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PRELIMINARY ASSESSMENT OF HYDROTHERMAL RISKS IN THE EUPHRATES–TIGRIS BASIN: DROUGHTS IN IRAQ

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This paper presents a temporal and spatial pattern of precipitation, surface air temperature, and drought occurrence in Euphrates–Tigris rivers basin with special emphases on Iraq. Historical records based on 115 years (1900–2014) of monthly precipitation and temperature data has been divided into four sub-periods, each of 30 years (first 1900–1929, second 1930–1959, third 1960–1989 and fourth 1985–2014) and studied separately. The results showed that the mean annual precipitation in Iraq for the four sub-periods is: 218.5, 202.1, 196.4, and 174.9 mm respectively, with an average of 198 mm. This indicates that the mean annual precipitation decreased by 43.6 mm (20 %) in the fourth sub-period compared to the first sub-period. The mean annual temperature for the four sub-periods in Iraq are 22.0, 21.9, 22.0, 22.8 °C respectively, with an average of 22.2 °C. This indicates that the average monthly temperature during the year in Iraq increased by 0.76 °C (3.45 %) in the fourth sub-period compared to the first sub-period. The probability of occurrence of dry (hot) periods in Iraq increased by 345.5 % (147.7 %) in the fourth sub-period compared to the first sub-period. Fortunately, the greatest drought occurrence is observed in western parts of Ira, where agriculture is irrigated, in rain-fed areas in the northern Iraq, there has also been a decrease in precipitation, but not so strong as in the west of the country. A preliminary conclusion about the current climatic desertification and its possible consequences for Iraq was drawn.

Keywords: Euphrates–Tigris rivers basin, Iraq, temperature, precipitation, climate change, Standardized Precipitation Index, z-score.

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Introduction

Climate change is considered to be the biggest challenge the mankind faced in the twenty first century [1]. Climatic change can cause significant impacts on water resources and the hydrological cycle, where the change of the temperature and precipitation will affect the evapotranspiration process. Both, quality and quantity of the runoff component will suffer some changes which will lead to a significant effect on sectors like agriculture, industry and urban development [2]. Also because of climate change and global warming, the increase in air temperature extremes will become more frequent and intense, as well as more widespread during the 21st century [3].

Drought has long been recognized as one of the most insidious causes of human misery and the natural disaster that annually claims most victims. Drought is defined based on the deficiency of precipitation that results in water shortage for activities related to use of water. It begins with the meteorological drought caused by precipitation deficiency. Prolonged meteorological drought can cause an agricultural drought as the precipitation deficit propagates

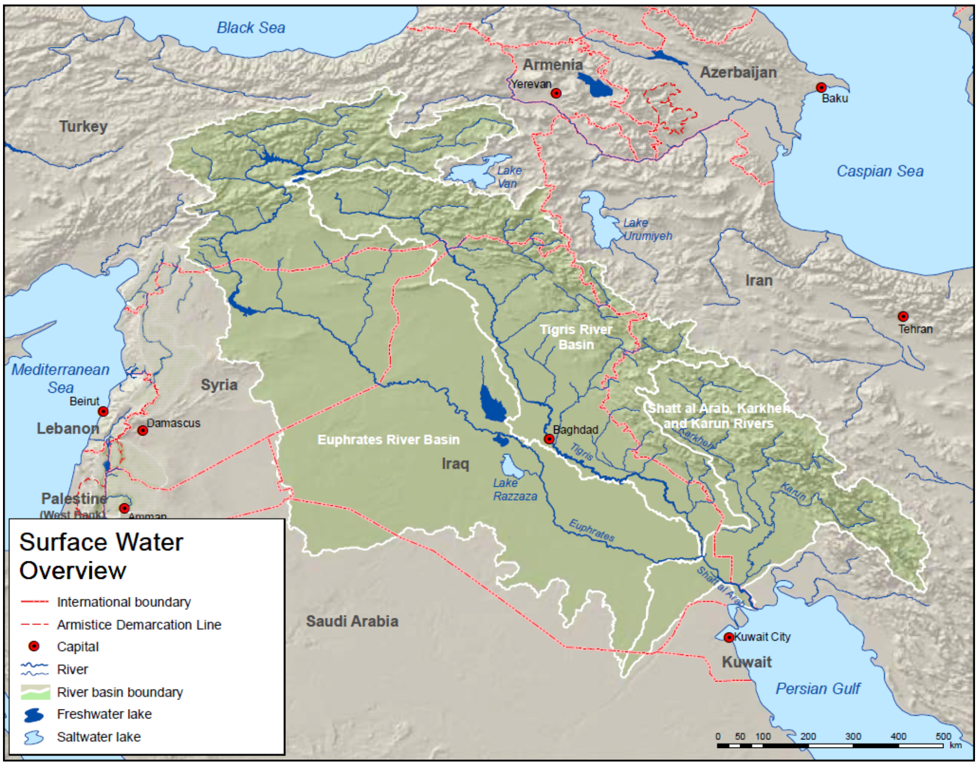


Fig. 1. Overview map of location and shared surface water within Euphrates–Tigris rivers basin

into soil moisture deficit and reduces crop production. Meteorological drought may be followed by hydrological drought, which can affect river flows, levels in lakes, and aquifer recharge [4].

