Understanding Precipitation Characteristics of Afghanistan at Provincial Scale

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Understanding Precipitation Characteristics of Afghanistan at Provincial Scale

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Abstract

This study examines the pattern and trend of seasonal and annual precipitation along with extreme precipitation events in a data scare, south Asian country, Afghanistan. Seven extreme precipitation indices were considered based upon intensity, duration and frequency of precipitation events. The study revealed that precipitation pattern of Afghanistan is unevenly distributed at seasonal and yearly scales. Southern and Southwestern provinces remain significantly dry whereas, the Northern and Northeastern provinces receive comparatively higher precipitation. Spring and winter seasons bring about 80% of yearly precipitation in Afghanistan. However, a notable declining precipitation trend was observed in these two seasons. An increasing trend in precipitation was observed for the summer and autumn seasons, however; these seasons are the lean periods for precipitation. A declining annual precipitation trend was also revealed in many provinces of Afghanistan. Analysis of extreme precipitation indices reveals a general drier condition in Afghanistan. Large spatial variability was found in precipitation indices. In many provinces of Afghanistan, a significantly declining trends were observed in intensity-based (Rx1-day, RX5-day, SDII and R95p) and frequency-based (R10) precipitation indices. The duration-based precipitation indices (CDD and CWD) also infer a general drier climatic condition in Afghanistan. This study will assist the agriculture and allied sectors to take well-planned adaptive measures in dealing with the changing patterns of precipitation, and additionally, facilitating future studies for Afghanistan.

Keywords: Precipitation, extreme precipitation indices, Trend analysis, Afghanistan

1. Introduction

Precipitation characteristics are indispensable for the hydrological analysis and efficient water resources management across the globe (Campling et al. 2001).Climate change has a significant influence on the global water cycle. Climate change results in a change in distribution, frequency, timing, and intensity of precipitation and seasonal water flows which possess a potential threat to food security (Tao et al., 2003; Kundzewicz, 2008; Trenberth, 2011; Murty et al., 2014; Suryavanshi et al., 2014; Joshi et al., 2016; FAO et al., 2012). Climate change is associated with frequent extreme weather events, such as droughts, heat waves and floods (Aggarwal and Singh, 2010). Extreme climatic events have a significant impact on various sectors such as agriculture, tourism, infrastructure etc and have a greater impact on the susceptibility of communities and ecosystems (Aguilar et al., 2005; Alexander et al., 2009).

Recent studies suggest that the frequency and intensity of extreme precipitation events are projected to increase in various parts of the world (Scoccimarro et al., 2013; Bintanja and Selten, 2014; Ikram et al., 2016; Brönnimann et al., 2018; Sharma and Goyal, 2020). Extreme events resulting from climate change pose a greater threat to the developing countries and would significantly impact their GDP (Mendelsohn et al., 2000; Yohe and Tol, 2002; Hope, 2006; Tol, 2009; Handmer et al., 2012; Nordhaus, 2014; Hallegatte and Rozenberg, 2017). Indices based on intensity, duration and frequency of extreme precipitation has been widely used as an indicator for evaluating the alteration in precipitation patterns (Peterson et al., 2001; Gachon et al., 2005; Kruger and Nxumalo, 2017). The applicability of extreme precipitation indices is appraised across continents such as North America (Aguilar et al., 2005; Vincent et al., 2006; Dos Santos et al., 2011; Akinsanola et al., 2020), South America (Grimm and Tedeschi, 2009; Valverdeand Marengo, 2014; Heidinger et al., 2018), Africa (Kruger, 2006; Hountondji et al., 2011; Tramblay et al., 2013; Kruger and Nxumalo, 2017), Europe (Turco and Llasat Botija,2011; Popov et al., 2019; Nigussieand Altunkaynak, 2019; Gentilucci et al., 2020),Australia (Haylock and Nicholls, 2000; Gallant et al., 2007; King et al., 2013; Zhu et al., 2020), and Asia (Sen Roy and Balling Jr, 2004; Qian and Lin, 2005; Shahid, 2011; Fu et al., 2013; Sharma and Babel, 2014; Balling et al., 2016; Jayawardena et al., 2018; Yosef et al., 2019; Ajjur and Riffi, 2020). The earlier studies suggest that the duration and the intensity of extreme precipitation are increasing in many regions of the world.

Asia is a huge the region in terms of both, population and geographical size. The climate and freshwater resources availability are highly diverse and require sub-regional scale assessment (Pfister et al., 2009). Wei et al. (2016), Peng et al. (2018) and Ma et al. (2020) reported a significantly increasing trend in summer precipitation and precipitation extremes over central Asia. Ta et al., (2018) reported a wetting trend in the winter season in the Central Asian region. However, Bothe et al. (2012), Greve et al. (2014), Feng and Zhang (2015) and Hu et al. (2019) reported a below normal and drying trend in the central Asian countries. Qian and Lin (2005) and Fu et al. (2013) found a decreasing trend of precipitation and extreme precipitation events in Northern and Northeastern China. However, they also reported an increasing trend of extreme precipitation events in the Southern China, Northwest China, Inner Mongolia, and in Tibetan Plateau. Balling et al. (2016) reported an increasing trend in extreme precipitation events across Iran. Manton et al., 2001 reported a significant decline in the number of rainy days and the frequency of extreme precipitation events over Southeast Asia and the western and central South Pacific regions. Several studies examined extreme precipitation events over the Indian subcontinent. Sen Roy and Balling Jr (2004) reported an increased frequency of extreme precipitation events in the northwestern Himalayas and the Deccan Plateau of India. They also found a decreasing trend in the extreme precipitation events over the eastern part of the Gangetic Plain. Dash et al. (2009) reported an increasing trend of dry spells in all the six homogeneous monsoon regions of India. An increasing trend in heavy rainy days was observed in North West, Central North East and North East regions of India. Bhatti et al., (2020) reported a general increasing trend in extreme precipitation indices over Pakistan. Shahid (2011) and Iskander et al. (2014) reported an increasing trend in intensity and heavy precipitation days and decreasing trends in consecutive dry days over Bangladesh. These studies reflect the heterogenic behaviour of precipitation on the Asian continent.

Afghanistan, located in the western part of South Asia, remains highly underdeveloped due to decades of war, civil conflicts, destroyed infrastructure and poor economic conditions of the larger population (Qureshi, 2002; Savage et al., 2009; NEPA, 2016). The agricultural production decreased by 3.5% per year during 1978-2004 and about 45% of household, including urban areas, are facing food shortage (FAO, 2018; Samuel, 2014; CSO, 2018; Kakar et al., 2019). In addition to this already apprehensive situation, climate change is putting pressure in form of frequent drought and flood events (Jones et al, 2009; Miyan, 2015; Iqbal et al., 2018). As per the Global Adaptation Index, Afghanistan ranked as one of the most vulnerable countries worldwide to climate change (Chen et al., 2015). About 80% of the population of the country inhabit in rural areas and about 58% of the GDP generated by agricultural and allied activities (Kawasaki et al., 2012). However, about one-third of irrigated land remains uncultivated, due to poor irrigation infrastructure, erratic water supply and improper water management (Maletta and Favre, 2003). Alteration in pattern and magnitude of precipitation may further affect the agricultural sector and socio-economic systems. The situation of agriculture in Afghanistan is critical and requires vital change for poverty reduction and future growth (World Bank, 2005). Historically, few studies have analyzed climate patterns and water resources over Afghanistan at different scale and periods (Shokory et al, 2017; Muhammad et al., 2017; Qutbudin et al., 2019; Sediqi et al, 2019; Rehana et al., 2019). These studies reported a noteworthy decline in water availability in Afghanistan. Provinces are the highest administrative unit in Afghanistan. They have an important coordinating role across the functions of administration and planning in Afghanistan (Yusufzada and Xia, 2019). To the best of our knowledge, none of the studies has examined spatial and temporal changes in the seasonal and extreme precipitation patterns at the provincial scale. Keeping in view, the present study is taken up to understand the patterns and trends of seasonal and annual precipitation, and extreme precipitation indices at the provincial scale.

2. Study Area

Afghanistan (29° 35'N- 38° 40'N latitude and 60° 31'E- 74° 55'E of longitude; Area 652000 Km^2) is a landlocked country surrounded by Turkmenistan, Uzbekistan and Tajikistan in the north; China and India in the far northeast, Pakistan to the south and southeast and Iran by the western side (Fig. 1).

