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# Trends of climate change in the Lower Indus Basin region of Pakistan

## Future implications for agriculture

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### Abstract

**Purpose** – Lower Indus Basin (LIB) region is the food basket of Pakistan, and climatic variation in response to global warming might severely affect the crop production and, thus, food security and ultimately to the economy of the country.

**Design/methodology/approach** – The authors analyzed the previous climatic factors data series of LIB region to investigate the past and present climatic trends and to predict the future changes. Climatic changes were monitored by studying temperature, rainfall and relative humidity (RH) dynamics at two locations (Lahore and Multan) of the LIB region, Pakistan, by using data from 1953 to 2006. The data were divided into two equal halves (1953-1979 and 1980-2006) and statistically compared for the aforementioned weather parameters.

**Findings** – The results suggested that mean minimum temperature (MMT) and overall mean temperature in winter were significantly increased, whereas few summer months had also experienced the reduction in both temperatures. However, few minor changes were also observed for the mean maximum temperature at both locations. The rainfall amount did not vary significantly at both locations, with the exception for the months of February and June at Lahore location, which experienced relatively higher rainfall in latter period (1980-2006). However, morning and evening RH was significantly increased at Multan throughout the year and for some selected months (February-March and May-July) at Lahore. However, the comparison of climatic data of both temporal halves suggested

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either dryer weather during winter months because of increase in MMT and/or increase in area under irrigated agriculture, resulting in more evaporation at both locations. Similarly, the data also indicated the early monsoon rainfall patterns in summer and late western depression rainfall spell during winter, which played key role to affect the crop yield because of irregular rain events.

**Research limitations/implications** – The current manuscript would be very useful for the disaster management authorities and agriculture sector to predict the future irregular trends of climate change in Pakistan. Moreover, current findings can be important tool toward the management of climatic changes issues (i.e. floods and dryer spells) and to formulate the future strategies for the improved crop growth in arid and/or semi-arid developing nations such as Pakistan.

**Originality/value** – The current manuscript, for the very first time, provided detailed insights into key climatic factors changes for past seven decades, into the severely climate change-affected areas of the world. Furthermore, agricultural sector is likely to be severely affected because of minor seasonal change in temperature and moisture, and have a strong food security impact, which can be reflected with current data set to cope with both ecological and economic impacts of climate change in Pakistan. The current findings would be useful to manage the climate change-related issues in Pakistan, including the social, environmental and economic.

**Keywords** Climate change, Temperature, Lower Indus Basin, Temperature and rainfall

**Paper type** Research paper

## 1. Introduction

Demands of food, fiber, housing and transportations for the rapidly increasing human population in the world are met at the expense of huge deforestation, more areas under cultivation of crops and more consumption of fossil fuels (Carmichael *et al.*, 2009). All these aforementioned factors reflect the emission of elevated greenhouse gases, which ultimately disturb the natural energy balance of the ecosystem and thus bring change in the temperature and precipitation profile of the regions (Schlesinger and Bernhardt, 2013; Smith and Smith, 2001). David *et al.* (1997) have studied diurnal temperature range (DTR), which is the difference between increases in the minimum temperature and maximum temperature using a wide range of data from 5,400 observing stations across the world. In this study, it has been documented that DTR has decreased in most parts of the world, and analysis has also shown that this has resulted, in part, from the daily minimum temperature increasing at a faster rate and/or decreasing at a slower rate than the daily maximum. However, there are some conflicting records in regions, such as New Zealand and in alpine regions of central Europe, where maximum and minimum temperatures increased at similar rate (Salinger, 1995). Similarly, increase in DTR in India is partly attributed to decrease in minimum temperature in the selected region (Weber *et al.*, 1994).

Most studies carried out in Indian subcontinent have confirmed trendless nature of monsoon rainfall (Thapliyal and Kulshrestha, 1991) and highlighted the greater inter-annual variability. However, few investigators reported that either significant increase and/or decrease in the amount of rainfall has been observed into some selected regions that constituted the small pockets within subcontinent. Some areas located in the north west and north east of the subcontinent have shown significant decrease in the monsoon rainfall (from −6 to 8 per cent of normal/100 years), whereas significant increase has been observed in central India and along the west coast (10-12 per cent of normal/100 years) (Rupakumar *et al.*, 1992). Singh and Sontakke (2002) have also reported an increasing trend in monsoon rainfall in the western Indo-Gangetic plain from 1900 to 1984 and decreasing trend in the central

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and eastern region. It generally reflected a westward shifting of increasing rainfall trends into the Indo-Gangetic plain during the last century. It has been documented that an increase in rainfall ranging from 2 to 19 per cent was observed in nine selected river basins in Northwest and Central India (Singh *et al.*, 2008). The highest increases have seen in Indus Basin, followed by Tapi River Basin. Moreover, very little variation in the amount of rainfall has been shown during monsoon season for the past century. Meanwhile, the maximum increase in rainfall amount has been reported during both pre- and post-monsoon seasons.

