



Regional scale spatiotemporal trends of precipitation and temperatures over Afghanistan

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Afghanistan is the most vulnerable to climate extremes related hazards, including droughts and floods that have caused huge impact on the socio-economic development of the country. The present study analysed the observed precipitation and temperature trends for seven agro-climatic zones of Afghanistan over the period 1951 to 2006 with Asian Precipitation-Highly-Resolved Observational Data Integration towards Evaluation of Water Resources (APHRODITE). The trend analysis was performed on daily data to test the increasing or decreasing rainfall and temperature trends using Mann-Kendall trend test for each agro-climatic zone of Afghanistan. The annual total precipitation has shown an increasing trend for the zones of South, South-West, East and Central, whereas, a decreasing trend has been observed for North, North-East and West zones of Afghanistan. The trend analysis of the precipitation with gridded data sets reveals for most parts of the Afghanistan, the rainfall has been observed to be decreasing. Whereas, an increasing trend of temperatures were observed for all seven agro-climatic zones of Afghanistan.

INTRODUCTION

An increase in the number and magnitude of extreme climate events has been observed globally in recent years causing huge loss of lives, extensive damages to crops, properties and immeasurable misery to millions of people (Hartmann et al. 2013). The issue of management of risks of extreme events and disasters under climate change adaptation has been main focus by the Intergovernmental Panel on Climate Change (IPCC) in the Special Report on Extremes (SREX) (IPCC, 2012). Globally, understanding past changes in the characteristics of extreme climate events became critical for reliable projections of future changes (Donat et al., 2013; Lin et al., 2017; Panda et al., 2017). Hence, the understanding the variability of precipitation and temperature extreme events in the historical data is essential. Moreover, the study of historical trends of climate extremes will serve as the basis for understanding the possible physical vulnerabilities and adaptive measures. To this end, the study of climate events has gained higher scientific and societal interest over the last few decades (e.g. Zhang et al. 2005; Donat et al. 2013;

Curry et al. 2014; Razavi et al. 2016; Bita Javidfakhr, 2017). The study of such climate trends may be critical for any arid to semiarid counties such as Afghanistan as it can directly impact the droughts, floods, heat waves etc. and can be more intense under climate change. Afghanistan is a landlocked semi-arid country and most vulnerable to precipitation extremes related hazards, including droughts, floods and heat waves that cause huge losses in life and property impacting the socio-economic development of the country. Currently, Afghanistan is among the countries with low levels of greenhouse gas (GHG) emissions. The Global Adaptation Index (2012) ranked Afghanistan as the most vulnerable countries in the world under climate change. There is a limitation over the climate extremes studies over Afghanistan due to limited weather data availability. More than three decades of war in Afghanistan that started in the late 1970s caused a huge interruption in water-resources data collection and destroying many of the older records of meteorological and hydrological data (Campbell, 2015). Specifically, only a few (e.g. Aich et al. 2017) climate change assessment studies have been carried out in the literature. In this context, the present study tried to use the open source data sets to analyze the current trends in the precipitation and temperatures. We report the changes and trends in precipitation and temperature extremes in the recent years for seven agro-climatic zones of Afghanistan.

MATERIALS AND METHODS

Case Study and Data

Afghanistan is a landlocked country and geographically highly heterogeneous with the glaciated peaks of the Hindukush and arid deserts of the South, located between 29-39° N to 60-75° E (Fig. 1). Entire Afghanistan is divided into seven agro-climatic zones following

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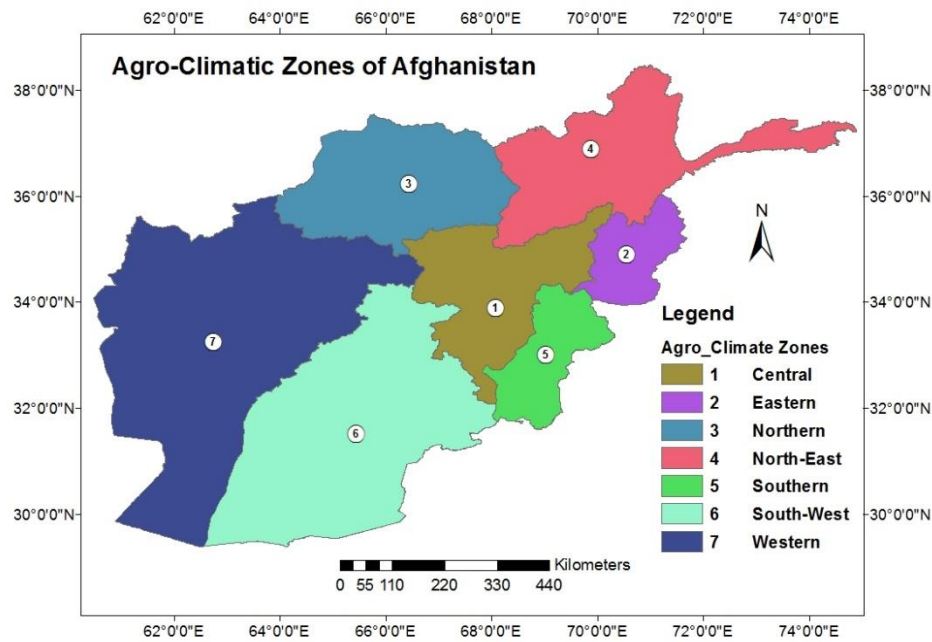