A common tool utilized to monitor current drought conditions is a drought index. Several drought indices can be used to forecast the possible evolution of an ongoing drought, in order to adopt appropriate mitigation measures and drought policies for water resources management. This is because a drought index is expressed by a numeric number, which is believed to be far more functional than raw data during decision-making [5]. Different indices are available globally to quantify drought, each with its own strengths and weaknesses [6]. These include the Palmer Drought Severity Index [7], Standardized Precipitation Index [8], Standardized Precipitation Evapotranspiration Index [9], Effective Drought Index [10], and many others. In this paper, the standardized precipitation index (SPI), proposed by McKee et al. [8] is used to analyze the characteristics of drought. There are a number of strengths to the SPI approach: (i) it only uses one relatively commonly available parameter (i.e. precipitation); (ii) it can be estimated for a variety of timescales (by calculating using precipitation data for a range of accumulation periods); (iii) it is relatively simple compared with other widely used indices such as the Palmer Drought Severity Index (PDSI); and (iv) it is spatially constant, again unlike the PDSI [11]. Since SPI is standardized and has a probabilistic interpretation, it can be used in risk assessment and decision-making [6].

Extreme heat events are among the most serious challenges for society coping with a changing climate and can be very harmful to human health, ecosystems, agriculture and economic sectors such as energy generation and tourism [3]. One of the popular tools used for analyzing the temperature time series datasets is the statistical z-score technique [3, 12].

The economic life of the Euphrates–Tigris Basin remains reliant on the rivers' waters. Historically, the agriculture of southeastern Anatolia, as well as of northern Iraq and Syria, has been entirely dependent on rainfall, with some minor mechanical irrigation systems particularly in Syria [13]. Iraq is one of the riparian countries within the Euphrates–Tigris Rivers basin in the Middle East region (Fig. 1 [14]); the region is currently facing water shortage problems due to the increase of the demand and climate changes [15].

As the country furthest downstream in the basin, Iraq is heavily dependent on precipitation in the highlands of Turkey and Iran. The population of Iraq in the 1980s was approximately 13.7 million people, and increased to 31 million in 2010s; and it is expected that the population will keep on increasing to reach 71.3 million in 2050 (the rate is about 3.6 %) [16]. According to the Ministry of Planning/ Central Statistical Organization/ Annual Statistical Abstract 2014–2016 [17], the total population of Iraq is about 36.004 million in 2014, and with the 437,065 km^2 total land area of Iraq, the population density is about 82.73 inhabitants/km^2. Although the contribution of agriculture to the overall Iraqi gross domestic product (GDP) is below 5 percent, one-third of people resides in rural areas and depends on agriculture for their livelihoods. After the public service and trade sectors, agriculture is the third largest provider of employment in the country, and the largest source of employment for the rural population [18].

According to the Ministry of Agriculture, "Annual Agricultural Statistical Data (2014)", Arable Area in Iraq represents 34 % of the total area of Iraq [19]. The republic of Iraq consists of 18 muqhaphas: Al-Anbar, Babil, Baghdad, Basra, Dhi-Qar, Al-Diwaniyah, Diyala, Dohuk, Erbil, Karbala, Kirkuk, Maysan, Muthanna, Najaf, Nineveh, Saladin, Sulaymaniyah, and Wasit. Within the agriculture sector, crop production constitutes the largest subsector and provides 75 percent of agricultural income. Crop production such as grains, primarily wheat and barley, are Iraq's main crops in the north and central rain fed areas (Kirkuk, Saladin, and Sulaymaniyah). The rain fed land in the northern part of the country is highly responsive to variations in the timing and quantity of precipitation [18].

In central and southern (Baghdad, Al-Diwaniyah, Diyala and others) areas, where agriculture is mainly irrigated by the Tigris and Euphrates, mixed farming systems (rice, wheat and barley) are predominant, and vegetables, mainly tomatoes and potatoes, are important, also. Crop production from irrigated land in Iraq is very sensitive to any change in the seasonal availability of water resources from the two main rivers Euphrates and Tigris. Dates are a major cash and food crop with fruit trees inter-planted in date palm orchards in southern Iraq. Meanwhile, livestock is the second largest subsector with 13.5 million heads of cattle, goats, and sheep, and 14 million of poultry, as of 2013 [18].

There have been many studies to assess hydrothermal risks around the world, but very few in Iraq. However, in [20] the frequency of drought for the period 1980 to 2010 in Iraq was investigated, based on monthly rainfall data collected from 39 meteorological stations distributed across the country, in [4] the standardized precipitation index (SPI) at different time scales, i.e., 3, 6, 12, and 24-month, were used to analyze the meteorological drought for the period 1937–2010 in northern Iraq, in [2] the historical records of the average monthly temperature and rainfall for the period of 1900–2009 for the Middle East and North Africa countries with special emphases on Iraq were studied, in [21] the trends of temperature for the period of 1941–2000 for Baghdad, Iraq were investigated, in [22] ten average climate indices (total rainfall, average temperature, maximum temperature, minimum temperature, number of days of dust rising, number of days of dust storm, relative humidity, atmospheric pressure at sea surface level, total evaporation and wind speed) were investigated at 24 meteorological stations in Iraq for 30 years, and finally in [23] the SPI at 9, 12-month time scales was used to study and analyze drought characteristics in Iraq dependent on the observed climate data from 10 meteorological stations during 1980–2011.

In this paper, the historical time series of the average monthly temperature and precipitation for the period of 1900–2014 (115 years) for the Euphrates–Tigris rivers basin was divided into four sub-periods of thirty years and investigated separately. Understanding and predicting the trends of hydrothermal risks including drought risks, heavy precipitation events, and periods of extremely high and low temperature in Iraq and using this knowledge could be helpful to support hydrothermal risks management and develop effective mitigation strategies. This paper aims to provide a comprehensive analysis of hydrothermal risks in the Euphrates–Tigris rivers basin with a special emphasis on Iraq as follows: (1) analysis of the spatial and temporal variation of precipitation; (2) analysis of the spatial and temporal variation of surface air temperature; and (3) analysis of the spatial and temporal variation of the 12-month hydrological SPI drought index and the temperature standardized z-score.

