# Projections of Crop Water Requirement in Pakistan under Global Warming

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**Abstract**

*Climate change has now been globally recognized as a challenging threat to the humanity. The anthropogenic activities are also among the driving forces besides others. The consequent impacts on various sectors, especially the agriculture, are more pronounced. Due to fact that the weather/climate has no political boundaries the developed industrial nations are polluting their regional environment and ecology. In this way the under developed and poor nations, like Pakistan, have to suffer severely. Besides this the availability and reservation of water resources are also a giant challenge in future, on international as well on regional level. Also due to political and strategic relationship to the neighboring countries, water availability would be a big problem for the country in near future. Future projections for climate are showing increasing trend in surface temperatures, which will ultimately augment some agrometeorological elements like reference crop evapotranspiration (ETo) etc. The current study is carried out to analyse the subsequent effects of increasing temperatures on ETo and on the agriculture water demand in the country. In the light of climate projections from various authentic sources like IPCC, increasing trends of 1-3°C have been studied which is likely in next 50 years. It has been concluded that the southern half of Pakistan may be the least affected areas in the time to come. However, in northern half, a sharp increase in water demand as compared to the present will appear leading to the enhanced risk of crop failure in rain fed areas where supplementary irrigation is not available. This study will help in crop monitoring and in the assessment that how much water available in future for crops; which type of crops would suit the climate, Better management and building of new water reservoirs may help to cope the situation for an improved agriculture growth.*

**Keywords:** Climate Change, Anthropogenic, Agrometeorology, Evapotranspiration, Temperature.

## Introduction

The availability of adequate water resources throughout a crop season is a burning issue worldwide as well as in the typically arid regions of Pakistan, Groundwater has been depleted, surface water is diminishing, irrigation water is rationalized. Fish industry may suffer when farmers use extra water for irrigation. There is a need to save every drop of water to keep the groundwater from being depleted, rivers, lakes and wetlands from drying out and to save endangered species from extinction.

Global temperature has increased by 0.3–0.6°C since the late 19th century and by 0.2–0.3°C over last 40 years. In the last 140 years, the 1990s was the warmest period (Jones and Briffa, 1992). In Indian context, Hingane et al., (1985) reported an increase in mean annual temperature by 0.4°C/100 years during the 20th century. However, increasing temperature trend is not valid over entire country; the northeast and northwest India shows some cooling. Kothawale and Rupa (2002) reported a rise of 0.5°C in mean annual temperature over last century. However, no systematic change in mean minimum temperature was observed.

The pattern of spatial and temporal changes in climatic variables due to global warming need more debate and studies are being conducted globally (Chattopadhya and Hulme, 1977; Georgaidi et al., 1991; Iglesias et al., 1994; Feddema, 1999 ). As a consequence of climatic changes, a significant impact on hydrological parameters, viz. runoff, evapotranspiration, soil moisture, ground water etc. is expected (Bultot et al., 1988).

Evapotranspiration is a major component of the hydrologic cycle. It is the transfer of water to the atmosphere by evaporation from the soil and plant surface as well. Evapotranspiration varies for vegetation types under different climatic conditions. Most of the crops in Pakistan needs irrigation and due to high evapotranspiration rate most of the water lost into the atmosphere. Due to increase in ETo,

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crop water requirement will also increase which would ultimately affect crop production. Due to limited water resources it is very difficult to overcome this problem.

The adoption of fixed values for crop surface resistance and crop height required an adjustment of the concept of reference evapotranspiration which was redefined as follows:

"*Reference evapotranspiration is the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height (12 cm), a fixed crop surface resistance (70 s m-1 ) and albedo (0.23), closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground having adequate water"* (Allen et. al., 1998).

The arid areas of Pakistan where the evapotranspiration rate is already high and water table is shallow, an increase in air temperature may cause loss of water rapidly and consequently which the aridity of soil would increase. If the evapotranspiration rate continues to increase then our water reservoirs in the form of small dams, ponds and canals etc would dry more rapidly and we will face water shortage. (Chaudhry and Rasul, 2004) studied that almost two third area of the country lies in arid region. Pakistan fulfills its water requirement from winter and summer rainfall along with the melting of snow fall from the glaciers.

Consumptive use of water or evapotranspiration is one of the important elements of the hydrological cycle from occurrence of precipitation until it reaches the ocean or returned to the atmosphere. The subject of consumptive use, which includes evaporation of water from land and water surfaces and transpiration by vegetation, is becoming increasingly more important, particularly in arid and semi arid areas of the world. The difference between the water vapor pressure at the evaporating surface and that of the surrounding atmosphere is the main driving force to remove water from the evaporation surface. As evaporation continues, the surrounding air becomes gradually saturated and the process slows down and might stops if the wet air is not transferred to the atmosphere.