The Lower Indus Basin (LIB) region is considered as the food basket of Pakistan and comprises total farmed area of 15.58 million hectares, out of which the total cultivated area is 14.03 million hectares. The major crops grown in the area (in the order they occupy area) are wheat, cotton, rice and sugar cane (Agricultural Census, 2010). The total population of Pakistan stands at 179.2 million (World Bank, 2012), out of which LIB region hosts 150 million people, and 70 per cent of people have agriculture as their profession (Pakistan Year Book, 2013). Being the bread basket of Pakistan, the region has contributed significantly toward the national gross domestic product owing to fertile lands, availability of abundant irrigation water and favorable climatic conditions that are conducive to grow number of different crops in different cropping systems. Pakistan, like some other developing countries, has been categorized as one of top countries of the world facing large number of environmental problems, including the effects of global climate change in form of growing frequency of droughts and flooding, increasingly erratic weather behavior, changes in agricultural patterns, irregular patterns in freshwater supply and the loss of biodiversity. Pakistan also possesses the world's third largest ice masses (Himalayas and their associated areas), which gained growing international attention because of its significant role in the global atmospheric circulation and sensitivity toward the preliminary indication in climate changes (Fowler and Archer, 2006). Previously, Fowler and Archer (2006) analyzed the data from some selected weather stations located in the Upper Indus Basin and indicated conflicting signals regarding climate change in the aforementioned region, which were critical enough for glacier melt down and river discharge. The objective of the present study was to investigate the extent of climate change in the LIB region and its future implication for agriculture. The key objectives and/or questions we would like to address in this study are:

- *Q1*. Would there be any differences in the mean minimum temperature (MMT), overall mean temperature (OMT) and mean maximum temperature (MXT) of the years from 1953 to 1979 (previous 27 years) to the data from years 1980-2006 (last 27 years) in the LIB?
- *Q2*. Were there any differences in the precipitation profile and relative humidity (RH) in the selected agricultural plain areas during aforementioned periods?
- *Q3*. Was there any difference in the magnitude of climate change at the two selected regions in the LIB?

The answers to these questions are critically important especially in terms of supplementary irrigation water demand, crop yield and thus for the economy of the country, as well as toward management of the climate changes related issues.

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## 2. Materials and methods

### *2.1 Data collection*

The data of monthly MMT and MXT along with mean monthly precipitation plus data on morning and evening RH (RH is measured in terms of percentage) of the two weather stations Lahore and Multan were provided by the meteorological office, Lahore for the period of 1953-2006. The main reasons we have chosen the weather data from these locations are subjected to their major agricultural importance. Moreover, Lahore region belongs to warm-semi arid, whereas Multan region falls in hot-arid climatic zone with annual rain fall from 250 to 500 mm and 125 to 250 mm at both locations, respectively (Ministry of Environment, Government of Pakistan, 2003). The Lahore region comprises the districts of Lahore, Gujranwala, Kasur, Hafizabad, Sailkot and Sheikhpura, and about 90 per cent of total area (2.78 million hectares) is under rice cultivation in these districts (Pakistan Bureau of Statistics, 2014), while approximately >80 per cent of area is under cotton cultivation in the Multan region, which comprises nine adjoining districts (Chaudhry *et al.*, 2009).

### *2.2 Study area*

*2.2.1 Lahore station.* This station lies between 31°15′–31°45′ N and 74°01′–74°39′ E, and the Lahore city is a divisional head quarter and provincial metropolis with a population of 6.3 million (Census Report, 1998). It is situated in semi-arid region of Pakistan with hot summer and mild winter temperature regimes. Most of the rainfall (>80 per cent of the total) in the region is received during the monsoon season, whereas dry condition occurs during rest of the year (Ministry of Environment, Government of Pakistan, 2003). Total area of the district is 176,343 ha, of which 142,957 ha of land is present in rural settings, which is utilized for agricultural activities. The major crops being grown in the district include wheat, rice, maize and sugarcane (Pakistan Bureau of Statistics, 2014). The major crop patterns included rice-wheat and maize-wheat with mostly irrigated conditions.

