DOI:10.28974/idojaras.2022.2.2

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 126, No. 2, April – June, 2022, pp. 185–201

Assessment of the change of trend in precipitation over Afghanistan in 1979–2019

Qurban Aliyar Assistant [1] and **Morteza Esmailnejad** [2,*]

[1] *Department of Forestry and Natural Resources*
Faculty of Agriculture, Bamyan University
Afghanistan

[2] *Department of Geography*
University of Birjand
Birjand, Iran

**Corresponding author E-mail: esmailnejad.m@birjand.ac.ir*

(Manuscript received in final form March 9, 2021)

Abstract— The civil war, harsh climate, tough topography, and lack of accurate meteorological stations have limited the number of consecutive synoptic data across Afghanistan. The global data (gridded precipitation datasets) pave the way to assess the precipitation indicators of climate, where stations are sparsely located. This study assessed the mean annual precipitation trend in 33 stations over Afghanistan. Non-parametric linear regression technique was employed to find upward and downward trends and magnitudes. The daily of precipitation was obtained from the database of the CPC-NOAA (Climate Prediction Center - National Oceanic Atmospheric Administration) for the period of 1979–2019. The CPC spatial resolution of daily precipitation is 0.5×0.5 degree. Analysis of mean annual precipitation showed a significant decreasing trend at six provinces in the north, while an increasing trend of 9.2 mm per decade has been observed at three provinces. In the south, a notable reduction of the precipitation trend has been experienced in Helmand, Kandahar, and Nimruz provinces, but Ghazni and Uruzgan show a positive trend. Data revealed that mean annual precipitation has remarkably decreased in the western part of Afghanistan. According to the study period, the mean annual rainfall in the central regions indicates a raise of 37.5 mm per decade in Kabul, while in Vardak, the precipitation increases up to 9.21 mm per year. Eastern regions include 8 provinces, and the eastern highland covers the smallest area that is mainly covered by rangeland and the largest existing forests. These regions are directly influenced by the moist air masses of Indian monsoon getting trapped at the high mountain slopes, and it can lead to an increase of rain. Data reveals an upward trend of precipitation in the eastern part of Afghanistan.

Key-words: climate change, Afghanistan, rainfall variation

1. Introduction

Climate change is a change in climatic parameters (such as temperature, precipitation, and their characteristics) and associated patterns (*Pachauri et al*., 2014). In this regard, changes in temperature and precipitation due to their association with phenomena such as drought, floods, and their hydrological and biological consequences are receiving more attention (*Sheila*, 2013). Despite this very alarming situation, almost no scientific literature on climate change and its impacts in the past, nor projected for the future, exists (World Bank, 2014). Therefore, climate change as effective process on social, economic, and environmental phenomena and processes has been considered by scientific circles. (*Groisman et al*., 1999) Afghanistan is frequently ranked among the countries most vulnerable to climate change *(Kreft, et al*., 2015). Afghanistan, as a society often based on the rural economy on natural resources. The livelihood of most Afghans depends on agriculture, and agriculture depends on rainfall. Changes in rainfall could lead to vulnerability for farmers in Afghanistan, which is happening. These resources are very vulnerable to climate change. More than 80% of the country's water resources (a total of 75 billion cubic meters of water, 55 billion cubic meters of which includes surface currents and 20 billion cubic meters of groundwater) come from the Hindu Kush Mountains and its rainfall (World Bank, 2014). Change in climate extremes was assessed that indicate reduction frosts and freeze and raising in hot days in most part of the world (*Karl et al.*, 1999). Climate variability is the one of the threats to water resources in tropical regions at large scale. Changes in precipitation have direct effects on water resources, agriculture, forestry, ecosystem, natural resources, plant cover, and drinking water (*Cannarozzo et al*., 2006). Precipitation generally increases in the extra-tropical areas, conversely, rainfall declines in the subtropical region (*Houghton*, 1996). Change in precipitation, evaporation, and snow cover extent have occurred significantly, during the last 50 years over the conterminous United States (*Kunkel et al.*, 1999; *Frei et al*., 1999). Precipitation shows a 10% increase since 1910 throughout the contiguous United States (*Karl* and *Knight*, 1998). Precipitation trend is seen as a long-term increase mostly in North America, mid- to high-latitude Eurasia, Argentina, and Australia during the period of 1900–1988 (*Dai et al*., 1997). Frequency of precipitation has been remarkable increased in U.S. since 1920, and less extreme events have occurred in some part of Canada (*Kunkel,* 2003). The average of precipitation has increased by more than 10% in Canada over the 20th century (*Groisman* and *Easterling,* 1994; *Mekis* and *Hogg*, 1999; *Akinremi et al*., 2001*; Cutforth et al.,* 2001). Heavy daily rainfall interrelated with global warming because of atmospheric water vapor and warmer air (*Solomon* and *Srinivasan*, 1995). Increased variance of precipitation has occurred everywhere that wet areas become wetter and arid areas become drier. Overall, precipitation increased at high latitudes (Northern Hemisphere), decreased in China, Australia, and the Small Island States in the Pacific, and its variance increased in equatorial regions. The changes in the major ocean currents also appear to be affecting precipitation patterns. For example, increased intensity and frequency of El Niño and ENSO seem to be associated with the evidence of an observed ‘‘dipole’’ pattern affecting Africa and Asia, although this time series is too short so far (*Dore*, 2005). The number and fequency of extremely intensive rainfalls were reduced in the southwestern and western parts of Australia, conversely, an increase in the extreme events can be observed in the eastern part of Australia (*Allan* and *Haylock*, 1993; *Nicholls* and *Lavery*, 1992: *Suppiah* and *Hennessy*, 1998; *Haylock* and *Nicholls*, 2000; *Hope et al*., 2010). The trend analysis of precipitation showed an upward trend in the annual rainfall over the period of 1955 to 2009 in the San Juan metropolitan area in Puerto Rico (*Méndez-Lázaro et al*., 2014). The study shows, that in the semi-arid Botswana, the rainfall variability decreased with a reduction of rainy days and a rise of drying throughout the area (*Batisani* and *Yarnal*, 2010). In Spain, plant cover change has occurred in the Mediterranean climate, and it is associated with an evolution of temperature and precipitation. The results shows a several decrease in the water supply with high dependence on precipitation (*Ceballos-Barbancho et al*., 2008). The annual precipitation has slightly decreased throughout China over the last five decades (*Zhai et al*., 2011). Conversely, the heaviest precipitations have significantly raised over the Yangtze River and West China during the last decades of the 20th century, while a reduction in the precipitation can be observed over the northern part of China (*Zhai et al.,* 1999b). Also, heavy precipitation and flash flood have occurred in the Caribbean (*Laing*, 2004). The precipitation has remarkably increased over Europe in the decades of the 20th century, while a downward trend shows a decline southward to the Mediterranean (*Schönwiese* and *Rapp*, 2013).