Fig. 1. Location map of Afghanistan and its provinces

The topography of the country is highly undulating with elevation ranging from 235-7472 m. The soil in Afghanistan is dominated by clay loam to sandy loam soils. The land cover of Afghanistan is dominated by rangeland (47% of total area) and barrens (27% of total area). The agriculture and allied areas (irrigated and rain-fed agriculture, fruit trees and vineyards) contribute only about 12% of the total geographical area; and prevail in Northern and few Eastern and Southeastern provinces (FAO, 2016). As per Köppen climate classification, Afghanistan has Warm desert, Semi-arid, Temperate dry summer, Mediterranean and Polar tundra climate systems. Summers are hot with a mean temperature of 24 °C to 33°C (during JJA) while the winter season is cold and wet with a mean temperature of 0°C to 8°C (during DJF) (Savage et al., 2009; Sediqi et al., 2019). The precipitation in Afghanistan is scanty and unevenly distributed with an annual average of about 300 mm. Asian monsoon system suppresses precipitation in most parts of Afghanistan; however, a few Southeastern provinces receive substantial precipitation during summer. At higher elevation, precipitation falls from November to April due to winter storms of the Mediterranean region(Qureshi 2002; Savage et al., 2009, Arun, 2012).

3. Materials and Method

3.1 Meteorological Data

Due to decades (1979-2001) of war and conflict in Afghanistan, there is a lack and unavailability of the observed historical precipitation datasets. To circumvent this issue, Climate Forecast System Reanalysis (CFSR) climate data is utilized (https://globalweather.tamu.edu/#pubs). The

CSFR data is tested worldwide against the observed dataset (El Afandi, 2014; de Lima and Alcântara, 2019) and established as a viable option for hydro-climatic predictions for the data scare region. The CFSR weather data is extensively used for prediction of surface flow (Fuka et al., 2013; Dile and Srinivasan, 2014; Jajarmizadeh et al., 2016); extreme hydrologic events (Lu et al., 2020); droughts (Mo et al., 2011; Chen et al., 2019; Martinez-Cruz et al., 2020); and precipitation indices and extremes (Schmocker et al., 2016; Ren and Ren, 2017; Khedhaouiria et al., 2018; Alexander et al., 2020; Chunxiang et al., 2020). In this study, the daily CFSR precipitation dataset was extracted for Afghanistan and weighted average precipitation is computed at the provincial scale for 1979-2013 (35 years) period. The daily precipitation data were then used to compute the seasonal and annual precipitation variability and trend for the 34 provinces of Afghanistan. For seasonal analysis, four seasons are considered: Season 1 (Spring season, March-May), Season 2 (Summer season, June-August), Season 3 (Autumn, September-November) and Season 4 (December-February, Winter).

3.2 Mann-Kendall Test

The Mann-Kendall (MK)test(Mann 1945; Kendall 1975) is a rank-based nonparametric test, widely used for estimating trends in hydroclimatic time series. In this study, before the MK test, the presence of serial correlation in the time series was tested using methodology proposed by WMO (1966) and Matalas (1967).

$$r_L = \frac{\sum_{t=1}^{n-L}(X_t - \bar{X}_t)\cdot(X_{t+L} - \bar{X}_{t+L})}{\left[\sum_{t=1}^{n-L}(X_t - \bar{X}_t)^2 \cdot \sum_{t=1}^{n-L}(X_{t+L} - \bar{X}_{t+L})^2\right]^{1/2}} \quad \text{....(1)}$$

The significance of the serial correlation was checked using, following equation (Yevjevich, 1971).

$$r_k = \frac{-1 \pm t_g\,(n-k-1)^{1/2}}{n-k} \quad \text{....(2)}$$

Where, $t_g = 1.645, 1.965, 2.326$ are at 90, 95 and 99 percent confidence interval, respectively;L = 0 to m, is the number of lags where m is the maximum lag (i.e. = $n/3$); n is the length of the series. The serial correlation was tested at lag 1 and if r_1 does not significantly differ from zero, then series is regarded to be free from persistence.

The MK test statics S is defined as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \quad \text{.....(3)}$$

Where, n is the number of data points and here x_j represents the data point at time j.

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1.........if\,(x_j - x_i) > 0 \\ 0.........if\,(x_j - x_i) = 0 \\ -1.........if\,(x_j - x_i) < 0 \end{cases} \quad \text{....(4)}$$

For n ≥10, S is approximately normally distributed with the mean E(s)=0 and variance given as

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \quad \text{....(5)}$$

Where m is the number of tied groups and t_i is the data points in the i^{th} group.

The standardized test statistic Z is computed as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} \text{if S} > 0 \\ 0 \text{ if S} = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} \text{if S} < 0 \end{cases} \quad \text{...(6)}$$

The statistical significance of test statistics Z is tested at three different significance levels i.e. 1%, 5% and 10%. If the time series exhibited a significant lag-1 serial correlation, then MK test with pre-whitening as suggested by Yue et al. (2002) is used.

The slope of the time data set is estimated using Thiel-Sen Approach given as

$$\beta = Median\left[\frac{x_j - x_i}{j - i}\right] \quad \text{....(7)}$$

where X_j and X_i are data values at times j and i (i>j), respectively.

The relative change is computed using the following equation (Some'e et al., 2012)

$$RC = \frac{n * \beta}{[x]} * 100 \quad \text{....(8)}$$

Where, n is the length of time series, β is the trend slope given by Sen's median estimator, and |x| is the absolute average value of the time series.

3.3 Sequential Mann-Kendall Test (SQMK test)

SQMK test (Sneyers, 1990; Modarres and Sarhadi, 2009) is applied to understand the fluctuations in the trend over the study period. This rank-based test is progressive and retrograde analyses of the MK test that present the sequential values of standardized variables with zero mean and unit standard deviation. The sequential values are calculated for the forward series (u(t)), and backward series (u'(t)) The intersection point of u(t) and u'(t) determine the beginning of a change in trend. The details of SQMK test used in this study can be referred from Partal and Kahya (2006) and Kumar et al. (2016).

3.4 Extreme Precipitation Indices

Expert Team for Climate Change Detection and Indices (ETCCDI), in the joint WMO/CCI/ETCCDMI/CLIVAR project(2007), suggested 11 precipitation indices, which describe particular attributes of precipitation extremes and suggest a perspective on climatic alterations. These precipitation indices characterize extreme precipitation based on intensity, duration and frequency of various precipitation events(Donat et al., 2013). Based on the climatology of Afghanistan, indices such as1-day maximum precipitation amount (Rx1-day); maximum 5-day precipitation amount (RX5-day); simple daily intensity index(SDII); annual count of days when precipitation ≥ 10mm (R10); Consecutive Dry Days (CDD); Consecutive Wet Days (CWD); yearly total precipitation when precipitation is greater than the 95th percentile daily precipitation (R95p)were considered. List of selected precipitation indices with their detailed definition is depicted in Table 1.

Table 1. Extreme precipitation indices with their detailed definition

4. Results

To understand the spatio-temporal changes in precipitation over Afghanistan, trend analysis is performed using the MK test. The trend analysis was performed at three different significance levels i.e. 1% (Z values > 2.326), 5% (Z values >1.965)and 10% (Z values > 1.645). The shift in the seasonal and annual precipitation over Afghanistan was also analyzed using Sequential MK test. This analysis was conducted at 5% significance level(± 1.96 of the standardized statistic).

The following section includes the spatial patterns and trend of seasonal and annual precipitation and extreme precipitation indices. To avoid complexities, slope and relative change reported only for the provinces having a significant trend.

4.1 Average Seasonal Precipitation characteristics

From this study, it appeared that about 80% of average annual precipitation, occurs in winter (129mm) and spring season (115 mm); the remaining 20% precipitation during summer (16 mm), and autumn season (42 mm). The average annual precipitation in Afghanistan is about 302 mm. In Afghanistan, the spring season (Mar-May) contribute about 38% of yearly average precipitation. Seasonal and annual precipitation distribution of Afghanistan is depicted in fig. 2.

Fig. 2. Seasonal and annual precipitation distribution inprovinces ofAfghanistan

The lowest precipitation was found in southern and south-west provinces like Helmand, Kandahar and Farah, (13-31 mm) while eastern provinces like Khost, Wardak, Kunar, Parwan yield highest precipitation (270 mm)observed during the spring season (Fig. 2a). Summer (June-Aug) is a dry season in Afghanistan (16 mm; 5% of average yearly precipitation). Southern and south-west provinces (Herat, Farah, Nimroz, Helmand) along with Baghlan and Faryab were almost dry (Precipitation< 2 mm) during summer season (fig. 2b). Nevertheless, due to the influence of Indian summer monsoon, Khost province receives highest summer season precipitation (154 mm). Autumn (Sept-Nov) is also a lean season in Afghanistan (14% of the average annual precipitation). Panjshir province receives the lowest precipitation (7 mm) while Nuristan (100 mm) and Nangarhar (136 mm)provinces witness high precipitation during the autumn season (fig. 2c). Like spring, the winter season brings about 43% of average yearly precipitation. Due to frequent western disturbance in the Mediterranean region, provinces like Kapisa, Nuristan and Nangarhar receive high precipitation (214-302 mm) during winter seasons (fig. 2d). Farah province receives the lowest precipitation (30 mm) during winters. On annual basis, Khost (447 mm) and Nangarhar (585 mm) province receive the highest precipitation while Farah province (68 mm) receives very less annual precipitation (Fig. 2e).

