# ETo Variation in Pakistan in Changing Climate

Naheed, G.[1, 2], D. H. Kazmi[2]

***Abstract***

*Pakistan has an agrarian economy where climate change and the consequent threat of global warming has become a great challenge. Out of two major cropping seasons in the country, Kharif is more important. Reference crop evapotranspiration (ETo) is one of the most important agro-meteorological parameters. In this region, ETo profile has been analyzed on a long time basis for Kharif season. The climatic data for maximum & minimum temperatures, mean relative humidity and mean wind speed is utilized for the two recent periods 1971-2000 & 1981-2010, for Pakistan. As the study region has a diversified type of climate, therefore, FAO Penman-Monteith method has been employed for ETo. This method shows minor deviations from the actual evapotranspiration data throughout the year in the climate of Pakistan. To investigate the major dependence of ETo variation, all the input parameters have been fed into a statistical model. Regression equation shows that ETo difference is mainly dependent on wind speed and max temperature. Both the actual and simulated values for ETo for most of the data points remained very much consistent with the actual values. Their mutual correlation is 0.81 and significant at the 0.01 level. The outcome of the study is in agreement with the recent findings in the context of climate change and global warming.*

## Introduction

It is well known to us that the temperature in tropics is at increase and the situation may be even worse by 2100. Also, due of collateral effect of some natural phenomena and anthropogenic activities, the meteorological extremes (like heavy rainfall or meteorological drought) are happening more frequently than ever (Rasul and Kazmi, 2011). Climate change is projected to result in terms of the intensification of a global hydrological cycle (Huntington, 2006; IPCC, 2013). Food security is the foremost objective for Pakistan Government and policy makers remain engaged to manage/design it. The agriculture of the country has been affected by various factors including underground water, land cover area and climate change. But the climate change and ground water shortage in addition to variability in evapotranspiration are considered the most crucial factor for crops. Before the flowering stage, high evapotranspiration rate decelerates the growth process. On the basis of ETo, the crop type for a particular region may be decided. For the last few years, harsh weather conditions have affected adversely the supplies of agriculture production, and will ultimately continue to be threatened in the coming years (GFSI, 2012).

The rain fed areas are mainly dependent on weather conditions, the relative impact of climate change in these areas is more pronounced than any of the irrigated areas. Sustainable availability of water is becoming the hot issue globally particularly for a developing country like Pakistan. Ground realities are more alarming for the country in the time to come (Rasul and Kazmi, 2011). On another side, increasing temperatures may have a positive impact on agriculture in the mountain areas, for instance through shortening of growing period for the winter season crops.

The interaction between meteorological parameters and crop's growth are more pronounced at some particular phonological stages. And it is weather, not climate which may be used as an input for the purpose of yield prediction in crop modelling. Although the seasonal weather forecasting is a tough task it may be the best input for a crop model. After establishing a relationship between the seasonal weather pattern and final yield, a proper modelling track may be designed (Challinor et al, 2003). The Evapotranspiration (ET) is an important hydrological process in the climate system (Lu et al., 2005) because it provides moisture to the atmosphere (Tenberth and Israr, 2014), which is perceived as the beginng of the Hydrological cycle. It also consumes energy, contributing to water and energy transfer. However, it is difficult to measure the ET directly from a large area, as a result, many empirical relationships and equations have been developed to

[1] ghazalnd@gmail.com,
[2] Pakistan Meteorological Department, Pitras Bukhari Road, Sector H-8/2, Islamabad, Pakistan.

estimate ET from meteorological data (Arnell, 2002). It is revealed that evapotranspiraton estimates can be used to make many practical applications, but the principle use is to predict the soil moisture deficit for irrigation (e.g. Schwap et al., 1993; Stern, 1994). Given the present and likely-hood of future change in climate (IPCC, 2013) there is need to understand the response of ET (Bates et al., 2008).

