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SEASONAL AND INTER-ANNUAL VARIATION OF PRECIPITATION IN IRAQ OVER THE PERIOD 1992-2010

Sezonowa i wieloletnia zmienność opadu w Iraku w latach 1992-2010

Słowa kluczowe: opad atmosferyczny, zmienność, trendy malejące, Irak
Key words: precipitation, variability, decreasing trends, Iraq

INTRODUCTION

Water is of great importance in human societies and it is a key driver of growth and sustainable development (Grey et al. 2013). Basic water security depends on the availability of freshwater resources, which in arid and semi-arid climates are becoming ever more scarce and thus fail to meet the demands of the local population. Water insecurity is tied to the scarcity of liquid water (blue water) or rainwater infiltrating the soil (green water) (Falkenmark 2013). Water shortages may originate from both climatic phenomena and water cycle disturbances on the local, regional, or global scale. Evidently, large-scale changes in temperature and precipitation recharging terrestrial water resources might lead to changes in the availability of surface and groundwater resources in a region, with consequent implications for agriculture, food production, and water supply for municipalities and industry, and the effective planning and management of water resources. Global average annual precipitation is likely to increase through the end of the century, however regionally changes are expected to vary significantly (IPCC 2013). Some regions might become even drier due to elevated temperature and lower precipitation (Zakaria

2013). In such transformed conditions more severe water shortages are likely to appear and threaten the livelihood of societies. Global average annual precipitation through the end of the century is expected to increase, although changes in the amount and intensity of precipitation will vary significantly by region

Concerning the territory of Iraq, positive trends in mean annual air temperatures time series were detected in two short separated periods, 1941–1980 and 1995–2013 (Muslih, Błażejczyk 2016). Based on data from seven weather stations across the country, the current warming period over Iraq was detected, which started in the mid 70s of the 20th century. The strongest warming trends were identified in the summer months. Some other studies have investigated precipitation variability over Iraq in the context of its spatial and temporal heterogeneity. A.M. Al-Salihi et al. (2014) analyzed annual and seasonal precipitation between 1981 and 2010. A downward trend in annual precipitation was detected at the majority of stations in Iraq; however, an upward trend at selected stations was also noticed. Points of change in annual precipitation occurred in selected time series in the 1990s. Other investigations were conducted by A.A. Azooz and S.K. Talal (2015) for 4 selected stations, covering a time period of one century. They have proved the existence of specific trends in mean monthly air temperatures and monthly precipitation for four major meteorological stations in Iraq. They have predicted an increase in temperature of about 2.2°C by 2050 and a 25% decrease of precipitation when compared to those of 1900. Analyses show that climate changes in Iraq have had a significant impact on regional and local water resources, both in terms of blue and green water (Al-Ansari et al. 2014, Osman et al. 2014, Abbasa et al. 2016, Shubbar et al. 2016).

While the majority of existing studies investigated changes in precipitation in Iraq by analyzing the time series at selected locations of rain gauges using a temporal window spanning from several decades up to a century, this study focuses on the period of 1992-2010. The reason behind the selection of this period was to detect and estimate the magnitude of existing trends in the precipitation time series for the most recent period and to start the analysis from a break point at which high annual anomalies over a latitudinal band at approximately 30 degrees latitude north occurred, as proved by D. L. Hartmann et al. (2013). In effect, this study is concerned with the extent to which past variability of precipitation provides information on the most recent trends and simultaneously gives an insight into the potential risks for the future. The results of trend analysis in precipitation series are important for policy makers, water resources management, and agriculture.

DATA AND METHODS

Monthly and annual precipitation data in the years 1992-2010 was used from twenty weather stations in Iraq (Fig. 1, Table 1) located mainly in the central and eastern part of the country.

In order to characterize the seasonal variation of precipitation in different regions of Iraq, mean, maximum, and minimum monthly precipitation registered at selected stations across the country were analyzed and characterized in the multi-year period 1992-2010.

