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ORIGINAL PAPER

Sensitivity analysis of the effective reconnaissance drought index

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Abstract

Many drought indicators with different difficulties have been applied in numerous climatic zones. The reconnaissance drought index, which is based on precipitation and potential evapotranspiration, is considered a powerful weather drought index in arid and semi-arid zones. The effective reconnaissance drought index, which is a modification of the reconnaissance drought index, is suggested to enhance ability of the reconnaissance drought index to evaluate agricultural drought. The estimation of this index is based on two climatic variables which are the potential evapotranspiration (PET) and effective precipitation. The FAO Penman–Monteith method is considered the reference equation to evaluate the potential evapotranspiration; however, it is difficult to apply in regions with shortage weather data due to the requirement for a large number of climatic variables. Consequently, this research is applied Hargreaves, Blaney–Criddle, and Thornthwaite methods to assess the impact of the effective precipitation and potential evapotranspiration estimation methods, elevation, and climatic conditions on the effective reconnaissance drought index as well as investigating the correlation between the reconnaissance drought index and the effective reconnaissance drought index. Data from 13 weather stations, over the time interval between 1979 and 2014, cover different elevations, and weather environments within the Greater Zab River Basin, North Iraq, has been selected. The obtained results indicated that there is no important effect on drought severity assessment (at 100% of weather stations) were detected by using the considered potential evapotranspiration methods at different elevations for different climate conditions. However, there is a clear effect for different the effective precipitation and potential evapotranspiration techniques at diverse altitudes and climatic conditions on the aridity evaluation that is assessed by effective reconnaissance drought index (at about 50% of the considered stations). Consequently, concern has to be paid to the effective precipitation and potential evapotranspiration evaluation methods, particularly at high elevations; this is because applying a range of approaches may cause errors in the water resources availability predictions.

Keywords Effective precipitation · Climatic indices · Aridity assessment · Drought evaluation · Agriculture drought · Water resources managing

Introduction

Background

Meteorological drought is measured as one of the central water-related vulnerabilities that is normally defined as a major decrease of the accessibility of water over a long interval as well as over a big area (Mohammed and Scholz 2017a, b, 2019; Obianyo 2019; Oo et al. 2020). Drought indicators are specified as one of the largely accepted methods for drought identification and recording (Giannikopoulou et al. 2014; Mohammed and Scholz 2017a). Several weather drought indices with diverse difficulty have been applied in different weather environments for numerous purposes (Heim 2002); AghaKouchak et al. (2015) listed the recent

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and probable effective application of remote sensing to help judgments on the evaluation of drought events.

Several drought indices with different difficulties have been applied in many climatic conditions for many uses. Some common examples of these indices are deciles, palmer drought severity index (PDSI), percent of normal, standardised anomaly index (SAI), rainfall anomaly index (RAI), standardised precipitation index (SPI), and surface water supply index (SWSI). For more about climatic drought indices, interested readers could refer to Heim (2002). SPI has been suggested as a general meteorological drought index by WMO (World Meteorological Organization) because of its ability to be evaluated for different reference intervals (Mohammed and Scholz 2017a; Memon and Shah 2019; Harisuseno 2020). The SPI index permits finding of diverse drought groups impacting many systems and zones. Yet, there are deficiencies linked to its failure to identify drought states evaluated not by a lack of precipitation but by a higher than typical atmospheric evaporative need. Recently, drought development researches (Sheffield et al. 2012; Dile and Srinivasan 2014; Vicente-Serrano et al. 2014 ; Ali et al. 2020) and drought scenarios under possible weather alter projections (e.g., Hoerling et al. 2012; Cook et al. 2014) based on drought indices that considered precipitation and the environmental evaporative need. Tigkas et al. (2012, 2015) established a review of the reconnaissance drought index (RDI), which can be estimated for any time period and can be successfully correlated to agricultural drought and straight connected to the local climatic environment (Tsakiris and Vangelis 2005). In the case of higher air temperatures, water needs are increasing; accordingly, RDI might be improved to be applied as an index for future drought assessment regarding various water sectors. Thus, RDI is suitable for research on climate instability conditions.

In 2016, RDI index was modified by Tigkas et al. and altered to effective RDI ($_{e}$RDI). With the proposed modification, the amount of water beneficially exploited by the agricultural systems can be represented more accurately, enhancing the performance of the index for agricultural drought analysis. They recommended $_{e}$RDI in agricultural regions with varied climates is better than RDI.

Recently, a vast majority of water resources discipline studies have considered RDI as a drought severity estimate index (e.g., Vangelis et al. 2013; Zarch et al. 2015; Memon and Shah 2019; Mohammed and Scholz 2017a, b, 2019, 2021; Ahmad et al. 2021). However; they just applied the original standardised form of the RDI index (RDI_{st}) exclusive of other figures and/or if there will be any altered in the drought severity assessment, if the techniques of PET altered and/or if the climate stations inside the same catchment have changed elevations as well as to the effect of the local weather environment. While Mohammed and Scholz (2017a) studied the sensitivity of RDI to different PET methods in addition to highlighting the index application as an aridity and climatic index; they have only considered RDI without giving any attention to $_{e}$RDI and the potential correlation between these two versions of the index. Moreover, they used data from many climatic conditions such as Mediterranean, Sahara, and humid conditions without considering the basin scale analysis only. Therefore, the key target of this research is to estimate the probable effect of the $_{e}P$ as well as PET estimation techniques, elevation, and weather environment on the spatial, and temporal inconsistency and assessment of a river basin aridity that is based on RDI or $_{e}$RDI as well as the correlation between the original and the modified RDI.

Aim and objectives

The RDI index gains foundation because of its small dataset needs, high sensitivity, flexibility, and appropriateness for weather unsteadiness (Zarch et al. 2015; Mohammed and Scholz 2017a; Ahmad et al. 2021; Mohammed and Yimam 2021); the index depends on a combination of P and PET. Therefore, it is essential to assess the $_{e}P$ and PET evaluation effect, elevation, and weather environment on the aridity and drought severity description evaluated by RDI whether it is original or modified. Recently, very few researchers in the field of water resources have considered eRDI for drought assessment such as Zarei et al. (2019) and Moghimi et al. (2021). Although they assessed the climatic drought severity in arid and semiarid regions using RDI and eRDI, however, they did not take into account the sensitivity analysis of these indices. Consequently, the focal plan of this research is to investigate the sensitivity of the modified version of the RDI index. To achieve the main research target, GZRB has been chosen as a represented basin study, which covers a variety of rather big watersheds and a large choice of weather and hydrologic environment. The upper part and lower part of the basin improvements differ generally. This implies a significantly large variety of uncertainties in the impact of climate change on the availability of water resources.

