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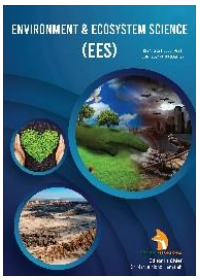

RESEARCH ARTICLE

MANN-KENDALL TEST: TREND ANALYSIS OF TEMPERATURE, RAINFALL AND DISCHARGE OF GHOTKI FEEDER CANAL IN DISTRICT GHOTKI, SINDH, PAKISTAN

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ABSTRACT

Temperature and precipitation variations have huge environmental, socio-economic impacts. This study aims to detect the trend of temperature, precipitation, and discharge from 2000-2020 in the district Ghotki. Mann Kendal test and Sen's slope were applied by using XLSTAT in MS Excel to investigate the significance of all trends. The results showed that the annual rainfall trend was increased with the highest intensity noted in 2003; 275mm and 2010; 271 mm. The trend in the monsoon season was increased with the highest slope 0.863 by comparing with non-monsoon which showed the slope was 0.642. The annual temperature was increased an average temperature recorded in 2016; 28.5 & 2018; 28 °C. Further, the summer-autumn season's trend has sharply increased. While the trend of Ghotki feeder discharge was slightly increased in January due to the continuous flow of water and less demand for water during the Rabi season. But in July, the highest discharge was recorded in 2010 due to heavy rainfall and flood situations over the study area. The trend in Kharif was continuously declined due to farmers started sowing sugarcane crops instead of rice and cotton which need less irrigation water. It is concluded that the performance of MK and SS tests was consistent at the verified significance level.

KEYWORDS

Trend analysis, Sen's slope, Climate variability, Non-parametric test, flow rate.

1. INTRODUCTION

Historical data of climatic factors temperature, rainfall, humidity, wind, and hydrological data flow rate, runoff, floods, and their trends have been acknowledged substantial attention. Climate change effects and variability have been examined by many scientists concerning long-term climatological trends particularly focused on temperature and precipitation. Trend development is an active area of interest for hydrologic parameters and climatic factors to study the climate changes scenarios and increase climate impact research. (Uzochukw, et al., 2015) stated that to forecast a loss of biodiversity, droughts, agricultural productivity, yield, floods, rainfall, humidity, and changes in temperature pattern required to be studied. (Chattopadhyay and Edwards, 2016) reported that trends of precipitation and temperature are significant to the investigation in the climate and hydrology sciences. (Klein-Tank et al., 2006) conducted a study on temperature and found that there was a negative DTR trend in south Asia. (Zahid and Rasul, 2011) showed that 1965-2009 extreme events of both highest and lowest temperature are rising throughout Pakistan. However, globally it has been concluded that the frequency and intensity of climatic factors and events are expanding day by day. (Roy et al., 2003) stated that the reasons for these fluctuations are not known yet but the impacts of these factors like El-Nino. Therefore, trend development for temperature, precipitation, and hydrology with time series is essential for planning and designing regional water resources management. Hydrological and hydro metrological trends development have different statistical test methods with time series. These methods are parametric and nonparametric tests (Dahmen and Hall, 1990, Chen et al., 2007). The parametric test is more powerful. The data for the parametric test must be independent and normally distributed. While nonparametric tests are the most common and require independent data but outliers are better tolerated.

The Mann Kendall (MK) test which is the non-parametric test with time-series trends (Mann, 1945; Kendall, 1975) mostly used by researchers in studying hydrological time series and climatic variations (Longobardi and Villani, 2010). The Mann Kendall test is mostly used to perceive an upward and downward trend i.e., monotonic trends in a series of environmental, climate, and hydrologic series of data. Particularly, the null hypothesis in this test points out no trend, whereas the alternative hypothesis shows the trend in the two-sided test one-sided may upward trend or downward trend (Pohlert 2020). Sen's slope (SS) estimator is another non-parametric technique mostly used for the analysis of hydrological and climatical

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datasets. This technique is used for the identification of trend magnitude. Although, the test computes the linear rate of change (slope) and the intercept. The MK test is broadly used in the literature because it is a powerful trend test for the actual analysis of seasonal and annual trends in hydrological data, climatic data, and environmental data. This test has been prioritized due to its applicability in time-series data, which does not track the statistical distribution. The overall main objective of this study is to analyze and understand the nature and variability of the climatic parameter's temperature, precipitation (annual and seasonal) with hydrological data of the Ghotki feeder canal particularly discharge by using MK trend test from 2000-2020 in district Ghotki. This study has been done on a local scale or district level. While the technique can be used on province and country levels. Hence, after assessing this technique, it may support managers and agricultural planners considering climatic variance to make strategies for crop production and water availability.

