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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 – We analyzed the previous climatic factors data series of lower Indus basin 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 dynamics at two locations (Lahore and Multan) of the LIB region, Pakistan by using data from 1953–2006. The data was 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 (OMT) in winter season 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 (MXT) at both locations. The rainfall amount did not vary significantly at both locations with the exception for the month of February and June at Lahore location, which experienced relatively higher rainfall in latter half (1980-2006). However, morning and evening relative humidity (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 either dryer weather during winter months due to increase in MMT and/or increase in area under irrigated agriculture resulting in more evaporation at both locations. Similarly, our data also indicated the early monsoon rainfall patterns in summer and late western depression rainfall spell during winter and played key role to affect the crop yield due to irregular rain events.

Practical 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 towards 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 like Pakistan.

Originality/value– The current manuscript, for the very first time, provided detailed insights into key climatic factors changes for last seven decades, into the severely climate change affected areas of the world. Furthermore, agricultural sector would likely to severely affect due to minor seasonal change in temperature and moisture, and have a strong food security impact, which can be reflected with current dataset 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.

Key words: Climate Change; Lower Indus Basin; Temperature; Rainfall, Agriculture.

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 area under cultivation of crops and more consumption of fossil fuels (Carmichael et al., 2009). All these aforementioned factors reflected the emission of elevated greenhouse gases, which ultimately disturbed the natural energy balance of the ecosystem and thus bring change in the temperature and precipitation profile of the regions (Schlesinger & Bernhardt, 2013; Smith & Smith, 2001). David *et al.* (1997) has 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 5400 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 like in 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 & 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 (-6 to 8% of normal/100yrs), while significant increase has been observed in central India and along the west coast (+10 to 12% of normal/100yrs) (Rupakumar *et al.*, 1992). Singh & Sontakke (2002) have also reported an increasing trend in monsoon rainfall in the western Indo-Gangatic plain from 1900 to 1984 and decreasing trend in the central 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 ranged from 2 to 19% were 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 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 Region (LIB) is considered as the food basket of Pakistan comprised of total farmed area of 15.58 million hectares and out of which 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 (Agriculture Census, 2010). The total population of Pakistan stands at 179.2 million (World Bank, 2012) and out of which LIB region hosts 150 million people and 70% of these have agriculture as their profession (Pakistan Year Book, 2013). Being the bread basket of Pakistan, the region has contributed significantly towards 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

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5 some other developing countries, has been categorized as one of top most countries of the world
6 facing large number environmental problems including the effects of global climate change in
7 form of growing frequency of droughts and flooding, increasingly erratic weather behavior,
8 changes in agricultural patterns, irregular patterns in freshwater supply and the loss of
9 biodiversity. Pakistan has also possessed world's third largest ice masses (Himalayas and their
10 associated areas) which gained growing international attention due to its significant role in the
11 global atmospheric circulation and sensitivity towards the preliminary indication in climate
12 changes (Fowler & Archer, 2006). Previously, Fowler & Archer (2006) analyzed the data from
13 some selected weather stations were located in the Upper Indus Basin and indicated conflicting
14 signals regarding climate change in the aforementioned region, which were critical enough for
15 glacier melt down and river discharge. The objective of the present study was to investigate the
16 extent of climate change in the LIB region and its future implication for agriculture. The key
17 objectives and/or questions; we would like address in this study are: (1) Would there be any
18 differences in the mean minimum temperature (MMT), overall mean temperature (OMT) and
19 mean maximum temperature (MXT) of the years from 1953-1979 (previous 27 years) to the data
20 from years 1980-2006 (last 27 years) in the LIB? (2) Were there any differences in the
21 precipitation profile and relative humidity (RH) in the selected agricultural plain areas during
22 aforementioned periods? (3) And last but not the least; was there any difference in the magnitude
23 of climate change at the two selected regions in the LIB? The answers to these questions are
24 critically important especially in terms of supplementary irrigation water demand, crop yield and
25 thus for the economy of the country and also towards management of the climate changes related
26 issues.
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33 **2. Materials and Methods**