Scientific resuls reveal that the trend of extreme rainfalls has been reduced remarkably over Southeast Asia and the western and central parts of the South Pacific in the period of 1965 to 1998 (*Manton et al*., 2001). Severity of precipitation in South and Central Asia shows little change with positive and negative trends during 1961–2000 (*Klein Tank et al*., 2006). Rainfall trends revealed a significant decrease in the southwest monsoon rainfall and an increase in the post-monsoon season in India (*Krishnakumar et al*., 2009). The precipitation decreased in the winter and post-monsoon seasons and raised in the monsoon and pre-monsoon seasons in the China-Pakistan economic corridor over the period of 1980–2016 (*Ullah et al*., 2019). A downward trend of precipitation can be shown in the West, Northwest, and Southwest, but an upward trend can be indicated in the most stations of Iran during 1960–2001(*Boroujerdy*, 2008). Long-term rainfall prediction is very important to countries thriving on agro-based economy. In Afghanistan, precipitation variation is poorly documented because of the inadequate spatial and temporal data coverage. The annual precipitation has been reduced in the North and West, while it raised at the rest of parts of Afghanistan (*Saboory* and *Tomer,* 2019). The annual precipitation presented reduction trend in the Kunduz River Basin on the northeastern part of Afghanistan during 1961 to 2010 (*Hassanyar et al*., 2018). Based on climate records and data available from the neighboring countries, the average precipitation has declined by 0.5 mm or 2% per decade since 1960 (*Aich et al*., 2017). The aim of this research is to investigate the precipitation series and their trends. Rainfall trend could be an evidence of climate change. In this study, due to the importance of precipitation in terms of agriculture, water resources, and energy production, time changes and the existence of rainfall changes in Afghanistan are discussed.

2. Materials and methods

2.1. Study area

Afghanistan is a vast country with an area of 647,500 km^2 and an estimated population 32.9 million people. Geographically it is located approximately between the 29–38 °N latitudes and 61–74 °E longitudes in the central zone of Asia, and a part of the country is located within the Hindu-Kush Himalayan region *Fig. 1*). Afghanistan has a predominantly dry continental climate, and the quantity and distribution of precipitation is key factor to recharge of water availability. Three-quarter of precipitation is occurring as snow during winter, where altitudes are more than 2500 m. The annual precipitation is less than 400 mm over the 75% of the country and higher values occur above 1000 m on in the mountains of the northwest. The temperature is approximately 33 °C in summer and 10 °C in winter, but in cold areas temperature could fall below -20 °C (*McSweeney et al*., 2013). Afghanistan's climate is arid to semi-arid with major daytime and nighttime temperature fluctuations. The annual precipitation ranges from less than 50 mm/year in the southwestern part of Afghanistan to 1000 mm/year in the northeastern highland. The monthly precipitation changes between 20 to 80 mm in winter and spring, and it is remarkably below 3 mm in summer, i.e., in the period of June to October (*Tünnermeier et al*., 2005).

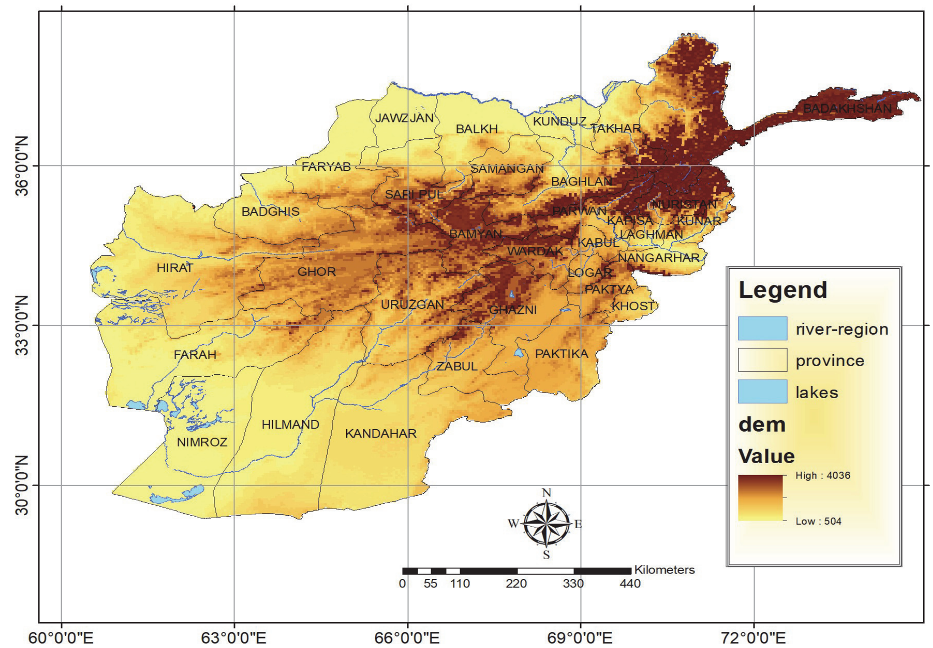

Fig. 1. Location of study area.

Daily precipitation data was obtained from the CPC-NOAA (Climate Prediction Center - National Oceanic Atmospheric Administration) website: https://psl.noaa.gov/data/gridded/data.cpc.global temp.html for the period of 1979–2019. The CPC spatial resolution of daily precipitation is 0.5×0.5 degree. Daily precipitation data were extracted for 33 provinces of Afghanistan covering the whole of the study area, except for the Bamyan province. The capital of every province chosen for the study, with specified latitudes, longitudes, and elevations are shown in *Table 1*.

The study examined the trend in observation time series of precipitation. For qualitative and quantitative analysis of data, the Run Test method was used, all data was normal. The data were validated in order to estimate the robustness of the results. Thus, reanalysis data were compared to observed data of some weather stations of the same time. According to the normal distribution of rainfall, linear regression could be used for the analysis of precipitation trend.