2. Materials and Methodology

2.1 Study Area

The district Ghotki was selected for the research study. The district is in the Sindh province of Pakistan. It is located in the northern part of Sindh and it is a gateway to upper Sindh bordering Punjab province. The district is situated between latitude 27°19'45.68"N, and 28°23'59.49"N and longitude 69° 09'51.01"E and 70°11'52.66"E, and on an average elevation of 71 meters above mean sea level. The river Indus flows along the western boundary of the district and its direction of flow is from North to South. The district is bounded by the district Rahimyar Khan (Punjab) in the northeast, Kashmore/Kandhkot in the west and north-west, Sukkur in the south and southwest, and India (Rajasthan) in the east (Figure 1). It is divided administratively into 5 talukas *viz.* Ghotki, Mirpur Mathelo, Daharki, Ubauro and Khan Garh. The district has 40 Union Councils and 248 Dehs. It covers an area of 6,365 km² or 636472 hectares (Shah and Siyal, 2019). It is a fertile area of Sindh which is irrigated through the Ghotki Feeder of the Guddu barrage irrigation system. The important crops grown in the district are rice, maize, wheat, cotton, sugarcane, and different varieties of pulses.

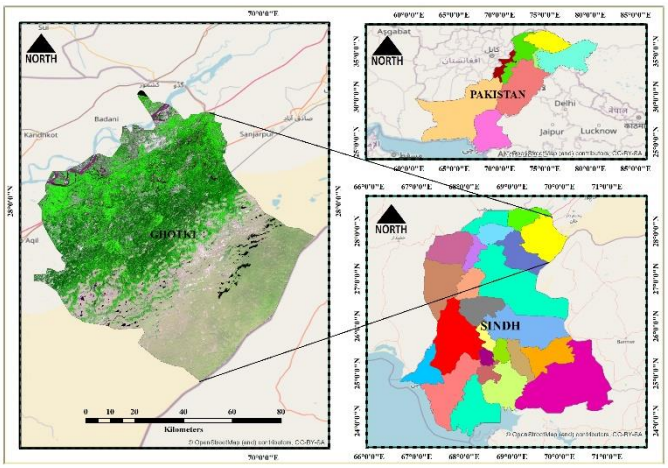

Figure 1: Layout base map of Ghotki district, Sindh, Pakistan

2.2 Data and Methods used for the analysis of trends

In this study, climatic parameters including annual and seasonal temperature (autumn, winter-spring, and summer), annual and seasonal precipitation (monsoon and non-monsoon) have complied for the year 2000-2020 (Figure 2). The hydrological data particularly the discharge/flow rate of the Ghotki Feeder canal for January and July months, where the highest discharge in July and lowest in January has been collected and compiled from 2000-2020 in MS Excel. The discharge data of the Ghotki feeder canal were collected from the Mirpur Mathelo taluka Irrigation office. The metrological data, temperature, and precipitation have been downloaded from Google earth (https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.04/ge/cruts_4.04_grid boxes.kml) and modified in MS Excel. The MK and SS test was computed by using XLSTAT in Microsoft Excel to investigate the significance of all trends and graphs were plotted. Whereas minimum, maximum, mean, annual, average, and seasonal temperature, precipitation, and flow rate were computed using Microsoft excel. The analyzed data is then used to detect the trend of climate change.