34 *Data collection*

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37 The data of mean monthly minimum and maximum temperatures along with mean
38 monthly precipitation plus data on morning and evening relative humidity (RHs) of the two
39 weather stations Lahore and Multan (Fig. 1) were provided by the meteorological office, Lahore
40 for the period of 1953 to 2006. The main reasons, we have chosen the weather data from these
41 locations are subjected to their major agricultural importance. Moreover, Lahore region belongs
42 to warm-semi arid while Multan region falls in hot-arid climatic zone with annual rain fall
43 ranges from between 250 to 500 mm and 125 to 250 mm at both locations, respectively (Ministry
44 of Environment, Government of Pakistan, 2003). The Lahore region comprised of the districts of
45 Lahore, Gujranwala, Kasur, Hafizabad, Sailkot, and Sheikhpura and about 90% of total area
46 (2.78 million hectares) is under rice cultivation in these districts (Pakistan Bureau of Statistics
47 2014), while approximately > 80 % of area is under cotton cultivation in the Multan region
48 which is comprised of nine adjoining districts (Chaudhry *et al.*, 2009).
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Study area

Lahore Station

This station areas is lying between $31^{\circ}15'-31^{\circ}45'$ N and $74^{\circ}01'-74^{\circ}39'$ E (Figure. 1) 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% of the total) in the region is received during the monsoon season, while dry condition occurs during rest of the year (Ministry of Environment, Government of Pakistan, 2003) Total area of the district is 176343-ha, of which 142957-ha of land is present in rural settings, which are 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.

Multan station

It is situated between $30^{\circ}12'0''\text{N}-30^{\circ}50'0''\text{N}$ and $71^{\circ}25'0''\text{E}-71^{\circ}25'0''\text{E}$ (Figure 1) and also possess divisional head quarter of Multan division and 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 condition with very high temperatures, which occasionally touch about $>45-50^{\circ}\text{C}$ during the month of May and June. The average annual rainfall of the region is just 123-mm and 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 is unique among the cropping systems (Chaudhry *et al.*, 2009). Complete crop failure is likely to occur in area without provision of irrigation water.

Data and statistical analysis

We divided 54-year data for mean minimum temperature (MMT), overall mean temperature (OMT) and mean maximum temperature (MXT), precipitation, and morning and evening RHs 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 RHs for both time periods and the differences were computed by subtracting means of last 27 years from the previous 27 years for the aforementioned climate variables. Finally the means for each month for both periods were compared using t-test and hypothesis of no difference between periods were rejected if p-value was less than 0.05.