Materials, data, and methods

Basin illustrative example

For illustration purposes, the Upper Zab River (UZR) has been selected as an example case study. In terms of water yield, Upper Zab River Basin (UZRB) is considered one the biggest branches of the Tigris River. Upper Zab River (UZR) starts in Turkey falls throughout the northern part of Iraq and then connects to the Tigris River with a 372-km length (Fig. 1). UZR and its branches are situated between latitudes 36°N and 38° N, and longitudes 43.3°E and 44.3°E with a region of about 42,032 km^2 and an elevation changed

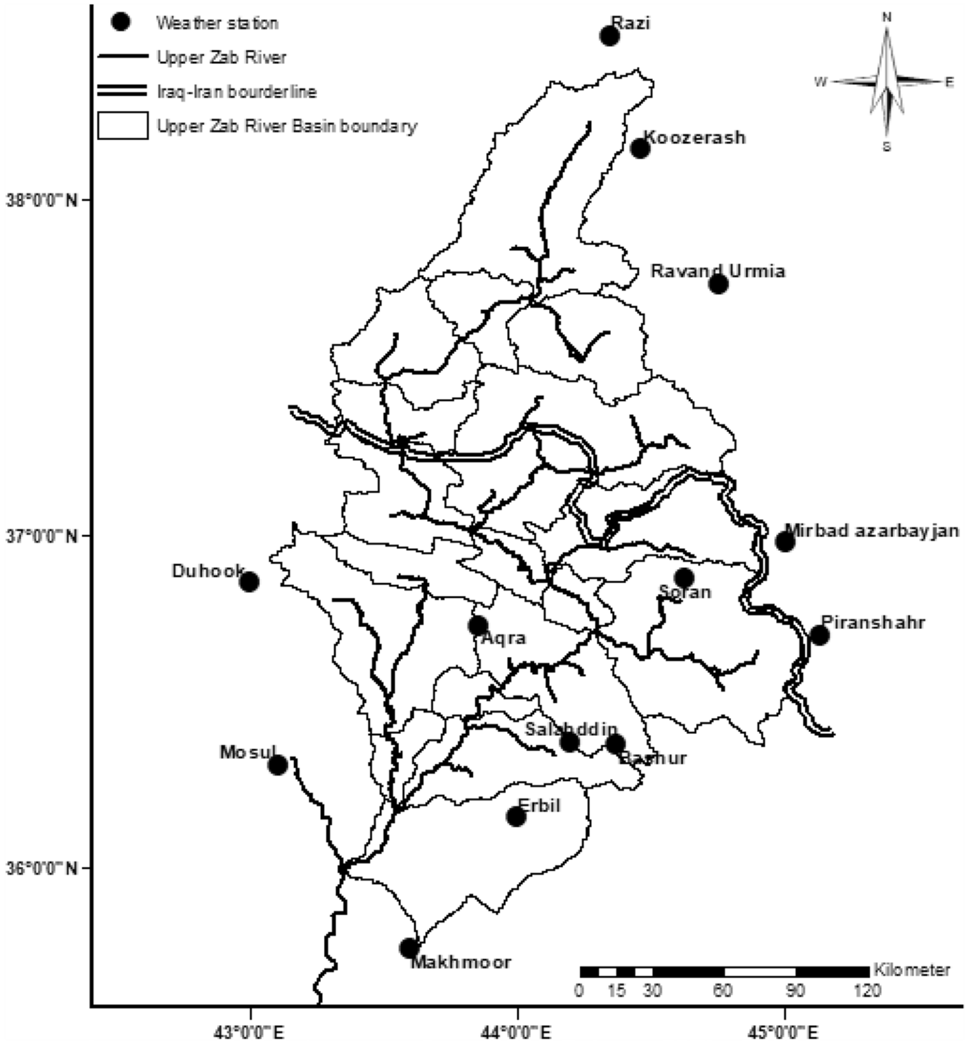


Fig. 1 The location of the Greater Zab River Basin includes the considered weather gauging stations sites

from 276 m above to 1980 mean sea level (masl). The river passes different environmental and atmospheric zones. The UZRB stream system illustrates large seasonal flow differences with most flow occurring during May and minimum seasonal discharge between July and December (Mohammed and Scholz 2019). The average and maximum flow rates of the river are 419 and 1320 m^3/s, respectively, correspondingly with average annual precipitation of the basin varies from 350 to 1000 mm (Mohammed and Scholz 2019).

Data collection and analysis

Daily weather data including minimum and maximum air temperature and precipitation collected from 13 climate gauging locations for the period from 1979 to 2014, which was provided by the Ministry of Agriculture and Water Resources (Kurdistan province, Iraq) (Table 1; Fig. 1). The Iraqi boundaries have been downloaded from the Global Administrative Areas (GADM 2012), while the UZRB shape files have been acquired from the Global and Land Cover Facility (GLCF 2015) databases.

The HG, ThW, and BC methods are considered to estimate PET. These methods are the most widely used due to their low data needs. Tigkas et al. (2016, 2017) have proposed the effective reconnaissance drought index ($_e$RDI) to enhance the RDI index accuracy for the characterisation of rural drought. $_eP$ possibly will be estimated as the sum of the rainfall that falls over a lake, the part of the rainfall that adds to subsurface water, and the quantity of water that is able to be utilised efficiently via the root of the plant, etc. $_eP$ can be calculated by a number of methods, which are the US Bureau of Reclamation, a figure of the monthly $_eP$ amounts depending on the equivalent monthly sum rainfall, a basic edition of the USDA-SCS technique, the experimental technique which has been suggested by FAO. For more details, the reader can investigate many recent articles such as (Tigkas et al. 2016; 2017). The drought indicators calculator (DrinC) tool is applied for the estimation of RDI, $_e$RDI, and $_eP$ (Tigkas et al. 2015). Figure 2 shows the details for the proposed methodology of the current study.

To achieve the study aim, UZRB has been selected as an illustrative basin. The basin has been divided into two main

Table 1 Station addresses with corresponding aridity index (AI) that estimated by three potential evapotranspiration estimation (PET) methods and long-term average climate parameters estimated by the Thiessen network