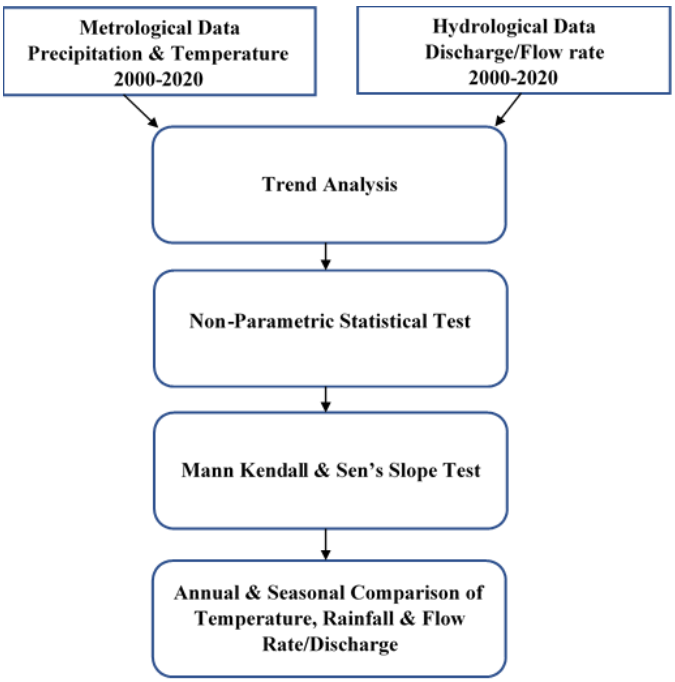

Figure 2: Flow chart diagram illustrating the methodology

2.3 The Mann- Kendall (MK) analysis

The non-parametric trend development is implemented only for reliable data. The MK has been generally practical where the data do not identical to a normal distribution (non-parametric). The Mann Kendall test is used globally to analyze trends in metrological variables (Tabari et al., 2015). World Metrological Data has been widely suggested for this test for free use to the public to assess trends (Shi et al., 2013) and to detect the statistically significant trends of long-term data. Two hypothesis tests have to be tested in the MK, Null hypothesis Ho and Alternative Hypothesis Ha. The null hypothesis defines there is no trend in the concerned time series and in the alternative hypothesis there is a significant trend in the time series. The MK test does not require the assumption of normality, and not only indicates the direction but not the magnitude of significant trends. The Mann Kendall test measured values (Xj-Xk), where j>k and test statistics S is computed exerting the formula.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(Xj - Xk) \quad (1)$$

Where Xj and Xk are the annual values in years j and k, j>k, respectively.

$$\operatorname{sgn}(Xj - Xk) = \begin{cases} 1 & \text{if } Xj - Xk > 0 \\ 0 & \text{if } Xj - Xk = 0 \\ -1 & \text{if } Xj - Xk < 0 \end{cases} \quad (2)$$

The test statistics τ can be computed as;

$$\tau = \frac{s}{n-(n-1)/2} \quad (3)$$

It is necessary to compute the probability associated with S and the sample size n, to statistically quantify the significance of the trend. The calculating formula of variance S is denominating as;

$$VAR(S) = \frac{1}{18}\left[(n-1)(2n+5) - \sum_{p=1}^{q} tp(tp-1)(2t_p+5)\right] \quad (4)$$

Where q is defined as the number of tied groups and t_p is the number of data in the p^{th} group. The values of S and VAR(S) are accustomed to calculate the test statistics Z which is following as;

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases} \quad (5)$$

Z score follows a normal distribution. At a choice of α=0.05 (95% confidence interval) and two-sided alternative, the critical values of 0.025 are equal to -1.96 to 1.96. The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance, while it is increasing if Z is positive and greater than the label of significance. If n≤10 the normal approximation test is used and a statistically significant trend is computed exerting the Z score. Mann Kendall & Sen's slope estimator test the Z score significance level at α:0-001, 0.05, and 0.1.

2.4 Sen's Slope Estimator

Sen's slope estimator is a method of nonparametric that was employed to exhibit the linear patterns in this study. This method is most effective than the regression equation. If a linear aptitude is present in a time series, then the true slope can be calculated by exerting a simple non-parametric procedure. In this case of linear model *f*(t) can be denominated as;

$$\mathbf{f(t) = Qt + B} \quad (6)$$

Where Q is representing slope, B is a constant value and t is time. To derive an estimate of slope Q, the slopes of all data pairs are calculated to exert the equation;

$$\mathbf{Q_i = \frac{Xj - Xk}{j - k}, i = 1, 2, 3, \ldots \ldots N, j > k} \quad (7)$$

If there are n values Xj in the time series there will be as many as N=n(n-1)/2 slope estimate Qi. To estimates B in the equation, the n values of difference Xi-Qt are calculated. An estimate of B is obtained from the given mean values. Data were processed using an Excel macro names MAKESENS created by (Salami et al., 2002).