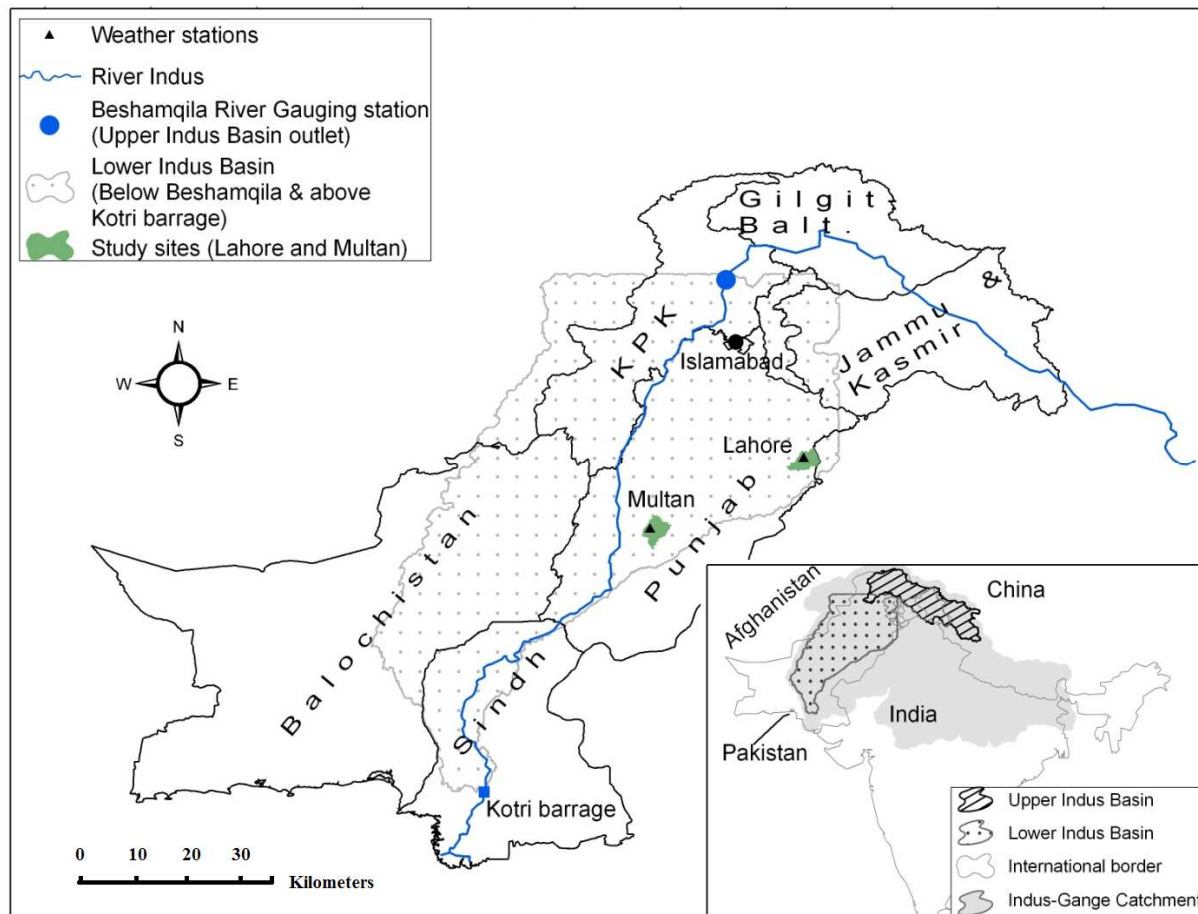


Figure 1. Study map presenting the study sites and important geographical layers.

3. Results and Discussion

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 as Table 1. The results suggested that MMT at Lahore station was significantly increased during fall (i.e., September, October, 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) and followed by 1.98 °C, 1.78 °C, 1.56 °C for December, January, and February in decreasing order, respectively. The April and May (spring) were also experienced significant ($p < 0.05$) increase in MMT, and which were 0.84 and 1.33 °C respectively. The magnitude of increase for the month of September and October was 0.58 and 0.92 °C 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 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 1). However, the magnitude of increase was relatively lower at Multan than those of Lahore. The highest increase among the both temporal halves was 1.33 °C for the month of November, followed by 1.12, 1.07 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), while MMT did not reflect any increase for the other months of the year. Land topographical and atmospheric features at Multan are much different from Lahore. Given that Multan falls under extreme arid climate as well as 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, and which was -1.12 °C (Table 2). Similar to Lahore, it cannot be seen any increase in MXT at Multan, except that the month of August, which 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 dataset of both weather stations (Table 1), except that the magnitude of difference in temperatures between both periods was decreased owing to calculations of further means of both MXTs and MMTs. Similar to the aforementioned MMT trends, the OMT data has also showed that months of September, November, December, January and February were significantly ($p < 0.05$) warmer at Lahore, and which is subjected due to increases in MMT during these months. On the other, MXT trends for Multan were also similar to 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 later halve, 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 due to evaporation of water from the soil surface and water bodies. Glacier melt up in the Himalaya range begins during these months and rivers passing through these areas 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 relative humidity (Table 3), where it can be seen the significant increase in morning (8:00 am) and evening (5:00 pm) RH%. While 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

Table 1. Mean minimum and overall mean temperature changes at selected weather stations in the Lower Indus basin region.