	Station		Lat (°)	Long (°)	Altit (m)	AI			Average		
	No	ID				HG	ThW	BC	T_m (°C)	*P* (mm)	PET (mm)
US	1	Razi	38.48	44.35	1980	0.72^5	0.92^5	0.62^5	5.36	661.53	860.18
	2	Koozerash	38.15	44.46	1344	0.69^5	2.75^5	1.76^5	5.18	754.73	912.79
	3	RavandUrmia	37.75	44.76	1290	0.68^5	1.26^5	0.81^5	7.70	495.90	1008.03
	4	MirbadAzarbayjan	36.98	45.01	1650	0.98^5	1.81^5	1.14^5	8.82	1099.06	1103.28
	5	Piranshahr	36.70	45.13	1350	1.20^5	2.75^5	1.40^5	12.25	1107.69	1309.73
	6	Soran	36.87	44.63	1132	0.78^5	1.40^5	0.87^5	9.76	812.22	1192.39
DS	7	Duhook	36.86	43.00	276	0.45^3	0.54^4	0.46^3	16.57	844.86	1275.51
	8	Aqra	36.73	43.86	555	0.49^3	0.58^4	0.49^3	19.54	844.86	1529.02
	9	Salahddin	36.38	44.20	1088	0.38^3	0.48^3	0.40^3	18.11	645.63	1499.26
	10	Bashur	36.37	44.37	977	0.44^3	0.43^3	0.45^3	18.11	645.63	1497.10
	11	Mosul	36.31	43.11	223	0.36^3	0.43^3	0.38^3	20.61	586.75	1646.54
	12	Erbil	36.15	44.00	1088	0.35^3	0.46^3	0.38^3	20.17	571.68	1664.42
	13	Makhmoor	35.75	43.60	306	0.21^3	0.25^3	0.23^3	21.26	360.79	1567.47
		Basin	–	–	–	0.55^5	1.06^5	0.73^5		1348.48	

US upstream, *DS* Downstream, *Lat* Latitude, *Long* longitude, *Altit* altitude, *HG* Hargreaves, *ThW* Thornthwaite, *BC* Blaney–Criddle, T_m mean air temperature, *P* Precipitation

[1] Hyper-arid ($AI \leq 0.03$)

[2] Arid ($0.03 < AI < 0.2$)

[3] Semi-arid ($0.2 < AI < 0.5$)

[4] Dry sub-humid ($0.5 < AI < 0.65$)

[5] Humid ($0.65 \leq AI$)

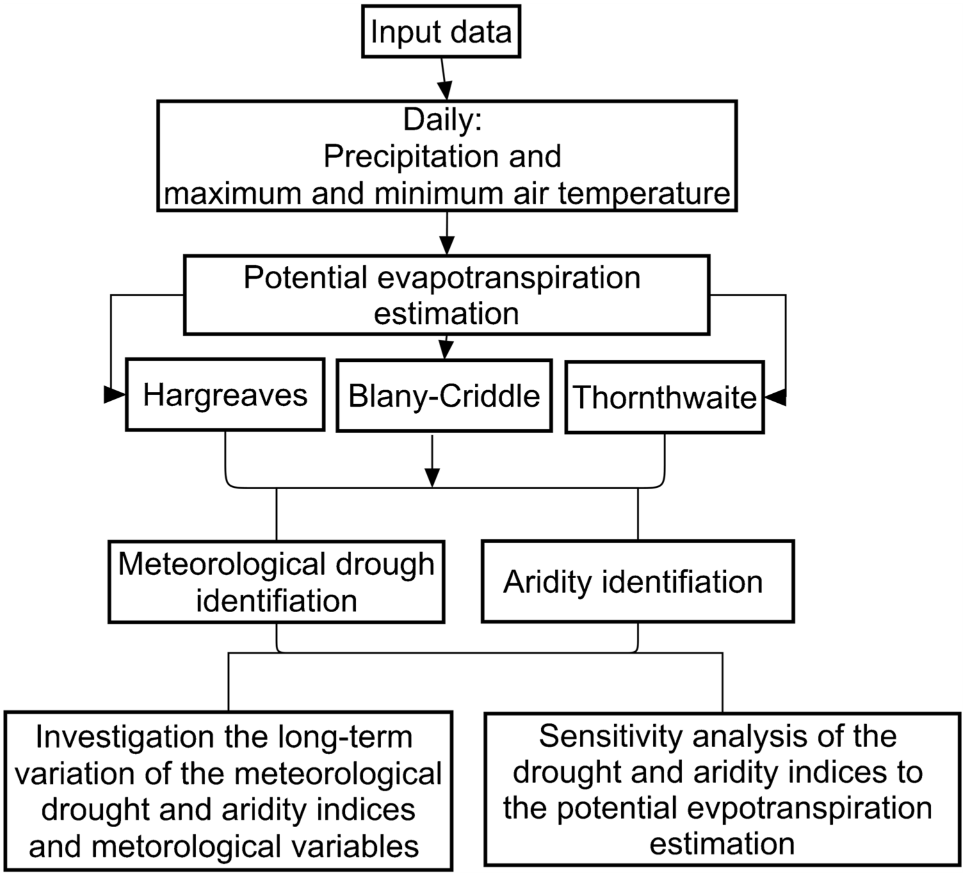


Fig. 2 The study research methodology flowchart

sub-basins covering two diverse elevations demonstrating usual low and high lands (Table 1). Table 1 lists the groups and positions of the considered stations. The upstream sub-basin stations are situated at an elevation ranging from 1132 to 1980 masl representing a mountainous area, while the stations that are located at the downstream sub-basin are situated at a low elevation varied from 276 to 1088 masl, as an example. The mean annual precipitation and mean air temperature for the upstream are ranged from (495.90–1107.69) mm and (5.18–12.25) °C, correspondingly. The equivalent averages for the downstream are (360.79–844.86) and (16.57–21.26) °C, respectively.

Primarily, the validity of the data time series has been investigated. The Excel program has been utilised for data adjustments and filling of several gaps. Then, through the DrinC software (Tigkas et al. 2015), PET, $\mathrm{RDI}_{\alpha 12}$, $_{\mathrm{e}}\mathrm{RDI}_{\alpha 12}$, $\mathrm{RDI}_{\mathrm{st}}$, $_{\mathrm{e}}\mathrm{RDI}_{\mathrm{st}}$, $_{\mathrm{e}}\mathrm{RDI}_{n}$, and RDI_{n} were estimated. The projection of the weather data on the UZRB has been performed using ArcGIS 10.3.

$_{\mathrm{e}}$RDI

The reconnaissance drought index (RDI) is primarily depending on the total P and PET for a definite time interval (Mohammed and Scholz 2019). This index is represented by initial ($\mathrm{RDI}_{\alpha k}$), normalised (RDI_{n}) and standard ($\mathrm{RDI}_{\mathrm{st}}$) figures. The $\mathrm{RDI}_{\alpha k}$ form could be applied as an aridity index, whereas RDIst can be applied as a drought severity index. The RDI is generally calculated by Eq. (1) (Vangelis et al. 2013).

$$RDI\alpha_0^i = \frac{\sum_{j=1}^{12} Pij}{\sum_{j=1}^{12} PETij} \quad i = 1 \ to \ N \text{ and } j = 1 \ to \ 12 \tag{1}$$

in which P_{ij} and PET_{ij} signify rainfall and potential evapotranspiration of the jth month of the ith hydrological year, which in Iraq start in October, for example, and N is the sum year figure.