*2.2.2 Multan station.* It is situated between 30°12′0′′N–30°50′0′′N and 71°25′0′′E–71°25′0′′E and also possess divisional head quarter of Multan division and is located in southern Punjab at the distance of 340 km from Lahore. The total population of the district is 3.1 million (Census Report, 1998), and most of the labor force is employed in agriculture sector. It is situated in extremely arid conditions with very high temperatures, which occasionally touch about >45-50°C during the month of May and June. The average annual rainfall of the region is just 123 mm, most of which is received during monsoon season (Ministry of Environment, Government of Pakistan, 2003). The major crops of the region are wheat, cotton and sugarcane, with wheat-cotton crop rotation being unique among the cropping systems (Chaudhry *et al.*, 2009). Complete crop failure is likely to occur in areas without provision of irrigation water.

### *2.3 Data and statistical analysis*

We divided 54-year data for MMT, OMT and MXT, precipitation and morning and evening RH into two equal time periods. The first period spanned from 1953 to 1979 (previous 27 years) and the second period comprised of data from 1980 to 2006 (later following 27 years). For each month, further means were computed for temperatures, precipitations and RH for both time periods, and the differences were computed by subtracting means of last 27 years from the previous 27 years for the aforementioned

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climate variables. Finally, the means for each month for both periods were compared using *t*-test, and hypothesis of no difference between periods was rejected if the *p*-value was less than 0.05.

## 3. Results and discussion

### *3.1 Temporal temperature variations at Lahore and Multan*

The magnitude of absolute differences between MMT and OMT for all months of latest period (1980 to 2006) and the previous 27 years (1953 to 1979) for Lahore and Multan are presented in Table I. The results suggested that MMT at Lahore station was significantly increased during fall (i.e. September, October and November) and winter (i.e. December, January and February) months in the last 27 years compared to previous period ($p < 0.05$). The highest increase was observed for the months of November (2.1°C), followed by 1.98°C, 1.78°C and 1.56°C for December, January and February in decreasing order, respectively. April and May (spring) also experienced significant ($p < 0.05$) increase in MMT, which were 0.84°C and 1.33°C, respectively. The magnitude of increase for the month of September and October was 0.58°C and 0.92°C, respectively, and were significantly different ($p < 0.05$) while comparing both time periods halves. The MMT did not change ($p > 0.05$) during the months of June, July and August, as well

| | Lahore | | | | Multan | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean minimum temperature (MMT) °C | | | | Mean minimum temperature (MMT) °C | | | |
| Months | 1953-1979 | 1980-2006 | Difference | *p*-value | 1953-1979 | 1980-2006 | Difference | *p*-value |
| January | 5.50 | 7.28 | *1.78* | *<0.0001* | 4.23 | 5.3 | *1.07* | *0.002* |
| February | 8.64 | 10.2 | *1.56* | *<0.0001* | 7.61 | 8.3 | *0.69* | *0.03* |
| March | 14.23 | 14.86 | 0.63 | 0.07 | 13.63 | 13.77 | 0.14 | 0.33 |
| April | 19.46 | 20.3 | *0.84* | *0.007* | 19.43 | 19.70 | 0.27 | 0.22 |
| May | 23.57 | 24.9 | *1.33* | *0.001* | 24.09 | 25.12 | *1.03* | *0.01* |
| June | 27.45 | 27.28 | −0.17 | 0.26 | 28.76 | 28.66 | −0.09 | 0.39 |
| July | 27.11 | 26.98 | −0.13 | 0.26 | 28.75 | 28.82 | 0.07 | 0.37 |
| August | 26.54 | 26.69 | 0.15 | 0.23 | 28.16 | 27.96 | −0.20 | 0.12 |
| September | 24.35 | 24.93 | *0.58* | *0.01* | 25.14 | 25.01 | −0.13 | 0.32 |
| October | 18.15 | 19.07 | *0.92* | *0.006* | 18.08 | 18.5 | 0.42 | 0.12 |
| November | 11.03 | 13.12 | *2.1* | *<0.0001* | 10.46 | 11.79 | *1.33* | *0.0002* |
| December | 6.49 | 8.47 | *1.98* | *<0.0001* | 5.49 | 6.6 | *1.12* | *0.0004* |
| | Overall mean temperature (OMT) °C | | | | Overall mean temperature (OMT) °C | | | |
| January | 12.43 | 13.29 | *0.86* | *0.001* | 12.39 | 12.94 | *0.55* | *0.01* |
| February | 15.45 | 16.27 | *0.82* | *0.02* | 15.46 | 15.95 | 0.49 | 0.11 |
| March | 20.96 | 20.93 | −0.03 | 0.47 | 21.25 | 21.10 | −0.15 | 0.35 |
| April | 26.82 | 27.17 | 0.35 | 0.21 | 27.3 | 27.75 | 0.45 | 0.15 |
| May | 31.19 | 31.9 | 0.71 | 0.09 | 32.06 | 33.0 | *0.94* | *0.04* |
| June | 34.08 | 33.44 | *−0.65* | *0.009* | 35.53 | 35.44 | −0.09 | 0.38 |
| July | 31.70 | 31.37 | −0.33 | 0.13 | 34.05 | 33.98 | −0.07 | 0.40 |
| August | 30.84 | 30.8 | −0.04 | 0.43 | 33.14 | 32.77 | *−0.37* | *0.04* |
| September | 29.56 | 29.92 | *0.36* | *0.04* | 31.17 | 30.88 | −0.29 | 0.08 |
| October | 25.49 | 25.75 | 0.26 | 0.19 | 26.37 | 26.29 | −0.08 | 0.40 |
| November | 19.07 | 20.33 | *1.26* | *<0.0001* | 19.45 | 20.22 | *0.77* | *0.002* |
| December | 13.99 | 15.19 | *1.20* | *0.0001* | 14.17 | 14.81 | *0.64* | *0.03* |

