Geo-spatial analysis of rainfall variability in Khyber Pakhtunkhwa Province, Pakistan

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Abstract. This paper explores geo-spatial analysis of rainfall variability in Khyber Pakhtunkhwa province, Pakistan**.** The concern region lies in the north-west of Pakistan and frequently faced the challenges of floods each year. This is an attempt to find out the rainfall trend and fluctuation which is one of the prime indicator of climate change. For this study, the daily rainfall data comprises of almost five decades (1975–2015). For achieving the study objectives, daily, monthly and mean annual rainfall data were analyzed using Mann-Kendall and Standard Deviation combined. Additionally, to further process the rainfall data spatio-statistically, GIS technology has been applied. The analysis specifies that a positive rainfall detected in the meteorological stations of Peshawar, Dir, Chitral, Drosh, Kakul and Saidu, whereas the moderate rainfall trend is detected in Cherat, Bannu, and Balakot. The remaining stations expressed no obvious trend, due to low time period of data.

Key words: Rainfall, Trend, Mann-Kendall test, Kendall Tau, Spatial Variability.

1. Introduction

Climate change is considered one of the major global issue having great impact on human as well as environment (Dawood et al., 2021). Additionally, it also adversely effects the human health, water resource and food security. Worldwide, the average temperature is increasing year to year resulting massive variability in term of rainfall trend (Xu et al., 2011; IPCC, 2014; Panthi et al., 2015). Subsequently, this rapid rise in earth average temperature ultimately causes rainfall variability, accelerate ice melting, evaporation, and runoff pattern (Dawood et al., 2021). These persistent variations in climatic elements results great effects on hydro-meteorological cycle (Ceppi et al., 2012). Climate change experts are applying diverse temporal data in order to measure the fluctuations in rainfall trend and pattern. In the scenario of climate change, rainfall was used for prediction purpose (Dawood et al., 2018). Additionally, rainfall trend has substantial effect on river discharge fluctuation (Beyene et al., 2010). In a country like Pakistan, in the past 30-years, there occurred a drastic change in the frequency of hydro-meteorological events (Martius et al., 2013; Rahman et al., 2018). Besides, the precipitation pattern is also become uncertain and hence posed various intimidations to the communities which is vulnerable (Rahman & Dawood, 2016). For example, in the year-2010, a 4-day precipitation spell in northern Pakistan has encouraged the super flood in the region, which is considered one of the conspicuous examples of varying precipitation pattern (Rahman et al., 2019).

Compared with other global research studies, the regional studies regarding precipitation extremes might hold more practical implication and consequently, provide assistance to higher authorities to formulate better strategies for the mitigation of possible disasters. Due to variability in climate, trend and fluctuation in rainfall pattern vary region to regions. Dawood et al., (2021) evaluated the possible changes in extreme precipitation and temperature in northern Pakistan during the period 1967–2015 and found that maximum of meteorological stations of the study area experienced significant changes in terms of precipitation. Furthermore, as variation in precipitation pattern is mainly caused by the recurrent variations in intensity and frequency, highlighting the ultimate significance, which might helpful in understanding the diverse characteristics of precipitation. The key purpose of this research study is to explore the adverse impacts of unexpected rainfall spell in the region. At the same time, it effects on the lives of the human lives that reside in the study area. Eventually, a comprehensive analysis of trend and variability in rainfall pattern have been conducted in Khyber Pakhtunkhwa.

In this study, rainfall has been selected as one of the crucial climatic indicators in order to analyze its fluctuation and trend. For acquiring the study objectives, the temporal data regarding rainfall were collected from Pakistan Meteorological Department, Peshawar. The rainfall temporal data of fifteen meteorological stations in Khyber Pakhtunkhwa (KP) were calculated and analyzed by applying Mann-Kendall test and Standard Deviation.

