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Quantification of spatio-temporal variations of potential evapotranspiration in lower Chenab Canal East

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Abstract

Potential Evapotranspiration (ET_o) is a major component of the hydrologic cycle whose precise estimation is central to water allocation, water resource management, irrigation scheduling, and hydrologic water balance studies. Present study was conducted to quantify the spatio-temporal variation in the command of Lower Chenab Canal (LCC) East, Rechna Doab, Pakistan. The ET_o was calculated using globally recognized Penman Monteith method in Cropwat 8.0 for 30-year average climatic data of four weather stations. Spatial analysis of data was performed by employing IDW interpolation technique in Arc GIS-10.1. The increasing trend was more pronounced from January to June and decreasing trend was observed from June to January. The maximum ET_o 7.95 mm/day was observed in hottest month of June, whereas minimum ET_o 1.55 mm/day was observed in month of January. The interpolated results of ET_o showed resemblance to local climatic condition and observed lowest ET_o 1641mm/yr at head and highest ET_o1777 mm/yr at tail of the study area. The results revealed that the 72% ET_o occurs in kharif season whereas, only 28% remains in rabi season. Local weathers parameters i.e. air temperature and sunshine hours are main cause of spatial variation in ET_o whereas, regional climate conditions contribute for temporal changes. Study confirmed high water demand during kharif period and increasing aridity toward tail of canal command. The results of research are useful for planning and efficient use of available water resources. Future work could be performed by using advanced techniques and should be linked to climate change scenario.

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Introduction

In recent years, climate changes, rising world population and associated food demand have resulted in adverse impacts on existing water resources. It is reported that fresh water withdrawals will also increase 18% and 50% by 2025 in developed and developing countries, respectively (UNEP, 2007).

Prospects of new water resources in Pakistan for agricultural development are not encouraging as most of the water resources have already been explored in quantitative or qualitative means. Thus, it is important to emphasis on judicious use of existing water resources in agriculture sector by proper evaluation, planning, designing and implementation. Vigilant management and execution of scanty water resources is a major challenge of the 21st century to feed hungry mouths.

One of the most important factors that needs special attention for agricultural water management is crop water demand which depends mainly on evapotranspiration. Foremost element for agricultural water management is crop evapotranspiration (ET_c) especially in arid and semi-arid regions like Pakistan. In fact, the key component of hydrologic cycle is evapotranspiration which consume over 60% of total global precipitation (Chow *et al.,* 1988).

Direct assessment of ET_c is difficult, time consuming, laborious and costly task due to heterogeneous relationship and complex interaction between the atmosphere, soil, and vegetation cover. Commonly, ET_c is calculated on the basis of reference evapotranspiration (ET_o) by multiplying with crop coefficient K_c.

$$ET_c = K_c \times ET_o \qquad (1)$$

Reliable estimation of ET_o is considered as the most important for water allocation, water resource management, irrigation scheduling, reservoir operation, water budget and crop water requirement studies. ET_o varies spatially and temporally from small to large scale, depending on local and regional climatic conditions and the comprehension of these variations is essential for estimation, operation and management of water resources. Potential evapotranspiration (ET_o) depends on different climatic factors and the influence of individual parameters on ET_o is very important to understand.

The significance of various climatic parameters on ET_ohas been studied by many researcher and reported that the solar radiation, air temperature, humidity and wind speed are the key parameters (Penman, 1948). Many researches were conducted for ET_o estimation and analysis across the world (Mohan, 1991; George *et al.*, 2002; Chuanyan *et al.*, 2004; DehghaniS anij *et al.*, 2004; Garcia *et al.*, 2004). Review of different studies revealed that there is not a single method for ET_oestimation, which is suitable for all climatic periods and regions.

The Penman Monteith equation is recommended as the standard method and used for ET_o estimation with limited weather data (Ladlani *et al.,* 2012; Trajkovic and Kolakovic, 2009) and proved well in different geographic, climate zones and time step calculations (Smith, 2000; Kashyap and Panda, 2001; Temesgen *et al.,* 2005; Yoder *et al.,* 2005; Allen *et al.,* 2006).

Therefore, the present study was conducted with a key objective to identify seasonal and monthly variation in ET_o in irrigation administrative units/subdivisions of Lower Chenab Canal Command area. Specific aim of the research was to identify the month and location of peak ET_o and spatio-temporal variation within the command area.