Figure 1 Seven Agro-Climatic Zones of Afghanistan with Provinces

to climate classification scheme of Köppen-Geiger system, Beekeeping survey report (2014) and Ministry of Agriculture, Irrigation and Livestock (MAIL) as Central, Eastern, Northern, North-East, Southern, South-West, and Western agro-climatic zones (Fig.1). The parts of Central, North, North-East and South agro-climatic zones have mid-latitude steppe climate, desert climate and Mediterranean climate. The parts of East and South-West agro-climatic zones have Mediterranean climate; and tropical and subtropical - steppe and desert climates. The parts of South-West and West agro-climatic zones have mid-latitude steppe, and desert climate; tropical and subtropical desert climate; and Mediterranean climate.

One of the major challenges in the initiation of the present study is the availability of long time series historical weather station meteorological data sets. Therefore, to understand the spatial variation of precipitation and temperature extremes, the study used a long time series fine scale gridded dataset, Asian Precipitation-Highly-Resolved Observational Data Integration towards Evaluation of Water Resources (APHRODITE) datasets for a 48-year period from 1951 to 2007 for analysing the spatial trends in the precipitation over Afghanistan. APHRODITE daily gridded precipitation is the long-term continental-scale datasets which considered a dense network of daily rain-gauge data (about 5000 to 12,000) with 14 quality control processes, such as controlling for erroneous values, repetition, homogeneity etc. (Hamada, 2011). The APHRODITE data is mainly developed for Asia including Himalayas, South and Southeast Asia and mountainous areas in the Middle East at 0.5 Degree resolution. The details of the data can be found at: <https://climatedataguide.ucar.edu/climate-data/aphrodite-asian-precipitation-highly-resolved-observational-data-integration-towards>. The APHRODITE data set is first extracted covering entire Afghanistan and further cropped to each agro-climatic zone to study the recent changes in the daily precipitation and temperature trends spatially.

Analysis Approach

The present study estimated the changes in each of the precipitation extreme statistics using linear and Mann-Kendall trend tests.

Linear Regression

One of the simplest methods to calculate the trend of the data is linear regression. The equation of linear regression line is given by:

$$Y = a + bX \quad (\text{Eq. 1})$$

Where, X is the explanatory variable and Y is the dependent variable, b is the slope of the line and a is the intercept. The slope of the regression describes the trend, with positive as increasing and negative as decreasing trend. The observed trend study is conducted by considering the rainfall and temperatures as dependent variables and time as explanatory variable.

Mann-Kendall Trend Test

The Mann-Kendall (Mann, 1945; Kendall, 1975) trend test is a non-parametric trend test, which has been widely used for trend detection in hydrologic and climate data to assess if there is an upward (positive) or downward (negative) trend of a variable of interest over time. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). The following procedure explains the Mann-Kendall trend test:

- The time series, X_i , of the variable, for which the trend test to be applied is considered as an ordered time series.
- Each of the data point, X_i , is compared with the all subsequent data values to estimate the Mann-Kendall statistic, S, as follows:

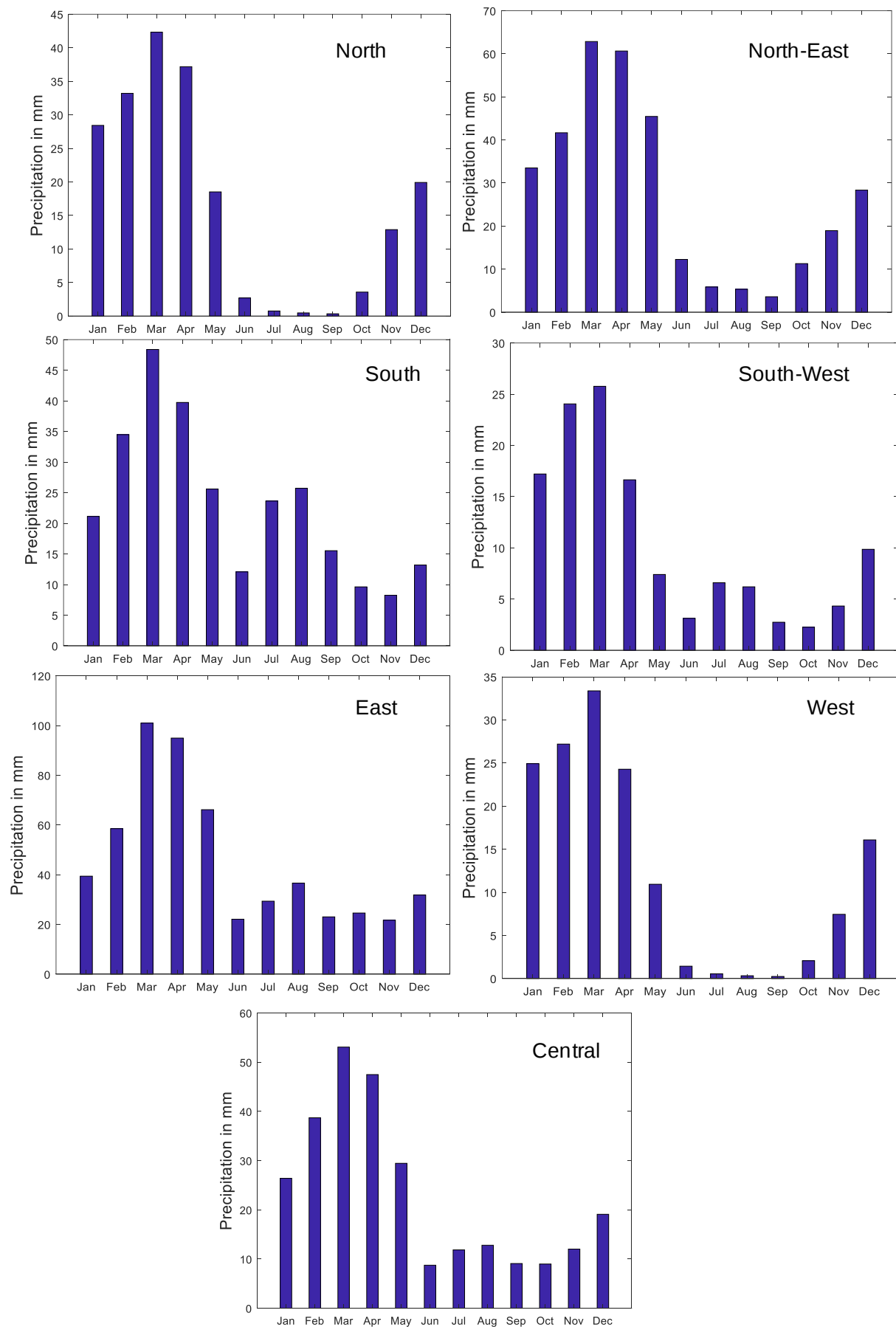


Figure 2 The Spatial average monthly precipitation from 1951 to 2007 for seven agro-climatic zones of Afghanistan

$$S_i = \sum_{i=2}^n \sum_{j=1}^{i-1} \text{sign}(x_i - x_j) \quad (\text{Eq.2})$$

$$\text{where } \text{sign}(x_i - x_j) = \begin{cases} 1 & \text{if } x_i > x_j \\ 0 & \text{if } x_i = x_j \\ -1 & \text{if } x_i < x_j \end{cases} \quad (\text{Eq.3})$$

- A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend.
- From the Mann-Kendall statistic, S , the normalized test statistics, Z , is computed as follows:

$$\text{if } S > 0, \quad Z = \frac{S - 1}{[\text{VAR}(S)]^{1/2}} \quad (\text{Eq.4})$$

$$\text{if } S = 0, \quad Z = 0 \quad (\text{Eq.5})$$

$$\text{if } S < 0, \quad Z = \frac{S + 1}{[\text{VAR}(S)]^{1/2}} \quad (\text{Eq.6})$$

where $\text{VAR}(S)$ is the variance of S . According to (Kendall, 1975) $\text{VAR}(S)$ can be written as follows:

$$\text{VAR}(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^g t_p(t_p-1)(2t_p+5) \right] \quad (\text{Eq.7})$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and t_p is the number of data points in the P^{th} group. The Z -value follows a standard normal distribution. For testing the decreasing or increasing trend a significance level α is used. The probability associated with the computed test statistics, Z -value is estimated. The trend is identified as decreasing if Z -value is negative and the computed probability is less than the level of significance and the trend is identified as increasing if the Z -value is positive and the computed probability is less than the level of significance. If the computed probability is greater than the level of significance, there is no trend.