2. Methods and Materials

1.1. Study area

The study area of the current research study is Khyber Pakhtunkhwa (KP), previously recognized as North West Frontier Province (NWFP). The province is ranked 3rd in case of population in Pakistan. In term of topography, it is a province holding a great diversity across Pakistan i.e. extreme climatic circumstances experiences in the entire province. In term of location, the province is bounded in the west by Federally Administered Tribal Area (FATA) and Afghanistan, whereas Punjab province is located in the east. Likewise, Gilgit-Baltistan (GB) and Azad Jammu and Kashmir (AJK) lies in the north-east direction and in the south Baluchistan province is situated (Fig. 1). Moreover, Peshawar is the provincial capital of Khyber Pakhtunkhwa. Khyber Pakhtunkhwa province possesses a total area of 74,521 km^2 with 31 million people according to April-2017 population census record. In the scenario of physiography, the concern province comprises Hindu Kush (HK), Hindu Raj, along with some section of lesser Himalayas and at the same time massive plain area bounded by high mountains (Khan, 2015).

The province is further sub-divided into four agriculture and ecological zones by the Environmental Protection Agency (EPA) of KP, due to topography, altitude, rainfall and temperature (GoP, 2016). In the study area (Khyber Pakhtunkhwa), there is exists great variability in in terms of elevation that varies in the south from 100 m to almost 7000 m above mean sea level (amsl) in the north (Fig. 1). The lofty Tirich Mir is the highest mountain peak in the Hindu Kush region having altitude of 7690 m above mean sea level (Rahman & Dawood, 2016). In the southern section of Hindu Kush, there situated the Hindu Raj Mountains range detached by Chitral River from HK region (Britannica, 2012; Rahman, 2015). Absolutely, Hindu Raj Mountains systems are the offshoot of HK (Dichter, 1967). Similarly, Hindu Raj Mountains are further sub-divided into three parallel ranges such as Kohistan, Dir and Swat in series that stretched in north-south direction (Dichter, 1967). These specific mountain ranges are detached by the Indus, Chitral, Drosh, Swat and Panjkora Rivers (Rahman & Khan, 2011). The exact elevation of these mountain systems deceases from north toward south.

The study region (Khyber Pakhtunkhwa) is drained by River Panjkora, River Swat and River Indus. In the eastern section of the province, the lofty ranges of Himalayas located. In the study area, Peshawar is the biggest plain that drained by River Swat and River Kabul (Britannica, 2012). For this study, Khyber Pakhtunkhwa is selected because of the adverse impacts of climate change in the past along with its natural disasters history (Rasul et al., 2012; Ullah et al., 2015; Malik, 2012).

1.2. Data collection

To obtained the study objectives, the daily rainfall data for five decades (1975–2015) has been collected from Pakistan Meteorological Department, for all the meteorological stations. In the study area (Khyber Pakhtunkhwa), there lies fifteen meteorological stations. Amongst all, Chitral, Drosh, Dir, Kalam, Malam Jabba, Balakot, Para Chinar and Pattan hold high elevation as compared to the remaining meteorological stations. In term of height, these meteorological stations have different altitudes. Therefore, the rainfall pattern is also varying according to the altitude. The rainfall varies from station to station depending upon the elevation. In order to acquire better results, spatial databases were developed using GIS technology.

Mann-Kendall (MK) test

The MK is a non-parametric model inserted to quantity the occurring possible rainfall trend (Douglas et al., 2000; Modarres & Silva, 2007). The MK test mathematically derived as;

