# Climate Change Implications for Wheat Crop in Dera Ismail Khan District of Khyber Pakhtunkhwa

Khan, A. A.[1], M. Ijaz[1], J. Muhammad[2], A. R. Goheer[1], G. Akbar[3], M. Adnan[1]

***Abstract***

*Temperature and rainfall are the major climate factors affecting crop growth and development, especially under rain-fed agriculture. The changing and diversified climatic conditions of Khyber Pakhtunkhwa (KPK) from northern to southern regions under the current climate change scenario may pose serious threat to crop production and livelihood. Addressing these issues and keeping in view the importance of wheat as a major staple crop of Khyber Pakhtunkhwa (KPK), this research study was conducted to assess the impact of climate change on net irrigation requirement (NIR), actual crop evapotranspiration (ETc) and reference crop evapotranspiration (ETo) of wheat crop using Penman Montieth method through CROPWAT model developed by Food and Agriculture Organization (FAO), while using historical weather data from 1961-2010 of Dera Ismail Khan. The results showed increasing temporal tendency in temperature and rainfall during the study period. Positive correlation was found between temperature and ETo, ETc and NIR, which indicate increasing tendency in water demand in future, thus may lead to negative consequences for crop growth and development, if appropriate measures were not undertaken timely. In contrast, rainfall showed negative correlation with ETo, ETc and NIR, which may support in meeting crop water demand in future, thus may boost wheat production. Importantly, the increasing temporal tendency of rainfall and temperature necessitate the need for greater rainwater harvesting to meet the increasing irrigation requirement in Dera Ismail Khan Division.*

**Key Words:** Water Requirement, CROPWAT, Net Irrigation Requirements, Reference Evapotranspiration Climate Change, Rabi Growing Season.

## Introduction

Climate change is a global phenomenon which attracted strong attention during the last two decades. Gradual changes in temperature and rainfall pattern are evident in many regions around the world. Based on scientific evidence an increase of 2 °C-4.5 °C in global-average surface temperatures is predicted by the end of the 21$^{st}$ century against the current rate of average air temperature rise of 2 °C per century (Salinger, 2005). The global air temperature has shown 0.3 °C–0.6 °C rise during the 19$^{th}$ century, 0.2 °C –0.3 °C during the last 40 years while 1990s decade was the warmest period of the previous century (Jones and Briffa, 1992). Similarly, Hingane et al., (1985) reported that until 1980s in past 20$^{th}$ century the global average temperature raised by 0.4 °C per 100 years. According to Kothawale and Rupa (2002), mean annual temperature raised by 0.5 °C over the last century. However uncertain, uneven, spatial and temporal distribution of rainfall on one hand not only create a flooding devastation but also become cause of longer dry spells evoking droughty conditions (Lai et al., 1998). The frequency and intensity of drought have been increased in recent decades in some parts of Asia and Africa whereas long term change in precipitation is evident in many places of the world (Wang et al., 2001). So it has been proved that climate change is a well-established and gospel fact and there is an intense need to be ready for the upcoming expected changes in climate. Different approaches and conditions (statistical, hydrological and biophysical and different scenarios defined by IPCC (Intergovernmental Panel on Climate Change) have been implemented by different organizations and researchers to predict and forecast the upcoming climate changes. According to (IPCC, 2007) in Asian reign both rainfall intensities and frequencies has increased.

Pakistan lie in a region subject to worse climate change induced risks. The most vulnerable and susceptible sector to climate change in Pakistan economy is Agriculture. A number of climatic factors including

[1] Scarpion982@gmail.com

Global Change Impact studies Centre (GCISC), Ministry of Climate Change, Islamabad, Pakistan.

2 Department of Water Management AUP

3 Climate Change, Alternate Energy and Water Resources Institute (CAEWRI), NARC, Islamabad, Pakistan.

evapotranspiration, rainfall pattern, land suitability, changes in sowing dates, temperature hike and water availability are affecting agriculture productivity. According to Mendelshon et al., (1993) climatic factors and parameters are crucial for crop yield and agricultural productivity. Climate change affects agriculture in many ways including shrinking of agricultural output and growing life of crops. Accelerated melting of glaciers on northern parts, frequent intense and extreme climatic events like drought, floods and heat wave are the signs of climate variation in Pakistan (Cruz et al. 2007). A number of studies with different approaches, techniques and tools have been conducted so for to study climate variation as well as the warming trend in Pakistan (Afzal et al, 2009; Chaudhry and Rasul, 2007; Chaudhry and Sheikh. 2002). The climate variations may have serious consequences for the agriculture and livelihood of farming communities of Pakistan in general and Khyber Pakhtunkhwa (KPK) province in particular. For instance, (Huq et al., 1999) reported that winters have become hotter and warmer in this region. Hussain and Mudasser (2007) stated that wheat yields can be declined by 7 % to 24 % and increased by14 % to 23 % if temperature raised from 1.5 to 3$^{o}$C in Swat and Chitral districts respectively. Similarly, precipitation increase of 5–15 % in future during the growing Rabi season shows a negligible impact on wheat yield. Moreover, Hussain et al., (2005) stated that in the sub mountainous region monsoon and winter seasons' temperatures have increased by 0.11 °C and 0.21 °C respectively. In the high mountain region winter temperature have increased by 0.46 °C. However, these studies are limited to temperature and precipitation and little concentration have been given to the ETo, crop water requirement (ETc) and NIR.