Table 1: Specific locations of the study area in Afghanistan

Provinces	**Study sites**	**Latitude (ºN)**	**Longitude (ºE)**	**Elevation (m.a.s.l.)**
Balkh	Balkh	36.75	66.89	348
Nangarhar	Jalalabad	34.41	70.47	568
Helmand	Lashkar-Gah	31.62	64.36	787
Kandahar	Aino-Mainah	31.63	65.77	1025
Zabul	Hazari	32.11	66.91	1579
Ghazni	Naw Adad	33.58	68.40	2225
Nimroz	Zaranj	30.96	61.87	489
Farah	Arg-Farah	32.37	62.10	660
Herat	Taraqi Park	34.34	62.21	933
Badghis	Qala-e- Naw	34.97	63.13	956
Paktika	Urgun	32.85	69.14	2321
Oruzgan	Khas Oruzgan	32.92	66.69	2211
Faryab	Afghan Kot	35.91	64.78	882
Sar-e-Pole	Sar-e-Pole	36.21	65.93	634
Jowzjan	Sheberghan	36.66	65.75	362
Samangan	Takht-Rostam	36.24	68.02	1027
Baghlan	Pol-e-Khomri	35.94	68.70	649
Kunduz	Kunduz	36.70	68.84	382
Takhar	Taleqan	36.73	69.53	802
Badakhshan	Fyz-Abad	37.10	70.53	1183
Panjshir	Bazark	35.31	69.51	1959
Kapisa	Mahmude-Raqi	35.01	69.34	1436
Parvan	Charikar	35.02	69.16	1604
Kabul,	Bagh-Bala	34.53	69.12	1848
Vardak	Maidan-Shahr	34.38	68.85	2182
Daykundi	Nili	33.73	66.14	2103
Ghowr	Chegcharan	34.52	65.25	2265
Paktia	Gardez	33.59	69.21	2308
Khost	Khost	33.33	69.92	1174
Nuristan	Parun	35.42	70.92	2758
Konar	Asadabad	34.87	71.15	819
Laghman	Mihtar-lam	34.66	70.21	758
Lowgar	Pole-Alam	34.00	69.01	1912

One method of trend analysis of time series is using linear regression models. In this model, the main assumption considers time series that contain a linear regression. Although this assumption is not implemented completely, it provides general overview of the time series. The linear regression is defined as follows:

$$Z_T = a + bT + e_T, \quad (1)$$

where Z_T is the climate variable, T is the time (T=1, 2, 3……n), b is the slope of line (change except of time), e_T is the error (residual or deviation) of the estimation, and a and b is are the regression coefficients (*Asakereh*, 2009). This study is used the method of least squares, the main objective of which is to fit a curve through the time series, so that the sum of the least square errors is minimum. The estimation of regression coefficient the method of least square is:

$$b = \frac{\sum_{i=1}^{n}(T_i - \overline{T})(Z_i - \overline{Z})}{\sum_{i=1}^{n} T_i - \overline{T}}, \quad (2)$$

$$a = \overline{Z} - b\overline{T}$$

where $\overline{T}$and $\overline{Z}$ are the mean of time and the mean of the climate parameter, respectively.

3. Discussion

3.1. Precipitation trend in the north

The analysis of rainfall data in the northern part of Afghanistan shows mostly reduction in precipitation over the period of 1979 to 2019. Data reveal decreasing precipitation trend in the northeastern provinces: data show a declining trend of -1.14 mm/year and a minimum rainfall of 69 mm in Baghlan, -0.25 mm/year and 88 mm in Kunduz, -2.56 mm/year and 111mm in Takhtar, and -5.85 mm/year in Badakhsan in 2000. Samangan and Faryab provinces shown a decrease in the average of rainfall (-0.38 mm/year and -0.49 mm/year), the minimum rainfall was 64 mm in 2001 and 72 mm in 2014, respectively. Balkh, Sar-e-Pole, and Jowzjan provinces represent a slight increase in precipitation with 0.63 mm/y, 0.75 mm/y, and 0.93 mm/y, the minimum amount of precipitation was 51 mm, 54 mm and 55 mm in 2001, respectively. Overall, the reduction in the precipitation trend was -9.2 mm per decade in the northern part of Afghanistan during study period. Similarly, the result of study *Salma et al.* (2012) shows a decreasing rainfall trend all over the Pakistan. The mean annual rainfall exhibits reduced trend in Russia, some part of Japan, North China, most parts of Northeast India, Indonesia, and Philippines (*Solomon et al.,* 2007). Conversely, the study carried out in the arid

Central Asia reveals an upward trend in precipitation during the past 80 years (*Chen et al*., 2011). The extreme precipitation events observed in summer ranged from 50 mm/day to 100 mm/day in North Xinjiang during 1951–2014 (*Huang et al*., 2017). Comparing the results with those of other researchers in neighboring countries such Iran and Pakistan, an absolute homogeneity assessment of precipitation time series in the arid region of Pakistan found them doubtful for the month of June at two stations (*Kamal et al*., 2018). Rainfall trend analysis of Iran in the last half of the twentieth century was performed. This study shows that the annual rainfall is decreasing at 67% of the stations, while the 24-hour maximum rainfall is increasing at 50% of the stations (*Figs. 2–7*) (*Modarres* and *Sarhadi*, 2009).

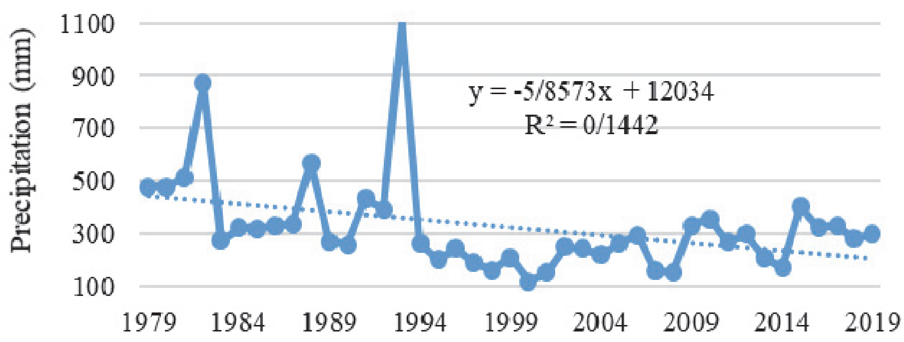

Fig. 2. Mean annual precipitation of Badakhshan province.

