Atmospheric Research 210 (2018) 1–14

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Observed changes in precipitation in China-Pakistan economic corridor during 1980–2016

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ARTICLE INFO

Keywords:
Mann-Kendall (MK) test
Sequential Mann-Kendall (SQMK) test
Precipitation trend
Monsoon precipitation

ABSTRACT

Changes in precipitation have been widely considered as a critical indicator of climate change. This is of prime importance to assess the strength and magnitude of these changes on regional and local scale. To document the observed changes in precipitation over China- Pakistan Economic Corridor (CPEC), the current study was conducted with monthly precipitation data from 53 meteorological stations across the CPEC. The non-parametric Mann- Kendall (MK), Sen's Slope (SS) estimator, and Sequential Mann-Kendall (SQMK) tests were used to assess the trends in precipitation data during 1980 to 2016. The results indicated that winter and post-monsoon precipitation were decreased at the rates of −0.26 and −0.02 mm per year, respectively. Monsoon, pre-monsoon and annual precipitation increased at the rates of 0.14, 0.13, and 0.02 mm per year, respectively. The spatial distribution of trends for seasonal and annual precipitation over different sub-climatic regions indicated that the trend is dynamic and varies from station to station. The station with SS and MK tests for the winter precipitation data showed an increasing (decreasing) trends at 14 (39) stations and only 1 (7) are significant at 0.05 level, respectively. The pre-monsoon, monsoon, post-monsoon, and annual precipitation indicated a positive (negative) trends over 40 (13), 31 (22), and 35 (18), 28 (25) stations with 3 (1), 5 (2), 2, 6 (7) significant stations at significance level of 0.05, respectively. The maximum positive and negative trends were detected at Parachinar (1.82 mm/year) and Dir (−1.86 mm/year) stations in pre-monsoon and winter precipitation, respectively. The mutations in temporal trends of seasonal and annual precipitation are very complex and dynamic during the study period. In winter, the rapid downward shifts were observed in 1984 and 1995. The mutations in pre-monsoon precipitation occurred after 1996s with a rapid upward/downward shift in 1997/2000. The monsoon precipitation shows a rapid decreasing shift since 1989 and an abrupt upward change in 2011. In post-monsoon precipitation, the rapid downward and upward changes were detected in 1989 and 1999, respectively. The mutations in annual precipitation were found in the first decade of the study period with a steep increase in 1982 and abrupt decrease in 1986. With respect to elevation dependency, the trend of long-term precipitation fluctuates and show a significant increasing trend in elevation zones of ≤500 m and ≥ 1500 m, while the trend decreases in 500–1000 m and 1000–1500 m elevation zones. Moreover, the winter, monsoon and annual precipitation shows negative correlation with elevation, while the pre-monsoon and post-monsoon precipitation show positive correlation with elevation. The findings of this study will help to address the problems of climate change and hydro-meteorological disasters in the regions. Further studies should focus on the climatic drivers of these changes in the regions.

1. Introduction

Precipitation is a key variable to study the climate and hydro-meteorology of a region. Changes in precipitation may lead to flood, drought, loss of biodiversity, agricultural productivity, and hydropower generation (Hu et al., 2016; Moazami et al., 2016; Sun et al., 2015; Zhang et al., 2015a, 2015b). The Intergovernmental Panel on Climate Change (IPCC) indicated that global warming has significantly affected

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https://doi.org/10.1016/j.atmosres.2018.04.007
Received 7 March 2018; Received in revised form 10 April 2018; Accepted 16 April 2018
0169-8095/

the precipitation patterns both spatially and temporally (IPCC, 2013). Changes in seasonal and annual precipitation are considered to be the critical indicators of climate change (Chou et al., 2013; Sorg et al., 2012). Therefore, detecting past trends, rapid mutation and variability in precipitation have become a core area of research in recent years (Ahmad et al., 2015; Xu et al., 2018). The accurate trend detection in precipitation can play a vital role in regional climate assessment and water resource management (Karpouzos et al., 2010; Rahman and Begum, 2013). Statistical techniques could be extended to analyze the trend in precipitation (Sharma et al., 2016). Until now, various statistical methods have been developed and employed for detection and shift of trend in precipitation time series (Jha and Singh, 2013; Martinez et al., 2012; Tabari et al., 2011). Among these, parametric and non-parametric methods are commonly used. The non-parametric method is preferred over parametric method because of non-normal distribution of data series (Sonali and Kumar, 2013).

Climate change studies have recognized that the spatio-temporal variations in precipitation exist between climatically different regions (Zhang et al., 2013). The amount of global land precipitation has been increased by 2% during the last century (New et al., 2001); however, this increase has not been homogenous both spatially and temporally (IPCC, 2013). The annual precipitation in Central Asia (Hu et al., 2016, 2017; Li et al., 2016) and Hindu Kush Himalayan Region of Tibetan Plateau (Ren et al., 2017; You et al., 2017) show increasing trends in recent decades. A significant positive trend was found in mean annual precipitation over the Northwestern China (Li et al., 2016), while a downward trend has been recorded in annual precipitation in Yellow River Basin of China (Zhang et al., 2014) during the last few decades. The annual precipitation shows a positive trend over India. (Subash and Sikka, 2014). Similarly, a significant upward trend was observed in annual, monsoon and pre-monsoon precipitation in Bangladesh (Endo et al., 2015; Shahid, 2010, 2011). Decreasing trend in mean annual precipitation was found over Iran during the last fifty years (Tabari and Talaee, 2011).