In order to detect drying trends in annual precipitation, the non-parametric rank-based Mann–Kendall test was applied. This test is widely used for trend detection in hydro-meteorological time series (Radziejewski, Kundzewicz 2004a) and was applied in different studies prior to this one (e.g. Longobardi, Villani 2011, Mondal et al. 2012, Duhan, Pandey 2013). The HYDROSPECT software (Radziejewski, Kundzewicz 2004b) was used to calculate the Mann-Kendall test statistic and statistical significance. Significance levels of 99.9%, 99%, and 95% correspond to the test statistics of 3.290, 2.575, and 1.960, respectively. The hypothesis that there is no trend is rejected when the value of the test statistic is greater in absolute value than the critical value at a chosen level of significance. Negative values of the test statistic indicate decreasing trends in precipitation. The Kendall-Theil robust line

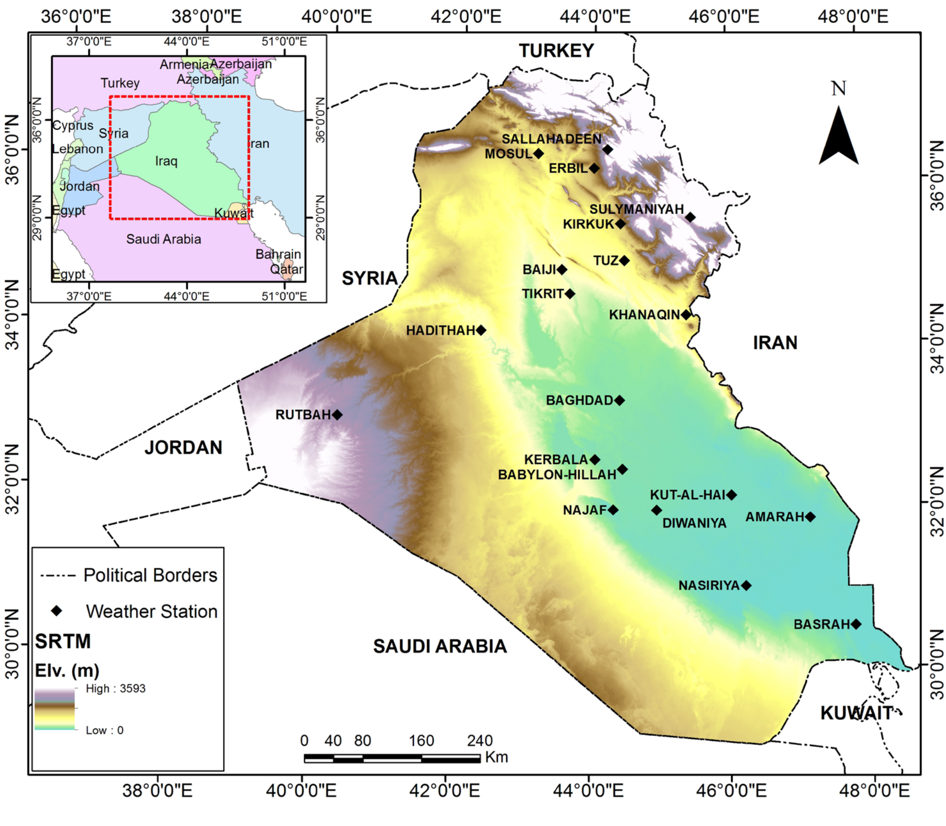

Fig. 1. Location of weather stations across Iraq on a background of DEM. Source: USGS (2004)

Table 1. Annual Precipitation (mm) at Meteorological Stations in Iraq recorded in years 1992-2010