**Table I.**
MMT and OMT changes at selected weather stations in the LIB region

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as month of March, which also did not register significant difference ($p > 0.05$) between the selected periods of data analysis.

The trends in MMT for fall and winter months from Multan weather station were similar to those from Lahore (Table I). However, the magnitude of increase was relatively lower at Multan than that at Lahore. The highest increase among the both temporal halves was 1.33°C for the month of November, followed by 1.12°C, 1.07°C and 0.69°C for the months of December, January and February in decreasing order, respectively. The month of May was the only other month which registered significant ($p < 0.05$) increase in MMT (1.03°C), whereas MMT did not reflect any increase for the other months of the year. Land topographical and atmospheric features at Multan are much different from those at Lahore. Given that Multan falls under extreme arid climate and nearness to the Great Thar and Cholistan desert coupled with less cloud cover during winter months, it can be expected that all these features might result in less entrapment of energy compared to Lahore and, thus, less increase in temperature. As far as looking into changes in MXT at weather station Lahore, it can be seen that none of months had experienced significant increase. Nevertheless, month of June showed a significant reduction ($p < 0.05$) in MXT, which was −1.12°C (Table II). Similar to Lahore, no increase in MXT is seen at Multan, except that the month of August, which

| | Lahore | | | | Multan | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean maximum temperature (MXT) °C | | | | Mean maximum temperature (MXT) °C | | | |
| Months | 1953-1979 | 1980-2006 | Difference | $p$-value | 1953-1979 | 1980-2006 | Difference | $p$-value |
| January | 19.36 | 19.3 | −0.06 | 0.43 | 20.55 | 20.58 | 0.03 | 0.46 |
| February | 22.26 | 22.34 | 0.08 | 0.44 | 23.31 | 23.59 | 0.28 | 0.31 |
| March | 27.69 | 27.00 | −0.69 | 0.09 | 28.88 | 28.43 | −0.44 | 0.22 |
| April | 34.17 | 34.03 | −0.14 | 0.40 | 35.17 | 35.8 | 0.63 | 0.15 |
| May | 38.8 | 38.9 | 0.10 | 0.44 | 40.22 | 41.06 | 0.84 | 0.10 |
| June | 40.71 | 39.59 | *−1.12* | *0.001* | 42.31 | 42.23 | −0.08 | 0.40 |
| July | 36.29 | 35.76 | −0.53 | 0.11 | 39.34 | 39.14 | −0.21 | 0.28 |
| August | 35.14 | 34.92 | −0.23 | 0.21 | 38.13 | 37.60 | *−0.53* | *0.03* |
| September | 34.77 | 34.92 | 0.15 | 0.32 | 37.2 | 36.74 | −0.46 | 0.06 |
| October | 32.84 | 32.44 | −0.4 | 0.16 | 34.67 | 34.09 | −0.58 | 0.08 |
| November | 27.11 | 27.54 | 0.43 | 0.08 | 28.45 | 28.66 | 0.21 | 0.27 |
| December | 21.49 | 21.9 | 0.42 | 0.18 | 22.85 | 23.00 | 0.15 | 0.36 |
| | Mean precipitation (mm) | | | | Mean precipitation (mm) | | | |
| January | 24.86 | 24.95 | 0.09 | 0.50 | 8.13 | 7.85 | −0.28 | 0.46 |
| February | 19.12 | 33.96 | *14.83* | *0.04* | 9.04 | 12.89 | 3.85 | 0.15 |
| March | 32.70 | 36.54 | 3.84 | 0.32 | 17.83 | 17.70 | −0.13 | 0.49 |
| April | 13.05 | 22.26 | 9.21 | 0.08 | 11.67 | 13.4 | 1.73 | 0.35 |
| May | 15.40 | 22.43 | 7.02 | 0.15 | 10.31 | 12.96 | 2.65 | 0.25 |
| June | 33.96 | 53.82 | *19.86* | *0.03* | 10.93 | 12.23 | 1.30 | 0.40 |
| July | 167.0 | 207.0 | 40.83 | 0.07 | 58.23 | 53.78 | −4.45 | 0.36 |
| August | 148.0 | 188.0 | 40.69 | 0.11 | 32.0 | 38.0 | 6.00 | 0.33 |
| September | 96.55 | 63.18 | −33.59 | 0.13 | 16.65 | 25.11 | 8.46 | 0.25 |