Keeping in view the above mentioned issues and vulnerability of KPK agriculture to climate change, the present study is focused on investigating changes in temperature and precipitation during the last fifty years (1961-2010) and their impact on ETo, crop evapotranspiration (ETc) and NIR of wheat in Dera Ismail Khan, southern zone of Khyber Pakhtunkhwa (KPK). The purpose of this paper is to document the impact of climate change on agriculture and water resources that have been occurred during last five decades in district Dera Ismail Khan and to devise future adaptation strategy to cope with the future expected changes in climate change.

## Materials and Methods

### Study Area

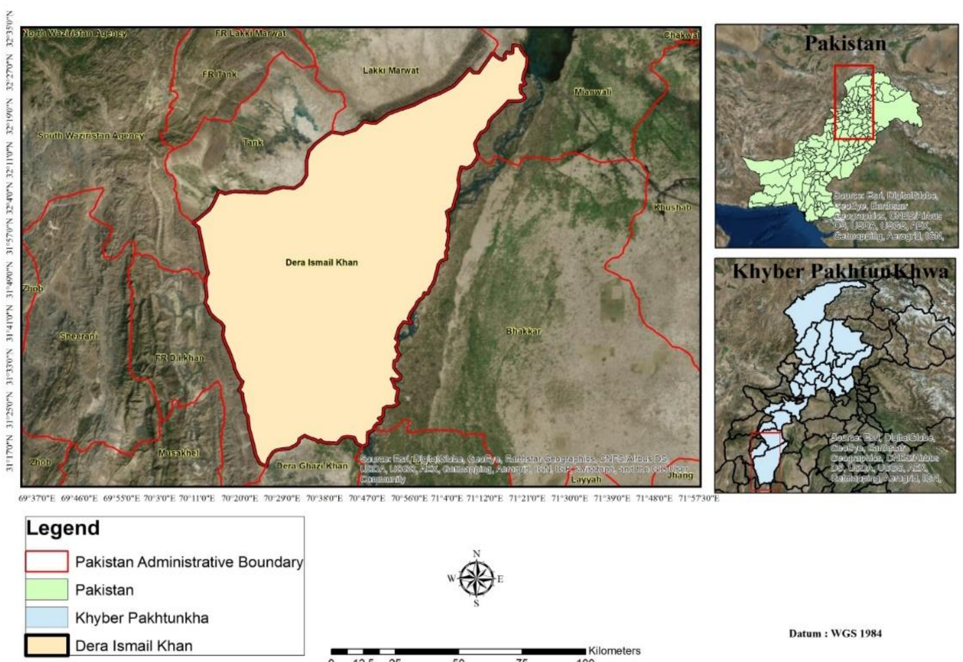


**Figure 1:** Map of Dera Ismail Khan.

Dera Ismail Khan is in the southern part of Khyber Pakhtunkhwa with a latitude (35.56 °N) and longitude (70.56 °E). The district lies in the arid zone where mean, minimum and maximum annual temperatures are 24 °C, 17 °C and 32 °C respectively. Agriculture is the major source of livelihoods in the district. Wheat is the dominant crop in the area during Rabi season and is sown from 1st of October to mid of November and harvested from 1st of April till the mid of May.

**Data Collection and Analysis**

The required data was obtained from Pakistan Meteorological Department (PMD) for Dera Ismail Khan for the years 1961 to 2010. The data was processed for the analyses in CROPWAT 8.0 model developed by the FAO (Clark et al. 2003). CROPWAT 8.0 model was used for calculating ETo, crop water requirement (ETc) and NIR of wheat crop. Reference crop evapotranspiration was computed through FAO Penman-Monteith method (equation 1) from meteorological data using FAO standard units.

$$ETo = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+373} \mathcal{U}_{2(e_s - e_a)}}{\Delta + \gamma(1 + 0.34\mathcal{U}_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The Kc values for wheat crop from FAO Irrigation and Drainage Paper No. 56 was incorporated in CROPWAT 8.0 model for the given duration of crop stages. The Crop Evapotranspiration (ETc) was calculated by multiplying the ETo with the crop coefficient (Kc) as shown in equation 2.

$$ETc = K_c * ET_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For simplicity of the research, fixed percentage (80%) of the total monthly rainfall was taken. Net irrigation requirement is the remaining part of crop water requirement after deducting the effective rainfall ($P_{eff}$) as given in equation 3.

$$I_{net} = ET_C - P_{eff} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where $I_{net}$ is Net Irrigation Requirement [mm/season], ETc is Crop Evapotranspiration [mm/season] and $P_{eff}$ is effective rainfall [mm/season].

Further to investigate changes in temperature, rainfall, Referece crop evapotranspiration (ETo), wheat crop water requirement (ETc) and wheat NIR was taken as linear function of time period according to equation 4.

$$\Delta(T, Rainfall, ETo, ETc\ and\ NIR) = \int Time\ Period(years) \quad \ldots\ldots\ldots\ldots (4)$$

For calculating temperature and rainfall interaction, rainfall was taken as a function of temperature. For ETo, wheat crop water requirement (ETc) and wheat NIR calculation, initially they were taken as a function of temperature and then as a rainfall and their impacts were investigated. To check the statistical significance that null hypothesis Ho: β = 0 the t-value of each parameter was calculated for significance level of 0.05 with the following equation 5.

$$t_{cal} = \frac{\hat{\beta}}{S.E(\hat{\beta})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where $\hat{\beta}$ is the coefficient (i.e. slope) and S.E is standard error of $\hat{\beta}$ which shows the rate of change in temperature or rainfall per unit time. It was calculated according to equation 6.

$$S.E_{yx} = \sqrt{\frac{\Sigma(y-\bar{y})^2 \frac{[\Sigma(x-\bar{x})(y-\bar{y})]^2}{\Sigma(x-\bar{x})^2}}{n-2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where n is number of sample size