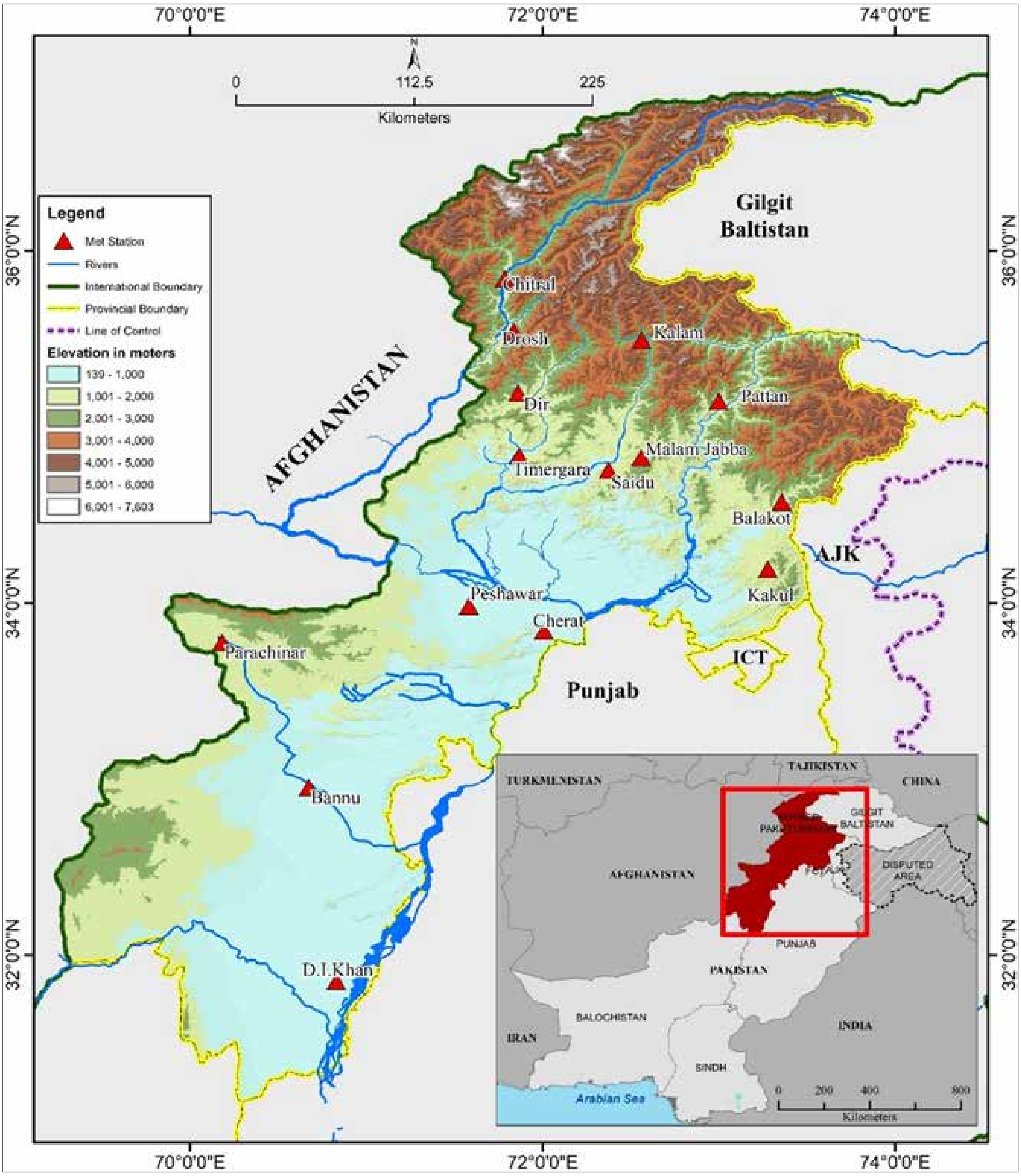

Figure 1. Location map of study area

$$s = \sum_{i-1}^{n-1} \sum_{j-i+1}^{n} Sign\left(T_j - T_i\right) \quad (1),$$

$$Sign\left(T_j - T_i\right) = \begin{Bmatrix} 1 \; if \; T_j - T_i > 0 \\ 0 \; if \; T_j - T_i = 0 \\ -1 if \; T_j - T_i < 0 \end{Bmatrix} \quad (2).$$

Similarly, the variance can be computed as;

$$Var\left(S\right) = \frac{n\left(n-1\right)\left(2n+5\right) - \sum_{i-1}^{m} t_i \left(t_i - 1\right)\left(2t_i + 5\right)}{18} \quad (3).$$

Standard Deviation (SD)

The standard deviation measures the amount of dispersion from its mean. In the calculated data, SD usually find out the occurring deviation regarding mean. The standard deviation value is high by existing great differences in the available data. Contrary to this, the value will be low if there are little variations exists. Moreover, the value of SD never be negative just because of the square root and it might be zero, when there is no variability in the linked data. Furthermore, the unit regarding standard deviation will be identical to the analyzed data possess. SD can be computed as;

$$s = \sqrt{\frac{1}{N-1} \sum_{i} \left(x_i - \overline{x}\right)^2} \quad (4).$$

Putting the sign σ in Eq. 5

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i} \left(x_i - \overline{x}\right)^2} \quad (5).$$

In eq. 4, S shows the SD that quantity the variation degree from the mean, represented by the sign σ (Eq. 5). In addition, Σ express the summation; $\bar{x}$ denotes mean of the associated data, while n shows the number of data points.