Station	**Latitude (degree)**	**Longitude (degree)**	**Elevation (m a.s.l.)**	**Year**						
				1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Basrah	30,52	47,78	2	165	178	153	132	214	233	74
Amarah	31,85	47,17	9	191	180	177	125	324	253	211
Nasiriya	31,02	46,23	3	115	118	110	112	18	160	153
Kut-Al-Hai	32,13	46,03	15	140	182	181	72	234	160	98
Diwaniya	31,95	44,95	20	112	192	148	103	117	113	108
Najaf	31,95	44,32	32	112	170	148	64	91	143	84
Kerbala	32,57	44,05	29	100	115	98	100	126	139	100
Babylon-Hillah	32,45	44,45	27	131	115	124	98	120	99	96
Baghdad	33,3	44,4	34	88	193	153	97	98	114	116
Hadithah	34,13	42,35	140	132	162	222	166	179	220	91
Rutbah	33,03	40,28	615	115	131	175	230	133	237	81
Kirkuk	35,47	44,4	331	669	595	365	286	399	495	288
Baiji	34,9	43,53	150	266	377	207	168	219	258	122
Mosul	36,32	43,15	223	577	633	440	296	529	361	222
Erbil	36,15	44	420	662	602	569	379	414	441	338
Sallahadeen	36,38	44,2	1088	557	644	927	453	486	674	597
Sulymaniyah	35,55	45,45	853	1008	874	953	659	787	855	624
Khanaqin	34,35	45,38	202	287	355	396	286	282	408	269
Tuz	34,88	44,65	220	477	478	420	266	285	383	201
Tikrit	34,58	44,3	107	282	198	238	201	203	244	83

Source: Iraq Meteorological Organization and Seismology 2014, Precipitation data, Ministry of Transportation, Baghdad, Iraq

Table 1. Annual Precipitation (mm) at Meteorological Stations in Iraq recorded in years 1992-2010. cont.

Station	Year											
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Basrah	239	130	127	90	92	184	96	174	139	67	90	32
Amarah	328	201	110	89	128	327	158	251	34	120	149	125
Nasiriya	157	108	63	151	88	99	106	246	113	66	57	58
Kut-Al-Hai	131	89	67	137	102	117	106	179	65	88	85	80
Diwaniya	99	223	93	186	132	57	101	107	44	44	46	49
Najaf	49	55	75	64	83	51	71	191	36	37	49	42
Kerbala	41	42	84	78	95	63	68	96	40	66	48	61
Babylon-Hillah	66	85	81	103	146	71	73	170	41	44	55	62
Baghdad	59	68	82	97	110	119	108	162	99	59	68	93
Hadithah	84	99	148	142	142	105	90	68	40	31	39	33
Rutbah	63	84	103	104	96	57	86	94	72	73	23	109
Kirkuk	230	234	277	462	513	312	249	458	173	135	226	267
Baiji	111	153	155	211	221	189	142	313	173	64	46	71
Mosul	177	273	262	391	340	357	295	511	194	216	224	241
Erbil	226	266	326	544	485	474	293	513	273	298	312	324
Sallahadeen	418	350	493	769	681	753	511	811	448	432	442	463
Sulymaniyah	339	505	513	930	811	743	546	813	589	380	615	476
Khanaqin	172	289	223	367	283	241	222	205	257	218	171	271
Tuz	151	189	217	309	250	197	191	327	201	136	158	244
Tikrit	110	167	180	178	142	135	122	197	114	120	123	201

Source: Iraq Meteorological Organization and Seismology 2014, Precipitation data, Ministry of Transportation, Baghdad, Iraq was applied to quantify the magnitude of the identified trends (Theil 1950, Helsel, Hirsch 2002,), as this method is less sensitive to outliers in comparison with simple linear regression. The Kendall-Theil Robust Line software (KTRLine-version 1.0) developed by the U.S. Geological Survey was used in the calculation (Granato 2006).

MEAN ANNUAL PRECIPITATION

Annual rainfall in Iraq varies spatially (Fig. 2). The lowest mean annual precipitation was recorded at the Kerbala, Najaf, and Hillah stations, where it amounted to less than 100 mm/yr. These stations reflect the conditions of the most arid south-west region of Iraq. Precipitation increases to the north-east. In arid and semi-arid regions to the north-east it falls within the range of 100-300 mm/yr. In Baghdad, Rutbah, Divaniya, Hadithah, Nasiriya, Kut-al-hai, Basrah, Tikrit, Baiji, and Amarah the annual precipitation does not exceed 200 mm/yr, while at Tuz and Thanakin it is close to 300 mm/yr (Fig. 2). Mosul and Kirkuk have relatively higher levels of precipitation, namely up to 340 mm/yr. Stations situated to the north-east (e.g. Salahadeen, Sulymaniyah) receive 400-700 mm/yr. However, in the northernmost mountainous region annual precipitation exceeds 1000 mm (Osman et al. 2014).