It is evident from Fig. 2 that in Afghanistan, the precipitation pattern is unevenly distributed. The western and southern provinces of Afghanistan receive the most limited precipitation. The shallow soils, bare rocks and minimal vegetation retain very less moisture (Bhattacharyya et al.,2004), leaving these provinces highly vulnerable to drought-like conditions. Nevertheless, due to the effect of westerlies and Indian summer monsoon, northeastern provinces of Afghanistan receive a fair amount of precipitation.

4.2 Seasonal and Annual trends of precipitation

Persistence and the trend in precipitation were analyzed for 34 provinces of Afghanistan (Table 2, Fig. 3). It can be seen that for the Spring season, Jowzjan, Daykundi, Kandahar, Nimroz, Helmand, Kapisa, Ghazni, Logar, Wardak, Zabul, Kabul and Panjshir provinces exhibited a significantly decreasing trend (Fig. 3a). The Panjshir province has the highest slope value (-2.83

mm/yr) while Nimroz Province has the least slope of -0.09 mm/yr. Ghazni province (-96%) has shown the largest relative change, whereas, the Zabul province (-45%) exhibited the smallest relative change in the spring season.

Table 2. Seasonal and Annual zmk, Slope and relative change values of the provinces having significant trends of precipitation

Fig. 3. Seasonal and annual trends and relative change of precipitation in provinces of Afghanistan

For the season 2 i.e. summer season, 11 provinces namely Khost, Kapisa, Bamyan, Ghor, Samangan, Herat, Kunduz, Badakhshan, Takhar, Baghlan and Laghman showed a significantly increasing trend (Fig. 3b). In the summer season, Samangan province exhibited the maximum slope (0.57 mm/yr) while Kapisa province showed the minimum slope (0.01 mm/yr). The largest relative change was observed in Badakhshan province (111%) and the least relative change was reported in Laghman province (7%). In the summer season, only Nimroz province had a significant decreasing trend (slope-0.09 mm/yr; RC-58%). In the case of Season 3, i.e. Autumn season, Kandahar, Helmand, Nangarhar, Paktiya, Khost, Zabul, Bamyan, Parwan, Ghor, Samangan, Balkh, Farah, Nimroz, sar-e pol and Panjshir provinces showed an increasing precipitation trend (Fig. 3c). The highest slope found in sar-e pol province (3.2 mm/yr) while Khost province exhibited the least slope (0.31 mm/yr). The highest RC was observed in Helmand province (151%), while the lowest RC was observed in Bamyan province (43%).In Season 4, i.e. winter season, Kandahar, Uruzgan, Helmand, Nangarhar, Paktiya, Zabul, Kapisa, Herat, Badghis, Jowzjan, Faryab and Baghlan provinces exhibited a decreasing trend (Fig. 3d). Uruzgan province (-2.98 mm/yr) had the highest slope while the least slope was reported in the Kapisa province (-1.13 mm/yr). The maximum RC was found in Herat province (-61%) and the minimum RC reported in Uruzgan province (-35%). Badakhshan (slope, 2.71 mm/yr; RC 59%) and Takhar (Slope, 3.59mm/yr; RC 44%) provinces showed an increasing precipitation trend in the winter season. In case of annual precipitation, only Khost province (slope 1.11 mm/yr; RC 45%) reflected an increasing trend; whereas, Kandahar, Logar, Zabul, Kapisa, Herat, Jowzjan, Faryab and Baghlan provinces exhibited a decreasing trend in the precipitation (Fig. 3e). The slope in annual precipitation varied from -1.4 mm/yr (Kapisa province) to 3.56 mm/yr (Zabul Province). The decremented yearly relative change ranges between -44 % (Herat province) to -32 % (Logar province).

Fig. 4a-e. shows the result of SQMK test for seasonal and annual precipitation in Afghanistan. In the spring season, an apparent decreasing trend of precipitation started in 1982(Fig. 4a). The change points were years 1982, 1983, 1985, 1987, 1991 and 1995. No significant trend was observed in the summer season, however, an increasing, non-significant trend, starting from the year 1982, was observed (Fig. 4b).In the Autumn season, (fig. 4c) an increasing trend, starting from the year 1982, was observed. A non-significant, decreasing trend was observed in the winter season during 1981-1986 (Fig. 4d). The annual precipitation of Afghanistan also remains trendless during the study period. However, a decreasing non-significant trend was found. The decreasing trend begins in the year 1982.

Fig. 4ae. Sequential values of the statistics u(t) and u'(t) from the MK test for seasonal and annual precipitation of Afghanistan.

4.3 Spatial patterns of Extreme Precipitation Indices

Fig. 5 exhibits the spatial patterns of mean values of extreme precipitation indices of different provinces.

Fig. 5. Spatial patterns of mean values of extreme precipitation indices in provinces of Afghanistan

For this study, the intensity-based extreme precipitation indices namely Rx1-day, RX5-day, SDII and R95p were selected. The 1-day maximum precipitation amount (Rx1-day) varied from 12 mm (Farah province) to 50 mm (Nangarhar province) (Fig. 5a). Uruzgan (46 mm), Kunar (45 mm) and Samangan (41 mm) province have a higher mean value of Rx1-day; whereas, Khost (14 mm), Nimroj (14 mm) and Kapisa (16 mm) provinces have lower mean values. To investigate the large precipitation events, maximum 5-day precipitation amount (RX5-day) was considered. Similar to Rx1-day, the mean values of RX5-day range from 17 mm (Farah province) to 99 mm (Nangarhar province) (Fig. 5b). Uruzgan (94 mm) and Samangan (92 mm) provinces showed higher values whereas, Nimroj (19 mm), Khost (21 mm) and Kapisa (28 mm)provinces showed lower values of RX5-day. To investigate the change in precipitation intensity, simple daily intensity index (SDII) is utilized. SDII is the ratio of yearly precipitation into the number of rainy days. A significantly increasing SDII indicate risks of extreme precipitation events of short duration, which may result in flash floods (Kruger and Nxumalo, 2017). The mean values of SDII do not show many spatial variations in the provinces of Afghanistan. The highest value of SDII was 9.5 mm/day while the lowest was 4 mm/day (Fig. 5c). The mean values of SDII indicate ‘low intensity’ precipitation (as suggested by Iskander et al., 2014) across Afghanistan. R95p refers to annual contribution from very wet days. R95p varied from8 mm (Farah province) to 146 mm (Samangan province) (Fig. 5d). Panjsir (137 mm) and Sar-e Pol province (132 mm) yield high values of R95p while Nimroj (11 mm) and Khost province (20 mm) exhibited low values of extreme precipitation.

Based on the duration of extreme precipitation events, two indices namely Consecutive Dry Days (CDD) and Consecutive Wet Days (CWD) were considered in this study. CDD and CWD are the maximum numbers of consecutive dry and wet days per year respectively. Mean values of CDD varied between 75 days (Panjsir province) to 207 days (Nimroj province) (Fig. 5e). The province like Herat (191 days) and Farah (199 days) also reflect extended dry days while Paktiya (87 days) and Nangarhar (87 days) provinces exhibit comparatively lesser CDD. Mean CWD range between 2 days (Farah, Nimroj and Khost province) to 10 days (Panjsir Province) (Fig. 5f). CWD does not show significant spatial variation; seven provinces have equal or less than 3 days of subsequent yearly wet days.

R10 index indicates the annual number of days when precipitation ≥ 10 mm. For R10 index, a threshold of precipitation of 10 mm was taken and it represents the number of days with heavy precipitations (Sharma and Goyal, 2020). R10 ranges from 1-day (Farah and Nimroj Provinces) to 29 days (Samangan Province) (Fig. 5g). Sar-e Pol (21 days) and Takhar (20 days) provinces exhibit comparative heavy precipitation days while Kapisa (2 days) and Khost (2 days) provinces reveal less ‘heavy precipitation’ days.

4.4 Trends of Extreme Precipitation Indices

Results of the trend, slope and relative change values of extreme precipitation indices (Fig. 6 and Table 3) are presented for the provinces having significant trends.