3. Results and Discussion

In this manuscript, Mann Kendal and Sen's slope estimator has been used for the determination of the time series trend for the year 2000-2020. The trend analysis is carried out for the District Ghotki by using annual and seasonal temperature (spring, summer, winter, and autumn), annual precipitation and seasonal (monsoon and non-monsoon), and Ghotki feeder canal discharge for the months of (January and July) highest and lowest flow rate from 2000-2020. The brief details of the results are presented in the following subsections.

3.1 Annual and Seasonal Rainfall Trends

The monsoon season provides a maximum involvement to annual rainfall in Pakistan, mainly during June, July, August, and September months. The rainfall trends annual and seasonal are shown in (Figure 3,5,7) The increasing trend was detected in annual and seasonal rainfall time series with a slope of 1.564, 0.863, and 0.642. respectively. The results of the MK test and Sen's slope revealed the trend in the time series for the annual, monsoon, and non-monsoon periods (Table 2). All the tests are measured at a 5% level of significance. The significant increasing trends were found in the annual, monsoon, and non-monsoon rainfall time series for the entire study area. The investigation of the distinction in the precipitation patterns over the district Ghotki indicates that there is a sharp increase in the trend of the rainfall. The trends of annual, monsoon, and non-monsoon rainfall much more rapidly increasing in the years 2010 due to heavy rainfall in the area.

Table 1: Summary statistics of Annual and Seasonal Precipitation mm of Ghotki district 2000-2020

Variable	Observations	Obs. without missing data	Minimum Precipitation mm	Maximum Precipitation mm	Mean	Std. Deviation
Annual Rainfall mm	21	21	37.20	270.7	118.2	58.12
Monsoon Precipitation mm	21	21	20.10	247.1	91.6	53.55
Non Monsoon Precipitation mm	21	21	8.40	60.5	26.6	13.83

Table 2: Illustrate Rainfall (Annual, Monsoon and Non-Monsoon) results of Ghotki district from 2000-2020

Parameters	Mann-Kendall Statistics (S)	Kendall's Tau	p-value	Sen's Slope	VAR (S)	Alpha	Test Interpretation
Annual Average Precipitation	24	0.114	0.487	1.56	1096.66	0.05	H_o Accept
Monsson Precipitation	22	0.105	0.526	0.86	1096.66	0.05	H_o Accept
Non-Monsoon Precipitation	44	0.210	0.194	0.64	1096.66	0.05	H_o Accept

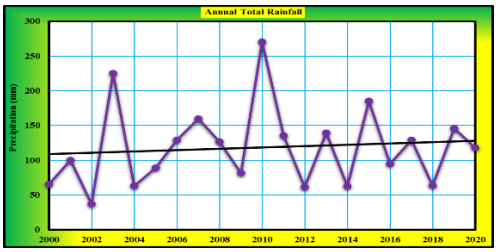

Figure 3: Represents Annual Total Rainfall Trend Line in Ghotki district 2000-2020