Schematic variation of Crop Coefficient in relation to different wheat crop development stages under normal conditions has been presented in Figure 2

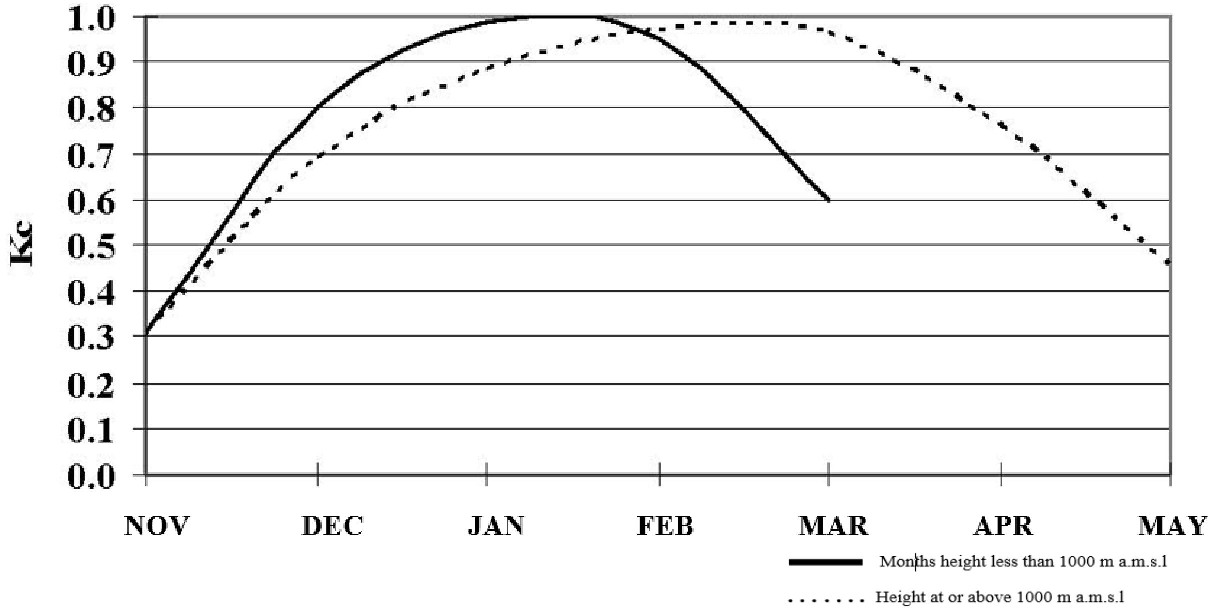


**Figure 2:** March of Crop Coefficient (Kc) for normal duration of Wheat growing season (Emergence to WaxMaturity) (Rasul.1993)

## Results and Discussion

### Temperature Interaction with Reference Crop Evapotranspiration (ETo), Crop Evapotranspiration (ETc) and Net Irrigation Requirements (NIR) of Wheat Crop

Climatic factors such as air temperature, rainfall, solar radiation, relative humidity and wind velocity are the major factors affecting crop water requirements and agronomic factors like biomass and crop yield (Rasul; 1993). Productivity of wheat and other many crop species falls markedly at high temperatures. Acute effects of high temperature are most striking when heat stress occurs during anthesis. Temperature increase sensitizes crop growth by increasing its evapotranspiration rate from crop canopy and soil surface. In our study temperature changes has been correlated with ETo, ETc and NIR for its impact assessment. Results showed linear regression and positive correlation of average seasonal temperature with seasonal ETo, wheat crop evapotranspiration (ETc) and NIR) as shown in Figure 3, 4 and 5 respectively for time period 1961-2010 in Dera Ismail Khan. The highest reference crop evapotranspiration and wheat crop evapotranspiration was identified as 474.94 mm and 412.1 mm in 2004 at highest recorded temperature of 19.05°C while lowest reference crop evapotranspiration and wheat evapotranspiration was reported 432.86 mm and 370.7 mm in 1983 and 2005 at 16.425 °C and 17.566 °C temperatures respectively for the study period. The reference crop evapotranspiration and wheat crop evapotranspiration has shown increasing tendency with increasing temperature which tended to impact on reference and wheat crop evapotranspiration throughout its growing season. Similarly net irrigation requirements of wheat crop showed an increasing tendency with increasing temperature which indicated 393.7mm as highest and 204.8mm as lowest at recorded temperature of 18.15 °C and 17.1 °C in 1971 and 2007 respectively. This increasing trend in crop water requirements and net irrigation requirements of wheat might have negative consequences for crop yield due to current climate induced risks, which indicate increasing temperature in the future.

