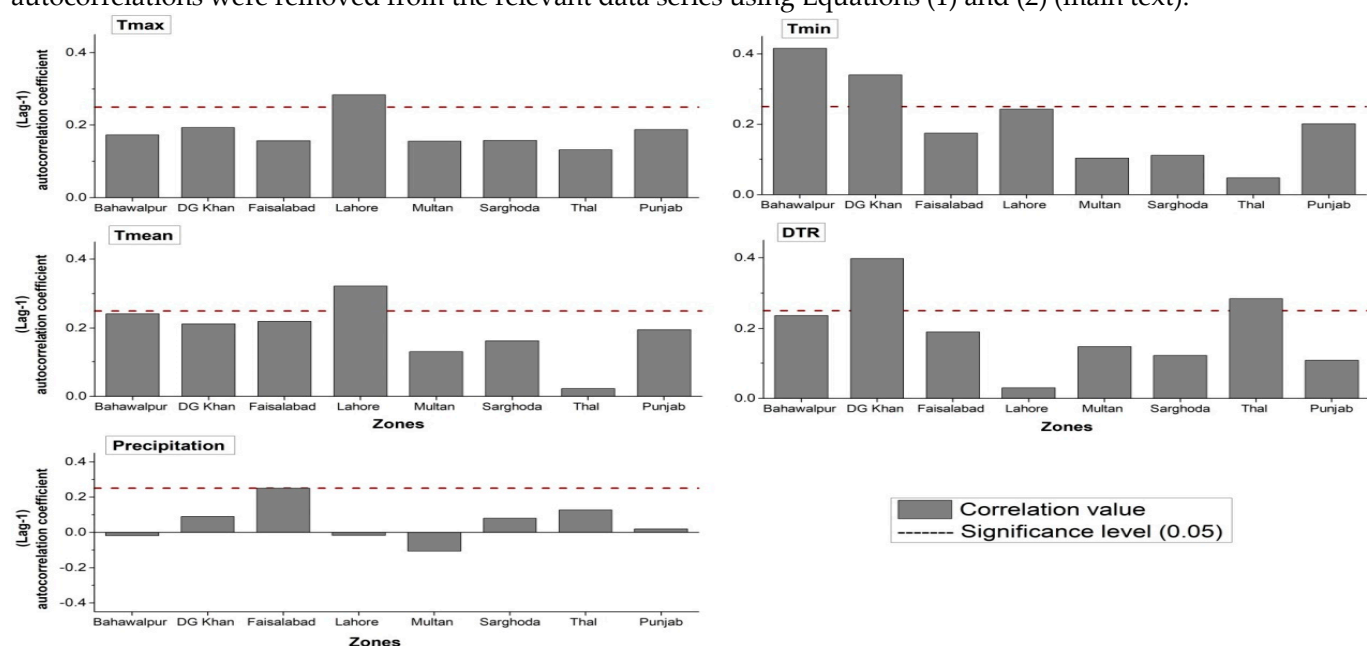


# Supplementary Materials: Temporal and Spatial Characteristics of Precipitation and Temperature in Punjab, Pakistan

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## 1. Analysis of time serial autocorrelation

The results indicate that, most of the annual air temperature indices and precipitation series are serially independent except few data series, particularly at Lahore, Bahawalpur, D.G Khan, and Thal zones. Therefore, to avoid the effects of autocorrelation on MK test, all the significant autocorrelations were removed from the relevant data series using Equations (1) and (2) (main text).



**Figure S1.** Time serial autocorrelation (lag-1) for the climatic variables of different zones.

**Table S1.** Meteorological station weighing factors corresponding to their zones, where  $A_b$  is the area defined by intersection of the Thiessen polygon and zone boundary;  $T_w$  is Thiessen-based station weights (i.e.,  $A_b / A_z$ );  $A_c$  is the values of temperature indices ( $T_{max}$ ,  $T_{min}$ ,  $T_{mean}$ , and DTR) and precipitation for different zones during the study period.