| October | 11.14 | 17.07 | 5.92 | 0.22 | 1.23 | 6.50 | 5.27 | 0.11 |
| November | 3.37 | 7.50 | 4.11 | 0.12 | 3.71 | 1.57 | −2.14 | 0.15 |
| December | 13.67 | 10.38 | −3.28 | 0.25 | 9.76 | 4.16 | −5.60 | 0.08 |

**Table II.** MXT and precipitation changes at selected weather stations in the LIB region

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had experienced significant cooling (−0.53°C) in the last 27 years as compared to previous period.

In general, basic trends in OMT were similar to what we have seen for MMT for the data set of both weather stations (Table I), except that the magnitude of difference in temperatures between both periods decreased owing to calculations of further means of both MXTs and MMTs. Similar to the aforementioned MMT trends, the OMT data have also showed that months of September, November, December, January and February were significantly ($p < 0.05$) warmer at Lahore, which is due to increases in MMT during these months. On the other hand, MXT trends for Multan were also similar to those for Lahore, though the warming was relatively lower, with the only exception for month of May, which experienced significant higher OMT (0.94°C) in the last 27 years as compared to those for the previous 27 years and relatively more warmer than Lahore (0.71°C). Moreover, few months had also significant cooling trends at both weather stations. For example, the month of June at Lahore was experiencing significant ($p <$ 0.05) cooling (−0.65°C) for both temporal halves. On the other hand, the months of July and August were also cooler for the latter half, though the differences were not significant when data of both periods were compared. Similarly, the month of August at Multan had also significant lower OMT (−0.37°C). The cooling effect could have been explained by evaporation of water from the soil surface and water bodies. Glacier melt up in the Himalayan range begins during these months and rivers passing through these areas have also registered their peak flow during these summer months (Rehman *et al.*, 1997). Moreover, rice is major crop of the Lahore region, which requires flooded irrigation, and its cultivation begins in late May and early June. Both activities resulted in higher evaporation rate, as supported by the data on RH (Table III), which shows the significant increase in morning (8:00 a.m.) and evening (5:00 p.m.) RH. Evaporation from river bodies and from soil surface during monsoon month of August might be responsible for cooling at Multan. Our results suggested that the rate of change in MMT per year at Lahore ranged from +0.02°C to +0.08°C. The rate of change was negligible in MXT, whereas the rate of change in OMT ranged from +0.01°C to +0.05°C per year during last 27 years. These results also coincide with the findings of Aizen *et al.* (1997), who also documented that rate of change in increase was ≈+0.01°C in Tien Shen mountain region that has an elevation below 2,000 m (from sea level). Our results are also supported by the findings of David *et al.* (1997), who suggested that diurnal temperature range was decreased in most parts of the World and is attributed to much faster increase in daily minimum temperatures throughout the world. Similarly, Yang *et al.* (2006) also reported that rate of increase in mean minimum temperature was more than that in mean maximum temperature based on the data from 1971 to 2004 in some selected parts of China.