Table 3: Zmk, Slope and relative change values of the provinces having significant trends of extreme precipitation indices

Fig. 6. Seasonal and annual trends and relative change of extreme precipitation indices in provinces of Afghanistan

A decreasing trend in 1-day maximum precipitation (Rx1-day) was observed in Jowzjan, Samangan, Baghlan and Logar provinces, whereas, an increasing trend was observed in Sar-e Pol province (Fig. 6a). The slope values range from-0.38 to 0.22 mm/year and RC values vary from -49% to 37%. For the 5-day maximum precipitation (Rx5-day) a declining trend was found in

Faryab, Ghor, Baghlan and Logar provinces whereas, no significant trend was observed in remaining provinces (Fig. 6b). The slope and RC vary from -0.62 mm/yr to 0.36 mm/yr and -63% to 29% respectively. The SDII exhibits a decreasing trend for Herat, Jowzjan, Samangan and Logar provinces and an increasing trend in Paktika and Badakhshan provinces (Fig. 6c). The slope and RC varied from -0.05 to 0.05 mm/day/yr and -29% to 26% respectively. Very wet day precipitation (R95p) exhibits a decreasing trend for Faryab, Logar, Samangan, Baghlan and Jowzjan provinces and an increasing trend in Badakhshan province (Fig. 6d). The slope varies from -4.71 to 1.65 mm/year and RC ranges from-113% to 86%. An increasing trend in CDD was observed in Kandahar, Zabul, Baghlan and Logar provinces with slope varying between -1.86 to 2.05 days/yr and RC varying from -39% to 54% (Fig. 6e). For the CWD, an increasing trend was observed in Nimroz and Farah provinces and the declining trend was observed in Baghlan province (Fig. 6f). The slope range from-0.06 to 0.03 days/yr and RC varied between -24% to 19 %. A decreasing trend in R10 was observed in Herat, Jowzjan, Samangan, Baghlan and Nangarhar provinces (Fig. 6g). The slope values and RC range from-0.33 to 0.06 days/yr and -85% to 71% respectively.

The results of SQMK test for extreme precipitation indices are presented in Fig. 7a-g. During the study period, no significant trend was observed in Rx1-day, RX5-day, R95p, SDII, CDD and CWD. The R10 index showed a significantly declining trend for a brief period of 2001-2010.

5. Discussions

The study reflects a grim situation of precipitation in Afghanistan. There is a significant decreasing trend in rainfall during the spring and winter season. It is noteworthy that about 80% of annual precipitation occurs during the spring and winter season. A considerable decreasing trend in spring precipitation will affect the irrigation and livelihood of South and Southeast provinces as the spring season contributes about 38% of annual precipitation. Provinces like Wardak, parts of Helmand, Nimroz and Kabul, Zabul, Daykundi, Panjshir and northern part of Kandahar are mostly dependent on rain-fed agriculture (FAO, WFP, IFAD, 2012). A decreasing trend in spring season precipitation will affect the sowing of spring wheat crop. Spring season is a growing period of wheat and barley crops (grains sown in winter season). Decreasing precipitation will induce critical water stress for winter grains, which in turn affect the crop production in those provinces. The trend of summer and autumn seasons indicated incremental precipitation. However, the contribution of summer (16 mm) and autumn seasons (42 mm) precipitation is minimal and it could be marginally beneficial for the agricultural activities. Winter wheat and barley crops are grown in the winter season. Rainfed wheat accounts for about 55% of wheat acreage in Afghanistan (Sharma, et. al. 2015). A decrease in the winter precipitation observed over Kandahar, Orazgaan, Zabul, Kapisa, Baghdes and Faryab province would adversely affect the crop yield. The decreasing annual pattern of precipitation may affect the major population of those provinces which relies on agricultural activities for their livelihood. The sequential MK test revealed that the year 1982 can be considered as change point of precipitation for seasonal and annual scales.

Farah, the driest province of Afghanistan, has least precipitation intensity while Nangarhar, the wettest province has the highest values of those indices. Badakhshan, the far northeastern highland province of Afghanistan exhibited an increasing trend of winter precipitation and extreme precipitation indices, which could result in frequent landslide and floods in Badakhshan province. Except for Badakhshan, most of the provinces revealed a significantly declining trend of precipitation intensity indices. Reduction in precipitation intensity could directly or indirectly affect general ecosystem functioning and could lead to frequent drought conditions in many parts of Afghanistan. Based on the duration of extreme precipitation events, CDD and CWD indices were analyzed. The western and southwestern provinces revealed long periods of consecutive dry days. The trend analysis of CDD revealed an increasing trend in a few eastern and southern provinces. The rising trends of these provinces infer prolonged drier climatic conditions for these provinces. Slight spatial variation was noted for CWD index; only one province exhibits declining while two provinces revealed a significantly rising trend. Based on the frequency of extreme events, R10 index assessed. A significantly declining trend was observed in northern, eastern and western provinces. The declining trend of heavy precipitation days again reveals a drier condition in Afghanistan. The result of this study is consistent with the earlier studies conducted in Afghanistan. Ridley et al. (2013) and Mukhopadhyay and Khan (2014) found that the Northeastern region of Afghanistan receives more precipitation due to onset of westerlies. Aich et al. (2017) found a decreasing trend in heavy precipitation (95th percentile), spring season and annual precipitation in Afghanistan. Qutbudin et al., (2019) and Rehana et al. (2019) also reported a declining trend of precipitation in northern, western and southwest parts of Afghanistan and indicated drier conditions.

The shrinking precipitation could influence agricultural sectors and influence the livelihood of the poorest communities of Afghanistan. Poor communities may fall in "vulnerability traps," where incompetency to overcome weather events can gradually increase their vulnerability to succeeding weather extremes (Dawson and Spannagle, 2009).To deal with the susceptibility of the farming community, some well-planned adaptation measures can be taken:-

1. Restructuring of existing and traditional irrigation systems and make them more resilient.
2. Induction of new varieties of less water consuming and drought-resistant crops.
3. Effective water conservation strategies can be planned and percolated at the community level.

6. Summary and Conclusion

In this study, an attempt is made to investigate the patterns and trends in seasonal and annual precipitation along with the extreme precipitation indices over Afghanistan during 1979-2013. Seven indices were selected based on intensity, duration and frequency of extreme precipitation. For trend analysis, a non-parametric MK test applied on various time series of precipitation and extreme indices. The main outcomes of this study are summarized below:

1. Winter (129 mm) and spring (115 mm) are predominant wet seasons that contribute about 80% of average annual precipitation (302 mm). However, a decreasing trend was observed in winter and spring season precipitation over most of the provinces. This could significantly affect the production of Wheat, Maize, Potato and Barley along with the orchard crops.
2. An increasing trend in summer and autumn season precipitation was observed over most of the provinces. It is noteworthy that summer (16 mm) and autumn season (42 mm) contribute only about 20% of the total precipitation.
3. A declining trend of annual precipitation was observed in most of the provinces of Afghanistan. In general, this shrinking precipitation will directly or indirectly affect the livelihood of the farming communities.
4. The extreme precipitation indices disclosed a substantial spatial variability across Afghanistan. Many provinces revealed a declining trend in the intensity-based (Rx1-day, RX5-day, SDII and R95p) and frequency-based (R10) precipitation indices. The precipitation duration based indices (CDD and CWD) also revealed long periods of dry

days. The extreme precipitation indices also indicate a general drier condition in Afghanistan.

5. To sustain the population and the economy there is a need for some well-planned adaptation measures which include developing a resilient water conservation and distribution system.