The paper is organized as follows: this Section examines the underlying concepts of drought impacts, the available indices to quantify drought and the previous works in literature; Section 1 gives a brief overview of the study area and describes the datasets and methods used; in Section 2, the spatial and temporal variation of precipitation, surface air temperature, and hydrological drought in the Euphrates–Tigris rivers basin were analyzed and discussed. Finally, the study is concluded in the last Section.

1. Region, data and methods

The Euphrates–Tigris River Basin is a transboundary basin (see Fig. 1 [12]) with a total area of 879,790 km^2 (13 % of Middle East) distributed mainly (98 %) between Iraq, Turkey, the Islamic Republic of Iran, the Syrian Arab Republic (Tab. 1, [24]). Iraq lies at 33° North latitude and 44° East longitude. The north south extents of Iraq's borders run from 37° 21' N in the north region along its northern border with Turkey to 29° 04' N along its southern border with Saudi Arabia. Iraq's east-west extent spans from 38° 56' in the Syrian Desert to 48° 36' in the vicinity of the Shatt al Arab [16].

Table 1

Country areas in the Euphrates–Tigris River Basin

Basin and countries included	Basin per country (Km^2)	% of total area of the basin	% of total area of the country
Euphrates–Tigris	879 790	100	-
Iraq	407 880	46.4	93.1
Turkey	129 190	21.8	24.5
Iran	166 240	18.9	9.5
Syria	96 420	11.0	52.1
Saudi Arabia	16 840	1.9	0.8
Jordan	220	0.03	0.2

The Euphrates and Tigris Rivers originate from the highlands of eastern Turkey, Iran, and Syria, and discharge south into Syria and Iraq, where they merge to feed the Mesopotamian marshlands in southern Iraq. Nearly all of the flow (90 %) of the Euphrates River originates in the highlands of eastern Turkey, with modest contributions from the Syrian highlands but only minimal additions from Iraq. The mountains in eastern Turkey contribute a smaller amount (40 %) to the Tigris river flow, and the remainder comes from numerous tributaries that originate in the Zagros Mountains between Iraq and Iran [25]. The Tigris and Euphrates Rivers are the most important surface water resources for Turkey, Syria and Iraq. They are also important to life, socioeconomic development, and political stability in the Middle East [26].

The upper basin of the rivers is characterized by the rock and mountain gorges of Anatolia and the high plateaus of Syria and Iraq. The climate of the catchment area may be regarded as being similar to a Mediterranean climate except some differences due to the presence of a mountainous region which is located within the Turkish territory. The climate is a hot-dry summer and cold-rainy winter with occasional snowfall taking place in the mountain region. The precipitation in Mesopotamian basin occurs between October and May. The annual precipitation over the Euphrates–Tigris Rivers basin ranges between 100 and 1000 mm [15, 27]. The heaviest precipitation occurs from December to February. Generally, snow melting begins in February causing higher discharges during spring flows (March to May or early June). Low water discharges are usually during the hotter and drier summer months (July to October). During this period the main source of the rivers runoff is groundwater. The average monthly temperatures range from 6 °C in January to 34 °C in July, but the temperatures decrease towards the north [15, 27, 28].

1.1. Dataset and calculations

The datasets used in this paper which are the observations of monthly mean surface air temperatures (at 2 m above surface) and monthly total precipitation are obtained from the University of Delaware Air Temperature dataset (Version 4.01) [29], which provides monthly global gridded high resolution station (land) data from the period 1900–2014. A large number of stations from the Global Historical Climate Network (GHCN) and various other sources are used in the production of this dataset [30]. All the results presented in this paper were calculated using MATLAB programming language version 8.5.0.197613 (R2015a), whereas the ArcGIS version 10.1 was used to simulate the results as geographical maps. The Euphrates–Tigris rivers basin shapefile used within the ArcGIS was projected using the map of the area presented in Fig. 1. The whole period covered 115 years (1900–2014), was divided into four sub-periods, each of 30 years as follows: first 1900–1929, second 1930–1959, third 1960–1989 and fourth 1985–2014. We mainly produced simple calculations of the mean values of temperature and precipitation for the sub-period and evaluated the difference between these values with the average for 115 years. The probability of occurrence of various categories of hot and cold months was defined as a month in which its absolute value of the standardized monthly mean temperature value exceeds 0.99 (|z-score| $>$ 0.99), as follows: 0.99 ≤ |z-score| ≤ 1.49 for moderate, 1.5 ≤ |z-score| ≤ 1.99 for very high, and |z-score| ≥ 1.99 for extreme, the z-score is calculated as follows:

$$z = \frac{\left(T - T_{mean}\right)}{\sigma}, \tag{1}$$

where T_{mean} and σ are the mean and standard deviation of the monthly time series temperature.

More complex calculations were needed in the calculation of Standardized Precipitation Index (SPI). The SPI [8] is widely used around the world for drought forecasting, frequency analysis, spatial-temporal analysis and climate impact studies. SPI is also recommended as a meteorological drought index by the World Meteorological Organization [6]. The computation of the SPI drought index for any location is based on the long-term precipitation record (at least 30 years) cumulated over a selected time scale. This long-term precipitation time series is then fitted to a gamma distribution, which is then transformed through an equal probability transformation into a normal distribution. Positive (negative) SPI values indicate wet (dry) conditions with greater (lower) than median precipitation [5].