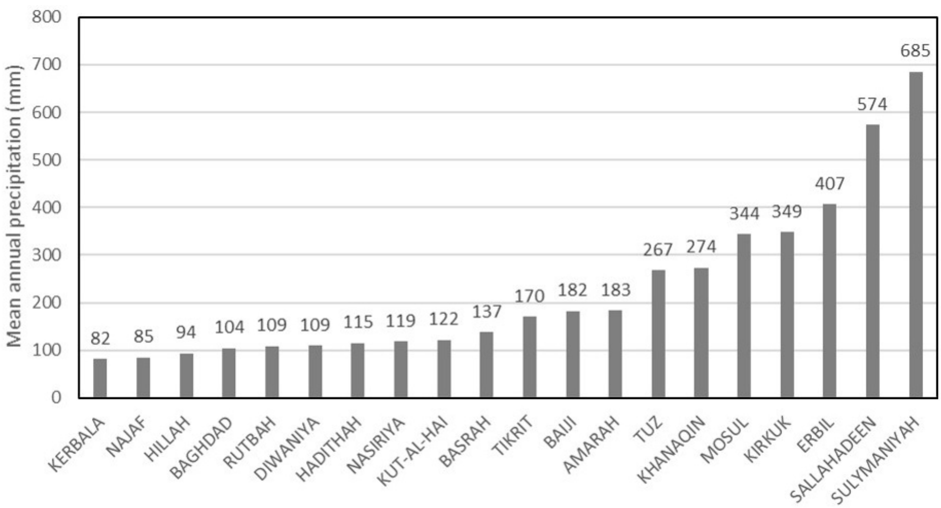

Fig. 2. Mean annual precipitation recorded in years 1992-2010

SEASONAL VARIABILITY OF MONTHLY PRECIPITATION

Precipitation in Iraq is characterized by strong seasonality, with hot and dry summers and winter rains. Monthly variability of maximum, minimum, and mean precipitation have been illustrated for nine selected weather stations in the northern region, the central region, and from west to east (Fig. 3). The rainless season begins in June and lasts until September. The rainy season begins in October and continues until May of the next year. Maximum precipitation in all of the westernmost stations is recorded in April, while in the central stations it is recorded in February and November and in the east-stations – the months of February, March, and April. Maximum mean precipitation is recorded in January in all of the stations, with an obvious increase toward the eastern regions. The attitude of curves show a vertical or longitudinal impact on the precipitation region, because the stations located in the western region have the same maximum precipitation month, and the mean of precipitation in the west is less than that in the central region of Iraq. In addition, the central region recorded a lower mean of precipitation than in the east of Iraq. We can also see a longitudinal impact on the precipitation season, with maximum rainfall that starts earlier in the east than in the central region and earlier in the central region than in the west. This reflects the impact of topography on precipitation in Iraq.

TRENDS IN TIME SERIES OF ANNUAL PRECIPITATION

In order to determine the existence of a trend in annual precipitation, the Mann-Kendall test was applied to the 19-element time series, and trend lines were fitted for each of the twenty weather stations. Results are presented in figures 4, 5, 6, and 7. Fitted lines show a declining tendency observed in all stations and negative slopes clearly show a decreasing (drying) trend in terms of precipitation. This drying tendency is statistically significant at most of the stations at a significance level within the range of 96.9-99.9% (Table 2). A very high significance level of over 95% means that the existence of a monotonic trend in time series is very probable. This level of significance was not attained for data from stations located in Amarah, Baghdad, and Salahadeen, where the estimated level of significance was 84.84%, 65.51%, and 57.89%, respectively. This means that there is no trend for these locations.

The slope of fitted trend lines informs about the trend magnitude. The trend magnitude ranges from 3.1mm/yr in Kerbala up to 21.5 mm/yr in Sulymaniyah (Table 2). This rate of change (for stations where the trend was confirmed) falls within the range of the 2.4 % of mean annual precipitation in the case of Khanaqin, and 7.6% in the case of Hadithah. The mean annual rate of change calculated as arithmetic mean for Iraq is 3.5% of mean annual precipitation calculated for the years 1992-2010.

