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Trend Detection in Hydro-Meteorological Variables Using Innovative Trend Analysis Technique: A Case Study of Kabul River Basin

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Abstract

Trend analysis is important for assessing the impacts of climate change on hydro-meteorological variables. This study investigated temporal trends in hydro-meteorological variables on monthly and seasonal scales in the Kabul River Basin for historical (1981–2022) and future climate projections under CMIP6 scenarios. The Innovative Trend Analysis (ITA) method was applied at confidence levels of 90% and 95% to identify trends. Results indicated a strong increasing trend in streamflow at Chitral (S_{ITA} = 3.214 cumecs/year) in June. While Nowshera has a strong decreasing trend (S_{ITA} = -13.448 cumecs/year) in the same month. Precipitation showed both increasing and decreasing trends at all stations, months, and seasons except at Peshawar. The maximum temperature showed an increasing trend at Peshawar and a decreasing trend at Drosh at monthly and seasonal timescales. The minimum temperature showed an increasing trend across most of the stations, while Drosh showed a decreasing trend in all months and seasons. The uniqueness of this study was to fill a significant research void by applying the Innovative Trend Analysis technique for trend detection of hydro-meteorological variables in the Kabul River Basin. The results of this study provide critical insights that can assist water resource policymakers in developing strategies to mitigate the adverse impacts of climate change in this transboundary basin.

Keywords: Trend Analysis; Hydro-meteorological variables; Kabul River Basin; Innovative Trend Analysis

1. Introduction

From 1880 to 2012, the average annual air temperature on the Earth's surface rose by 0.65–1.06 °C. This warming has been associated with hydroclimatic changes, including changes in storms, floods, droughts, and evapotranspiration in different regions (Khan et al., 2023). Climatic variability can substantially affect agroecosystems and their productivity (Muthoni, 2020). Understanding regional climate change therefore requires careful assessment of changes in precipitation and temperature (Nawaz et al., 2019). A decline in rainfall can contribute to water shortages and drought, with potential consequences for crop production and food security (Cengiz et al., 2020). Trend analysis is consequently important for understanding changes in hydro-meteorological variables and supporting climate adaptation and water-resources planning (Ahmed et al., 2017).

Trend detection in hydro-meteorological variables such as streamflow, precipitation, and temperature is commonly performed using statistical approaches. Parametric methods, such as linear regression, generally rely on assumptions concerning the distribution and variance of the data. Non-parametric methods, including the Mann–Kendall (MK), Spearman's rho (SR), and modified MK tests, have fewer distributional requirements but may still require consideration of serial independence and the nature of the trend (Mirabbasi et al., 2020). These considerations can affect trend detection in hydro-meteorological time series. Innovative Trend Analysis (ITA) provides a graphical approach for identifying increasing, decreasing, and non-monotonic patterns and can also quantify trend magnitude (Şen, 2012, 2017). The Kabul

River Basin (KRB) has complex mountainous terrain and strong spatial variability in rainfall, snowmelt, temperature, and streamflow. ITA is therefore useful for examining the magnitude and within-series structure of trends, while statistical significance should be interpreted separately from the direction and magnitude of the detected trend.

Miao et al. (2012) conducted an analysis of Yellow River's streamflow and found a consistent decreasing trends between 1956 and 2008. Yıldız et al. (2019) examined trends in natural streamflow within the Upper Euphrates River Basin in Turkey and reported a decline in annual natural flow. Sharma and Babel (2018) investigated the impacts of climate change on streamflow in the Mae Klong River Basin and reported seasonal changes in projected streamflow. Khalil et al. (2018) analysed seasonal and annual rainfall and streamflow trends in the Mae Klong River Basin, Thailand, and reported contrasting wet- and dry-season rainfall patterns. Khan et al. (2024) applied ITA, Mann–Kendall, and Sen's slope methods to hydro-meteorological variables and reservoir characteristics in northern Pakistan and reported broadly similar trend directions between ITA and Mann–Kendall analyses. Khan et al. (2023) analysed precipitation, mean temperature, and streamflow in the Kabul River Basin using Mann–Kendall and Sen's slope methods. They reported increasing streamflow trends at Chitral and Chakdara during winter and spring, and a non-significant decreasing trend at Nowshera. These previous findings provide a basis for comparison with the present ITA results.

The literature review indicates that relatively few studies have applied Innovative Trend Analysis (ITA) to hydro-meteorological variables in the Kabul River Basin. This study therefore analyses historical hydro-meteorological variables and future meteorological variables at monthly and seasonal timescales using ITA. The historical variables include streamflow, precipitation, maximum temperature, and minimum temperature, while future projections include precipitation, maximum temperature, and minimum temperature under SSP245 and SSP585. Future periods are divided into near future (2023–2048), mid-future (2049–2074), and far future (2075–2100). The study integrates historical observations with future climate projections to characterize the direction and magnitude of hydro-meteorological trends in the transboundary Kabul River Basin.

2. Study area

The Kabul River Basin is a transboundary river basin between Pakistan and Afghanistan, which spans from 65° - 75° E and 32.5° - 37.5° N (Fig. 1). The Kabul River originates from the Hindukush mountains and ends in Nowshera by joining the Indus River. Its total length is 700 km, with 560 km in Afghanistan and 140 km in Pakistan, which makes the drainage area about 92,279 km^2 (Taraky et al., 2021). The elevation of the basin ranges from 7701 meters in Konar Valley to 249 meters in Nowshera. The amount of precipitation varies across the entire basin, with more than 1600 mm of precipitation occurring in the north, mostly in solid form, which becomes a source of streamflow in summer due to melting of snow (Khan et al., 2023). The average annual temperature of the basin is 13 °C, which varies significantly across the entire basin (Mehmood et al., 2022).

3. Materials and Methods

3.1. Data

Monthly meteorological data (precipitation, maximum temperature, and minimum temperature) for nine stations were obtained from the Pakistan Meteorological Department (PMD), Regional Centre Peshawar, and the Afghanistan Meteorological Department (AMD), Regional Centre Kabul. Daily hydrological discharge data for four stations were provided by Water And Power Development Authority (WAPDA). Future meteorological data were derived from CMIP6 projections under SSP245 and SSP585 scenarios. The historical meteorological and hydrological station details are provided in Table 1, while the statistical properties of the historical precipitation and streamflow data are summarized in Table 2.

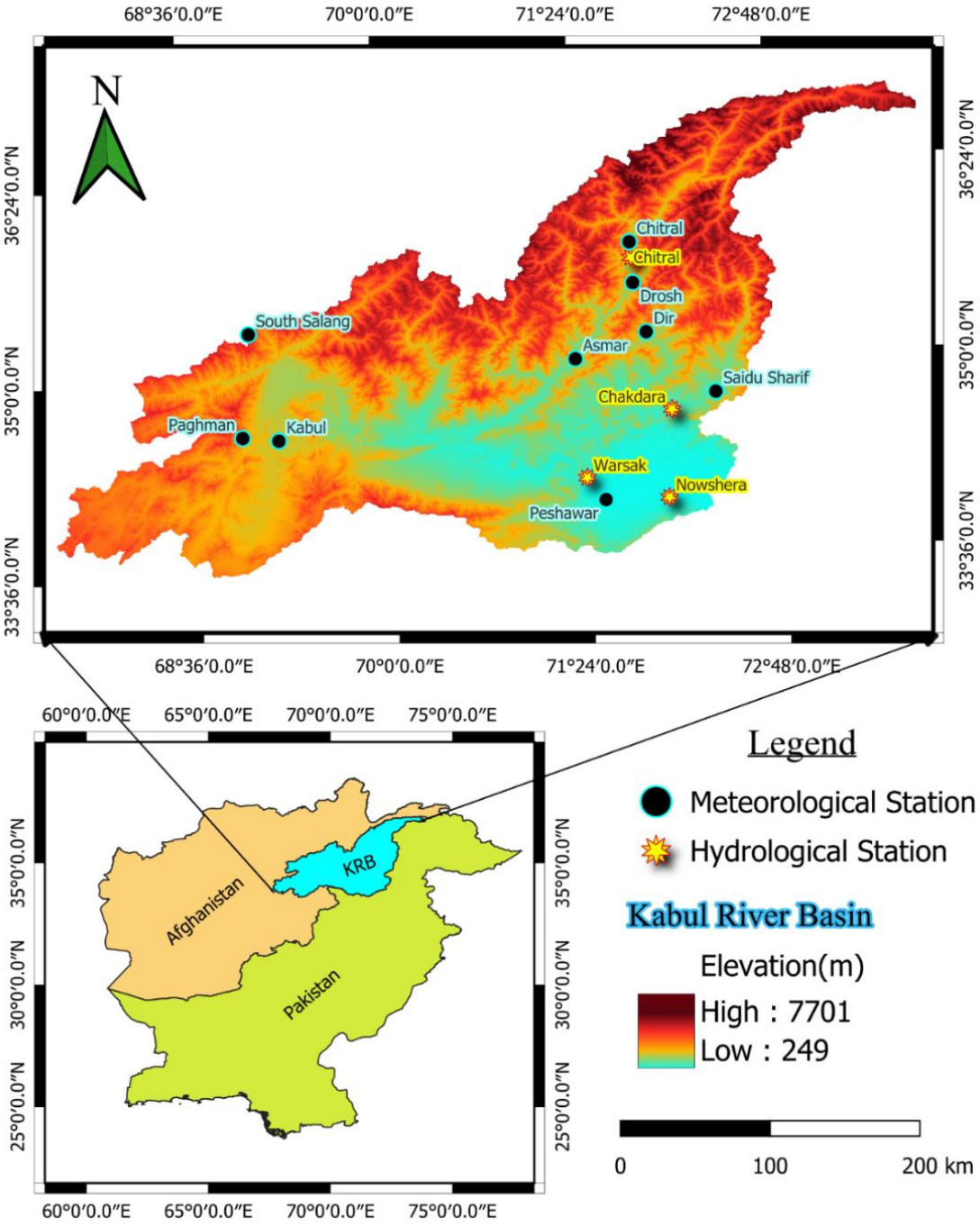

Fig. 1. Map of the Kabul River Basin showing hydrological and meteorological stations.

Table 1: Hydro-meteorological stations and their characteristics in the Kabul River Basin.

Meteorological Stations						
S. No	**Station**	**Latitude**	**Longitude**	**a***	**b**	**Precipitation Period**
1	Peshawar	34.01°	71.52°	1981-2022	1981-2022	1981-2022
2	Saidu Sharif	34.75°	72.35°	1981-2022	1981-2022	1981-2022
3	Dir	35.20°	71.87°	1981-2022	1981-2022	1981-2022
4	Chitral	35.85°	71.78°	1981-2022	1981-2022	1981-2022
5	Drosh	35.56°	71.79°	1981-2022	1981-2022	1981-2022
6	Kabul	34.56°	69.21°	1981-2022	1981-2022	1981-2022
7	Paghman	34.59°	68.95°	1981-2022	1981-2022	1981-2022
8	South Salang	35.33°	69.03°	1981-2022	1981-2022	1981-2022
9	Asmar	35.03°	71.36°	1981-2022	1981-2022	1981-2022
Hydrological Stations						
S. No	**Station**	**Name of river**	**Latitude**	**Longitude**	**Discharge Period**	
1	Chitral	Chitral	35.86°	71.79°	1981-2015	
2	Chakdara	Swat	34.64°	72.03°	1981-2009	
3	Warsak	Kabul	34.18°	71.40°	1981-2015	
4	Nowshera	Kabul	34.01°	71.98°	1981-2015	

Note: a = maximum-temperature period; b = minimum-temperature period.

Table 2: Statistical properties of historical precipitation and streamflow data in the Kabul River Basin.

a. Meteorological Stations							
Station	**Min. PPT (mm)**	**Max. PPT (mm)**	**Average PPT (mm)**	**Median PPT (mm)**	**Std. Dev (mm)**	**CV (%)**	**Skewness**
Asmar	0	460.50	92.93	74.60	75.82	81.60	1.34
Chitral	0	262.10	39.29	21.20	45.32	115.36	1.75
Dir	0	526.90	111.47	87.00	90.09	80.82	1.31
Drosh	0	391.58	45.15	26.40	49.38	109.37	2.18
Kabul	0	194.10	40.32	31.35	36.65	90.89	1.16
Paghman	0	163.20	40.82	33.45	33.75	82.67	1.03
Peshawar	0	485.09	49.90	32.36	56.50	113.23	2.68
Saidu	0	472.00	84.64	71.35	72.37	85.50	1.48
Salang	0.2	298.20	72.94	64.40	58.40	80.06	0.88
b. Hydrological Stations							
Station	**Min. Flow (cumecs)**	**Max. Flow (cumecs)**	**Ave. Flow (cumecs)**	**Median Flow (cumecs)**	**Std. Dev (cumecs)**	**CV (%)**	**Skewness**
Chakdara	26.15	723.76	192.55	142.11	151.10	78.48	0.91
Chitral	56.38	1250.61	283.46	138.10	274.55	96.86	1.28
Nowshera	114.30	3530.32	828.60	495.89	688.29	83.07	1.13
Warsak	114.71	2193.73	559.64	330.32	469.04	83.81	1.16

3.2. Innovative Trend Analysis

The Innovative Trend Analysis method, introduced by Şen (2012), is used to detect trends in hydro-meteorological time series. The data series is divided into two equal segments representing the first and second halves of the record. Each segment is independently sorted in ascending order. The sorted first-half values are plotted on the x-axis, while the sorted second-half values are plotted on the y-axis. Scatter points above the 1:1 (45°) line indicate an increasing trend, whereas points below the line indicate a decreasing trend. Points close to the 1:1 line indicate little or no trend over the corresponding magnitude range (Şen, 2012, 2017).

The ITA method also allows interpretation of low-, medium-, and high-magnitude data clusters. These clusters enable trend detection across different magnitude ranges within the time series. A cluster close to the 1:1 line indicates little or no trend for that value range, whereas clusters positioned above or below the line indicate increasing or decreasing behaviour, respectively (Khalil, 2023).

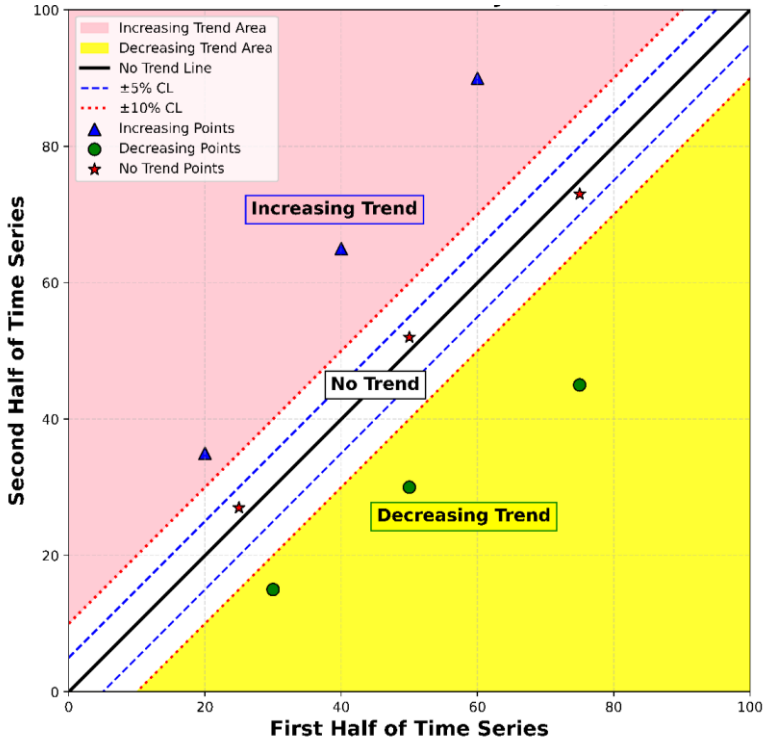

Fig. 2. Graphical representation of Innovative Trend Analysis (ITA).

The ITA trend slope (SITA) is calculated following Şen (2017) using the equation below.

$$S_{ITA} = \frac{2(\bar{x}_j - \bar{x}_i)}{n} \quad \textbf{(1)}$$

where $\bar{x}_j$ and $\bar{x}_i$ are the arithmetic means of the first and the second halves of the time series data, and n is the total number of data points in the time series.

The trend indicator (ϕ) is calculated following Khalil (2023).

$$\phi = \frac{1}{n}\sum_{i=1}^{n}\frac{10(x_j - x_i)}{\bar{x}_i} \quad \textbf{(2)}$$

where ϕ is the trend indicator, xi is the data series in the first halve, xj is the data series in the second halve, and the relevant mean is the mean of data series in the first halve. A positive value of ϕ indicates an increasing trend, whereas a negative value indicates a decreasing trend. Statistical significance was assessed at 90% and 95% confidence levels using the confidence limits applied in the ITA analysis. Trends were considered statistically significant when the plotted points fell outside the corresponding confidence limits. Thus, the direction and magnitude of an ITA trend should be distinguished from its statistical significance.

4. Results

Trend analysis of hydro-meteorological variables, including streamflow, precipitation, maximum temperature, and minimum temperature, was carried out at monthly and seasonal timescales. The four seasons were defined as winter (December–February), spring (March–May), summer (June–August), and autumn (September–November) (Khan et al., 2023). For ITA, each station's time series was divided into two approximately equal halves. Meteorological data were divided into 1981–2001 and 2002–2022. Hydrological observations were available through 2015; however, to obtain equal-length halves for the ITA calculation, the analysis for the main hydrological stations used 1981–1997 and 1998–2014. Chakdara was analysed using 1981–1994 and 1995–2008 because of its shorter record. A Python script was developed to implement the ITA calculations, including trend slope (SITA), trend indicator (ϕ), and the 90% and 95% confidence limits, and to generate monthly and seasonal plots and summary tables. The script is available from the corresponding author upon reasonable request.

4.1. Trend in historical data

4.1.1. Hydrological data (1981-2015)

On monthly and seasonal timescales, none of the hydrological stations showed a statistically significant trend at either the 90% or 95% confidence level. Nevertheless, the ITA plots indicated both increasing and decreasing patterns across different months and seasons (Table 3; Fig. 3).