The $\mathrm{RDI}_{\alpha k}$ values are equivalent to the gamma and log-normal distributions in different locations for different intervals for which they were investigated (Tigkas 2008). Concerning the earlier distribution, $\mathrm{RDI}_{\mathrm{st}}$ would be estimated by Eq. (2), (Tigkas 2008).

$$\mathrm{RDI}_{st}^{i} = \frac{Y_i}{\sigma_y} \tag{2}$$

in which y_i is the ln (αki), $\bar{y}$, and σy are the mean and the equivalent standard deviation of y_i, respectively.

The RDI index has been used effectively for an extensive variety of applications in diverse areas of the globe (e.g., Mohammed and Scholz 2017a, b, 2019). The RDI_{st} positive value connects to a wet interval; the severity of drought raises once RDI_{st} figures are the smallest amount. The severity of drought can be grouped into mild, moderate, severe, and extreme groups with particular restrictions of − 0.5 to − 1.0, − 1.0 to − 1.5, − 1.5 to − 2.0, and < -2.0, correspondingly. Diverse intervals such as 3, 6, 9, and 12 months can be used to estimate RDI (Tigkas et al. 2012). Furthermore, arid zones are categorised into (hyper-, arid-, semi-) arid and dry sub-humid classes with the corresponding $RDI_{\alpha 12}$ limits of < 0.03, 0.03 to 0.20, 0.20 to − 0.50 and 0.50 to 0.75, correspondingly (UNESCO 1979).

To improve the ability of RDI in identifying agricultural drought, the total precipitation can be replaced by ${}_{e}P$, which accurately represents the amount of water that is useful for the crop yield. Founded on the weather conditions of the study region, ${}_{e}P$ can be anticipated with one of the experimental techniques that explained in the many studies (Tigkas et al. 2016, 2017). The effective precipitation theory has many understanding depending on different research purposes. ${}_{e}P$ could be considered the whole value of P that falls directly to the open water bodies such as reservoirs, the ratio of P that penetrates to groundwater. In this study, the US Bureau of Reclamation (USBR) has applied to estimate ${}_{e}P$. USBR method has been suggested as an experimental technique to estimate ${}_{e}P$ applying groups of the sum monthly rainfall (Tigkas et al. 2017). The technique is fitting mostly for semi-arid and arid zones (Tigkas et al. 2017).

For aerial drought analysis, it is highly recommended to apply the same methodology for the calculation of ${}_{e}P$ to get consistent results. To estimate ${}_{e}$RDI and keep low data needs, monthly data of both ${}_{e}P$ and PET are utilised. The modified alpha figure of the RDI is estimated based on Eq. (1) after replacing P by ${}_{e}P$ in the

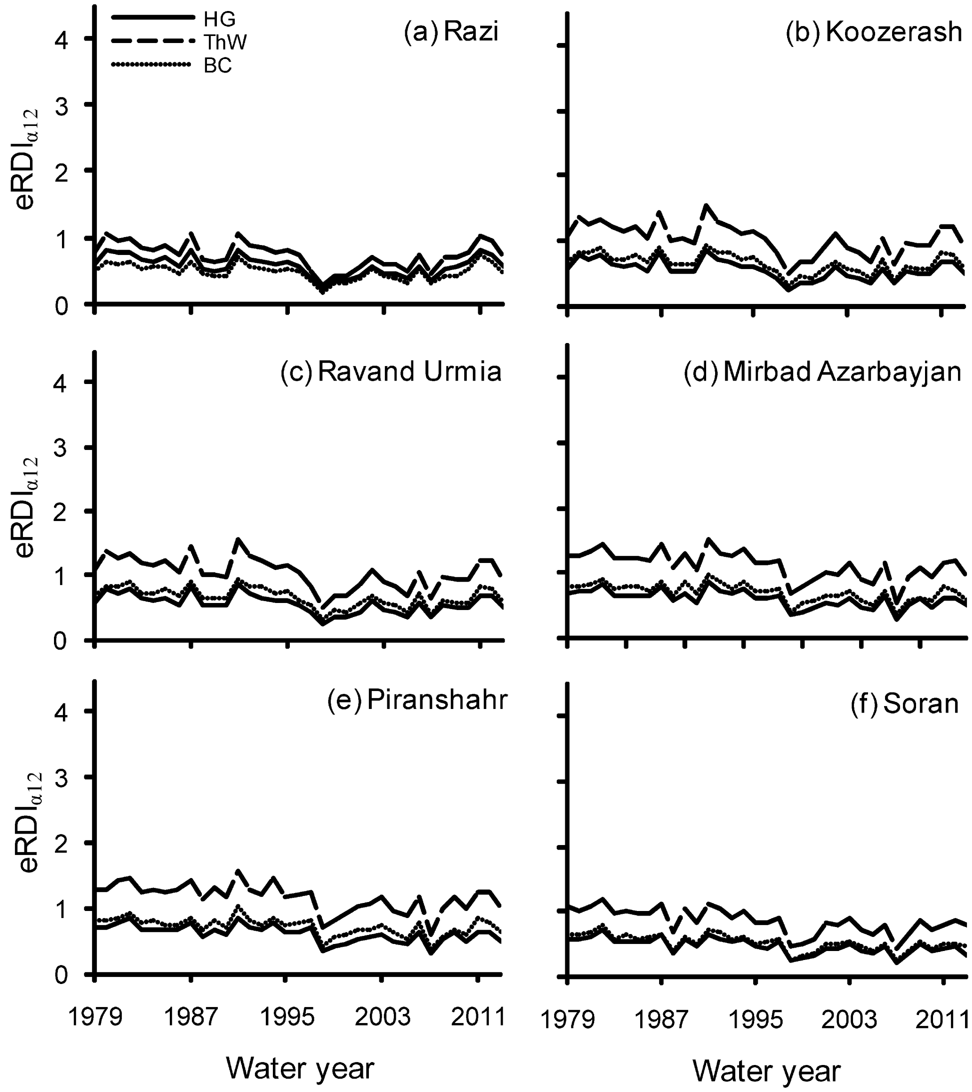


Fig. 3 The initial form of the reconnaissance drought index (RDIα12) values calculated by Hargreaves (HG), Thornthwaite (ThW), and Blaney–Criddle (BC) potential evapotranspiration (PET) techniques at the upstream sub-basin gauging stations of the Upper Zap River Basin