Zones	Area (km <sup>2</sup> )	Bisectional Area (km <sup>2</sup> )	Stations	Station Weight	$A_c$
	$A_z$	$A_b$		$T_w$	
<b>Bahawalpur</b>	46,671.53	12,025.93	Bahawalnagar	0.25	Mean annual and seasonal values for each zone
		13,561.26	Bahawalpur	0.29	
		78.15	Lahore	0.002	
		20,830.06	K. Pur	0.44	
		176.11	Fsd	0.004	
<b>Multan</b>	26,077.70	4727.06	Bahawalnagar	0.18	
		4263.16	Bahawalpur	0.16	
		69.77	Lhr	.003	
		11,148.89	Multan	0.42	
		5283.05	Fsd	0.20	
<b>D.G. Khan</b>	31,291.45	213.06	Bahawalpur	0.007	
		8400.87	Multan	0.26	
		7000.10	K. Pur	0.22	
		2680.09	D.I. Khan	0.086	

	108.84	Rohri	0.003
	473.66	Jacobabad	0.01
	12,414.81	Barkhan	0.39
<b>Faisalabad</b> 16,335.84	579.37	Lhr	0.03
	289.58	Multan	0.01
	1225.45	Jhelum	0.07
	13,663.34	Fsd	0.83
	578.08	Sarghoda	0.03
<b>Lahore</b> 21,936.44	10,990.39	Lhr	0.50
	6869.81	Sialkot	0.31
	715.80	Jhelum	0.03
	3289.68	Fsd	0.15
	2.66	D.I. Khan	0.000
<b>Sarghoda</b> 40,394.22	321.97	Sialkot	0.008
	5505.12	Jhelum	0.13
	2649.01	Fsd	0.06
	4929.16	Multan	0.12
	1444.46	Islamabad	0.03
	8035.42	D.I. Khan	0.19
	3336.67	Mianwali	0.08
	14,172.38	Sarghoda	0.35
<b>Thal</b> 26,353.83	1449.47	Jhelum	0.05
	4025.27	Murree	0.15
	11,013.67	Islamabad	0.41
	9278.95	Mianwali	0.35
	536.45	Sarghoda	0.02

**Table S2:** Absolute changes of temperature ( $^{\circ}\text{C}$ ) indices in the Punjab irrigation zones during the second period (1992–2017) compared to the first period (1967–1991) by using Mann–Whitney (MW) test.

Zones	Annual	Winter	Spring	Summer	Autumn	Rabi	Kharif
<b>T<sub>max</sub></b>							
Bahawalpur	0.26	-0.03	0.66	-0.25	0.69	0.49	0.07
D.G. Khan	0.08	0.41	0.51	-0.57	-0.01	0.35	-0.18
Faisalabad	0.08	-0.11	0.78	-0.03	-0.31	0.09	0.10
Lahore	0.15	-0.02	0.91	-0.15	-0.13	0.31	0.01
Multan	0.07	-0.25	0.69	-0.22	0.07	0.22	-0.05
Sargodha	0.09	-0.21	0.58	-0.25	-0.49	-0.01	-0.17
Thal	<b>0.44</b>	<b>0.77</b>	<b>0.94</b>	0.10	-0.06	<b>0.75</b>	0.13
<b>T<sub>min</sub></b>							
Bahawalpur	<b>1.01</b>	<b>1.09</b>	<b>1.26</b>	<b>0.44</b>	<b>1.20</b>	<b>1.15</b>	<b>0.88</b>
D.G. Khan	<b>0.38</b>	<b>0.63</b>	<b>0.54</b>	0.01	<b>0.49</b>	<b>0.54</b>	0.22
Faisalabad	<b>0.88</b>	<b>0.91</b>	<b>1.22</b>	0.27	<b>1.10</b>	<b>1.02</b>	<b>0.73</b>
Lahore	<b>0.65</b>	<b>0.53</b>	<b>0.96</b>	0.24	<b>0.85</b>	<b>0.70</b>	<b>0.60</b>
Multan	<b>0.85</b>	<b>1.08</b>	<b>1.13</b>	0.17	<b>1.02</b>	<b>1.06</b>	<b>0.63</b>
Sargodha	<b>0.81</b>	<b>0.92</b>	<b>1.11</b>	0.27	<b>0.96</b>	<b>0.96</b>	<b>0.67</b>
Thal	<b>0.52</b>	0.45	<b>0.65</b>	0.25	<b>0.71</b>	<b>0.54</b>	<b>0.50</b>
<b>T<sub>mean</sub></b>							
Bahawalpur	<b>0.64</b>	<b>0.53</b>	<b>0.96</b>	0.10	<b>0.98</b>	<b>0.82</b>	<b>0.47</b>
D.G. Khan	0.23	<b>0.52</b>	0.53	-0.36	0.24	<b>0.44</b>	0.02
Faisalabad	<b>0.48</b>	<b>0.40</b>	<b>1.00</b>	0.12	<b>0.39</b>	<b>0.56</b>	<b>0.41</b>
Lahore	<b>0.40</b>	<b>0.25</b>	<b>0.94</b>	0.05	<b>0.36</b>	<b>0.50</b>	<b>0.30</b>
Multan	<b>0.46</b>	<b>0.42</b>	<b>0.91</b>	-0.02	<b>0.54</b>	<b>0.64</b>	<b>0.29</b>
Sargodha	<b>0.36</b>	<b>0.36</b>	<b>0.84</b>	-0.01	0.23	<b>0.47</b>	<b>0.25</b>
Thal	<b>0.48</b>	<b>0.61</b>	<b>0.80</b>	0.18	<b>0.32</b>	<b>0.64</b>	<b>0.31</b>
<b>DTR</b>							