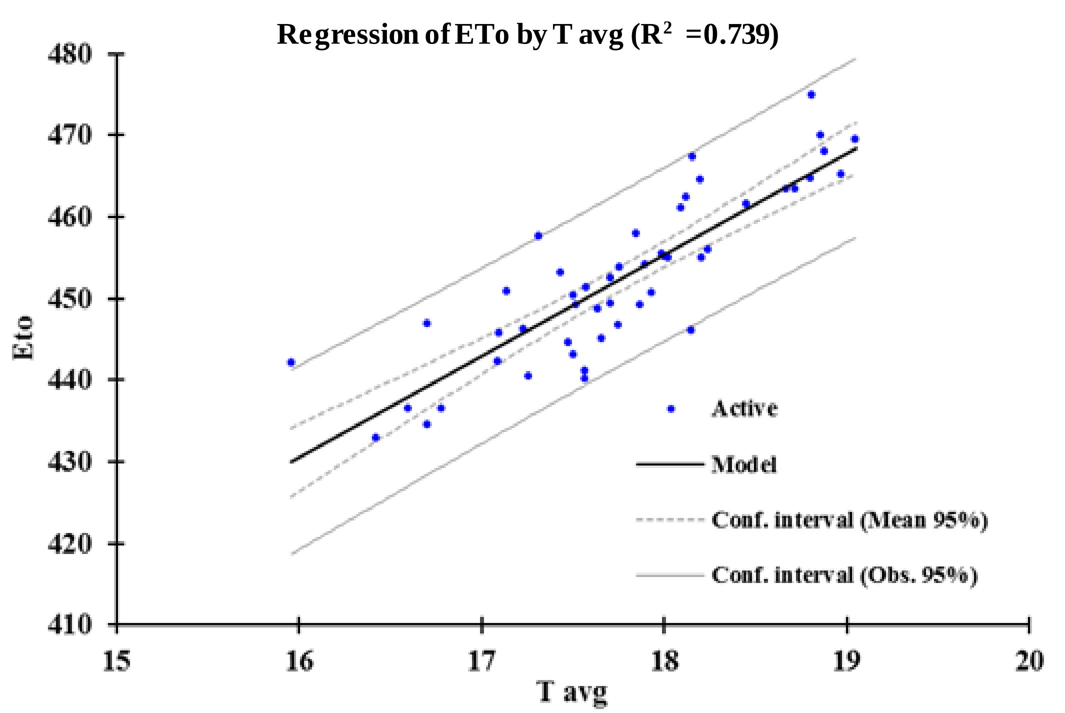


**Figure 3:** Relation between temperature and reference crop evapotranspiration (ETo).

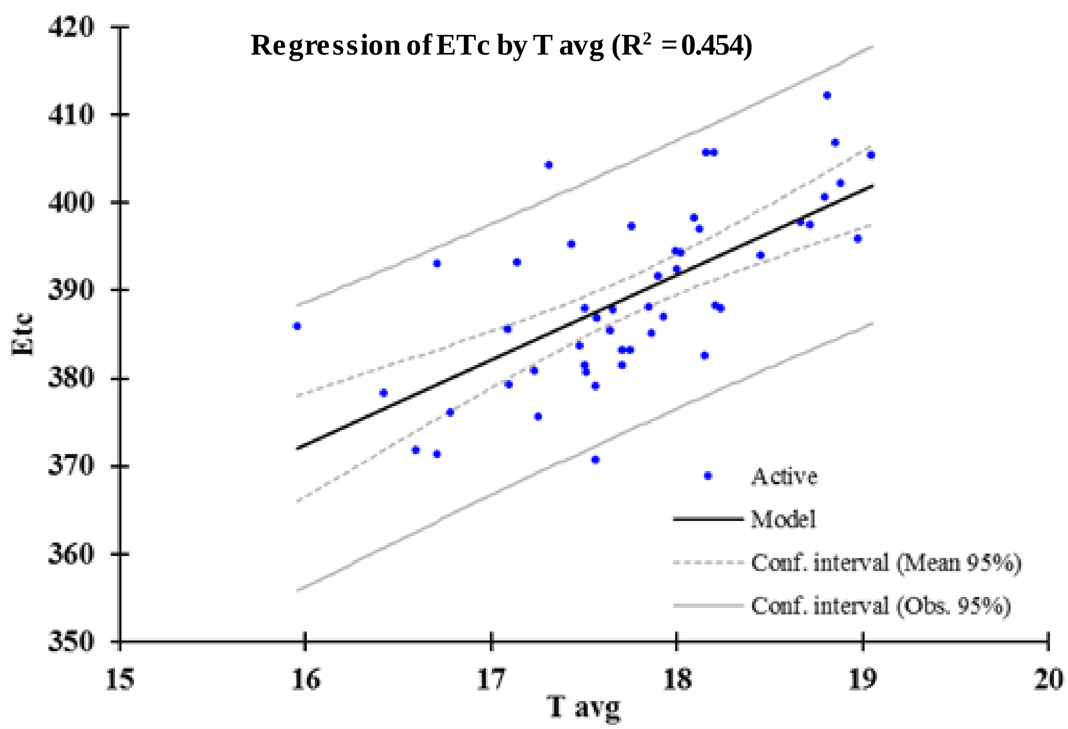


**Figure 4:** Relation between temperature and wheat crop evapotranspiration (ETc)

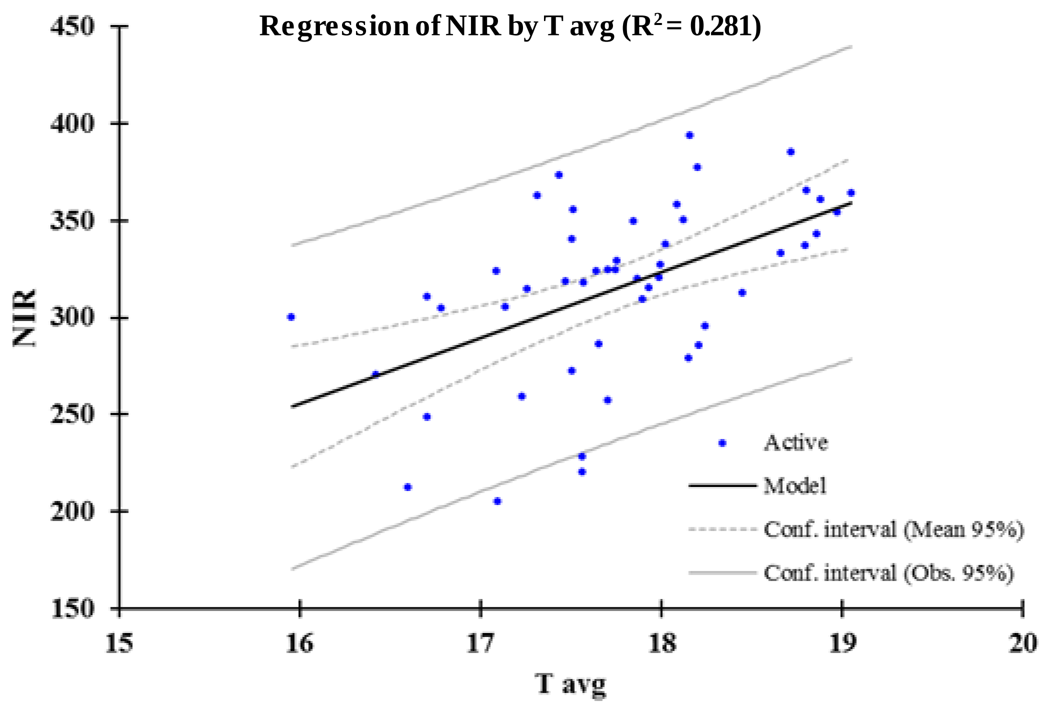


**Figure 5:** Relation between temperature and net irrigation requirements (NIR).

### Rainfall Interaction with Reference Crop Evapotranspiration (ETo), Crop Evapotranspiration (ETc) and Net Irrigation Requirements (NIR) of Wheat Crop

Rainfall is an important limiting climatic