In designating water use by crops, evaporation and transpiration are combined as evapotranspiration, conventionally called consumptive use. The relative amount of direct evaporation from land and water surface and transpiration depend usually on the amount of ground cover, incoming solar radiation, wind, temperature and humidity conditions. The term consumptive is used for the water consumed by plants for their metabolic activities. In Pakistan, three principal climatic factors; day length, temperature and evaporation are consistent with the temperate tropical climate generally found in the latitudinal range of 24-30°N. The latitude also modifies the climate in the north and northwestern parts of the country where climatic characteristics more closely approach those associated with subtropics. The day lengths vary from 10 hours in January to 14 hours in June. Most of the crops grown in Pakistan are neutral with respect to photoperiodicity so this has little effect on crop growth. Temperature is more important factor in wheat at higher latitudes (PARC, 1982).

## Methodology

Evapotranspiration is an estimated parameter that depends upon temperature, humidity, wind speed and solar radiation. Air temperature is considered important climatic parameter that directly influences the evapotranspiration. In the light of increasing future trend in temperature, this study has been conducted on the assumption the temperature increase of 1°C, 2°C and 3°C from their current normal values. Climatic normal as produced by PMD for the most recent available period i.e, 1971-2000 was utilized in the study.

The motive behind was to explore that what would be the impact of increasing temperature on evapotranspiration and what areas would be the most vulnerable, in the context of crop production. Two major crop seasons are being considered in the study; Rabi (October to April) and Kharif (May to September). Also for a simple picture, considering the geographical and climatic features, Pakistan is distributed into two major parts i.e. north & south.

A large number of more or less empirical methods were developed by numerous scientists and specialists worldwide to estimate evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limitation at global level. FAO expert consultation in 1990 reached unanimous agreement in recommending Penman-Monteith approach as the best performing method to estimate evapotranspiration of a reference crop ETo and adopted the estimates for bulk surface and aerodynamic resistance as elaborated by Allen et. al., (1998) as standard values for the reference crop.

The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies. As Pakistan has diversified type of climate and over all performance of FAO Penman-Monteith has shown better results than other evapotranspiration calculation method. Rasul, 2009 also recommended that this method shows minor deviations from the actual evapotranspiration data onward the year in climate of Pakistan and claims the best method to estimate evapotranspiration.

**Reference evapotranspiration (FAO Penman-Monteith)**

The FAO Penman-Monteith equation (Allen et al., 1998) is given by:

$$ETo = \frac{0.408\Delta(R_a - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where,

| | | |
|---|---|---|
| $ETo$ | = | reference evapotranspiration [mm day$^{-1}$]; |
| $R_a$ | = | net radiation at the crop surface [MJ m$^{-2}$ day$^{-1}$]; |
| $G$ | = | soil heat flux density [MJ m$^{-2}$ day$^{-1}$]; |
| $T$ | = | mean daily air temperature at 2 m height [°C]; |
| $u_2$ | = | wind speed at 2 m height [m s$^{-1}$]; |
| $e_s$ | = | saturation vapour pressure [kPa]; |
| $e_a$ | = | actual vapour pressure [kPa]; |
| $e_s$-$e_a$ | = | saturation vapour pressure deficit [kPa]; |
| $\Delta$ | = | slope vapour pressure curve [kPa °C$^{-1}$]; |
| $\gamma$ | = | psychrometric constant [kPa °C$^{-1}$] |

In above equation the value 0.408 converts the net radiation Rn expressed in MJ/m2/day to equivalent evaporation expressed in mm/day. Because soil heat flux is small compared to Rn, particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, the estimation of G is ignored in the ETo calculator and assumed to be zero. This corresponds with the assumptions reported in the FAO Irrigation and Drainage Paper 56 for daily and 10-daily time periods. Allen et. al., (1998) stated that the soil heat fluxes beneath the grass reference surface is relatively small for that time period.

## Scope of Study

Climate change has become a global issue and most of the countries of the world are facing worst of conditions due to global warming. Global warming has also influenced Pakistan as the air temperature is increasing throughout the country consequently more glaciers melting and augmenting evaporative demand. The purpose of this study is to develop evapotranspiration scenario in the context of increasing temperature which may not only help in better water management but in the estimation of crop water requirements as well, through the analysis of evaporative demands in the country.

