The relationship between climate variability and wheat yield in Tashkent province

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Abstract. This study focuses on the relationships between climate variability and wheat yield in Tashkent province. It contains a time series study of precipitation, temperature, and wheat yield, as well as the assessment of the link between yield and climatic factors and an examination of the influence of climate change on crop production using a regression model. Time series results of temperature present a positive trend in mean temperature in Bustanlik and Urtachirchik. Annual minimum temperature, the minimum temperature in spring, minimum temperature between September and May have changed significantly in Bustanlik over the years ($p<0.05$). Total precipitation shows a favourable trend in Bustanlik but a negative trend in Urtachirchik. There is no significant change detected in the time series. The magnitude of the change in climate variables shows no clear tendency. Wheat yield has changed significantly and increased up to 1.34 c/ha every year between 1998-2014. The highest association is determined between wheat yield and minimum temperature in the growing season (0.77) while the highest correlation was identified with the summer maximum temperature (-0.41) in Urtachirchik. The linear multiple regression model forecasted the wheat yield with a mean error of 0.08 c/ha in Urtachirchik and 0.06 c/ha in Bustanlik district.

1 Introduction

Agriculture's contribution to Uzbekistan's GDP fell from 37% to 17% between 1991 and 2017, yet it remains an important economic sector in the nation. In 2018, the rural population accounted for 49.4% of the total population or around 16 million people. This industry employs more than a third of the country's workforce [1].

According to the FAO, Uzbekistan produces 6.84 million tons of wheat per year and is the second-largest producer of wheat in Central Asia after Kazakhstan [2]. The total area under crops in the Tashkent region is 338.1 thousand hectares [3], of which 133.4 thousand hectares are cultivated with wheat [4].

Wheat, rice, and corn demand are predicted to rise to 390 million tonnes by 2024 and 3.3 billion tonnes by 2050, an increase of 800 million tonnes from 2014[5]. However, facing this demand will not be easy for farmers for several reasons, including climate change [6].

On the one hand, according to the Intergovernmental Panel on Climate Change (IPCC), each of the last four decades has been warmer than any previous decade since 1850. The global surface temperature in the first two decades of the twenty-first century (2001-2020) was 0.99 [0.84 to 1.10] °C higher than in the previous two decades (1850-1900). During 1950, average precipitation over land has most certainly increased, with a greater rate of increase since the 1980s (medium confidence). With high confidence, hot extremes have gotten more frequent and intense throughout most locations since the 1950s, whereas cold extremes have become less often and less severe. Under the extremely low GHG emissions scenario, the average temperature for 2081-2100 is very likely to be higher by 1.0°C to 1.8°C compared to 1850-1900. With more global warming, heavy precipitation events will intensify and become more common in most locations (very likely) [7].

On the other side, it is anticipated that the world's population would expand to 9.725 billion by 2050 [8]. Climate change trends and their effects on agricultural production must be studied to ensure sustainable agriculture. There are several studies, which attempted to analyze the impact of climate elements to crop yield by statistical models [9–12]. Most of them are focused to find the “best fit” model to predict crop yield by using several climate variables.

Poudel and Shaw (2016) conducted a study to determine relationships between historical climatic data and yield data for rice, maize, millet, wheat, and barley based on a regression model in Nepal. The study starts with a trend analysis (using Mann-Kendall and Sen’s Slope methods) of the last 30 years of temperature and precipitation data. The results show that climate variables had no significant impact on crop yields across the board. Regression analysis revealed negative relationships between maize yield and summer precipitation, as well as between wheat yield and winter minimum temperature, and a positive relationship between millet yield and summer maximum temperature [9].

Another study will employ statistical models to determine how tea yield responds to maximum temperature, lowest temperature, and precipitation over Nandi East Sub-County. The trend analysis findings also reveal a favorable tendency in rainfall and lowest temperature. Furthermore, climate factors during certain months in both the present and prior years were favorably connected with tea yield. 70% of the projections generated by the created model were correct [11].

The same research is published in northern Ghana. Temperature, number of dry days, onset, annual rainfall and cessation explained about 43%, 32%, 30%, 25% and 14%, respectively of the variations in the yields of groundnut, sorghum, millet, maize and rice [12].

As a result, this study focuses on understanding how the climate is changing and how it affects crop production in Tashkent province. The objectives of this study are as follows: (i) to conduct a time series analysis of precipitation, temperature, and wheat yield; (ii) to evaluate the link between yield and climatic factors using a regression model.