Various studies have been conducted to detect time-space trends in annual and seasonal precipitation in Pakistan (Asmat and Athar, 2017; Hartmann and Buchanan, 2014; Sheikh et al., 2015). An overall increasing trend in annual precipitation has been observed over northwestern Pakistan (Ahmad et al., 2015; Gadiwala and Burke, 2013), while significant decreasing trend was found over southern parts of the country (Hanif et al., 2013). Moreover, the annual precipitation shows an upward trend in southwestern parts of Pakistan while the central parts show a decreasing trend in annual precipitation (Hussain and Lee, 2014). Similarly, in the northern and northeastern highlands of Pakistan, the annual and monsoon precipitation is increasing, while in the southeast region, the post-monsoon precipitation shows an increasing trend (Ahmed et al., 2017). The southern Punjab region of Pakistan experiences a decreasing trend in annual precipitation (Abbas et al., 2014). The above cited studies have provided detail information about the precipitation trend over different parts of the country. However, these studies are either limited to a small region, low station density, short temporal coverage or different data sources. Thus this study is an improvement in terms of the CPEC region, intended time scale, stations' density, and data source. Moreover, no attempt has been made so far, to conduct a detail study on the analysis of extreme temperature events over CPEC. Therefore, the present study focused on assessment of the spatio-temporal changes in precipitation over China- Pakistan Economic Corridor (CPEC). The current study is the first of its nature being conducted on climate change perspective in the CPEC region.

The CPEC is a flag project of the Belt and Road Initiative (BRI) and will play a significant role in regional integration and development in near future (Irshad et al., 2015; Qureshi, 2015). Related studies revealed that the regions along the CPEC routes are highly sensitive to climate change due to recent global warming trends (Asmat and Athar, 2017; Iqbal and Athar, 2018; Yamada et al., 2016). Therefore, it needs more attention to study the variability and tendencies of precipitation patterns in the target area for climate friendly planning. The present study aims to analyze the precipitation variability and to detect the spatio-temporal trend of precipitation over the CPEC routes during 1980–2016. For this purpose, we used various statistical methods and techniques. The non-parametric Mann-Kendall (MK) test was employed to detect the significant monotonic trend; the Sen's Slope (SS) estimator test was used to quantify the magnitude/slope of the trend; the Sequential Mann-Kendall (SQMK) test was applied to detect the abrupt temporal shift or change in the trend. The analyses were carried for the CPEC as well as for three climatic regions: Region-1 (R-1), Region-2 (R-2), and Region-3 (R-3) on annual and seasonal (winter, pre-monsoon, monsoon, and post-monsoon) basis.

2. Study area

The China-Pakistan Economic Corridor (PEC) is a pilot project of the Belt and Road Initiative (BRI) (Abid and Ashfaq, 2016). The CPEC is extended from northeast to South of Pakistan with geographical coordinates of $25^0\ 24'$ to $36^0\ 10'$ North latitude, and $63^0\ 21'$ to $74^0\ 59'$ East longitude. It connects the Pakistani Port of Gawadar to Chinese City of Kashgar (Markey, 2016). The CPEC consists of two main routes with a total length of 4918 km, i.e. Western route and Eastern route. The western route is located in the West of Pakistan, passes through most parts of the Khyber Pakhtunkhwa and Baluchistan Provinces, while the eastern route is located in the East of Pakistan, encompasses the major parts of the Punjab and Sindh provinces. The CPEC is intended to promote connectivity across Pakistan with a network of highways, railways, and pipelines accompanied by energy, industrial, and other infrastructure development projects in order to boost Pakistan's economic growth (Markey, 2016). Subject to the prime location of the Gawadar port, the corridor gives China's access to South Asia, Middle East, Africa, and Europe (Ahmar, 2016; Chaziza, 2016). The CPEC is stretched from North to South of Pakistan and its network of highways, railways, and industrial zones will be extended to the whole country. Therefore, the whole Pakistan is considered as a study area in this paper.

Pakistan is located in South Asian region with geographical coordinates of $23.6^0 - 38^0$ North latitude and 61^0–78^0 East longitude. The country covers an area of 796,096 km^2. Pakistan has a diverse and complex landscape ranging from world famous Himalayas and Karakoram mountains in the North and northwest, with flat agricultural plains of Indus River Basin in the Centre and coast of Arabian Sea in the South (Ashiq et al., 2010). The elevation of the area ranges from 0 to 8611 m above sea level in the North with world's second highest mountain peak Mount Godwin-Austin (K2). Most parts of the country are arid to semi-arid with significant spatio-temporal variability in climatic conditions. The northern parts of the country are dominated by humid to arid climate while the southern parts are dominated by coastal climate. Similarly, the tropical and continental climate can be observed in the central parts of the country (Asmat and Athar, 2017). Precipitation over Pakistan is mainly subjected to two types of weather systems: summer and winter precipitation (Khan et al., 2014). Due to large topographic and temperature contrast, the precipitation pattern is multifarious in Pakistan during both summer and winter seasons (Hanif et al., 2013; Hussain and Lee, 2013). The monsoon depressions originating from the Bay of Bengal enters in the country from East to northeast during the months of July to September with high intensity (~55% to 60% of annual budget) (Asmat and Athar, 2017; Hussain and Lee, 2013). The winter precipitation occurs as a result of Westerly disturbances originating from the Mediterranean Sea and enters in the country from northeast to southeast during the months of December to March with moderate intensity (~30% of annual budget) (Asmat et al., 2017; Dimri et al., 2015; Wang et al., 2011). Both the summer and winter precipitations account for more than ~90% of the annual precipitation budget.