factor which provides favorable environment to root zone during dry days and keep biomass above threshold level and sustain crop growth. When effective

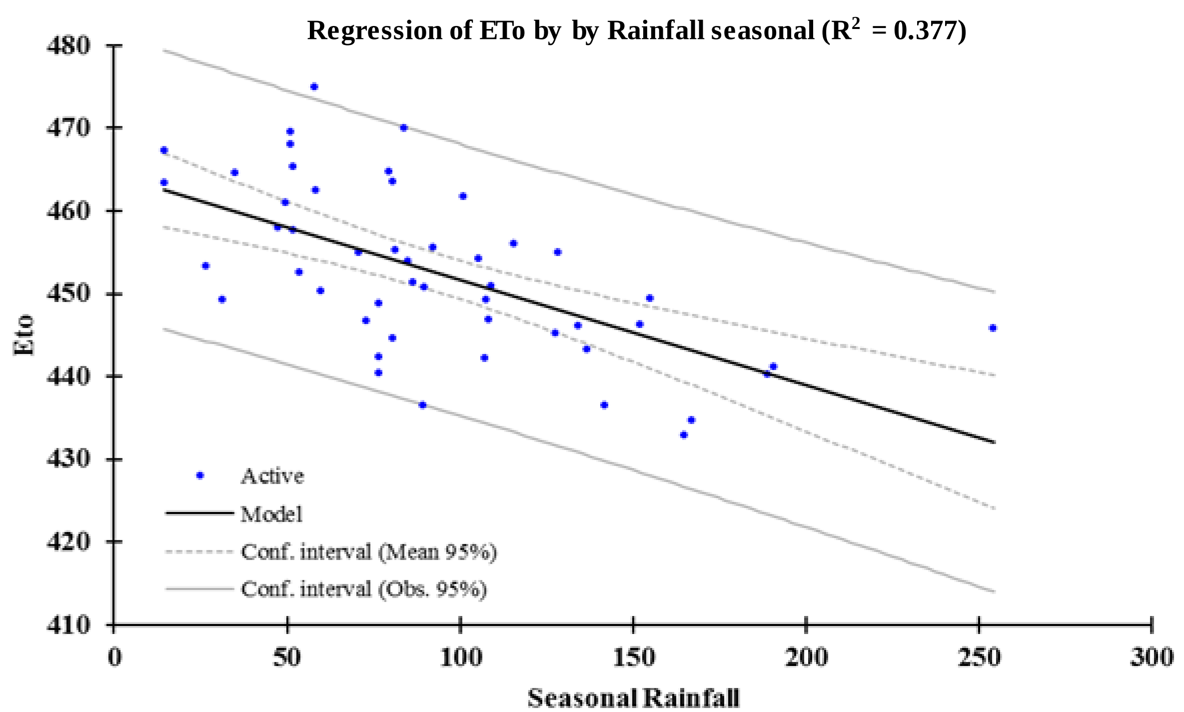


**Figure 6:** Relation between rainfall and reference crop evapotranspiration (ETo).

rainfall is less than one fourth or one eighth of water requirements, the crop experiences water stress and both the crop growth and final yield are affected (Raman and Murthi; 1971). Wheat crop water requirements are different under different water regimes to sustain growth and development which can

