Characteristic of precipitation concentration index in Qilian mountains, Northwest China

C C Zhao¹, S X Yao²³ and Q F Li¹
¹College of Geography and Environmental Engineering, Lanzhou City University, Lanzhou, 730000, China
²College of Mathematics, Lanzhou City University, Lanzhou, 730000, China

E-mail: yaoshixia@163.com

Abstract. Start your abstract here Precipitation played a major role in providing water supply in the arid and semi-arid regions of mountains during the main contributor to runoff. The climate trend was analyzed by using precipitation concentration index for 47 meteorological stations that are located inside and surrounding the Qilian Mountains. The results have shown that the distribution of precipitation concentration index is increasing from eastern to western, and is larger in northern slope than that in southern slope. The precipitation concentration index has a good linear relationship with the latitude and longitude, and complicated with the altitude. The trend of precipitation concentration index is more significant in the west which is affected by westerly circulation than that in the east which is influenced by East Asian monsoon in Qilian mountains.

1. Introduction
As one of the most critical components in the global water cycle, precipitation is widely used in analysis of climate change to understanding the hydrological processes [1-3]. Accurate and reliable precipitation data are important not only for the study of trends and variability but also for the management and policy decisions of water resources, as well as assessing the impacts of climate change [4,5]. In general, situ observation is the most common ways of obtaining precipitation. The precipitation data obtained by rain gauge measurement are considered to be the most accurate even though they subject to different types of errors such as sampling, inherent measurement, and uncertainty in sub-catchment [6,7]. Although satellite remote sensing and numerical modelling have the advantage of high temporal and spatial resolution, wide coverage and short sampling time, it’s accuracy still need to be calibrated by ground observation [8,9].

Melting water of glacier and snow is the major sources of many inland rivers in alpine mountain regions, and plays a major role in maintaining the ecological environment and social development in the middle and lower stream. With the climate warms, the arid and semi-arid mountain region areas respond more sensitively, the ecosystem becomes more vulnerable during the change of water cycle process, such as accelerated melting of glaciers, and, intensified degradation of permafrost [10]. Understanding and knowledge the characteristics of variability and trends of precipitation is limited by the scarcity and unreasonable distribution of stations in arid and semi-arid mountain regions, especially in high mountains over 4000 m. Furthermore, precipitation measurement becomes more difficult due to the complex topography of mountainous.

In this study, precipitation data of 47 stations were selected to analyze the spatial distribution of
precipitation concentration index during 1960 to 2017 in the Qilian Mountains. The variability and trend of precipitation concentration index is analyzed to detect the variability of precipitation using the climate trend coefficient method, in order to provide the scientific basis in regional water resources management and climate change response.

2. Study area and data

2.1. Study area
The Qilian Mountains (36°30'–39°30'N, 93°30'–103°00'E), are located in the arid and semi-arid region of northwestern China. It borders the Hexi Corridor in the northeast and the Qaidam Basin in the southwest at margin of the Tibetan Plateau [11,12]. It is composed of a series of parallel mountains and valleys with a NW trend and stretches approximately 850 km from the east to the west, and 250-400 km from the south to the north [13,14]. The terrain of Qilian mountains rises from northeast to southwest, most of whose peaks are higher than 4000 m, with Mount Tuanjie being the highest peak (Tuanjie Peak 5826 m). Due to its location in the hinterland of Eurasia and far away from the ocean, its vapor is mainly controlled by the East Asian monsoon in the eastern part (Wuwei–Laji Mountain), and affected by westerly circulation in the west part (Yingzui Mountain–Da Qaidam). The evaporation of water vapor from Qinghai Lake in the southeast of Qilian is an important source of water in the surrounding regions. Due to the geographical location and water vapour limitation, there are usually more precipitation in mountains than in piedmont plain. The average annual precipitation is in between 150 mm and 410 mm, and the distribution is very uneven in temporal and spatial [12,15].

2.2. Data
We acquired the precipitation data of 47 stations from 1960 to 2017 inside and surrounding the Qilian mountains from the National Climate Centre of China (China Meteorological Administration - CMA). The meteorological stations measure the precipitation with resolution of 0.1 mm. In total, 58 meteorological stations surrounding the study area are available for the period of 1980–2013 while most of them are located in the foothills (below 3000 m a.s.l.; figure 1). There are five meteorological stations with more than 1 year of missing data, and four meteorological stations with too short records. In order to ensure the results accuracy, those meteorological stations were excluded from the analysis.