### *3.2 Temporal precipitation changes at Lahore and Multan*

The data regarding the differences in the amount of precipitation for the periods of last 27 and previous 27 years are presented in Table II. The results suggested that mean precipitation was almost increased for all months of the year in last 27 years at Lahore, but substantial increases were reported for the months of June, July, August and February, which were +20, +41, +41 and +14.8 mm per month, respectively, though significant differences were only reported for the months of February and June ($p < 0.05$). The mean precipitation was decreasing non-significantly during the month

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| Months | Lahore 8:00 a.m. humidity (%) 1953-1979 | 1980-2006 | Difference | *p*-value | Multan 8:00 a.m. humidity (%) 1953-1979 | 1980-2006 | Difference | *p*-value |
|---|---|---|---|---|---|---|---|---|
| January | 84.37 | 84.44 | 0.07 | 0.47 | 82.88 | 88.52 | *5.63* | *0.0004* |
| February | 75.66 | 75.96 | 0.29 | 0.42 | 73.63 | 83.07 | *9.44* | *<0.0001* |
| March | 63.07 | 67.81 | *4.74* | *0.004* | 65.15 | 76.88 | *11.74* | *<0.0001* |
| April | 47.92 | 48.70 | 0.77 | 0.35 | 51.03 | 57.48 | *6.44* | *0.006* |
| May | 39.63 | 42.88 | *3.25* | *0.03* | 42.44 | 48.33 | *5.88* | *0.0004* |
| June | 49.37 | 52.15 | *2.77* | *0.04* | 51.33 | 53.37 | 2.03 | 0.054 |
| July | 72.07 | 73.88 | 1.81 | 0.14 | 66.03 | 68.81 | *2.77* | *0.03* |
| August | 77.37 | 78.14 | 0.77 | 0.21 | 70.25 | 73.7 | *3.44* | *0.01* |
| September | 71.00 | 73.00 | 2.0 | 0.14 | 68.48 | 74.93 | *6.44* | *0.0001* |
| October | 65.59 | 71.70 | *6.11* | *0.0007* | 62.48 | 75.19 | *12.70* | *<0.0001* |
| November | 74.48 | 79.11 | *4.62* | *0.0001* | 72.85 | 84.96 | *12.10* | *<0.0001* |
| December | 84.55 | 84.22 | -0.33 | 0.41 | 83.37 | 88.26 | *4.88* | *<0.0001* |
| | 5:00 pm humidity (%) | | | | 5:00 pm humidity (%) | | | |
| January | 48.00 | 51.22 | 3.22 | 0.09 | 39.70 | 45.56 | *5.88* | *0.001* |
| February | 38.11 | 43.85 | *5.74* | *0.01* | 33.52 | 39.70 | *6.20* | *0.0002* |
| March | 34.63 | 40.22 | *5.59* | *0.0003* | 29.33 | 37.14 | *7.81* | *<0.0001* |
| April | 25.11 | 27.37 | 2.25 | 0.08 | 23.00 | 25.74 | 2.74 | 0.07 |
| May | 20.96 | 24.4 | *3.44* | *0.01* | 20.22 | 22.62 | 2.41 | 0.07 |
| June | 28.85 | 32.52 | *3.66* | *0.01* | 26.59 | 28.52 | *1.93* | *0.049* |
| July | 53.3 | 57.22 | *3.93* | *0.03* | 43.41 | 46.93 | *3.52* | *0.02* |
| August | 59.70 | 61.88 | 2.18 | 0.10 | 46.93 | 51.11 | *4.19* | *0.01* |
| September | 50.33 | 51.55 | 1.22 | 0.30 | 41.82 | 47.11 | *5.3* | *0.007* |
| October | 41.82 | 42.88 | 1.07 | 0.29 | 34.07 | 39.22 | *5.15* | *0.002* |
| November | 47.33 | 48.14 | 0.81 | 0.26 | 41.63 | 47.11 | *5.78* | *0.001* |
| December | 53.44 | 53.11 | -0.33 | 0.49 | 47.44 | 51.70 | *4.26* | *0.03* |