2 Materials and methods

2.1 Study area

The study area is in Tashkent region in the western part of Tien Shan Mountain. For the analysis, two of the districts were selected Bustanlik and UrtaChirchik, one in the piedmont plains and the second in the lowland (Figure. 1). Agriculture in the lowlands is mostly focused on irrigation, but the piedmont plains of the Bustanlik area are entirely rainfed. The total area of the province is 15,600 km2, and more than 20% of the total area is engaged in agriculture [13].

The climate in the area is continental. The annual minimum and maximum temperatures are −26°C and +46°C. The total amount of precipitation reaches up to 800–1200 mm per year and falls in autumn and spring. The vegetation period is 210-215 days in the year [14]. The district is covered by mountains such as the Western Tien Shan, Karzhantau, Pskem, Ugam and Chatkal.

Urtachirchik is in the middle of Tashkent Province. The climate in the district is arid continental. The absolute summer mean maximum temperature is +36°C. The area of Urtachirchik district is 510 km. The vegetation period is about 200 days [15].

Bustanlik is the largest district in the province. The climate in the area is continental. The annual minimum and maximum temperatures are −26°C and +46°C. The total amount of precipitation reaches up to 800–1200 mm per year and falls in autumn and spring. The vegetation period is 210-215 days in the year [16]. The district is covered by mountains such as the Western Tien Shan, Karzhantau, Pskem, Ugam and Chatkal [14].

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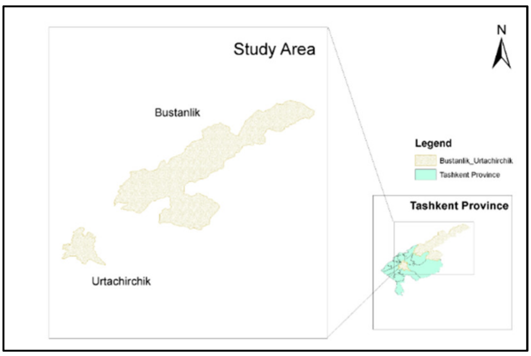

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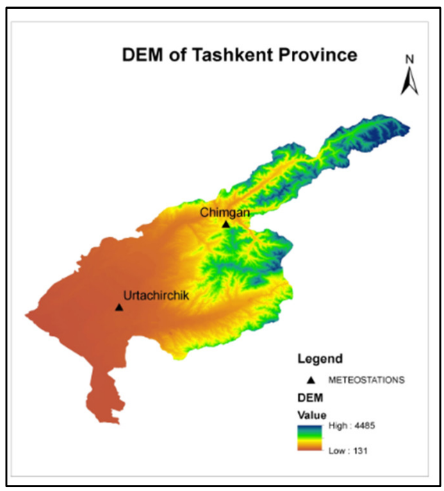

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Fig. 1. Maps of the study area (left) Location of Bustanlik and Urtachirchik districts and (right) Digital elevation model and meteorological station.

2.2 Research methodology

Analyses

The research attempted to use a multiple linear regression model to predict the yield of wheat based on changes in mean, maximum, minimum temperature, and precipitation over the area of study. Correlation analysis was done to determine the statistical relationship between the variables. Regression was conducted using XLSTAT statistical software. Attempts were made to reach up with a multiple linear regression equation that best represents the relationship between the variables.

Trend analysis: Mann Kendall and Sen's slope test. To conduct time series analyses for climate and crop yield data, the Mann-Kendall and Sen`s slope tests were completed. The seasonal and annual trends were analyzed for the following variables (Table 1):

Table 1. Produced climate variables.

$T_{mean\ annual}$	$T_{mean\ sep\_may}$	$T_{min\ summer}$	$T_{max\ spring}$	Pcp_{winter}
$T_{mean\ autumn}$	$T_{min\ annual}$	$T_{min\ sep\_may}$	$T_{max\ summer}$	Pcp_{spring}
$T_{mean\ winter}$	$T_{min\ autumn}$	$T_{max\ annual}$	$T_{max\ sep\_may}$	Pcp_{summer}
$T_{mean\ spring}$	$T_{min\ winter}$	$T_{max\ autumn}$	Pcp_{annual}	Pcp_{sep_may}
$T_{mean\ summer}$	$T_{min\ spring}$	$T_{max\ winter}$	Pcp_{autumn}	