In most cases, the probability distribution that best models observational precipitation data is the Gamma distribution. The gamma distribution is defined by its frequency or probability density function [5, 31]:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}, \text{ for } x > 0, \tag{2}$$

where $\alpha > 0$ is the shape parameter, $\beta > 0$ is the scale parameter, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ is the Gamma function, which is defined by the integral:

$$\Gamma(\alpha) = \int_0^{\alpha} \gamma^{\alpha-1} e^{-\gamma} d\gamma. \tag{3}$$

Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation total for a station. The maximum likelihood solutions are used to optimally estimate α and β for n precipitation observations:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right); \quad \text{where } A = ln(\bar{x}) - \frac{\sum ln(x)}{n} \text{ and } \beta = \frac{\bar{x}}{\alpha} \tag{4}$$

The cumulative probability G(x) is given by:

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\beta\Gamma(\alpha)} = \int_0^x x^{\alpha-1} e^{-x/\beta} dx \tag{5}$$

The Gamma function is not defined by $x = 0$, and since there may be no precipitation, the cumulative probability becomes:

$$H(x) = q + (1-q)\,G(x) \tag{6}$$

Where q is the probability of no precipitation. H(x) is the cumulative probability of precipitation observed. The cumulative probability is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. SPI is categorized based on their range values, is shown in Tab. 2.

Table 2

Drought classification based on SPI

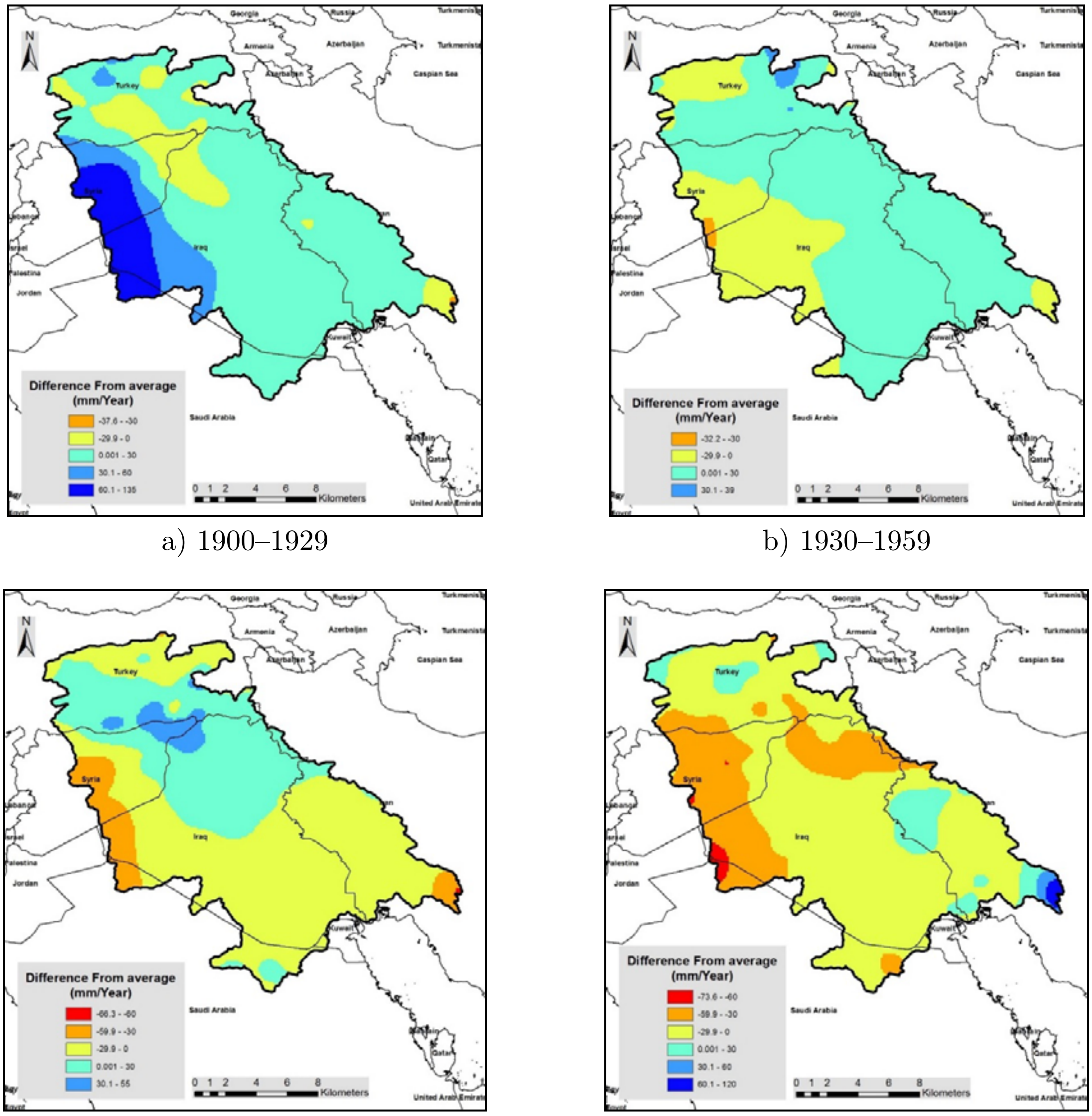
SPI values	Class	SPI values	Class
2.00 and more	Extremely wet	–2.00 and less	Extremely dry
1.50 to 1.99	Very wet	–1.50 to –1.99	Very dry
1.00 to 1.49	Moderately wet	–1.00 to –1.49	Moderately dry
0.99 to 0.00	Normal	0.00 to –0.99	Near normal

2. Results and discussion

2.1. Spatial and temporal analysis of regional precipitation

There is a large spatial variation in precipitation amount over the Euphrates–Tigris rivers (ET) basin. Fig. 2 (a) illustrates the spatial variation of the precipitation anomalies for the first sub-period compared to the average of the whole period from 1900 to 2014, positive precipitation anomalies (up to 143.6 mm above normal) dominate 87.4 % of the area within the ET basin, whereas negative precipitation anomalies (down to 37.5 mm below normal) dominate 12.6 % of the region, with a mean of 19.15 mm and standard deviation of 27.0 mm.

