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Analysis of recent changes in maximum and minimum temperatures in Pakistan

M. Anjum Iqbal [a,*], A. Penas [b,c], A. Cano-Ortiz [d], K.C. Kersebaum [a], L. Herrero [b,c], S. del Río [b,c,**]

[a] Leibniz Centre for Agricultural Landscape Research, Institute of Landscape Systems Analysis, Eberswalder Straße 84, 15374 Müncheberg, Germany
[b] Department of Biodiversity and Environmental Management (Botany), Faculty of Biological and Environmental Sciences, University of León, Campus de Vegazana s/n. E-24071, León, Spain
[c] Mountain Livestock Institute (CSIC-ULE), Spain
[d] Department of Interra Sustainability, Resources Engineering and SL Spain Square, Salamanca, Spain.

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ABSTRACT

Data from 37 weather stations with records of maximum and minimum temperatures (Tmax and Tmin hereafter) were used to analyse trends in both variables at a monthly, seasonal and annual resolution. Sen's slope and Mann–Kendall statistical tests were applied to calculate the sign and slopes of trends and their statistical significance. A correlation analysis was also performed to study possible relationships between temperatures and certain teleconnection patterns with an influence on Northern Hemisphere temperatures: the North Atlantic Oscillation (NAO), Arctic Oscillation (AO), El Niño-Southern Oscillation (ENSO), and North Sea Caspian Pattern (NCP). The study reveals that Tmax has significantly increased (in over 30% of sites) in the pre-monsoon season and yearly. The sharpest increases were observed in March. Tmin clearly showed positive trends in the pre-monsoon season and at the annual scale. It is also worth noting a cooling trend in the northern areas during the study period. Tmax increased faster than Tmin in the northern areas in all the seasons studied and at annual resolution, while the opposite occurred in the rest of the country (except in the pre-monsoon season).
The highest correlation coefficients between patterns and Tmax and Tmin were seen in the months of the pre-monsoon season: with NAO from January to March; with ENSO in May and with NCP in the late pre-monsoon season (May). AO was the pattern with the lowest relationships with temperatures. These results could have a significant influence on agriculture and water resources in Pakistan if these trends are maintained in the future.

1. Introduction

The Fifth Report (AR5) published by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013) shows that temperature data (calculated by linear trend) increased by 0.72 °C [0.49 to 0.89 °C] during the period 1951–2012, and points to a slower warming rate – 0.05 °C/decade [−0.05 to 0.15 °C] – between 1998 and 2012 than since 1951 (0.12 °C/decade) [0.08 to 0.14 °C]. The report continues to support the conclusions of the AR4 that it is highly likely that on the global scale there has been both a decrease in the number of cold nights and days and an increase in the number of warm nights and days.

For Asia, AR5 suggests that mean annual temperature has increased in the past century over most of the region, although monitoring coverage is insufficient at high altitudes and in some areas of the interior. The warming trend was particularly strong between November and March (cold season) in the period 1901–2009, with an increase of 2.4 °C in the mid-latitude semiarid area of Asia.

It is essential to conduct analyses that detect the magnitude and direction of climate variables in order to design models that can predict their evolution and their effects on environmental and human resources. Changes in mean surface temperature are useful signs of variability and climate change; other climate variables that have attracted similar interest are monthly mean maximum and minimum temperatures (hereafter Tmax and Tmin). Jin and Dickinson (2002) and Tangborn (2003) reported that over the last 50 years warming over land has been associated with increases in Tmax and Tmin. In addition to this, Braganza et al. (2004) point out that changes in mean maximum and minimum temperatures provide more useful information than mean temperature alone and Zhang et al. (2007) mentioned that the impacts of Tmax and Tmin on the environment and on agriculture are much more significant than mean temperature. Temperature plays a key role in agricultural production at the regional level (Gupta et al., 2010; Lobell et al., 2012; Wheeler an von Braun, 2013; Bapuji Rao et al., 2014). Maximum and minimum temperatures have their significance in the development and growth plants during the life cycle.