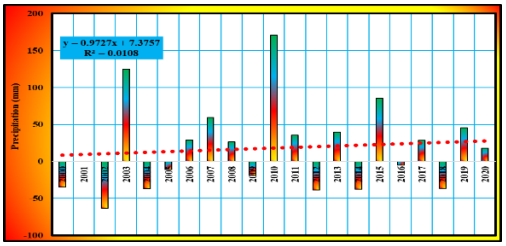

Figure 4: Annual Rainfall Deviation in Ghotki district 2000-2020

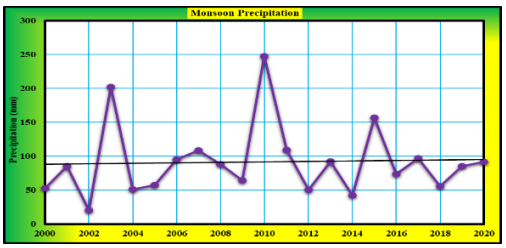

Figure 5: Represents Monsson Rainfall Trend Line in Ghotki district 2000-2020

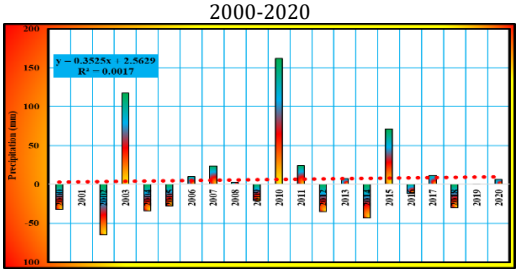

Figure 6: Monsoon Rainfall Deviation in Ghotki district 2000-2020

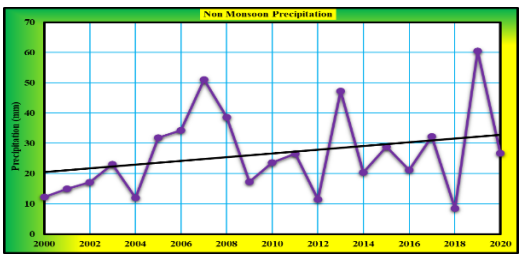

Figure 7: Represents Non-Monsoon rainfall trend line from 2000-2020 in district Ghotki

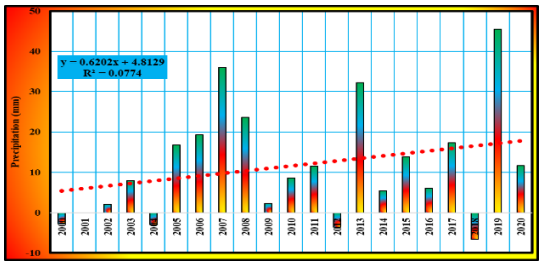

Figure 8: Non-Monsoon Season Rainfall Deviation in Ghotki district 2000-2020

3.2 Annual and Seasonal Temperature Trends

Annual and seasonal temperature (spring, winter, autumn, and summer) trends are shown in (Figures 9,11,13,15,17). There was an increase in the trend of annual average temperature and the slope was identified as 0.012. Summer and autumn temperatures have sharply increased in the trend and the slope was estimated at 0.025 and 0.028. While the trend of the winter and spring season also increased and the slope was determined as 0.010 and 0.005 respectively. The results of the Mann Kendall test and Sen's slope revealed the trend in the time series for the annual, spring, winter, autumn, and summer season (Table 4). All tests are considered at a 5% level of significance.

Table 3: Summary statistics of Annual and Seasonal Temperature of Ghotki district 2000-2020

Variable	Observation	Obs. without missing data	Min Temperature °C	Max Temperature °C	Mean	Std. deviation
Annual	21	21	26.42	27.95	27.24	0.338
Autumn	21	21	26.50	27.86	27.42	0.354
Spring	21	21	28.66	32.26	30.16	0.888
Winter	21	21	15.83	18.70	17.18	0.730
Summer	21	21	33.66	34.83	34.19	0.336

Table 4: Illustrate temperature (annual average, winter, spring, summer, and autumn) for the year 2000-2020

Parameters	Mann-Kendall Statistics (S)	Kendall's Tau	p-value	VAR (S)	Sen's Slope	Alpha	Test Interpretation
Annual Avg Temperature	36	0.171	0.291	1096.6	0.012	0.05	H_0 Accept
Spring Temperature	7	0.033	0.856	1095.6	0.005	0.05	H_0 Accept
Winter Temperature	14	0.067	0.695	1096.6	0.010	0.05	H_0 Accept
Autumn Temperature	75	0.360	0.025	1093.6	0.024	0.05	H_0 Reject
Summer Temperature	67	0.320	0.046	1095.6	0.028	0.05	H_0 Reject