The trend analysis is performed on APHRODITE daily data to test the increasing or decreasing rainfall trends using Mann-Kendall trend test for each zone spatially. To estimate the rainfall trends in terms of increasing or decreasing, the Mann-Kendall trend test is carried out at each grid point. Changes in the daily precipitation trends in recent years with reference to distant past are assessed by dividing the historical data into two-time slices as 1951-1990 and 1991-2007. The period of 1951-1990 is considered as base period as followed by several studies in the literature (Sharma & Mujumdar, 2017), which often depend on the availability of the climate data. Further, the period 1961 to 1990 is likely to have larger anthropogenic trends embedded in the climate data (<https://www.ipcc.ch/ipccreports/tar/wg1/483.htm>). Throughout the manuscript, the study considered a trend as being significant if it is statistically significant at the 5% level ($p\text{-value} < 0.05$).

RESULTS AND DISCUSSION

The spatial average monthly precipitation from 1951 to 2007 for seven agro-climatic zones of Afghanistan is shown in Fig.2. The maximum precipitation occurrence months are observed as January, February, March, April and May for all zones of Afghanistan. Whereas, June, July,

August, September, October, November and December and generally considered as dry months. To study the precipitation trends at annual scale, the annual total precipitation for each zone is estimated for a period of 1951 to 2007 with APRODITE data. Zone wise annual precipitation is calculated from the mean precipitation of all valid gridded points of APRODITE data encompassing each zone. The annual total rainfall has decreased over North zone at a rate of 0.5 mm/decade, whereas for North-East zone as 17.3mm/decade, the West zone at a rate of 6.3 mm/decade. However, the annual total rainfall over South zone has increased at a rate of 2.8 mm/decade, the South-West zone at a rate of 1.7 mm/decade, the East zone at a rate of 10.7 mm/decade, the Central zone at a rate of 6.3 mm/decade. Overall, the annual total rainfall has shown an increasing trend for the zones of South, South-West, East and Central, whereas, a decreasing trend has been observed for the zones of North, North-East and West zones based on linear regression trend test as shown in Figure. 3. Further, the trend analysis was performed on daily data to test the increasing or decreasing rainfall trends using Mann-Kendall trend test for each grid point for various zones of Afghanistan. The change in the rainfall variability in recent years with reference to distant past was assessed by dividing the historical data into two time slices as 1951-1990 and 1991-2007. The trend analysis of the rainfall with gridded data sets also reveals that for most part of the Afghanistan region the rainfall has been observed as decreasing.

The spatial average monthly temperature from 1961 to 2006 for seven agro-climatic zones of Afghanistan is shown in Fig. 4. The maximum temperature can be observed in the months of May, June, July and August, with hottest month as July for all seven zones of Afghanistan. The annual average temperatures from 1961 to 2006 are studied for the possible trend in the temperature with spatially averaged annual average temperature with APRODITE data (Figure. 12). Figure.5 shows the spatially averaged annual average temperature trends over seven agro-climatic zones of Afghanistan for the observed period of 1961 to 2006 with APRODITE data. The annual average air temperature has increased over the North zone at a rate of 0.4 °C/decade, the North-East zone at a rate of 0.3 °C/decade, the South zone at a rate of 0.02 °C/decade, the South-West zone at a rate of 0.4 °C/decade, the East zone at a rate of 0.1 °C/decade, the West zone at a rate of 0.4 °C/decade, the Central zone at a rate of 0.2 °C/decade. All seven agro-climatic zones of Afghanistan have shown an increasing trend of temperatures in recent years.

CONCLUSIONS

The study has investigated the spatio-temporal analysis of precipitation and temperatures for seven agro-climatic zones of Afghanistan using gridded daily long time series datasets of APHRODITE from 1951 to 2007. The maximum precipitation occurrence months were observed as January, February, March, April and May for all zones of Afghanistan. Whereas, June, July, August, September, October, November and December and generally considered as dry months. The annual total precipitation has shown an increasing trend for the zones of South, South-West, East and Central, whereas, a decreasing trend has been observed for the zones of North, North-East and West zones. The changes in the magnitude of daily gridded precipitation in recent years (1991-2007) with reference to distant past (1951-1990) were analysed with significant decreasing trends ($p\text{-value} < 0.05$) for most parts of Afghanistan. The temperature was observed as maximum in the months of May, June, July and August, with hottest month as July for all seven zones of Afghanistan. The daily temperature trend analysis has revealed