Table 3: Innovative Trend Analysis of streamflow data at monthly and seasonal timescales in the Kabul River Basin.

Hydrological Streamflow Stations																
Month/	**Chitral**				**Warsak**				**Nowshera**				**Chakdara**			
Season	1*	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.20	0.22	1.69	2.01	-0.26	-0.13	5.50	6.56	-1.08	-0.34	12.32	14.67	1.0	1.7	9.44	11.25
February	0.24	0.30	1.49	1.78	0.85	0.44	6.89	8.21	1.92	0.59	27.70	33.00	1.5	1.9	12.47	14.85
March	0.26	0.33	1.53	1.82	2.24	0.82	21.40	25.50	-0.33	-0.06	64.27	76.57	1.6	0.9	19.79	23.57
April	0.70	0.66	5.36	6.38	0.90	0.14	60.04	71.54	-6.12	-0.52	102.14	121.70	1.0	0.3	21.45	25.56
May	2.20	0.99	15.63	18.62	-4.22	-0.35	75.62	90.10	-4.59	-0.26	109.23	130.15	1.6	0.3	22.94	27.34
June	3.21	0.59	28.53	34.00	-11.1	-0.68	95.66	113.98	-13.4	-0.59	143.31	170.75	2.6	0.4	35.27	42.02
July	1.24	0.13	44.28	52.75	-7.06	-0.44	105.57	125.79	-11.3	-0.50	169.85	202.37	0.7	0.1	35.75	42.59
August	-2.20	-0.24	27.44	32.69	-4.47	-0.39	62.93	74.98	-6.94	-0.41	124.15	147.92	0.2	0.0	24.21	28.84
September	-1.23	-0.26	17.68	21.07	0.90	0.18	20.86	24.86	-2.66	-0.35	47.33	56.39	1.0	0.5	15.67	18.67
October	0.10	0.05	7.50	8.93	1.54	0.59	10.79	12.86	-1.56	-0.40	23.27	27.73	1.3	1.1	11.87	14.14
November	0.39	0.30	3.42	4.08	1.12	0.53	6.83	8.14	-1.06	-0.35	14.68	17.49	1.1	1.5	8.71	10.38
December	0.43	0.40	2.58	3.08	0.62	0.30	6.35	7.57	-2.53	-0.84	14.92	17.78	0.8	1.2	8.49	10.12
Winter	0.21	0.21	1.61	1.92	0.39	0.18	4.85	5.78	-0.54	-0.16	15.95	19.01	0.8	1.0	8.86	10.55
Spring	1.23	0.86	7.04	8.39	0.33	0.05	44.27	52.75	-3.90	-0.32	86.44	102.99	1.6	0.4	20.49	24.42
Summer	0.59	0.07	25.90	30.86	-8.11	-0.52	79.28	94.47	-12.6	-0.57	126.73	151.00	0.7	0.1	28.88	34.41
Autumn	-0.49	-0.17	8.37	9.97	1.28	0.37	11.75	14.00	-2.10	-0.41	25.45	30.32	0.9	0.6	11.46	13.65

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

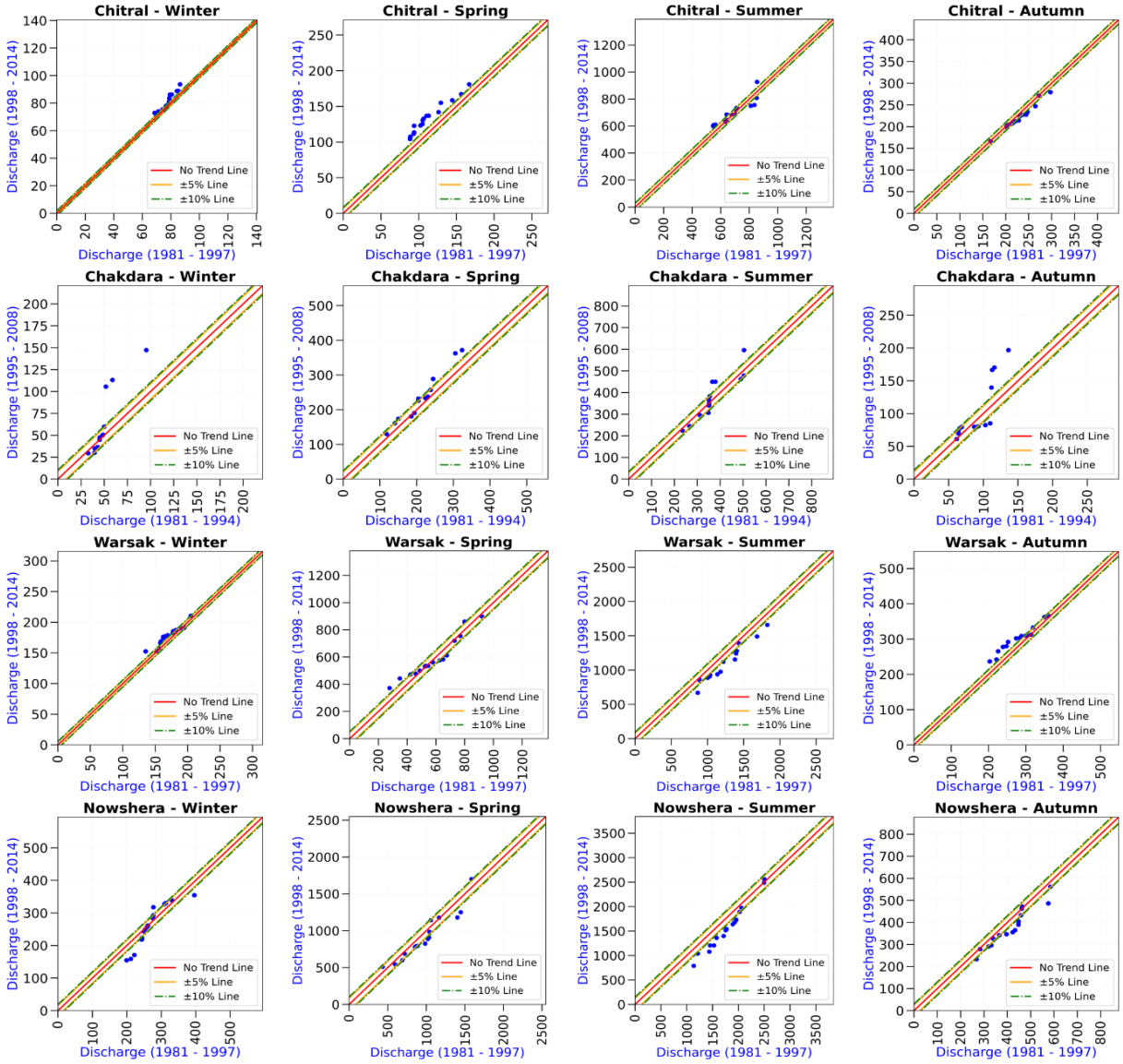

Fig. 3. Graphical results of Innovative Trend Analysis for streamflow stations at the seasonal scale in the Kabul River Basin.

4.1.2. Meteorological data (1981-2022)

On monthly and seasonal timescales, precipitation, maximum temperature, and minimum temperature did not show statistically significant trends at either the 90% or 95% confidence level. Precipitation nevertheless exhibited both increasing and decreasing patterns across stations and seasons (Table 4; Fig. 4). The maximum temperature showed increasing ITA patterns at Peshawar and decreasing patterns at Drosh at monthly and seasonal timescales (Table 5; Fig. 5).

At several stations, increasing and decreasing patterns varied by month and season. These directional patterns should not be interpreted as statistically significant because the corresponding confidence-level tests did not identify significant trends. The largest positive ITA slope for minimum temperature was observed at Chitral in January (S_{ITA} = 0.421 °C/year), while the largest negative slope was observed at Drosh in May (S_{ITA} = −0.420 °C/year). The minimum temperature showed both increasing and decreasing patterns among stations and months (Table 6; Fig. 6).

4.2. Future Data (2023–2100)

4.2.1. Meteorological Parameters for SSP245 Scenario

Tables and Figures 7-9 provide monthly results of ITA for SSP245 scenario. Results of near, mid and far future at Asmar station are presented as an example.

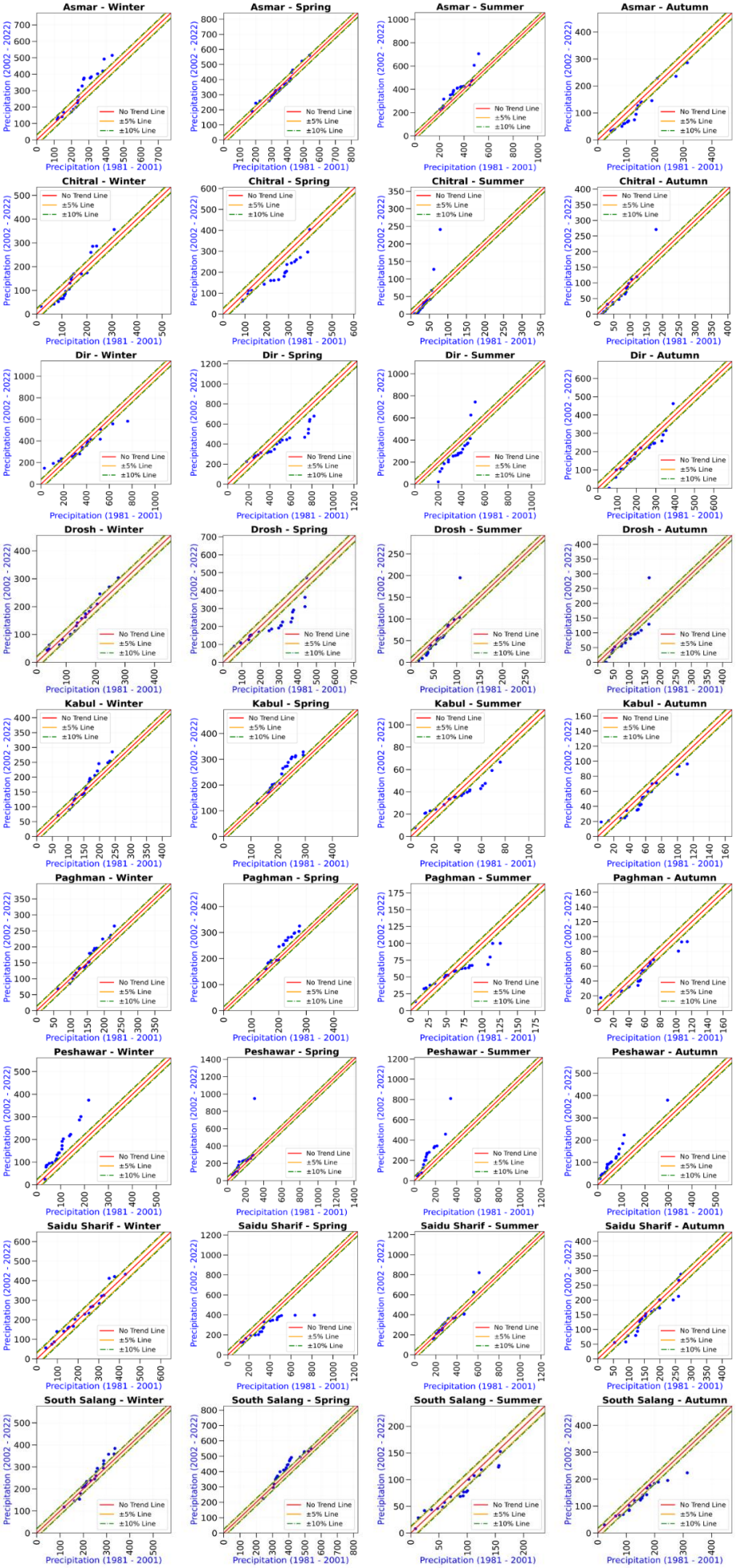

Fig. 4 Graphical results of Innovative Trend Analysis of historical precipitation stations at the seasonal scale in KRB.

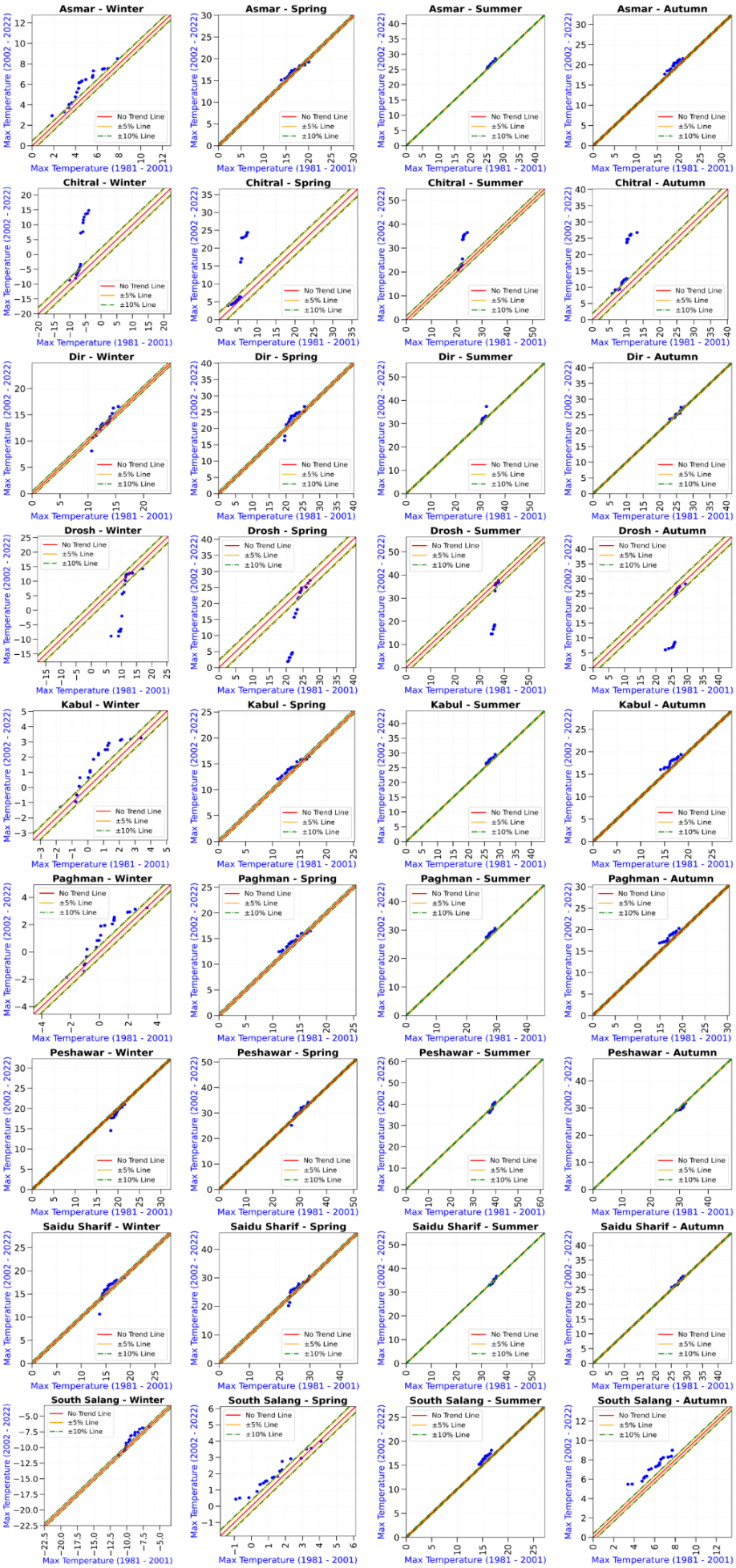

Fig. 5 Graphical results of Innovative Trend Analysis of historical maximum temperature stations at the seasonal scale in KRB.

Table 4: Innovative Trend Analysis of historical precipitation data at monthly and seasonal timescales in the Kabul River Basin.