Fig. 2 (b) illustrates the spatial variation of the precipitation anomalies for the second sub-period, positive precipitation anomalies (up to 38.45 mm above normal) dominate 73.7 % of the area within the ET basin, whereas negative precipitation anomalies (down to 32.2 mm below normal) dominate 26.3 % of the region, with a mean of 4 mm and standard deviation of 10.7. Fig. 2 (c) illustrates the spatial variation of the precipitation anomalies for the third sub-period, positive precipitation anomalies (up to 54.5 mm above normal) dominate 36.6 %



a) 1900–1929

b) 1930–1959

c) 1960–1989

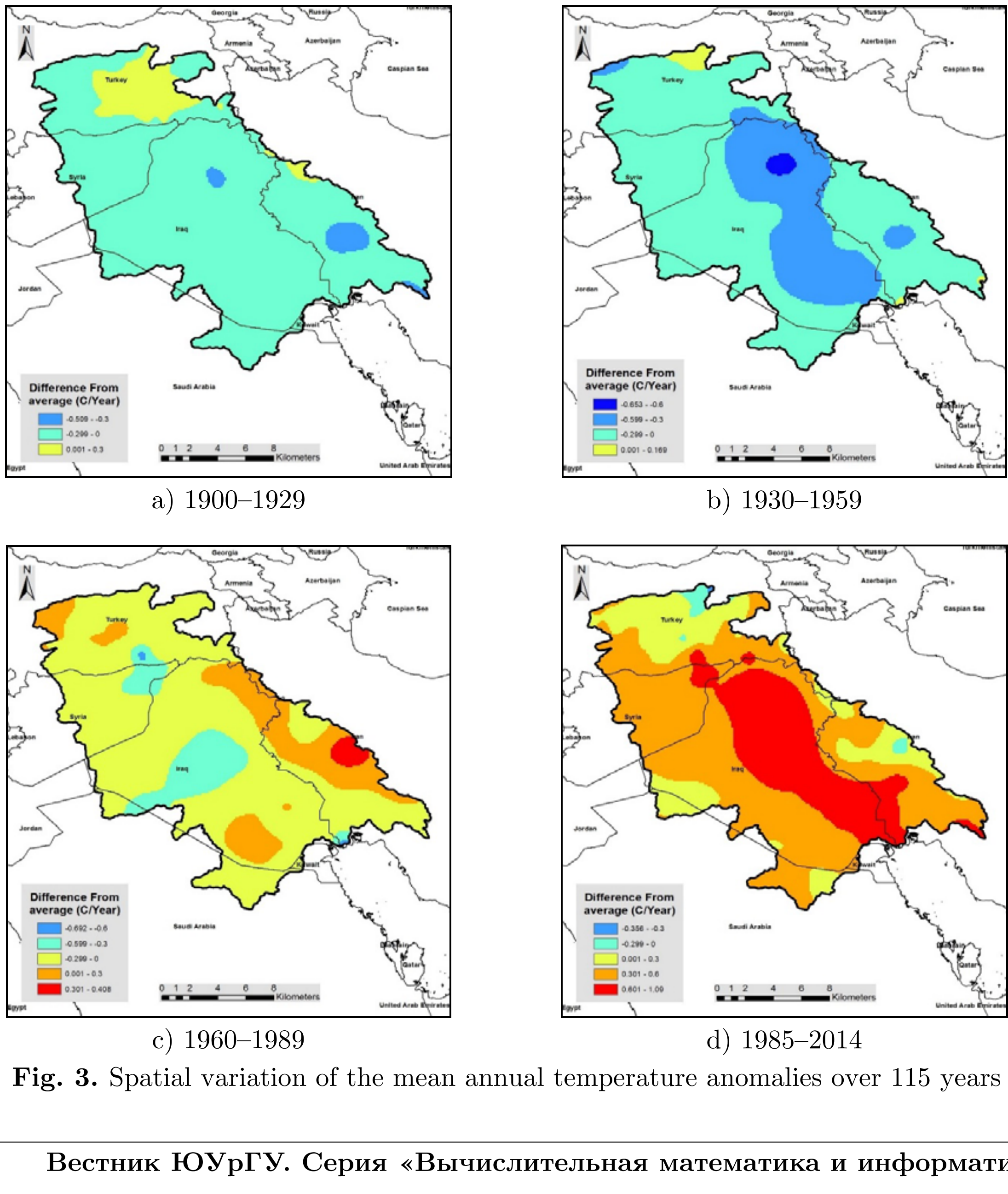
d) 1985–2014

Fig. 2. Spatial variation of the mean annual precipitation anomalies over 115 years

of the area within the ET basin, whereas negative precipitation anomalies (down to 66.3 mm below normal) dominate 63.4 % of the region, with a mean of –66.3 mm and standard deviation of 54.5 mm. Finally, Fig. 2 (d) illustrates the spatial variation of the precipitation anomalies for the fourth sub-period. Positive precipitation anomalies (up to 120.2 mm above normal) dominate only 10 % of the area within the ET basin, whereas negative precipitation anomalies (down to 73.6 below normal) dominate 10 % of the region, with a mean of –19.15 mm and standard deviation of 18.60 mm.