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Author's Contribution

Shakti Suryavanshi: Conceptualization, Investigation and Writing-original draft

Nitin Joshi: Conceptualization, Methodology, Writing-review and editing

Hardeep Kumar Maurya: Data Curation, Visualization

Divya Gupta: Writing-review and editing

Keshav Kumar Sharma: Editing

Availability of data and material

Some or all data, models that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability

Available on request

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Conflict of Interest

The authors declare no conflict of Interest

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Table 1. Extreme precipitation indices with their detailed definition

Precipitation Index	Indicator Name	Definition	Units
Based on intensity			
Rx1-day	1-day maximum precipitation	Maximum 1-day precipitation amount	mm
RX5-day	5-day maximum precipitation	Maximum 5-day precipitation amount	mm
SDII	Simple daily intensity index	Yearly precipitation divided by number of rainy days	mm/day
R95p	Very wet days	Yearly total precipitation when precipitation is greater than the 95^{th} percentile daily precipitation	mm
Based on duration			
CDD	Consecutive Dry Days	Maximum number of consecutive dry days (when precipitation<1 mm) in a year	days
CWD	Consecutive wet Days	Maximum number of consecutive wet days (when precipitation≥1 mm) in a year	days
Based on frequency			
R10	Heavy precipitation days	Annual count of days when precipitation ≥ 10mm	days

Table 2. Seasonal and Annual Zmk, Slope and relative change values of the provinces having significant trends of precipitation

Provinces	Season 1 (Spring Season)			Season 2 (Summer Season)			Season 3 (Autumn season)			Season 4 (Winter Season)			Yearly		
	zmk	Slope (mm/ yr)	RC (%)	zmk	Slope (mm/ yr)	RC (%)	zmk	Slope (mm/ yr)	RC (%)	zmk	Slope (mm/ yr)	RC (%)	zmk	Slope (mm/y r)	RC (%)
Kabul	-2.22	-0.84	-79	0.62	-	-	1.05	-	-	-0.80	-	-	-1.02	-	-
Qandahar	-2.17	-0.55	-75	-0.62	-	-	1.96	1.17	89	-1.88	-1.33	-55	-1.65	-1.99	-44
Helmand	-1.90	-0.21	-58	1.23	-	-	3.38	1.75	151	-1.45	-	-	-0.14	-	-
Ningarhar	-0.99	-	-	-0.77	-	-	1.85	2.43	63	-0.85	-	-	-1.36	-	-
Paktiya	-1.33	-	-	-0.80	-	-	1.79	1.08	54	0.48	-	-	0.62	-	-
Paktika	-1.5	-	-	-0.58	-	-	1.36	-	-	-0.25	-	-	-0.08	-	-
Ghazni	-1.64	-1.07	-96	1.19	-	-	1.19	-	-	0.05	-	-	0.36	-	-
Orazgaan	-1.29	-	-	0.34	-	-	1.56	-	-	-1.7	-2.98	-35	-1.24	-	-
Khost	-1.05	-	-	1.66	0.02	15	1.81	0.31	57	0.96	-	-	2.01	1.11	45
Logar	-2.04	-1.42	-74	-0.22	-	-	0.99	-	-	-1.33	-	-	-1.67	-2.35	-32
Wardak	-1.76	-2.11	-68	0.65	-	-	1.3	-	-	0.08	-	-	-1.13	-	-
Zabal	-1.66	-0.47	-45	-0.3	-	-	1.67	1.32	53	-1.98	-2.88	-59	-1.93	-3.56	-41
Kapisa	-2.3	-0.40	-89	1.64	0.01	31	0.08	-	-	-1.73	-1.13	-57	-1.67	-1.4	-43
Daikondi	-2.14	-0.60	-74	1.53	-	-	1.07	-	-	-1.22	-	-	-0.76	-	-
Bamyan	-1.19	-	-	1.7	0.35	59	1.93	1.14	43	0.85	-	-	-0.36	-	-
Parwan	-1.59	-	-	1.36	-	-	2.61	2.20	65	0.99	-	-	-0.42	-	-
Ghor	-1.26	-	-	1.64	0.14	64	2.01	1.11	55	-1.16	-	-	-1.22	-	-
Samangan	-1.27	-	-	1.93	0.57	81	1.95	3.03	49	-0.34	-	-	-0.34	-	-
Balkh	-0.86	-	-	1.5	-	-	1.9	1.30	69	-1.61	-	-	-0.73	-	-
Farah	-0.35	-	-	0.97	-	-	2.55	0.58	102	-0.25	-	-	0.96	-	-
Nemroz	-2.38	-0.09	-58	-2.38	-0.09	-58	3.46	0.75	138	-0.79	-	-	0.73	-	-
Herat	-1.36	-	-	1.68	0.02	33	1.44	-	-	-2.61	-1.81	-61	-2.1	-2.27	-44
Badghes	-0.8	-	-	4.26	0.07	59	1.3	-	-	-2.3	-1.85	-47	-1.47		
Jowzjan	-1.86	-0.86	-62	1.2	-	-	1.27	-	-	-2.41	-2.58	-52	-1.7	-3.02	-33
Faryab	-1.4	-	-	-1.4	-	-	1.36	-	-	-2.6	-2.58	-52	-2.07	-2.14	-37
Sare pol	-0.96	-	-	1.36	-	-	2.78	3.20	66	0	-	-	-0.85		
Konduz	-1.36	-	-	1.91	0.12	46	1.59	-	-	0.56	-	-	-0.22		
Badakshan	-1.56	-	-	2.47	0.40	111	1.27	-	-	2.49	2.71	59	0.93		
Takhar	-1.59	-	-	2.38	0.45	79	0.99	-	-	2.18	3.59	44	-1.1		
Baghlan	-0.25	-	-	2.17	0.09	67	-0.48	-	-	-1.87	-1.66	-53	-2.01	-2.27	-37
Noristan	-1.44	-	-	1.07	-	-	1.39	-	-	0.71	-	-	-0.05		
Panjshir	-1.78	-2.83	-51	1.33	-	-	3.06	2.60	62	1.33	-	-	0.28		
Kunar	-1.24	-	-	0	-	-	1.42	-	-	0.02	-	-	-0.65		
Laghman	-1.4	-	-	1.73	0.01	7	0.99	-	-	-1.59	-	-	-1.05		

Table 3: Zmk, Slope and relative change values of the provinces having significant trends of extreme precipitation indices

Provinces	RX1 day			RX5 day			SDII mm			R10 mm			CDD day			C
	zmk	Slope (days/yr)	RC (%)	zmk	Slope (days/yr)	RC (%)	zmk	Slope mm/yr	RC (%)	zmk	Slope (mm/yr)	RC (%)	zmk	Slope (days/yr)	RC (%)	zmk
Herat	-	-	-	-	-	-	-1.76	-0.05	-29	-2.71	-0.12	-85	-	-	-	-
Farah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.02
Faryab	-	-	-	-1.76	-0.29	-30	-	-	-	-	-	-	-	-	-	-
Ghor	-	-	-	-2.07	-0.45	-40	-	-	-	-	-	-	-	-	-	-
kandahar	-	-	-	-	-	-	-	-	-	-	-	-	1.85	2.05	44	-
Jowzjan	-2.27	-0.36	-45	-	-	-	-2.67	-0.04	-26	-2.13	-0.14	-55	-	-	-	-
Sar-e Pol	-1.76	-0.33	-36	-	-	-	-	-	-	-	-	-	-	-	-	-
Zabul	-	-	-	-	-	-	-	-	-	-	-	-	1.65	1.74	37	-
Paktika	-	-	-	-	-	-	2.36	0.05	26	-	-	-	-	-	-	-
samangan	-1.99	-0.38	-33	-	-	-	-2.07	-0.05	-20	-2.10	-0.33	-40	-	-	-	-
Baghlan	-1.82	-0.27	-46	-2.56	-0.59	-63	-	-	-	-2.14	-0.08	-62	2.14	1.30	30	-2.93
Logar	-2.36	-0.31	-49	-1.96	-0.45	-36	-1.82	-0.02	-15	-	-	-	2.19	1.94	54	-
Nangarhar	-	-	-	-	-	-	-	-	-	-1.85	-0.21	-39	-	-	-	-
Badakhshan	2.44	0.22	37	-	-	-	3.27	0.04	26	-	-	-	-	-	-	-
Nimroz	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.06