Kendall Tau

The Kendall Tau also known as 'Kendall Rank Correlation Coefficient' is a non-parametric test denoted by a Greek letter τ measure association between ranked data column. Kendall Tau hold the values between 0 and 1, where 0 express no relation, while 1 indicate a perfect association.

Statistically, Kendall Tau can be expressed as;

$$\tau = \frac{2}{n\left(n-1\right)} \sum_{i<j} \text{sgn}\left(xi - xj\right)\text{sgn}\left(yi - yj\right) \quad (6),$$

where τ represent Kendall Tau, Σ shows summation, while n indicates number of pairs.

3. Results and Discussion

3.1. Rainfall Variability

In the study region, most of the rainfall received in the summer months (monsoon) and contrary to this, the winter rainfall collected from western disturbances. For the current analysis of all the meteorological stations, Mann-Kendall test was applied for the trend detection using Addinsoft Excel state software. Similarly, Kendall Tau has been used to investigate the association between ranked data column, while standard deviation inserted to find the degree of dispersion. Likewise, for spatial analysis, Kriging technique was applied using GIS technology. This analysis revealed that the rainfall greatly fluctuates from one meteorological station to another depending upon their geographic location. In the study area (Khyber Pakhtunkhwa), there are located fifteen meteorological stations having different elevations and geometric positions (Fig. 2).

Among these, the stations that are lies comparatively at higher altitude indicates sufficient quantity of rainfall. In term of altitude, these meteorological station Malam Jabba (2691 m) is on the top followed by Kalam (2103 m), whereas the stations having the lowest height include Peshawar and D.I. Khan, while rest of the meteorological stations express fluctuation. In all the meteorological stations, Malam Jabba and Kalam are considered the wet stations as these collects the higher amount of precipitations. Contrary to this, though Chitral and Drosh are located in higher altitude but still received less amount of rainfall. One of the reasons is that these meteorological stations located in the rain shadow areas. The present analysis shows that there exists great variation in annual rainfall and varies from one station to another. After statistical analysis that the meteorological station of Dir express great fluctuation in term of annual rainfall.

The resultant analysis specifies that the highest average annual rainfall recorded at Malam Jabba i.e. 1388 mm with a SD of 178 mm for the time series data (Table 1). Similarly, Balakot documented 1585 mm of rainfall having standard deviation 365, just followed by Dir (1388 mm) with a standard deviation of 225, whereas the remaining stations exhibit variations in term of average annual rainfall. The remaining meteorological stations express low variability. The Figure 3, the blue colour indicate higher concentration of rainfall, whereas the yellow colour express low concentration. The results show that the rainfall concentration decreases from dark blue towards light yellowish. These maps were prepared using GIS technology.