2.2. Temperature anomaly in ET basin

Fig. 3 (a) illustrates the spatial variation of the temperature anomalies for the first sub-period compared to the average of the whole period from 1900 to 2014. Positive temperature anomalies (up to 0.162 °C above normal) dominate 8.4 % of the area within the Euphrates– Tigris Rivers basin, whereas negative temperature anomalies (down to 0.51 °C below normal) dominate 91.6 % of the region, with a mean of –0.12 °C and standard deviation of 0.09 °C.



a) 1900–1929 b) 1930–1959

c) 1960–1989 d) 1985–2014

Fig. 3. Spatial variation of the mean annual temperature anomalies over 115 years

Fig. 3 (b) illustrates the spatial variation of the temperature anomalies for the second sub-period. Positive temperature anomalies (up to 0.17 °C above normal) dominate 1.52 % of the area within the Euphrates–Tigris Rivers basin, whereas negative temperature anomalies (down to 0.65 °C below normal) dominate 98.5 % of the region, with a mean of –0.24 °C and standard deviation of 0.13. Fig. 3 (c) illustrates the spatial variation of the temperature anomalies for the third sub-period. Positive temperature anomalies (up to 0.41 °C above normal) dominate 18.40 % of the area within the Euphrates–Tigris Rivers basin, whereas negative temperature anomalies (down to 0.69 °C below normal) dominate 81.60 % of the region, with a mean of –0.12 °C and standard deviation of 0.15 °C. Finally, Fig. 3 (d) illustrates the spatial variation of the temperature anomalies for the fourth sub-period. Positive temperature anomalies (up to 1.09 °C above normal) dominate 98.6 % of the area within the Euphrates–Tigris Rivers basin, whereas negative temperature anomalies (down to 0.355 °C below normal) dominate 1.4 % of the region, with a mean of 0.46 °C and standard deviation of 0.216 °C.

2.3. Precipitation and temperature by country

Variation in precipitation amount depending on the area of each country located within the basin is demonstrated by Tab. 3.

Table 3

Change of annual precipitation and temperature in ET basin shared by countries

Country	1900–1929	1930–1959	1960–1989	1985–2014	mean	units
Turkey	595.6	594.5	595.4	573.8	589.8	mm
	12.62	12.48	12.55	12.91	12.64	°C
Syria	270.9	220.2	213.0	181.9	212.5	mm
	18.69	18.63	18.58	19.27	18.79	°C
Iran	341.0	341.2	321.7	333.6	334.4	mm
	19.21	19.19	19.39	19.78	19.39	°C
Iraq	218.5	202.1	196.4	174.9	198.0	mm
	22.0	21.9	22.0	22.76	22.2	°C

This indicates that the average total precipitation during the year in all countries of basin decreased in the fourth sub-period compared to the first sub-period, and all countries have precipitation in 1985–2014 lower than average. The amount in countries with lower part of basin: Syria and Iraq decreased by 33 % and 20 %, and countries of upper part of basin Iran and Turkey decreased by only 2–4 %. A large spatial variation in temperature over the Euphrates–Tigris rivers basin was detected, also. This indicates that mean annual temperature in Syria and Iraq increased by 3–3.5 %, respectively, in the fourth sub-period compared to the first sub-period. In Turkey and Iran temperature rising is 2.5 %–3 %.

2.4. Seasonal precipitation and temperature change in Iraq

Using the average of the whole period 1900–2014 as a precipitation benchmark for all other sub-periods, Tab. 4 illustrates the mean precipitation anomalies (mm) for rainy months of the four sub-periods in Iraq. What distinguishes the comparison is that the decrease in mean monthly precipitation took place during all rainy months within the fourth sub-period.

Table 4

Mean of monthly precipitation anomalies (mm) for the four sub-periods in Iraq

Month	1900–1929	1930–1959	1960–1990	1985–2014
Jan	3.911	2.305	–1.132	–6.101
Feb	3.444	0.626	1.162	–6.278
Mar	2.990	–0.039	0.365	–3.979
Apr	2.312	0.242	1.241	–4.555
Nov	3.615	–0.681	–0.940	–2.393
Dec	2.495	3.299	–1.404	–5.268

The mean monthly temperature over 115 years in Iraq fluctuated between the lowest and highest values of 6.86 °C during January and 32.17 °C during July respectively. Using the average of the whole period 1900–2014 as a temperature benchmark for all other sub-periods, Tab. 5 illustrates the mean monthly temperature anomalies for the 12 months of the four sub-periods in Iraq. What distinguishes the comparison of the four sub-periods with the average is that the decrease in mean monthly temperature took place during all months.