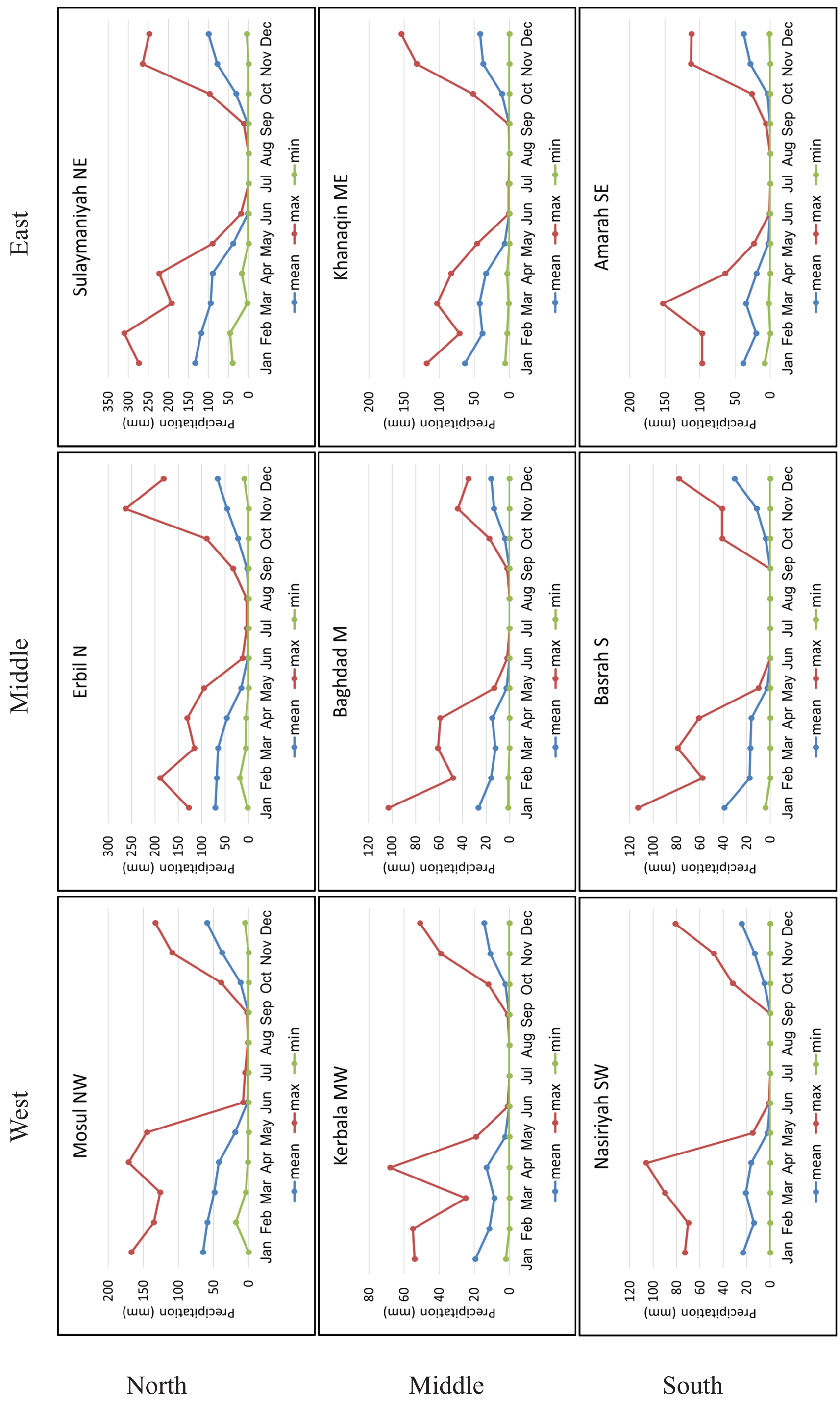

Fig. 3. Mean, maximum, and minimum monthly precipitation at selected weather stations in years 1992-2010