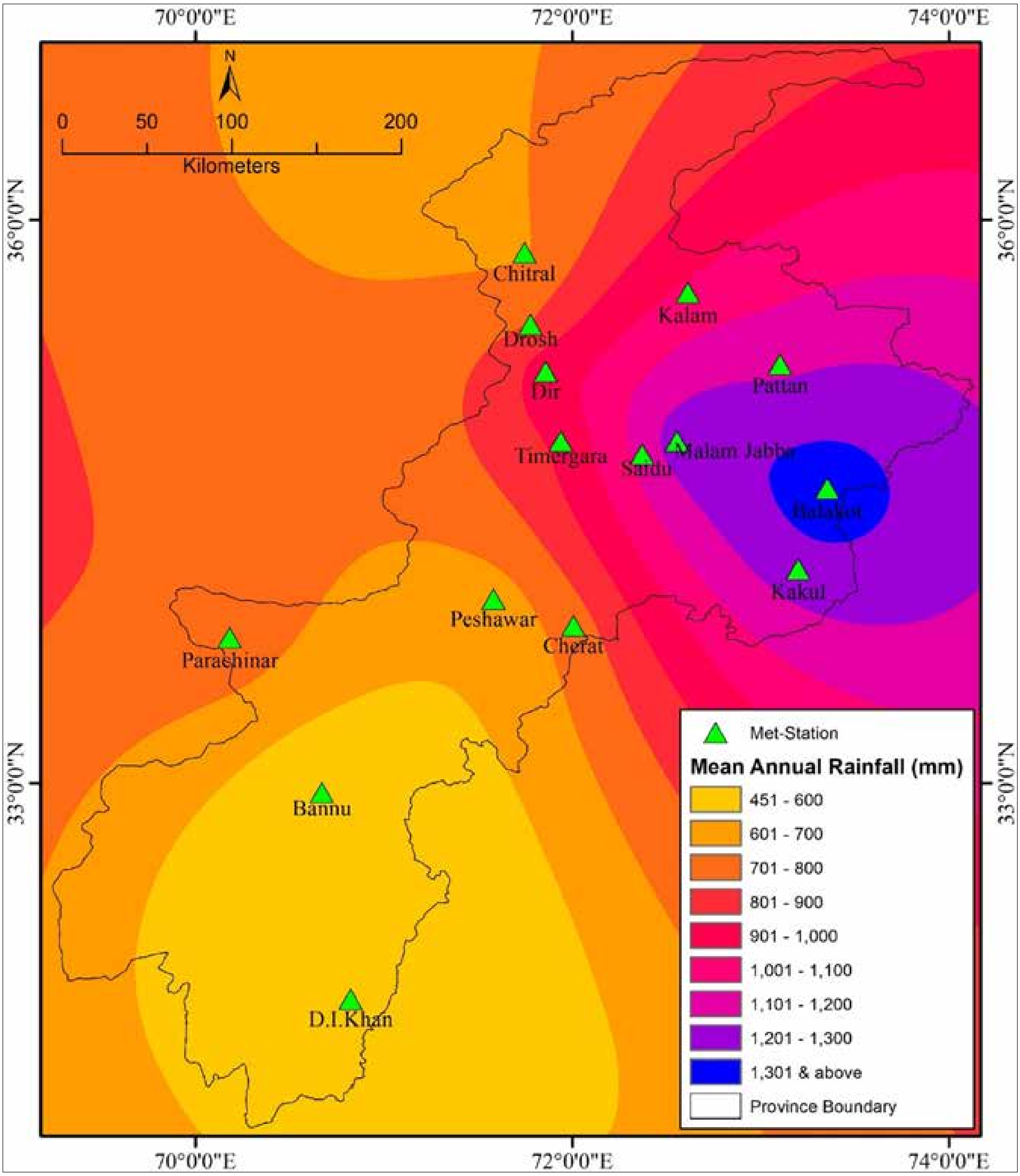

Figure 2. Spatial distribution of mean annual rainfall of all the meteorological stations.