![Figure 1. The distribution of the stations in the Qilian Mountains.](image)
2.3. Precipitation Concentration Index (PCI)

The precipitation concentration index (PCI) was put forward by [16]. It is an index to analyze the heterogeneity of precipitation and the relationship between variability and monthly precipitation distribution. PCI can be calculated as the following formula:

\[
P_{CI} = \frac{\sum_{i=1}^{12} P_i^2}{\left(\sum_{i=1}^{12} P_i\right)^2} \times 100
\]  

(1)

where \( P_i \) is the monthly precipitation in the \( i \)th month.

Usually, the distribution of precipitation is uneven in different month. The larger the difference in monthly precipitation, the larger the concentration of precipitation during intra-annual. According to [16], PCI values that are less than 10 indicate a uniform monthly rainfall distribution in the year, whereas values from 11 to 20 denote seasonality of precipitation distribution. Values above 20 correspond to climates with substantial monthly variability in precipitation amounts. Therefore, the greater the PCI value, the more variable the monthly precipitation.

3. Results

The PCI was calculated for each meteorological station during the period of 1960–2017 in the Qilian Mountains (figure 2). The PCI ranged from 18 to 45 which indicated substantial monthly variability of precipitation in Qilian Mountains. The pattern of PCI is shown to have increased from east to west, and the PCI of Hexi Corridor in north slope is larger than in south slope. Among these, PCI values from about one-third of the stations are below 20, which denote seasonality of precipitation distribution where mainly distribute in the eastern part of Qilian mountains influenced by the East Asian monsoon. Except LH, the PCI values of other stations is ranged from 21 to 33 which denote rainfall occurred in a few months. The precipitation is influenced by the westerly circulation in the western part of the Qilian Mountains, the water vapour brought by westerly circulation is very limited because of tail of westerly circulation. Though, the water vapour mainly comes from the regional circulation which makes the precipitation more concentrated. According to statistic monthly precipitation of all stations, the result has shown that the precipitation mainly occurs from June to August, accounting for more than 70% of the annual precipitation. The mount of precipitation accounts for less than 15% in dry season (form October to April of next year). It can be seen that the distribution of precipitation is very uneven, mainly occurred in summer in Qilian Mountains. Therefore, the variability of precipitation has significantly influenced the growth of vegetation.

\[\text{Figure 2. The distribution of PCI in Qilian mountains.}\]

Figure 3 illustrates the relationship between the PCI and the geographical characteristics of the
analyzed stations (altitude, longitude and latitude). The relationship between PCI and altitude is more complicated. At the beginning of 1000 m, the PCI decreased with the increasing of altitude. PCI reached the minimum about 2500 m. Then, the PCI increased with the increasing of altitude. The correlation between PCI and longitude and latitude is significant with a linear trend, with correlation coefficient of 0.88 and 0.78, respectively. The correlation is negative between PCI and longitude with a linear trend of -1.33 per degree (figure 3(b)). The correlation is positive between PCI and latitude with a linear trend of 2.1 per degree (figure 3(c)). The characteristics of spatial distribution for PCI displayed that the spatial distribution of precipitation in the Qilian Mountains. The distribution of precipitation increased from west to east, and decreased from south to north. The relationship between precipitation and altitude is not a simple linear.

Figure 3. Relationships between mean annual precipitation and (a) altitude, (b) longitude, and (c) latitude.

The slope of PCI was calculated for each station during the period of 1980–2013 in the Qilian Mountains (figure 4). The value of PCI slope for each station is below zero which indicated that the concentration of precipitation decreased in whole Qilian Mountains. In order to facilitate the presentation of variability, all values of PCI are taken in absolute to indicate size. The PCI is reduced to be smaller in the east than in the west of Qilian mountains. The slope of PCI has shown an increasing from east to west in the Hexi Corridor on the northern slope of Qilian Mountain. It can be seen that the change of PCI is not significant in the eastern part of Qilian mountains affected by East Asian monsoon. However, the PCI is decreasing significant that indicated the concentration of precipitation has changed from substantial monthly to seasonality in the western part of Qilian mountains influenced by westerly circulation.
The slope of PCI in Qilian mountains.