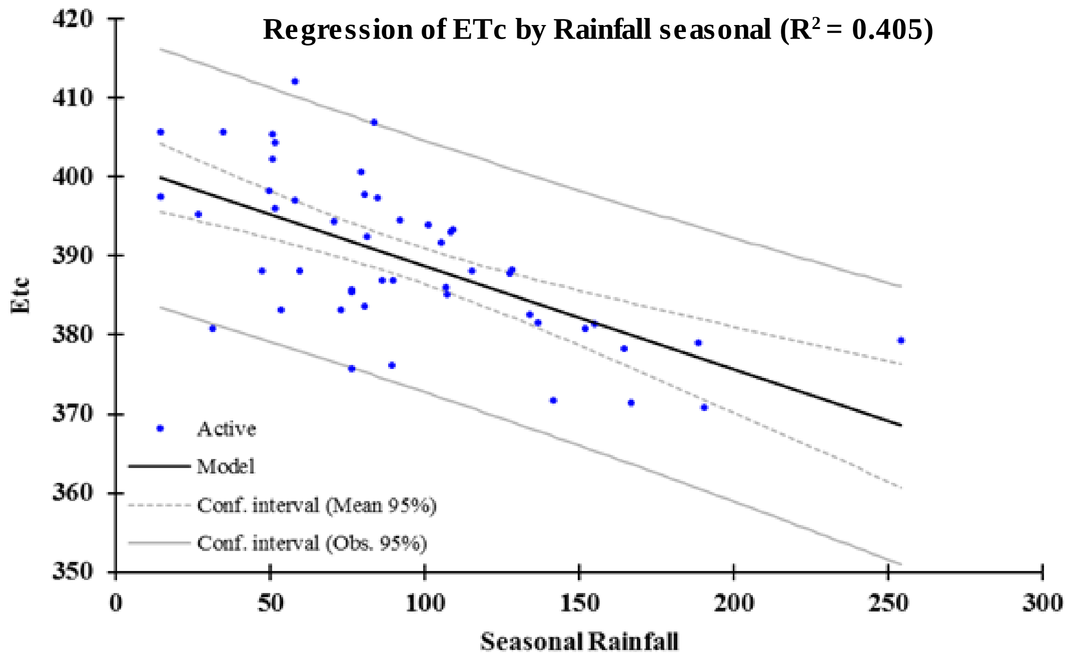


**Figure 7:** Relation between rainfall and wheat crop evapotranspiration (ETc).

be measured through satisfaction index % indicator. Humid regions reflects the areas which have sufficient soil moisture and amount of rainfall received are greater than crop water requirements thus contributes 100 % in fulfilling crop water requirements. Dera Ismail Khan comes under moderately dry

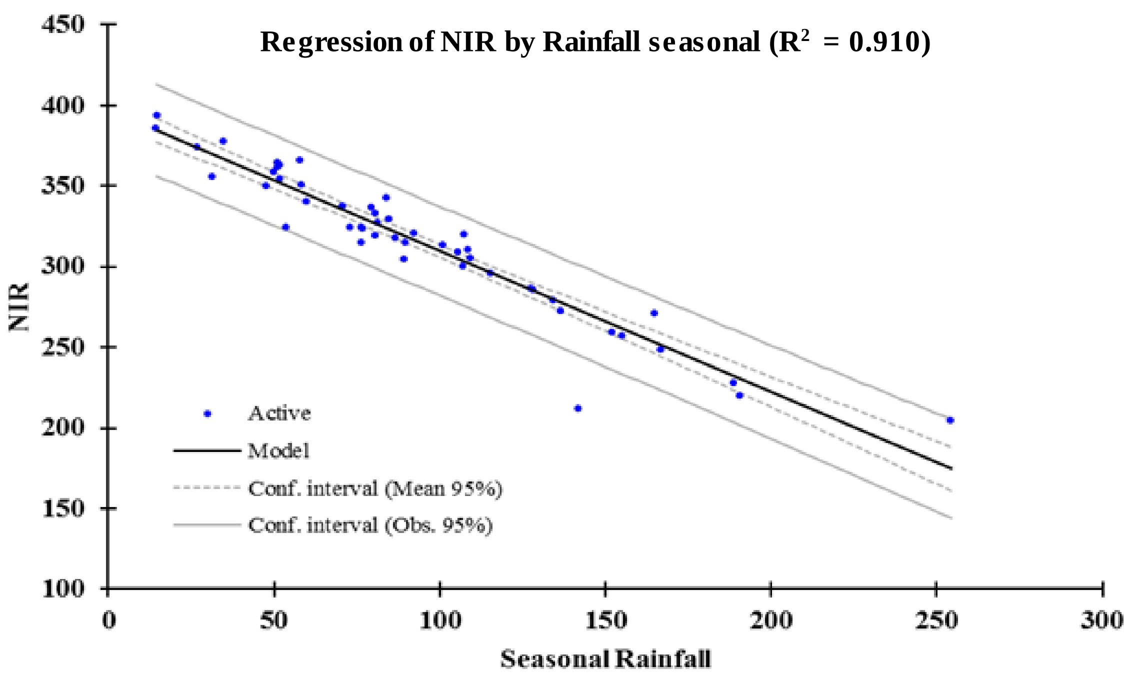


**Figure 8:** Relation between rainfall and net irrigation requirements of wheat (NIR).

(MD) area where irrigation must be arranged for fair crop growth as supplemental source. Though rainfall as a contributing element in satisfying wheat water requirements in Dera Ismail Khan which affect net irrigation requirements of wheat crop but its role in affecting reference and crop evapotranspiration is minor. Highest 188.89 mm and lowest 14.52 mm rainfall was recorded in 1992 and 2000 whereas highest 393.7 mm and lowest 204.8 mm net irrigation requirements were recorded for year 1971 and 2007 respectively. Overall negative correlation was found between rainfall and reference crop evapotranspiration and net irrigation requirements of wheat crop for the historical period 1961-2010 which has been shown in Figure 6, 7 and 8.