where, T-Air temperature, Pcp-Precipitation, min – minimum, max - maximum

Mann-Kendall is a non-parametric test that compares the magnitudes of the values and identifies a trend in the time series [18]. Particularly, this method can be used for non-normally distributed time series data [9]. The dataset is evaluated in ordered time series and each value is compared to all values in the dataset. The initial value of the Mann-Kendall statistic supposed as no trend (S=0). Each subsequent value is calculated by incrementing or decrementing by one based on the dataset's prior (higher or lower) values. S's final value is the sum of all increments and decrements.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \tag{1}$$

where, $$sign(x_j - x_k) = \begin{cases} 1\ if\ (x_j - x_k) > 0 \\ 0\ if\ (x_j - x_k) = 0 \\ -1\ if\ (x_j - x_k) < 0 \end{cases}$$

$x_1, x_2, \ldots, x_n$ - n data points

x_n - n data points

x_j - data points at j time

The next step is to calculate the variance of S, since it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend.

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

where,

n – the number of data points

g - the number of tied groups (a tied group is a set of sample data having the same value)

t_p - the number of data points in the pth group

Compute a normalized test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{[VAR(S)]^{\frac{1}{2}}}\ if\ S > 0 \\ 0\ if\ S > 0 \\ \frac{S+1}{[VAR(S)]^{\frac{1}{2}}}\ if\ S < 0 \end{cases} \qquad) \qquad (3$$

If Z>0, it means an increasing trend whereas Z<0 indicates a decreasing trend. The calculations were completed with 95% confidence. In this test, the null hypothesis (H0) means that there is no trend whereas the alternate hypothesis (H1) shows there is a trend in time series. If the computed p-value is lower than the significance level alpha=0.05, one will reject the null hypothesis H0, and accept the alternative hypothesis H1.

Next, the magnitude of a time series trend was evaluated by a simple non-parametric method suggested by Sen. The slope is computed using Equation 4:

$$\beta = Median\left(\frac{x_j - x_i}{j - i}\right), j > 1 \tag{4}$$

where,

β – Sen`s slope estimate

β>0 means an upward trend in a time series. Otherwise, the dataset shows a downward trend in the time series.

Climate-Crop Yield Relationship

Correlation coefficient and multiple regression analyses have been performed to determine the climate-crop yield relationship. The correlation coefficient Pearson was used to evaluating the strength of the association and shows a linear relationship between climate variability and crop yield. The range of correlation coefficients is -1 to +1. The complete independence variables represent 0. The following equation was used in the computation [9]:

$$r = \frac{\sum(x-y)(y-y)}{\sqrt{\sum(x-x)^2(y-y)^2}} \quad (5)$$

where,

x – independent variable

y – dependent variable

Multiple linear regression analysis includes more than one independent and one dependent variable. This function allows you to make predictions about one variable based on what you know about another unknown variable. The statistical behavior of the various variants of the regression model was used to determine the "best fit" model. In the computation, Equation 6 was employed [11]:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \dots \beta_n x_n \quad (6)$$

where,

Y – crop yield (predictand)

x – climate variable (predictor)

β – coefficients of the climate variables

β_0 – constant

Data

Climate data from two meteorological stations was used in this study. The first is Chimgan meteorological station, which is in Bustanlik district, and the second is Tuyabogiz in Urtachirchik. Chimgan is situated 1670 meters and Tuyabogiz 500 meters above sea level. The meteorological stations of the Centre of Hydrometeorological Service under the Cabinet of Ministries of the Republic of Uzbekistan (Uzhydromet) record daily climate variables. Both meteorological stations provide temperature and precipitation data. However, while maximum and minimum temperatures were not recorded beyond 2011, climatic data from Tuyabogiz between 1990 and 2014 and Chimgan between 1990 and 2011 were utilized in this work. Based on the available daily mean, maximum, minimum temperature, and the sum of precipitation were produced variables for future analysis (Table 1).

One of the main crops of the study area, winter wheat (Triticum aestivum) was considered in the study. Winter wheat yield data was obtained from The State Committee of the Republic of Uzbekistan on Statistics (UZSTAT). It is noted that the wheat yield information is available only after 1998 for the province in UZSTAT. Wheat is grown in the study region from September to July each year. The annual wheat yield data from 1998 to 2014 of the provinces was used in this paper.

