Chapter 5

Drought Analysis and Water Resources Management Inspection in Euphrates–Tigris Basin

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Additional information is available at the end of the chapter

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Abstract

Growing population, increasing basin development, and progressively declining water supplies are typical water resources issues in the Middle East. Drought is one of the most damaging climate-related hazards that affect more people than any other. For identifying drought-prone areas in the Euphrates–Tigris Basin, multifold aspects of drought and its features such as the frequency of drought occurrence and its spatial distribution were assessed. The long-term precipitation data were collected from different meteorological stations of Turkey and Iran, and standard precipitation index (SPI) was calculated. Due to the lack of raw data, the literature works on drought were used in Syria and Iraq to obtain a drought perception in these countries. Moreover, the policy of water resources management and the hydraulic works in these regions were considered. The results show significant changes in the precipitation in these regions over the past decades. The projects undertaken in the basin are not in line with the principles of integrated water resources management and intensify the drought and caused marshland demise in the downstream of the basin. The results of a comprehensive analysis of precipitation variation and water management in this research can alter the policy of water resources management in order to avoid drought in the basin.

Keywords: Euphrates, Rainfall, SPI, Tigris, *Water Resources*

1. Introduction

Water has played a vital role in the Euphrates–Tigris Basin (ETB), especially in Mesopotamia, which is the fertile land between the Euphrates and Tigris (ET) Rivers. Climate change together with increasing population makes the water resources an important issue in the region [1], which affects the social and economic conditions of this region. Very low precipitation caused a steep decline in agricultural productivity in the rain-fed ET drainage basins and displaced hundreds of thousands of people [2]. Climate change could seriously affect the water resources and lead to serious disputes among the countries that have territories in the ETB [3]. Bozkurt and Sen [1] investigated future climate change in the ETB and found that Turkey and Syria are most vulnerable to climate change, and downstream countries, especially Iraq, suffer more because they rely on the water released by the upstream countries. Middle East Region significantly suffers from decreasing water resources due to climate change [4]. The Middle East and North Africa (MENA) region represents 5% of the total world population, whereas contains only 0.9% of global water resources. The number of water-scarce countries in the Middle East and North Africa has risen from 3 in 1955 to 11 by 1990. Another seven countries, including Iran, are expected to join the list by 2025 [5]. ETB is in the midst of a water crisis and the worst drought in decades. At the current decline rate of water, the water supply in the basin will not be enough to avert such a widespread humanitarian crisis [6]. The recent drought that began from 2003 has further strained the limited water resources in the region [7]. Voss et al. [8] used Gravity Recovery and Climate Experiment (GRACE) satellite mission and [8] concluded an alarming rate of decrease of approximately –2.7 cm/yr water height, equal to 143.6 km^3, in the total water storage from 2003 to 2009. SPI[1] is an index for extract drought periods that considers precipitation only and the negative values of SPI indicate droughts. Karavitis et al. [9] used different scales of SPI for droughts in Greece and they declared that SPI has had high ability to announce drought. Paulo et al. [10] used SPI for several sites of Alentejo, Portugal, to find drought classes. A reported SPI in stations inside Syria, as a part of ETB, is presented by Skaf and Mathbout [11]. Their findings and results from literatures showed that the duration of most extreme drought in terms of intensity and areal extent in Syria corresponds to 1998–1999, 1972–1973, 2007–2008, and 1999–2000, respectively. Syria is one of the most economically affected countries by drought. Erian [12] showed that in Eastern Syria rainfall dropped to 30% of the annual average in 2008 and a main tributary of the River Euphrates dried up. Timimi and Jiboori [13] investigated the frequency of drought for the period of 1980–2010 in Iraq, based on SPI. Their results reveal that the country, in the past 30 years, faced frequent nonuniform drought periods in an irregular repetitive manner.

As severity of drought may have different effects in different regions and systems due to the underlying vulnerabilities, so the assessment of drought is a complex process [14]. The objectives of this study are to identify drought vulnerability at multiple time steps, so the effects of rainfall deficiency on water resources in the region and water resources management in ETB can be accessed. The drought vulnerability and water management information presented in

[1] Standardized Precipitation Index

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this study can be applied in other sectors and used by water managers to ensure that they will act timely and effectively to tackle the drought-related losses in the regions.