Meteorological precipitation stations																
Month/	Chitral				Kabul				Peshawar				Saidu Sharif			
Season	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.153	0.380	9.249	11.02	0.088	0.172	7.106	8.466	0.466	1.384	9.121	10.868	0.273	0.475	15.711	18.720
February	0.485	0.842	10.563	12.586	0.049	0.076	7.778	9.267	2.625	6.030	15.369	18.312	1.062	1.026	18.754	22.345
March	-1.456	-1.214	15.979	19.039	0.629	0.773	9.295	11.075	0.182	0.212	16.484	19.640	-3.137	-1.853	22.544	26.861
April	-0.249	-0.338	9.798	11.674	0.861	1.321	8.833	10.525	1.965	4.540	14.298	17.036	-0.984	-0.856	18.228	21.719
May	-0.579	-1.29	7.262	8.652	0.316	0.603	6.885	8.203	1.298	6.056	13.746	16.378	-0.341	-0.559	10.792	12.858
June	-0.356	-2.497	3.673	4.376	-0.066	-0.314	3.262	3.887	1.962	14.135	18.647	22.217	0.986	2.248	12.197	14.532
July	0.104	1.111	4.568	5.442	0.151	1.915	2.652	3.160	2.807	7.239	16.077	19.156	-0.171	-0.125	22.007	26.221
August	0.374	4.533	5.863	6.986	-0.094	-1.127	2.494	2.972	0.764	1.104	14.382	17.136	0.043	0.038	16.453	19.603
September	-0.261	-1.632	5.137	6.121	-0.073	-0.782	2.113	2.518	1.232	5.351	7.782	9.273	-0.368	-0.506	9.907	11.804
October	0.067	0.321	9.705	11.564	-0.046	-0.273	3.714	4.425	0.290	1.247	9.855	11.742	-0.532	-1.097	11.482	13.681
November	0.123	0.431	7.957	9.48	-0.088	-0.339	4.365	5.201	0.631	5.346	5.670	6.755	0.242	0.777	8.273	9.858
December	-0.779	-2.006	8.056	9.599	0.487	1.443	6.745	8.036	0.155	0.831	6.051	7.210	-0.468	-0.998	12.222	14.562
Winter	-0.1	-0.07	20.53	24.461	0.609	0.381	13.299	15.846	3.071	3.080	19.719	23.495	0.473	0.214	28.013	33.378
Spring	-2.889	-1.161	24.402	29.075	1.497	0.701	14.319	17.061	3.107	1.940	36.898	43.964	-4.443	-1.229	37.829	45.073
Summer	0.167	0.502	10.616	12.649	-0.19	-0.477	4.384	5.223	5.794	4.536	37.323	44.470	0.662	0.210	35.735	42.577
Autumn	-0.254	-0.362	13.276	15.819	-0.315	-0.564	6.548	7.802	2.282	3.623	19.567	23.313	-0.728	-0.446	15.694	18.699
Month/	Asmar				Dir				Drosh				South Salang			
Season	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	-0.220	-0.268	12.589	15.000	0.707	0.805	20.538	24.471	0.252	0.680	9.905	11.801	-0.095	-0.127	8.721	10.391
February	1.037	0.935	16.746	19.952	-0.348	-0.199	25.791	30.730	0.789	1.370	11.235	13.387	0.356	0.374	10.013	11.930
March	-1.254	-0.705	19.703	23.476	-3.532	-1.465	30.770	36.662	-0.939	-0.822	17.359	20.683	0.886	0.625	13.279	15.822
April	1.598	1.588	16.926	20.167	-0.784	-0.504	17.882	21.306	0.213	0.243	15.832	18.864	1.281	1.050	12.261	14.608
May	0.512	1.059	6.479	7.720	-0.649	-0.685	12.383	14.754	-0.550	-0.923	9.211	10.975	0.073	0.071	13.339	15.893
June	0.410	1.053	5.696	6.787	0.291	0.514	9.231	10.999	-0.184	-0.912	4.525	5.392	-0.339	-0.600	8.529	10.162
July	1.224	0.797	21.818	25.996	-2.104	-1.396	20.553	24.489	-0.285	-1.373	4.985	5.940	0.428	2.607	5.906	7.036
August	1.285	0.926	15.789	18.812	-1.401	-1.018	16.565	19.737	0.118	0.730	4.619	5.503	-0.103	-1.213	3.539	4.217
September	-0.896	-1.719	7.193	8.570	-0.662	-0.889	12.627	15.045	-0.112	-0.567	4.727	5.632	-0.402	-1.344	6.461	7.699
October	0.101	0.336	9.263	11.037	-0.398	-0.590	19.007	22.646	-0.428	-1.305	10.527	12.543	-0.261	-0.464	9.473	11.287
November	-0.272	-0.678	9.132	10.881	0.181	0.304	16.502	19.661	0.172	0.603	7.548	8.993	-0.255	-0.474	8.211	9.783
December	0.932	2.134	12.552	14.955	-1.161	-1.609	17.139	20.421	-0.681	-1.791	8.976	10.695	0.562	1.032	8.716	10.385
Winter	1.823	0.715	27.294	32.520	-0.889	-0.255	38.448	45.810	0.209	0.150	18.073	21.534	0.666	0.279	16.914	20.153
Spring	-0.010	-0.003	23.559	28.071	-4.647	-0.913	45.531	54.250	-2.860	-1.047	28.295	33.714	1.692	0.431	21.630	25.771
Summer	2.668	0.763	27.181	32.386	-3.221	-0.887	34.624	41.254	-0.182	-0.313	9.184	10.943	-0.427	-0.495	10.669	12.712
Autumn	-1.295	-0.986	18.521	22.068	-1.124	-0.522	25.249	30.083	-0.589	-0.673	13.458	16.035	-1.048	-0.707	15.282	18.208

Month/	Paghman			
Season	1	2	±CL90	±CL95
January	0.050	0.098	6.791	8.092
February	-0.012	-0.021	7.143	8.511
March	0.486	0.672	8.229	9.805
April	0.837	1.465	8.355	9.955
May	0.312	0.502	7.968	9.494
June	-0.127	-0.377	5.425	6.464
July	0.203	1.601	3.609	4.301
August	-0.177	-1.165	4.206	5.012
September	-0.126	-1.008	2.724	3.245
October	-0.063	-0.364	3.750	4.469
November	-0.085	-0.361	4.059	4.836
December	0.408	1.255	6.460	7.697
Winter	0.441	0.290	12.374	14.743
Spring	1.342	0.652	13.627	16.236
Summer	-0.373	-0.569	7.258	8.648
Autumn	-0.367	-0.645	6.534	7.785

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

Table 5: Innovative Trend Analysis of historical maximum-temperature data at monthly and seasonal timescales in the Kabul River Basin.

Meteorological maximum temperature stations																
Month/	Chitral				Kabul				Peshawar				Saidu Sharif			
Season	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.421	-5.423	1.974	2.352	0.060	-5.637	0.492	0.586	-0.036	-0.205	0.359	0.427	0.028	0.212	0.443	0.528
February	0.362	-6.956	1.947	2.320	0.009	5.396	0.482	0.575	-0.033	-0.175	0.716	0.853	0.013	0.088	0.751	0.895
March	0.418	-41.744	1.943	2.314	0.093	1.710	0.632	0.753	0.079	0.353	0.592	0.706	0.116	0.618	0.679	0.809
April	0.358	7.962	2.010	2.395	-0.005	-0.039	0.554	0.660	0.024	0.082	0.577	0.687	0.014	0.056	0.883	1.052
May	0.214	1.823	1.707	2.034	-0.025	-0.121	0.514	0.613	-0.015	-0.043	0.856	1.020	-0.058	-0.186	0.959	1.143
June	0.283	1.499	1.526	1.819	0.041	0.168	0.337	0.402	-0.025	-0.065	0.336	0.400	-0.061	-0.175	0.535	0.638
July	0.219	0.975	1.196	1.425	0.030	0.113	0.234	0.278	-0.016	-0.043	0.498	0.594	0.010	0.030	0.364	0.433
August	0.251	1.161	1.203	1.434	0.044	0.172	0.209	0.248	-0.022	-0.065	0.473	0.564	0.014	0.044	0.362	0.431
September	0.286	1.601	1.339	1.595	0.081	0.372	0.357	0.425	-0.021	-0.063	0.263	0.313	-0.009	-0.029	0.496	0.591
October	0.362	4.225	1.740	2.073	0.069	0.447	0.385	0.458	-0.012	-0.042	0.314	0.374	0.015	0.058	0.557	0.663
November	0.305	90.594	1.898	2.262	0.008	0.077	0.532	0.634	-0.051	-0.205	0.328	0.390	-0.030	-0.140	0.563	0.671
December	0.391	-6.811	1.987	2.368	0.055	1.968	0.598	0.712	-0.019	-0.098	0.328	0.391	0.006	0.041	0.551	0.656
Winter	0.389	-5.874	1.907	2.272	0.044	7.108	0.376	0.448	-0.036	-0.180	0.330	0.394	0.030	0.191	0.387	0.461
Spring	0.330	6.329	1.791	2.135	0.029	0.208	0.380	0.453	0.031	0.102	0.511	0.609	0.025	0.095	0.617	0.735
Summer	0.277	1.256	1.337	1.593	0.042	0.156	0.214	0.255	-0.011	-0.030	0.268	0.320	0.003	0.010	0.200	0.239
Autumn	0.352	3.797	1.671	1.991	0.060	0.363	0.308	0.367	-0.032	-0.103	0.222	0.264	0.015	0.054	0.295	0.351
Month/	Asmar				Dir				Drosh				South Salang			
Season	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.072	2.586	0.589	0.702	0.028	0.248	0.504	0.600	-0.278	-3.085	1.837	2.189	0.049	-0.485	0.427	0.509
February	0.003	0.076	0.491	0.585	0.017	0.141	0.869	1.036	-0.326	-2.823	2.203	2.625	0.007	-0.082	0.413	0.492
March	0.079	0.822	0.612	0.729	0.114	0.752	0.675	0.804	-0.227	-1.506	1.928	2.297	0.086	-1.726	0.471	0.561
April	-0.008	-0.050	0.534	0.636	0.049	0.227	0.826	0.985	-0.358	-1.579	2.114	2.518	-0.002	-0.146	0.454	0.541
May	-0.044	-0.194	0.526	0.627	-0.037	-0.136	1.036	1.234	-0.420	-1.468	2.148	2.560	-0.014	-0.186	0.508	0.605
June	0.024	0.094	0.315	0.376	-0.012	-0.038	0.546	0.650	-0.342	-1.006	2.121	2.528	0.052	0.420	0.321	0.383
July	0.017	0.068	0.229	0.273	0.055	0.182	0.418	0.498	-0.317	-0.899	1.851	2.205	0.041	0.258	0.236	0.281
August	0.029	0.123	0.178	0.212	0.062	0.211	0.451	0.538	-0.215	-0.650	2.048	2.440	0.053	0.336	0.239	0.285
September	0.069	0.309	0.301	0.358	0.025	0.089	0.451	0.538	-0.224	-0.744	2.148	2.560	0.092	0.755	0.411	0.490
October	0.065	0.358	0.397	0.474	-0.007	-0.030	0.680	0.810	-0.234	-0.971	2.081	2.479	0.074	1.384	0.424	0.506
November	0.016	0.116	0.527	0.627	-0.085	-0.437	0.862	1.027	-0.294	-1.660	1.868	2.225	0.001	-0.204	0.600	0.714
December	0.069	0.987	0.656	0.782	-0.038	-0.273	0.907	1.080	-0.243	-2.170	1.794	2.138	0.034	-0.475	0.560	0.667
Winter	0.052	1.106	0.419	0.500	0.015	0.111	0.444	0.530	-0.314	-2.822	1.864	2.221	0.033	-0.360	0.327	0.389
Spring	0.015	0.090	0.382	0.455	0.046	0.209	0.565	0.673	-0.373	-1.603	2.040	2.430	0.029	2.092	0.315	0.375
Summer	0.026	0.101	0.180	0.215	0.055	0.174	0.293	0.349	-0.349	-0.960	1.964	2.340	0.052	0.335	0.223	0.266
Autumn	0.056	0.297	0.310	0.369	0.006	0.025	0.283	0.338	-0.337	-1.281	1.912	2.279	0.063	1.064	0.333	0.396

Month/	Paghman			
Season	1	2	±CL90	±CL95
January	0.060	-4.158	0.535	0.638
February	0.006	-12.134	0.482	0.575
March	0.095	1.821	0.625	0.744
April	-0.003	-0.023	0.568	0.676
May	-0.020	-0.095	0.499	0.594
June	0.047	0.189	0.347	0.414
July	0.034	0.124	0.239	0.284
August	0.049	0.181	0.222	0.264
September	0.086	0.378	0.379	0.452
October	0.071	0.434	0.387	0.461
November	0.005	0.046	0.556	0.663
December	0.050	1.949	0.642	0.765
Winter	0.042	12.600	0.398	0.474
Spring	0.032	0.227	0.376	0.448
Summer	0.047	0.168	0.225	0.268
Autumn	0.061	0.355	0.316	0.376

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

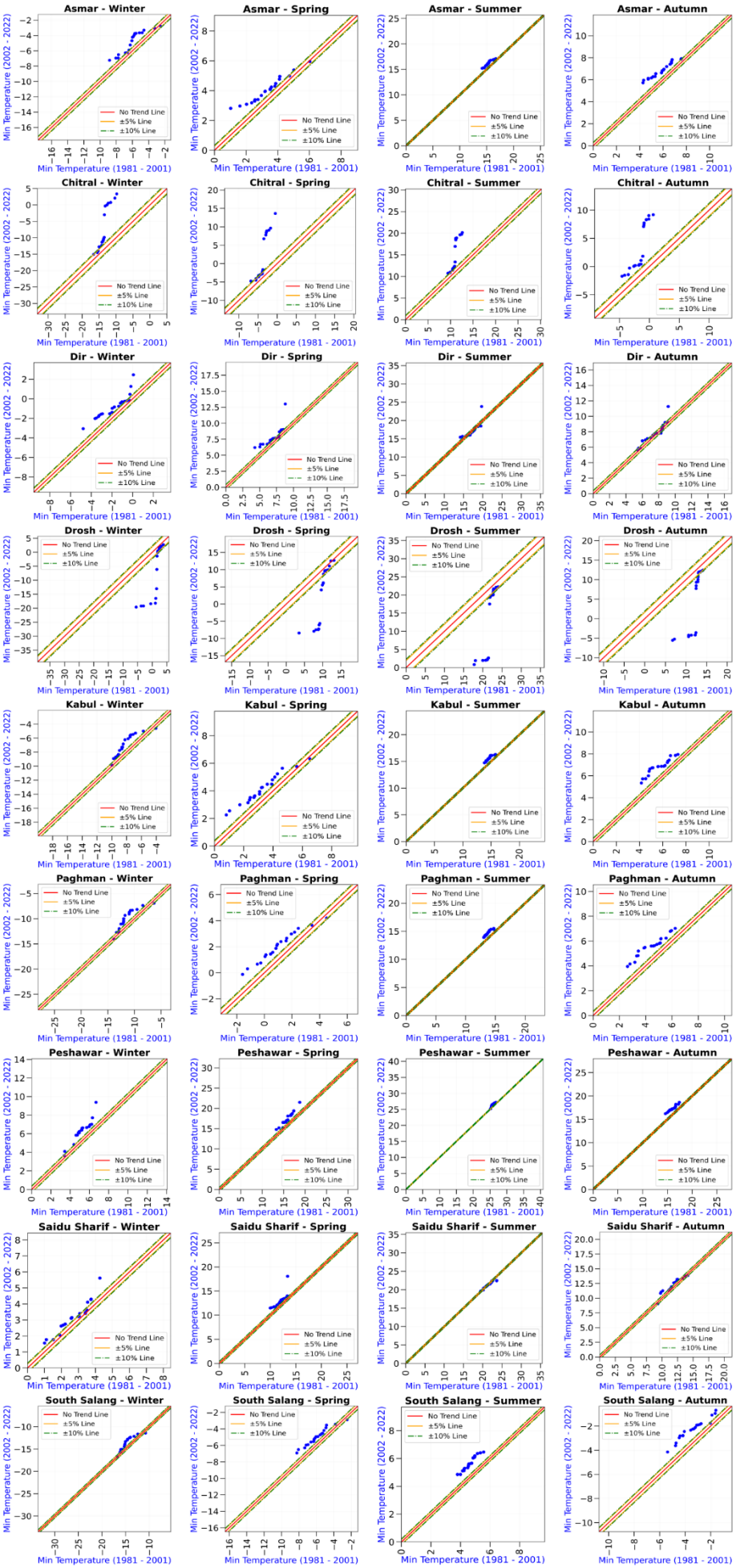

Fig. 6 Graphical results of Innovative Trend Analysis of historical minimum temperature stations at the seasonal scale in KRB.

Table 6: Innovative Trend Analysis of historical minimum-temperature data at monthly and seasonal timescales in the Kabul River Basin.

Meteorological minimum temperature stations																
Month/ Season	Chitral				Kabul				Peshawar				Saidu Sharif			
	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.353	-2.487	1.533	1.826	0.075	-0.791	0.536	0.638	0.031	0.795	0.314	0.374	0.006	0.346	0.252	0.300
February	0.309	-2.641	1.606	1.914	0.023	-0.300	0.512	0.610	0.067	1.093	0.591	0.705	0.055	1.547	0.511	0.608
March	0.337	-3.981	1.481	1.765	0.112	-3.411	0.572	0.682	0.069	0.658	0.388	0.463	0.056	0.790	0.365	0.435
April	0.266	-6.938	1.389	1.655	0.014	0.391	0.461	0.549	0.062	0.409	0.430	0.513	0.046	0.408	0.312	0.372
May	0.203	10.545	1.424	1.697	-0.006	-0.062	0.408	0.486	0.093	0.466	0.783	0.933	0.035	0.226	0.758	0.903
June	0.206	2.704	1.026	1.223	0.050	0.392	0.250	0.298	0.051	0.211	0.276	0.328	-0.015	-0.079	0.416	0.496
July	0.163	1.358	0.796	0.949	0.043	0.291	0.189	0.225	0.029	0.117	0.165	0.197	-0.016	-0.074	0.288	0.343
August	0.141	1.227	0.639	0.761	0.047	0.330	0.193	0.230	0.010	0.039	0.173	0.206	-0.023	-0.111	0.281	0.335
September	0.163	2.248	0.688	0.819	0.077	0.736	0.301	0.359	0.021	0.097	0.287	0.342	-0.008	-0.047	0.480	0.572
October	0.283	-9.506	1.164	1.387	0.071	1.400	0.334	0.398	0.083	0.553	0.334	0.398	0.017	0.160	0.541	0.645
November	0.228	-2.540	1.308	1.559	0.006	0.749	0.413	0.492	0.080	0.883	0.314	0.374	0.001	0.019	0.407	0.485
December	0.298	-2.407	1.386	1.651	0.060	-1.032	0.608	0.724	0.062	1.277	0.315	0.375	-0.011	-0.408	0.342	0.407
Winter	0.323	-2.394	1.462	1.742	0.058	-0.709	0.408	0.487	0.057	1.099	0.304	0.362	0.022	0.818	0.247	0.295
Spring	0.274	-7.363	1.371	1.633	0.044	1.341	0.337	0.402	0.079	0.494	0.427	0.508	0.051	0.433	0.339	0.404
Summer	0.185	1.697	0.827	0.986	0.047	0.319	0.169	0.201	0.032	0.122	0.137	0.163	-0.008	-0.039	0.239	0.285
Autumn	0.247	-14.539	1.027	1.224	0.057	0.998	0.258	0.307	0.063	0.395	0.234	0.279	0.020	0.174	0.332	0.396
Month/ Season	Asmar				Dir				Drosh				South Salang			
	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.084	-1.168	0.553	0.659	0.037	-1.345	0.396	0.472	-0.336	235.185	2.006	2.390	0.064	-0.425	0.495	0.589
February	0.010	-0.197	0.515	0.613	0.069	-6.337	0.633	0.754	-0.319	-20.744	2.094	2.495	0.018	-0.127	0.476	0.568
March	0.080	-4.664	0.456	0.543	0.049	1.927	0.388	0.463	-0.274	-6.253	1.804	2.150	0.116	-1.078	0.567	0.676
April	0.025	0.800	0.372	0.444	0.035	0.527	0.364	0.433	-0.303	-3.117	1.595	1.901	0.007	-0.150	0.447	0.532
May	-0.002	-0.027	0.348	0.415	0.026	0.242	0.832	0.991	-0.324	-2.221	1.874	2.233	0.003	-0.287	0.419	0.499
June	0.042	0.327	0.260	0.310	0.022	0.151	0.648	0.772	-0.322	-1.684	1.849	2.203	0.057	2.035	0.256	0.305
July	0.038	0.244	0.203	0.242	-0.039	-0.216	0.455	0.542	-0.361	-1.666	1.912	2.279	0.051	0.981	0.240	0.286
August	0.043	0.284	0.199	0.237	-0.010	-0.060	0.516	0.615	-0.343	-1.680	1.935	2.306	0.047	0.938	0.206	0.246
September	0.067	0.588	0.272	0.324	0.002	0.015	0.643	0.766	-0.316	-1.901	1.843	2.196	0.075	4.309	0.303	0.361
October	0.062	1.161	0.365	0.435	-0.004	-0.059	0.464	0.553	-0.261	-2.506	1.518	1.809	0.076	-2.055	0.429	0.511
November	0.012	-24.052	0.390	0.465	-0.011	-0.552	0.449	0.535	-0.291	-4.958	1.493	1.779	0.001	-0.016	0.483	0.575
December	0.063	-1.348	0.482	0.574	0.006	-0.469	0.529	0.630	-0.317	-15.146	1.728	2.058	0.053	-0.410	0.609	0.726
Winter	0.059	-0.987	0.408	0.487	0.054	-2.842	0.364	0.433	-0.346	-29.467	1.949	2.322	0.050	-0.340	0.388	0.463
Spring	0.036	1.083	0.278	0.331	0.046	0.657	0.365	0.435	-0.328	-3.285	1.762	2.099	0.046	-0.781	0.334	0.398
Summer	0.043	0.284	0.188	0.224	0.002	0.009	0.403	0.480	-0.386	-1.779	1.939	2.310	0.050	1.091	0.179	0.213
Autumn	0.049	0.840	0.250	0.297	0.014	0.182	0.323	0.385	-0.337	-2.798	1.645	1.960	0.057	-1.653	0.291	0.347
Month/ Season	Paghman															
	1	2	±CL90	±CL95												
January	0.086	-0.672	0.677	0.807												
February	0.019	-0.175	0.638	0.761												
March	0.128	-2.223	0.658	0.783												
April	0.013	0.911	0.480	0.572												
May	-0.005	-0.062	0.398	0.475												
June	0.049	0.451	0.235	0.280												
July	0.047	0.327	0.205	0.244												
August	0.049	0.346	0.204	0.243												
September	0.078	0.794	0.307	0.366												
October	0.072	1.783	0.358	0.426												
November	-0.002	0.234	0.551	0.656												
December	0.068	-0.737	0.781	0.930												
Winter	0.064	-0.557	0.516	0.614												
Spring	0.050	5.106	0.360	0.429												
Summer	0.048	0.350	0.171	0.203												
Autumn	0.056	1.263	0.289	0.344												