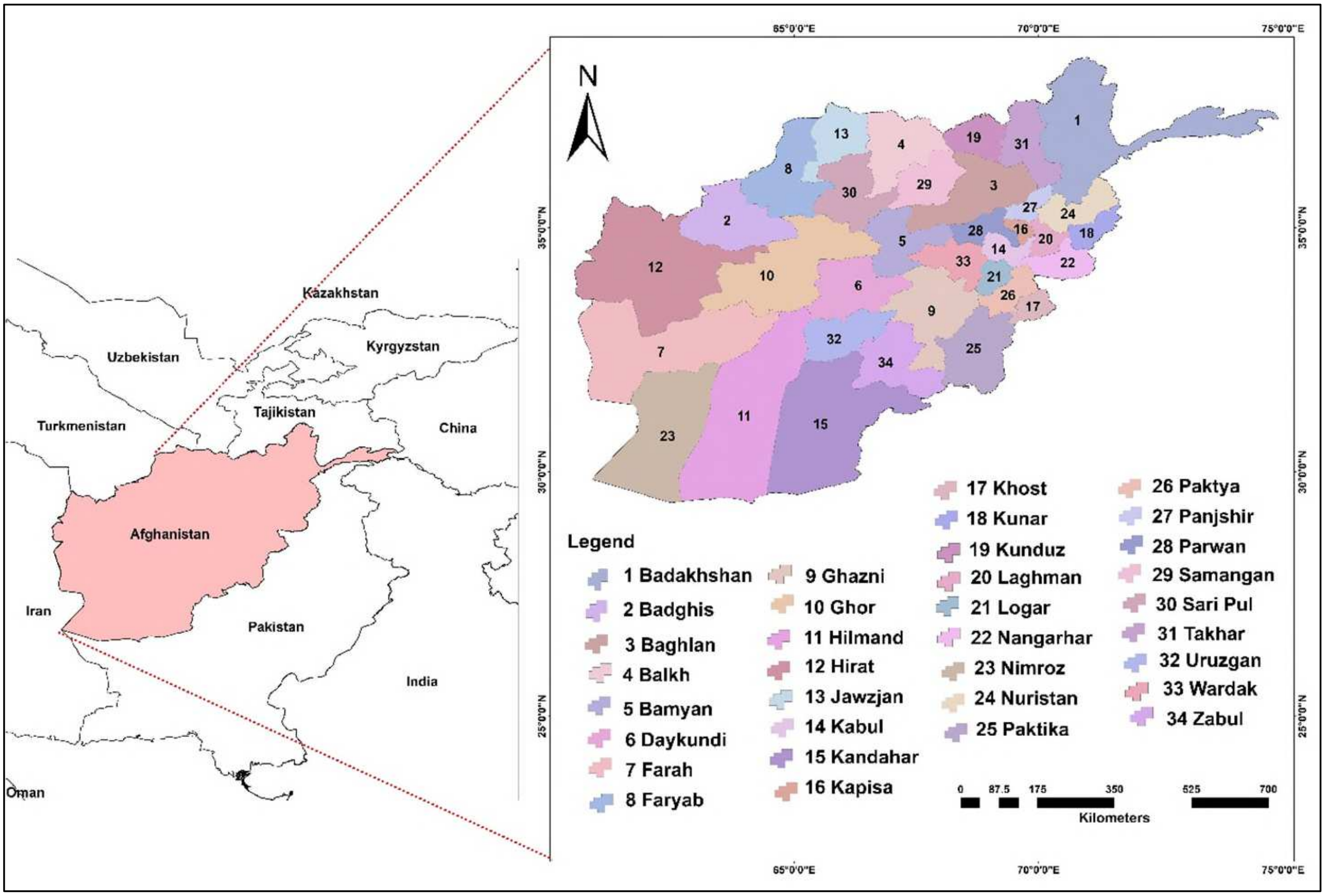
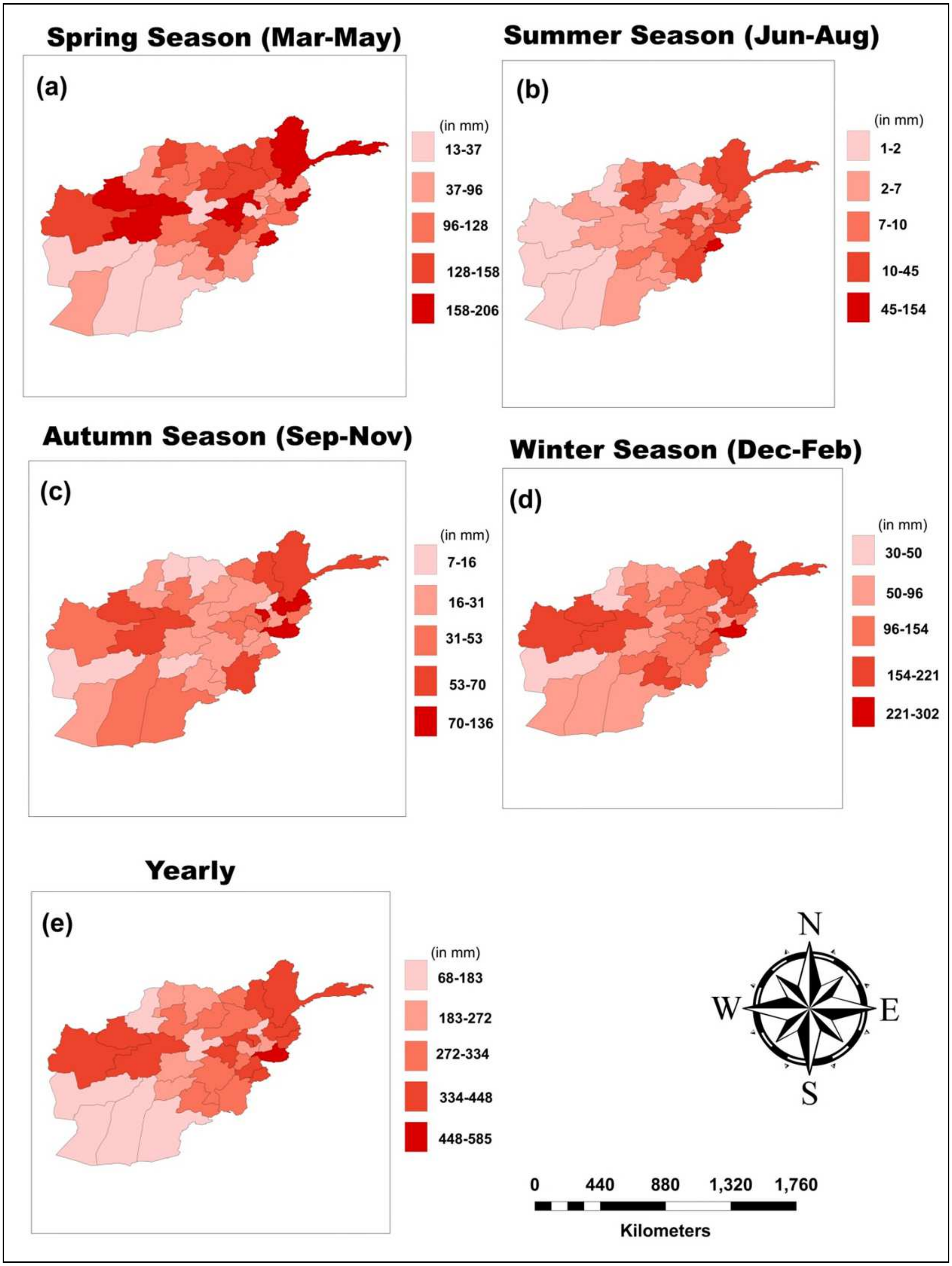


Fig. 1. Location map of Afghanistan and its provinces



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852 *Fig. 2. Seasonal and annual precipitation distribution in the provinces of Afghanistan*