Water requirement mainly depends on climatic factors such as air temperature, solar radiation, relative humidity, wind velocity and agronomic factors like is stage of the crop development as well (Rasul, G., 1993). Like all crops, cotton plant's water requirement is mainly dependent on the environment. The dryer and hotter the environment is, the more water plant requires. Cotton has been wrongly cited as a water intensive crop, but it is very drought tolerant and use about the same amount of water as other major crops like millet, sorghum etc.(Zwart, S.J., and G.M., Bastiaanssen, 2004). Cotton's global water foot print is about 2.6 % of the world's water use, lower than other commodities (e.g., Soybeans 4 %, Maize 9 %, Wheat 12 %, and Rice 21 %) (Hoekstra, A. Y., and A. K., Chapagain, 2007)

The Rabi (October–March) and Kharif (April–September) are the two major cropping seasons in Pakistan. The Rabi crops are mainly wheat, rapeseed, and chickpeas, while the Kharif crops are rice, cotton, sugarcane, maize and sorghum. The crop water requirements vary according to crop growing season. The annual crop water requirements vary in the Indus region depending on the agro-climatic conditions. The average crop water requirements of some major crops are given in Table 1.1. These values represent the total water requirement of crops. The actual requirement of irrigation may be less, depending upon the effective rainfall and groundwater conditions. Moreover, these values also include evaporation and percolation losses (Rasul and Kazmi, 2013).

**Table 1:** Crop water requirement/consumptive use for lower Chenab canal system.

| Sr. No. | Crop | Consumptive use for Lcc System (mm) |
|---|---|---|
| 1 | Wheat | 309 |
| 2 | Oil Seeds | 258 |
| 3 | Rabi Minor | 382 |
| 4 | Cotton | 713 |
| 5 | S-Cane | 1533 |
| 6 | Maize | 341 |
| 7 | Rice | 658 |
| 8 | Sorghum | 625 |
| 9 | Kharif Minor | 790 |

(Source:A.S. Shakir & M.M.Qureshi)

As reference crop evapotranspiration (ETo) is mainly based on a few basic meteorological elements like mean daily temperature, relative humidity, bright sunshine hours and wind speed etc, therefore, any of its impact on the final yield may be due to the combined effect generated by all these elements or individual effects of any of the elements. In other words, ETo portrays a collective picture for all these elements.

## Data and Methodology

To calculate ETo (method detailed in section 2.1), the climatic data for maximum & minimum temperature, mean relative humidity and mean wind speed has been utilized for two recent periods 1971-2000 & 1981-2010, for all the available 49 meteorological stations of Pakistan.

In the next step, ETo difference between the two periods is calculated. In the following equation, ETo for the period 1971-2000 is represented by $N_1$ ($N_1$ = ETo 1971-2000) and ETo for the period 1981-2010 is represented by $N_2$ ($N_2$=ETo 1981-2010). This difference is plotted in the form of maps using the GIS software for an important cropping season “Kharif” (May to September).

$$ETo\ Difference = N_2 - N_1 \qquad \text{.......} (1)$$

**FAO Penman-Monteith Equation**

A large number of more or less empirical methods were developed by numerous scientists and specialists over the globe to estimate evapotranspiration by employing different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limitations at the global level. FAO expert's consultation in 1990 reached unanimous agreement in recommending Penman-Monteith approach as the best performing method to estimate ETo as it adopts the estimates for a bulk surface with aerodynamic resistance as elaborated by Allen et. al., 1998.

As Pakistan has a diversified type of climate and generally FAO Penman-Monteith has shown better results in comparison to other evapotranspiration calculation method. Rasul, 2009 also recommended that this method shows minor deviations from the actual evapotranspiration data over the years in climatic conditions of Pakistan and therefore, considered as the best available method to estimate evapotranspiration. The FAO Penman-Monteith equation is a close, simple representation of the physical and physiological factors governing the evapotranspiration process. The mathematical expression for the sake of calculation simplified as follow:

$$ETo = \frac{0.408\Delta(R_a - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad \text{..... (2)}$$

Where

ETo , reference evapotranspiration (mm per day)

$R_a$ , net radiation at the crop surface (MJ/m² per day)

G , soil heat flux density (MH/m² per day)

T , mean daily air temperature at 2m height (°c)

$u_2$ , wind speed at 2m height (m/s)

$e_s$ , saturation vapor pressure (kPa)

$e_a$ , Actual vapor pressure (kPa)

$e_s - e_a$ , saturation vapor pressure deficit (kPa)

Δ , Slope of vapor pressure curve ( kPa per °C)

γ , Psychometric constant (kPa per °C)

In above equation the value 0.408 converts the net radiation Rn expressed in MJ/$m^2$/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.