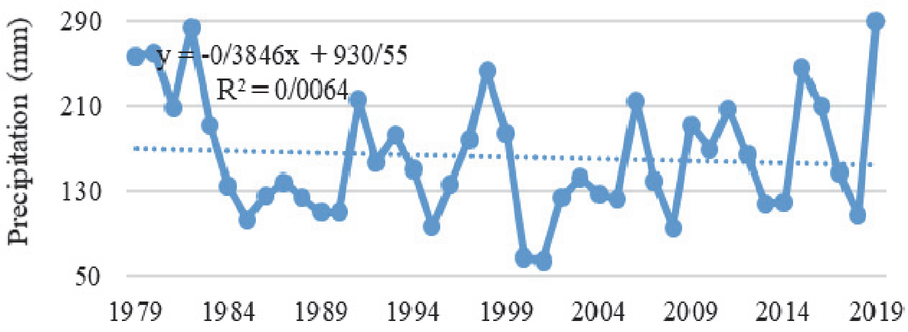

Fig. 3. Mean annual precipitation of Samangan province.

3.2. Changes in the precipitation in the west and south

This investigation has shown a decreasing trend in the precipitation in all western and southern provinces of Afghanistan. In the southern provinces, a significant reduction in precipitation has been observed in Helmand, Kandahar, Zabul, and Nimruz provinces with the value of -3.24 mm/y, -3.27 mm/year, -1.09 mm/year, and -0.35 mm/year, and the minimum precipitation was 4 mm, 28 mm, 54 mm, and 6 mm in 2018 and 2001, respectively. Ghazni and Uruzgan provinces show a positive trend of precipitation in the southern part of Afghanistan. The result is consistent with findings of other researchers: *Ahmad et al.* (2015) highlighted negative and positive trends of precipitation during 1961 to 2011 in the Swat River Basin, Pakistan. Rainfall was increasing during summer while decreasing in winter over the period of 1945–2004 in Faisalabad (*Cheema et al.*, 2006). Studies examined the latitudinal precipitation trend in Pakistan, which show raise in high latitudes and no noteworthy trend in lower latitudes (*Hanif et al.,* 2013; *Ahmad et al.*, 2014). The Panjab has experienced a significant increasing precipitation trend during 1961–2014 (*Khattak* and *Ali*, 2015). The finding of *Sheikh et al.* (2015) indicates most extreme precipitation raise in South Asia, consistent with the globally averaged result.

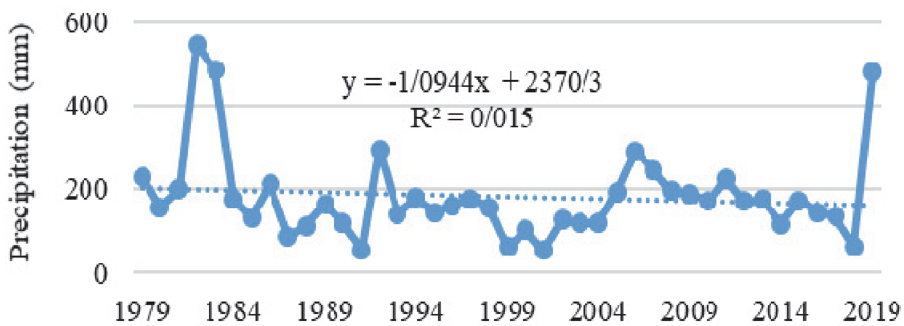

Fig. 4. Mean annual precipitation of Zabul province.

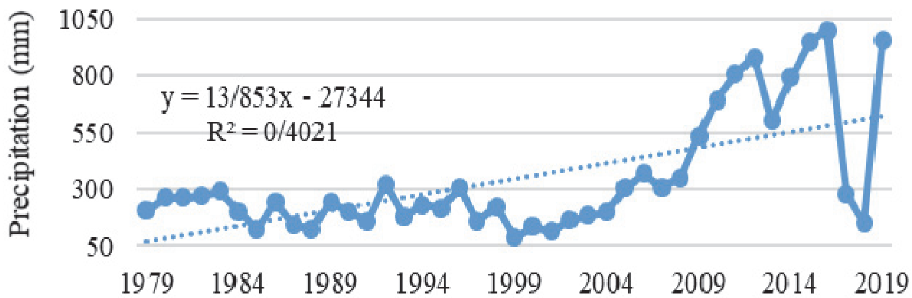

Fig. 5. Mean annual precipitation of Ghazni province.

Data in *Table 2* shows that the mean annul precipitation decreased over the study period in the western part of Afghanistan. Data show a high declining trend of -0.44 mm/year in Farah province in the West, -0.19 mm/year in Herat and 0.17 mm/year in Badghis province. Generally, the average decline of precipitation is -2.44 mm/year per decade. The result of this study is in a good agreement with the report of *Modarres* and *Sarhadi* (2009), which presents negative trend of annual rainfall in the northern and northwestern parts of Iran in the last decades of twentieth century. *Nasri* and *Modarres* (2009) carried out a study in the western and eastern parts of Iran receiving similar results: negative trend of precipitation. The finding of *Raziei et al*. (2005) indicated mostly downward trend of precipitation in the arid and semi-arid regions of Iran (*Modarres* and *da Silva*, 2007; *Tabari et al.,* 2012). A study conducted by *Sadeghi* and *Hazbavi* (2015) has shown a small general reduction trend in the seasonal rainfall in Iran in the period 1970–1992.