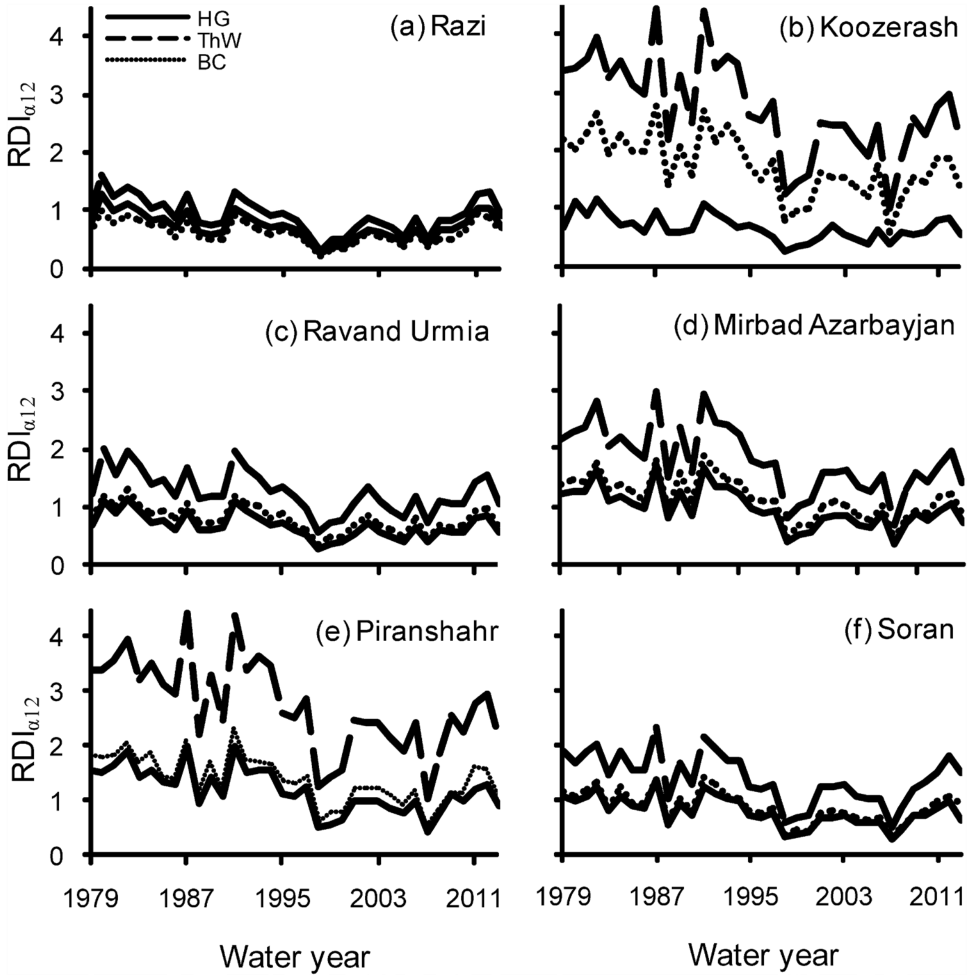


Fig. 4 The initial form of the effective reconnaissance drought index (eRDIα12) values calculated by Hargreaves (HG), Thornthwaite (ThW), and Blaney-Criddle (BC) potential evapotranspiration (PET) techniques at the upstream sub-basin gauging stations of the Upper Zap River Basin

numerator. The other two figures of the index are estimated by the same processes, as explained for RDI.

Furthermore, the choice of appropriate reference time-period for the RDI index calculation should be also taken into consideration. This study considered a hydrological year, which is starting from October, as a basis for the RDI estimation. This selection would be helpful in many hydrological applications such as early-warning and drought monitoring and rational assessment of water deficits (Tigkas et al. 2017).

Results and discussion

The key purpose of this study is to investigate the prospective impact of the potential evapotranspiration estimation techniques on the assessment of a region's aridity and weather drought that were evaluated by RDI and $_{e}$RDI. The application of different techniques for the assessment of the potential evapotranspiration variable could lead to errors in the prediction of water resources availability. Therefore, the choice of the best technique for the estimate of the potential evapotranspiration is critical.

The location of the meteorological station and the method of potential evapotranspiration estimation could have an important impact on the computation as well as the evaluation of the regional aridity calculated by RDI$_{\alpha 12}$ and/or $_{e}$RDI$_{\alpha 12}$. Figures 3 and 4 present results of the annual values of RDI$_{\alpha 12}$ and $_{e}$RDI$_{\alpha 12}$ for the US sub-basin, which are characterised by high elevations and precipitation and low air temperature and potential evapotranspiration (Table 1). Figures 3 and 4 prove that there is a substantial difference in the values of alpha form of the original and the effective RDI for changed altitudes by applying diverse PET methods, which in turn influence notably local aridity evaluation. The values of both RDI$_{\alpha 12}$ and $_{e}$RDI$_{\alpha 12}$ that are created by BC and HG techniques are quite identical, and the most considerable differences are revealed via the ThW technique. It is critical to note that, for all the US sub-basin stations, ThW produced higher RDI$_{\alpha 12}$ and $_{e}$RDI$_{\alpha 12}$ values, while HG had the lowest ones. The quantities computed by ThW are principally higher than the quantities estimated by the other two techniques for the US sub-basin. ThW strongly overestimates RDI$_{\alpha 12}$ and $_{e}$RDI$_{\alpha 12}$ under humid conditions and at high altitudes (Figs. 3(b, d, e) and 4(b, c, e, and f)) because the equation does not consider the air saturation shortage; it is generally calibrated for moderate weather at small altitudes. While Blaney–Criddle method assesses precisely without big variations in the datasets, the gained outcomes by BC are similar to the figures created through HG (Figs. 3(a, c, f) and 4(b and c)). HG and BC could be considered the main methods to estimate PET for the studies region. The lead of HG is supported by a number of water resources studies (Vangelis et al. 2013; Tigkas et al. 2015; Mohammed and Scholz 2017a).

Furthermore, Figs. 5 and 6 present results of the annual values of RDI$_{\alpha k}$ and $_{e}$RDI$_{\alpha k}$ for the DS sub-basin stations, which are characterised by low elevations and precipitation and high air temperature and potential evapotranspiration (Table 1). The results of these figures show that there are minor and/or no alteration in the annual values of RDI$_{\alpha k}$ and $_{e}$RDI$_{\alpha k}$ (part of the analysis are not presented) through using different methods of PET, which cannot be considered important because it does not effect evaluation of the regional aridity. The different figures, in spite of their variations, continue unvarying within the same aridity group exclusive of any threshold value, which may not be the case for lesser intervals. Therefore, it is recommended to use shorter time intervals such as 3, 6, and 9 months to estimate