2. Methodology

2.1. Study area

The Euphrates and Tigris, with 3000 and 1850 km lengths, respectively, are the most important rivers in the Middle East, which have been supporting agriculture in the ETB region since many centuries. Both rivers are fed by numerous tributaries, and the entire river system drains a vast mountainous region. They start from mountain ranges of today's Turkey and Kurdistan, and flow southeast through Iraq to the Persian Gulf. In the southern Iraq, both the rivers merge to feed the Mesopotamian marshlands, the land between the Euphrates and Tigris rivers. These marshlands used to be the largest wetland ecosystem in the western Eurasia and Middle East [15], which once covered over 15,000 km^2 of interconnected lakes, mudflats, and wetlands.

The headwater catchment generating the flow of ET is entirely located in the north and eastern parts of the ETB in the highlands of Turkey, Iraq, and Iran as a result of watershed's topography. The flow is regulated by the storage capacity of the limestone aquifers of the Taurus and Zagros mountains [16]. The annual precipitation in the upstream of ETB typically exceeds 1000 mm whereas in the south of Iraq it was found to be less than 100 mm. Most of this precipitation occurs as snow in winter and the water resources are mostly available in the form of snowmelt water during spring and winter [15]. As shown in **Figure 1**, the ETB spreads in the territories of Iraq (46%), Turkey (22%), Iran (19%), Syria (11%), Saudi Arabia (1.9%), and Kuwait (0.03%) [1]. Details of ET river systems are presented in **Table 1**.

Figure 1. The Euphrates–Tigris Basin and the riparian countries.

Country	River length (km)		Basin area (km²)	
	Euphrates	Tigris	Euphrates	Tigris
Iran	0	0	0	131,784
Turkey	1230	400	124,320	46,512
Syria	710	44	75,480	776
Iraq	1060	1418	177,600	209,304
Total	3000	1862	377400	387,600

Table 1. The Euphrates–Tigris characteristics.

2.2. Data

A challenge to conduct this research was the paucity of precipitation and water resources management data for the region. Inconsistent monitoring combined with a lack of data transparency and accessibility is a problem that plagues water managers in the ETB. Data shortage and inaccessibility result in an incomplete understanding of water availability and use in this area [8]. In this research, daily precipitation data were collected from Iran Meteorological Organization and Regional Water Companies located in the west and northwest of Iran, and inside or close to the ETB. Similarly, in Turkey daily precipitation data were collected from the climate stations located in the East of Turkey, which are operated by the Turkish State Meteorological Service. For Syria and Iraq, where availability of raw data for precipitation and water management was very limited, the data analyses presented in previous researches were considered.

2.3. Drought analysis

In this study, drought vulnerability in the regions of ETB, which are the main origins to supply water to the whole basin, was investigated. To check the quality of dataset, each daily total is compared with the climatological daily total maximum for the corresponding site. For this, stations with consistent and complete precipitation records were selected. Cumulative distribution of daily precipitation for each month was applied to obtain the monthly values. Missing data of the stations were completed by using the linear stochastic model called the Thomas-Fiering model. This model is based on the first-order Markov model and represents a set of 12 regression equations. The well-known Thomas-Fiering model equation is described as [17]

$$\frac{x_{i,j} - \overline{P_j}}{S_j} = \frac{x_{i,j-1} - \overline{P_{j-1}}}{S_{j-1}} + a_{ij}\sqrt{\left(1 - r_j^2\right)} \quad (1)$$

where $X_{i,j}$ is the predicted rainfall for the jth month from the $(j-1)$th month at time i, P_j is the mean monthly rainfall during month j, Sj is the standard deviation of monthly rainfall during month j, a_{ij} is the independent standard normal variable at time i in the jth month, and r_j is the serial correlation coefficient for rainfall from the (j – 1)th month to the jth month. Negative values obtained after applying Equation 1 were ignored. To identify the presence of drought or wet spells intensity for multiple time scales, several indices have been developed and adopted. The most well-known index is the SPI developed by McKee et al. [18]:

$$\mathrm{SPI} = \frac{X_i - \bar{X}}{\sigma} \tag{2}$$

where X_i is the rainfall, $\bar{X}$ is the arithmetic mean, and σ is the standard deviation of the series. The SPI provides a quick and handy approach to assign a single numeric value to the rainfall which can be compared across regions with markedly different climates and to reflect the impact of rainfall deficiency on the availability of various water sources [19]. The relative simplicity is a huge advantage of this index [20] and is among one of the most used indices by the researchers around the world. Therefore, its effectiveness in assessing the nature of the phenomenon has been tested in many climatic realities. Separate SPI value is calculated for a selection of time scales. McKee et al. [18] calculated the SPI for 3-, 6-, 12-, 24-, and 48 month time scales and defined the range for a "drought event" for any of the time steps and categorized the SPI to define various drought intensities (**Table 2**). In **Table 2**, negative and positive values of SPI represent rainfall less than and more than normal, respectively. For an equivalent normal distribution and adequate choice of fitted theoretical distribution of the actual data, the SPI can be considered as the value of standard deviations that the measured value would move away from the long-term mean.

Drought Class	SPI	Classification
3	>2.00	Extremely wet
2	1.50–1.99	Very wet
1	1.00–1.49	Moderately wet
0	−0.99	Near normal
−1	−1.00 to −1.49	Moderately dry
−2	−1.50 to −1.99	Severely dry
−3	−2.00	Extremely dry

Table 2. SPI drought categories.

To determine the area of influence of each individual station and utilized synthetic precipitation series in the study area, Thiessen polygons were employed. Since precipitation is not distributed normally, a transformation is first applied so that the transformed precipitation values follow a normal distribution. Different statistical distributions are announced to model the time-series data. The gamma distribution to fit climatological data is the most well-known distribution [21] which is defined using its probability density function:

$$g\left(x\right) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{x}{\beta}} \quad for\, x > 0 \tag{3}$$

where $\alpha > 0$ is the shape parameter, $\beta > 0$ is the scale parameter, and $x > 0$ is the amount of precipitation. Here, the gamma function is defined as $\Gamma(\alpha)$. To calculate the SPI value, the gamma stochastic distribution was transformed into the standard normal distribution. In this study, to compute the SPI for drought analysis, the Drought Indices Package (DIP) software presented by Morid et al. [22] was used. The package is capable of calculating and displaying SPI values at 3-, 6-, 12-, and 24-month time steps.

3. Results and discussion

Drought indices were analyzed at a regional scale in reference to the rainfall regime in the countries of ETB. **Figure 2** presents samples of calculated SPI values and the measured rainfalls for stations in Iran for the 24-month time scales.

Apart from few stations such as the Khooshemehr station (**Figure 2a**), over the years of study, the calculated SPI indices indicated significant drying in many parts of ETB located inside Iran. There were both short-duration and long-duration droughts. Most of droughts were occurred during 1999–2014 in the stations (**Figure 2b–d**). Furthermore, the hyetographs shown in **Figure 2** indicated the considerable spatial and temporal changes in the precipitation total series of Iran, during the study period. Comparing the negative value of SPI in **Figure 2**, it could be concluded that the severity of drought in the Sanandaj station is more than the other stations considered in this study.

Biox et al. and Chen et al. [15, 23] showed that dams and reservoirs intensify the effect of drought on downstream community composition and structure. Therefore, it can be concluded that the severity of drought for these regions is attributed to the construction of dams or much withdrawal of water for irrigation in Sirvan watershed as a sub-basin of the Euphrates-Tigris basin. Consistent with the findings of this research, the drought occurrence in Iran is particularly more in its western and eastern parts, as reported by many researches [24, 25].

Turkey is a part of highlands of the ETB that receives much of the precipitation in form of snow in winter season. The samples of results for drought analysis using SPI and recorded rainfalls in the upper part of ETB, particularly in Turkey, are presented in **Figure 3**.