## Results and Discussion

### Rabi Season

October is the start of growing season of Rabi crop which extends upto April/May. Wheat, Barley and pulses are the major Rabi crops. The season starts with the driest months of October and November in which little amount of rainfall is received in the country. Due to the drier conditions in these months, sowing is generally started in late November or in the beginning of December as germination and initial crop establishment requires some moisture in the soil produced in the from of precipitation. The snow falling areas with low temperature have long dormancy period due to which harvesting extended upto May. Winter rains (December to March) play a very vital role during Rabi season but its affectivity is still restricted to higher latitudes and leeward sides of the mountain ranges. Also long dry spells prevail some times which became risky at critical stage of the crop development and result into poor yield. Risk is always involved if crops are sown under rainfed conditions without providing proper/supplementary irrigation.

Fig-1(a) shows that the normal evapotranspiration lies between 30 and 130 mm in the northern half of the country. It touches the lowest values during the month of December and then gradually increases again upto the highest values at the end of the season. Also with the increasing temperatures the evapotranspiration for this half of the country has the highest positive deviation during the first cold month of the season i.e December. In the last month April, the deviation is the lowest.

Water requirement of a region depends upon the evapotranspiration which is a climatic parameter. In the current scenarios of global warming, it is important to determine that what would be the expected impact on evapotranspiration by increasing temperature. Rabi season (October-April) comprise mostly of the winter months in which temperature normally remains low throughout the country. In sub-mountainous and high mountainous regions of north and western low mountains, temperature tends to fall below zero, particularly during December to February. The evaporative demands of the atmosphere therefore remain low or some time stops in these areas.

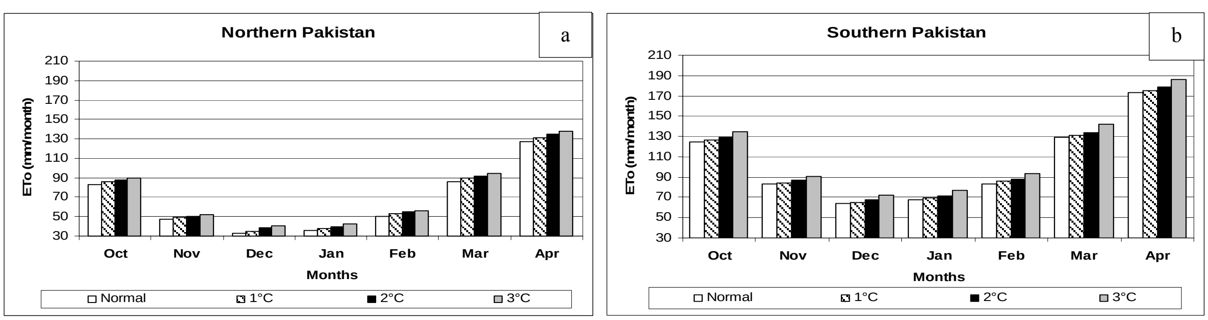


**Figure 1:** Monthly changes in the reference crop EP(ETo) against Temperature rise 1, 2, 3 °C compared to prevailing (normal ) during Rabi Season in the **a.** Northern half and **b.** Southern half of Pakistan

Fig-1(b) shows that the normal evapotranspiration lies between 60 and 185mm in the southern parts of the country. It touches the lowest figures during the months of December & January and then gradually increases as the season progresses toward crop maturity. Also with the increasing temperatures the evapotranspiration increase is much higher during the coldest months of the season i.e December-February, especially for 3°C rise. It may be because of the mostly dry and cold weather conditions in this region. In the other cases also (for 2° & 3°C rise) the situation is not too different.

Ghazala, stated that under convection conditions during summer (March to April and somewhere in May) with hot and windy weather, the ETo values generally shoot up. Generally the wheat crop at this time is in grain formation stage (the period of highest water requirement), therefore frequent irrigation is required. When water demand will increase due to rise in temperature , more water should be available to satisfy the crop water requirement for getting good harvests.

### Kharif Season

Kharif season commences with Rabi harvest i.e. May and completes by the end of the calendar year. Cotton and rice are the important field crops. Kharif season begins with the driest and hottest months (May & June) of the year. However, monsoon rain during July to September plays positive role in coping with the moisture stress conditions to some extent. These rains prove to be helpful to reduce the evaporative demand of the atmosphere by increasing the humidity in the atmosphere particularly in the northern half of the country. These rainfalls also decrease the temperature in northern half of the country as compares to other half. The southern half of the country receives meager amount of rainfall which is insufficient to compensate the loss of moisture through evapotranspiration due to high temperature and drier atmosphere. However sometime cyclonic activity cause heavy rainfall creating a sudden change along the coastal areas of Pakistan.