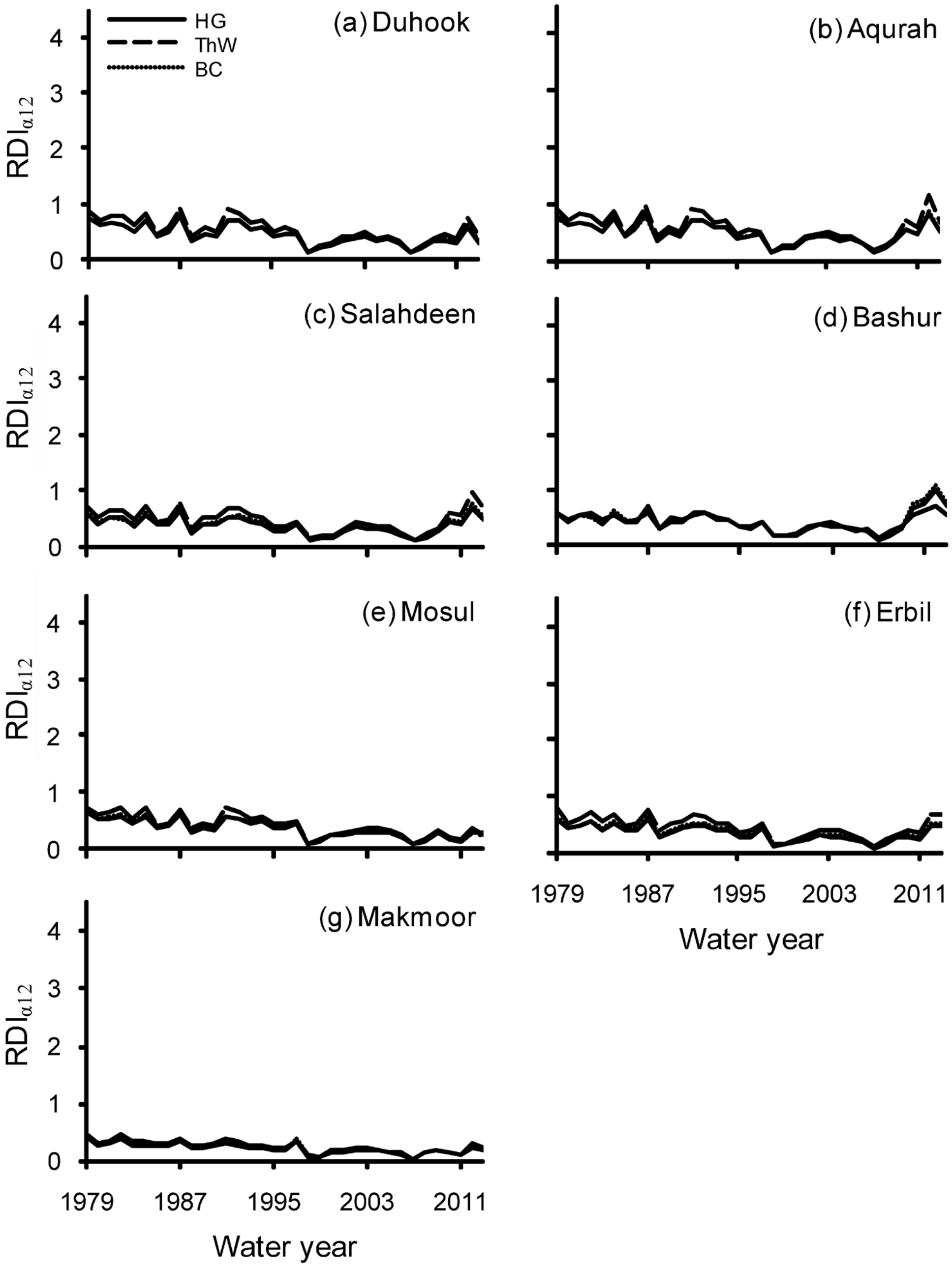
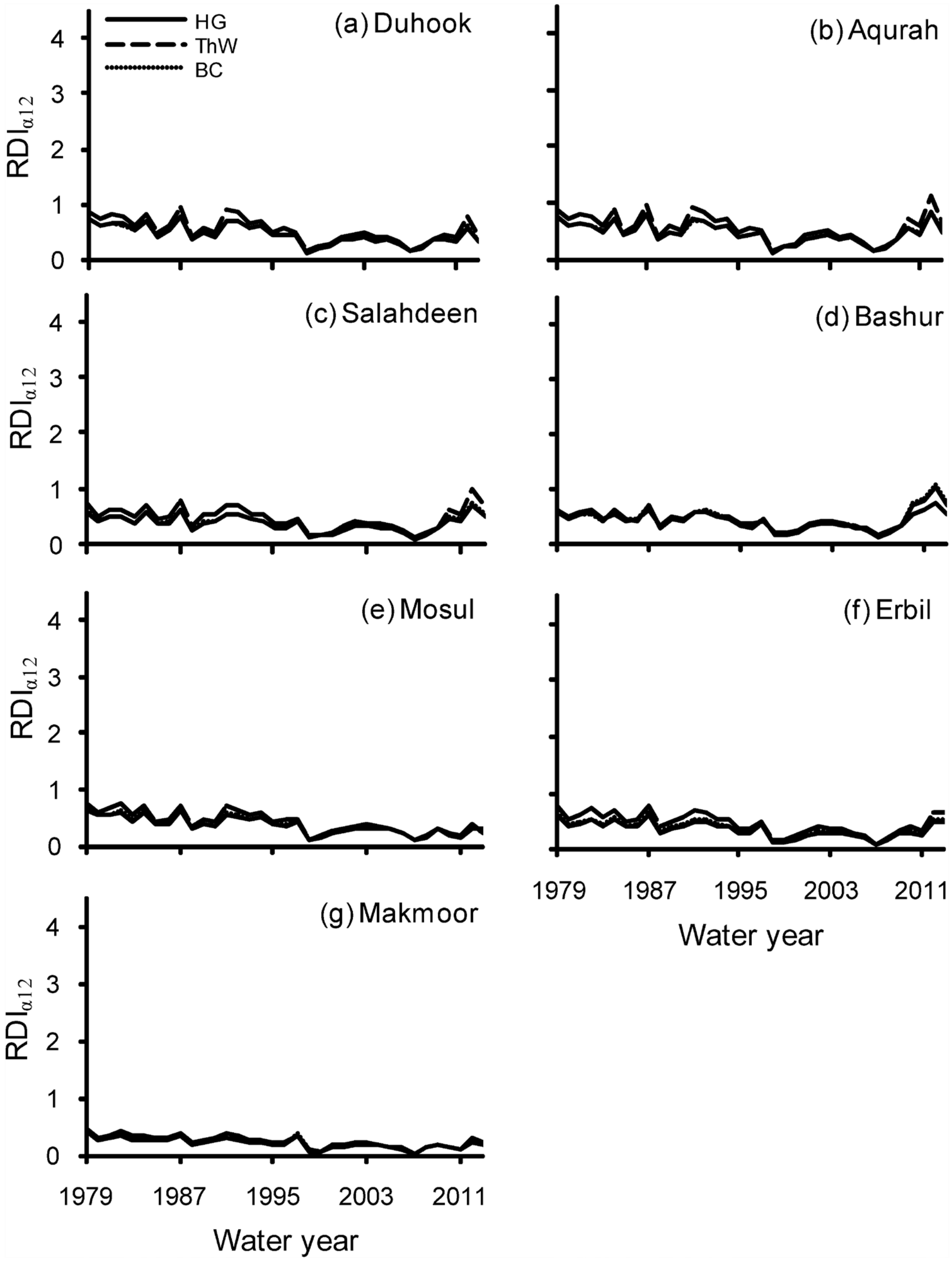