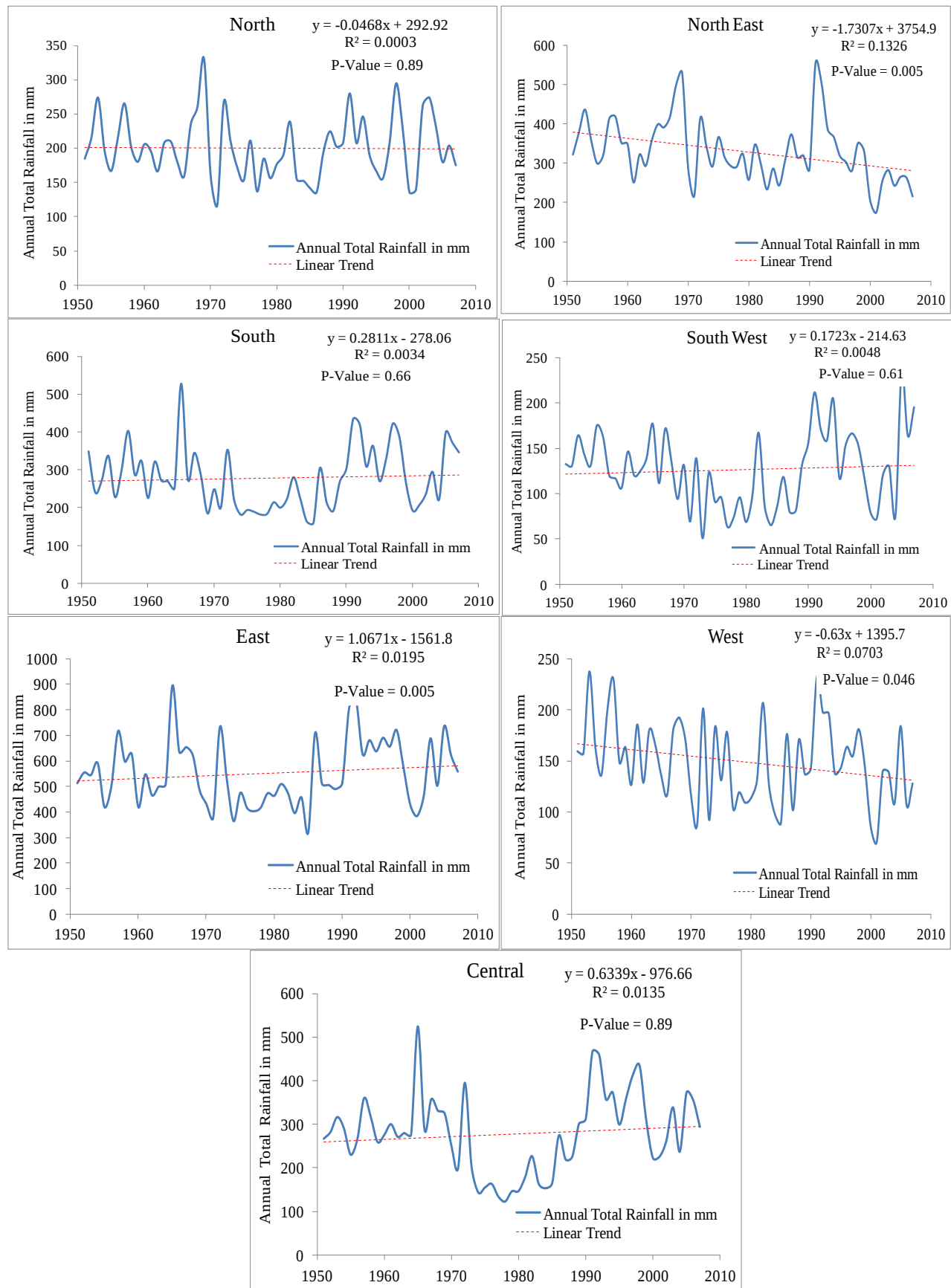


Figure 3 The spatially averaged annual total rainfall trend over seven agro-climatic zones of Afghanistan for the observed period of 1951 to 2007 with APRODITE data