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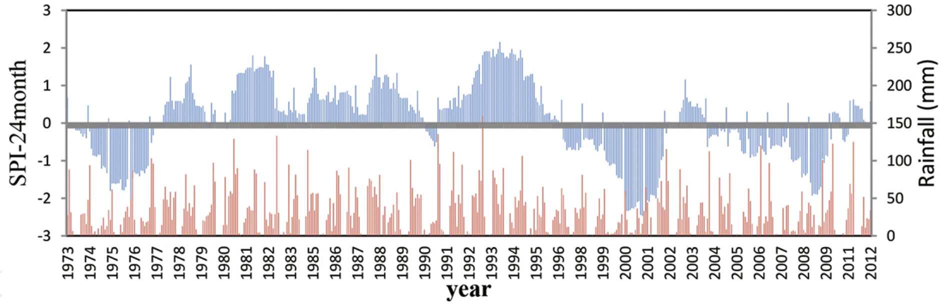
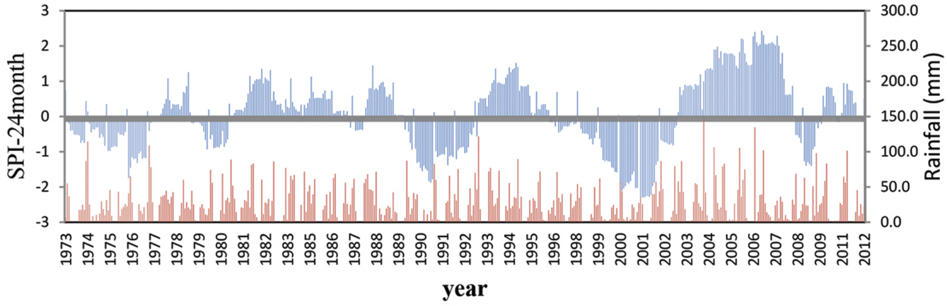
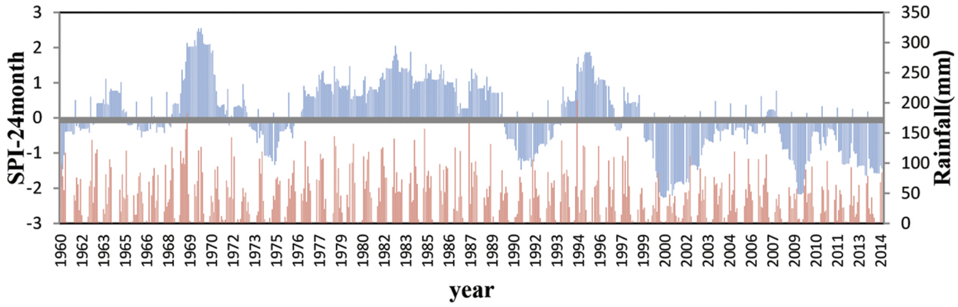