Materials and methods

Study area

The research was conducted for selected area of Lower Chenab Canal (LCC) East circle located in Rechna Doab i.e. interfluvial area between Chenab and Ravi.

The selected area covered two administrative divisions of LCC-East i.e. Lower Gugera and Burala with 0.515 Mha gross command area and 0.392

Mhacultivable command area for the administrative management of the irrigation network as shown in Fig. 1. It lies between longitude 72°11'47" to 73°32'2"East and 30°32'26" to 31°29'23" North along the Ravi River. Research area include half of Faisalabad District and two-third Toba Tek Singh.

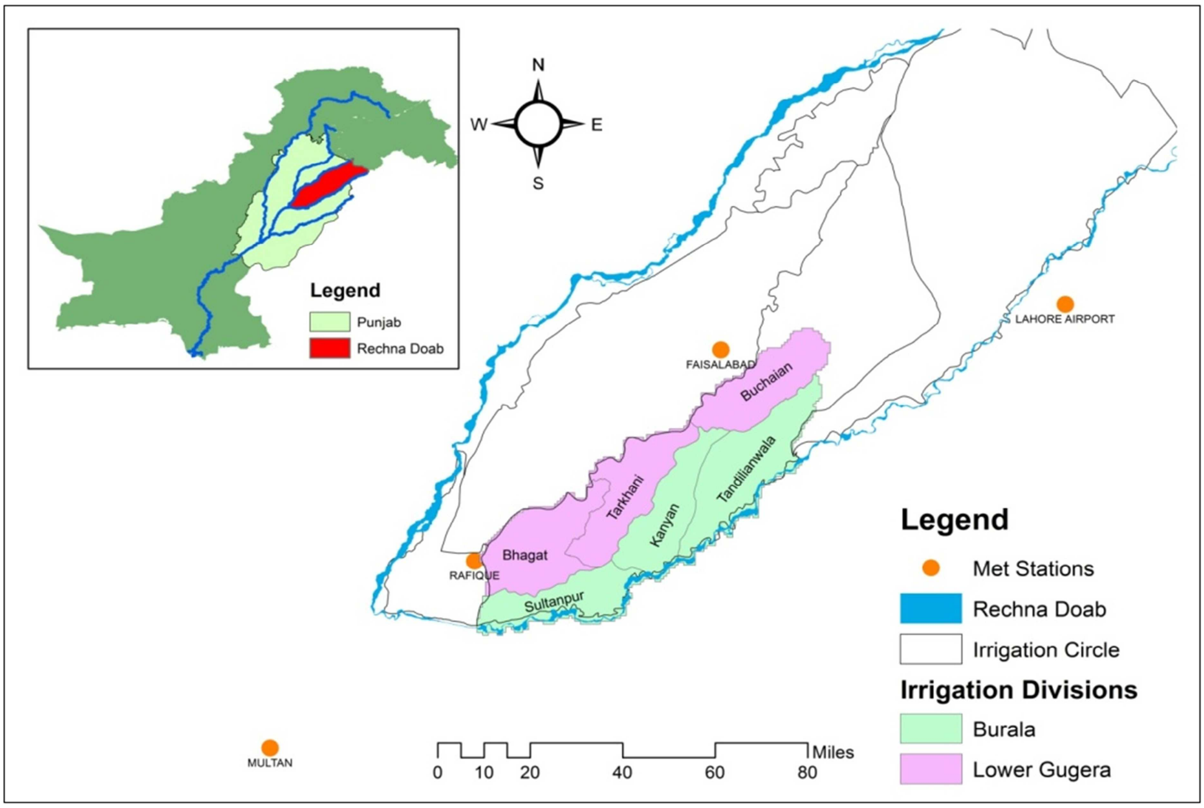

Fig. 1. Geographical location of study area.

Weather parameters

Weather data of four weather stations (Fig. 1) located within and close to the Rechna Doab were used for ET_o calculation. The 30-year mean monthly value of maximum and minimum air temperature (T_{max}°C and T_{min}°C), relative humidity (RH %), sunshine hours (h), 24-h wind speed (m/s) at a 2 m height and precipitation were used to estimate $ET_o$and aridity index. Table 01 provides details of average data of four selected stations.