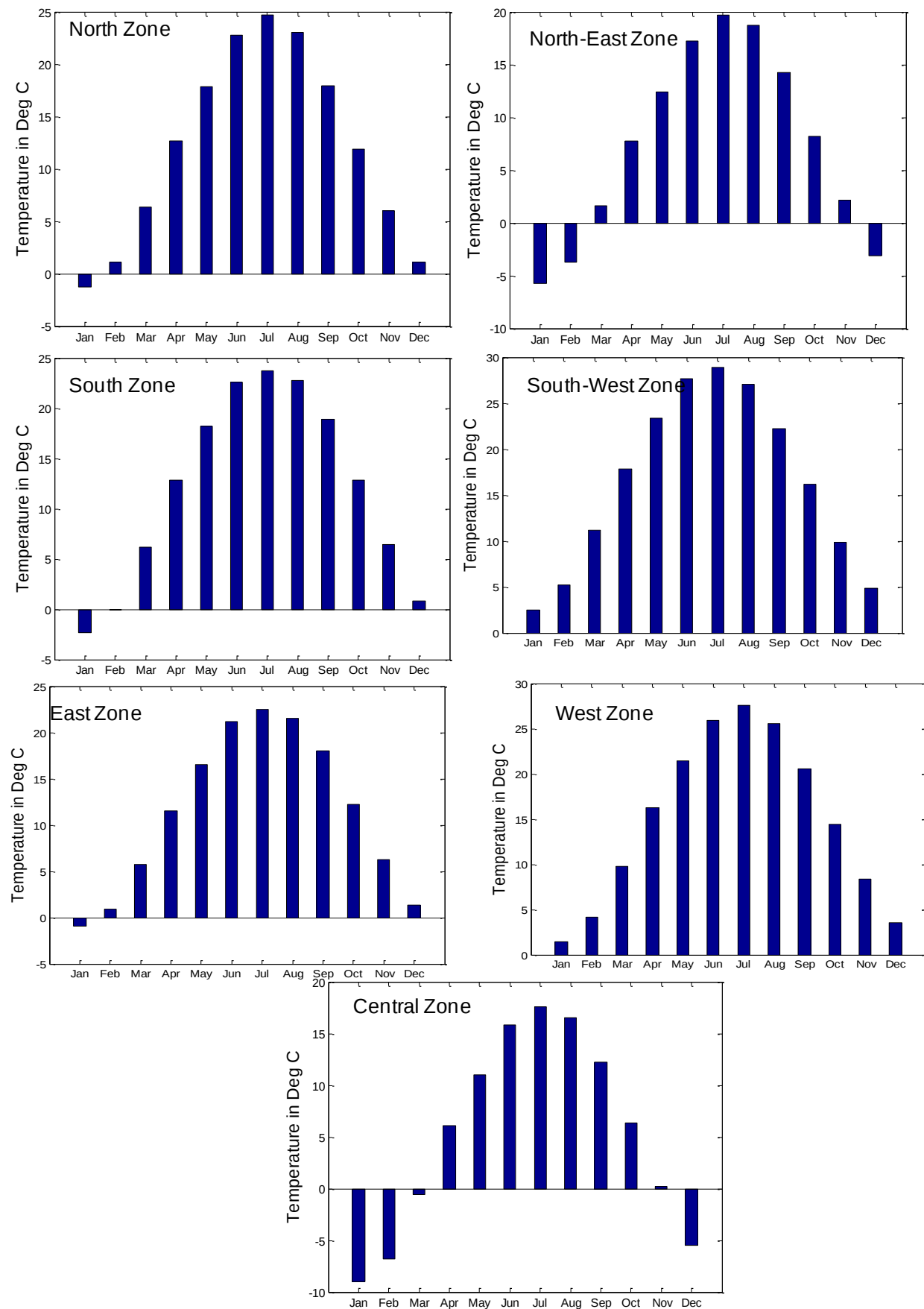


Figure 4 The Spatial average monthly temperature from 1961 to 2006 for seven agro-climatic zones of Afghanistan