**Regression Equation**

In the next step, to investigate the major dependence of ETo on any of the contributors, Tx, Tn, UU & ff, all these parameters have been fed into a statistical model ‘SPSS'. Accordingly, a regression equation has been developed as shown below.

$$Y = aX_1 + bX_2 - C \qquad \text{....... (3)}$$

Where

Y = ETo,

$X_1$ = ff (wind speed),

$X_2$ = Tx (max temperature)

a = 8.808, b = 9.501, C = -0.743

The equation (3) shows that ETo is mainly dependant on wind speed and max temperature. Which is in accordance with the definition of ETo and findings of recent studies. The details of its implementation will be discussed in the later sections.

## Results and Discussion

In this section, besides ETo, all the utilized parameters are discussed comprehensively with the help of GIS maps. Also, the modeled and actual ETo differences are elaborated separately. Kharif season commences with Rabi season's harvesting (i.e. May) and completes by the end of the calendar year. The season begins with the driest and hottest months (May & June) of the year. Cotton and rice are the important field crops of the season. However, monsoon rains during July to September plays a positive role in coping with the moisture stress conditions to some extent. These rains prove helpful in reducing 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 the northern half of the country as compare to downstream areas. According to Ghazala and Rasul, 2010, the mid as well as the southern half of the country with high temperature and drier atmospheric conditions, receive lower amount of rainfall which is insufficient to compensate the loss of moisture through evapotranspiration. However, sometimes cyclonic activity causes heavy rainfall creating a sudden change along the coastal belt of the country.

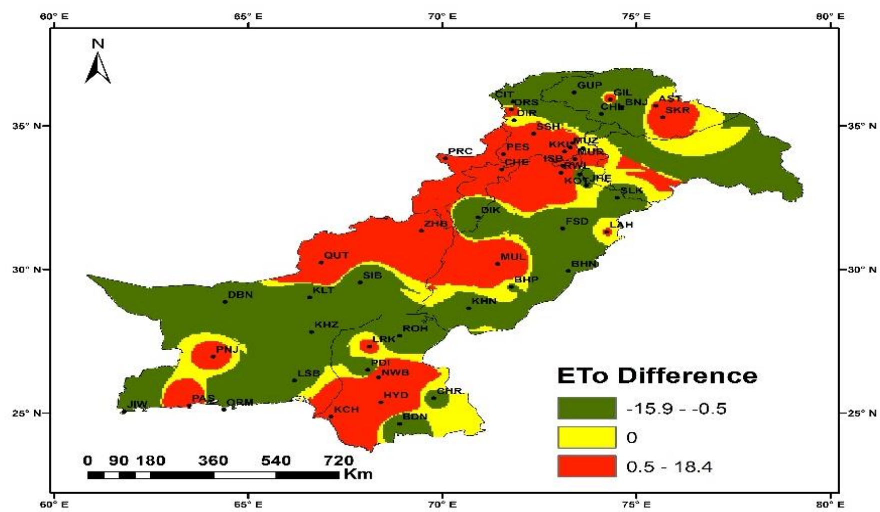


**Figure 1:** ETo Difference map for the period 1971-2000 and 1981-2010.

Figure 1 shows generally decreasing trend for ETo in most parts of the country. However, western Punjab, most parts of KPK, northern and south western Baluchistan, small regions in Gilgit Batlistan & and partially Sindh (from southwest up to Tharparkar desert) show an increasing trend of ETo. Therefore, the water requirement is higher during Kharif Season in the particular areas where rate of evapotranspiration is higher. Importantly, all the data points have shown a significant difference for ETo between the said period.

Due to high temperature and driest atmosphere during May and June, evaporative demands are very high in the country especially in the southern half. Monsoon rainfall plays a vital role in reducing the evaporative demand to some extent and fulfilling the water requirement of crops in rain fed 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. One of the prominent Kharif crop 'cotton' generally grows better on low elevated or plain areas. However, the continuous rise in temperature is more alarming and challenging condition for our agriculture sector.