3 Results and discussion

The mean, minimum, maximum temperature, and accumulated precipitation of the seasonal, growing period, annual trend analysis has been analyzed using Man-Kendall and Sen's Slope methods. As well, the trend analysis of the crop yield and the relationship with the climatic variables has been performed. The multiple linear regression analysis was conducted between annual crop yield and climate variables. Climate variables were considered the explanatory variables, and crop yield was considered the dependent variable.

Temperature trend
Figure 2 shows the time series of the annual mean temperature. There is a positive trend in the mean temperature in both districts. Table 2 shows that the annual minimum temperature, minimum temperature in spring, and minimum temperature between September and May in Bustanlik have all changed over time (p 0.05). However, there is no significant change in climate variables in Urtachirchik during the time series.

The findings in Bustanlik are consistent with findings of past studies by Erdanev et al., which analyzed climate change in Tashkent province based on the reanalysis data. The results demonstrate the increasing trend of average monthly temperature in January, April, July and October [19].

Another study reported a determination of the largest increase (more than 1ºC) in monthly mean temperature in the western part of Tashkent province. Temperature changes in the province's northeast (1.26 0C) reached a degree of significance of more than 95% in the current 1991-2016 period, according to the trend analysis [20].

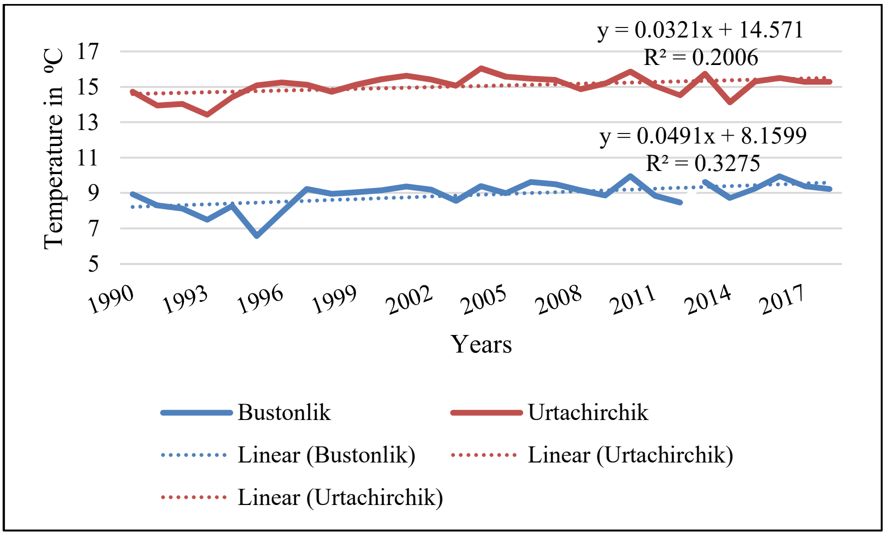

Fig. 2. The Time Series of the Annual Mean Temperature over the Study Area

Bustanlik's mean temperature climbed by up to 0.140C each year, whereas Urtachirchik's mean temperature decreased by up to -0.150C per year, omitting autumn and summer seasons. Bustanlik's minimum temperature rose by up to 0.2000C every year. A similar positive trend can be seen in Urtachirchik with the temperatures increasing up to 0.07ºC/year excluding minimum temperature in winter (-0.084ºC/year). Maximum temperature in most cases in both districts decreased up to -0.21ºC/year. However, maximum temperature in spring is increased by 0.07ºC in Bustanlik and 0.03ºC/year in Urtachirchik (Figure 2).

Table 2. Trend analysis results for the temperature

Variable	Bustanlik			Urtachirchik			
	Sen's slope	p-value	Significance	Sen's slope	p-value	Significance	Alpha value
Tmean annual	0.021	0.584	No	-0.026	0.484	No	0.05
Tmean autumn	0.031	0.956	No	0.006	0.837	No	0.05
Tmean winter	0.007	0.956	No	-0.159	0.138	No	0.05
Tmean spring	0.142	0.228	No	-0.111	0.484	No	0.05
Tmean summer	0.055	0.511	No	0.073	0.482	No	0.05
Tmean sep_may	0.033	0.324	No	-0.017	0.458	No	0.05
Tmin annual	0.101	0.004	Yes	0.019	0.711	No	0.05
Tmin autumn	0.143	0.228	No	0.064	0.232	No	0.05
Tmin winter	0.113	0.351	No	-0.084	0.230	No	0.05
Tmin spring	0.206	0.032	Yes	0.070	0.186	No	0.05
Tmin summer	0.080	0.089	No	0.061	0.174	No	0.05
Tmin sep_may	0.137	0.004	Yes	0.002	0.902	No	0.05
Tmax annual	-0.038	0.476	No	-0.069	0.064	No	0.05
Tmax autumn	-0.029	0.913	No	-0.067	0.343	No	0.05
Tmax winter	-0.125	0.298	No	-0.210	0.083	No	0.05
Tmax spring	0.073	0.661	No	0.036	0.805	No	0.05
Tmax summer	-0.023	0.742	No	-0.008	0.902	No	0.05
Tmax sep_may	-0.022	0.584	No	-0.070	0.077	No	0.05