Fig. 5 The initial form of the reconnaissance drought index (RDIα12) values calculated by Hargreaves (HG), Thornthwaite (ThW), and Blaney-Criddle (BC) potential evapotranspiration (PET) techniques at the downstream sub-basin gauging stations of the Upper Zap River Basin

Fig. 6 The initial form of the effective reconnaissance drought index (eRDIα12) values calculated by Hargreaves (HG), Thornthwaite (ThW), and Blaney-Criddle (BC) potential evapotranspiration (PET) techniques at the downstream sub-basin gauging stations of the Upper Zap River Basin



the $RDI_{\alpha k}$ and ${}_{e}RDI_{\alpha k}$ values than annual values. The results regarding the $RDI_{\alpha 12}$ are consistent with the results obtained by Mohammed and Scholz 2017a.

Figure 7 shows spatial analysis outcomes of $RDI_{\alpha 12}$ and ${}_{e}RDI_{\alpha 12}$ values. Note that $RDI_{\alpha 12}$ and ${}_{e}RDI_{\alpha 12}$ are notably advanced for wet location (represented by the US sub-basin stations; Table 1) concerning the entire dataset and related to advanced variations compared to semi-arid weather condition (represented by the DS sub-basin stations; Table 1). Eventually, and for explanation purposes, Fig. 8(a and b) represents how $RDI_{\alpha 12}$ and ${}_{e}RDI_{\alpha 12}$ values, at a basin scale, could be altered with substantial temporal variations.

Figures 9 and 10 show the temporal variations of RDI_n, ${}_{e}RDI_n$, RDI_{st}, and ${}_{e}RDI_{st}$, using different PET methods, at the US and the DS sub-basins, respectively, coupled with the precipitation and effective precipitation. The values could be measured around identical regardless of station location, elevation, and the potential evapotranspiration assessment method applied.

In sum and based on the obtained results, it is recommended to use HG and BC for the estimation of either RDI

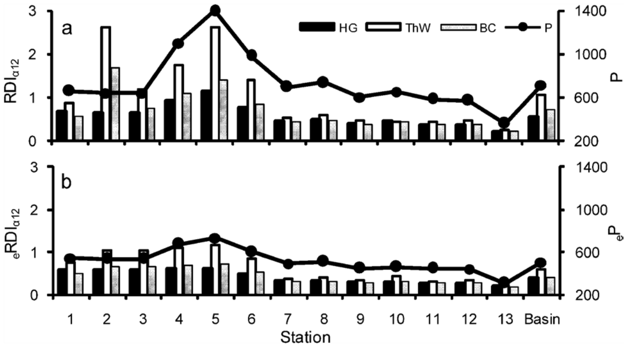


Fig. 7 The spatial distribution of the annual initial form of the original ($RDI_{\alpha12}$) and the effective reconnaissance drought ($_eRDI_{\alpha12}$) values using Hargreaves (HG), Thornthwaite (ThW), and Blaney-Criddle (BC) potential evapotranspiration techniques coupled with the annual average values of the basin precipitation (P)

or $_e$RDI with the target to avoid the ThW method, mainly for humid climatic conditions, which are represented by the US stations. Additionally, the HG technique gives the generally precise consequences. Because RDI uses the key element of evapotranspiration, however keeping the required information to a minimum, the BC and HG techniques are the mainly suitable alternatives for estimating PET for the RDI and $_e$RDI in geographical regions with similar climatic conditions. Table 2 reveals the one-way ANOVA statistical analysis at 0.05 significant level of the $_eRDI_{\alpha12}$ estimated by various evapotranspiration methods.

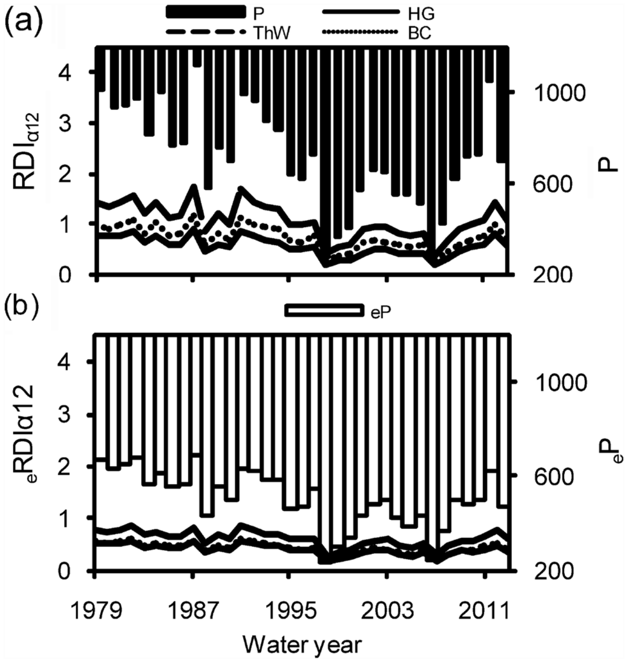


Fig. 8 Long-term variations of the initial form of the original ($RDI_{\alpha12}$) and the effective reconnaissance drought ($_eRDI_{\alpha12}$) values estimated by Hargreaves (HG), Thornthwaite (ThW), and Blaney-Criddle (BC) potential evapotranspiration techniques coupled with the annual average values of the basin original and effective precipitation (*P*, $_eP$)

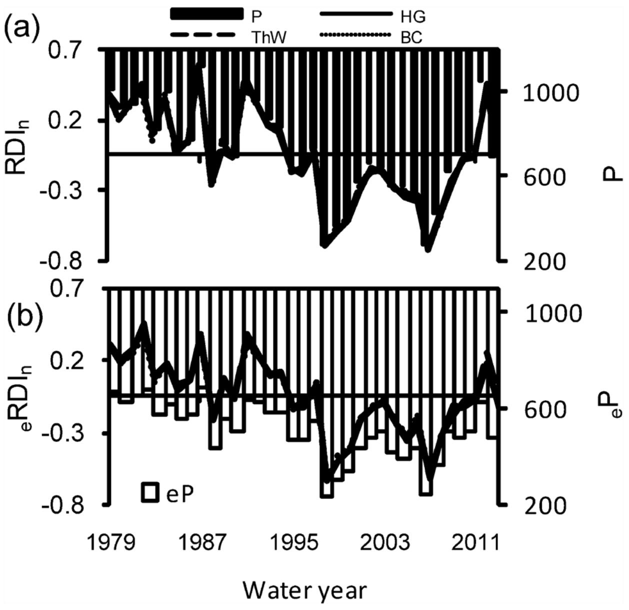


Fig. 9 Long-term variations of the normalised form of the original (RDI_n) and the effective reconnaissance drought ($_eRDI_n$) values estimated by Hargreaves (HG), Thornthwaite (ThW), and Blaney-Criddle (BC) potential evapotranspiration techniques coupled with the annual average values of the basin original and effective precipitation (*P*, $_eP$)