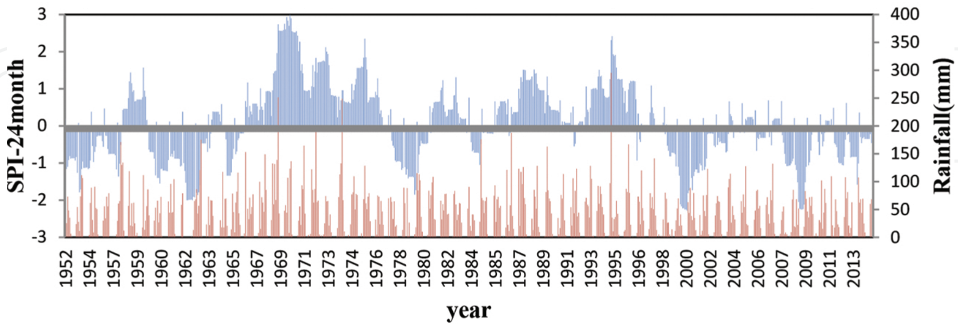
a. Khormazard station, W-Azerbaijan



b. Khooshemehr station, W-Azerbaijan

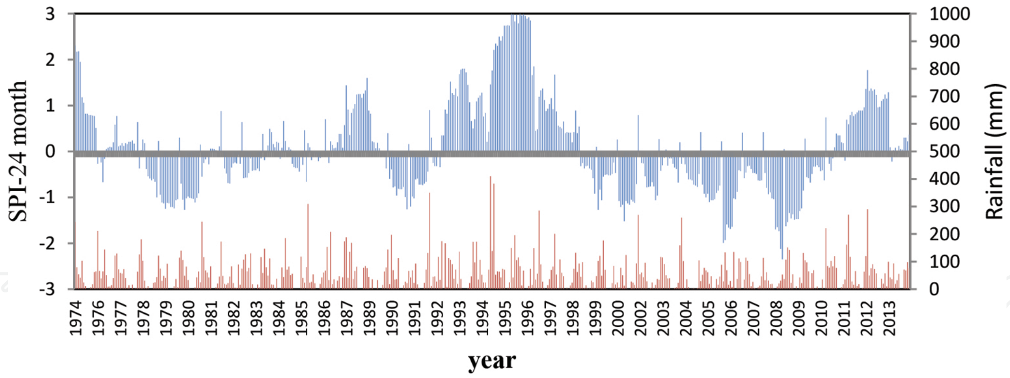


c. Sanandaj station, Kurdistan

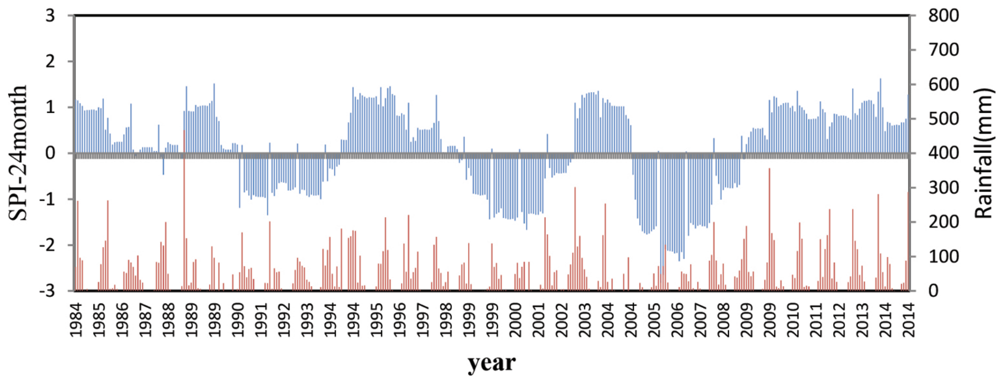


d. Kermanshah station, Kermanshah

Figure 2. The 24-SPI index and monthly rainfall for stations in Iranian part of the ETB: (a) Khormazard station, W-Azerbaijan; (b) Khooshemehr station, W-Azerbaijan; (c) Sanandaj station, Kurdistan; and (d) Kermanshah station, Kermanshah.



a. Adana/Incirlik Station



b. Bodrum station

Figure 3. The 24-SPI index and monthly rainfall for stations in the Turkish part of the ETB: a. Adana/Incirlik station and b. Bodrum station.

In this research, the results of drought analysis for many stations in Turkey revealed that the regions of these stations experienced frequent moderate, severe, and extremely droughts for all years as shown in **Figure 3a**. However, in a few stations no drought was detected using SPI index (**Figure 3b**). Overall, a significant change in rainfall was determined in Turkey. These results are consistent with that reported by Bozkurt and Sen [1].

3.1. Water management

The ETB is associated with ancient civilization where irrigation schemes had been developed about the 5 millennium B.C. The headwater basin generating ET flows was entirely located in the north and eastern parts of the basin in the highlands of Turkey, Iraq, and Iran. Its hydrology and topography provide critical insight into understanding how hydraulic works affect the lower ETB, particularly the marshlands in south and middle of Iraq. Huge drainage and damming operations on the ET river systems in Iraq, Syria, Iran, and Turkey have diminished around 85% of the Mesopotamian marshlands, which originally covered an area of 20,000 km^2 [26]. The three rivers that feed the marshlands originate from riparian countries and all of these countries have extensive plans for control water resources to expand their irrigated agriculture. Construction and planning of mega structural water resources development

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projects began in the early twentieth century in the region [27]. United Nation Environment Programme (UNEP)[2] in 2001 reported that the dams stores five times more than the Euphrates annual flow and twice that of the Tigris. **Table 3** shows the large dams according to the International Commission on Large Dams, ICOLD [28].