**Temporal Changes in Temperature**

The linear regression relation of average temperature during the growing session of wheat crop has been shown in Figure 9. Figure shows that although there is variation in the season average temperature in the study area but there is an increasing trend in temperature. The analyses show that there is 28 percent positive correlation of temperature with time period. The quantification of the increase in temperature has been shown in Table 1.The overall average wheat seasonal temperature was found to be 17.42 °C, with a maximum value of 19.05 °C for the year 2004 while lowest was observed to be 15.95 °C for the year 1986. The beta value for temperature indicates that there is 0.01 °C increase in temperature for each additional year from 1961 (as 1) to 2010 (as 50). Linear regression model shows that average temperature during the growing session of wheat has been increased from 17.43 °C to 18.11 °C for the last half century (1961 to 2010). In other words, the seasonal average temperature has been increased 0.68 °C in 2010, which is 3.9 percent more than 1961 (17.43 °C). For Pakistan as a whole, a 0.57 °C of increase in mean annual temperature has been reported during the period of 1901 till 2000 and an increase of 0.87 °C in mean maximum temperature during the period of 1960-2007 by others. Other studies conducted with different methods and at different scales also support the warming tendency of the Pakistani climate.

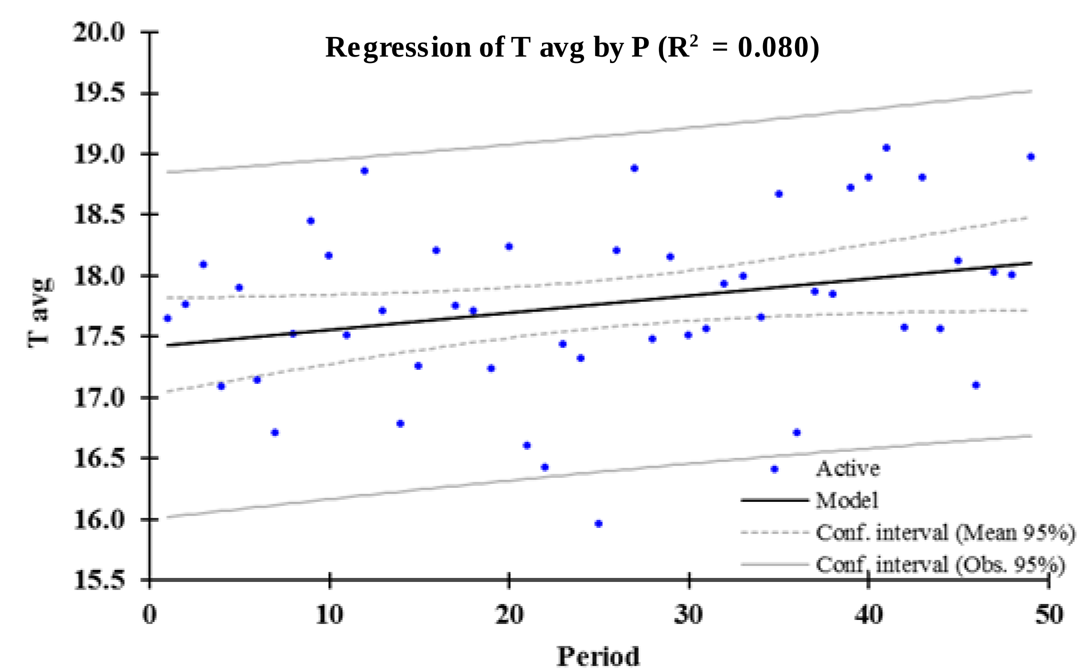


**Figure 9:** Temporal changes in temperature trend 1961-2010.

**Temporal Changes in Total Rainfall**

Changes in total rainfall during the growing session of wheat are shown in Figure 10. The analyses show that there is 11.4 % positive correlation between rainfall variations with time. The figure shows an increasing trend in rainfall with time period. The quantification of rainfall increase is calculated in Table 1. Table 1 shows that there is additional 0.38 mm increase in rainfall for each additional year of time period since 1961. The overall total average rainfall during the study period for growing session of wheat was found to be 93 mm with a maximum value of 254 mm observed for the year 2007 and minimum value of 15 mm observed for the year 2000. The overall increase in the total rainfall indicated by linear regression model was 18.83 mm for the duration of 50 years (1961 to 2010). This increase is 22.39 % of modulated value for 1962.

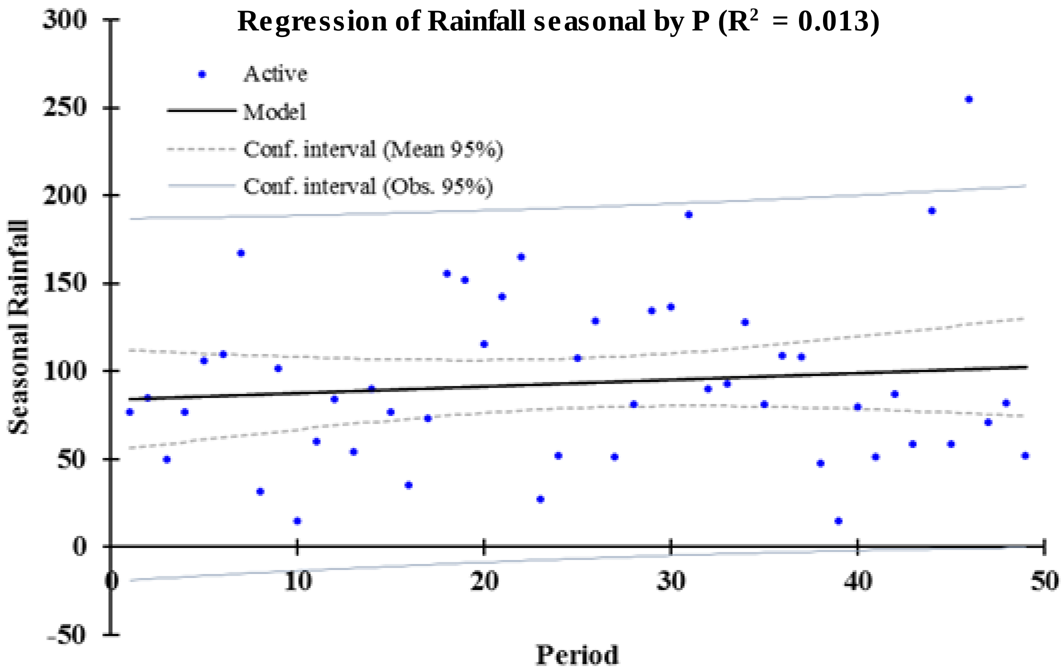


**Figure 10:** Temporal changes in rainfall trend 1961-2010.

**The Total Changes In Temperature, Rainfall, ETo, ETc and NIR During The Study Period In Dera Ismail Khan are Summarized in Table 1**