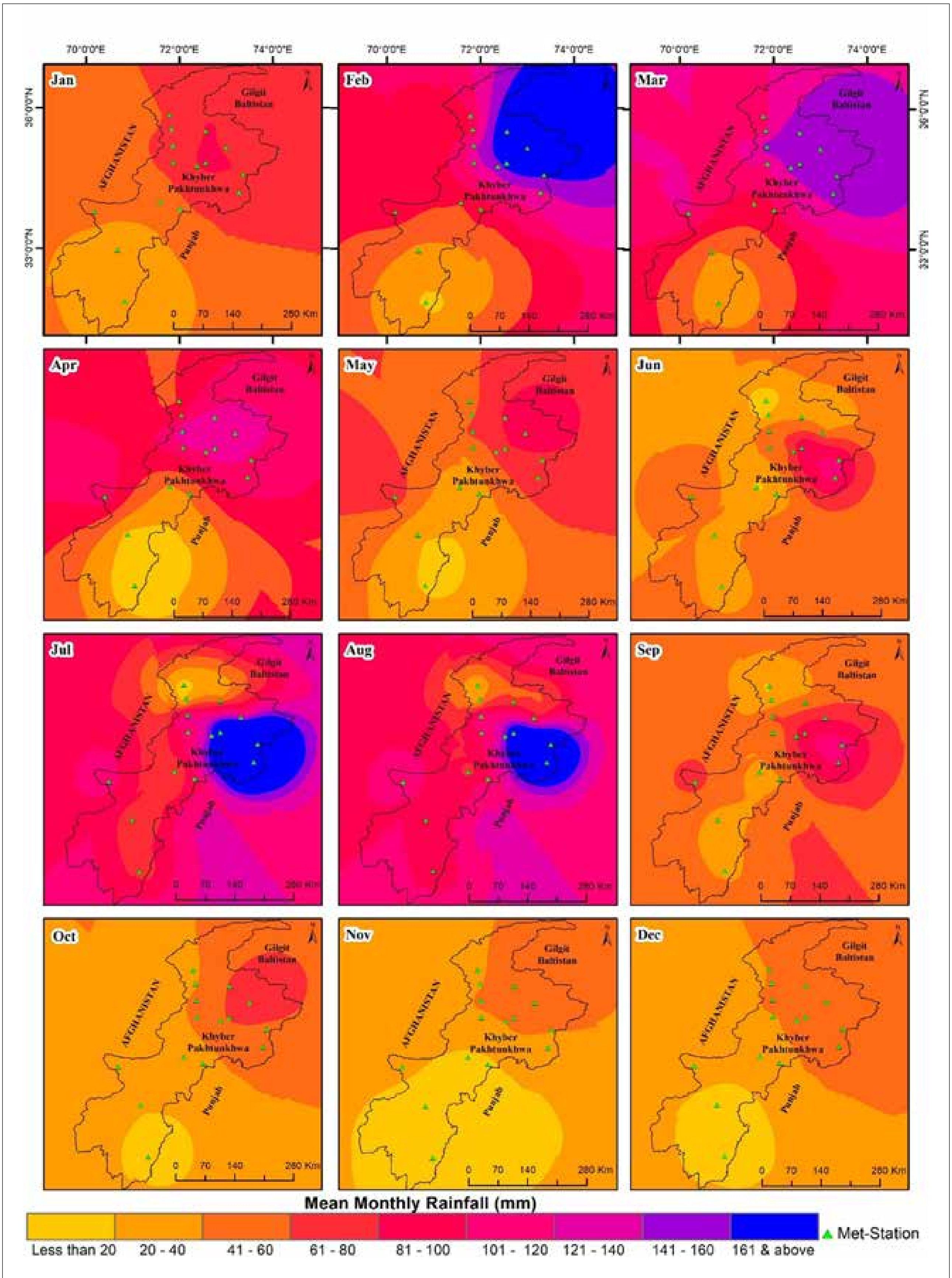

Figure 3. Spatial distribution of mean annual rainfall of all the meteorological station.

Table 1. Average rainfall Standard Deviation results and altitude of all the 15 met stations

S.No	Met Station	Altitude (m)	Avg. Rainfall (mm)	Standard Deviation
1	Chitral	1498	432	117
2	Drosh	2230	554	123
3	Dir	1375	1388	225
4	Timergara	823	788	124
5	Saidu	949	972	218
6	Kalam	2103	1009	133
7	Malam Jabba	2591	1590	178
8	Balakot	1020	1585	365
9	Kakul	1260	1332	176
10	Peshawar	345	444	145
11	Bannu	340	345	136
12	Parachinar	1720	925	375
13	Pattan	2275	1042	137
14	Cherat	520	612	195
15	D.I. Khan	170	311	111

3.2. Mann-Kendall (MK) test results and trend estimation

Mann-Kendall test ran on the temporal data of mean annual rainfall for all the fifteen meteorological stations. As per MK rules, if the p-value is smaller than the standard level i.e. 0.05, the null-hypothesis (H_o) will certainly be rejected. The rejection of null-hypothesis (H_o) demonstrates that trend exists in the available data, expressing that the results are significant. Contrary to this, if the p-value is greater than the standard level, H_o will be accepted. The acceptance of H_o express that there is no possible trend in the analyzed data, and ultimately the results are statistically insignificant.