Estimation of potential evapotranspiration

The Penman Monteith (PM) equation is globally recognized, widely employed and well tested using lysimeter data with different climatic conditions. Allen *et al.,* (1998) reported that PM Equation had been adopted as standard method for computing ET_o by various organizations i.e. Food and Agriculture Organization (FAO), American Society of Civil Engineers (ASCE) and International Commission for Irrigation and Drainage (ICID).

In present study, monthly average potential evapotranspiration was calculated by the PM-FAO equation, based on data from four weather stations located within/around the study area and subsequently interpolated by inverse distance weighing (IDW) technique. Potential evapotranspiration was calculated by using PM equation. The variables of Penman equation were described in FAO Irrigation and Drainage Paper No. 56 (Allen, *et al.*, 1998) and the value 0.408 converts the net radiation R_n expressed in MJ/m²/day to equivalent evaporation expressed in mm/day.

$$ETo = \frac{0.408\,\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,U_2)} \quad (2)$$

Spatial analysis

Weather parameters as point data were converted into continuous surface data using spatial interpolation techniques. The spatial analysis of ET_o across the canal command and different subdivision was performed by inverse distance weighing (IDW) interpolation techniques. Arc-Map provides a raster data of interpolated ET_o and these values were converted into integer values by using integer calculator. Raster to polygon conversion tool was used to convert raster data into vector. Vector polygon was intersected with subdivision maps using overlay analysis tool to interconnect the ET_o value of each polygon with subdivision. Geo-processing tool was used to aggregate ET_o with statistics mean value of polygon with subdivision. Flow chart for calculation and spatial analysis of $ET_o$is given in Fig. 2.

Estimation of aridity index

Aridity Index (AI) represent the drought-wetness variations for crop water demand to satisfy evapotranspiration needs. Thornthwaite (1948) defined aridity index as the ratio of difference between potential evapotranspiration and precipitation to potential evapotranspiration. It is calculated using equation (3) given below.

$$AI = \frac{(ETo - P)}{ETo} \quad (3)$$

Whereas

P = monthly total precipitation (mm)

ET_o= monthly potential evapotranspiration (mm).

Aridity Index varied from 0 to 1 where higher value represent aridity/drought and lower values indicate wetness. Negative value indicates that precipitation is higher than potential evapotranspiration. In present study, monthly aridity index was calculated to observe the aridity level in study area.

Results and discussion

Climatic conditions and potential evapotranspiration

Climatic conditions were studied by using 30-year mean monthly climatic data of four selected weather stations i.e. Lahore, Faisalabad, Rafique and Multan. Trend of different climatic parameters on 30-year mean monthly basis for study area is shown in Fig. 3. Summer is long and hot, lasting from April through October with maximum daytime temperatures ranging from 21.8 ˚C to 49.8 ˚C and winter period considered as October to April with maximum daytime temperatures ranging between 15 ˚C to 27 ˚C and sometimes falling below zero at night.

Table 1. Average climatic data of selected stations.

Months	T_{min} (°C)	T_{max} (°C)	Humidity (%)	Wind (m/sec)	Sunshine (hr)	Precipitation (mm)
Jan	5.66	19.71	49.59	0.73	6.30	12.46
Feb	8.52	22.64	43.00	1.50	6.89	20.44
Mar	13.86	27.66	39.04	1.74	7.81	24.78
Apr	19.50	34.75	27.43	1.85	9.06	20.67
May	24.63	39.77	24.20	1.89	9.50	15.67
Jun	27.72	40.85	31.14	2.20	8.86	33.64
Jul	27.83	37.67	50.36	2.25	7.94	109.68
Aug	27.24	36.49	55.51	2.19	8.17	91.23
Sep	24.66	35.83	48.60	1.70	8.76	39.48
Oct	18.34	33.26	39.90	0.79	8.64	7.96
Nov	11.88	27.93	46.45	0.33	7.91	3.35
Dec	6.89	22.22	51.24	0.32	6.64	6.90

The highest precipitation occurs during the monsoon period from mid-July to mid-September and contributes about 60 percent of average annual precipitation. Incorporated corrected.

Temporal variation

Monthly percentile of potential evapotranspiration was analyzed and results showed two major slices, small slices contribute less than 10%, which represents winter season and large slices contribute more than 10% which represents summer season.