Table 2. Summary statistics of the Mann-Kendall test and estimated rate of change in precipitation related to the mean annual value

Station	Test Statistic	Significance Level (%)	Rate of change (mm/yr)	Percent (%) of Mean Annual Precipitation
Basrah	-2.274	97.70	-6	4,4
Amarah	-1.434	84.85	-5	2,7
Nasiriya	-2.204	97.24	-3,2	2,7
Kut-Al-Hai	-2.414	98.42	-5	4,1
Diwaniya	-2.414	99.63	-5	4,6
Najaf	-2.834	99.54	-4,5	5,3
Kerbala	-2.834	99.54	-3.1	3,8
Babylon-Hillah	-2.764	99.42	-3,8	4
Baghdad	-0.945	65.51	-1.2	1,2
Hadithah	-3.673	99.97	-8.8	7,6
Rutbah	-2.414	98.42	-4,6	4,2
Kirkuk	-2.554	98.93	-14	4
Baiji	-2.274	97.70	-8,6	4,7
Mosul	-2.344	98.90	-13,2	3,8
Erbil	-2.064	96.90	-10,6	2,6
Sallahadeen	-0.805	57.89	-6,4	1,1
Sulymaniyah	-2.414	98.42	-21,5	3,1
Khanaqin	-2.764	99.42	-6,5	2,4
Tuz	-2.694	99.29	-11,6	4,4
Tikrit	-2.204	97.24	-6	3,5

CONCLUDING REMARKS

The analysis demonstrates a broad temporal and spatial variability in precipitation on the territory of Iraq. Seasonality is reflected by the existence of the rainless season, which extends from June until September, and the rainy season, which begins in October and continues until May of the next year. Precipitation varies widely throughout the country. In the highly elevated northern region the impact of topography on the amount of precipitation is revealed. Besides it was shown that the eastern region of Iraq receives more rain than the central region, which itself receives more rain than the western region.

The analysis exhibits significant drying trends detected at most of analyzed weather stations. Statistically significant drying trends were confirmed by the Mann-Kendall test at 17 weather stations. At three stations (Amarah, Baghdad, and Salahadeen) drying signals have occurred (negative values of slope of the Kendall-

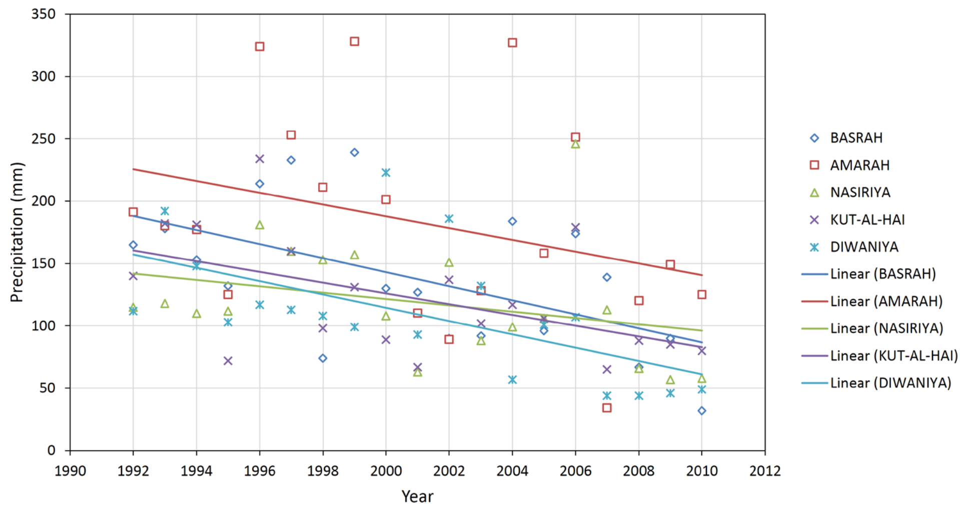

Fig. 4. Linear trend in annual precipitation at selected stations (Basrah, Amarah, Nasiriyah, Kut-Al-Hai and Diwaniya)