Table 2. Changes in precipitation across Afghanistan over the period of 1979 to 2019

Location	**Mean change of precipitation per year (mm)**	**Precipitation variation (mm)**
Balkh	0.63	25
Jalalabad	9.64	395
Lashkar-Gah	-3.24	-133
Aino-Mainah	-3.27	-134
Hazari	-1.09	- 44
Naw Adad	13.85	567
Zaranj	-0.35	- 14
Arg-Farah	-0.44	- 18
Taraqi Park	-0.19	- 8
Qala-e- Naw	-0.17	- 7
Urgun	15.44	663
Khas Oruzgan	2.85	116
Afghan Kot	-0.49	- 20
Sar-e-Pole	0.75	30
Sheberghan	0.93	38
Takht-Rostam	-0.38	- 16
Pol-e-Khomri	-1.14	- 47
Kunduz	-0.25	- 10
Taleqan	-2.56	- 105
Fyz-Abad	-5.85	- 240
Bazark	-1.44	- 59

Table 2. Continued

Location	Mean change of precipitation per year (mm)	Precipitation variation (mm)
Mahmude-Raqi	3.71	152
Charikar	2.40	98
Bagh-Bala	9.21	378
Maidan-Shahr	9.21	378
Nili	2.73	112
Chegcharan	0.44	18
Gardez	15.83	649
Khost	19.66	806
Parun	1.34	55
Asadabad	6.14	252
Mihtar-lam	10.30	423
Pole-Alam	13.53	555

3.3. Precipitation trend in the central regions

The central part of Afghanistan is characterized by low and highly variable precipitation due to the Himalayan mountain ranges. Farther south, monsoon effects moderate the climate near the Pakistan border and increases the rainfall as far inland as central part of Afghanistan. According to the 1979–2019 period, the mean annual rainfall increased in six provinces in the central region except Panjshir province, where it decreased by -1.44 mm/year. *Fig. 2* shows the mean annual precipitation trend of seven provinces in the central region indicating raise of 37.5mm per decade in Kabul, while in Vardak the precipitation increased by 9.21 mm per year. In Growr, the precipitation regions: 0.44 mm/year. Eastern regions include eight provinces, and the eastern highland is covering the smallest area that is mainly covered by rangeland and largest existing forests. This regions are directly influenced by the moist air masses of Indian monsoon getting trapped at the high mountain slopes, which can lead to the increase of rain. *Table 2* reveals upward trend of precipitation in the eastern regions: Khost, Paktia, Paktika, Lowgar, and Laghman show high rainfall rates 19.6 mm, 15.8 mm, 15.4 mm, 13.5 mm, and 10.3 mm per year, respectively.

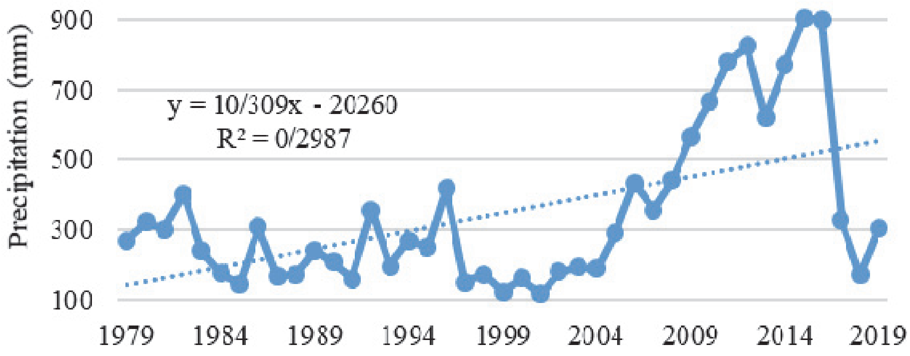

Fig. 6. Mean annual precipitation of Laghman province.

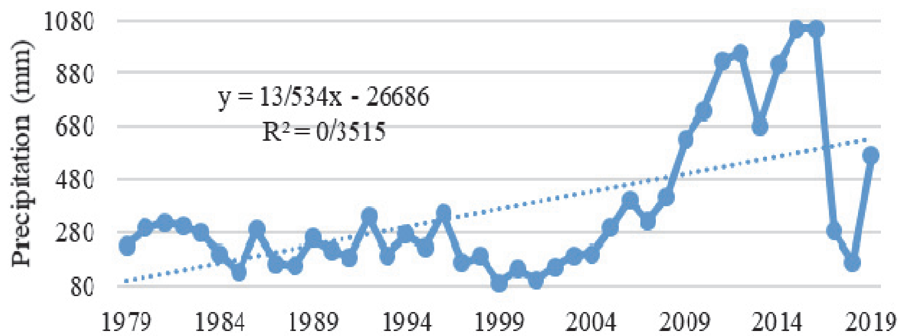

Fig. 7. Mean annual precipitation of Lowgar province.

The rest of provinces in the eastern area show lower rates of rainfall in the study period. Overall, the mean precipitation trend increased by 114.5 mm per decade. The result of this study is similar to the findings of *Alexander et al*. (2006) showing significant increases of precipitation. The findings of *Keggenhoff et al.* (2014) indicated that heavy and extremely heavy precipitation to total precipitation have increased between 1971 to 2010 in Georgia. Studies carried out in Pakistan, that have argued upward annual precipitation trend in the northern highland and sub-Himalayan ranges (*Iqbal et al.,* 2019; *Ahmed et al*., 2017; *Hussain* and *Lee*, 2013). Recent study of *Gajbhiye et al.,* (2016) further outlined a significant increasing of precipitation in both seasonal and annual rainfall amounts during 1901 to 2002 in the Sindh River Basin, India. A research was conducted by *Sen Roy* (2009), which investigated raising trends in extreme heavy precipitation in the high elevation parts of India. Ont he contrary to this study, significant decreasing trends of precipitation, *Martinez et al.* (2012) revealing the precipitation has negative trend in October and May in Florida. Other studies mostly observed negative trend on monthly rainy days in Iran (*Soltani et al*., 2012; *Rahimzadeh et al*., 2009). Also, the findings of studies mostly noticed decreasing trends in precipitation over Iran (*Some'e et al*., 2012; *Tabar*i and *Talaee*, 2011). A study assessed by *Zhai et al.* (2005) revealed that the annual precipitation decreased over the southern northeast parts of China, while a significant increase was detected in western region.