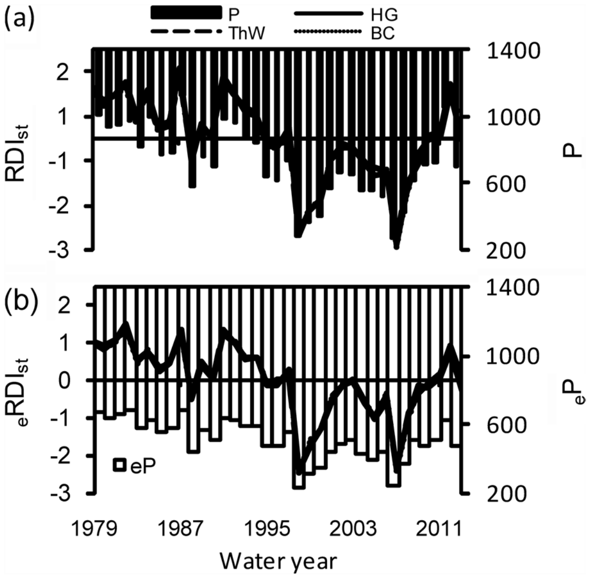


Fig. 10 Long-term variations of the standardised form of the original (RDI_{st}) and the effective reconnaissance drought ($_eRDI_{st}$) values estimated by Hargreaves (HG), Thornthwaite (ThW), and Blaney-Criddle (BC) potential evapotranspiration techniques coupled with the annual average values of the basin original and effective precipitation (*P*, $_eP$)

Table 2 Statistical performance indicator, one-way ANOVA analysis at 0.05 significant level, of the annual reconnaissance drought index for the initial values α_k at $k=12$ months (${}_{e}\mathrm{RDI}_{\alpha 12}$) estimated by various evapotranspiration methods

	Station		ANOVA		
Location	No	ID	HG	ThW	BC
US	1	Razi	*	0.153	*
	2	Koozerash	*	*	*
	3	RavandUrmia	*	0.152	*
	4	MirbadAzarbayjan	*	*	*
	5	Piranshahr	*	0.312	*
	6	Soran	*	0.545	*
DS	7	Duhook	0.136	0.990	0.176
	8	Aqra	0.125	0.996	0.149
	9	Salahddin	0.059	0.059	*
	10	Bashur	0.989	0.937	0.879
	11	Mosul	0.242	0.888	0.483
	12	Erbil	0.013	0.727	0.087
	13	Makhmoor	0.265	0.793	0.631
		Basin	*	0.012	*

US upstream, *DS* downstream, *HG* Hargreaves method, *ThW* Thornthwaite method, *BC* Blaney–Criddle method

$^{*} < 0.05$

Conclusions

Meteorological drought is a natural, recurring feature of climate that is caused by the rainfall shortage during a long time period (annual, seasonal, monthly, etc.), which can be affected in water resources field. Therefore, investigating the severity of drought can help water resources managers mitigate and reduce its damages. To evaluate the severity of drought severity and the aridity of a region that located in arid and semi-arid climate, RDI and eRDI (developed by Tigkas et al. 2016) that are a few of the newest indices for drought severity assessment (with an emphasis on agricultural drought) were used, and the results of these indices were compared. The RDI and eRDI indices have been suggested in this study as a climatic index to find changes in the drought and aridity of a geographical area. The main advantage of the considered method is that the RDI integrates in a single index both precipitation and potential evapotranspiration. Using the alpha or the normalised RDI form, more consistent climate variable trends can be identified compared to applying time series of potential evapotranspiration and precipitation separately.

Results of this paper indicated that no important influence on the $\mathrm{RDI}_{\alpha 12}$ and ${}_{e}\mathrm{RDI}_{\alpha 12}$ at the downstream sub-basin stations, which characterised as semi-arid climate, and on RDI_{st}, ${}_{e}\mathrm{RDI}_{st}$, RDI_{n}, and ${}_{e}\mathrm{RDI}_{n}$ at the basin scale, was identified during the chosen potential evapotranspiration estimates at diverse elevations. Small differences shown for several years cannot be considered essential, as they do not affect aridity assessment and drought severity specified via RDI. The different figures, regardless of their differences, continue in the same class of aridity without exceeding an aridity threshold. Yet, this could not be the case for lesser intervals, in order that it is greatly suggested to use shorter intervals such as 3, 6, and 9 months designed for more study.

For many stations at the upstream sub-basin such as Kooserash, Mirbad, and Piranshahr, $\mathrm{RDI}_{\alpha 12}$ and ${}_{e}\mathrm{RDI}_{\alpha 12}$ values are notably different by applying the selected potential evapotranspiration methods. The variations are considered important, as they affect noticeably the aridity assessment reported by $\mathrm{RDI}_{\alpha 12}$ and ${}_{e}\mathrm{RDI}_{\alpha 12}$. The variation could turn out to be clearer for shorter intervals. Consequently, it is extremely suggested to consider time intervals such as 3, 6, and 9 months for more study.

Moreover, at the upstream sub-basin stations, $\mathrm{RDI}_{\alpha 12}$ and ${}_{e}\mathrm{RDI}_{\alpha 12}$, are directly affected by the chosen potential evapotranspiration technique at diverse heights. Thus, the choice of the potential evapotranspiration estimation method, mainly at high elevation, is critical. Thus, the use of diverse methods possibly will cause mistakes in evaluation of water resources accessibility. A major departure has been recorded when the $\mathrm{RDI}_{\alpha 12}$ and ${}_{e}\mathrm{RDI}_{\alpha 12}$ are estimated applying different potential evapotranspiration techniques. Differences were observed from station to another and for different elevations. Additionally, for almost all the considered stations, it has been noticed that the HG technique accomplished comparatively better than other methods. This study is recommended to be carried out another time for other areas and weather environments to assess the effect of altitude on the selection of potential evapotranspiration technique and the estimate of the ${}_{e}\mathrm{RDI}_{\alpha 12}$. Considerations for smaller intervals such as 9, 6, and 3 months are as well suggested, which would result in an additional overview of the study finding.

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Declarations

Conflict of interest The author declares no competing interests.

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