**Table 1:** Models parameters and Climate Changes

| Parameters | Alpha (a) | Beta (b) | Value in 1961 | Value in 2010 | Total Changes | Percent Changes |
|---|---|---|---|---|---|---|
| Temperature (°C) | 17.42 | 0.01 | 17.43 | 18.11 | 0.68 | 3.90 |
| Rainfall (mm) | 83.73 | 0.38 | 84.11 | 102.94 | 18.83 | 22.39 |
| ETo (mm) | 448.86 | 0.15 | 449.01 | 456.36 | 7.35 | 1.64 |
| ETc (mm) | 387.40 | 0.09 | 387.49 | 391.90 | 4.41 | 1.14 |
| NIR (mm) | 318.62 | 0.12 | 318.84 | 322.84 | 4.00 | 1.25 |

## Conclusion and Recommendations

The following conclusions can be drawn from this research study;

- Climate changes trend to increase temperature (3.9 %) and rainfall (22 %) in Dera Ismail Khan District in future which confirm the climate change since 1960.
- Increasing temperature may increase irrigation water demand of wheat crop (1.14 %) which may affect crop yield and biomass if appropriate managements are not applied.

- The increasing rainfall due to climate change may reduce irrigation water demand of wheat crop in D.I Khan which may boost crop production but need suitable management practices on farms to utilize the increasing rainfall for crop production.
- A comprehensive study is needed to be conducted for future scenarios using CORDEX data for Dera Ismail Khan region to assess the future impacts of climatic factors and parameters on crop water productivity
- Suitable adaptation strategy (rainwater harvesting and efficient use of harvested rainwater) needs to be pursued in Dera Ismail Khan for mitigating climate change impacts and improving food security.

## References

**Afzaal, M., and M. A. Haroon, 2009:** "Interdecadal Oscillations and the Warming Trend in the Area-Weighted Annual Mean Temperature of Pakistan." Pakistan Journal of Meteorology 6(11): 13–19.

**Chaudhry, Q. Z., and G. Rasul, 2007:** "Global Warming and Expected Snowline Shift along Northern Mountains of Pakistan. Proceedings of 1st Asiaclic Symposium."

**Chaudhry, Q. Z., and M. M. Sheikh, 2002:** Climate Change and its Impact on the Water Resources of Mountain Regions of Pakistan, Pakistan Journal of Geography, Vol.11, & 12, No.172 June-December.

**Clark, D., M. Smith, and K. Askari, 2003:** Cropwat for windows: User Guide. Land and Water dev. Div. FAO.Italy.

**Cruz, V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li, and N. HuuNinh, 2007:** Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. vanderLinden and C. E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 471.

**Hingane, L. S., K. R. Kumar, and B. V. R. Murty, 1985:** Long term trends of surface air temperature in India. J. Climatol., 5: 521-528.

**Huq, S., Z. Karim, M. Asaduzzaman, and F. Mahtab, 1999:** Development of Climate Change Scenarios with General Circulation Models, In Vulnerability and Adaptation to Climate Change for Bangladesh, 13-20.

**Hussain S. S., M. Mudasser, 2007:** Prospects for wheat production under changing climate in mountain areas of Pakistan – An econometric analysis. Agricultural Systems 94: 494–501.

**IPCC, 2007c: Asia in Climate Change 2007:** Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergoranmental Panel on Climate Change Cambridge. Cambridge University Press, 469 – 506.

**Jones, P. D., and K. R. Briffa, 1992:** Global surface air temperature variations during the twentieth century: Part 1, spatial, temporal and seasonal details. The Holocene 2:165-79.

**Kothawale, D. R., and K. R. Kumar:** Tropospheric temperature variation over India and links with the Indian summer monsoon: 1971-2000, Mausam, 53.

**Lai, M., P. H. Whettori, A. B. Pittodi, and B. Chakraborty, 1998:** The Greenhouse Gas Induced Climate Change Over the Indian Sub-Continent as Projected by GCM Model Experiments Terrestrial. Atmospheric and °C eanic Sciences, TAO, 9(iv), 663-669.

**Mendelshon, R., W. D. Nordhaus., and D. Shaw, 1993:** Measuring the Impact of Global Warming on Agriculture. Cowles Foundation for Research in Economics at Yale University, Cowles Foundation Discussion Paper No. 1045.

**Raman, C. R. V., B. S. Murthi, 1971:** Water availability periods for crop planning (Rep. No.173), India Meteorological Department, Poona.

**Rasul, G., 1993:** Water requirement of wheat crop in Pakistan. Journals of energy and applied sciences, Vol.12, No.2, July-Dec, 1993.

**Salinger, M. J., 2005:** Guest editorial, increasing climate variability and change: reducing the vulnerability. Climate Change 70:1–3.

**Wang, B., W. Renguang, and K. M. Lan, 2001:** Inter annual Variability of the Asian Summer Monsoon: Contrasts between the Indian and the Western North Pacific–East Asian Monsoons. Journal of Climate, (14), 4073-4090.