**Influence of large-scale circulation and interannual modes of climate variability on seasonal drought characteristics over Pakistan**

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**Fig. S1.** Spatial patterns of the monthly Rabi and Kharif seasons during wet and dry years drought conditions over Pakistan (1983 – 2019).



**Fig. S2.** Composite analysis’s of 2m air temperature and relative humidity at 850 hPa monthly anomaly for Rabi season, Kharif season, and annual dry and wet years over SA (Pakistan) during 1983 – 2019. The contours indicate relative humidity at 850 hPa, and the shaded portion represents 2m air temperature.

**Table S1**

Summary of the selected 53 meteorological in-situ stations data and their altitude.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Stn. Code | Stations | Latitude (°N) | Longitude (°E) | Altitude (m) |
| AST | Astore | 35.37 | 74.90 | 2167 |
| BDN | Badin | 24.63 | 68.90 | 10 |
| BWR | Bahawalnagar | 29.95 | 73.85 | 161 |
| BWL | Bahawalpur | 29.40 | 71.78 | 116 |
| BLK | Balakot | 34.55 | 72.35 | 980 |
| BRK | Barkhan | 29.88 | 69.72 | 1097 |
| BUN | Bunji | 35.67 | 74.63 | 1372 |
| CHT | Cherat | 33.82 | 71.55 | 1301 |
| CHR | Chhor | 29.88 | 69.72 | 5 |
| CHL | Chilas | 35.42 | 74.10 | 1250 |
| CHT | Chitral | 35.85 | 71.83 | 4198 |
| DLD | Dalbandin | 28.88 | 64.40 | 848 |
| DIK | D.I. Khan | 31.82 | 70.92 | 173 |
| DIR | Dir | 35.20 | 71.85 | 1369 |
| DRH | Drosh | 35.57 | 71.78 | 1464 |
| FSL | Faisalabad | 31.43 | 73.13 | 185 |
| GDP | Gahridopatta | 34.22 | 73.62 | 812 |
| GIL | Gilgit | 35.92 | 74.33 | 1459 |
| GUP | Gupis | 36.17 | 73.40 | 2155 |
| MJD | Moenjodaro | 27.37 | 68.10 | 40 |
| HDB | Hyderabad | 25.38 | 68.42 | 543 |
| ISB | Islamabad | 33.70 | 73.08 | 55 |
| JCB | Jacobabad | 28.30 | 68.47 | 287 |
| JHL | Jhelum | 32.93 | 73.73 | 56 |
| JIW | Jiwani | 25.07 | 61.80 | 1308 |
| KAK | Kakul | 34.18 | 73.25 | 21 |
| KLT | Kalat | 29.03 | 66.58 | 87 |
| KCH | Karachi | 24.90 | 66.93 | 1231 |
| KHP | Khanpur | 28.65 | 70.68 | 510 |
| KDR | Khuzdar | 27.83 | 66.63 | 613 |
| KHT | Kohat | 33.57 | 71.43 | 215 |
| KTL | Kotli | 33.52 | 73.90 | 87 |
| LHR | Lahore | 31.52 | 74.40 | 283 |
| MWL | Mianwali | 32.55 | 71.55 | 210 |
| MUL | Multan | 30.20 | 71.43 | 122 |
| MUR | Murree | 33.92 | 73.38 | 2167 |
| MZD | Muzaffarabad | 34.37 | 73.48 | 701 |
| NOK | Nokkundi | 28.82 | 62.75 | 682 |
| PDN | Padidan | 26.85 | 68.13 | 46 |
| PAN | Panjgur | 26.97 | 64.10 | 980 |
| PCH | Parachinar | 33.90 | 70.08 | 1725 |
| PSN | Pasni | 25.27 | 63.48 | 4 |
| PSH | Peshawar | 34.02 | 71.58 | 359 |
| QTA | Quetta | 30.25 | 66.88 | 1600 |
| RHR | Rohri | 27.70 | 68.90 | 66 |
| SAD | Saidu Sharif | 34.73 | 72.35 | 961 |
| SGD | Sargodha | 32.05 | 72.67 | 187 |
| SBA | Sh\_Benazirabad | 26.25 | 68.37 | 37 |
| SLK | Sialkot | 32.50 | 74.53 | 251 |
| SIB | Sibbi | 29.55 | 67.88 | 133 |
| SKR | Skardu | 35.30 | 75.68 | 2209 |
| ZHB | Zhob | 31.35 | 69.47 | 69 |
| LSB | Lasbella | 26.27 | 66.17 | 1405 |

**Table S2**

Statistical validation results of nRMSE, MAE, and R2 for Rabi, Kharif seasons, and annual timescales over Pakistan.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Seasonal & annual droughts | Statistics | Climate Indices | | | | | | |
| DMI | ENSO | IOD | Nino4.0 | PDO | SST | Sunspot |
| Rabi season | nRMSE | 1.08 | 1.51 | 2.62 | 3.21 | 1.74 | 1.08 | 2.37 |
| R2 | 0.01 | 0.15 | 0.01 | 0.14 | 0.01 | 0.01 | 0.01 |
| MAE | 0.04 | 0.61 | 2.41 | 2.62 | 0.73 | 0.43 | 1.73 |
| Kharif season | nRMSE | 1.23 | 1.43 | 1.73 | 1.23 | 1.92 | 1.23 | 1.94 |
| R2 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 |
| MAE | 0.75 | 0.80 | 3.13 | 2.64 | 1.08 | 0.75 | 1.33 |
| Annual timescale | nRMSE | 6.78 | 3.14 | 4.00 | 5.53 | 4.06 | 1.78 | 4.52 |
| R2 | 0.06 | 0.05 | 0.01 | 0.08 | 0.04 | 0.06 | 0.03 |
| MAE | 0.17 | 0.49 | 2.50 | 2.56 | 0.74 | 0.17 | 3.34 |

**Table S3**

Summary of wet and dry years for Rabi, Kharif seasons, and annual timescale over Pakistan during the period of 1983–2019.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Rabi season | | Kharif season | | Annual timescales | |
| Dry years | Wet years | Dry years | Wet years | Dry years | Wet years |
| 1985 | 1988 | 1985 | 1983 | 1985 | 1988 |
| 1989 | 1990 | 1987 | 1988 | 1987 | 1991 |
| 1999 | 1991 | 1989 | 1994 | 1989 | 1998 |
| 2000 | 1998 | 1993 | 1998 | 1993 | 2006 |
| 2001 | 2005 | 2001 | 2006 | 1999 | 2007 |
| 2004 | 2007 | 2002 | 2007 | 2000 | 2010 |
| 2014 | 2013 | 2009 | 2010 | 2002 | 2013 |
| 2018 | 2015 | 2014 | 2017 | 2014 | 2017 |