Months	Lahore				Multan			
	Mean Minimum Temperature (MMT) °C				Mean Minimum Temperature (MMT) °C			
	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 2. Mean maximum temperature and precipitation changes at selected weather stations in the Lower Indus Basin region

Months	Lahore				Multan			
	Mean Maximum Temperature (MXT) °C				Mean Maximum Temperature (MXT) °C			
	1953-1979	1980-2006	Difference	p-value	1953-1979	1980-2006	Difference	p-value

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5	January	19.36	19.3	-0.06	0.43	20.55	20.58	0.03	0.46
6	February	22.26	22.34	0.08	0.44	23.31	23.59	0.28	0.31
7	March	27.69	27.00	-0.69	0.09	28.88	28.43	-0.44	0.22
8	April	34.17	34.03	-0.14	0.40	35.17	35.8	0.63	0.15
9	May	38.8	38.9	0.10	0.44	40.22	41.06	0.84	0.10
10	June	40.71	39.59	-1.12	0.001	42.31	42.23	-0.08	0.40
11	July	36.29	35.76	-0.53	0.11	39.34	39.14	-0.21	0.28
12	August	35.14	34.92	-0.23	0.21	38.13	37.60	-0.53	0.03
13	September	34.77	34.92	0.15	0.32	37.2	36.74	-0.46	0.06
14	October	32.84	32.44	-0.4	0.16	34.67	34.09	-0.58	0.08
15	November	27.11	27.54	0.43	0.08	28.45	28.66	0.21	0.27
16	December	21.49	21.9	0.42	0.18	22.85	23.00	0.15	0.36
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19		Mean Precipitation (mm)				Mean Precipitation (mm)			
20	January	24.86	24.95	0.09	0.50	8.13	7.85	-0.28	0.46
21	February	19.12	33.96	14.83	0.04	9.04	12.89	3.85	0.15
22	March	32.70	36.54	3.84	0.32	17.83	17.70	-0.13	0.49
23	April	13.05	22.26	9.21	0.08	11.67	13.4	1.73	0.35
24	May	15.40	22.43	7.02	0.15	10.31	12.96	2.65	0.25
25	June	33.96	53.82	19.86	0.03	10.93	12.23	1.30	0.40
26	July	167.0	207.0	40.83	0.07	58.23	53.78	-4.45	0.36
27	August	148.0	188.0	40.69	0.11	32.0	38.0	6.00	0.33
28	September	96.55	63.18	-33.59	0.13	16.65	25.11	8.46	0.25
29	October	11.14	17.07	5.92	0.22	1.23	6.50	5.27	0.11
30	November	3.37	7.50	4.11	0.12	3.71	1.57	-2.14	0.15
31	December	13.67	10.38	-3.28	0.25	9.76	4.16	-5.60	0.08
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in MXT while the rate of change in OMT ranged from +0.01°C to +0.05°C per year during last 27 years. These results are also coincide by the findings of Aizen *et al.* (1997), who also documented that rate of change in increase was $\approx +0.01^\circ\text{C}$ in Tien Shen mountain region having elevation below 2000-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 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 mean maximum temperature based on the data from 1971 to 2004 in some selected parts of China.

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 were presented as Table 2. 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 of September ($\sim -33\text{mm}$) for the dataset of both temporal halves

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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 & Kulshrestha, 1991, who also found trendless nature in the amount of precipitation in selected regions in India. The shift of precipitation towards 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 % increase in amount of precipitation globally from a period 1981 to 2000. Warming is leading to increase in moisture holding capacity of the atmosphere and thus may change the regional as well as 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 3). Thereafter, from 1990 to 2006, the only month of July had experience 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 was compared for both periods (Table 2). 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 region. Most of this region fall 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 resulted in decreasing the levels of ground water by 4 to 5 meters in the region (Steenbergen & Oliemans, 1998).

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Considering the moisture availability together with increase in mean minimum temperature in this region (Table 1), there would definitely be repercussions not only for crop plants but for functioning of natural ecosystems as well. Firstly, increase in mean minimum temperature will favor more evaporation of water from soil to the atmosphere during night hour and will deplete soil moisture at much rapid rates. Secondly, 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% 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 decreases the amount of moisture available during planting time as well as during crop growth cycles and decrease in water use efficiency. In natural ecosystem, aridity plus higher temperatures will favor more abundance of C₄ grasses over C₃ as they are more water use efficient and will likely evolve much quicker than C₃ plants to adapt more frequent drought like condition in near future (Nelson & Cox, 2013).