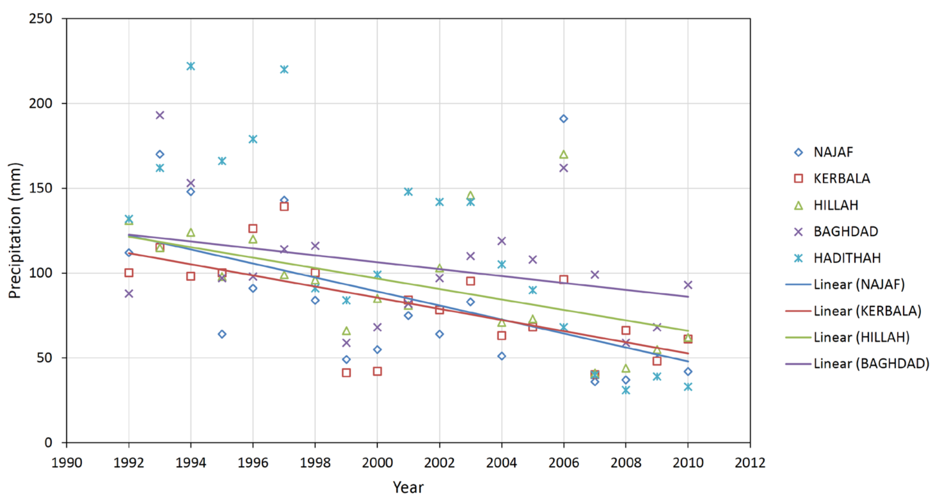

Fig. 5. Linear trend in annual precipitation at selected stations (Najaf, Karbala, Hillah, Baghdad and Haditha)

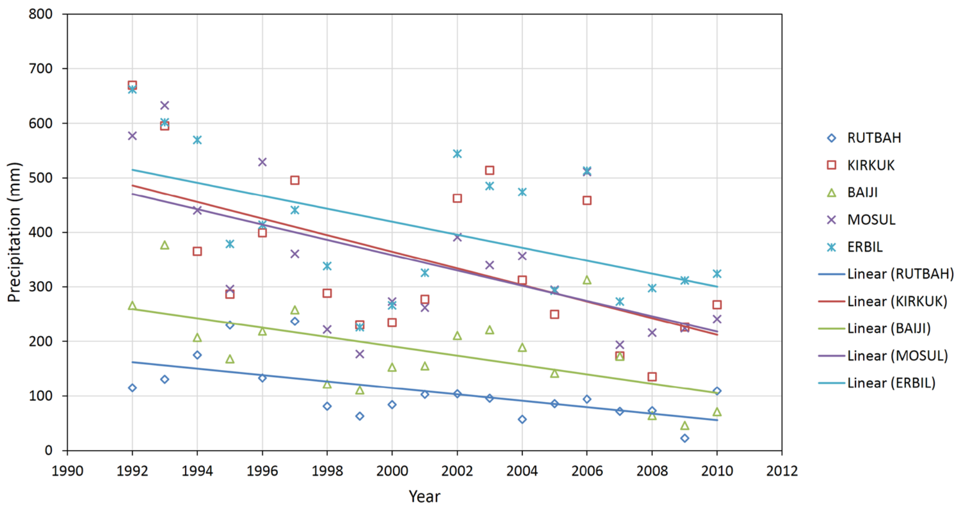

Fig. 6. Linear trend in annual precipitation at selected stations (Rutbah, Kirkuk, Baiji, Mosul and Erbil)