Precipitation trend

Figure 3 shows the time series of the annual total precipitation. There is a positive trend in precipitation in Bustanlik and a negative trend in Urtachirchik. From Table 3, it is noted that there is no significant change detected in the time series. Bustanlik's annual total, spring, and precipitation are all decreasing, whereas Urtachirchik's precipitation is decreasing in all circumstances, up to -2.12 mm/year excluding autumn precipitation. Autumn and winter precipitation in Bustanlik is raised by 2.59 mm/year and 0.95 mm/year, respectively.

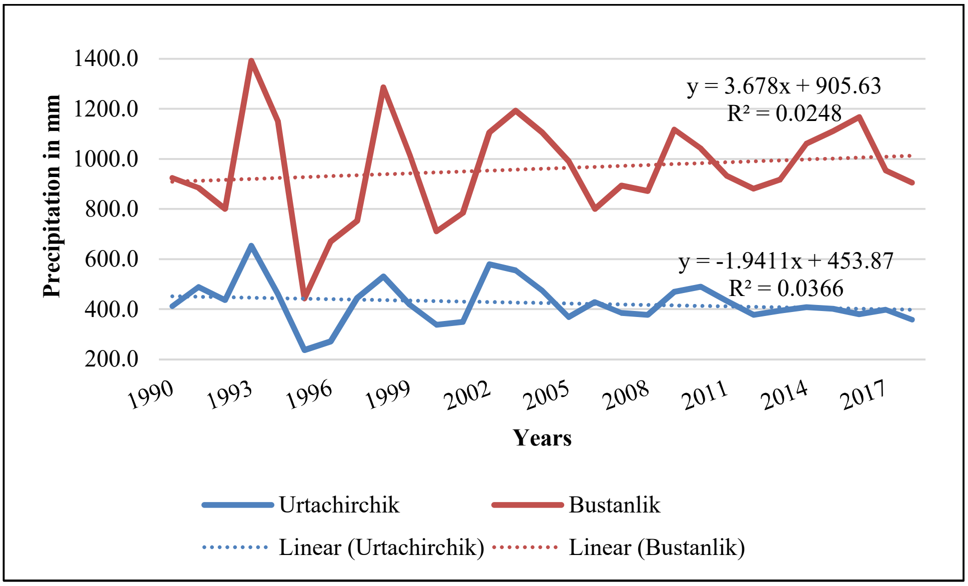

Fig. 3. The Time Series of the Total Precipitation over the Study Area.

Table 3. Trend analysis results for the precipitation

Variable	Bustanlik			Urtachirchik			
	Sen's slope	**p-value**	**Significance**	**Sen's slope**	**p-value**	**Significance**	**Alpha value**
Pcp annual	-8.100	0.743	No	-2.126	0.773	No	0.05
Pcp autumn	2.592	0.743	No	0.040	0.967	No	0.05
Pcp winter	0.950	0.743	No	-1.165	0.837	No	0.05
Pcp spring	-1.980	1.000	No	-1.357	0.837	No	0.05
Pcp summer	-4.550	0.189	No	-0.973	0.127	No	0.05
Pcp sep_may	1.936	0.913	No	-2.049	0.711	No	0.05

The research findings by Erdanaev et al. (2015) also pointed towards the variable trend of precipitation. A little decrease in precipitation over the croplands, pasturelands and grasslands was identified in the study [19]. Moreover, Gafforov et al. reported a significant decline in the average monthly rainfall and an increase in winter rainfall intensity in the province [21]. On the one hand, in contrast, our results indicate a decreasing trend of winter precipitation in Urtachirchik. On the other hand, the decline of precipitation in March consisted of the negative trend in spring precipitation in both districts.

