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## Short communication

### Trend analysis of hydrometeorological parameters and groundwater depth in Peshawar district, Pakistan

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Extreme weather events and their impacts are becoming increasingly frequent worldwide. Groundwater plays a vital role in the water cycle, maintaining the ecosystem stability and sustainability (Cui and Shao, 2005; Chidiac and Mahmoodzadeh, 2013) and acts as one of the important sources of drinking water, irrigation, and inflows into most streams or rivers. Fluctuations in groundwater depth can cause prolonged droughts, and excessive pumping for agricultural or urban use can cause porous rock formation, which will affect every aspect of life (Qureshi, 2018; Khan *et al.*, 2024a). The fluctuations in hydro-meteorological factors and water resources have been attributed to global warming and climate change, prompting researchers to conduct trend analyses for more precise forecasts prior to implementing mitigation and adaptation strategies (Almazroui, 2020). Climate change is contributing to reduced stream flow and is also impacting other meteorological parameters, such as wind speed and humidity (Abayomi *et al.*, 2015).

Sen's slope estimate (Sen, 1968) and Mann-Kendall test (Mann 1945) have been used in trend analysis of climatic and hydrometeorological parameters across the globe (Abayomi *et al.*, 2015; Khan *et al.*, 2024b; Shahid and Rahman, 2021; Alam *et al.*, 2021). This study focuses on detecting precipitation and temperature trends in selected zones of Peshawar Province (Khyber Pakhtunkhwa), Pakistan, and to know their effect on the groundwater level.

#### Study area and data

The study area was the district of Peshawar of Khyber Pakhtunkhwa province of Pakistan (Fig.1). The geographic coordinates of the well sites under different zones are shown in Table 1. Monthly data for precipitation (PPT) and mean temperature (Tmean) from 2006 to 2023 were obtained from Pakistan Meteorological Department (PMD) for Peshawar. Data of Kabul

River was collected from the Irrigation Department. Mean monthly (2006-2023) groundwater depth data were obtained from Water and Sanitation Services Peshawar.

#### Trend analysis

The hydro-climatic time series data were checked by using a statistical method to determine if there's a pattern in the data. The Mann-Kendall test was used for recognizing trends in hydro-meteorological parameters without needing specific assumptions. The non-parametric Sen's Slope estimator was employed to assess the strength of a trend in a dataset over time. The Excel template MAKESENS (Mann-Kendall test for trend and Sen's slope estimates) was used to identify positive and negative trends and to compute the linear trend slope of each parameter (temperature, precipitation, evapotranspiration, groundwater depth (GWD), sunshine duration, drainage and river flow) over the study region.

#### Monthly variations of hydrometeorological parameters

The mean monthly climatic parameters (precipitation, temperature and sunshine), river and drainage flow rates and ground water depth for the study region presented Table 2 show that the monthly rainfall varies between 12.2 mm in December to 67.3 mm in July. February to March and July to September are the months receiving higher rainfall. The average temperature varies between 11.2 °C in January to 31.8 °C in June and July. River flows are higher during summer season (May to September) when temperatures are more than 28.5 °C. Drainage flow account very less in comparison to river flow. Ground water depths are highest in Zone C followed by Zone D and Zone B. In Zone A the ground water depth varies least during the year and ranged between 14.63 m to 17.08 m.

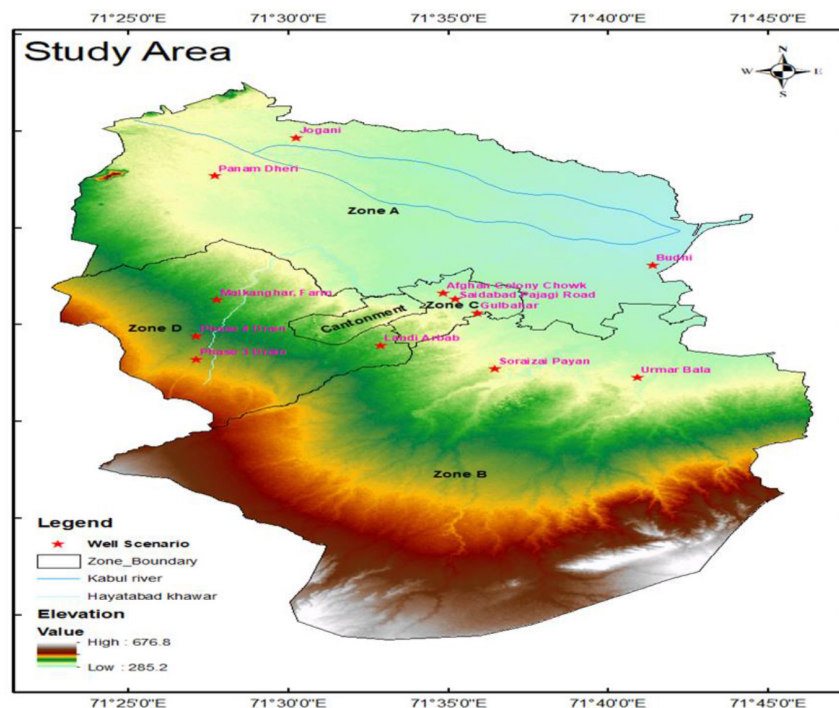
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**Table 1:** Geographic coordinates of groundwater monitoring wells in the Peshawar district