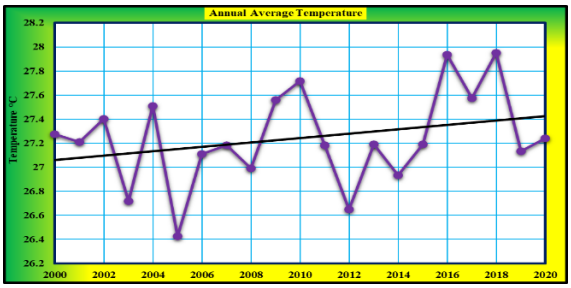

Figure 9: Represents Annual Average Temperature Trend Line in the Ghotki district 2000-2020

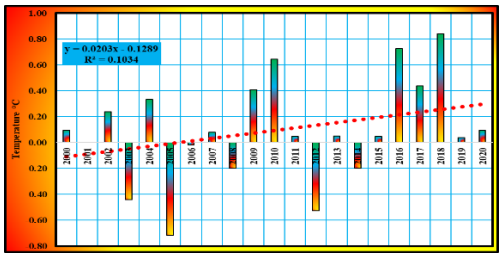

Figure 10: Represents Annual Average Temperature Deviation in Ghotki district 2000-2020

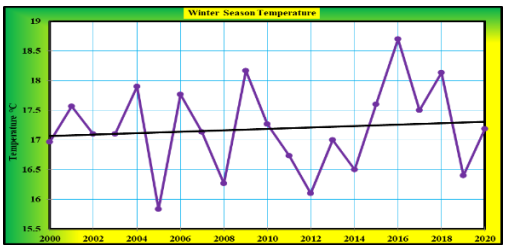

Figure 11: Represents Winter Season Temperature Trend Line in Ghotki district 2000-2020

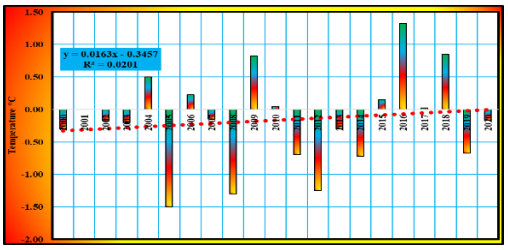

Figure 12: Represents Winter Temperature Deviation in Ghotki district 2000-2020

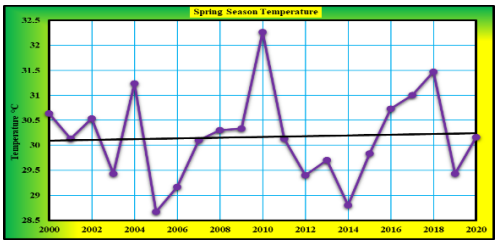

Figure 13: Represents Spring Season Temperature Trend in Ghotki district 2000-2020

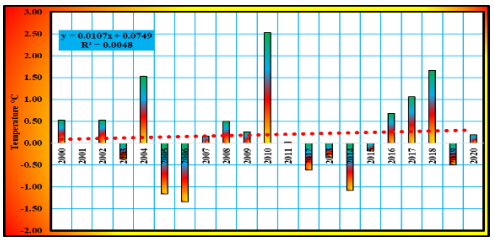

Figure 14: Represents Spring Temperature Deviation in Ghotki district 2000-2020

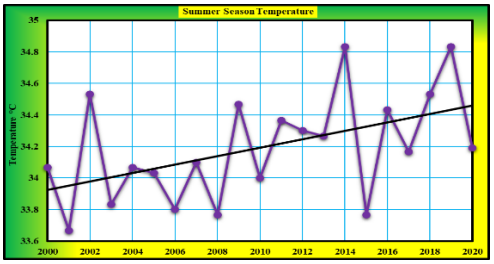

Figure 15: Represents Summer Season Temperature Trend in Ghotki district 2000-2020