Crop yield trend

Figure 4 illustrates the time series of the wheat yield between 1998 and 2016. There is a positive trend in the wheat yield in both districts. Table 4 presents significant rates and magnitudes for wheat yield in all districts of Tashkent province.

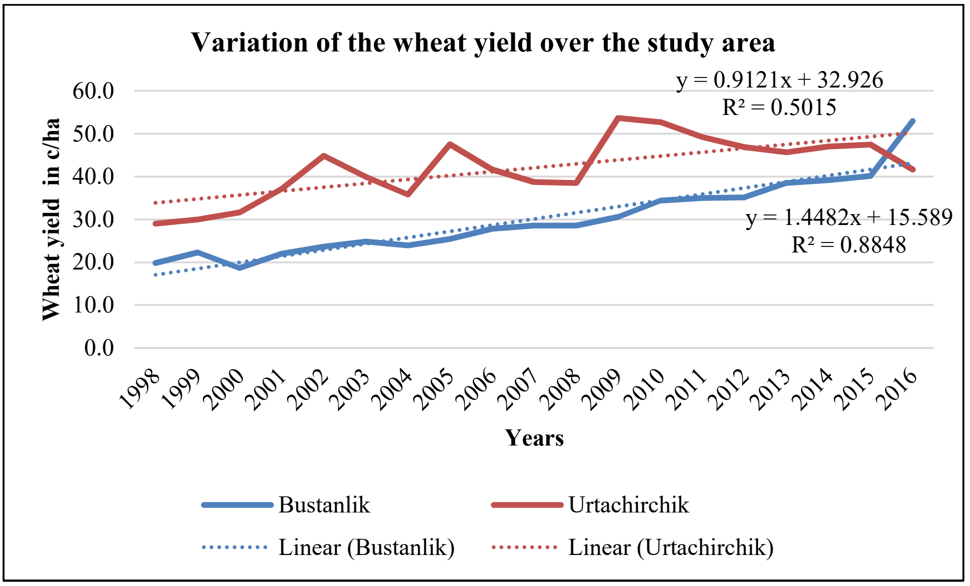

Fig. 4. The Time Series of the Variation of the Wheat Yield over the Study Area.

Table 4. Trend analysis results for yield in Tashkent province.

Districts	Significance	P-value	Sen's slope	Alpha value
Okkurgan	Yes	<0.0001	1.476	0.05
Ohangaron	No	0.248	0.325	0.05
Bekobod	Yes	0.001	0.858	0.05
Bustonlik	Yes	<0.0001	1.340	0.05
Buka	Yes	0.003	0.856	0.05
Zangiota	Yes	0.000	1.356	0.05
Kibray	Yes	0.000	1.438	0.05
Kuyichirchik	Yes	0.003	1.610	0.05
Parkent	Yes	0.009	0.350	0.05
Pskent	Yes	<0.0001	1.760	0.05
Urtachirchik	Yes	0.005	0.981	0.05
Chinoz	Yes	<0.0001	0.750	0.05
Yukorichirchik	Yes	<0.0001	1.538	0.05
Yangiyul	No	0.142	-0.390	0.05

From the table, it is noted that there is a significant trend in all districts excluding Ohangaron and Yangiyul. In most districts, Sen's slope values increase between 0.32 and 1.76 c/ha/year. Only in Yangiyul, has the yield decreased to -0.39 c/ha every year. The districts that are chosen as a study area, have a significant wheat yield trend and increase up to 1.34 c/ha per year. It is apparent that wheat yield is increasing at a different level in the province. To determine the relationship between the climate factors and wheat yield, we have conducted correlation and multivariate regression analysis.

Correlation analyses of climate variables with wheat yield

Correlation and multivariate regression analyses were conducted to determine the relationship between the climate factors related to the wheat cultivation period and wheat yield in the time series (Table 5). The results reveal that there was a strong and positive relationship between wheat yield and the minimum temperature in the growing season (0.77), whereas there was a moderate positive correlation between mean temperature of the growing season (0.52), minimum temperature of autumn (0.47) and minimum temperature of spring (0.54) in Bustanlik. The weakly positive correlation can be seen with the total precipitation in winter (0.23).

The finding indicates a low correlation between wheat yield and climatic factors in Urtachirchik than in Bustanlik. The highest negative correlation was identified with the maximum temperature in summer (-0.41). The maximum temperature in the growing season (-0.35) and maximum temperature in autumn (-0.30) has a moderate negative correlation while minimum temperature in the growing season (-0.33) has a moderate positive correlation with the yield. The total precipitation in spring, summer and growing season has a weakly positive correlation of 0.21, 0.24 and 0.23, respectively.