Fig-2(a) shows that the normal evapotranspiration lies between 115 and 195 mm in the northern parts of the country. It touches the lowest figures during the month of September. Also during the hottest month of the season, average deviation is observed. It depicts that increasing temperature may not augment the water requirements, in this area.

Due to high temperature and driest atmosphere during May and June evaporative demands are very high in the country especially in the southern side. Monsoon rainfall plays a very vital role to reduce the evaporative demand to some extent and also fulfills the water requirement of crops in rainfed areas of the country. Rasul et al., (1993) stated that increase in temperature will directly influence the evapotranspiration rate and water requirement of crops, in the country. Also cotton crop generally grows better on low elevated plains. The increase in temperature is being observed in the southern parts of the country which lies in low latitude. Good rainfall received in southern parts but due to its less quantity there is always shortage of water.

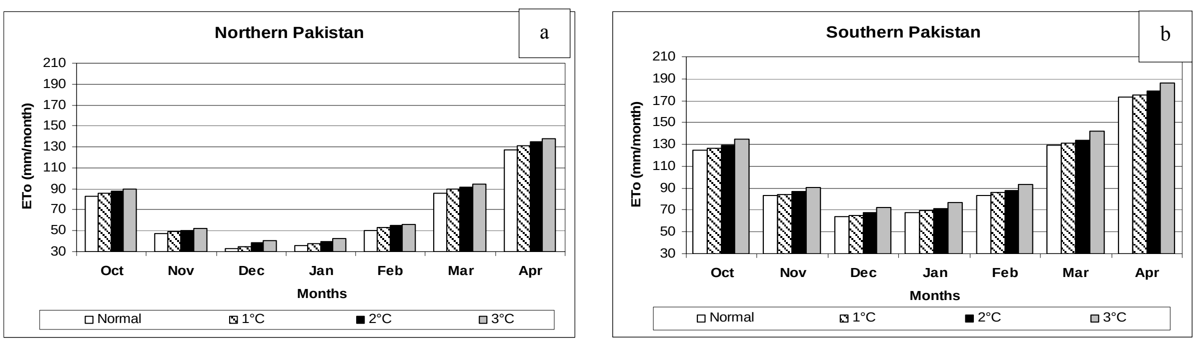


**Figure 2:** Monthly changes in the reference crop EP(ETo) against Temperature rise 1, 2, 3 °C compared to prevailing (normal ) during Kharif Season in the **a.** Northern half and **b.** Southern half of Pakistan

Fig.2(b) shows that during the month of July, maximum deviation is recorded. It depicts that increasing temperature may enhance the water requirement condition, in this area. But during this month there is a lot of water available in the form of precipitation and river flow. The normal Evapotranspiration in southern parts of country for the Kharif season lies between 155 and 225 mm in the southern parts of the country. In the northern parts it touches the lowest figures during the month of September.

**Table 1:** Month wise normal & projected ETo with temperature increments of 1, 2, 3 °C in Northern half of Pakistan

| Months | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Normal** | 67.9 | 83.5 | 129.5 | 173.5 | 218.3 | 215.5 | 194.8 | 177.5 | 155.0 | 124.6 | 83.4 | 64.1 |
| **1°C Rise** | 69.5 | 85.6 | 131.2 | 175.5 | 219.9 | 216.5 | 197.2 | 178.5 | 156.4 | 126.2 | 84.2 | 65.1 |
| **2°C Rise** | 71.6 | 87.6 | 133.8 | 178.6 | 224.4 | 221.9 | 200.0 | 182.1 | 160.3 | 129.2 | 86.8 | 67.4 |
| **3°C Rise** | 76.9 | 93.2 | 141.7 | 186.3 | 232.5 | 229.1 | 207.8 | 189.6 | 166.4 | 134.3 | 90.3 | 72.3 |

**Table 2:** Month wise normal & projected ETo with temperature increments of 1, 2, 3 °C in Southern half of Pakistan

| Months | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Normal** | 36.0 | 50.6 | 85.7 | 127.4 | 170.4 | 182.5 | 165.9 | 147.8 | 118.6 | 82.5 | 47.0 | 33.2 |
| **1°C Rise** | 38.1 | 53.3 | 89.5 | 130.6 | 175.9 | 187.4 | 170.7 | 152.7 | 122.6 | 86.0 | 49.1 | 34.9 |
| **2°C Rise** | 40.0 | 55.0 | 92.0 | 135.3 | 179.9 | 191.4 | 174.2 | 155.4 | 124.8 | 87.6 | 50.4 | 38.6 |
| **3°C Rise** | 42.2 | 56.2 | 94.1 | 138.1 | 183.5 | 194.5 | 178.0 | 159.0 | 128.4 | 90.0 | 51.8 | 40.2 |

Rasul, (2000) stated that weather factors like temperature and relative humidity play an important role in varying the water requirement for sugar cane in different parts of the country. On the other hand the excessive moisture resulted in low efficiency of added nutrients.