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

Precipitation showed predominantly increasing ITA patterns across many station–month combinations. In the near future (2023–2048), the largest positive slope was observed at Dir in February (S_{ITA} = 6.86 mm/year), while the largest negative slope was observed at Dir in March (SITA = −10.50 mm/year). In the mid-future (2049–2074), the largest positive slope was observed at Dir in July (S_{ITA} = 7.93 mm/year), while the largest negative slope was observed at Drosh in April (S_{ITA} = −6.22 mm/year). In the far future (2075–2100), the largest positive slope was observed at Drosh in January (S_{ITA} = 4.46 mm/year), while the largest negative slope was observed at Dir in November (S_{ITA} = −4.52 mm/year). These results are illustrated in Figures 7–9; Asmar station examples are provided in Table 7.

Maximum temperature generally showed increasing ITA patterns across many station–month combinations. The largest positive slope was observed at Paghman and South Salang in December (S_{ITA} = 0.14 °C/year), while the largest negative slope was observed at Kabul in May (S_{ITA} = −0.08 °C/year). Results for the SSP245 scenario are shown in Figures 7–9 and Table 8 provides the Asmar station example.

Minimum temperature also showed increasing ITA patterns across many station–month combinations. In the near future, the largest positive slope was observed at Paghman in December (S_{ITA} = 0.17 °C/year), while the largest negative slope was observed at Paghman in November (S_{ITA} = −0.10 °C/year). In the mid-future, the largest positive slope was observed at Peshawar in October (S_{ITA} = 0.14 °C/year), while the largest negative slope was observed at South Salang in January ($_{SITA}$ = −0.03 °C/year). In the far future, the largest positive slope was observed at Paghman in February (S_{ITA} = 0.12 °C/year), while the largest negative slope was observed at South Salang in October (S_{ITA} = −0.08 °C/year). Results are shown in Figures 7–9 and Table 9 provides the Asmar station example.

4.2.2. Meteorological Parameters for SSP585 Scenario

Precipitation generally showed increasing ITA patterns across many station–month combinations, although the far-future period showed more mixed behaviour. In the near future, the largest positive slope was observed at Saidu Sharif in May (SITA = 8.46 mm/year), while the largest negative

slope was observed at Drosh in April (S_{ITA} = −3.58 mm/year). In the mid-future, the largest positive slope was observed at Dir in August (S_{ITA} = 6.99 mm/year), while the largest negative slope was observed at Saidu Sharif in September (S_{ITA} = −18.06 mm/year). In the far future, the largest positive slope was observed at Saidu Sharif in June (S_{ITA} = 4.24 mm/year), while the largest negative slope was observed at Peshawar in August (S_{ITA} = −6.56 mm/year). Results are shown in Figures 10–12 and Table 10 provides the Asmar station example.

Maximum temperature generally showed increasing ITA patterns across many station–month combinations. In the near future, the largest positive slope was observed at South Salang in May (S_{ITA} = 0.14 °C/year), while the largest negative slope was observed at Saidu Sharif in March (S_{ITA} = −0.06 °C/year). In the mid-future, the largest positive slope was observed at Asmar and Dir in December (S_{ITA} = 0.16 °C/year), while the largest negative slope was observed at Drosh and Peshawar in May (S_{ITA} = −0.05 °C/year). In the far future, the largest positive slope was observed at Peshawar in March (S_{ITA} = 0.15 °C/year), while the largest negative slope was observed at Kabul in May (S_{ITA} = −0.08 °C/year). Results are shown in Figures 10–12 and Table 11 provides the Asmar station example.

Minimum temperature also showed increasing ITA patterns across many station–month combinations. In the near future, the largest positive slope was observed at Paghman in December (S_{ITA} = 0.17 °C/year), while the largest negative slope was observed at Paghman in November (S_{ITA} = −0.10 °C/year). In the mid-future, the largest positive slope was observed at Peshawar in October (S_{ITA} = 0.14 °C/year), while the largest negative slope was observed at South Salang in January (S_{ITA} = −0.03 °C/year).

Table 7: Innovative Trend Analysis of future SSP245 precipitation data for Asmar station at monthly timescale.

Asmar Precipitation SSP245												
Month/	**Near Future (2023-2048)**				**Mid Future (2049-2074)**				**Far Future (2075-2100)**			
Season	1*	2*	±CL9	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.38	0.28	21.69	25.84	1.16	1.13	19.18	22.86	1.24	1.11	18.07	21.53
Februar	3.40	2.19	19.22	22.90	2.66	1.37	26.28	31.31	-1.52	-0.66	21.44	25.55
March	-4.08	-1.16	29.77	35.47	-0.98	-0.33	24.64	29.35	1.22	0.48	24.37	29.04
April	1.73	0.96	23.61	28.13	-1.23	-0.62	21.26	25.33	-1.23	-0.59	19.70	23.48
May	-0.14	-0.16	7.00	8.34	1.74	2.88	8.60	10.24	1.60	2.69	7.59	9.04
June	-0.20	-0.25	7.75	9.24	-0.31	-0.38	6.49	7.74	-0.07	-0.10	7.47	8.90
July	2.69	1.01	19.02	22.66	0.59	0.21	20.95	24.97	-0.02	-0.01	31.27	37.26
August	-0.73	-0.29	22.18	26.43	-0.74	-0.29	21.17	25.22	0.05	0.02	16.91	20.15
Septem	-0.29	-0.61	5.48	6.54	-0.56	-1.03	6.59	7.85	0.22	0.48	5.91	7.04
October	0.64	1.42	8.37	9.97	0.69	1.81	8.40	10.01	-0.19	-0.68	5.25	6.25
Novemb	0.83	1.51	9.12	10.87	0.63	0.99	11.54	13.75	-1.68	-2.10	13.23	15.76
Decemb	-1.63	-1.33	19.14	22.81	-1.10	-0.93	15.49	18.46	0.63	0.65	18.92	22.54

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

Table 8: Innovative Trend Analysis of future SSP245 maximum-temperature data for Asmar station at monthly timescale.

Asmar maximum temperature SSP245												
Month/	**Near Future (2023-2048)**				**Mid Future (2049-2074)**				**Far Future (2075-2100)**			
Season	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	-0.09	-0.98	0.89	1.06	-0.01	-0.08	0.78	0.93	0.09	1.00	0.89	1.06
February	-0.06	-0.65	0.63	0.75	-0.04	-0.35	0.85	1.01	0.13	1.29	0.76	0.91
March	0.04	0.25	0.74	0.88	0.08	0.39	0.70	0.84	0.12	0.58	0.93	1.11
April	0.09	0.34	0.59	0.70	0.02	0.06	0.70	0.84	0.02	0.08	0.59	0.70
May	0.05	0.14	0.65	0.77	-0.11	-0.25	0.61	0.73	-0.07	-0.16	0.55	0.66
June	0.06	0.15	0.35	0.42	0.02	0.05	0.35	0.42	-0.01	-0.03	0.39	0.47
July	0.00	-0.01	0.21	0.24	0.02	0.05	0.23	0.27	0.03	0.06	0.38	0.46
August	0.01	0.03	0.19	0.23	0.02	0.06	0.19	0.22	0.00	0.00	0.20	0.24
September	0.01	0.04	0.25	0.29	0.02	0.05	0.19	0.22	-0.02	-0.06	0.20	0.24
October	0.02	0.06	0.35	0.42	-0.02	-0.05	0.32	0.38	0.00	0.00	0.23	0.27
November	-0.04	-0.17	0.46	0.54	0.00	0.01	0.55	0.65	0.08	0.30	0.63	0.76
December	0.11	0.75	0.94	1.12	0.04	0.26	0.68	0.81	0.08	0.47	0.88	1.05

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

Table 9: Innovative Trend Analysis of future SSP245 minimum-temperature data for Asmar station at monthly timescale.

Asmar minimum temperature SSP245												
Month/	**Near Future (2023-2048)**				**Mid Future (2049-2074)**				**Far Future (2075-2100)**			
Season	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.00	0.04	0.67	0.80	0.00	0.03	0.56	0.67	0.00	0.02	0.60	0.72
February	0.00	-0.08	0.59	0.70	0.05	-0.87	0.59	0.70	0.07	-1.43	0.55	0.65
March	0.06	-9.53	0.54	0.65	0.06	15.36	0.44	0.52	0.04	2.37	0.60	0.71
April	0.09	1.55	0.43	0.52	0.06	0.74	0.44	0.53	0.02	0.21	0.42	0.50
May	0.03	0.22	0.37	0.44	-0.01	-0.06	0.37	0.44	-0.03	-0.16	0.34	0.40
June	0.04	0.19	0.26	0.31	0.02	0.08	0.27	0.32	0.00	0.00	0.26	0.31
July	0.02	0.07	0.17	0.20	0.01	0.04	0.16	0.19	0.03	0.09	0.21	0.25
August	0.00	0.01	0.21	0.25	0.02	0.09	0.17	0.20	0.01	0.05	0.14	0.17
September	0.03	0.14	0.21	0.25	0.02	0.09	0.18	0.21	-0.02	-0.06	0.13	0.16
October	0.04	0.31	0.45	0.53	0.10	0.81	0.46	0.55	-0.03	-0.19	0.40	0.48
November	-0.06	-2.17	0.40	0.48	0.06	2.67	0.50	0.60	0.00	-0.03	0.40	0.48
December	0.09	-2.03	0.49	0.59	0.05	-1.44	0.53	0.63	0.00	0.08	0.46	0.54

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

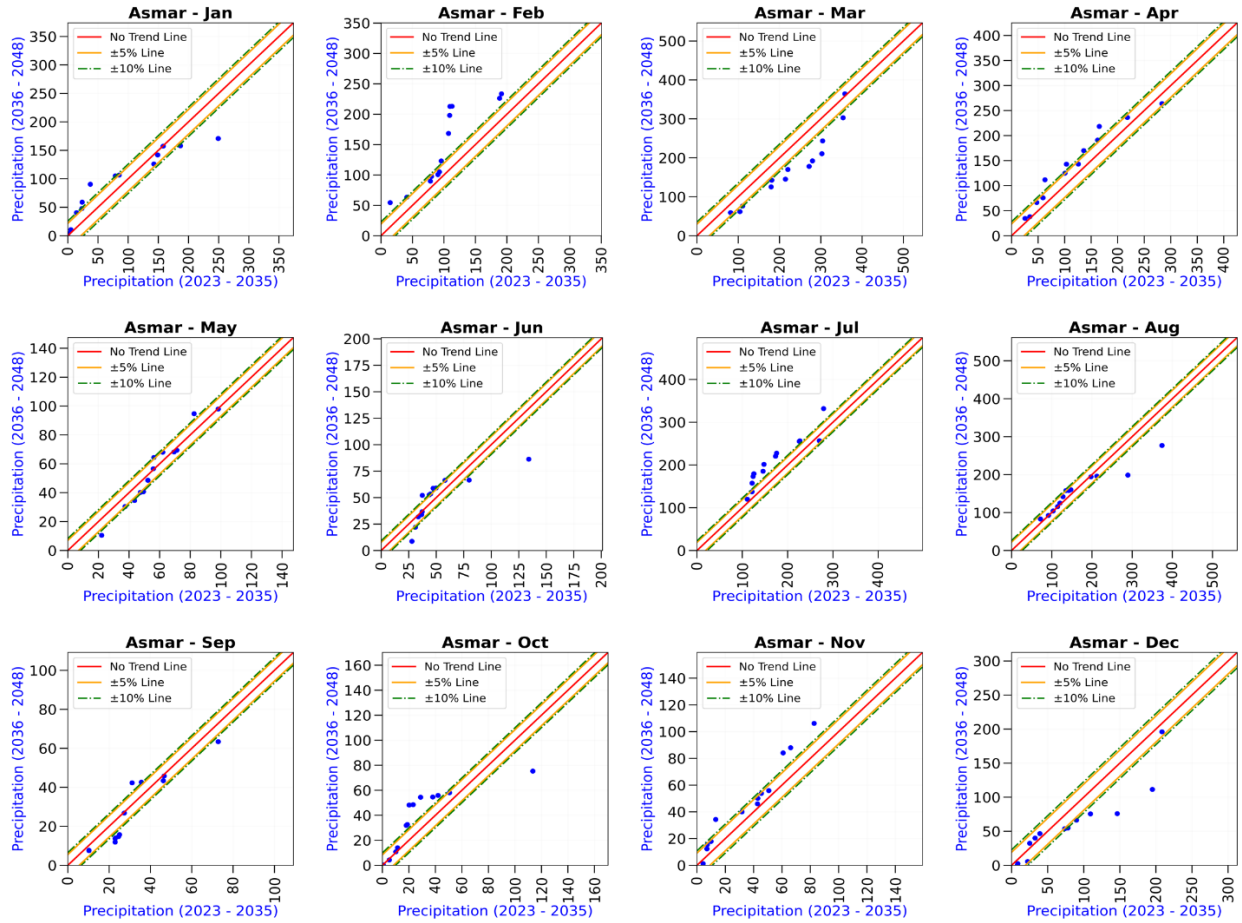

Fig. 7a. Results of ITA for near-future SSP245 precipitation at monthly timescale.

In the far future, the largest positive slope was observed at Peshawar in May (S_{ITA} = 0.25 °C/year), while no decreasing trend was observed at any station. Results are shown in Figures 10–12 and Table 12 provides the Asmar station example.

None of the future trends in precipitation, maximum temperature, or minimum temperature were statistically significant at the 90% or 95% confidence level for either SSP245 or SSP585 across the near-, mid-, and far-future periods. Therefore, the reported positive and negative slopes describe the direction and magnitude of ITA patterns rather than statistically significant long-term changes.