Table 5. Correlation analyses of climate variables with yield.

Variable	**R^2**	
	Bustanlik	**Urtachirchik**
$T_{mean\ autumn}$	0.160	0.050
$T_{mean\ winter}$	0.085	-0.058
$T_{mean\ spring}$	0.248	0.106
$T_{mean\ sommer}$	-0.112	-0.107
$T_{mean\ sep\_may}$	0.518	0.021
$T_{min\ autumn}$	0.468	0.171
$T_{min\ winter}$	0.222	0.090
$T_{min\ spring}$	0.543	0.268
$T_{min\ sommer}$	-0.040	0.259
$T_{min\ sep\_may}$	0.768	0.333
$T_{max\ autumn}$	0.091	-0.303
$T_{max\ winte}$r	-0.034	-0.177
$T_{max\ spring}$	-0.014	-0.112
$T_{max\ sommer}$	-0.157	-0.411
$T_{max\_sep\_may}$	0.195	-0.350
Pcp_{autumn}	0.071	0.084
Pcp_{winter}	0.232	0.154
Pcp_{spring}	0.135	0.211
Pcp_{sommer}	0.078	0.238
$Pcp_{\_sep\_may}$	0.142	0.232

Wheat yield change and Sen`s slope test results for the time series between 1996-2016 are represented by ArcGIS 10.3. From the wheat yield change map (Figure 5), it is obvious that the wheat yield increases in the northeastern and central parts of the province while in the southeastern and western parts decreases. The sharp change by year is determined in the northwestern and southeastern parts.

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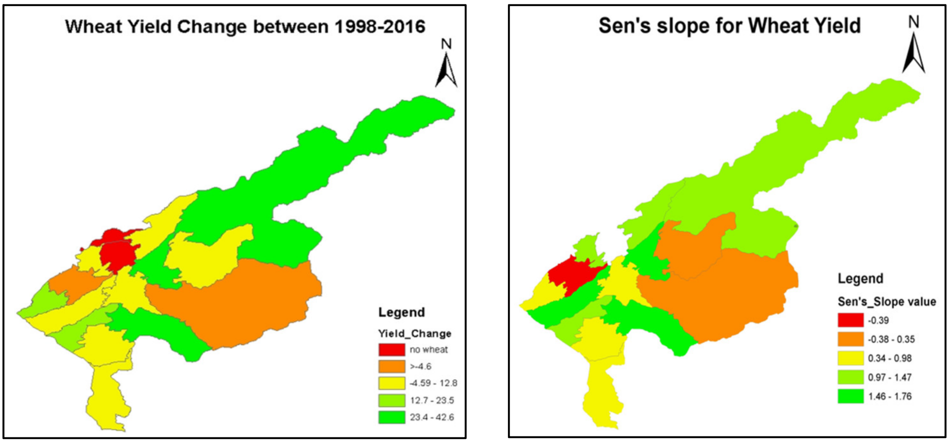

Fig. 5. Wheat yield change between 1998-2016, values are given in center/hectare (right) and Sen`s slope values for wheat yield, values are given in center/hectare/year (left).

Multiple linear regression analysis

To assess whether there is a direct relationship between climatic variables and crop yield in Bustanlik and Urtachirchik, multiple linear regression analysis between mean, maximum, temperature, total precipitation, and wheat yield was performed. Attempts were made to produce a multiple linear regression equation that best represents the relationship between the variables. The "best fit" model is presented below (Table 6).

Table 6. Multiple regression relationship between climate variables and yield.

Province	**Regression Function**	**Adjusted R2**	**Significance**
Bustanlik	Y = 52.81*Tmin sep_may-3.63*Tmax sep_may	0.85	<0.0001
Urtachirchik	Y= 74.54+20.63*Tmean spring-16.28*Tmax spring	0.63	<0.0001