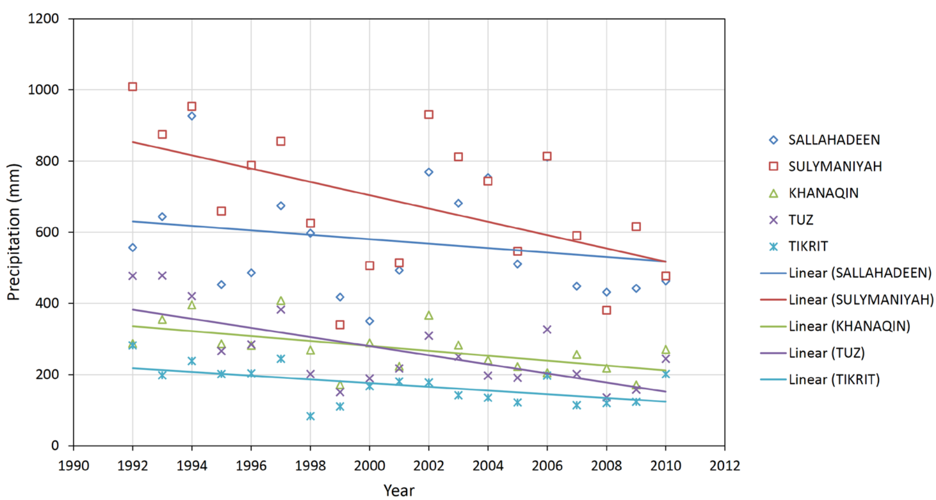

Fig. 7. Linear trend in annual precipitation at selected stations (Salahadeen, Sulaymaniyah, Khanaqin, Tuz and Tikrit)

Theil robust line), which, however, were not statistically significant. The rate of change for Iraq amounts to 3.5% of mean annual precipitation calculated for the years 1992-2010.

Declined precipitation over Iraq amplifies already existing water shortages due to relatively low precipitation and high potential evapotranspiration. In face of climate changes characterized by increased air temperature and decreased precipitation, the risk of water scarcity is becoming increasingly higher. Prolonged drying trends might have a subsequent negative impact on the environment, society, and the socio-economic situation of Iraq. In such a situation, an elaboration of adaptation strategies seems to be obligatory.

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Summary

Iraq suffers from severe droughts, which are an inherent feature of its changing climate conditions. The shortage of water has a negative impact on agricultural land and is associated with a high risk of desertification. Thus, the identification of wetness conditions over a multi-year period is a challenging issue. In this paper, monthly and annual precipitation figures from twenty weather stations in Iraq were analyzed in order to provide insight into the seasonal and inter-annual variation and temporal trends in precipitation over the period of 1992–2010. The non-parametric rank-based Mann–Kendall test was applied to detect trends in annual series and the Kendall-Theil robust line was used to quantify their magnitude. The Mann-Kendall test statistic shows negative values for all stations and this emphasizes a climate change trend toward scarcity in precipitation. Most of the stations show a high significance level of more than 95%, while at the stations of Amarah, Baghdad, and Salahadeen only a drying signal was detected. The rate of change for Iraq amounts to 3.5% of mean annual precipitation calculated for the years 1992-2010.

Streszczenie

Irak doznaje wyjątkowo dotkliwych susz, które są nieodłącznym elementem zmieniających się warunków klimatycznych. Niedobory wody spowodowane niedostatkiem opadów mają niekorzystny wpływ na rolnictwo, a ponadto potęgują ryzyko pustynnienia. Z tego względu istotnym zagadnieniem jest ocena zasilania opadem Iraku w skali wieloletniej. W niniejszej pracy analizowano miesięczne i roczne sumy opadu zarejestrowane na dwudziestu stacjach meteorologicznych w Iraku, głównie w jego części centralnej i wschodniej. Celem pracy była analiza zmienności sezonowej opadu na podstawie sum miesięcznych, a także ocena trendów czasowych zaznaczających się w seriach czasowych rocznych sum opadu w latach 1992-2010. Do wykrycia i zbadania istotności statystycznej zastosowano regresję liniową oraz nieparametryczny test Manna-Kendalla. Uzyskano ujemne wartości statystyki testu Manna-Kendalla dla wszystkich stacji meteorologicznych, co świadczy o tendencji malejącej rocznych sum opadu. Większość stacji wykazuje istotne zmiany na poziomie istotności statystycznej powyżej 95%, natomiast na stacjach Al-Amara, w Bagdadzie i Salahadeen wykryto zmiany w kierunku malejącym, ale nieistotne statystycznie. Średnie tempo zmniejszania się opadów oszacowano na 3.5% średniej sumy rocznej opadów w wieloleciu 1992-2010.