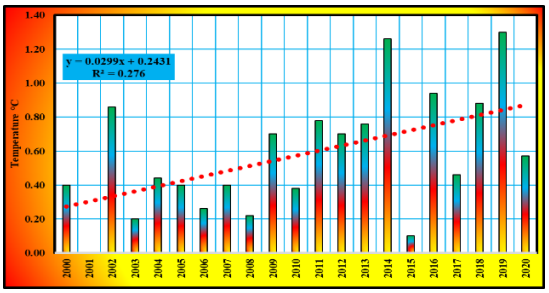

Figure 16: Summer Temperature Deviation in Ghotki district 2000-2020

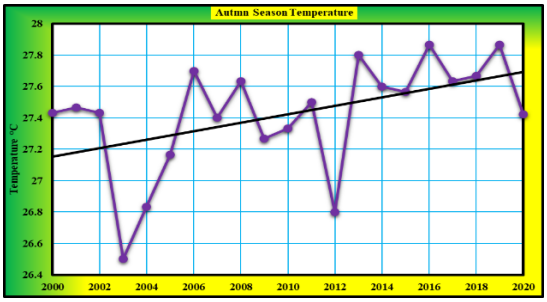

Figure 17: Represents Autumn Season Temperature Trend Line in Ghotki district 2000-2020

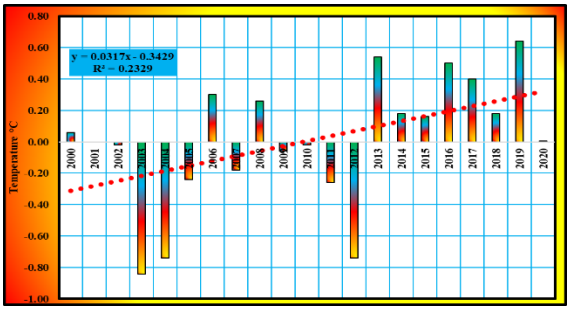

Figure 18: Represents Autumn Temperature Deviation in Ghotki district 2000-2020

3.3 Ghotki Feeder Discharge January & July Trends

Ghotki Feeder canal provides a maximum contribution of irrigation water for the agricultural land as well as the industrial sector in the area. The flowing water has been delivered at the highest demand for the Kharif period and lowest supply in the Rabi season. The discharge trend for January and July from 2000-2020 is shown in (Figures 19 & 21). The decreasing trend was observed in July 2000-2020. There was an increase in the water supply in the Ghotki feeder in 2010 due to heavy rainfall and flood in the study area. The slope was identified in the trend of July as -42.028. While in January -1.050. The trend has been increased due to a continuous flow of water in the irrigation network and low demand for crops in the Rabi season.

Table 5: Summary statistics of January and July Discharge of Ghotki feeder canal from 2000-2020

Variable	Observations	Obs. without missing data	Min Discharge Cusecs	Max Discharge cusecs	Mean	Std. deviation
January Discharge cusecs	21	21	2134	6433	3472.95	1157.62
July Discharge cusec	21	21	10700	13878	11547.79	623.13

Table 6: Illustrate Ghotki feeder discharge trends in January and July for the year 2000-2020

Parameters	Mann-Kendall Statistics (S)	Kendall's Tau	p-value	VAR (S)	Sen's Slope	Alpha	Test Interpretation
Discharge cusec January	-3	-0.014	0.952	1096.66	-1.050	0.05	H_o Accept
Discharge cusec July	-140	-0.667	<0.0001	1096.66	-42.028	0.05	H_o Reject

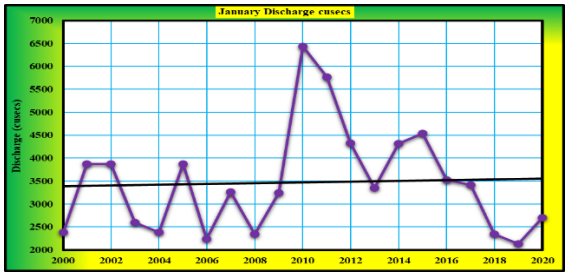

Figure 19: Represents January Month Discharge Trend Line of Ghotki Feeder Canal 2000-2020

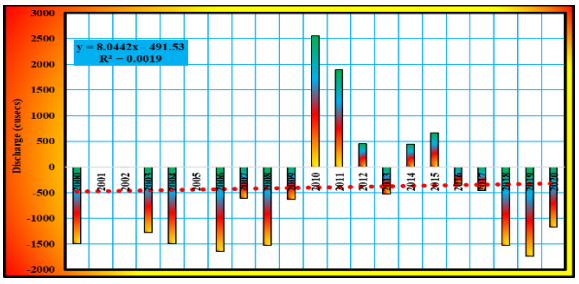

Figure 20: January Month Discharge of Ghotki Feeder Deviation in Ghotki district 2000-2020