## Conclusion

Above analysis shows that global warming will be a big threat for agriculture sector in the near future. The increase in temperature will not only amplify the evaporation but also the water requirement of the crops and other consumers. Due to high water demand and shortage of water, most of the crops would not be able to give better yield or it will be difficult for them to survive in these harsh/extreme weather conditions. The point of concern is that not only the Southern but also the northern parts of Pakistan will have to face high evapotranspiration rate due to increase in temperatures. Ultimately, the agroclimatic regions may change i.e. humid into semiarid and arid into extremely arid.

## Recommendations

It is recommended that the traditional methods of irrigation have to be changed and new/effective methods like sprinkler, drip irrigation be adopted, to avoid the loss of water into the atmosphere. Also drought resistant cultivars should be introduced which may require less amount of irrigation water to complete the life cycle.

## References

**Allen, R.G., L.S. Pereira, D. Raes, and Smith, M., 1998:** Crop evapotranspiration. FAO Irrigation and Drainage. Paper 56, Rome, p. 300.

**Bultot, F., G.L. Dupriez, and D. Gellens, 1988:** Estimated annual regime of energy balance components, evapotranspiration and soil moisture for a drainage basin in case of a CO2 doubling. Climate Change 12,39–56.

**Chattopadhya, N., and M. Hulme, 1977:** Evaporation and potential evapotranspiration in India under condition of recent and future climatic change. Agric. Forest Meteorol. 87, 55–73.

**Chaudhry, Q.Z., and G. Rasul, 2004**: Agroclimatic Classification of Pakistan Science Vision (Vol.9, No.1-2&3-4), (July-Dec, 2003 &Jan-Jun, 2004), 59-66.

**Feddema, J.J., 1999:** Future African water resources: interactions between soil degradation and global warming. Climatic Change 42 (3), 561–596.

**Georgiadi, A.G., F.H.M. Ven, D. Gutknecht, D.P. Loucks, and K.A. Salewicz, 1991:** The change of the hydrological cycle under the influence of global warming. Hydrology for the Water Management of Large River Basins, IAHS Publication No. 201, pp. 119–128.

**Ghazala, N., and A. Mahmood, 2009:** Water requirement for Wheat Crop in Pakistan. Pakistan Journal of Meteorology, Vol.6.No.11, 89-96

**Ghazala, N., and G. Rasul, 2010:** Water requirement for cotton Crop in Pakistan Journal of Meteorology, Vol.6.Issue No.12, 74-84

**Hingane, L.S., R. K. Kumar, R. Murthy, and V. Bh., 1985:** Long-term trends of surface air temperature in India. J. Climatol. 5, 51–528.

**Iglesias, A., H.L. Corcoles, W. Canadas, M.I. Minquez, M. Borin, and M. Sattin, 1994:** Current and future strategies for water use optimization in corn hybrids of different growth durations under climate change scenarios. In: Proceedings of the Third Congress of the European Society for Agronomy, 18–22 September 1994. Padova University, Abano-Padova, Italy, pp. 374–375.

**Jones, P.D. and K.R. Briffa, 1992:** Global surface air temperature variations during the twentieth century": Part I. Spatial, temporal and seasonal details. The Holecene 2, 165–179.

**Kothawale, D.R., and R, K. Kumar, 2002:** Tropospheric temperature variations over India and links with the Indian summer monsoon. 1971–2000. Mausam 53 (3), 289–308.

**PARC, 1982:** Consumptive use of water for crops in Pakistan. Pakistan Agricultural Research Council, Islamabad.

**Rasul, G., 2000:** water requirement of spring sugar cane in Pakistan. Science vision, Vol. 5(4), April-June.

**Rasul, G., 2009:** Performance Evaluation of Different Methods for Estimation of Evapotranspiration in Pakistan's Climate. Pakistan Journals of Meteorology, Vol.5, No.10, Jan-June, 2009, pp.25-36.