Table 5

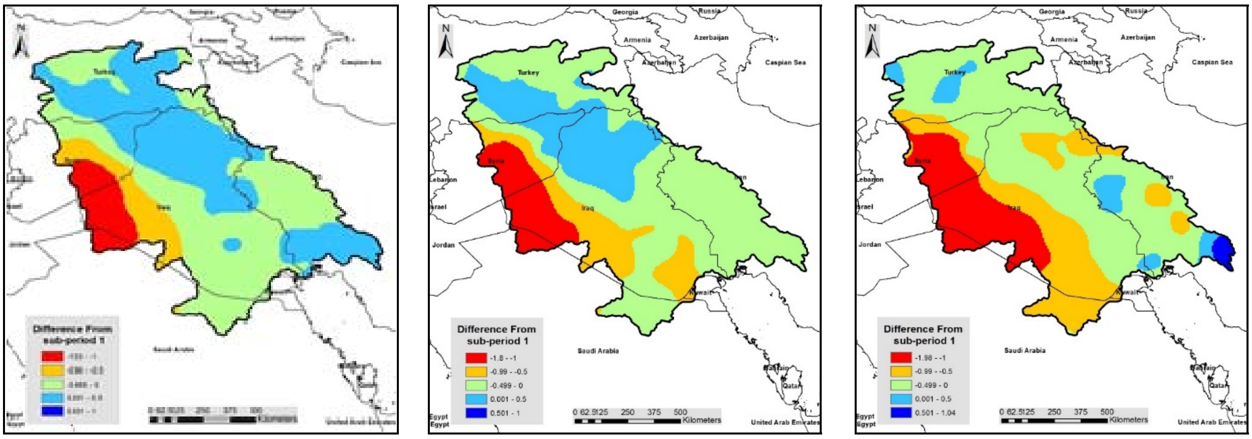
Mean of monthly temperature anomalies °C for the four sub-periods in Iraq

Month	1900–1929	1930–1959	1960–1990	1985–2014
Jan	–0.136	–0.205	–0.042	0.459
Feb	–0.316	–0.296	0.119	0.592
Mar	–0.264	–0.481	0.054	0.829
Apr	–0.301	–0.292	–0.137	0.876
May	–0.371	–0.414	–0.011	0.955
Jun	–0.284	–0.541	–0.116	1.130
Jul	–0.096	–0.458	–0.101	0.785
Aug	–0.045	–0.226	–0.340	0.733
Sep	0.117	–0.369	–0.072	0.389
Oct	0.135	–0.062	–0.388	0.378
Nov	0.318	–0.017	–0.388	0.104
Dec	–0.027	–0.186	–0.161	0.449

2.5. Analysis of drought index and temperature z-score

The SPI drought index was calculated at 12-month time scale and analyzed at a regional scale in reference to the mean monthly precipitation in Iraq. Fig. 4 (a) illustrates the spatial variation of the 12-month SPI anomalies for the second sub-period compared to the average of the first sub-period from 1900 to 1929. Positive anomalies up to 0.336 above normal (wet) dominate 38.43 % of the area within the Euphrates–Tigris Rivers basin, whereas negative drought anomalies down to 1.53 below normal (dry) dominate 61.57 % of the region.

Fig. 4 (b) illustrates the spatial variation of the SPI anomalies for the third sub-period. Positive anomalies (up to 0.425 above normal) dominate 21.86 % of the area within the Euphrates–Tigris Rivers basin, whereas negative SPI anomalies (down to 1.804 below normal)



a) 1930–1959 b) 1960–1989 c) 1985–2014

Fig. 4. Spatial variation of the SPI 12-month anomalies compared to the average of the first sub-period 1900–1929

dominate 78.14 % of the region. Finally, Fig. 4 (c) illustrates the spatial variation of the drought index anomalies for the fourth sub-period. Positive anomalies (up to 1.04 above normal) dominate 6.69 % of the area within the Euphrates–Tigris Rivers basin, whereas negative anomalies (down to 1.98 below normal) dominate 93.31 % of the region.

The probability of occurrence of various categories of wet and dry periods depending on the 12-month timescale of the SPI in Iraq is shown in Tab. 6.

Table 6

Drought classification based on 12-month SPI in Iraq for the four sub-periods

Class	1900–1929 No. months	%	1930–1959 No. months	%	1960–1989 No. months	%	1985–2014 No. months	%
Extremely wet	12		12		12		10	
Very wet	21	18.6	25	20.0	27	18.3	3	4.7
Moderately wet	34		35		27		4	
Near normal	260		244		237		245	
Moderately dry	21		29		32		50	
Very dry	1	6.1	14	12.2	17	15.8	21	27.2
Extremely dry	0		1		8		27	

A simple comparison can be made by using SPI of the first sub-period as a benchmark for all other sub-periods. In the second (third) sub-period, 12.22 % (15.83 %) of the time series revealed dry periods with varying intensities, indicating that drought frequency increased by 100(159) % compared to the first sub-period. And finally, the fourth sub-period revealed 27.22 % dry periods, indicating that drought frequency increased by 345.5 %.

It should be noted, however, that the greatest reduction in annual precipitation is observed in most arid western parts of Iraq, where agriculture is mainly irrigated (see Fig. 2 and Fig. 4). So here the impact of reduction of precipitation can be partially compensated. In

Table 7

Temperature classification based on z-score in Iraq for the four sub-periods

Class	1900–1929 No. months	%	1930–1959 No. months	%	1960–1989 No. months	%	1985–2014 No. months	%
Extremely Cold	6	16.4	15	18.9	10	18.9	4	7.2
Very Cold	16		15		19		9	
Moderately Cold	37		38		46		13	
Near normal	253		261		237		218	
Moderately Hot	29	12.8	26	8.3	31	15.8	54	31.7
Very Hot	15		4		11		35	
Extremely Hot	2		0		2		25	

rain-fed areas in the northern Iraq, there also was a decrease in precipitation, but not so strong as in the west of the country.