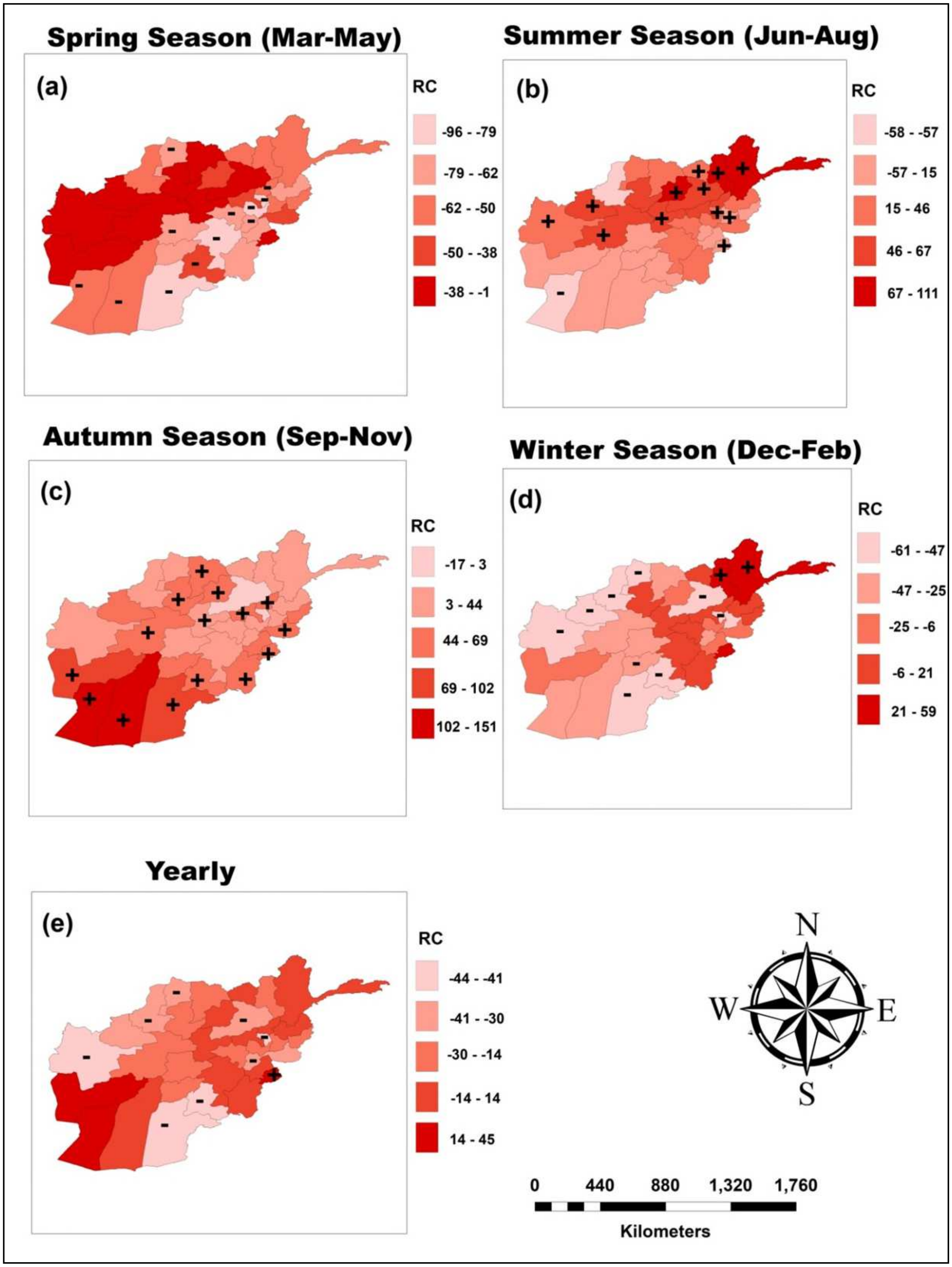

Fig. 3. Seasonal and annual trends and relative change of precipitation in the provinces of Afghanistan

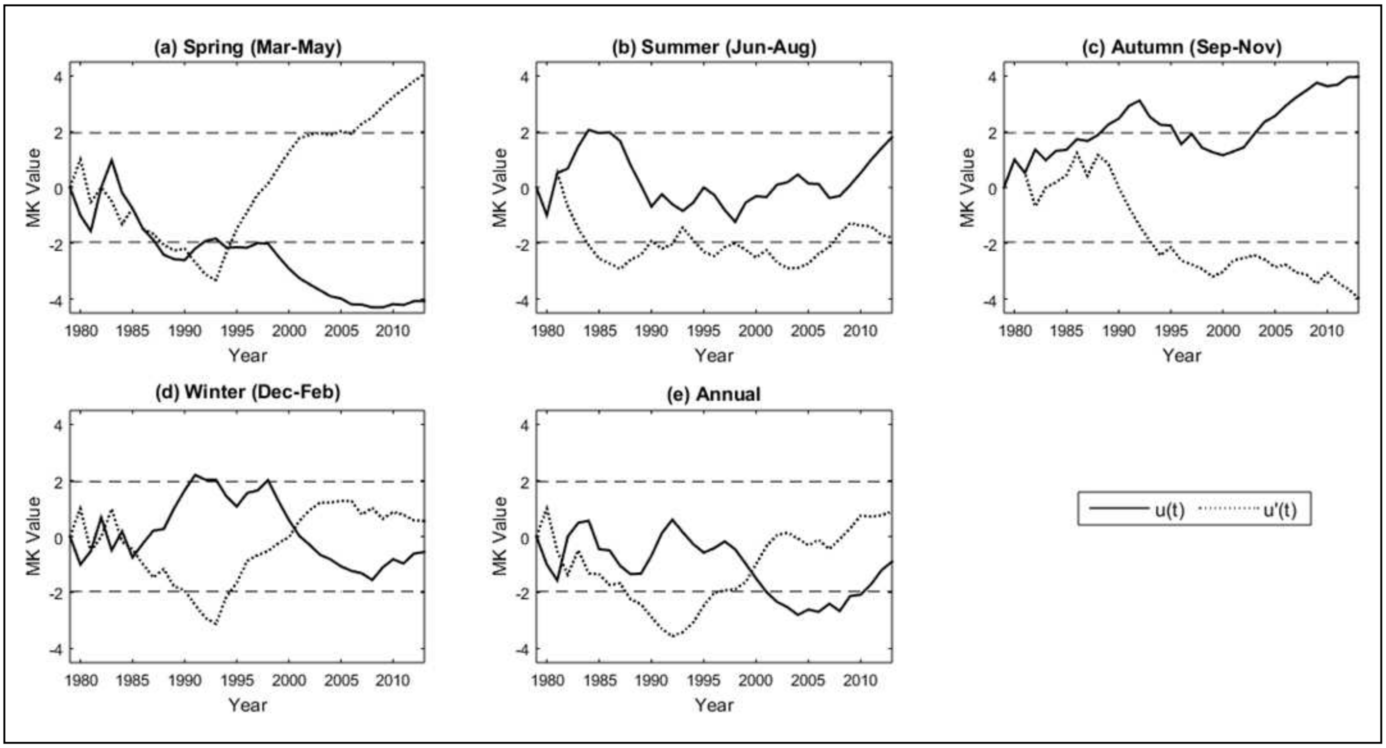

Fig. 4. Sequential values of the statistics u(t) and u'(t) from the MK test for seasonal and annual precipitation of Afghanistan. The solid and dashed lines represent u(t) and u(t') statistics respectively. The horizontal dashed represent 95% confidence limit.

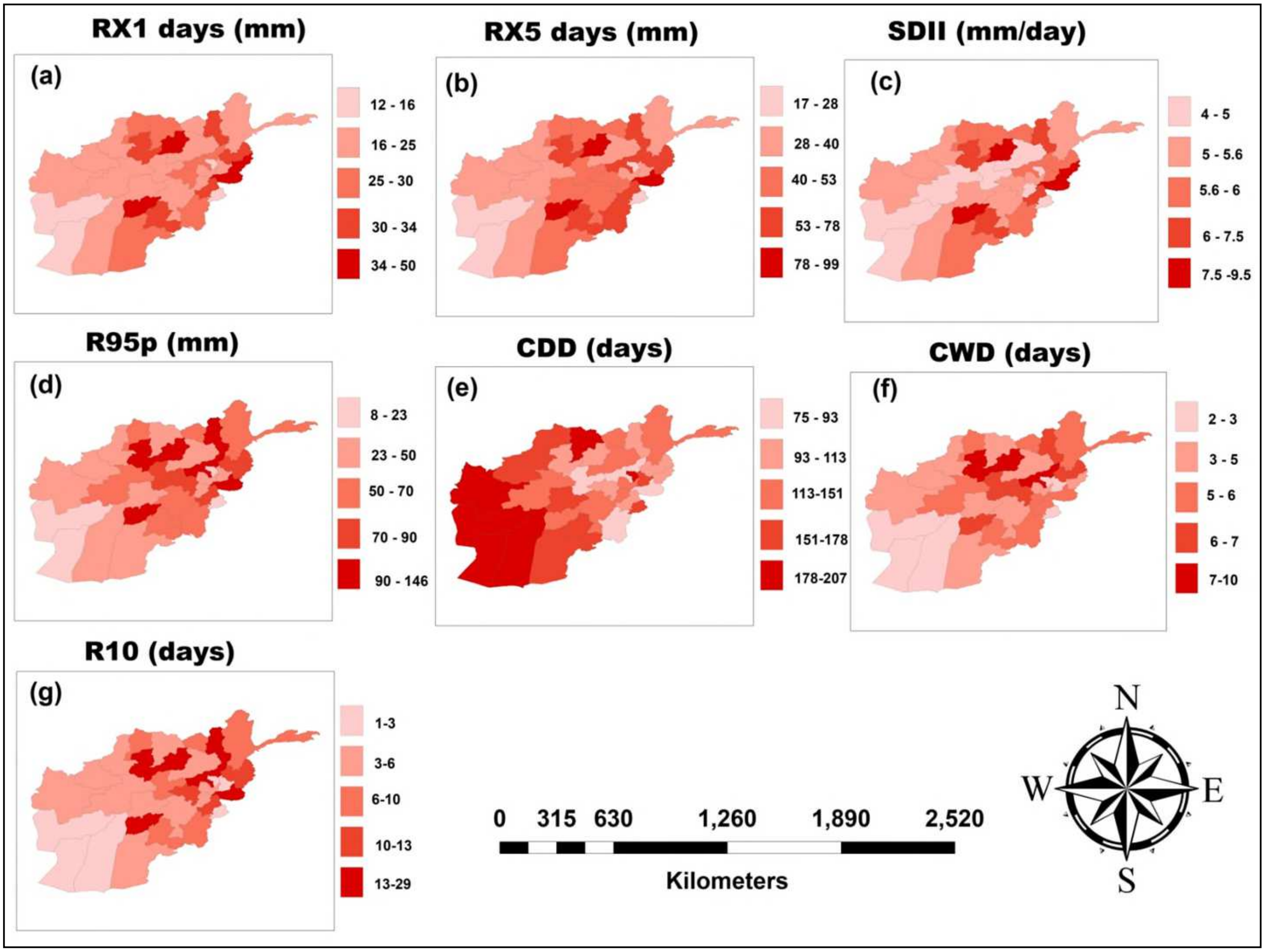

Fig. 5. Spatial patterns of mean values of extreme precipitation indices in the provinces of Afghanistan