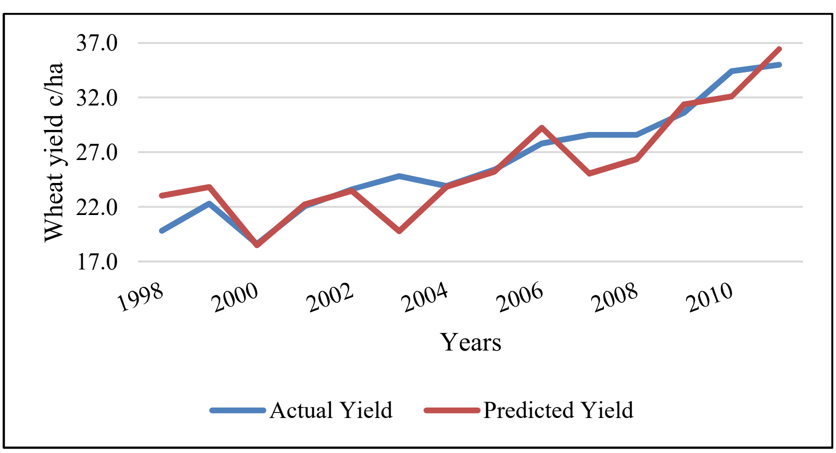

Fig. 6. Line chart of Actual and Predicted Yield in Bustanlik.

Figures 6 and 7 show a line chart representing the regression model that was developed and judged to be best representing the best model performance. The wheat yield was projected with a mean error of 0.08 c/ha in Urtachirchik and 0.06 c/ha in Bustanlik district using the linear multiple regression model. The p-value, indicating the significance of the model is very low in both cases while in Bustanlik adjusted R^2 is higher (0.85) than in Urtachirchik (0.63).

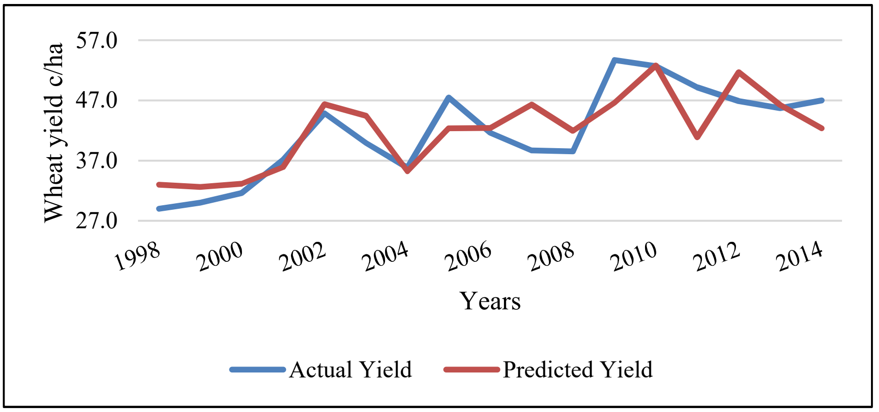

Figure 7. Line chart of Actual and Predicted Yield in Urtachirchik.

4 Conclusions

The following findings are drawn from this study, which examines the link between winter wheat production and climatic variables like as temperature and precipitation in Tashkent region and proposes a forecasting model: GansuTime series results based on the Mann-Kendall test of temperature show a positive trend in the mean temperature in Bustanlik and Urtachirchik. However, the precipitation Figures reflect a distinct trend: total precipitation is positive in Bustanlik and negative in Urtachirchik. There is no significant change detected in precipitation over the time series. Sen`s slope analysis indicates no clear tendency of the magnitude of the change in climate variable. Wheat yield had significant change and increased up to 1.34 c/ha every year.

This study finds that wheat yield in Bustanlik is more strongly connected with climatic factors than in Urtachirchik. In Urtachirchik, the strongest connection was found between wheat yield and the minimum temperature during the growing season (0.77), while the lowest correlation was found between wheat output and the July maximum temperature (-0.41). However, the results of the linear multiply regression analysis revealed that in Bustanlik the best statistical results were obtained by using minimum and maximum temperature in the growing season while in Urtachirchik maximum and mean temperature forecasted the wheat yield than other climate variables. The model forecasted the wheat yield with the mean error of 0.08 c/ha in Urtachirchik and 0.06 c/ha in Bustanlik district. The p-value is very low in both cases while in Bustanlik adjusted R2 is higher (0.85) than in Urtachirchik (0.63). Therefore, it is recommended in further research to consider other factors such as irrigation and water availability for assessing yield response in the region.

Assessing the influence of climate change on production enables long-term agricultural operational management and assures food security sustainability. This study's findings may be normal, but they might also help forecast the possibility of a negative effect induced by climate change in the region. Adapting agricultural techniques such as altering sowing dates and modifying wheat varieties depending on future climatic indicators may lessen the negative impact of climate change on wheat output to enhance the forecasting model.

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