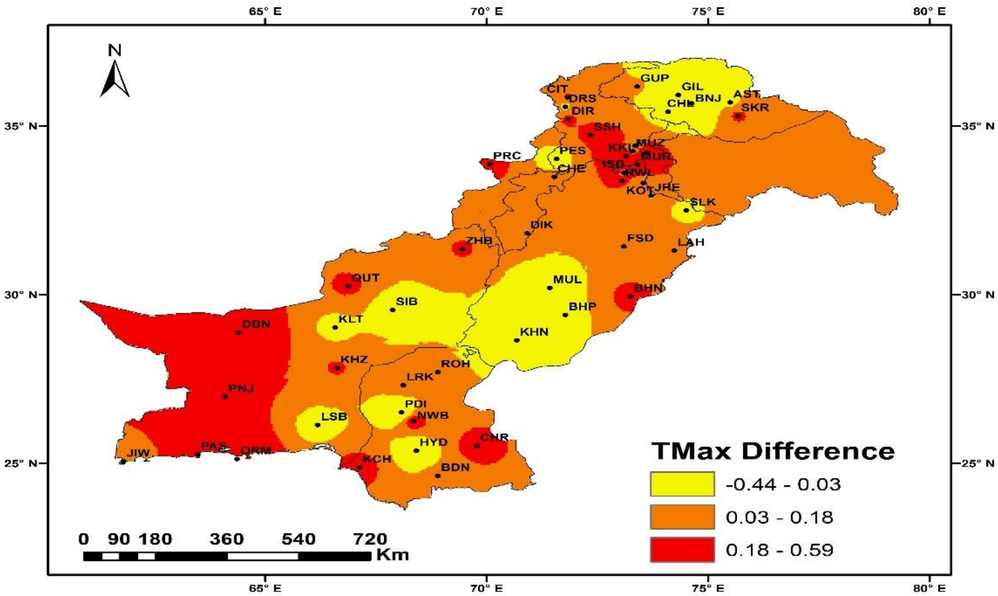


**Figure 2:** Difference of Kharif Maximum (°C) temperature for the period 1971-2000 and 1981-2010.

Figure 2 show increasing trend for maximum temperatures over most parts of the country. Where as southern Punjab, Gilgit Baltistan and isolated places in Baluchistan and Sindh are showing decreasing trend.