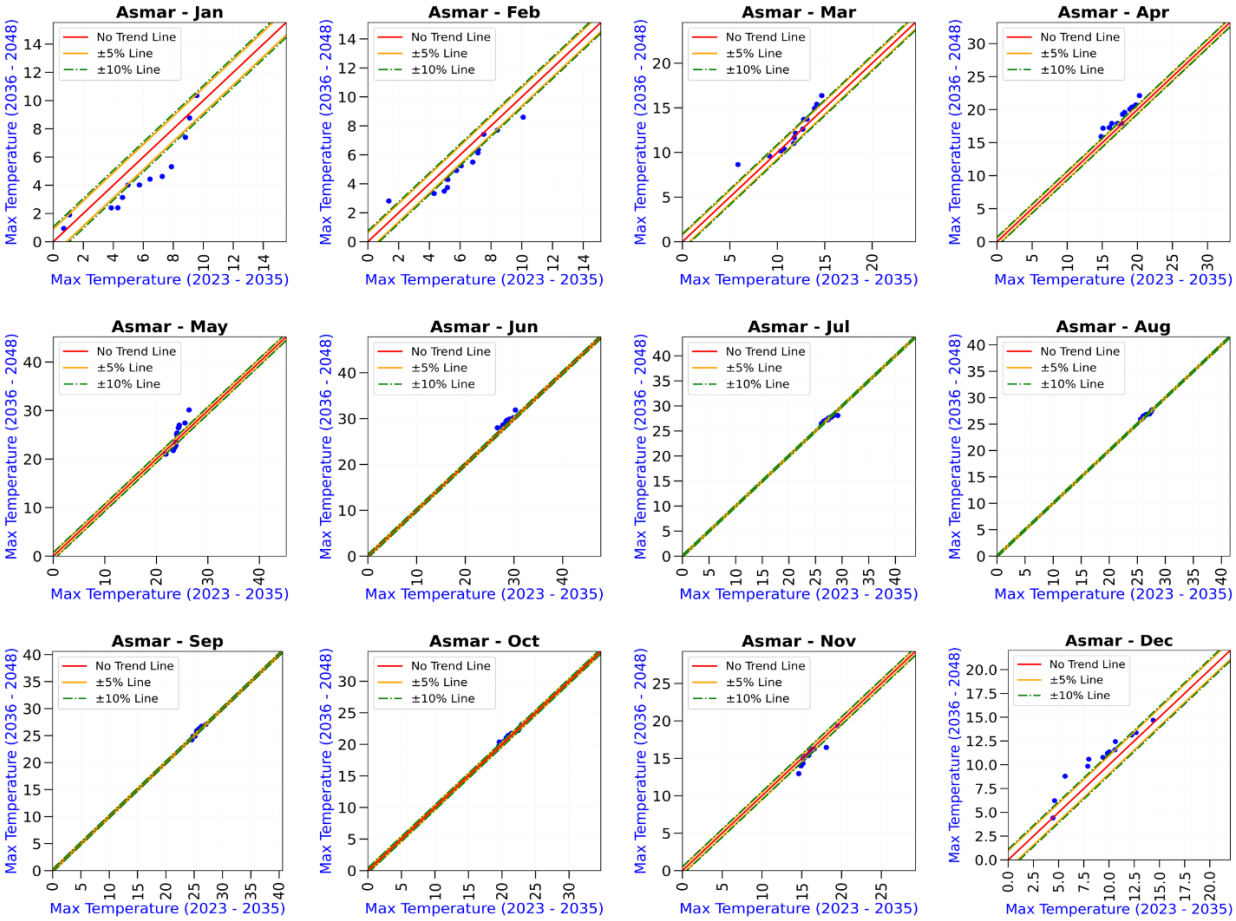

Fig. 7b. Results of ITA for near-future SSP245 maximum temperature at monthly timescale.

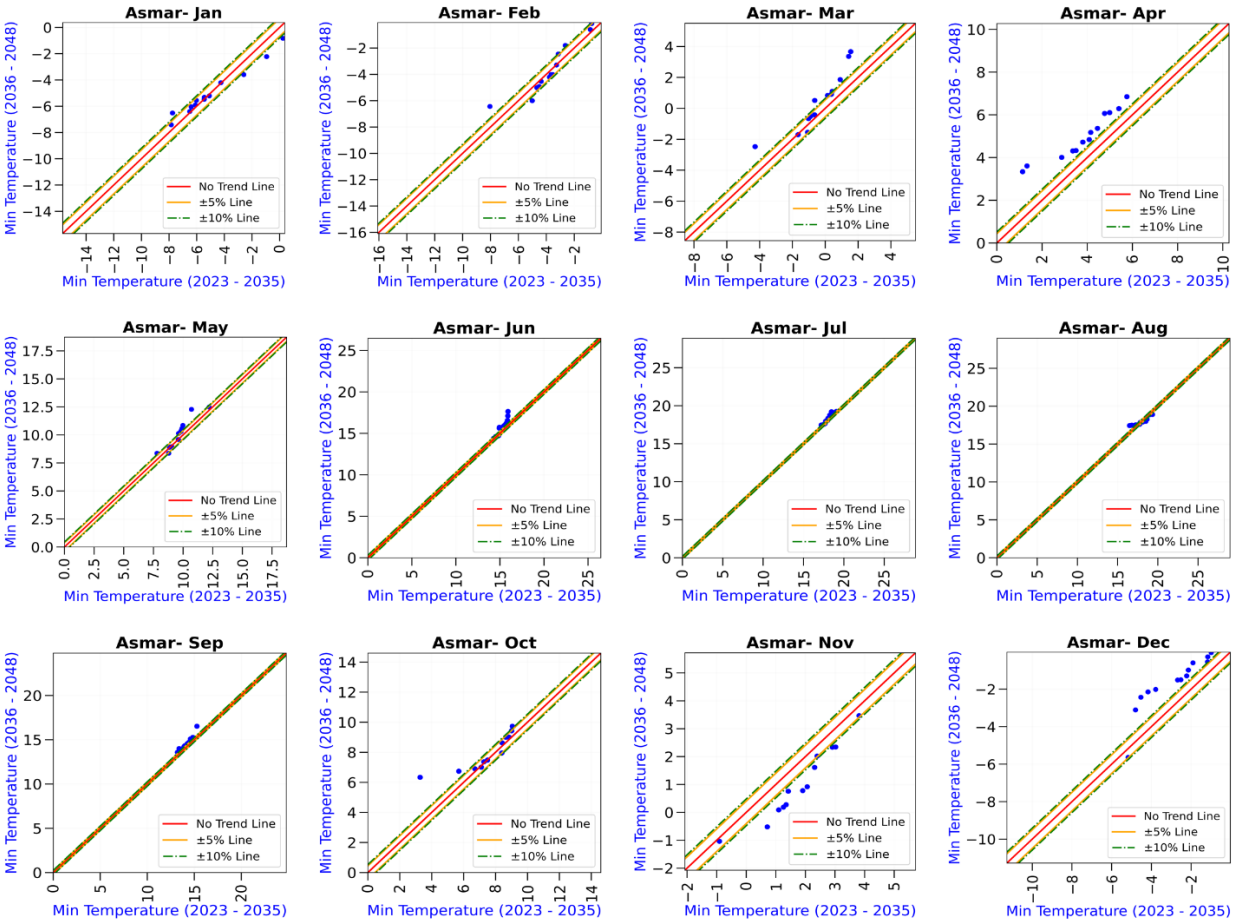

Fig. 7c. Results of ITA for near-future SSP245 minimum temperature at monthly timescale.

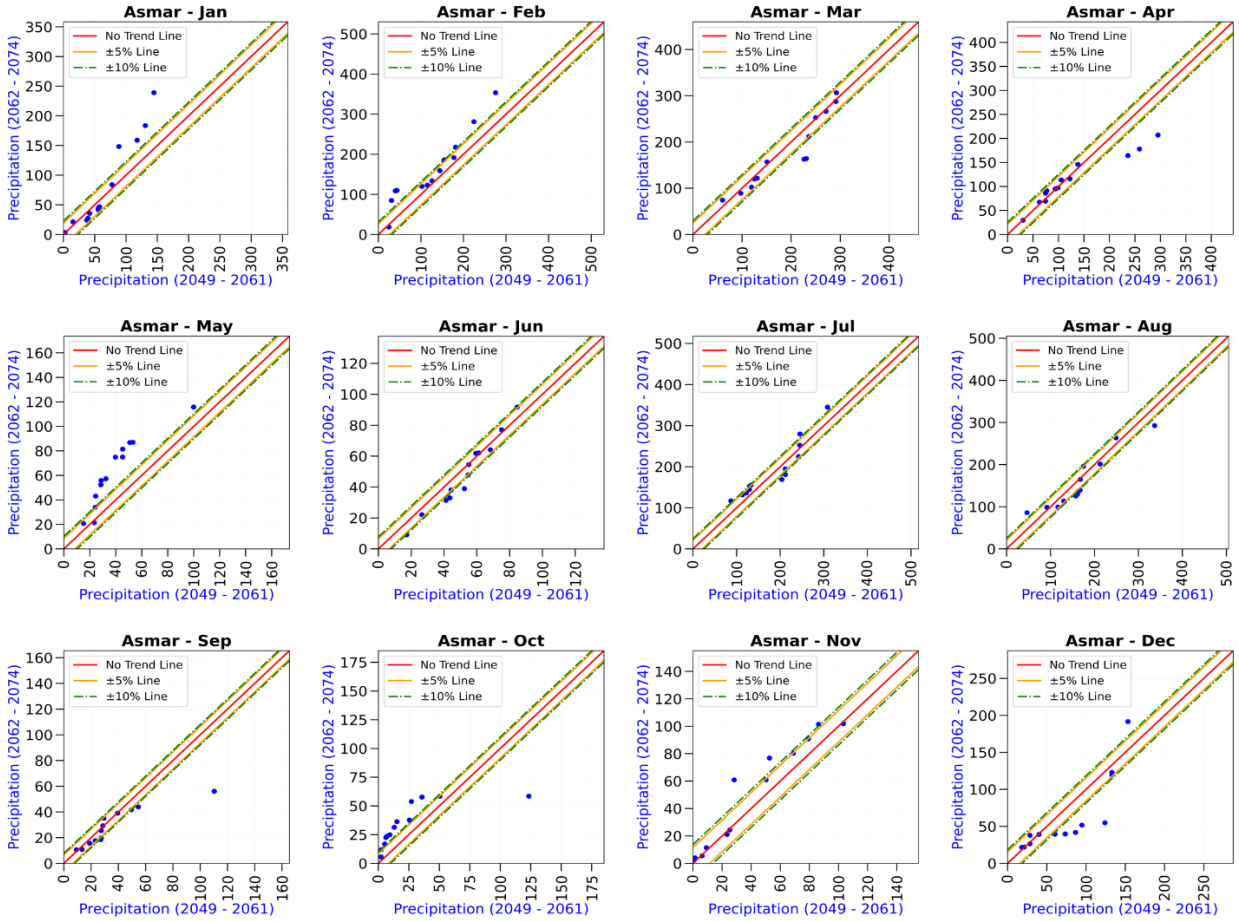

Fig. 8a. Results of ITA for mid-future SSP245 precipitation at monthly timescale.

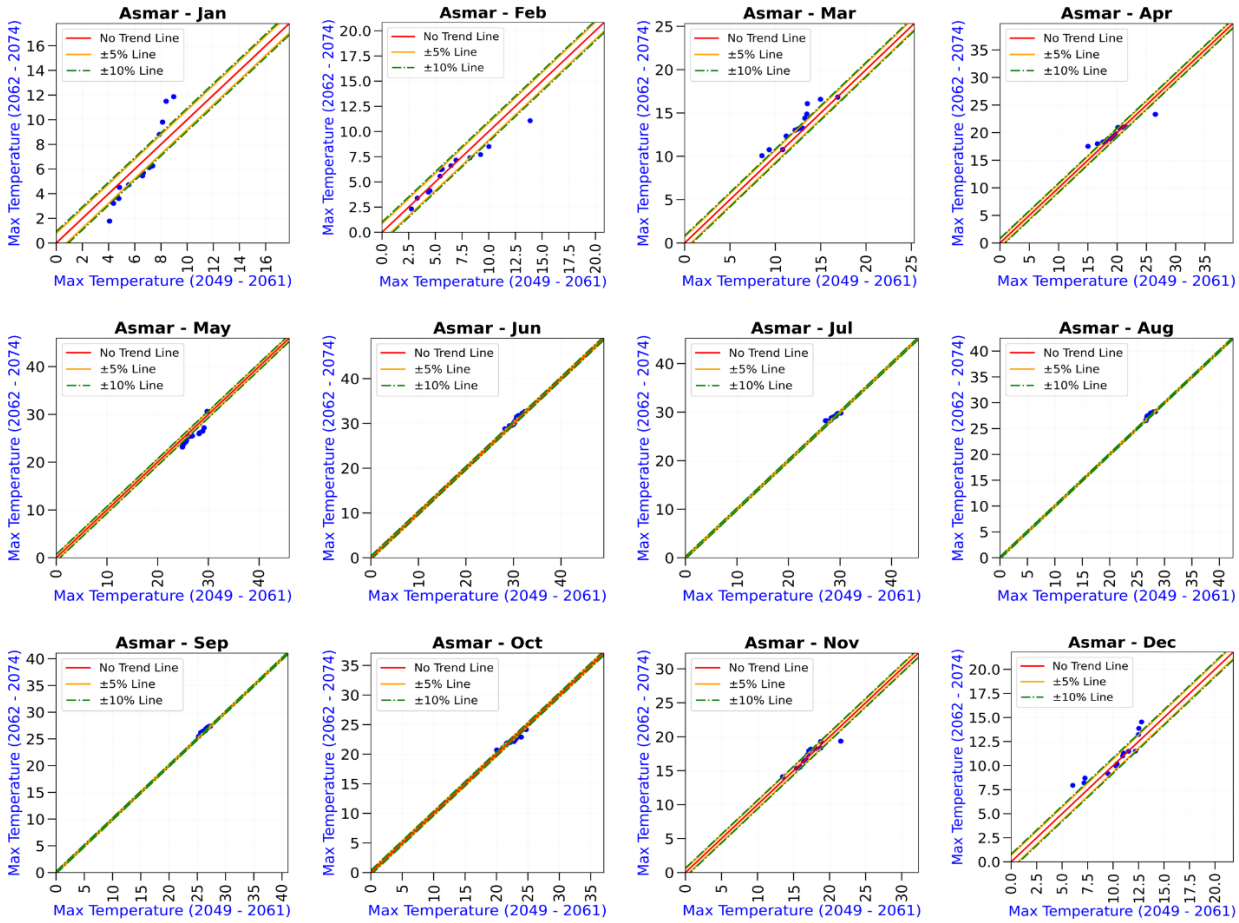

Fig. 8b. Results of ITA for mid-future SSP245 maximum temperature at monthly timescale.

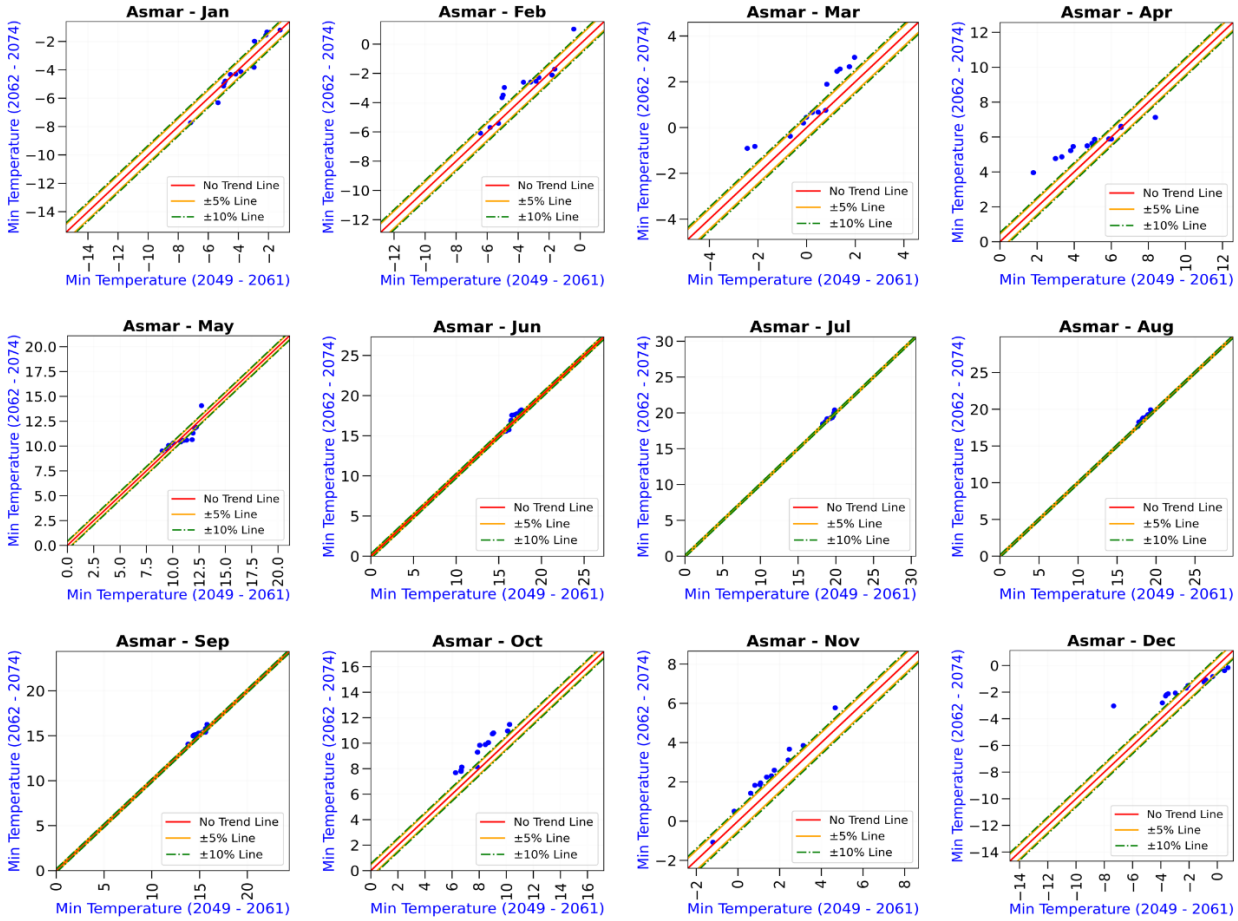

Fig. 8c. Results of ITA for mid-future SSP245 minimum temperature at monthly timescale.