The surface air temperature z-score was calculated and analyzed at a regional scale in reference to the mean monthly temperature in Iraq. The probability of occurrence of various categories of relatively cold and hot conditions depending on the z-score in Iraq is shown in Tab. 7. As in the case of precipitation, z-score of the first sub-period can be used as a benchmark for all other sub-periods. Thus, 8.3 % (15.8 %) of the second (third) sub-periods were presented by hot conditions, indicating that it decreased (increased) by 35.16 % (23.44 %) in the relation to the first sub-period. And finally, during fourth sub-period, the 31.7 % of the time were occupied by hot conditions, 147.7 %. Obviously, winter and summer effects of warm and cold weather are different, so that we examined seasonal distribution of the number of months with more colder (warmer) than normal (Tab. 8).

As can be seen from Tab. 8, the greatest number of months with significant excess of normal temperatures ($>$ 9 cases) was observed in the last period, from March to September, with a maximum of frequency up to 14 months in July. This actually means the likelihood to observe of high temperatures every third summer. Note that during the winter months, when there is a noticeable decrease in precipitation (5–6 mm, see Tab. 4), the frequency of the warm events (5–7 cases) was lower than in summer and was balanced by number of cold events (3–5).

Conclusion

If one combines the results of Sections 2.1–2.5, it turns out that the increase in the frequency of dry months (Tab. 7) and the decrease in winter rainfall (Tab. 4) are accompanied by the moving of hydrological drought borders, from deserts of Syria and west of Iraq to upper and lower Mesopotamia (Fig. 4). Here, in a densely populated valley of the Tigris, the major increase in temperature was observed during last 30-years (Fig. 3 (d)). This increase coincides with the end of the rainy season and the onset of summer. It is evident that the establishment of more hot regional conditions, in general, is accompanied by increased frequency of extremely high summer temperatures (Tab. 8), that indirectly indicate about pos-

Table 8

Seasonal distribution of hot and cold events based on z-score

Month	No. hot months ($Z \geq 1$)				No. cold months ($Z \leq -1$)			
	1900–29	1930–59	1960–90	1985–2014	1900–29	1930–59	1960–90	1985–2014
Jan	4	2	3	5	4	4	6	3
Feb	4	2	9	7	6	5	6	4
Mar	4	4	4	9	7	7	5	4
Apr	3	3	4	10	7	5	6	0
May	3	2	4	13	6	6	6	1
Jun	2	0	2	13	7	7	5	1
Jul	5	0	3	14	3	10	4	2
Aug	2	2	2	12	3	6	8	0
Sep	4	3	2	9	3	8	4	0
Oct	6	3	2	9	4	3	11	3
Nov	5	5	5	7	4	2	7	5
Dec	4	4	4	6	5	5	7	3

sible growth heat waves in the main metropolitan areas of Iraq (Basra, Baghdad and Mosul).

Given the decreasing precipitation in arid areas east of Iraq and increase in summer temperatures nearby lowlands, one can speak about the current climatic desertification of Iraq. On the other hand, the assessment of hydrothermal risks, expressed in standardized precipitation index and temperature, said about generally normal hydrological conditions at the headwaters of the Tigris and Euphrates (Fig. 4). This, despite the construction of dams in the upper basins of these rivers, is conducive to the flow of water into Iraq. That, in turn, compensates for the increase in water consumption for irrigation, associated with a decrease in the atmospheric water component and an acceleration of moisture loss by soil evaporation and by vegetation transpiration at higher temperatures. One notable problem of last 30 years (Fig. 4 (d)) is the emergence of some “spots of drought” in the east and north-east of Iraq. Here, in the basin of the left tributaries of the Tigris, apart from irrigated agriculture, rainfed farming and pasture fields are widely practiced.

The results above indicate about significant decrease (increase) of annual precipitation (temperature) occurred during last century in some parts of the Euphrates–Tigris Rivers basin. Slow climatic changes are accompanied by growing numbers of dry months, when rainfall is far below normal, and the increasing frequency of extremely hot months.

It is obvious that the response to climate change will be different both in agricultural and natural landscapes of Iraq and adjacent territories. The evaluation and verification of this response are the subjects of new study and should be useful for national adaptation to climate change.

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ПРЕДВАРИТЕЛЬНАЯ ОЦЕНКА ГИДРОТЕРМАЛЬНЫХ РИСКОВ В БАССЕЙНЕ ЕВФРАТА И ТИГРА: ЗАСУХИ В ИРАКЕ

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В работе исследованы пространственно-временные аномалии месячных температур и осадков, в бассейне рек Евфрат–Тигр, а также изменение частоты засух в республике Ирак. Весь ряд данных с 1900 по 2014 год были разделен на четыре тридцатилетних интервала (1900–1929, 1930–1950, 1960–1989, 1985–2014), для которых вычислены средние значения температуры и сумм осадков, индексы засушливости и другие характеристики. Анализ показал, что среднее количество осадков в Ираке за четыре интервала последовательно уменьшалось с 218,5, 202,1, 196,4 до 174,9 мм, при среднем значении за весь период 198 мм. Таким образом, примерно за 100 лет наблюдается 20 % уменьшение осадков. Среднегодовая температура в последний тридцатилетний период напротив, выросла по сравнению с началом 20 века на 0,76 °C, или на 3,45 %. При этом частота засушливых (жарких) месяцев в Ираке увеличилась на 345 % (148 %) за столетие. Отмечено, что увеличение засушливости, в большей мере, наблюдается в зонах орошаемого земледелия западного Ирака. На севере и северо-востоке страны, где сосредоточены районы богарного земледелия и пастбищного животноводства, рост частоты засушливых условий, более умеренный, чем на западе Ирака. Сделан вывод о текущем климатическом опустынивании Ирака и его возможных следствиях.

Ключевые слова: бассейн рек Евфрат–Тигр, Ирак, температура, осадки, изменение климата, z-оценка, стандартизованный индекс осадков.

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