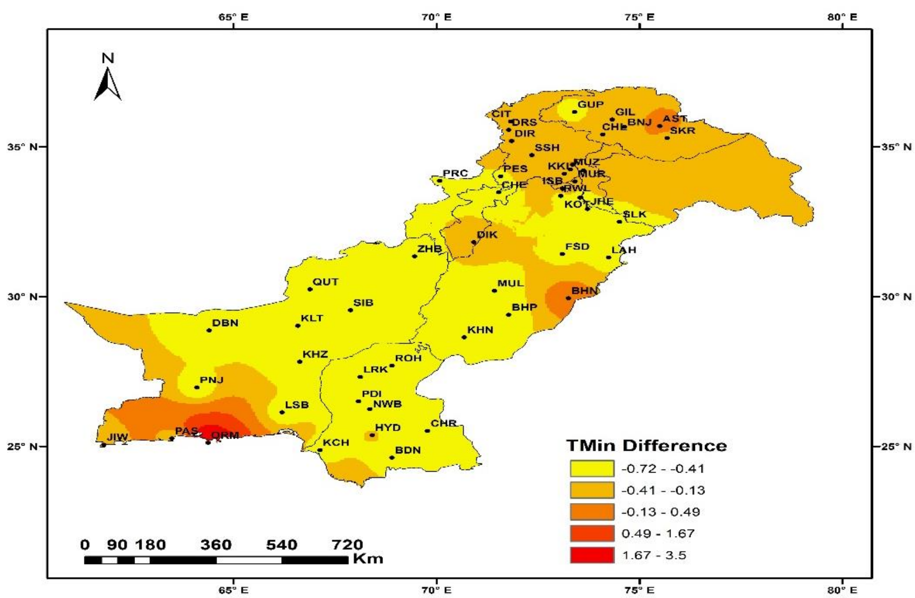


**Figure 3:** Difference of Kharif Minimum (°C) temperature for the period 1971-2000 and 1981-2010.

Figure 3 shows decreasing trend for minimum temperatures in most parts of the country. However, AJK, Gilgit Baltistan, isolated places in eastern Punjab and southwestern Balochistan hold the increasing trend for minimum temperatures. High temperatures provide higher amount of energy to convert liquid water into vapor. Besides, in warm conditions, plants open their stomata and release more water into the atmosphere which results in high rate of evapotranspiration.

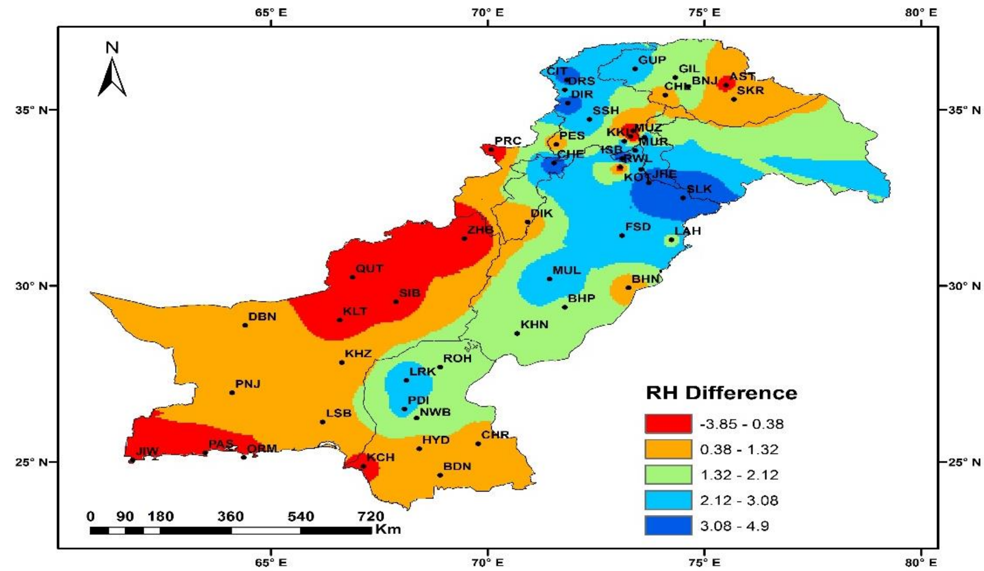


**Figure 4:** Difference of mean Relative Humidity (%) for the period 1971-2000 and 1981-2010.

In Figure 4**,** Northern Punjab and northern parts of KPK shows a sharp increasing trend for mean relative humidity. Which means, in these areas humidity had been increased for the period 1981-2010 as compared to the former period 1971-2000. However the southwestern tip and northern Baluchistan hold the decreasing trend for mean relative humidity. Generally, most parts of the country are showing an increasing trend for humidity.