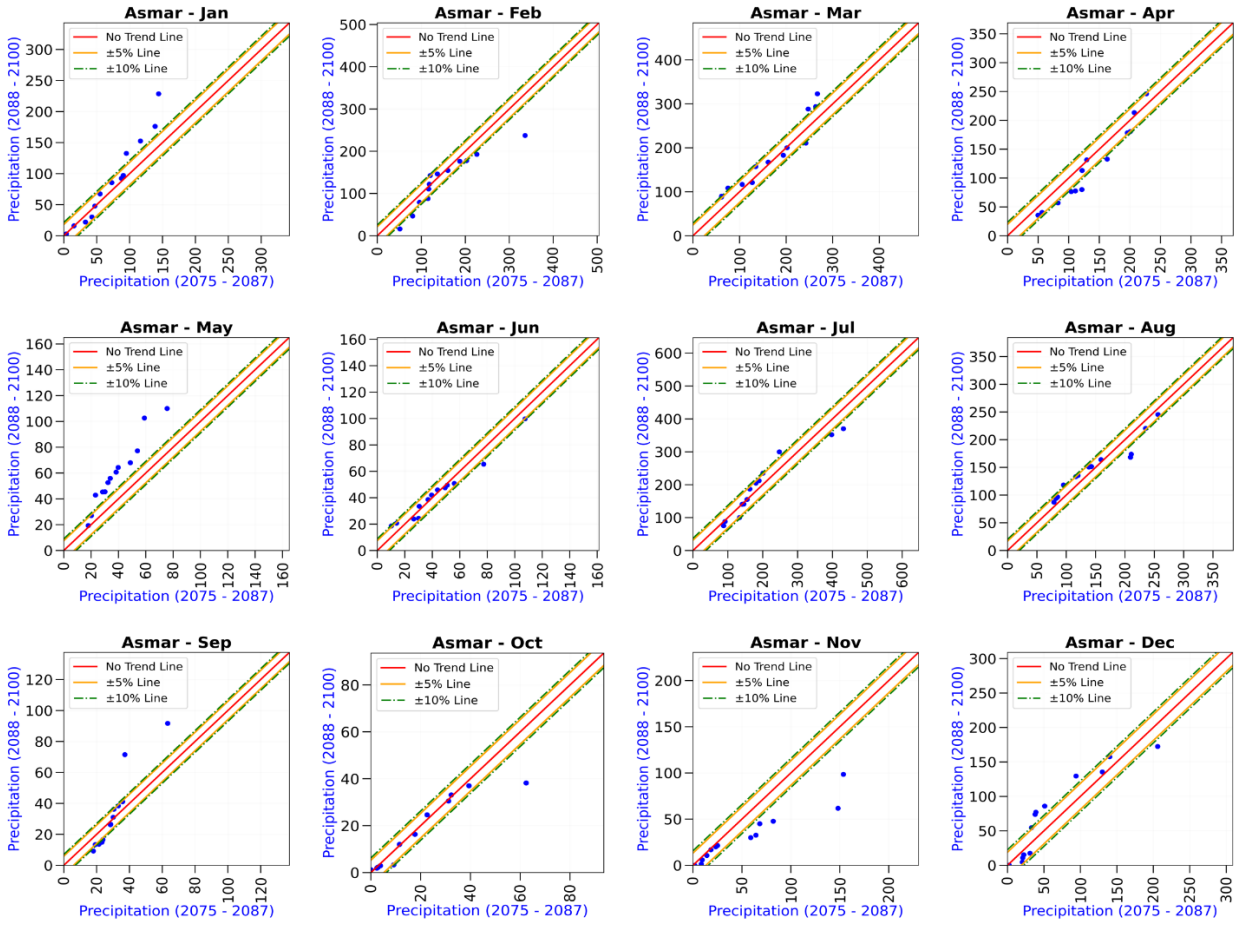

Fig. 9a. Results of ITA for far-future SSP245 precipitation at monthly timescale.

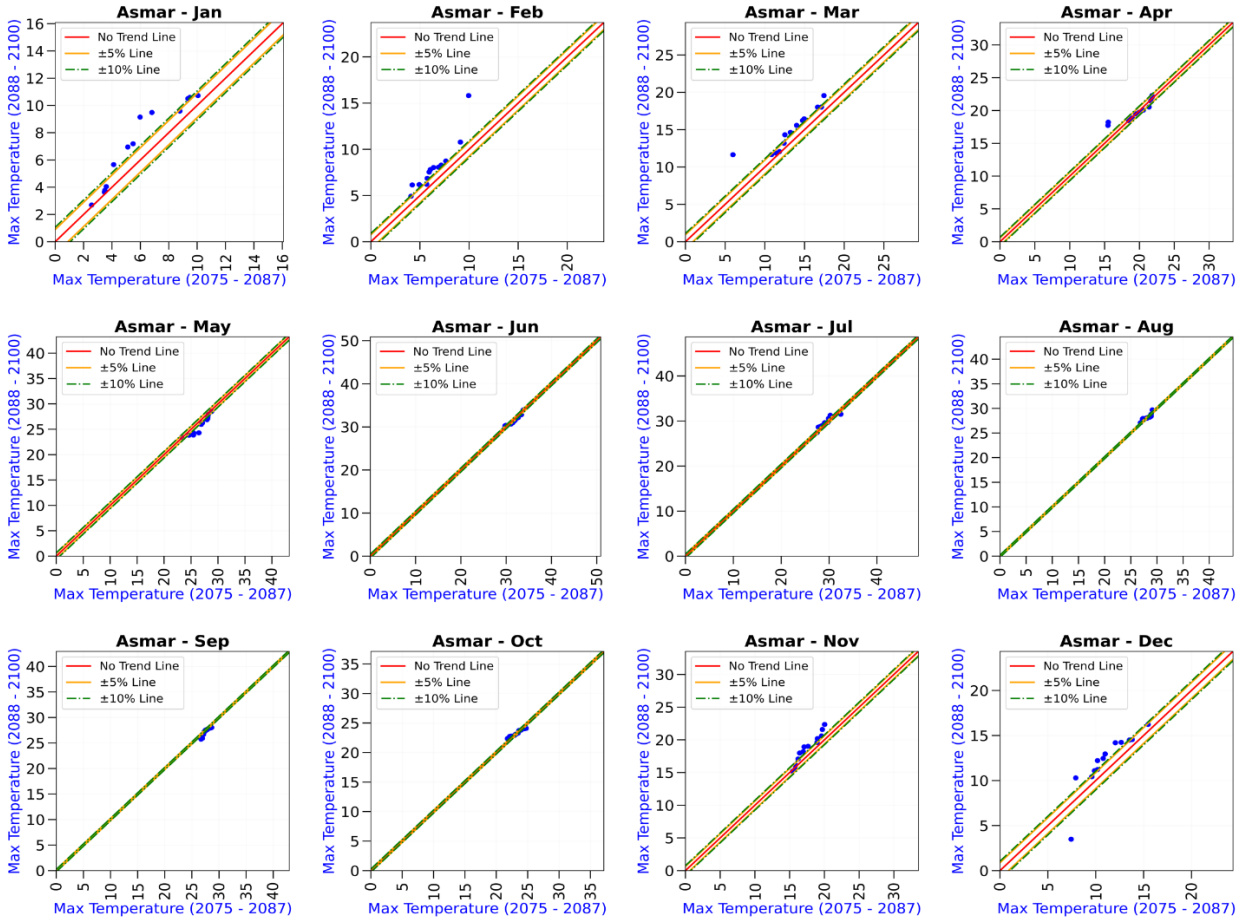

Fig. 9b. Results of ITA for far-future SSP245 maximum temperature at monthly timescale.

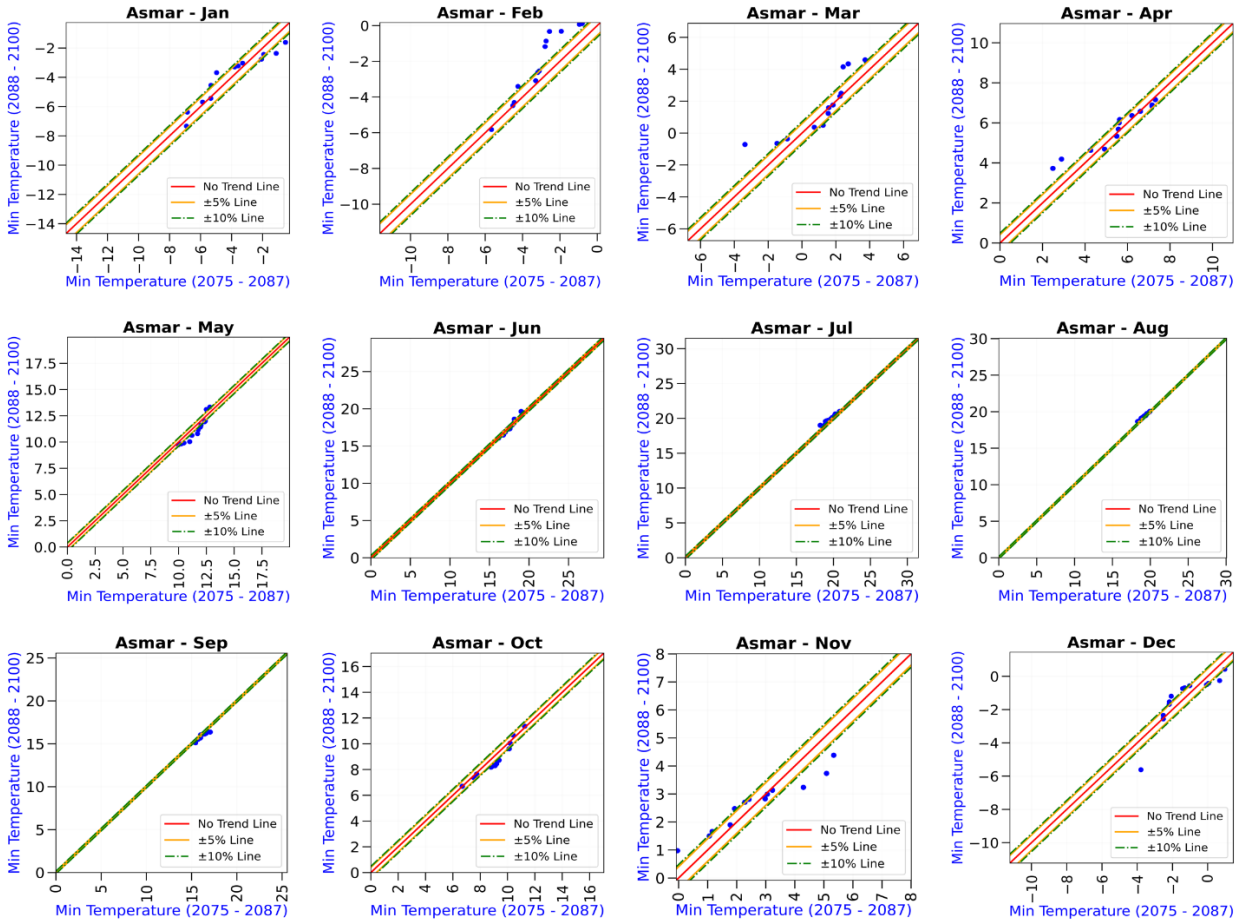

Fig. 9c. Results of ITA for far-future SSP245 minimum temperature at monthly timescale.

Table 10: Innovative Trend Analysis of future SSP585 precipitation data for Asmar station at monthly timescale.

Asmar Precipitation SSP585												
Month/	**Near Future (2023-2048)**				**Mid Future (2049-2074)**				**Far Future (2075-2100)**			
Season	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	1.71	1.60	22.01	26.22	-2.13	-1.50	17.31	20.63	-2.72	-1.84	22.30	26.57
February	1.44	0.80	22.18	26.42	1.46	0.84	24.40	29.07	0.04	0.02	17.80	21.20
March	4.79	2.32	21.25	25.32	-0.03	-0.01	22.61	26.94	0.74	0.28	27.25	32.47
April	-0.66	-0.32	19.98	23.81	-2.53	-1.16	20.24	24.11	1.06	0.64	14.55	17.33
May	-0.43	-0.39	7.15	8.52	0.55	0.62	5.29	6.31	-1.16	-1.17	6.91	8.23
June	0.56	0.88	6.61	7.88	-0.57	-0.67	5.94	7.07	0.03	0.04	7.35	8.76
July	3.48	1.25	31.21	37.18	-3.59	-1.06	22.58	26.91	1.77	0.56	25.03	29.83
August	3.89	1.53	30.05	35.81	3.19	1.19	21.90	26.09	-3.29	-0.85	25.29	30.14
September	0.11	0.22	3.98	4.74	-0.41	-0.67	5.18	6.17	-0.01	-0.02	5.19	6.19
October	-0.12	-0.23	9.76	11.63	0.17	0.48	8.91	10.62	-1.91	-3.36	7.86	9.36
November	-0.33	-0.47	10.72	12.77	1.78	3.38	14.59	17.39	-0.01	-0.02	10.02	11.94
December	0.90	1.21	15.29	18.21	-1.51	-1.28	13.28	15.82	-1.66	-1.73	13.11	15.62

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

Table 11: Innovative Trend Analysis of future SSP585 maximum-temperature data for Asmar station at monthly timescale.

Asmar maximum temperature SSP585												
Month/	**Near Future (2023-2048)**				**Mid Future (2049-2074)**				**Far Future (2075-2100)**			
Season	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.13	1.82	0.75	0.90	0.06	0.55	0.79	0.94	0.20	1.73	1.04	1.24
February	0.06	0.88	0.61	0.72	0.04	0.34	0.85	1.02	0.19	1.59	1.02	1.22
March	-0.06	-0.30	0.64	0.76	0.02	0.08	0.86	1.02	0.13	0.58	0.82	0.98
April	0.03	0.09	0.61	0.73	0.14	0.46	0.61	0.73	0.02	0.07	0.73	0.87
May	0.11	0.30	0.57	0.68	-0.04	-0.09	0.60	0.72	0.21	0.50	0.65	0.77
June	0.00	0.01	0.36	0.43	0.08	0.17	0.42	0.50	0.06	0.11	0.41	0.48
July	0.03	0.08	0.28	0.33	0.10	0.23	0.29	0.35	0.06	0.13	0.34	0.40
August	0.03	0.06	0.23	0.27	0.04	0.10	0.24	0.28	0.09	0.19	0.26	0.31
September	0.03	0.06	0.22	0.27	0.11	0.28	0.33	0.40	0.07	0.15	0.27	0.33
October	0.04	0.12	0.35	0.42	0.04	0.11	0.42	0.51	0.13	0.35	0.42	0.50
November	0.12	0.50	0.55	0.65	0.08	0.29	0.61	0.73	0.12	0.40	0.62	0.74
December	0.09	0.60	0.75	0.89	0.16	1.02	0.99	1.18	0.19	0.91	0.73	0.87

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

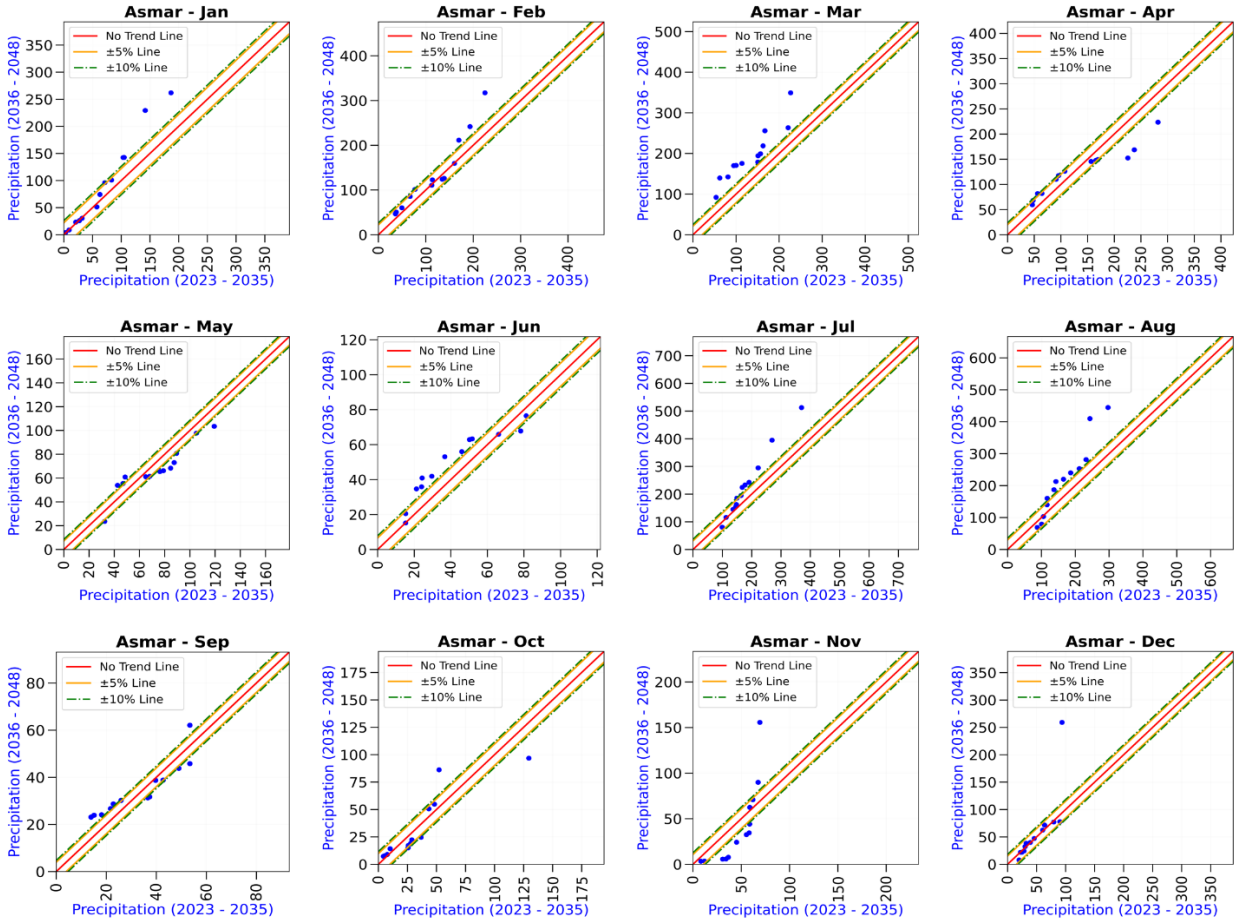

Fig. 10a. Results of ITA for near-future SSP585 precipitation at monthly timescale.