Bahawalpur	<b>-0.75</b>	<b>-1.12</b>	-0.59	<b>-0.69</b>	<b>-0.57</b>	<b>-0.66</b>	<b>-0.82</b>
D.G. Khan	-0.3	-0.22	-0.03	<b>-0.41</b>	<b>-0.5</b>	-0.19	<b>-0.4</b>
Faisalabad	<b>-0.79</b>	<b>-1.01</b>	-0.44	<b>-0.31</b>	<b>-1.41</b>	<b>-0.93</b>	<b>-0.63</b>
Lahore	<b>-0.49</b>	-0.55	-0.06	-0.39	<b>-0.98</b>	-0.39	<b>-0.59</b>
Multan	<b>-0.78</b>	<b>-1.33</b>	-0.43	<b>-0.39</b>	<b>-0.95</b>	<b>-0.85</b>	<b>-0.68</b>
Sargodha	<b>-0.9</b>	<b>-1.13</b>	<b>-0.53</b>	<b>-0.52</b>	<b>-1.45</b>	<b>-0.96</b>	<b>-0.84</b>
Thal	-0.07	0.32	0.29	-0.15	<b>-0.77</b>	0.21	-0.37

Bold and italic showed significant change with Mann–Whitney (MW) test at 95% confidence level.

**Table S3.** Annual and seasonal trends of temperatures (°C/decade) indices and precipitation (mm /decade) in the Punjab irrigation zones during 1967–2017 by using Mann–Kendall and Sen’s slope.