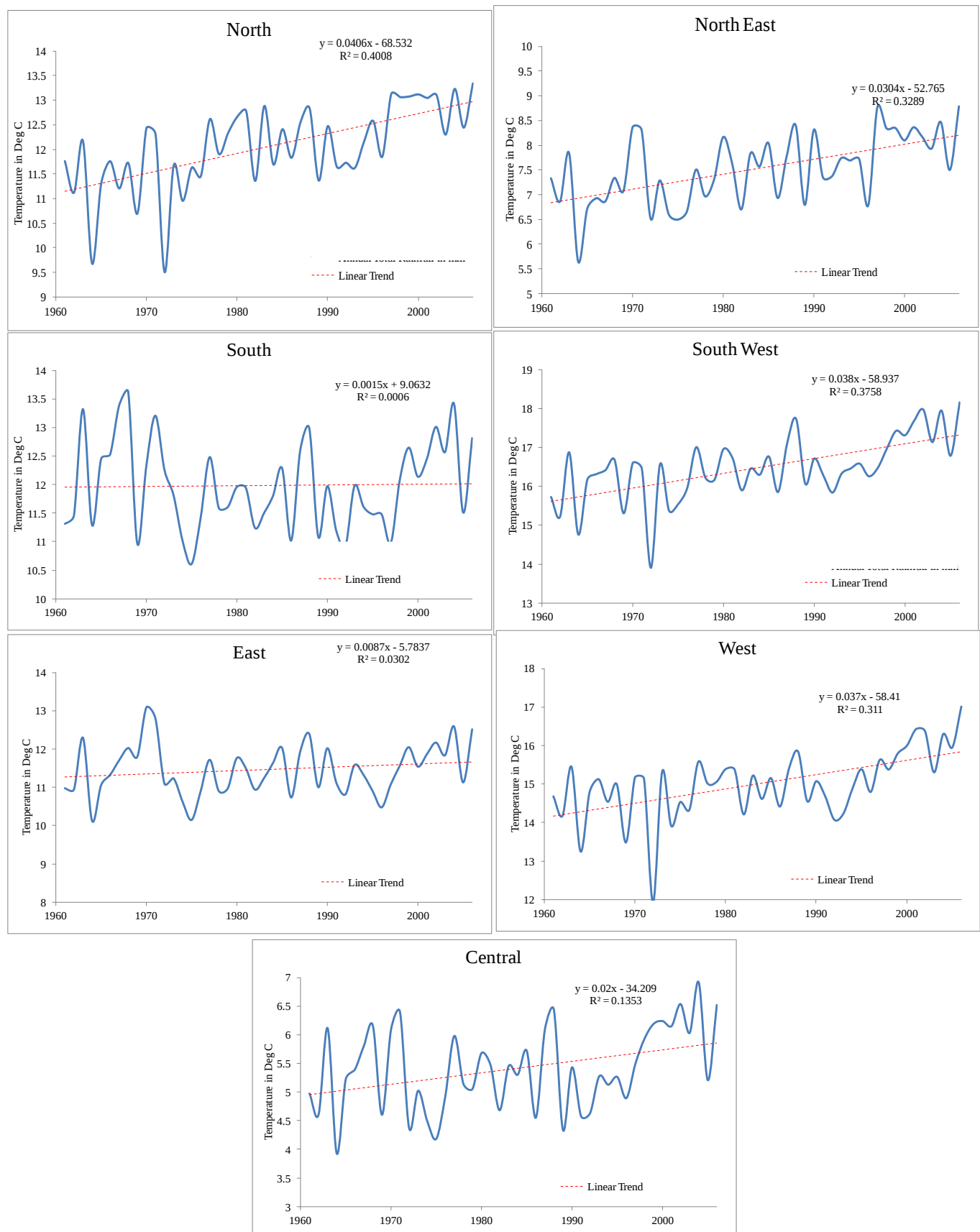


Figure 5 The spatially averaged annual average temperature trend over seven agro-climatic zones of Afghanistan for the observed period of 1961 to 2006 with APRODITE data

positive trends of temperatures for two time periods of 1951-1990 and 1991-2007 with Mann-Kendall trend test at 5% significance level. Overall, the North, North-East and West zones of Afghanistan are more vulnerable with decreasing precipitation and increasing temperatures indicating more dry and warm periods indicating increasing drought conditions. Whereas, the South, South-West, East, and Central zones are more vulnerable with increasing trends of both precipitation and temperatures indicating increase of more wet and warm climates. The zonal level precipitation extremes analysis carried in the present study has a benefit to the stakeholders and farmers in the agricultural water availability and demands perspective.