4. Conclusion

This study identified the mean annual trend in precipitation of 33 provinces from the 34 provinces of Afghanistan from 1979 to 2019. The center of each province was selected as study site with specific latitudes, longitudes, and elevations. The method used was the non-parametric linear regression trend in time series for rainfall parameters. The trend of precipitation may be attributed to the regional climate changes, local land use, and high emission of greenhouse gases from various sources, i.e., population density, industry, infrastructure, building, transport, agriculture, deforestation, and rearing livestock. The daily precipitation data were extracted from the database of CPC-NOAA (Climate Prediction Center - National Oceanic Atmospheric Administration), and they were analyzed by the linear regression trend. The analysis of rainfall data shows a declining trend in the northeastern provinces such as Baghlan, Kunduz, Takhar, and Badakhshan. Samangan and Faryab indicated a negative trend of precipitation, while Balkh, Sar-e-Pole, and Samangan were revealed with slight increase on precipitation trend in the northern part of Afghanistan showing -9.2mm per decade generally. In the south, a significant reduction was observed in the precipitation trend in Helmand, Kandahar, and Nimruz provinces, but Ghazni and Uruzgan showed positive trend. *Table 2* revealed that the mean annual precipitation significantly decreased in the western part of Afghanistan. Central parts of Afghanistan are characterized by low and highly variable precipitation due to Himalayan mountain ranges. Farther south, the monsoon effects moderate the climate near the Pakistan border and increases rainfall as far inland as the central parts of Afghanistan. According to the 1979–2019 period, the mean annual rainfall increase in six provinces in central region except Panjshir province decrease -1.44 mm per year. *Fig. 2* shows the mean annual precipitation trend of seven provinces in the central region indicating raise of 37.5 mm per decade in Kabul, while in Vardak, while in the highest precipitation increase was 9.21 mm per year. Eastern regions include eight provinces, and the eastern highland is covering the smallest area, which is mainly covered by rangeland and the largest existing forests. This regions are directly influenced by the moist air masses of Indian monsoon getting trapped at the high mountain slopes, and it can lead to the increase of rain. Data reveals upward trend of precipitation in the eastern regions, that Khost, Paktia, Paktika, Lowgar, and Laghman showed high rainfall rate, and the rest of provinces in the eastern area showed lower rate of rainfall in the study period.

References

Ahmad, I., Tang, D., Wang, T., Wang, M., and *Wagan, B*., 2015: Precipitation trends over time using Mann-Kendall and spearman's rho tests in swat river basin, Pakistan. *Adv. Meteorol. 2015,* 431860. https://doi.org/10.1155/2015/431860

Ahmad, W., Fatima, A., Awan, U.K., and *Anwar, A*., 2014: Analysis of long term meteorological trends in the middle and lower Indus Basin of Pakistan—A non-parametric statistical approach. *Glob. Planet. Change 122*, 282–291. https://doi.org/10.1016/j.gloplacha.2014.09.007

Ahmed, K., Shamsuddin, S., Eun-Sung, C., Tarmizi, I., and *Xiao-Jun, W*., 2017: Spatial distribution of secular trends in annual and seasonal precipitation over Pakistan. *Climate Res. 74*, 95–107. https://doi.org/10.3354/cr01489

Aich, V., Akhundzadah, N.A., Knuerr, A., Khoshbeen, A.J., Hattermann, F., Paeth, H., and *Paton, E.N*., 2017: Climate Change in Afghanistan Deduced from Reanalysis and Coordinated Regional Climate Downscaling Experiment (CORDEX)—South Asia Simulations. *Climate*, 5(2), 38. https://doi.org/10.3390/cli5020038

Akinremi, O.O., McGinn, S.M., and *Cutforth, H.W*., 2001: Seasonal and spatial patterns of rainfall trends on the Canadian prairies. *J. Climate 14*, 2177–2182. https://doi.org/10.1175/1520-0442(2001)014<2177:SASPOR>2.0.CO;2

Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., ... and *Tagipour, A.,* 2006: Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res.*: *Atmos.*, 111(D5). https://doi.org/10.1029/2005JD006290

Allan, R.J. and *Haylock, M.R.,* 1993: Circulation features associated with the winter rainfall decrease in southwestern Australia. *J. Climate* 6, 1356–1367. https://doi.org/10.1175/1520-0442(1993)006<1356:CFAWTW>2.0.CO;2

Asakereh, H. 2009: Power spectrum analysis of the time series of Tabriz annual temperature.

Batisani, N. and *Yarnal, B.,* 2010: Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. *Appl. Geograp.*, 30, 483–489. https://doi.org/10.1016/j.apgeog.2009.10.007

Boroujerdy, P. K., 2008: the analysis of precipitation variation and quantiles in Iran. In Proceedings of the 3rd WSEAS International Conference on Energy and Environment, University of Cambridge, UK, 248–253.

Cannarozzo, M., Noto, L.V., and *Viola, F.* 2006: Spatial distribution of rainfall trends in Sicily (1921–2000). *Phys. Chem. Earth*, *31*, 1201–1211. https://doi.org/10.1016/j.pce.2006.03.022

Ceballos-Barbancho, A., Morán-Tejeda, E., Luengo-Ugidos, M.Á., and *Llorente-Pinto, J.M.,* 2008: Water resources and environmental change in a Mediterranean environment: the south-west sector of the Duero river basin (Spain). *J. Hydrol. 351*, 126–138. https://doi.org/10.1016/j.jhydrol.2007.12.004

Cheema, M.A., Farooq, M., Ahmad, R., and *Munir, H.,* 2006: Climatic trends in Faisalabad (Pakistan) over the last 60 years (1945-2004). *J. Agric. Social Sci. 2*, 42–45.

Chen, F., Huang, W., Jin, L., Chen, J., and *Wang, J.,* 2011: Spatiotemporal precipitation variations in the arid Central Asia in the context of global warming. *Sci. China Earth Sci. 54*, 1812–1821. https://doi.org/10.1007/s11430-011-4333-8

Cutforth, H.W., Akinremi, O.O., and *McGinn, S.M.,* 2001: Seasonal and spatial patterns of rainfall trends on the Canadian prairie. In Soils and Crops Workshop. *J. Climate 14*, 2177–2182. https://doi.org/10.1175/1520-0442(2001)014<2177:SASPOR>2.0.CO;2

Dai, A., Fung, I.Y., and *Del Genio, A.D.,* 1997: Surface observed global land precipitation variations during 1900–88. *J. Climate 10*, 2943–2962. https://doi.org/10.1175/1520-0442(1997)010<2943:SOGLPV>2.0.CO;2

Dore, M.H., 2005: Climate change and changes in global precipitation patterns: what do we know? *Environ. Int. 31*, 1167–1181. https://doi.org/10.1016/j.envint.2005.03.004

Frei, A., Robinson, D.A., and *Hughes, M.G.,* 1999: North American snow extent: 1900–1994. *Int. J. Climatol. 19*, 1517–1534. https://doi.org/10.1002/(SICI)1097-0088(19991130)19:14<1517::AID-JOC437>3.0.CO;2-I

Gajbhiye, S., Meshram, C., Singh, S.K., Srivastava, P.K., and *Islam, T.,* 2016: Precipitation trend analysis of Sindh River basin, India, from 102-year record (1901–2002). *Atmos. Sci. Lett. 17*, 71–77. https://doi.org/10.1002/asl.602