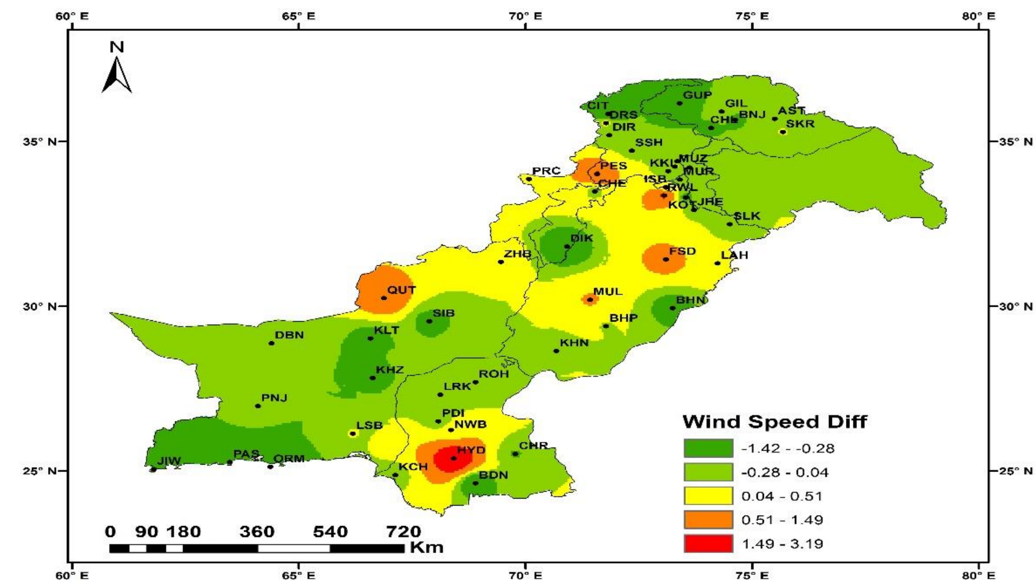


**Figure 5:** Difference of mean Wind speed (knots) for the period 1971-2000 and 1981-2010.

In Figure 5, most parts of the country show decreasing trend for mean wind speed where as central-northern Punjab, southern KPK, some parts of northern Baluchistan and central-coastal Sindh have an increasing trend for wind speed for the period 1971-2000 to 1981-2010.

Four meteorological parameters have been employed to calculate ETo. According to equation (3) shows that ETo variation is mainly dependent on wind speed and max temperature. Which is in accordance with the definition of ETo and results obtained in recent studies. Based on equation (3), the model produced simulations for ETo. Both actual and simulated values for ETo difference are shown in the Figure 6, for all the employed locations of the country. The actual and simulated values are strongly correlated (R = .81) at 0.01 significant level. It can be observed that overall, the model performed well. Although there are some stations with larger differences but for most of the locations, the simulations are very much consistent with the actual values for ETo (Figure 1 & 6 "Simulated Diff").

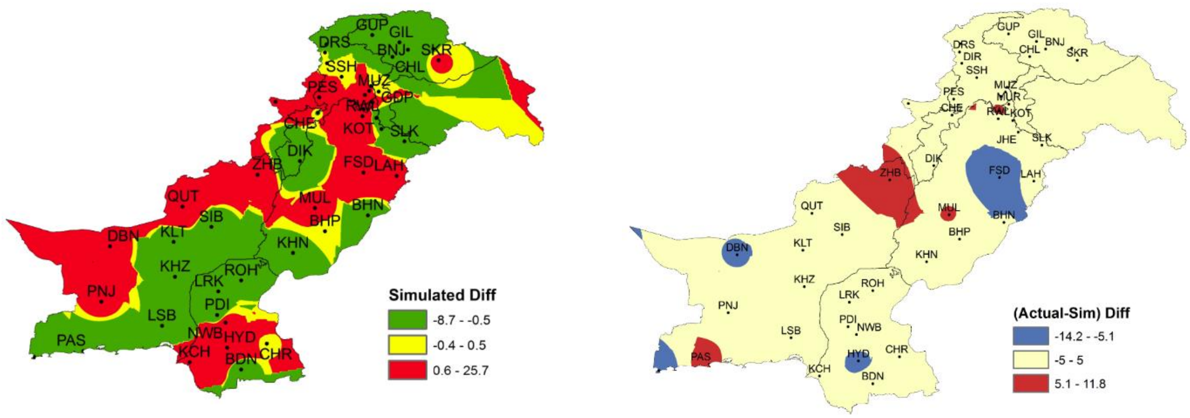


**Figure 6:** Actual and simulated ETo for all the employed stations of Pakistan.

## Conclusion

Bhutiyani et al., 2009 stated that since late 19th century, the temperature data shows a significant increasing trend on annual basis over the North Western Himalayan region. The temperatures are at increase throughout the region especially in the northern parts of the country. Pakistan has an agrarian economy where climate change and the consequent threat of global warming have become a great challenge (Rasul and Kazmi, 2011). The Rabi (October–March) and Kharif (April–September) are the two major cropping seasons in Pakistan. Kharif is of more importance as it holds three major crops; rice, cotton and sugarcane. ETo is one of the most important agro-meteorological parameters which is mainly dependent on air temperature. Accordingly, ETo profile has been analyzed on long term basis for Kharif season. It has been revealed in this study that there is mixed trend for ETo difference (1971-2000 to 1981-2010) for different stations in the region. But the change is mainly due to wind speed and max temperature. The regression model projected results are very much in agreement with the actual ETo change. Therefore, it can be concluded that the variation in ETo profile over different areas of Pakistan (Figure 1) are mainly dependent on wind velocity and day temperatures. The outcome of the study seems in agreement with the recent findings in the contexts of climate change and global warming. The results obtained will be helpful in further agro-meteorological research in this important region of south Asia in order to cope with future challenges.