Zones	T <sub>max</sub>	T <sub>min</sub>	T <sub>mean</sub>	DTR	Precipitation
<b>Annual</b>					
Bahawalpur	0.01	<b>0.35</b>	<b>0.20</b>	<b>-0.36</b>	<b>18.30</b>
D.G. Khan	0.00	<b>0.13</b>	0.07	<b>-0.13</b>	<b>16.70</b>
Faisalabad	0.01	<b>0.31</b>	<b>0.15</b>	<b>-0.29</b>	<b>16.63</b>
Lahore	0.02	<b>0.22</b>	<b>0.11</b>	<b>-0.20</b>	<b>23.45</b>
Multan	0.02	<b>0.34</b>	<b>0.16</b>	<b>-0.35</b>	<b>15.01</b>
Sargodha	0.04	<b>0.29</b>	<b>0.13</b>	<b>-0.34</b>	<b>25.55</b>
Thal	<b>0.12</b>	<b>0.20</b>	<b>0.16</b>	-0.08	<b>34.83</b>
<b>Winter</b>					
Bahawalpur	-0.08	<b>0.37</b>	<b>0.16</b>	<b>-0.46</b>	1.56
D.G. Khan	0.15	<b>0.21</b>	<b>0.20</b>	0.05	-1.74
Faisalabad	-0.09	<b>0.32</b>	<b>0.10</b>	<b>-0.40</b>	0.23
Lahore	-0.09	<b>0.22</b>	0.08	<b>-0.24</b>	0.11
Multan	-0.13	<b>0.43</b>	<b>0.15</b>	<b>-0.55</b>	0.95
Sargodha	-0.11	<b>0.36</b>	<b>0.13</b>	<b>-0.41</b>	0.25
Thal	<b>0.30</b>	<b>0.22</b>	<b>0.25</b>	0.06	-1.00
<b>Spring</b>					
Bahawalpur	0.13	<b>0.48</b>	<b>0.31</b>	<b>-0.30</b>	<b>3.53</b>
D.G. Khan	0.11	0.17	<b>0.15</b>	0.07	5.06
Faisalabad	0.24	<b>0.47</b>	<b>0.34</b>	<b>-0.17</b>	2.76
Lahore	0.25	<b>0.29</b>	<b>0.28</b>	-0.08	0.64
Multan	0.18	<b>0.46</b>	<b>0.32</b>	<b>-0.28</b>	2.79
Sargodha	0.17	<b>0.39</b>	<b>0.28</b>	<b>-0.22</b>	3.84
Thal	<b>0.29</b>	<b>0.26</b>	<b>0.26</b>	0.02	3.71
<b>Summer</b>					
Bahawalpur	-0.12	<b>0.16</b>	0.02	<b>-0.28</b>	<b>10.26</b>
D.G. Khan	-0.22	0.07	-0.14	<b>-0.18</b>	10.12
Faisalabad	-0.01	0.11	0.03	<b>-0.15</b>	1.91
Lahore	-0.06	0.04	-0.01	<b>-0.14</b>	11.76
Multan	-0.09	0.09	-0.01	<b>-0.19</b>	1.78
Sargodha	-0.11	0.06	-0.02	<b>-0.17</b>	11.76
Thal	0.00	0.06	0.03	-0.05	10.83
<b>Autumn</b>					
Bahawalpur	-0.03	<b>0.46</b>	<b>0.26</b>	<b>-0.43</b>	<b>3.50</b>
D.G. Khan	-0.01	<b>0.21</b>	<b>0.10</b>	<b>-0.19</b>	0.78
Faisalabad	-0.13	<b>0.37</b>	<b>0.13</b>	<b>-0.48</b>	<b>8.27</b>
Lahore	-0.06	<b>0.32</b>	<b>0.10</b>	<b>-0.39</b>	<b>4.06</b>
Multan	-0.11	<b>0.42</b>	<b>0.17</b>	<b>-0.46</b>	<b>4.90</b>
Sargodha	-0.19	<b>0.37</b>	0.09	<b>-0.57</b>	<b>7.55</b>
Thal	-0.07	<b>0.29</b>	<b>0.10</b>	<b>-0.36</b>	<b>9.81</b>
<b>Rabi</b>					
Bahawalpur	0.03	<b>0.41</b>	<b>0.24</b>	<b>-0.40</b>	<b>5.24</b>
D.G. Khan	0.09	<b>0.18</b>	<b>0.14</b>	0.06	1.23
Faisalabad	0.00	<b>0.34</b>	<b>0.16</b>	<b>-0.31</b>	2.83

Lahore	0.08	<b><i>0.26</i></b>	<b><i>0.15</i></b>	<b><i>-0.18</i></b>	2.26
Multan	0.02	<b><i>0.43</i></b>	<b><i>0.21</i></b>	<b><i>-0.40</i></b>	3.46
Sargodha	0.03	<b><i>0.34</i></b>	<b><i>0.16</i></b>	<b><i>-0.37</i></b>	6.05
Thal	<b><i>0.22</i></b>	<b><i>0.22</i></b>	<b><i>0.24</i></b>	0.01	5.22
<b>Kharif</b>					
Bahawalpur	-0.01	<b><i>0.33</i></b>	<b><i>0.16</i></b>	<b><i>-0.33</i></b>	<b><i>17.21</i></b>
D.G. Khan	-0.08	0.09	0.00	<b><i>-0.17</i></b>	13.42
Faisalabad	-0.03	<b><i>0.30</i></b>	<b><i>0.15</i></b>	<b><i>-0.27</i></b>	16.12
Lahore	-0.01	<b><i>0.22</i></b>	<b><i>0.10</i></b>	<b><i>-0.21</i></b>	23.38
Multan	-0.02	<b><i>0.28</i></b>	<b><i>0.12</i></b>	<b><i>-0.30</i></b>	11.68
Sargodha	-0.06	<b><i>0.24</i></b>	<b><i>0.09</i></b>	<b><i>-0.27</i></b>	21.58
Thal	0.00	<b><i>0.17</i></b>	<b><i>0.09</i></b>	-0.13	30.92

Bold and italic showed a significant trend with Mann–Kendall (MK) test at 95% confidence level.