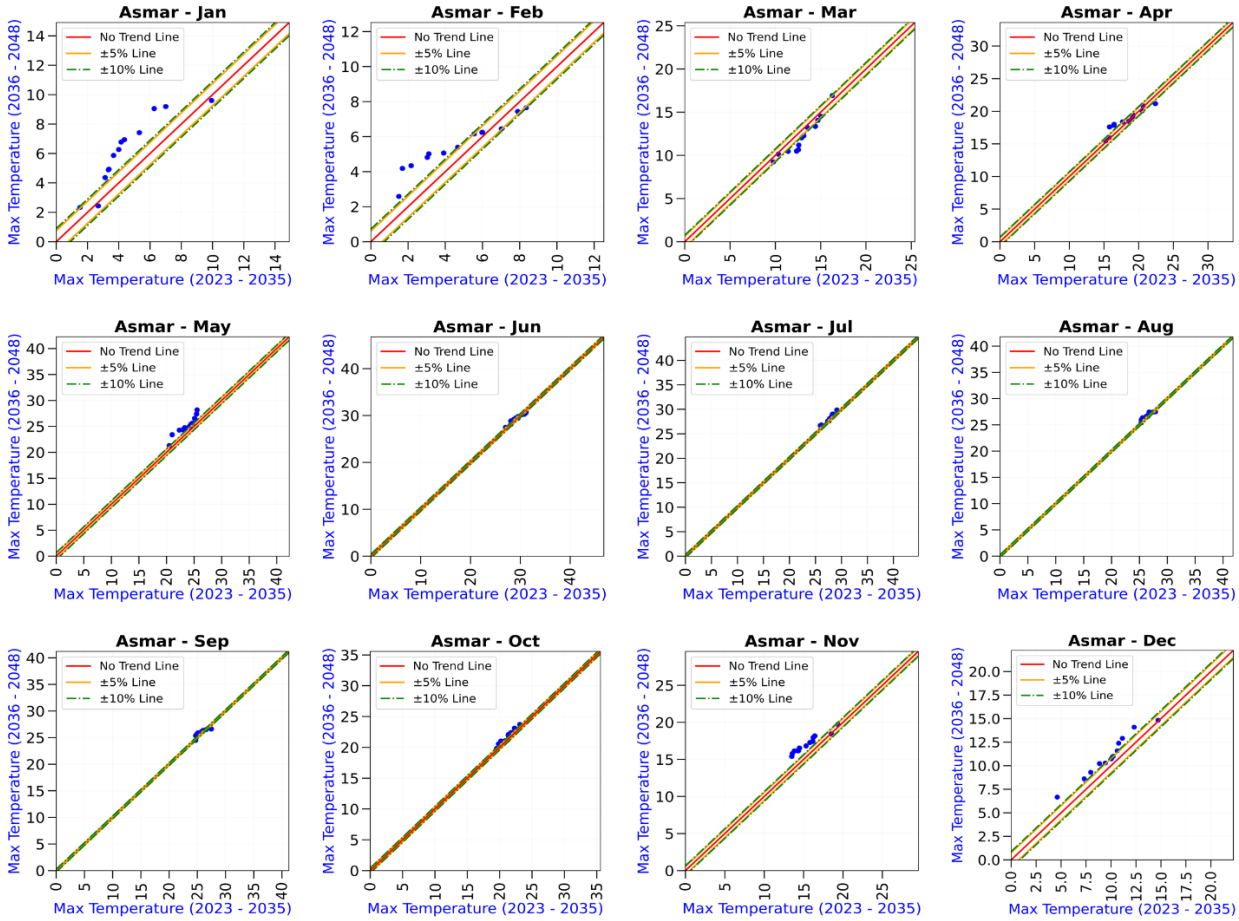

Fig. 10b. Results of ITA for near-future SSP585 maximum temperature at monthly timescale.

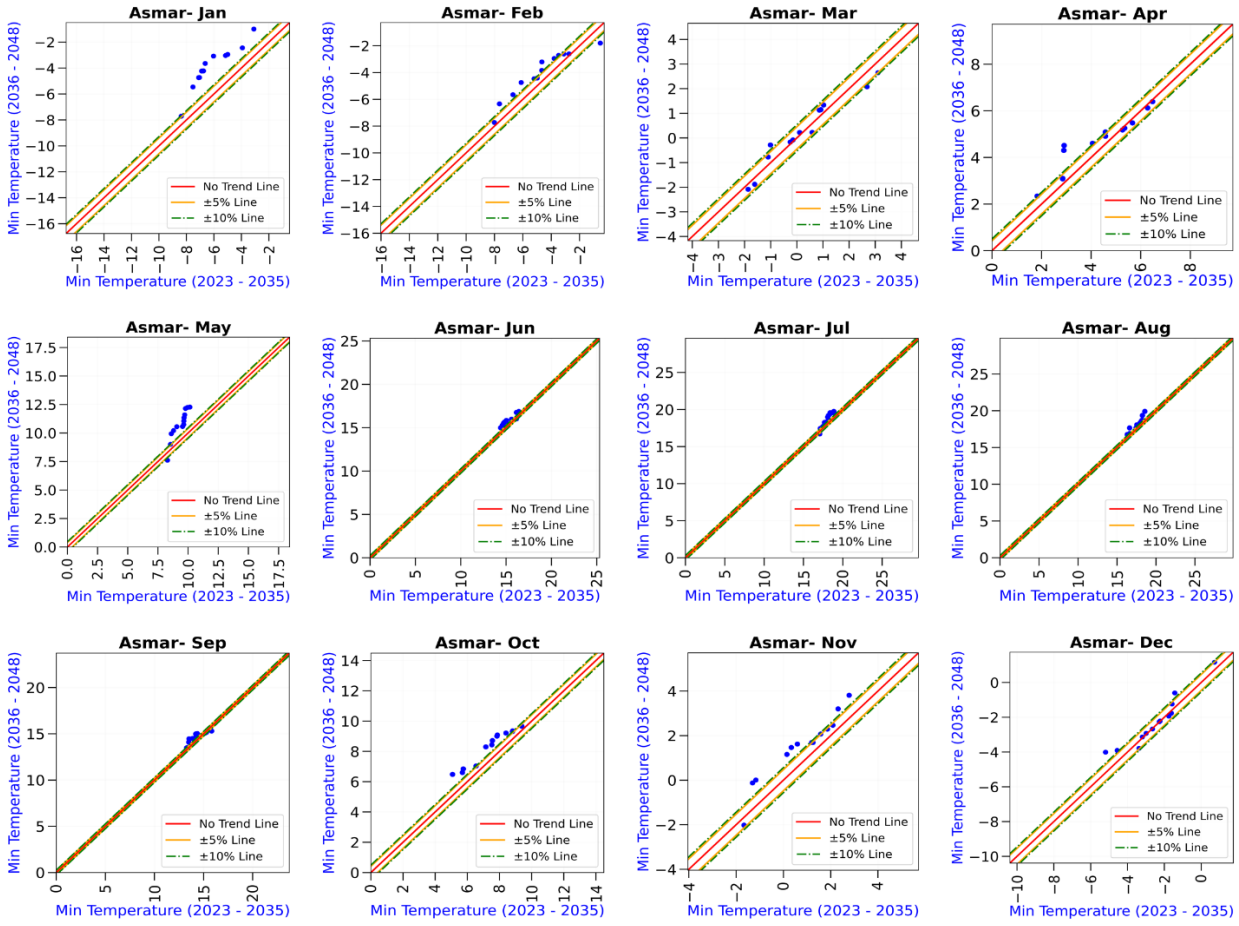

Fig. 10c. Results of ITA for near-future SSP585 minimum temperature at monthly timescale.

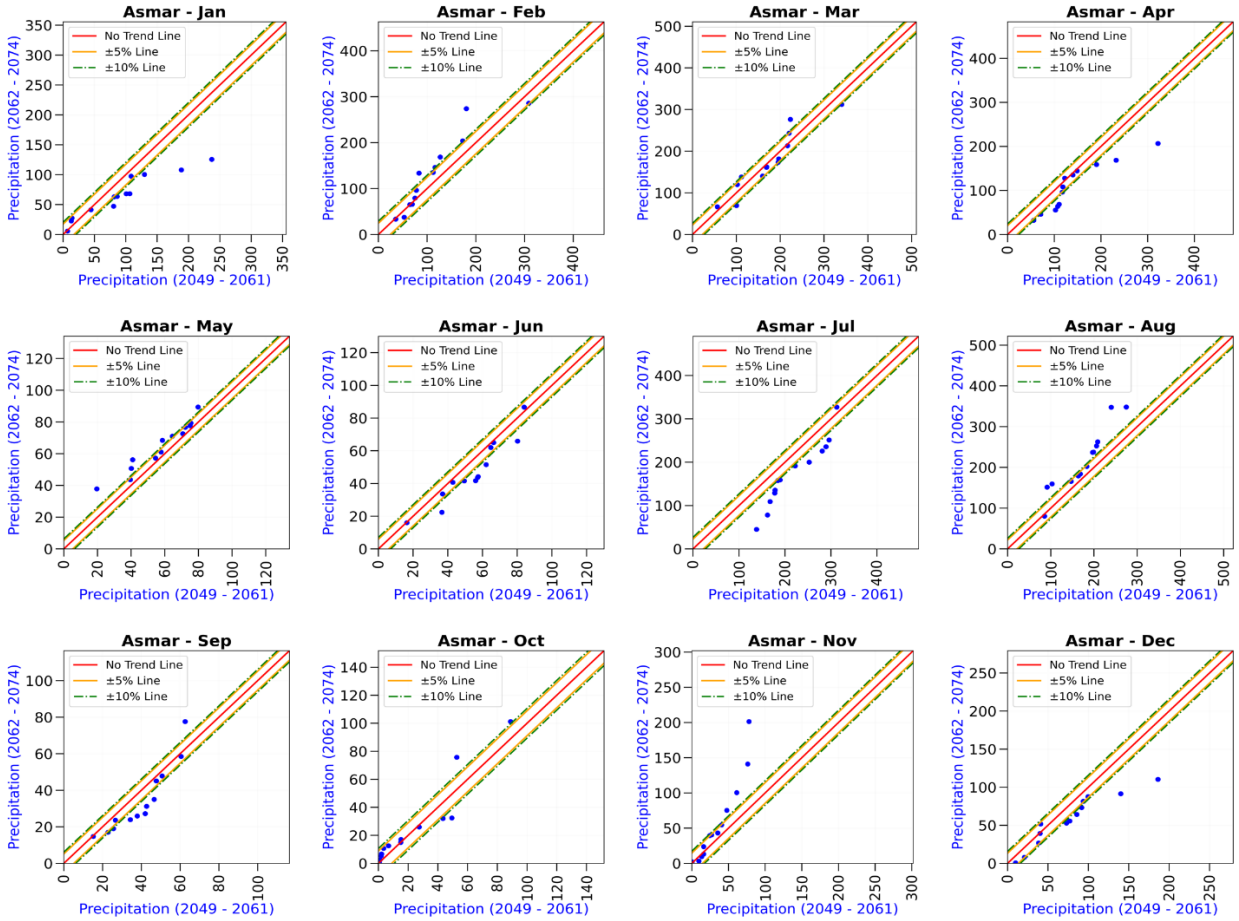

Fig. 11a. Results of ITA for mid-future SSP585 precipitation at monthly timescale.

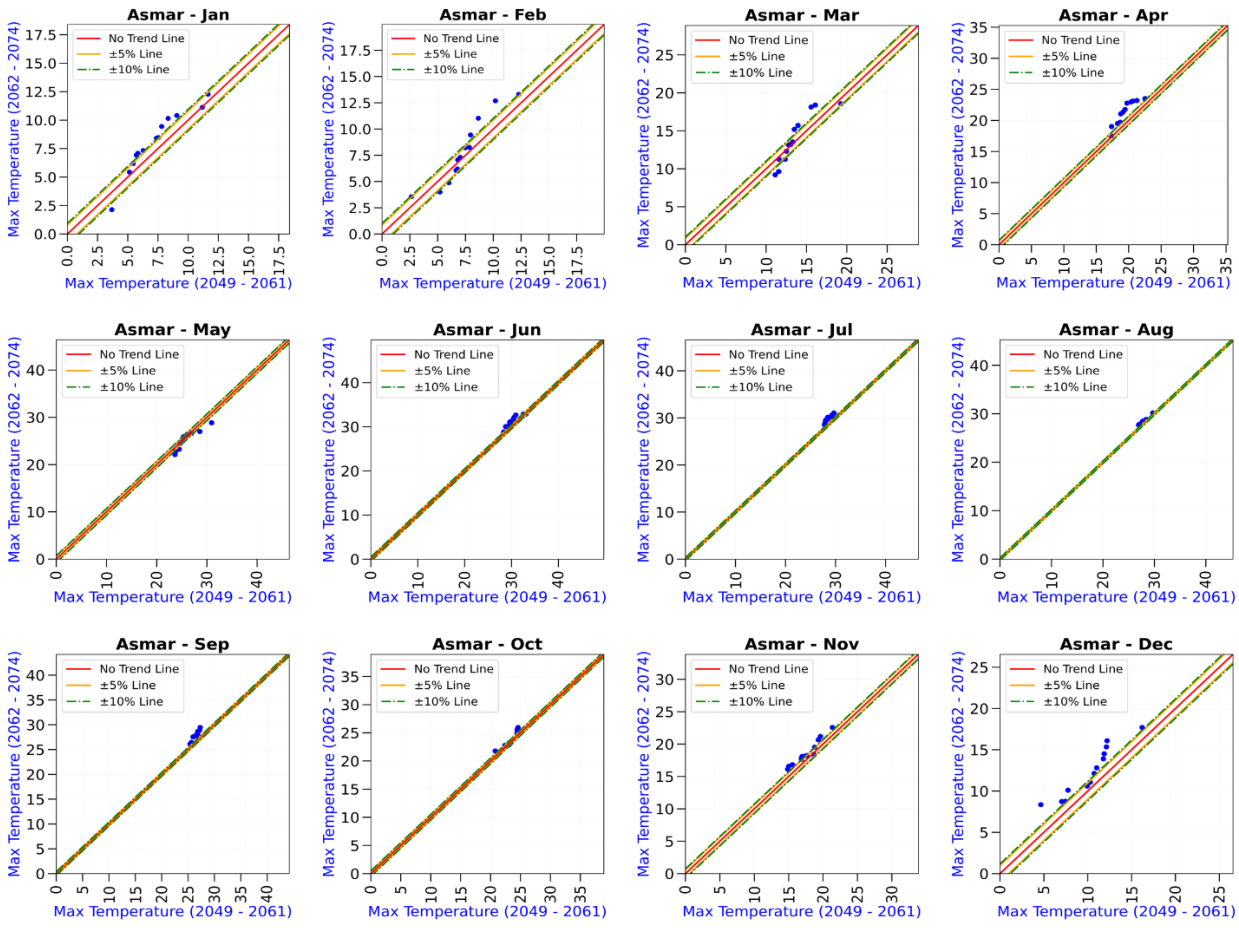

Fig. 11b. Results of ITA for mid-future SSP585 maximum temperature at monthly timescale.

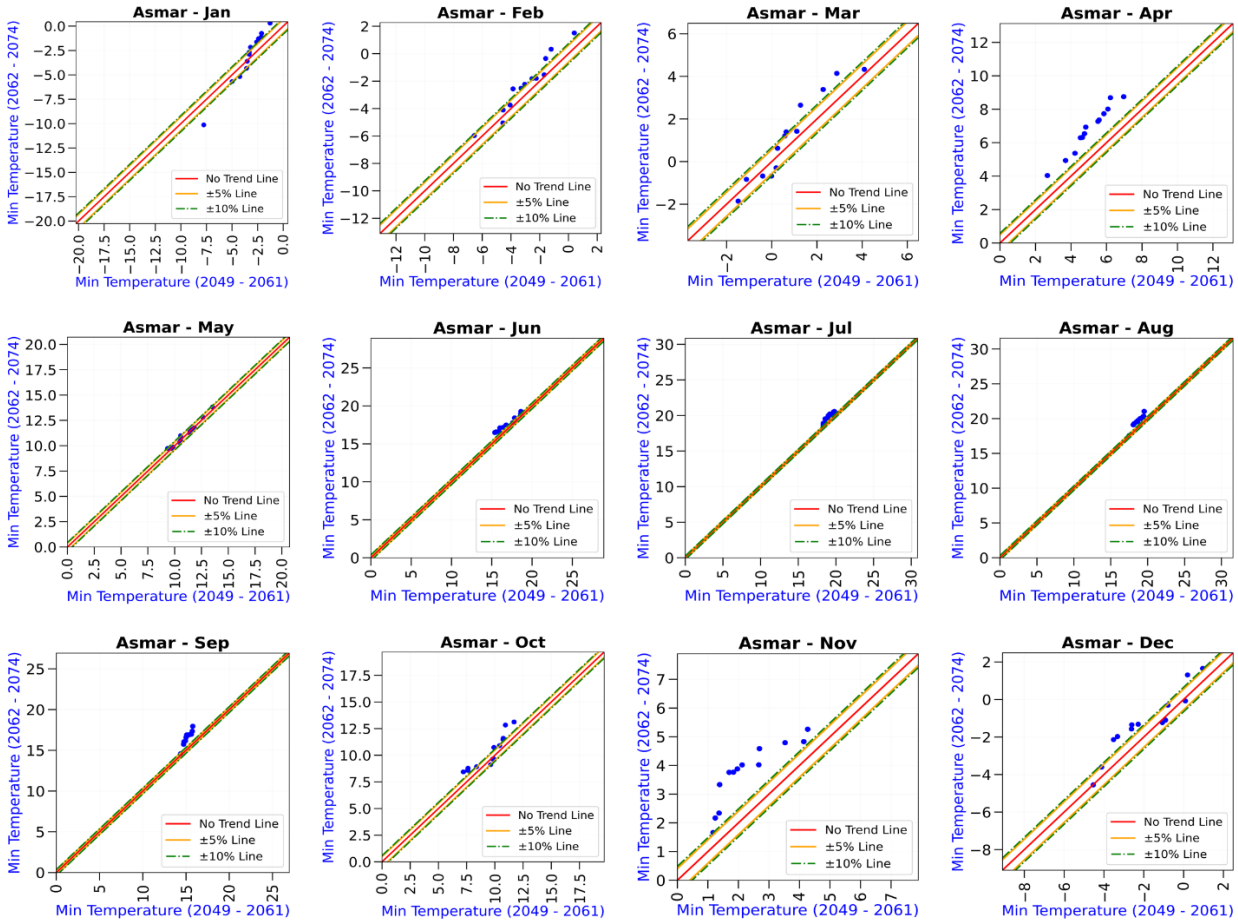

Fig. 11c. Results of ITA for mid-future SSP585 minimum temperature at monthly timescale.