REFERENCES

1. Afghanistan Statistical Organization (CSO), Ministry of Agriculture, Irrigation and Livestock, Agriculture data 2008-2016.
2. Aich V, Akhundzadah NA, Knuerr A, Khoshbeen AJ, Hattermann F, Paeth H, Scanlon A, Paton EN. (2017) Climate Change in Afghanistan Deduced from Reanalysis and Coordinated Regional Climate Downscaling Experiment (CORDEX)—South Asia Simulations, *Clim.* 2017, 5, 38; doi:10.3390/cli5020038.
3. Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Tank Klein AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL (2006) Global Observed Changes in Daily Climate Extremes of Temperature and Precipitation. *J. Geophys. Res. Atmos.*, 111, Article ID: D05109.
4. Beekeeping survey report, Beekeeping and Animal Husbandry Development Project (BAHDP) and Beekeeping Development Project (BDP), Ministry of Agriculture, Irrigation and Livestock (MAIL), Conducted from September –November 2014.
5. Bita Javidfakhr. (2017). The analysis of the effects of climate change on geologic natural hazards. *Climate Change*, 3(11), 797-803
6. Campbell J. (2015) A dry and ravaged land: investigating water resources in Afghanistan, *Earth* 60 (1&2), 48-55. <http://www.earthmagazine.org/article/dry-and-ravaged-land-investigating-water-resources-afghanistan>.
7. Curry CL, Sillmann J, Bronaugh D, Alterskjaer K, Cole JNS, Ji D, Kravitz B, Kristjánsson JE, Moore JC, Muri H, Niemeier U, Robock A, Tilmes S, Yang S (2014) A multimodel examination of climate extremes in an idealized geoengineering experiment, *J. Geophys. Res. Atmos.*, 119, 3900–3923, doi: 10.1002/2013JD020648.
8. Donat MG, Alexander LV, Yang, Durre I, Vose R, Dunn RJH, Willett KM, Aguilar E, Brunet M, Caesar J, Hewitson B, Jack C, Klein Tank AMG, Kruger AC, Marengo J, Peterson TC, Renom M, Oria Rojas C, Rusticucci M, Salinger J, SanhouryElRayah A, Sekele SS, Srivastava AK, Trewin B, Villarreal C, Vincent LA, Zhai P, Zhang X, Kitching S. (2013) Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset, *J. Geophys. Res. Atmos.*, 118, 2098–2118, doi:10.1002/jgrd.50150.
9. Easterling DR, Meehl GA, Parmesan C, Chagnon SA, Karl T, Mearns LO. (2000) Climate extremes: observation, modelling and impacts. *Sci.* 289:2068–2074.
10. Frich P, Alexander LV, Della-Marta P, Gleason B, Haylock M, Klein Tank AMG and Peterson T (2002) Observed Coherent Changes in Climatic Extremes during the 2nd Half of the 20th Century. *Clim. Res.*, 19, 193-212. <https://doi.org/10.3354/cr019193>
11. Hamada A, Arakawa O, Yatagai A, (2011). An automated quality control method for daily rain-gauge data. *Global Environ. Res.*, 15, 183–192.
12. Hartmann DL, Klein Tank AMG, Rusticucci M, Alexander L, Brönnimann S, Charabi Y, Dentener F, Dlugokencky E, Easterling D, Kaplan A, Soden B, Thorne P, Wild M, Zhai PM. (2013) Observations: Atmosphere and Surface Supplementary Material, In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Stocker T.F. et al., (Eds.) available on www.climatechange2013.org and www.ipcc.ch.
13. IPCC (2012): Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.
14. Jamal Abdul Naser, S., Jun-ichiro, T., Hiroyuki, Y., Bjør, K. (2017), Intra-seasonal Variation of Rainfall and Climate Characteristics in Kabul River Basin, *Central Asian Journal of Water Research* (2017) 3(2): 24-40, Special Issue on Water Use Management Challenges in Central Asia and Afghanistan.
15. Jamal Abdul Naser, S., Jun-ichiro, T., Ryo, N., (2015). Climate change impacts on water resources in Kabul River Basin, Afghanistan, WECC 2015 Conference, PS 3-3-25. Available at: http://www.jfes.or.jp/wecc2015/program/poster/dec_1.html.
16. Kendall MG (1975) Rank Correlation Method; Griffin: London, UK.
17. Köppen and Wladimir (1884) Translated by Volken E, Brönnimann S. The thermal zones of the earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world. *Meteor. Zeits.*, Vol.20, No. 3, 351-360 (June 2011).
18. Mann HB (1945) Nonparametric tests against trend, *Econometrica* 1945, 13, 245–259.
19. Razavi T, Switzman H, Arain A, Coulibaly P (2016) Regional climate change trends and uncertainty analysis using extreme indices: A case study of Hamilton, Canada, *Clim. Risk Manag.*, <http://dx.doi.org/10.1016/j.crm.2016.06.002>.
20. Sharma S, Mujumdar PP (2017) Increasing Frequency and Spatial Extent of Concurrent Meteorological Droughts and Heatwaves in India, *Sci. Rep.* (Nature Publishing Group), 7,15582, doi:10.1038/s41598-017-15896-3.
21. Zhang X, et al. (2005) Trends in Middle East climate extreme indices from 1950 to 2003, *J. Geophys. Res.*, 110, D22104, doi:10.1029/2005JD006181.
22. Zhang X, Yang F (2004) User Manual; RClimDex 1.0; Climate Research Branch Environment: Downsview, ON, Canada.

Article Keywords

Mann-Kendall trend test, Agro-climatic zones, APHRODITE, Regression

Acknowledgments

The authors would like to thank the Ministry of Agriculture, Irrigation and Livestock (MAIL) and AGROMET, Afghanistan for the permission to use meteorological data. This publication is a part of the Climate Change Adaptation Project, MAIL, GoIRA by MgtWell Consulting Services through a project awarded ID no. 00087639 through the GEF/UNDP Grant No. 00076056 between the period of August 2016 and May 2017.

Author Contributions

Rehana, S. has designed the problem. Rehana, S. and S.K. Tomer performed the precipitation extreme indices trend analysis. Rehana, S. wrote the paper with critical input and contribution on analysis, interpretation of the results with input from all authors. Other authors contributed in terms of data sharing and analysis. All authors have reviewed the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Article History

Received: 14 February 2019

Accepted: 04 April 2019

Published: July - September 2019

Citation

Rehana S, Krishna Reddy P, Sai Bhaskar Reddy N, Abdul Raheem Daud, Shoaib Saboory, Shoaib Khaksari, Tomer SK. Regional scale spatiotemporal trends of precipitation and temperatures over Afghanistan. *Climate Change*, 2019, 5(19), 141-149

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