## Acknowledgement

The authors would like to acknowledge and grateful to Dr. Muhammad Athar Haroon, Meteorologist at Pakistan Meteorological Department Pakistan, for his technical assistance in plotting GIS maps.

## References

**Allen, R. G., L. S. Pereira, D. Raes, and M. Smith, 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.

**Arnell, N. W., 2002:** Hydrology and Global Environmental Change, Pearson: Harlow.

**Bates, B. C., Z. W. Kundzewicz, S. Wu, and J. P. Palutikof (Eds.), 2008:** Climate change and water, Intergovernmental Panel on Climate Change Secretariat, Geneva, Switzerland.

**Challinor, A. J., J. M. Slingo , T. R. Wheeler, P. Q. Craufurd, and D. I. F. Grimes, 2003:** Toward a Combined Seasonal Weather and Crop Productivity Forecasting System: Determination of the Working Spatial Scale, Journal of Applied Meteorology, Volume 42 Issue 2, February.

**Di Falco, S., and Chavas, J. P., 2009:** On crop biodiversity, risk exposure and food security in the highlands of Ethiopia. American Journal of Agriculture Economics, 91(3), 599-611.

**GFSI, 2012:** Global food security index. An assessment of food affordability, availability and quality. A report from the Economist Intelligence Unit.

**Ghazala, N., and G. Rasul, 2010:** Recent Water Requirement of Cotton Crop in Pakistan. Pakistan Journals of Meteorology, Vol.6, No.12, January, 2010, pp.75-84.

**Hoekstra, A. Y. and A. K. Chapagain, 2007:** Water footprints of nations: Water use by people as a function of their consumption pattern. Water Resour Manage 21:35–48.

**Huntington, T.G., 2006:** Evidence for intensification of the global water cycle: review and synthesis. Journal of Hydrology, 319(1), 83-95.

**IPCC, Summary for Policymakers. In: climate Change, 2013:** The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschhung, A. Nauels, Y. Xia, V. Bex and P .M. Midgley (eds. )]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lower Chenab Canal System in Pakistan. WIT Transactions on Ecology and the Environment, Vol 80.

**Lu, J. B., G. Sun, S. G. McNulty, and D. M. Amataya, 2005:** A comparison of six potential evapotranspiration methods for regional use in the southeastern United States. Journal of the American Water Resources Association, 41, 621-633.

**Monteith, J. L., 1965:** Evaporation and environment. pp. 205-234.

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

**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.

**Rasul, G., and D. H. Kazmi, 2011:** Climate Change and Challenges to Crop Production; Proceedings of International Workshop on Plant Conservation & Reversing Desertification: A Way Forward, PMAS Arid Agriculture University, Rawalpindi, Pakistan, October 12–13,2009, p. 81–99.

**Schwab, G. O., D. D. Fangmeier, W. J. Elliot, and R. K. Fervert, 1993:** Soil and Water Conservation engineering, 4th Edition. John Wiley and Sons, Inc. New York. p.57.

**Shakir, A. S., & Qureshi, M. M., 2005:** Crop water requirement and availability in the

**Stern, P., 1994:** Small Scale Irrigation. Intermediate Technology Publication Ltd., Southampton Row, London. p.69.

**Trenberth, K. E., and G. R. Asrar, 2014:** Challenges and opportunities in water cycle research: WCRP contributions. In The Earth's Hydrological Cycle (pp. 515-532). Springer Netherlands.

**Zwart, S. J. and G. M. Bastiaanssen, 2004:** Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agricultural Water Management 69(2):115-133.