Country	Name	Nearest city	River	Year	Height (m)	Capacity (MCM)
Iran	Karoun 3	Eizeh	Karoun	2004	205	2970
	Dez	Andimeshk	Dez	1962	203	2856
	Karoun 1	Masjedsoleyman	Karoun	1976	200	3139
	Masjedsoleyman	Masjedsoleyman	Karoun	2001	177	230
	Gavoshan	Kamyaran	Gaveh Roud	–	136	550
	Karkheh	Andimeshk	Karkheh	2001	127	5575
	Vahdat	Sanandaj	Gheshlagh	–	80	224
	Eilam	Eilam	Baraftab and Chaviz	–	65	71
	Guilangharb	Guilangharb	Guilangharb	–	51	17
	Shahghasem	Yasouj	Parikedoun	1996	49	9
	Hana	Samirom	Hana	1996	36	48
	Bane	Baneh	Banechay	–	20	4
	Chaghakhor	Boldaji	Aghbolagh	1992	13	42
	Zrivar	Marivan	Zarivar	–	11	97
Total						15,832
Turkey	Keban	Elazig	Firat	1975	210	31,000
	Karakaya	Diyarbakir	Firat	1987	173	9580
	Ataturk	Sanliurfa	Firat	1992	169	48,700
	Ozluce	Bingol	Peri	2000	144	1075
	Kralkizi	Diyarbakir	Maden	1997	126	1919
	Kuzgun	Erzurum	Serceme	1996	110	312
	Dicle	Diyarbakir	Dicle	1997	87	595
	Batman	Batman	Batman	1999	85	1175
	Erzincan	Erzincan	Goyne	1997	81	8
	Zemec	Van	Hosap	1988	80	104
	Kockopru	Van	Zilan	1992	74	86
	Kayalikoy	Kirklareli	Kaya	1986	72	150
	Demirdoven	Erzurum	Timar	1996	67	34

[2] United Nation Environment Programme

Country	Name	Nearest city	River	Year	Height (m)	Capacity (MCM)
	Tercan	Erzincan	Tuzla	1988	65	178
	Birecik	Sanliurfa	Firat	2000	63	1220
	Sarimehmet	Van	Karasu	1991	62	134
	Sultansuyu	Malatya	Sultansaya	1992	60	53
	Mursal	Sivas	Nih	1992	59	15
	Surgu	Malatya	Surgu	1969	55	71
	Polat	Malatya	Findik	1990	54	12
	Goksu	Diyarbakir	Goksu	1991	52	62
	Kayacik	Karaburun		2002	50	117
	Hancagiz	Gaziantep	Nizip	1989	45	100
	Camgazi	Adiyaman	Doyran	1999	45	56
	Medik	Malatya	Tohma	1975	43	22
	Hacihidir	Sanliurfa	Sehir	1989	42	68
	K.Kalecik	Elazig	Kalecik	1974	39	13
	Gayt	Bingol	Gayt	1998	36	23
	Devegecidi	Diyarbakir	Devegecidi	1972	33	202
	Dumluca	Mardin	Bugur	1991	30	22
	Karkamis	Kahramanmaras	Firat	2000	29	157
	Cip	Elazig	Cip	1965	23	7
	Palandoken	Erzurum	Gedikcayiri	1997	19	1558
	Porsuk	Erzurum	Masat	1999	17	770
Total						99,598
Syria	Al Tabka	At Thawrah	Euphrates	–	–	11,200
Total						11,200
Iraq	Mosul	Mosul	Tigris	1983	131	12,500
	Derbendi Khan	Ba'qubah	Diyola river	1962	128	3000
	Dokan	–	Lesser Zab	1961	116	6800
	Haditha	Haditha	Euphrates	1984	57	8200
	Hamrin	Ba'qubah	Diyola river	1980	40	4000
	Dibbis	–	Lesser Zab	1965	15	3000
	Samarra-Tharthar	Samarra	Tigris	1954	–	72,800
Total						110,300

Table 3. Large dams in the ETB.

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While the water resources development has been considered as one of the causes for damaging the marshland ecosystem [15] and intensifying the drought effects, it can be seen from the data in **Table 3** that the basin is now deeply regulated with cumulative storage capacity of riparian countries. Apart from the dams listed in **Table 3**, more than 20 dams are planned or are currently under construction in the basin. Further investigation shows that increased agricultural demand driven by land use policy and cropping pattern intensified the pressures on water resources in the ETB. In addition, the use of well water, mostly for agricultural needs, has rapidly increased in the ETB, causing a drop in the water level of the aquifers. Groundwater loss is found to be the major source of water reduction in the region. Voss et al. [8] reported a reduction in groundwater within last 12 years, equal to 1.73 cm/yr height.