Groisman, P., Karl, T., Easterling, D., Knight, R., Jamason, P., Hennessy, K., Suppiah, R., Page, C., Wibig, J., Fortuniak, K., Razuvaev, V., Douglas, A., Førland, E., and *Zhai, P.*, 1999: Changes in the probability of extreme precipitation: important indicators of climate change. *Climat. Change 42*, 243–283. https://doi.org/10.1023/A:1005432803188

Groisman, P. Y., and Easterling, D. R. 1994: Variability and trends of total precipitation and snowfall over the United States and Canada. *Journal of Climate*, 7(1), 184-205. https://doi.org/10.1175/1520-0442(1994)007<0184:VATOTP>2.0.CO;2

Hanif, M., Khan, A.H., and *Adnan, S.*, 2013: Latitudinal precipitation characteristics and trends in Pakistan. *J. Hydrol. 492*, 266–272. https://doi.org/10.1016/j.jhydrol.2013.03.040

Hassanyar, M.H., Tsutsumi, J.I.G., Nakamatsu, R., and *Omid, S.M.,* 2018: The Analysis Of Temporal Variability, Trend Of Precipitation And River Discharge Of Kunduz River Basin, *Afghanistan. Manage. Res*. 5(4), 69–78. https://doi.org/10.29121/ijetmr.v5.i4.2018.210

Haylock, M. and *Nicholls, N.,* 2000: Trends in extreme rainfall indices for an updated high quality data set for Australia, 1910–1998. *Int. J. Climatol. 20*, 1533–1541. https://doi.org/10.1002/1097-0088(20001115)20:13<1533::AID-JOC586>3.0.CO;2-J

Hope, P., Timbal, B., and *Fawcett, R.,* 2010: Associations between rainfall variability in the southwest and southeast of Australia and their evolution through time. *Int. J. Climatol. 30*, 1360-1371. https://doi.org/10.1002/joc.1964

Houghton, E., 1996: Climate change 1995: The science of climate change: contribution of working group I to the second assessment report of the Intergovernmental Panel on Climate Change (Vol. 2). Cambridge University Press.

Huang, W., Chang, S.Q., Xie, C.L., and *Zhang, Z.P.,* 2017: Moisture sources of extreme summer precipitation events in North Xinjiang and their relationship with atmospheric circulation. Advances in Climate, *Change Res. 8*, 12–17. https://doi.org/10.1016/j.accre.2017.02.001

Hussain, M.S. and *Lee, S.,* 2013: The regional and the seasonal variability of extreme precipitation trends in Pakistan. *Asia-Pacific J. Atmos. Sci. 49*, 421–441. https://doi.org/10.1007/s13143-013-0039-5

Iqbal, Z., Shahid, S., Ahmed, K., Ismail, T., and *Nawaz, N.,* 2019: Spatial distribution of the trends in precipitation and precipitation extremes in the sub-Himalayan region of Pakistan. *Theor. Appl. Climatol. 137,* 2755–2769. https://doi.org/10.1007/s00704-019-02773-4

Kamal, A., Shamsodin, S., Tarmmizi, I., Nadeem, N., and Xio, W., 2018: Absolute homogeneity assessment of precipitation time series in an arid region of Pakistan. *Atmosfera 31*, 301–316. https://doi.org/10.20937/ATM.2018.31.03.06

Karl, T.R., Nicholls, N., and *Ghazi, A.,* 1999: In: Weather Climate Extremes Clivar/GCOS/WMO workshop on indices and indicators for climate extremes workshop summary. 3–7. https://doi.org/10.1007/978-94-015-9265-9_2

Karl, R. and *Knight, R.,*1998:Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States, *Bull. Amer. Meteorol. Soc. 79*, 231–242. https://doi.org/10.1175/1520-0477
Keggenhoff, I., Elizbarashvili, M., Amiri-Farahani, A., and *King, L.* 2014: Trends in daily temperature and precipitation extremes over Georgia, 1971–2010. *Weather Climate Extrem. 4*, 75–85. https://doi.org/10.1016/j.wace.2014.05.001
Khattak, M.S. and *Ali, S.,* 2015: Assessment of temperature and rainfall trends in Punjab province of Pakistan for the period 1961-2014. *J.f Himalayan Earth Sci. 48(2).*
Klein Tank, A.M.G., Peterson, T.C., Quadir, D.A., Dorji, S., Zou, X., Tang, H., ... and Sikder, A. B. 2006: Changes in daily temperature and precipitation extremes in central and south Asia. *J. Geophys. Res.: Atmos.*, 111(D16). https://doi.org/10.1029/2005JD006316
Kreft, S.; Eckstein, D.; Dorsch, L., and *Fischer, L.,* 2015: Global Climate Risk Index 2016: Who Suffers Most from Extreme. Think Tank and Research. Germanwatch. https://germanwatch.org/sites/default/files/publication/13503.pdf
Krishnakumar, K.N., G.S.L.H.V. Prasada Rao, and *C S. Gopakumar*, 2009: Rainfall trends in twentieth century overKerala, India. *Atmos. Environ. 43*, 1940–1944. https://doi.org/10.1016/j.atmosenv.2008.12.053
Kunkel, K.E., 2003: North American trends in extreme precipitation. *Natural Hazards 29*, 291–305. https://doi.org/10.1023/A:1023694115864
Kunkel, K.E., Andsager, K., and *Easterling, D.R.,* 1999: Long-term trends in extreme precipitation events over the conterminous United States and Canada. *J. Climate 12*, 2515–2527. https://doi.org/10.1175/1520-0442(1999)012<2515:LTTIEP>2.0.CO;2
Laing, A.G., 2004: Cases of heavy precipitation and flash floods in the Caribbean during El Nino winters*. J Hydrometeorol. 5*, 577–594. https://doi.org/10.1175/1525-7541(2004)005<0577:COHPAF>2.0.CO;2
Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., Chambers, L.E., and *Inape, K.,* 2001: Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998. *Int. J. Climatol.* 21, 269–284. https://doi.org/10.1002/joc.610
Martinez, C.J., Maleski, J.J., and *Miller, M.F.,* 2012: Trends in precipitation and temperature in Florida, USA. *J. Hydrol 452*, 259–281. https://doi.org/10.1016/j.jhydrol.2012.05.066
McSweeney, C., New, M., and *Lizcano, G.* 2013: UNDP climate change country profiles: Afghanistan.
Mekis, E. and *Hogg, W.D.,* 1999: Rehabilitation and analysis of Canadian daily precipitation time series. *Atmos.-ocean 37*, 53–85. https://doi.org/10.1080/07055900.1999.9649621
Méndez-Lázaro, P.A., Nieves-Santiango, A., and *Miranda-Bermúdez, J.,* 2014: Trends in total rainfall, heavy rain events, and number of dry days in San Juan, Puerto Rico, 1955-2009. *Ecol. Soc.* 19(2), 50. https://doi.org/10.5751/ES-06464-190250
Modarres, R. and *da Silva, V.* 2007: Rainfall trends in arid and semi-arid regions of Iran. *J. Arid Environ. 70*, 344–355. https://doi.org/10.1016/j.jaridenv.2006.12.024
Modarres, R. and *Sarhadi, A.,* 2009: Rainfall trends analysis of Iran in the last half of the twentieth century, *J. Geophys. Res. Atmos. 114(3),* 1–9. https://doi.org/10.1029/2008JD010707
Nasri, M. and *Modarres, R.,* 2009: Dry spell trend analysis of Isfahan Province, Iran. *Int. J. Climatol. 29*, 1430–1438. https://doi.org/10.1002/joc.1805
Nicholls, N. and *Lavery, B.,* 1992: Australian rainfall trends during the twentieth century. *Int. J. Climatol. 12*, 153–163. https://doi.org/10.1002/joc.3370120204
Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... and *van Ypserle, J.P., 2014.* Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, 151.
Rahimzadeh, F., Asgari, A., and *Fattahi, E.* 2009: Variability of extreme temperature and precipitation in Iran during recent decades. *Int. J. Climatol. 29*, 329–343. https://doi.org/10.1002/joc.1739
Raziei, T., Arasteh, P.D., and *Saghafian, B.,* 2005: Annual rainfall trend in arid and semi-arid regions of Iran. In ICID 21st European Regional Conference. 15–19.