**Table III.** Mean morning and evening RH changes at selected weather stations in the LIB region

of September (~−33 mm) for the data set of both temporal halves observed in this study. Larger *p*-values ($p > 0.05$) for the precipitation data of both halves at both locations suggest the presence of large intra annual variation. These results are in agreement with Thapliyal and Kulshrestha, 1991, who also found trendless nature in the amount of precipitation in selected regions in India. The shift of precipitation toward higher side in our data for latter half, i.e. 1980 to 2006, could partly be attributed to the significant wetness during the decade of 1980s. The fact can be justified by the findings of Treydte *et al.*, 2006, who also suggested overall 6 per cent increase in amount of precipitation globally in the period of 1981-2000. Warming leads to increase in moisture holding capacity of the atmosphere and thus may change the regional and global rainfall distribution patterns (Trenberth *et al.*, 2003). This may also be evident from increases in both morning and evening RH at both weather stations (Table III). Thereafter, from 1990 to 2006, the only month of July had experienced significant reduction in precipitation (data not shown) at both weather stations, but overall no major effect was monitored during the same period. The results similar to these were also reported by Rupakumar *et al.* (1992) in some selected parts of India. We did not see any significant changes in precipitation when data of weather station Multan were compared for both periods (Table II). However, absolute amount of precipitation was much lower at Multan than at Lahore, as it is located further southwards and falls into more arid/dessert climate

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region. Most of this region falls in arid and semi-arid climate; thus, successful crops can only be grown by using supplemental irrigations. To fulfill these water requirements, the LIB has world's largest canal irrigation system which irrigates 5.08 million hectares (Agriculture Statistics of Pakistan, 2011), and additional 3.30 million hectares are irrigated by some 0.902 million tube wells run on electricity and diesel (Agricultural Statistics of Pakistan, 2011), and this has resulted in decreasing the levels of ground water by 4-5 m in the region (van Steenbergen and Oliemans, 1998).

Considering the moisture availability together with increase in MMT in this region (Table I), there would definitely be repercussions not only for crop plants but also for functioning of natural ecosystems as well. First, increase in MMT will favor more evaporation of water from soil to the atmosphere during night hour and will deplete soil moisture at much rapid rates. Second, increase in MMT will also enhance dark respiration of the plants and thus will deplete more net photosynthates, and, ultimately, lesser will be available to support other plant activities (Turnbull *et al.*, 2001). Previously, "it has also been suggested that rice yield is reduced by 10 per cent with an increase of MMT @ 1°C in the Philippine" (Shaobing *et al.*, 2004). Keeping in view the water shortage during the growing season, a complete crop failure will occur more often in future if supplemental water availability will not be insured for this region. Moreover, increases in temperature both at day and night time may also lead to more evaporation from water and soil surfaces and, thus, decrease in the amount of moisture available during planting time and during crop growth cycles and decrease in water use efficiency. In natural ecosystem, aridity plus higher temperatures will favor more abundance of $C_4$ grasses over $C_3$, as they are more water use efficient and will likely evolve much quicker than $C_3$ plants to adapt more frequent drought-like condition in near future (Nelson and Cox, 2013).

On the basis of aforementioned trends in the minimum and overall temperatures, we can forecast the increasing water demands for widely grown crops in the future, which can be possibly met by drawing more water from ground water resources. Thus, more pressures on already depleting ground water resources in the region might occur. Therefore, it is strongly urged that some effective water resource should be adopted to store more water to build dams to meet the demands of canal irrigation and which ultimately will reduce the dependence on ground water. This will also not only help in recharging the ground water but also result in improvement of its quality, which is being deteriorated in many regions because of intrusion of saline water in the regions where more good quality is withdrawn than recharged. Our results were also compared to those as reported in previous studies (Muñoz, 2008; Edward and Reilly, 2014).

### *3.3 Temporal Relative humidity changes at Lahore and Multan*

The data regarding 8:00 a.m. RH for both weather stations are shown in Table III. At Lahore, the months of April, May, June, October and November were having significant increase in RH, which ranged from 2.77 per cent for the month of June to 6.11 per cent for the month of November ($p < 0.05$). At Multan, when data for both temporal halves were compared, the morning RH increased significantly ($p < 0.05$) throughout the year, with exception to the month of June, and ranged from 2.77 per cent for the month of July to 12.70 per cent for the month of November. Moreover, the values were also relatively much higher than those of Lahore.