The effect of manmade projects is greatest in the lower part of the basin in the marshlands in Iraq mainly in intensifying dust storm origins inside Iraq [29]. The marshlands have been desiccated through the combined actions of upstream damming in riparian countries as well as the development of extensive downstream drainage projects, in the past 30 years [3]. Without doubt Turkey is in the strongest position with regard to its potential control of a large part of the water resources of the ETB mainly due to the Southeast Anatolia Project (GAP). The project area neighbors with Syria in south and Iraq in southeast, which includes 22 dams and 19 hydropower plants and irrigation networks on the ETB.

It seems that there is a mismanagement of water resources in the region. As a few instances, the Tabqa dam in Syria planned to irrigate 640,000 ha of land. However, so far only 240,000 ha of land can be irrigated due to salinization and poor quality of land. Consistently, since 1990s large water management projects have been developed in Iran under a major policy to control surface water to serve other purposes such as irrigation and drinking. Thus, more than 20 dams have been constructed or are under construction in the Tigris Basin and an increasing amount of water is diverted from the rivers. The Karkheh is one of the largest dams in Iran with a reservoir capacity of 5.6 *Billion Cubic Meter* to irrigate 320,000 ha of land and produce 520 MW of hydroelectricity. Conversely, because of the water crisis and low water levels in Iran, the Karkheh dam irrigates one-third of the anticipated area and cannot produce even 1 kWh of energy in its lifetime. In Sirvan watershed, as a part of ETB inside Iran, more than 10 dams were constructed in the last decades without accomplishing the irrigation and drainage system. While Iran is facing a critical water shortage currently, huge amount of water is lost through evaporation from unusable dams and reservoirs.

In Iraq, because of inadequate leveling, lack of know-how, and poor water management practices, water is often poorly distributed. In the southern part of Iraq, diversion canals within the irrigation command area divert the ETB water from rivers to cultivated lands. Poor maintenance throughout the primary formal supply system caused water losses at all its stages of primary delivery. However, only about 30% of water supply available for irrigation annually actually reaches crops [30]. Overall, the irrigation system in Iraq is inefficiently managed.

More than 90% of water resources are used for agriculture. The on-farm water application rates in the region are high, and irrigation has a low efficiency. Keshavarz et al. [31] reported that overall irrigation efficiency in Iran ranges from 33 to 37%, which is lower than the average for both developing (45%) and developed (60%) countries. The most prominent causes of irrigation inefficiency in the study areas include improper design of irrigation facilities, poor maintenance, careless operation, negligible water prices, and inadequate training of farmers.

4. Conclusions

In this research, drought and water resources managements were investigated in ETB. Moreover, the calculated SPI for Iran and Turkey and those reported for Syrian and Iraq confirmed that there are various dry periods, which affect these countries, especially during the past 15 years. Among these four countries, Turkey has less severity and frequency of drought than the other three countries, and Syria has the most. This problem will affect the stream flow strongly. Thus, the annual flow of the Euphrates and Tigris entering Iraq and groundwater sources in the riparian countries declined drastically. Drought has negative impact on health, the agricultural production, and economic condition of most people who live in ETB; and food scarce makes migration from these dry areas and expected to increase further in the future. Apart from deficiency of rainfall, the rules to control the amount of water in riparian countries of ET lead to a decrease in the water flow in the two rivers. It should be noted that each riparian country has the right to use, in an equitable and reasonable manner, the water of the international watercourses in its respective territory. Emphasis on acquired rights without considering the principles of integrated water resources managements to achieve the optimal use of water by the riparian countries is the major cause of water decline in the ETB. The ETB has to be considered as forming one single transboundary stream system, and should be managed accordingly. It seems that the impact of hydraulic works needs to be reassessed and mitigated by ensuring a minimal water flow to sustain life in the ETB, particularly in Mesopotamian marshlands. A portfolio of water and land resources should be drawn up and jointly evaluated. Such realities remind us that we need to act now to restore ETB ecosystems on a global scale.

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