Zone	Well name	Scenarios	Longitude (°E)	Latitude (°N)
A	Panam Dheri	Near River	71.462	34.128
A	Budni	Near River	71.690	34.051
A	Jogani	Near River	71.504	34.161
B	Urmar Bala	Unpaved area	71.681	33.954
B	Soraizai Payan	Unpaved area	71.607	33.961
C	Gulbahar	Paved area	71.598	34.010
C	Afghan Colony Chowk	Paved area	71.581	34.027
C	Saidabad Pajagi Road	Near Natural Drain	71.587	34.022
D	Landi Arbab	Paved area	71.548	33.982
D	Malkanghar, Farm	Unpaved area	71.463	34.021
D	Phase-III Drain	Near Natural Drain	71.452	33.970
D	Phase-IV Drain	Near Natural Drain	71.452	33.990

**Fig. 1:** Location map of study are with well locations**Table 2:** Mean monthly data of hydrometeorological parameters

Month	PPT (mm)	Temp (°C)	River flow (Cumecc)	Drainage flow (Cumecc)	GWD (m)			
					Zone A	Zone B	Zone C	Zone D
Jan	34.5	11.2	406.2	0.29	14.63	16.83	21.42	14.14
Feb	59.1	14.1	484.9	0.30	15.51	17.19	22.08	15.04
Mar	64.9	19.3	554.4	0.32	15.54	17.36	22.76	16.26
Apr	52.2	24.5	811.1	1.03	16.49	18.03	22.06	17.25
May	20.9	29.4	1115.2	0.37	15.59	19.49	21.93	17.90
Jun	19.9	31.8	1244.0	0.36	15.75	20.18	24.03	20.51
Jul	67.3	31.8	1509.6	1.24	16.29	20.95	23.21	22.06
Aug	64.5	30.8	1444.1	0.33	17.05	20.86	24.03	22.83
Sep	27.0	28.9	1024.22	0.36	17.08	21.11	24.96	23.30
Oct	13.3	23.9	739.10	0.37	16.97	21.08	25.91	23.57
Nov	19.4	17.1	574.66	0.39	16.80	22.74	24.70	24.54
Dec	12.2	12.4	494.15	0.24	15.95	22.93	25.18	22.96

**Table 3:** Trend analysis for hydrometeorological parameters using Mann–Kendall

Month	PPT	Tmean	River flow	Drainage flow	GWD Zone A	GWD Zone B	GWD Zone C	GWD Zone D
Jan	-0.65	-0.08	-2.31*	0.00	5.52*	5.55*	5.69*	5.56*
Feb	-0.72	0.45	-2.31*	-0.23	5.72*	5.66*	5.72*	5.55*
Mar	0.00	0.53	-1.93	0.34	5.59*	5.72*	5.72*	5.69*
Apr	0.30	0.61	-0.34	0.00	5.62*	5.72*	5.69*	5.76*
May	-0.23	-0.76	-0.19	-0.42	5.69*	5.68*	5.69*	5.76*
Jun	0.57	0.15	0.11	-0.04	5.50*	5.76*	5.69*	5.76*
Jul	0.72	0.00	0.11	0.46	5.69*	5.72*	5.76*	5.72*
Aug	0.45	-0.08	-1.86	0.58	5.69*	5.76*	5.72*	5.76*
Sep	-0.23	1.89	-0.99	0.73	5.62*	5.72*	5.72*	5.76*
Oct	0.97	0.00	-1.37	0.65	5.61*	5.76*	5.76*	5.76*
Nov	1.10	-1.82	-1.90	0.42	5.59*	5.76*	5.54*	5.76*

\* Significant trends

**Table 4:** Sen's slope trend analysis values of hydrometeorological parameters

Month	PPT	Tmean	River flow	Drainage flow	GWD Zone A	GWD Zone B	GWD Zone C	GWD Zone D
Jan	-0.74	-0.017	37.21*	0.000	0.25*	0.229*	0.47*	0.261*
Feb	-1.95	0.033	42.94*	0.000	0.33*	0.305*	0.53*	0.305*
Mar	-0.14	0.036	-15.36	0.002	0.35*	0.305*	0.45*	0.366*
Apr	0.56	0.024	-14.61	0.000	0.41*	0.356*	0.49*	0.457*
May	-0.27	-0.063	-8.52	-0.002	0.30*	0.483*	0.41*	0.443*
Jun	0.4	0.002	2.02	0.000	0.30*	0.610*	0.37*	0.680*
Jul	1.15	0.003	2.28	0.001	0.37*	0.610*	0.59*	0.671*
Aug	1.2	-0.007	-24.29	0.001	0.42*	0.474*	0.61*	0.724*
Sep	-0.24	0.087	-8.80	0.002	0.30*	0.457*	0.63*	0.762*
Oct	0.19	0.002	-20.79	0.005	0.53*	0.440*	0.61*	0.740*
Nov	1.22	-0.039	-20.95	0.000	0.41*	0.526*	0.51*	0.813*
Dec	0.001	-0.038	-22.00	0.004	0.30*	0.508*	0.56*	0.727*

\* Significant trends are shown in bold

**Trends in hydrometeorological parameters**

The Mann-Kendall test results (Table 3) show a consistent rise in groundwater depth (GWD) across all four zones (A–D) of Peshawar district, indicating a steady groundwater decline. Precipitation (PPT) shows no significant trend, while river flow has significantly decreased, particularly during the dry and post-monsoon months (January, February, August, and December), reducing surface water availability and recharge potential most notably in Zone A near the river. Overall, the decline in groundwater is primarily driven by hydro-meteorological stress reduced river flow, and temperature, while stable rainfall fails to compensate for the loss. Sen's slope trend analysis results for these parameters are presented in Table 4.

Thus, the trend analysis in hydrometeorological parameters assessed using Mann-Kendall and Sen's slope for Peshawar revealed significant increasing trend in groundwater depth in all zones of the entire area although there was no significant increasing trend in temperature and precipitation. Also, it has been observed that decreasing trends of river flow were observed in January and February.

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