Figure 4. The slope of PCI in Qilian mountains.

4. Conclusions
In the Qilian Mountains, the distribution of PCI has shown to be smaller in eastern part that is influenced by East Asian monsoon than that in western part which is affected by westerly circulation. The relationship is significant between PCI and longitude/latitude with well linear trend, but the relationship is complex between PCI and altitude. The concentration of precipitation is change less in eastern part than in western part. It shows that the pattern of PCI is change from substantial monthly to seasonality in the western part of Qilian mountains.

Acknowledgments
This study was supported by the National Natural Science Foundation of China (No. 41771087). The authors would like to express their gratitude to Dr. Q D Zhao and X N Wang, State Key Laboratory of Cryospheric Science, Cold and Arid Regions of Environmental and Engineering Research Institute, Chinese Academy of Sciences, Dr. X Y Wang, Key Laboratory of Western China's Environmental Systems (Ministry of Education), College of Earth and Environmental Sciences, Lanzhou University, for their valuable suggestions and cooperation.

References
[1] Sayemuzzaman M and Jha M K 2014 Seasonal and annual precipitation time series trend analysis in North Carolina, United States Atmos Res. 137 183-94
[2] Bitew M M, Gebremichael M, Ghebremichael L T et al 2012 Evaluation of high-resolution satellite rainfall products through streamflow simulation in a hydrological modeling of a small mountainous watershed in Ethiopia J. Hydrometeor. 13 338-50
[3] Silverman N L and Maneta M P 2016 Detectability of change in winter precipitation within mountain landscapes: Spatial patterns and uncertainty Water Resour. Res. 52 4301-20
[4] Jiang S, Ren L, Yang H et al 2012 Comprehensive evaluation of multi-satellite precipitation products with a dense rain gauge network and optimally merging their simulated hydrological flows using the Bayesian model averaging method J. Hydrol. 452 213-25
[5] Liu J, Du H, Wu Z et al 2016 Recent and future changes in the combination of annual temperature and precipitation throughout China Int. J. Clim. 37 821-37
[6] Aghakouchak A, Habib E and Bárdossy A 2010 A comparison of three remotely sensed rainfall ensemble generators Atmos. Res. 98 380-99
[7] Chen M, Xie P, John E et al 1997 Global land precipitation: A 50-yr monthly analysis based on gauge observations B. Am. Meteorol. Soc. 78 2539-58
[8] New M, Todd M, Hulme M et al 2001 Precipitation measurements and trends in the twentieth century Int. J. Clim. 21 1889-922
[9] Xie P, Janowiak J E, Arkin P A et al 2003 Gpcp pentad precipitation analyses: an experimental dataset based on gauge observations and satellite estimates J. Clim. 16 2197-214
[10] Sun Q, Miao C, Duan Q et al 2018 A review of global precipitation data sets: Data sources, estimation, and intercomparisons Rev. Geophys. 56 1-29
[11] Zhang Y, Tian Q, Gou X et al 2015 Annual precipitation reconstruction since ad 775 based on tree rings from the qilian mountains, northwestern China Int. J. Clim. 31 371-81
[12] Tian Q, Gou X, Zhang Y et al 2007 Tree-ring based drought reconstruction (A.D. 1855–2001) for the Qilian Mountains, Northwestern China Tree-Ring Res. 63 27-36
[13] Geng H, Pan B, Huang B et al 2017 The spatial distribution of precipitation and topography in the Qilian Shan Mountains, northeastern Tibetan Plateau. Geomorphology 2017 S0169555X17303628
[14] Sun M, Liu S, Yao X et al 2018 Glacier changes in the Qilian Mountains in the past half-century: Based on the revised first and second Chinese glacier inventory. J. Geogr. Sci. 28 206-20
[15] Wang H, Zhang B, Jin X H et al 2009 Spatio-temporal variations analysis of air temperature and precipitation in Qilian Mountainous Region Based on GIS J.Desert Res. 29 1196-202
[16] Oliver J E 1980 Monthly precipitation distribution: A comparative index Professional Geogr. 32 300-9