Significant variation was also observed for two cropping season i.e. rabi and kharif. Major chunk of potential evapotranspiration 72% occurred during kharif cropping season, whereas remaining 28% contribute in rabi season as shown in Fig. 4. Threefold more potential evapotranspiration in kharif season takes place due to hot weather conditions and long sunshine duration as compared to other months.

Thomas (2000) conducted a research to identify the influence of different climatic parameters on potential evapotranspiration and reported sunshine duration as main parameter in South China whereas relative humidity, wind speed and maximum temperature exert more influence in northwest, central, and northeast China.

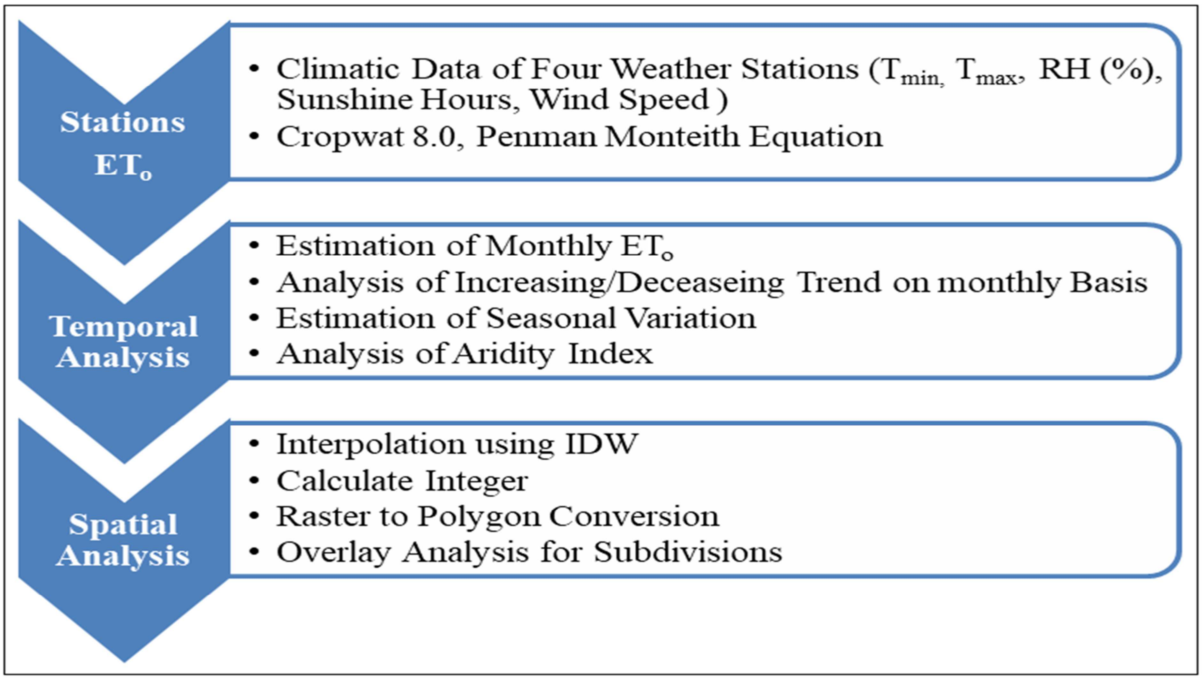

Fig. 2. Flow chart for calculation and spatial analysis of ET$_o$

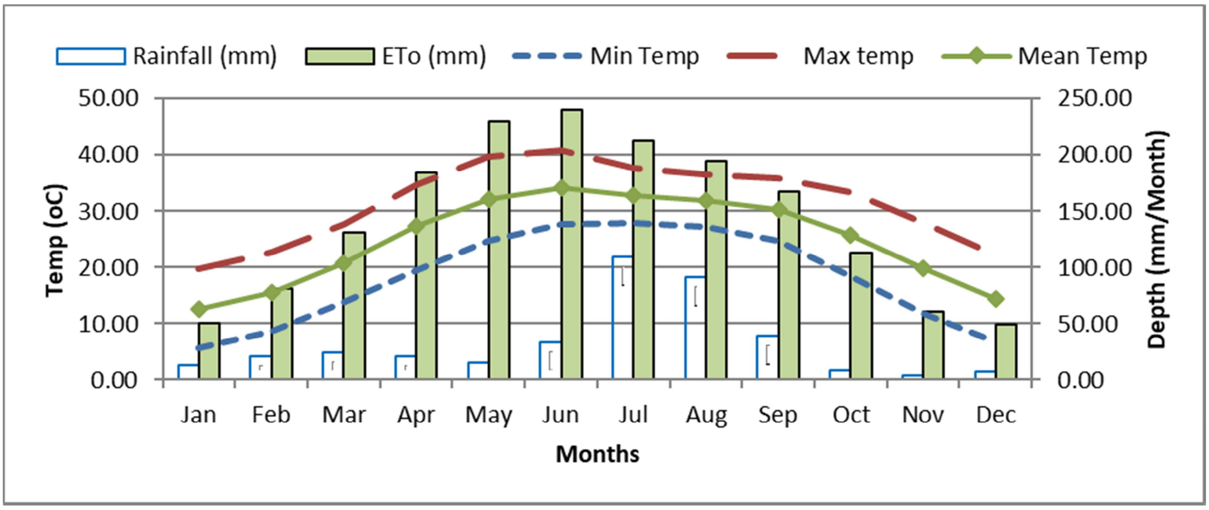

Fig. 3. Weather conditions of study area.