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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 and 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 into improvement of its quality, which is being deteriorated in many regions due to 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 (Munoz, 2008; Edward & Reilly, 2014).

Temporal Relative Humidity changes at Lahore and Multan

The data regarding 8:00 am RH % for both weather stations is showed as Table 3. At Lahore, the months of April, May, June, October, and November were having significant increase in RH, which ranged from 2.77 % for the month of June to 6.11% for the month of November ($p < 0.05$). At Multan, when data for both temporal halves compared, the morning RH% increased significantly ($p < 0.05$) throughout the year with exception to the month of June and ranged from 2.77% for the month of July to 12.70% for the month of November. Moreover, the values were also relatively much higher than those of Lahore.

As for as evening (5:00 pm) 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 (%) were recorded for the month of February (5.79 %) and March (5.59 %), while the remaining months had seen increase that ranged from 3.4 to 3.9% during last 27 years. At Multan trends were similar to those of morning RHs ($p < 0.05$) 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%, 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 1) 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% (see Figure 1 and 2 Supporting information). Similarly, no relationship was seen between OMT and MXT with evening RH% at both locations in the lower Indus basin region. It can be seen that relationship between MMT of few months and increases in morning RH% at both weather stations suggesting that increases in MMT is causing more water to evaporate into the atmosphere. However, dataset showed that in many cases when MMT was not varied significantly but still significant increase in morning RH%. This could be attributed to increases in amount of evaporative surface in the region. The population as well as 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) and 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, and which has increased dramatically during last two decades. However, currently upto 29% 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 suggesting more

Table 3. Mean morning and evening relative humidity changes at selected weather stations in the Lower Indus Basin region.

Months	Lahore				Multan			
	1953-1979	1980-2006	Difference	p-value	1953-1979	1980-2006	Difference	p-value
	8:00 am Humidity %				8:00 am Humidity %			
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

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 and 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 and thus ultimately resulted 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; Willicoquet *et al.*, 1998).

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5 The amount of RH % in atmosphere controls the air circulation, the direction, and intensity
6 of the air movement which are also vital for clouds formation as well as for the precipitation
7 (Smith & Smith, 2001). Moist air is more unstable than dry air and thus increase in RH% always
8 leads to more violent thunder storms (Trenberth, 2011). Therefore, in future, the likelihood of
9 high intensity thunderstorm might increase and accompanied by more intense precipitation
10 events which might cause more surface runoff and flash flooding than more gentle rain fall
11 which generally soaks the soils. This was evident in the severe river floods in the lower Indus
12 Basin that happened during 2008-9, 2010, and 2014 causing huge loss of life, property and
13 economy of the country (Pakistan Year Book, 2011; Economic survey of Pakistan, 2014).
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16 Now the questions are why both RH (morning and evening) are increasing at both weather
17 stations? This answer to this question lies in increasing the area under irrigation as discussed in
18 temperature section. In the past three decades there was phenomenal increase in usage of ground
19 water through large number of tube well throughout the region. Since MMT and OMT were
20 increasing causing more water to evaporate from large surface area in the form of increased area
21 under irrigation at both locations.
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24 **4. Conclusion**