Saboory, S.K., and *Tomer, S.K.,* 2019: Regional scale spatiotemporal trends of precipitation and temperatures over Afghanistan.

Sadeghi, S.H.R., and *Hazbavi, Z.* 2015: Trend analysis of the rainfall erosivity index at different time scales in Iran. *Nat.Hazard. 77*, 383–404. https://doi.org/10.1007/s11069-015-1607-z

Salma, S., Rehman, S., and Shah, M. A. 2012: Rainfall trends in different climate zones of Pakistan. *Pakistan J. Meteorol. 9(17)* 37–47.

Schönwiese, C.D. and *Rapp, J.* 2013: Climate trend atlas of Europe based on observations 1891–1990. Springer Science and Business Media.

Sen Roy, S. 2009: A spatial analysis of extreme hourly precipitation patterns in India. *Int. J. Climatol. 29*, 345–355. https://doi.org/10.1002/joc.1763

Sheikh, M.M., Manzoor, N., Ashraf, J., Adnan, M., Collins, D., Hameed, S. ... and *Islam, N.* 2015: Trends in extreme daily rainfall and temperature indices over South Asia. *Int. J. Climatol. 35*, 1625–1637. https://doi.org/10.1002/joc.4081

Sheila M. 2013: Climate change adaptation and water resource management: A review of the literature, Energy Economics, Available online 19 September 2013, ISSN 0140-9883.

Solomon, S.D et al., 2007*:* Climate Change 2007: The Physical Science Basis; IPPC. 2007; Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Solomon, S., and *Srinivasan, J.,* 1995: Radiative forcing of climate change. Climate change, 108-118, Cambridge University Press, New York.

Soltani, S., Saboohi, R., and *Yaghmaei, L.* 2012: Rainfall and rainy days trend in Iran. *Climatic Change 110*, 187–213. https://doi.org/10.1007/s10584-011-0146-1

Some'e, B.S., Ezani, A., and *Tabari, H.,* 2012: Spatiotemporal trends and change point of precipitation in Iran. *Atmos. Res. 113*, 1–12. https://doi.org/10.1016/j.atmosres.2012.04.016

Suppiah, R. and *Hennessy, K. J.* 1998: Trends in total rainfall, heavy rain events and number of dry days in Australia, 1910–1990. *Int. J. Climatol. 18*, 1141–1164. https://doi.org/10.1002/(SICI)1097-0088(199808)18:10<1141::AID-JOC286>3.0.CO;2-P

Tabari, H. and *Talaee, P.H.,* 2011: Temporal variability of precipitation over Iran: 1966–2005. *J. Hydrol. 396*, 313–320. https://doi.org/10.1016/j.jhydrol.2010.11.034

Tabari, H., Abghari, H., and *Hosseinzadeh Talaee, P.* 2012: Temporal trends and spatial characteristics of drought and rainfall in arid and semiarid regions of Iran. *Hydrol. Proc. 26*, 3351–3361. https://doi.org/10.1002/hyp.8460

Tünnermeier, T., Houben, G., and *Himmelsbach, T.* 2005: Hydrogeology of the Kabul Basin, part I: geology, aquifer characteristics, climate and hydrography. Foreign Office of the Federal Republic of Germany, *AA-Gz'GF07*, 885(3), 16.

Ullah, S., You, Q., Ullah, W., and *Ali, A.* 2018: Observed changes in precipitation in China-Pakistan economic corridor during 1980–2016. *Atmos. Res. 210*, 1–14. https://doi.org/10.1016/j.atmosres.2018.04.007

World Bank. 2014: Scoping Strategic Options for Development of the Kabul River Basin a multi- sector decision support system approach, document of World Bank.

Zhai, P., Sun, A., Ren, F., Liu, X., GAO, B., and *Zhang, Q.* 1999a. Changes of climate extremes in China. In Weather and Climate extremes (pp. 203-218). *Springer*, Dordrecht. https://doi.org/10.1007/978-94-015-9265-9_13

Zhai, P. M., Ren, F. M., and *Zhang, Q.* 1999b: Detection of trends in China's precipitation extremes. *Acta Meteorologica Sinica*, 57(2), 208–216.

Zhai, P., Zhang, X., Wan, H., and *Pan, X.* 2005: Trends in total precipitation and frequency of daily precipitation extremes over China. *J. Climate 18*, 1096–1108. https://doi.org/10.1175/JCLI-3318.1