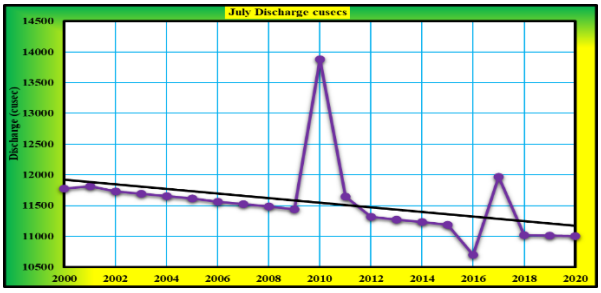

Figure 21: Represents July Month Discharge Trend Line of Ghotki Feeder Canal 2000-2020

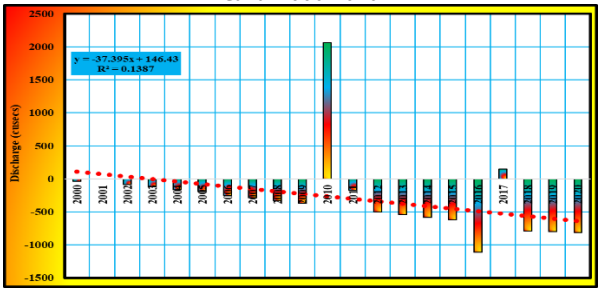

Figure 22: July Month Discharge Deviation of Ghotki Feeder in Ghotki district 2000-2020

4. Conclusion

The main target of this study is to detect and analyze trends of temperature, precipitation, discharge (annual and seasonal) from 2000-2020 in the district Ghotki by using the Mann Kendal test. The significance level has been tested at a 5% level. The results of the study have been concluded that the annual rainfall trend has increased from 2003 to 2019. The highest rainfall was noted in 2003 and 2010 (225 & 271 mm). There

was the highest rainfall occurred over the study area in 2010. The monsoon season trend was also increased and the slope was 0.863 was noted. While comparing monsoon and non-monsoon rainfall, there was a sharp increase in the non-monsoon period and the slope was estimated as 0.642. The trend of annual temperature has also been increased and the highest average temperature was recorded in 2016 and 2018 (28.5 & 28 °C). The summer and autumn season trend has sharply increased. While in the case of the Ghotki feeder flow rate the trend of discharge in January has increased due to the regular flow of water and less demand for water during the Rabi season. But in July month the highest discharge was recorded in 2010 due to heavy rainfall and flood situations over the study area and in the region. The supply of water and trend has been decreased in the Kharif season. The demand for irrigation water has the highest in the study area.

All the relevant past studies and literature on temperature and rainfall trends have a significant increase in the province and at the regional level in Pakistan. Researchers and Metrologists have proposed many climate change adaptations based on the analysis. In the present manuscript the annual and seasonal temperature, rainfall, and discharge reveal that there was an increase in trends at a lower significance level. The following conclusions can be made from studies: Change in temperature and precipitation emphasizes a new aspect of climate change effects on the study area and warn of a new challenge for water resources management in the semi-arid area facing climate change. The decreasing trend of discharge in the Kharif season might affect the water demand to meet the needs of growing communities, farmers, energy producers, and manufacturers. Irrigation and navigation would be affected severely. The findings of this study will help to streamline the policy adopted to combat variability and changes in the Ghotki district.

4.1 Future Directions

A proper plan of surface water consumption for irrigation is necessary to be prepared and implementation of the plan is needed and to be monitored. Climate variability not only affects the socio-economic factors but also the production of major crops including cotton, wheat, sugarcane, and rice in the region. It is recommended on a priority basis the different climate effect reduction and adaptive policies to overcome the food security and sustainability in the district.

4.2 Limitations of The Study

This study was carried out in MS excel and the data was taken from the different climate monitoring web portals. Thus, it is recommended that GIS and Remote sensing-based studies should be conducted in the district. The main focus should be on major crops including cotton, wheat, and sugarcane.

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