis of the Rainfall Anomaly Index (RAI) of (12) weather stations in Erbil governorate was performed and found extreme values of droughts and wet events that have been rarely recorded in past recorded history and showed multi-successive drought years in all stations with different extents. The years (2005, 2007, 2008, 2010, and 2017) were marked as dry. The 2007 drought year was common in all stations, with RAI ranging from −2.2 to −6.2 in the region, and in 2010, with RAI ranging from −2.6 to −6.6. In most stations (such as in Erbil, Banslawa, Qushtapa, Khabat, etc…), the 2007 drought continued for a long period (six years in most stations), and for Qushtapa station lasted 11 years, the longest in the region and a rare case. The 2017 drought years were also common in all stations (except Sidakan in 2017), marked as an “Extremely dry” class event, and was the driest year for the study period for six stations RAI = −0.1 to −6.1. On the other hand, RAI which can assess wet events also, showed that Years (2003, 2006, 2018, and 2019) were the wettest in all stations in the study period of 20 years. Quastapa, in particular, faced an “Extremely humid” year in 2018 with RAI = 13.3. In conclusion, the RAI index can accurately and easily indicate dry and wet years. The study concluded that low rainfall stations are most affected by dry/wet conditions, and when a drought (or wet) event occurs in the study area, it hits all the stations to different extents.

Conflict of interest

No conflict of interest.

References

[1] Wilhite DA. In: Wilhite DA, editor. Drought: a global assessment, vol. 1. London: Routledge; 2000. p. 3−18.

[2] Bhaga TD, Dube T, Shekede MD, Shoko C. Impacts of climate variability and drought on surface water resources in sub-saharan africa using remote sensing: a review. Rem Sens 2020;12:4184. https://doi.org/10.3390/rs12244184.

[3] Gabler RE, Petersen JF, Trapasso LM, Sack D, Sager RJ, Wise DL. Essentials of physical geography. 8th ed. CA, USA: Thomson BooksCA, USA; 2007.

[4] Dai A. Drought under global warming: A review. Wiley Interdiscip Rev Clim Change 2011;2(1):45−65. https://doi.org/10.1002/wcc.81.

[5] Abbas KA. Investigation and analysis of precipitation variability and drought conditions in the federal region of Kurdistan-Iraq. PhD thesis. Kurdistan region, Iraq: Salahaddin University; 2008.

[6] Fadhil AM. Drought mapping using geoinformation technology for some sites in the Iraqi Kurdistan region. Int J Digit Earth 2011;4(3):239−57. https://doi.org/10.1080/17538947.2010.519635.

[7] Mustafa NF, Rashid HM, Ibrahim HM. Aridity index based on temperature and rainfall data for Kurdistan Region-Iraq. J Univ Duhok 2018;21(1):65−80. https://doi.org/10.26682/sjuod.2018.21.1.6.

[8] Gaznayee HAA, Al-Quraishi AMF, Mahdi K, Ritsema C. A geospatial approach for analysis of drought impacts on vegetation cover and land surface temperature in the Kurdistan Region of Iraq. Water 2022;14:927. https://doi.org/10.3390/w14070927.

[9] Alee MM, Danandeh Mehr A, Akdegirmen O, Nourani V. Drought assessment across Erbil using satellite products. Sustainability 2023;15:6687. https://doi.org/10.3390/su15086687.

[10] Dafouf S, Lahrach A, Tabyaoui H, El Hafyani M, Benaabidate L. Meteorological drought assessment in the Ziz Watershed, (South East of Morocco). Ecol Eng Environ Tech 2022;23(6):243−63. https://doi.org/10.12911/22998993/155824.

[11] Baez-Villanueva OM, Zambrano-Bigiarini M, Miralles DG, Beck HE, Siegmund JF, Alvarez-Garreton C, et al. On the time scale of meteorological, soil moisture, and snow drought indices to assess streamflow drought over catchments with different hydrological regimes: A case study using a hundred Chilean catchments. Preprint, egusphere-2023-1911, https://doi.org/10.5194/egusphere-2023-1911; 2023.

[12] Saeed M, Abbas K. Analysis of climate and drought conditions in the federal region of Kurdistan. Int Sci J Environ Sci 2012;2(1):1−10.

[13] Gaznayee HAA, Al-Quraishi AMF. Analysis of agricultural drought, rainfall, and crop yield relationships in Erbil Province, the Kurdistan Region of Iraq based on Landsat timeseries

MSAVI2. J Adv Res Dyn Control Syst 2019;11(12-Special Issue): 971–82. https://doi.org/10.5373/JARDCS/V11SP12/20193249.

[14] Jameel M, Hameed S, Shemal K, Al-Ansari N, Abed SA. Spatial and temporal assessment of drought in the Northern prone of Iraq using standardized precipitation index. Engineering 2023;15:691–708. https://doi.org/10.1016/j.eng.2023.02.012.

[15] Van Rooy MP. A rainfall anomaly index independent of time and space. Notos 1965;14:43–8.

[16] Khalaf AA, Hummadi AH. Time series analysis of drought indices for monitoring desertification and land degradation. Iraqi Natl J Earth Sci 2023;23(2):189–202. https://doi.org/10.33899/earth.2023.139660.1068.

[17] Natarajan N, Vasudevan M, Raja SA, Mohanpradap K, Sneha G, Shanu SJ. An assessment methodology for drought severity and vulnerability using precipitation-based indices for the arid, semi-arid and humid districts of Tamil Nadu, India. Water Supply 2023;23(1):54. https://doi.org/10.2166/ws.2022.415.