* Correspondence to: M.A. Iqbal, Leibniz Centre for Agricultural Landscape Research, Institute of Landscape Systems Analysis, Eberswalder Straße 84, 15374 Müncheberg, Germany.
** Correspondence to: S. del Río, Department of Biodiversity and Environmental Management (Botany), Faculty of Biological and Environmental Sciences, University of León, Campus de Vegazana s/n. E-24071, León, Spain. Tel.: +34 987291558.
E-mail addresses: anjumuaf123@gmail.com (M.A. Iqbal), apenm@unileon.es (A. Penas), anacanor@hotmail.com (A. Cano-Ortiz), lherc@unileon.es (L. Herrero), sriog@unileon.es (S. del Río).

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Tmax and Tmin values beyond a threshold can adversely affect the agricultural productivity (Abbas, 2013; Bapuji Rao et al., 2014). In addition to this, the variation in Tmax and Tmin in an area influences on the reference evapotranspiration, which has a big impact on the assessment of crop water requirements (Ullah et al., 2001). This is especially important in Pakistan, which is basically an agrarian country. The developing society of Pakistan needs improved knowledge and understanding of temperature fluctuations and their influence on agriculture, notably on plant growth and the development of certain types of crops, and particularly at stages such as flowering and harvesting. On this point, Iqbal et al. (2011) showed that temperature increases lead to a reduction in the growing cycle of the maize crop in Faisalabad.

A number of studies on Tmax and Tmin trends at different time scales and levels have been documented in Pakistan over the past few decades. At local level, these studies have been basically focused on the major cities of the country: Sadiq and Qureshi (2010) analysed Tmax and Tmin for the period 1961–2007 in the five major cities of Pakistan; Sajjad et al. (2009) studied trends for Karachi, Cheema et al. (2006) for Faisalabad and Sadiq and Ahmed (2012) examined variations in diurnal maximum temperature over Chaklala (Islamabad). At regional scale some researches can be mentioned for the northern areas of Pakistan: Hussain et al. (2005) studied the climatic variability in the mountain regions of the country in winter and monsoon seasons and its implications for water and agriculture; Fowler and Archer (2006) and Khattak et al. (2011) analysed trends in Tmax and Tmin in the Upper Indus River Basin and Bocchiola and Diolaiuti (2013) investigated trends in the upper Karakoram and its possible impacts on the behaviour of glaciers. More recently, Ahmad et al. (2014) carried out an analysis of long-term meteorological trends in the middle and lower Indus basin of Pakistan and Yaseen et al. (2014) tested the existence of trends in the annual and seasonal Tmax, Tmin and Diurnal Temperature Range (DTR) in the Mangla watershed.Some other regions of Pakistan have been also studied by Rasul et al. (2012) (Sindh region) and Abbas (2013) (Punjab region). For the whole country, Sheikh et al. (2009) carried out a complete study about the climate profile and past climate changes in Pakistan including trends in Tmax and Tmin. More recently, some of these authors (Sheikh et al., 2015) analysed extreme temperatures indices over South Asia. Choi et al. (2009) also investigated changes in temperature extremes in some countries of Asia and Revadekar et al. (2013) reported the impact of altitude and latitude changes in temperature extremes over South Asia.

Some studies about temperatures for neighbouring areas of Pakistan in the last decade include: Bapuji Rao et al. (2014), Jhajharia and Singh (2011), Jhajharia et al. (2014), Panda et al. (2014), Pingale et al. (2014) and Subash and Sikka (2014) in India; Tabari et al. (2011), Kousari et al. (2013) and Shirvani (2015) in Iran; and Su et al. (2006), Qin et al. (2010) and Wang et al. (2014) in China.