After applying MK test to all the meteorological stations, the results express diversity in case of rainfall trend. Moreover, the results further revealed that H_o is rejected for the meteorological stations; Chitral (p-value=0.03), Drosh (p-value=0.04), Dir, Saidu (p-value=0.02), Kakul (p-value=0.01) and Peshawar i.e. p-value=0.05 (Table 2). The all the above mentioned p-value specifies the values less than the standard level. Subsequently, as the resultant values are significant, H_o will be rejected. Opposite to these, for the remaining meteorological stations, H_o will be accepted, which revealed that no noteworthy trend has been seen in the available data. As per MK test rules, the p-values were exceeding that standard level.

Additionally, the Mann-Kendall Tau, which is denoted by the symbol (τ) shows link among the data. The value of MK Tau is in between 0 and 1. Hence, the value that close to "1", will possess stronger association, while the value close to zero express poor relationship.

4. Conclusion

After geo-spatial analysis, the results indicate that due to diversity in rainfall data, there is great variations exist. The statistical techniques run on the mean monthly and mean annual temporal data. This study investigates the rainfall variability in Khyber Pakhtunkhwa province, Pakistan**.** The study region is located in the north-west section of

Table 2. Mann-Kendall test results for all the fifteen meteorological stations

Met Station	Kendal's Tau	Longitude	Latitude	P-value Two tailed	Model Remarks
Chitral	0.30	71° 44′ 50″ E	35° 49′ 34″ N	0.03	H_o Rejected
Drosh	0.25	71° 46′ 46″ E	35° 26′ 40″ N	0.04	H_o Rejected
Dir	0.32	71° 51′ 37″ E	35° 11′ 33″ N	0.05	H_o Rejected
Timergara	-0.15	71° 50′ 26″ E	34° 49′ 33″ N	0.08	H_o Accepted
Saidu	0.29	72° 21′ 38″ E	34° 44′ 58″ N	0.02	H_o Rejected
Kalam	0.17	72° 36′ 57″ E	35° 36′ 51″ N	0.61	H_o Accepted
Malam Jabba	0.14	72° 33′ 28″ E	34° 49′ 23″ N	0.80	H_o Accepted
Balakot	0.17	73° 21′ 22″ E	34° 34′ 15″ N	0.36	H_o Accepted
Kakul	0.25	73° 12′ 06″ E	34° 08′ 28″ N	0.01	H_o Rejected
Peshawar	0.22	71° 33′ 56″ E	34° 00′ 54″ N	0.05	H_o Rejected
Bannu	0.13	70° 40′ 18″ E	32° 57′ 01″ N	0.81	H_o Accepted
Parachinar	0.16	70° 10′ 54″ E	33° 46′ 31″ N	0.42	H_o Accepted
Pattan	0.15	73° 06′ 17″ E	35° 13′ 54″ N	0.92	H_o Accepted
Cherat	0.15	71° 44′ 50″ E	33° 50′ 21″ N	0.21	H_o Accepted
D.I. Khan	0.18	70° 57′ 10″ E	31° 48′ 56″ N	0.44	H_o Accepted

Pakistan that recurrently faced various disasters every year. After applying statistical techniques, the resultant analysis express that an increasing rainfall trend predicted in the meteorological stations of Dir (0.05), Chitral (0.03), Drosh (0.04), Peshawar (0.05), Kakul (0.01) and Saidu (0.02). All these stations have a p-value less than 0.05 (95%). Therefore, the Null-Hypothesis (H_o) should be rejected. Similarly, moderate rainfall trend is found in Bannu (0.09), Cherat (0.06) and Balakot (0.07) meteorological stations. In case of moderate trend, the p-value is slightly greater than the standard value, hence the Null-Hypothesis (H_o) may be accepted. The remaining stations exhibit no clear rainfall trend because of low time period of data. All these variations in the scenario of rainfall attributed to the climate change phenomenon.

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References

Beyene T., Lettenmaier D. & Kabat P., 2010, Hydrologic impacts of climate change on the Nile River Basin: implications of the 2007 IPCC scenarios. Climate Change 100(3): 433–461.