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

- Agricultural Census. (2010). Agricultural Statistics of Pakistan. Statistics Division, Pakistan Bureau of Statistics, Government of Pakistan.
- Agriculture Statistics of Pakistan. (2011). Area irrigated by different sources. Pakistan Bureau of Statistics. http://www.pbs.gov.pk/sites/default/files/agriculture_statistics/publication/Agricultural_Statistics_of_Pakistan_201011/tables/Table64.pdf
- Agricultural Statistics of Pakistan. (2011). Number of tube wells. Pakistan Bureau of Statistics. http://www.pbs.gov.pk/sites/default/files/agriculture_statistics/publications/Agricultural_Statistics_of_Pakistan_201011/tables/Table107.pdf
- Ahmed, M., Hassan, F.U., Aslam, M. and Aslam, M. A. (2012). Physiological attributes based resilience of wheat to climate change. *International Journal of Agriculture and Biology* Vol. 14 No 3, pp. 407–412.
- Aizen, V.B., Aizen, E.M., Melack J.M. and Dozier, J. (1997). Climate and hydrologic changes in the Tien Shan, central Asia. *Journal of Climate*, Vol. 10 No. 6, pp, 1393-1404.
- Carmichael, G., Adhikary, B., Kulkarni, S., Allura, A., Tang, Y., Streets, D., Zhang, Q., Bond, T., Ramanathan, V., Jamroensa, A., Marrapu, P., 2009. Asian Aerosols: Current and Year 2030 Distributions and Implications to Human Health and Regional Climate Change. *Environmental Science and Technology*, 43, 5811–5817.
- Census Report. (1998). Population of District Lahore. <http://census.gov.pk/PUNJAB/LAHORE.htm>
- Chaudhry, M.J. (1990). The adoption of Tubewell Technology in Pakistan. *The Pakistan Development Review*, Vol. 29 No. 3-4, pp. 3-4.
- Chaudhry, I.S., Khan, M.B. and Akhtar, M.H. (2009). Economic Analysis of Competing Crops with Special Reference to Cotton Production in Pakistan: The Case of Multan and Bahawalpur Regions. *Pakistan Journal of Social Sciences*, Vol. 29 No 1, pp. 51-63.
- David, R.B., Horton, P. D., Jones, T.C., Peterson, T.R., Karl, D.E., Parker, M.J., Salinger, V., Razuvayev, N., Plummer, P. Jamason, N., and Folland, C.K. (1997). Maximum and Minimum Temperature Trends for the Globe. *Science*, Vol. 277 No. 5324, pp 364 – 366.
- Economic Survey of Pakistan. (2014). Ministry of Finance and Economic affair, Government of Pakistan. www.finance.gov.pk/survey_1314.html
- Fowler, H.J., and Archer, D.R. (2006). Conflicting signals of climatic change in the Upper Indus Basin. *Journal of Climate*, Vol. 19 No. 17, pp. 4276-4292.
- Laghari, A. N., Vanham, D. and Rauch, W. (2012). The Indus basin in the framework of current and future water resources management. *Hydrology and Earth System Sciences*. Vol. 16, 1063–1083.
- Ministry of Environment. (2003). Pakistan’s Initial Communication on climate change. Government of Pakistan, Islamabad. pp. 1-92.