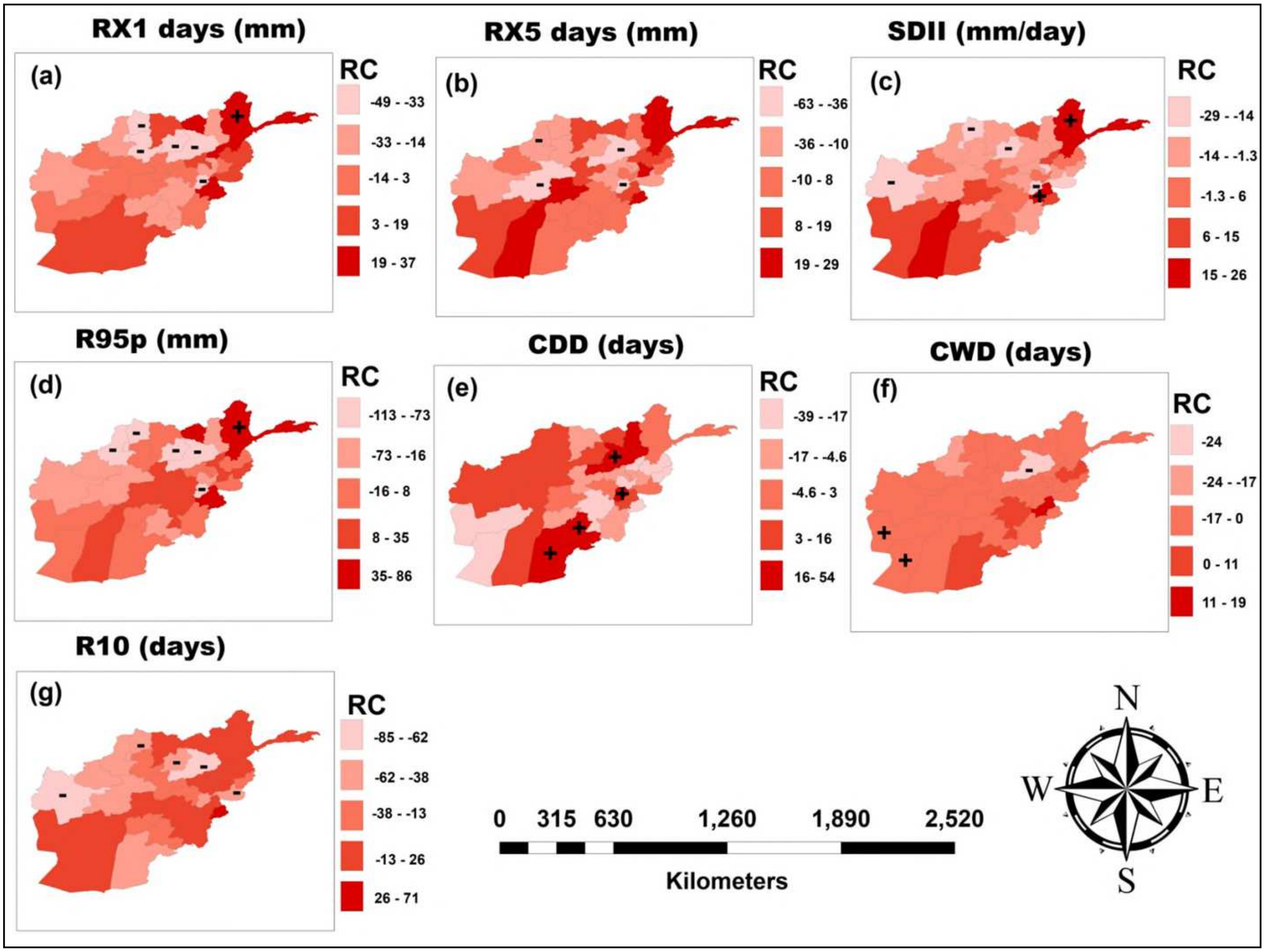

Fig. 6. Seasonal and annual trends and relative change of extreme precipitation indices in the provinces of Afghanistan

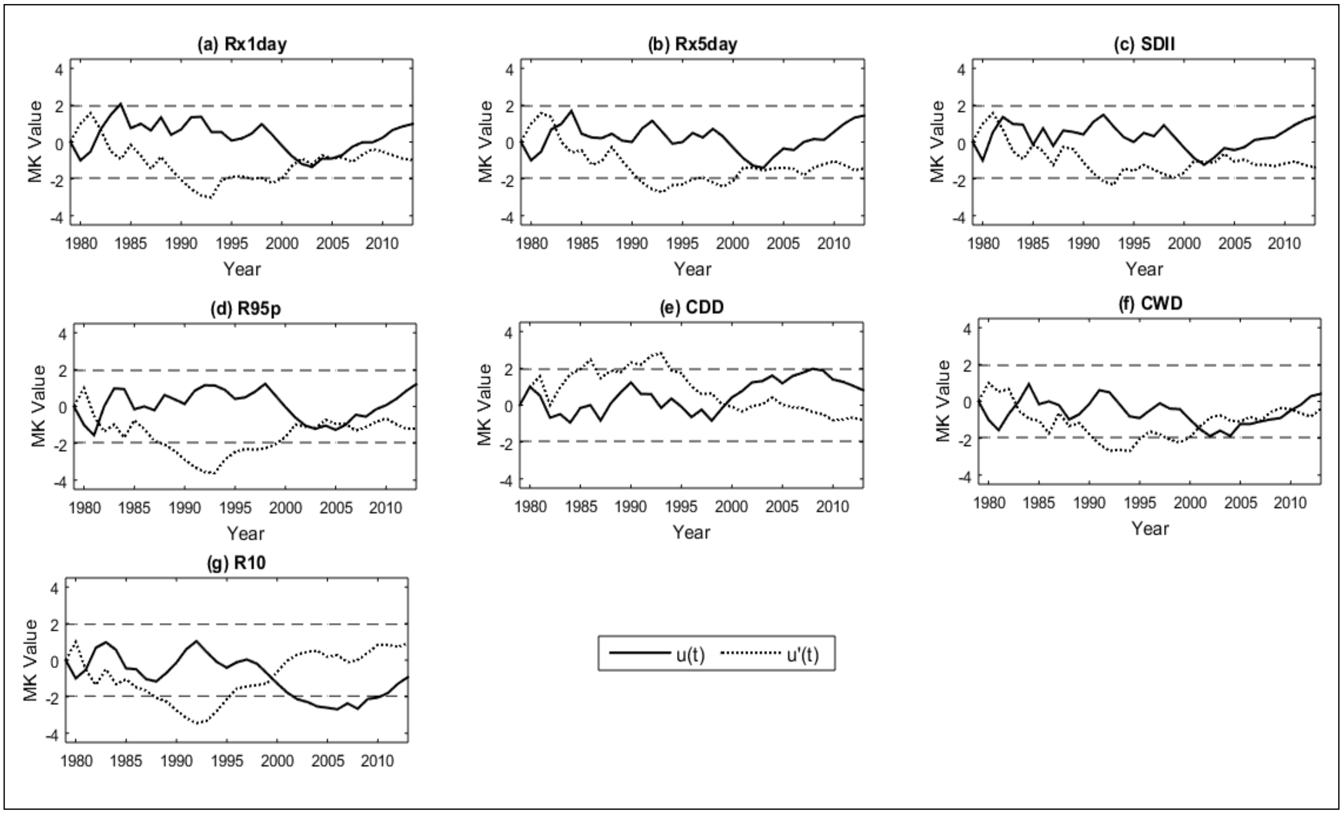

Fig. 7. *Sequential values of the statistics u(t) and u'(t) from the MK test for extreme precipitation indices of Afghanistan. The solid and dashed lines represent u(t) and u(t') statistics respectively. The horizontal dashed represent 95% confidence limit.*