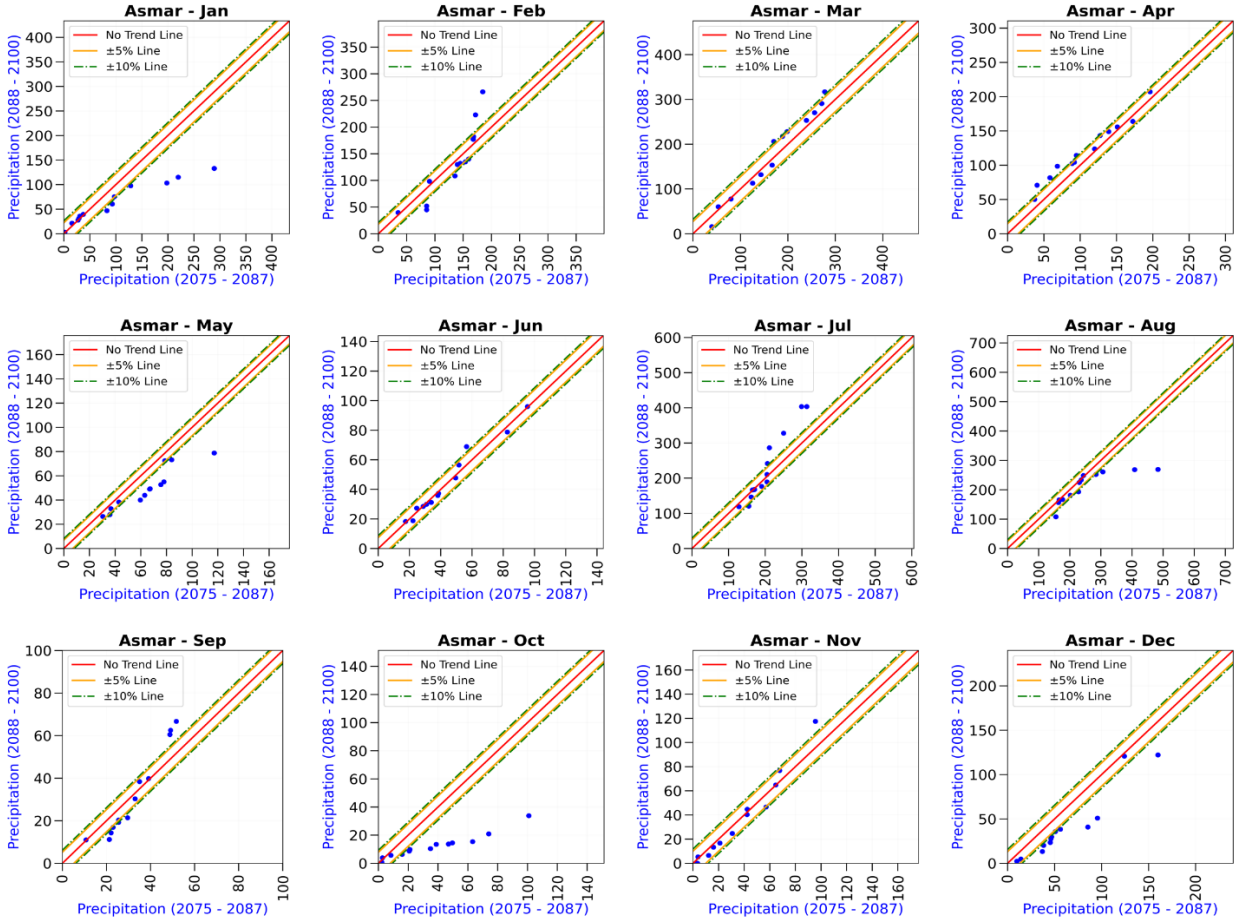

Fig. 12a. Results of ITA for far-future SSP585 precipitation at monthly timescale.

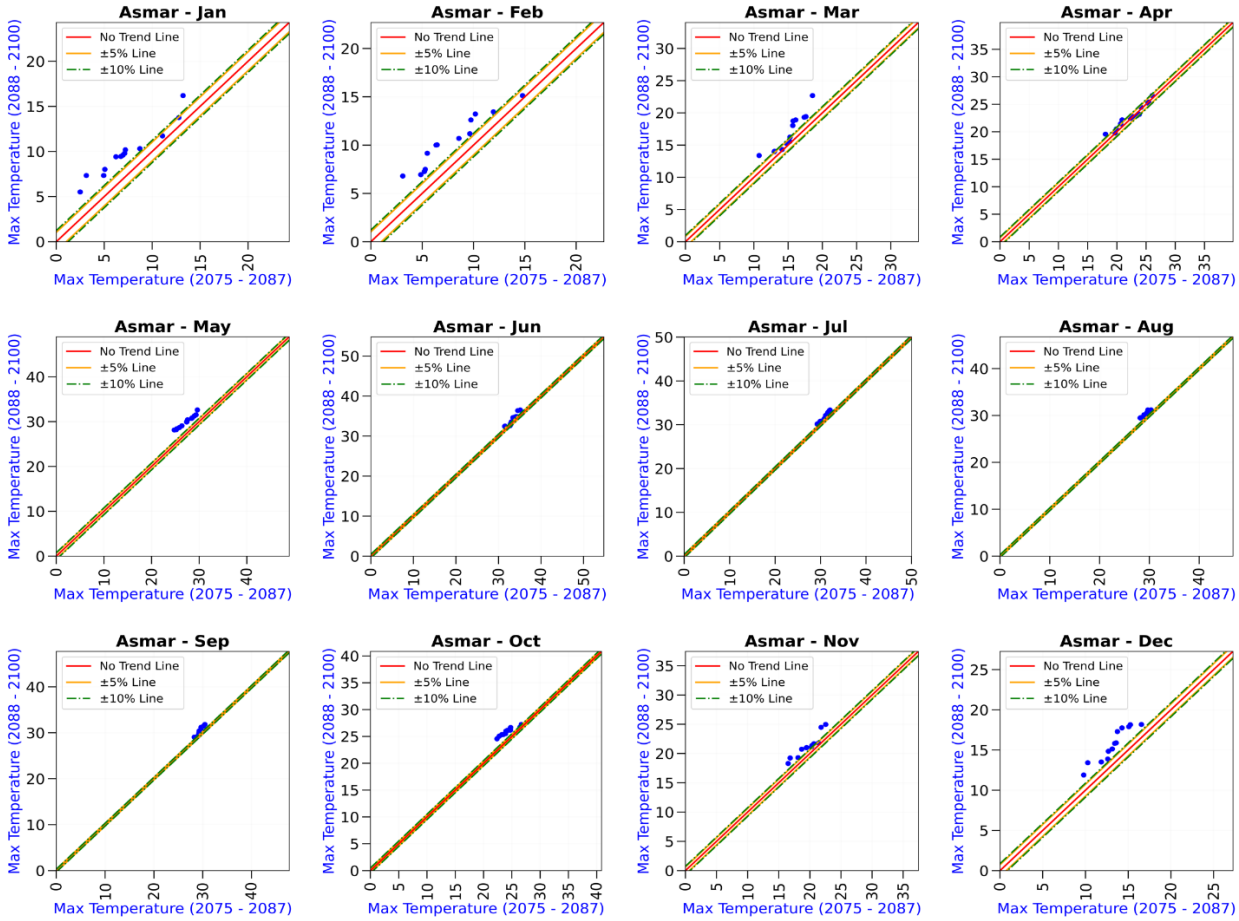

Fig. 12b. Results of ITA for far-future SSP585 maximum temperature at monthly timescale.

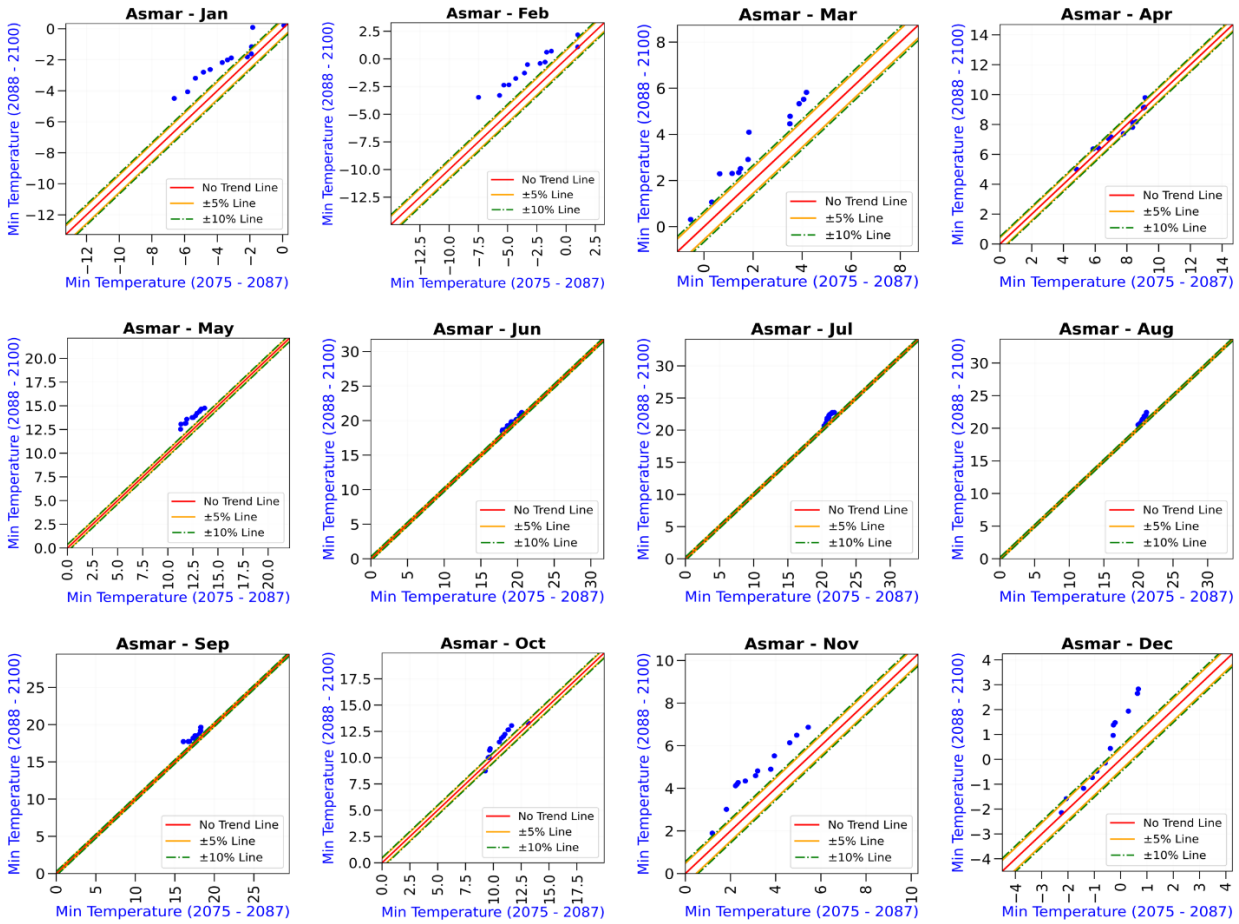

Fig. 12c. Results of ITA for far-future SSP585 minimum temperature at monthly timescale.

Table 12: Innovative Trend Analysis of future SSP585 minimum-temperature data for Asmar station at monthly timescale.

Asmar minimum temperature SSP585												
Month/	**Near Future (2023-2048)**				**Mid Future (2049-2074)**				**Far Future (2075-2100)**			
Season	1*	2*	±CL90	±CL95	1	2	±CL90	±CL95	1	2	±CL90	±CL95
January	0.17	-1.80	0.60	0.72	0.02	-0.39	0.70	0.83	0.10	-1.95	0.56	0.67
February	0.05	-0.70	0.60	0.71	0.05	-1.16	0.62	0.73	0.17	-3.59	0.76	0.91
March	0.00	0.33	0.45	0.54	0.03	2.21	0.56	0.67	0.10	3.04	0.56	0.66
April	0.03	0.43	0.42	0.51	0.13	1.73	0.49	0.58	0.00	0.00	0.42	0.50
May	0.11	0.74	0.39	0.47	0.01	0.03	0.37	0.44	0.10	0.54	0.32	0.38
June	0.04	0.16	0.22	0.26	0.05	0.19	0.32	0.39	0.04	0.14	0.26	0.31
July	0.05	0.17	0.26	0.31	0.06	0.20	0.22	0.26	0.07	0.22	0.24	0.29
August	0.04	0.16	0.26	0.31	0.07	0.25	0.27	0.33	0.06	0.19	0.21	0.25
September	0.03	0.13	0.22	0.26	0.11	0.47	0.31	0.37	0.07	0.26	0.24	0.29
October	0.07	0.60	0.41	0.49	0.05	0.37	0.49	0.58	0.07	0.40	0.41	0.48
November	0.06	4.66	0.47	0.56	0.11	3.06	0.41	0.48	0.12	2.37	0.48	0.57
December	0.02	-0.44	0.46	0.55	0.05	-1.69	0.55	0.65	0.08	-8.46	0.44	0.52

Note: 1 = trend slope (S_{ITA}); 2 = trend indicator (ϕ).

5. Discussion

The available literature shows that trend studies are limited in the Kabul River Basin. Latif et al. (2021) reported non-significant decreasing trends in Chitral River flow during the monsoon and autumn seasons, and on an annual scale. These observations are broadly consistent with the present study, which identified a non-significant decreasing autumn streamflow pattern at Chitral.

Khattak et al. (2015) observed decreasing flow at the Warsak hydrometric station during summer and on an annual scale for 1962–2011. The present ITA analysis also indicates a decreasing pattern at Warsak, although the main ITA period used for the analysis was 1981–2014. Khan et al. (2023) used Mann–Kendall and Sen's slope methods to analyse streamflow, precipitation, and mean temperature in the Kabul River Basin. Their reported increasing streamflow patterns at Chitral and Chakdara during winter and spring, together with a non-significant decreasing pattern at Nowshera, provide useful points of comparison with the present ITA results.

Although many stations showed increasing or decreasing ITA patterns, most were not statistically significant at either the 90% or 95% confidence level. Therefore, the detected directional patterns should be interpreted as evidence of variability within the analysed records rather than as definitive evidence of statistically significant long-term shifts in hydro-meteorological behaviour.

The differences in streamflow patterns between upstream (Chitral) and downstream (Nowshera) stations, also reported by Khan et al. (2023), may reflect the combined influence of climatic variability, topography, snow and glacier melt, reservoir operations, and water withdrawals within the KRB. These factors provide plausible hydrological explanations for spatial differences in flow behaviour; however, the present trend analysis does not independently quantify the contribution of each factor. Land-use change, irrigation demand, urbanization, and transboundary water-management conditions may also affect runoff and streamflow and should therefore be considered when interpreting the observed patterns.

The Kabul River Basin is a transboundary basin shared by Pakistan and Afghanistan and is exposed to floods and droughts. Khan et al. (2023) reported severe floods in 2010 and 2022 and drought periods during the late 1990's and early 2000's. Long-term, consistent observations remain important for assessing hydro-climatic variability. The present study uses multi-decadal records, but differences in station record length and the shorter Chakdara record limit direct comparison across all stations. These data limitations should be considered when interpreting the spatial variability of ITA results.

Where decreasing precipitation coincides with increasing temperature, water-resource pressures may increase because reduced precipitation can lower surface-water availability while higher temperature can increase evaporative demand. However, the present study does not quantify these impacts directly; the implications should therefore be regarded as potential

consequences requiring further hydrological and impact assessment.

These potential changes could place additional pressure on water resources and increase vulnerability of crops and livestock to drought. Rising maximum temperature may increase evaporative demand, reduce soil moisture, and alter crop growing conditions. The combined effects highlight the need for improved water management, continued monitoring, and climate-adaptation planning. Quantification of future impacts would require additional hydrological, agricultural, and socio-economic modelling.

6. Conclusion

This study investigated historical hydro-meteorological variables and future meteorological variables under SSP245 and SSP585 using Innovative Trend Analysis. The historical analysis identified both increasing and decreasing patterns in streamflow, precipitation, and temperature variables, while most detected patterns were not statistically significant at the 90% and 95% confidence levels. Future projections also showed positive and negative ITA slopes across station–month combinations, but none of the reported future trends were statistically significant at these confidence levels. The results therefore indicate substantial spatial and temporal variability in the Kabul River Basin rather than a uniformly significant long-term trend.

Based on these findings, future work should strengthen water-resources planning by considering the spatial variability of streamflow, precipitation, and temperature. Monitoring of upstream snow- and glacier-fed catchments, downstream flow, and climate variables should be maintained and expanded where possible. Efficient irrigation, water conservation, and drought- and flood-preparedness measures can be evaluated according to local conditions. Future studies should also integrate hydrological modelling, land-use information, reservoir operations, and additional climate models to quantify the physical impacts of projected changes. Continued data sharing between relevant agencies in Pakistan and Afghanistan would further improve basin-scale assessment.

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Authors' contribution

Shah Faisal conceptualized the study, designed the methodology, performed data analysis, and prepared the original draft of the manuscript. Alamgir Khalil assisted in methodology development, visualization, and revision of manuscript. Uzair Khan assisted in revising and editing the manuscripts. Mahmood Alam Khan contributed by providing data and revision of manuscript.

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Conflict of interest

The authors declare no conflict of interest with anyone.

Data availability statement

Data will be made available upon reasonable request from the corresponding author.

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