Apart from the rise in greenhouse gas concentrations caused by anthropogenic activity (IPCC, 2013), the increase detected in temperature is also due to some natural factors influencing climate variables. Many authors have connected climate variability with global climate patterns. Teleconnection patterns can affect vast areas (such as the Northern Hemisphere) and explain much of the variability and trends in precipitation and temperature at the regional scale (Trigo and Palutikof, 2001; Vicente-Serrano and Lopez-Moreno, 2006; López-Bustins et al., 2008; Rizou et al., 2015; Rios-Cornejo et al., 2015). Some studies in Asia have also focused on the relationship between climate and patterns in recent decades: Tatli (2007) in the region 50°W–120°E, 0°–80°N; Syed et al. (2010) in Central–Southwest Asia; Villafuerte and Matsumoto (2015) in Southeast Asia; Khan et al. (2008), Saaed et al. (2011), Revadekar et al. (2013) and Afzal et al. (2013) in Pakistan; Ghasemi and Khalili (2006, 2008) in Iran; Türkes and Erlat (2009) in Turkey; Almazroui et al. (2015) in the Arab region and Lakshmi et al. (2014), Panda et al. (2014), Panda and Kumar (2014) in India and Wang et al. (2015) in China.

The main goal of the present study is to contribute to the existing knowledge of trends (sign and magnitude) in Tmax and Tmin in Pakistan in recent decades. This study also analyses possible relationships between Tmax and Tmin and some teleconnection patterns. Authors consider that the contribution of this study is based on the following points: trends in both variables (Tmax and Tmin) are analysed at different time scales (monthly, seasonal and annual) at the same time and during the same period. Most studies focus on some specific month or season but not at all time scales. Secondly, the whole country is analysed using the same methodology. It is sometimes difficult to compare results when analysing different areas or periods under study. Finally, four teleconnection patterns are used to explore possible relationships between them and the variables in the study, whereas most studies focus on only one or two patterns and most them referred to rainfall. Authors consider that this type of study is important due to the notable influence of Tmax and Tmin on agriculture and water resources in Pakistan.

The paper is organized as follows:

The next section contains a brief description of the study area. The data and methods section includes the different statistical methods used to uncover trends in both variables and possible relationships with teleconnection patterns, while the results and discussion section shows the main findings of the study. Finally, the conclusions of the research are presented in the last section.

2. Study area

Pakistan is an autonomous country in Southwest Asia located between latitudes 24°N–37°N and longitudes 60°E–75°E, with a land area of 880,940 km^2. It borders the Arabian Sea, between India in the east, Iran and Afghanistan in the west, and China in the north.

The climate in Pakistan varies widely from place to place. It receives monsoon rainfall in summer and rainfall from western systems in winter. The climate is generally arid to semiarid, characterised by hot summers and cold winters, with major variations between extremes of temperature at given locations (Chaudhry and Rasul, 2004), except on the southern slopes of the Himalayas and in the sub-mountain region, where the annual rainfall ranges from 760 mm to 2000 mm (Shirazi et al., 2006; Chaudhry et al., 2009).

Average temperatures are strongly dependent on this topography, with the coolest annual temperatures (below zero) occurring in the Himalayan region, and higher average temperatures in the lower-lying southeast. Average temperatures do not exceed 15 °C in the warmest months (May to September) in the north, while in the south they can reach 35 °C. Temperatures are well below zero in the coolest months (November to February) at the highest altitudes, and between 20 and 25 °C in the low-lying south (McSweeney et al., 2008). The normal annual maximum temperature ranges from 15 to 35 °C and the normal minimum temperature from 0 to 20 °C (Chaudhry et al., 2009).

3. Data and methods

Thirty-seven weather stations provided by the Pakistan Meteorological Department (PMD) with maximum and minimum temperature data records between 1952 and 2009 were used in the current study (Fig. 1). All the meteorological stations considered in the study have at least 20 continuous and common years with Tmax and Tmin data. There were no gaps in the temperature series collected.

The Runs Test (Thom, 1966) with a confidence level of 95% was used to analyse the homogeneity of the series. This test is recommended by the World Meteorological Organization (WMO) to check the homogeneity of meteorological data, and has been used by several authors in climate studies (Martín-Vide et al., 2006; Modarres and Rodrigues, 2007; Dikbas et al., 2010). Data from all the weather stations analysed passed the homogeneity test.

Seasonal series were obtained from monthly values following the proposal of Jhajharia et al. (2009) and Subash and Sikka (2014): winter