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As far as evening (5:00 p.m.) RH at weather station Lahore was concerned, significant increases ($p < 0.05$) were observed during the months of February, March, May, June and July. The highest increases of RH (per cent) were recorded for the month of February (5.79 per cent) and March (5.59 per cent), whereas the remaining months had seen increase that ranged from 3.4 to 3.9 per cent during past 27 years. At Multan, trends were similar to those of morning RH ($p < 0.05$) and were reported for most months, with exception to the months of April and May. However, relative increase in morning RH was on the lower side for the months of June and February and ranged from 1.93 to 7.81 per cent, respectively. Elevated values for both morning and evening RH at Multan as compared to Lahore and can be explained by more arid climatic conditions, where OMT was relatively higher throughout the year (Table I) and might be responsible for more evaporation of water from the soil and water bodies in the region. As the temperature decreases, RH increases, as evident in relatively much higher values of morning RH at both weather stations. Overall, we did not see any relationship between MMT and OMT with morning RH. Similarly, no relationship was seen between OMT and MXT with evening RH at both locations in the LIB region. It can be seen that relationship between MMT of few months and increases in morning RH at both weather stations suggest that increases in MMT is causing more water to evaporate into the atmosphere. However, the data set showed that in many cases, MMT was not varied significantly, but still significant increase in morning RH was observed. This could be attributed to increases in amount of evaporative surface in the region. The population and area under irrigated agriculture has also increased many times during the two temporal halves used for the comparison. This was further supported by the huge increases in number of tube wells, which stood at 0.902 million in 2011 (Agriculture Statistics of Pakistan, 2011), which were extensively used for irrigation purposes and which were only modest 0.257 million in the early 1980s and their number was only 31,000 in 1964-65 (Chaudhry, 1990). Practically, in the early 60s, the very small proportion of ground water was utilized for the irrigation, which has increased dramatically during last two decades. However, currently, up to 29 per cent of the total area in the LIB region has been irrigated by tube wells. (Laghari *et al.*, 2012). This scenario was also true for the evening RH, where increase also did not show direct relationship with MXT and OMTs at both stations, and suggests more evaporation from increased irrigated activities. However, few months where this increases might be attributed to either MMT and/or OMT and pinpointing that aridity is increasing during those months. There are severe implications of increased RH to the agriculture in this region. The direction of movement of moisture is from soil to atmosphere; thus, soils will quickly dry out and, more often, drought-like conditions will prevail in future, especially at the planting time of most crops in the region. This might force the farmers to deep planting but with the price tag of poor germination, thus ultimately resulting into lower yields. Moreover, increase in RH might also influence the evolution of pathogens and vulnerability of animals and plants through their attack (Muñoz, 2008).

The amount of RH in atmosphere controls the air circulation, the direction and intensity of the air movement which are also vital for clouds formation and precipitation (Smith and Smith, 2001). Moist air is more unstable than dry air, and, thus, increase in RH always leads to more violent thunder storms (Trenberth, 2011). Therefore, in future, the likelihood of high intensity thunderstorm might increase and is accompanied by more intense precipitation events, which might cause more surface runoff and flash

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flooding than more gentle rain fall, which generally soaks the soils. This was evident in the severe river floods in the LIB that happened during 2008-2009, 2010 and 2014, causing huge loss of life, property and economy of the country (Pakistan Year Book, 2011; Economic survey of Pakistan, 2014).

Now the questions are why both RH (morning and evening) are increasing at both weather stations. The answer to this question lies in increasing area under irrigation, as discussed in temperature section. In the past three decades, there was phenomenal increase in usage of ground water through large number of tube wells throughout the region, as MMT and OMT were increasing causing more water to evaporate from large surface area in the form of increased area under irrigation at both locations.

## 4. Conclusion

The current manuscript, for the very first time, provided detailed insights into key climatic factors changes for past seven decades and into the severely climate change affected areas of the world. Our current observations highlighted that the MMT was significantly increased during fall, winter and spring months at both weather stations during last 27 years compared to the previous period and were also responsible for significantly higher OMTs for selected months at both locations as well. Overall "we did not see any change in precipitation profile in the region owing to presence of large intra-annual variation in the amount of precipitation data at both weather stations". However, we did see significant increase in morning and evening RH, which was relatively higher at Multan than at Lahore and that increase was to some extent caused by MMT and OMT, but was mainly attributed to increases in evaporation from large irrigated area of the LIB region, which was brought under irrigation during the past 27 years. If similar trends in increase in MMT, OMT and RH will be continued in future, then it might cause significant reductions in crop yields owing to increase in night time dark and day time both dark and photorespiration in plants. Moreover, increase in RH will likely cause more violent thunder storms with more intense precipitation, which will generate more runoff and flooding than soaking soil profile thoroughly and, thus, more pressure on already depleting surface and ground water resources for successful husbandry of crops. The current findings can be important tool toward the management of climatic changes issues (i.e. floods and dryer spells) and to formulate the future strategies for the improved crop growth in arid and/or semi-arid developing nations such as Pakistan.

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