- 1
2
3
4
5 Pakistan Bureau of Statistics. (2014). Agriculture Statistics <http://www.pbs.gov.pk/sites/default>
6 [/files/tables/area_production_crops_0.pdf](http://www.pbs.gov.pk/sites/default/files/tables/area_production_crops_0.pdf)
7
- 8 Pakistan Census Report, Government of Pakistan. (1998).
9 <http://www.statpak.gov.pk/depts/pco/>.
10
- 11 Pakistan Year Book, (2008). Federal Bureau of Statistics, Govt. of Pakistan. <http://www.statpak>
12 [.gov.pk/depts/fbs/publications/yearbook2008/yearbook2008.html](http://www.statpak.gov.pk/depts/fbs/publications/yearbook2008/yearbook2008.html)
13
- 14 Pakistan Year Book. (2011). Federal Bureau of Statistics, Government of Pakistan. <http://www>.
15 [statpak.gov.pk/depts/fbs/publications/yearbook2011/yearbook2011.html](http://www.statpak.gov.pk/depts/fbs/publications/yearbook2011/yearbook2011.html)
16
- 17 Pakistan Year Book. (2013). Federal Bureau of Statistics, Government of Pakistan. <http://>
18 www.statpak.gov.pk/depts/fbs/publications/yearbook2013/yearbook2013.html
19
- 20 Rehman, S.S., Sabir, M.A. and Khan. J. (1997). Discharge characteristics and suspended load
21 from rivers of Northern Indus Basin, Pakistan. *Geological Bulletin of University of*
22 *Peshawar*. Vol. 30 No. 1, pp, 325-326.
23
- 24 Nelson, D.L. and Cox, M.M. (2008). Lehninger Principles of Biochemistry. 5th edition W.H.
25 Freeman, USA. pp. 1100
26
- 27 Rupakumar, K., and Pant, G.B., Parthasarathy B. and Sontakke, N.A. (1992). Spatial and
28 subseasonal patterns of the long-term trends of Indian summer monsoon rainfall.
29 *International Journal of Climatology*, Vol. 12 No. 3, pp, 257-268.
30
- 31 Salinger, M. J. (1995). Southwest Pacific temperatures: Trends in maximum and minimum
32 temperatures. *Atmospheric Research*, Vol. 37, pp, 87–100.
33
- 34 Schlesinger, W.H. and Bernhardt. E.S. (2013). Biogeochemistry: An analysis of global change.
35 3rd edition. Elsevier. pp. 688
36
- 37 Shaobing P., Jianliang, H., Sheehy, J.E., Laza R.C., Visperas, R.M., Zhong, X., Centeno, G.,
38 Khush G.S. and Cassman, K.G. (2004). Rice yields decline with higher night
39 temperature from global warming. *Proceedings of the National Academy of Sciences*,
40 Vol. 101, pp. 9971–9975.
41
- 42 Singh, N. and Sontakke, N.A. (2002). On climatic fluctuations and environmental changes of
43 the Indo-Gangetic plains, India. *Climate Change*, Vol. 52 No. 3, pp. 287-313.
44
- 45 Singh, P., Kumar, V., Thomas T. and Arora, M. (2008). Changes in rainfall and relative
46 humidity in river basins in northwest and central India. *Hydroogical Processes*, Vol. 22
47 No 16, pp. 2982-2992.
48
- 49 Smith, R.L. and Smith, T.M. (2001). Ecology and field biology. Sixth edition. Benjamin
50 Cummings. New York. USA.
51
52
53
54
55
56
57
58
59
60

- 1
2
3
4
5 Van Steenberg, F., and Oliemans. W. (1998). Groundwater resource management in
6 Pakistan. ILRI Workshop: Ground water management: Sharing responsibility for an
7 open access resource. pp. 93-110
8
9
10 Thapliyal, V. and Kulshrestha, S.M. (1991). Climatic changes and trends over India. *Mausam*,
11 Vol. 42, pp. 333-338.
12
13 Trenberth, K. E., Dai, A., Rasmussen, R.M. and Parsons, D.B. (2003). The changing character
14 of precipitation. *Bulletin of American Meteorological Society*, Vol. 84 No. 9, pp. 1205–
15 1217
16
17 Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate Research*, Vol.
18 47 No. 2, pp. 123–138.
19
20
21 Treydte, K. S., Schleser, G. H., Helle, G., Frank, D. C., Winiger, M., Haug, G. H., and Esper, J.
22 (2006). The twentieth century was the wettest period in northern Pakistan over the past
23 millennium. *Nature*, Vol. 440, pp.1179-1182
24
25
26 Turnbull, M.H., Whitehead, D., Tissue, D.T., Schuster, W.S.F., Brown, K.J., and Griffin, K.L.
27 (2001). Responses of leaf respiration to temperature and leaf characteristics in three
28 deciduous tree species vary with site water availability. *Tree Physiology*, Vol. 21 No 9,
29 pp. 571-578.
30
31 World Bank (2012). Total populations of different countries <http://data.worldbank.org/>
32 [/indicator/SP.POP.TOTL](http://data.worldbank.org/indicator/SP.POP.TOTL)
33
34 Weber, R.O, Talkner P. and Stefanicki, G. (1994). Asymmetric diurnal temperature change in
35 the Alpine region. *Geophysics Research Letters*, Vol. 21 No 8, pp. 673-676.
36
37
38 Yang, X., Zhang, Y., Zhang, W., Yan, Y., Wang, Z., Ding M. and Chu, D. (2006). Climate
39 change in Mt. Qomolangma region since 1971. *Journal of Geographical Sciences*, Vol.
40 16 No 3, pp. 326-336.
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