Britannica E., 2012, Khyber Pakhtunkhwa Province, Pakistan, from Encyclopedia Britannica, inc. https://www.britannica.com/place/ Khyber-Pakhtunkhwa

Ceppi P., Scherrer S.C., Fischer A.M. & Appenzeller C., 2012, Revisiting Swiss temperature trends 1959–2008. Int J Climatol 32(2): 203–213

Dawood M., Rahman A.U., Mahmood S., Rahman G. & Nazir S., 2021, Assessing the impact of climatic change on discharge in Swat river basin using fuzzy logic model. Arabian Journal of Geosciences 14(18): 1–16.

Dawood M., Rahman A.U., Ullah S., Rahman G. & Azam K., 2018, Spatio-temporal analysis of temperature variability, trend, and magnitude in the Hindu Kush region using Monte Carlo and Sen's slope approaches. Arabian Journal of Geosciences 11(16): 1–15.

Dichter D., 1967, The North-West frontier of West Pakistan: a study in regional geography. Clarendon Press, Oxford.

Douglas E.M., Vogel R.M. & Kroll C.N., 2000, Trends in floods and low flows in the United States: impact of spatial correlation. J Hydrol 240: 90–105.

Govt of Pakistan (GoP), 2016, Pakistan Economic Survey. Finance Division, Govt. of Pakistan, Islamabad.

IPCC, 2014, Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. Core Writing Team, R.K. Pachauri, L.A. Meyer (eds.). IPCC, Geneva, Switzerland.

Khan F.K., 2015, Pakistan geography economy and people, 4th edition. Oxford University Press, Pakistan.

Martius O., Sodemann H., Joos H., Pfahl S., Winschall A., Croci-Maspoli M., et al., 2013, The role of upper level dynamics and surface processes for the Pakistan flood of July 2010. Q J R Meteorol Soc 139(676): 1780–1797.

Malik S., 2012, 'Case study: exploring demographic dimensions of flood vulnerability in rural Charsadda, Pakistan', Master thesis: appendix 4, available at: https://assets.publishing. service.gov.uk/media/57a08a65ed915d3cfd000746/Indus Floods Research Appendix 4. pdf

Modarres R. & Silva V.P.R., 2007, Rainfall trends in arid and semi-arid regions of Iran. J Arid Environ 70: 344–355.

Panthi J., Dahal P., Shrestha M.L., Aryal S., Krakauer N.Y., Pradhanang S.M., et al., 2015, Spatial and temporal variability of rainfall in the Gandaki river basin of Nepal Himalaya. Climate 3(1): 210–226.

Rahman G., Rahman A. & Samiullah D.M., 2018, Spatial and temporal variation of rainfall and drought in Khyber Pakhtunkhwa Province of Pakistan during 1971–2015. Arab J Geosci 11(3): 1–13.

Rahman A. & Dawood M., 2016, Spatio-statistical analysis of temperature fluctuation using Mann–Kendall and Sen's slope approach. Clim Dyn 48(3): 783–797.

Rahman A. & Khan A.N., 2011, Analysis of flood causes and associated socio-economic damages in the Hindukush region. Nat Hazards 59(3): 1239–1260.

Rahman A.U., Mahmood S., Dawood M., Rahman G. & Chen F., 2019, Impact of climate change on flood factors and extent of damages in the Hindu Kush Region, [in:] Oxford Research Encyclopedia of Natural Hazard Science. DOI:10.1093/acrefore/9780199389407.013.316

Rasul G., Mahmood A., Sadiq A. & Khan S.I., 2012, Vulnerability of the Indus Delta to climate change in Pakistan. Pakistan Journal of Meteorology 8(16): 89–107.

Ullah R., Shivakoti G.P. & Ali G., 2015, Factors effecting farmers' risk attitude and risk perceptions: the case of Khyber Pakhtunkhwa, Pakistan. International Journal of Disaster Risk Reduction 13: 151–157.

Xu H., Taylor R.G. & Xu Y., 2011, Quantifying uncertainty in the impacts of climate change on river discharge in sub-catchments of the Yangtze and Yellow river basins, China. Hydrol Earth Syst Sci 15(1): 333–344.