The monthly potential evapotranspiration data was analyzed and results revealed the significant variation. The ET$_o$ demonstrated rising trend from January to June and declining trend from June to December as shown in Fig. 5. The maximum increase 53 mm/month was observed in April and sharp rise was observed from January to February. Similarly, maximum decrease 54.5 mm/month was observed in

October and abrupt decline was observed November to December. These finding are consistent with local weather conditions as shown in Fig 3. Evapotranspiration start increasing with rise in temperature in start of summer season. Change in ET_o is based on temperature and other climatic parameters (Cohen *et al.,* 2002; Roderick and Farquhar, 2002; Irmak *el al.,* 2012).

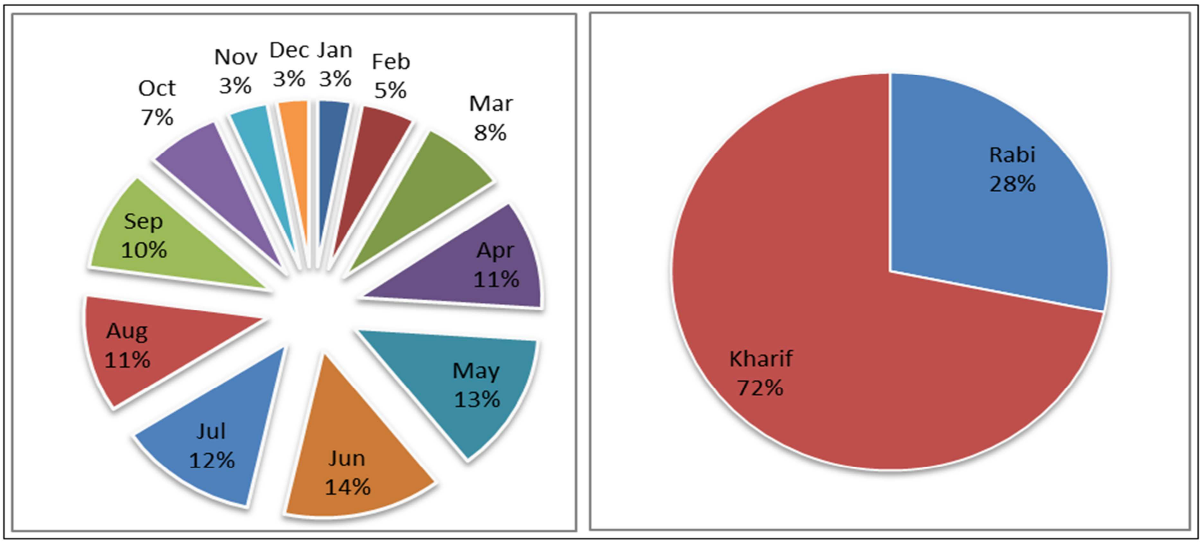

Fig. 4. Mothly and seasonal contribution in annual potential evapotranspiration.

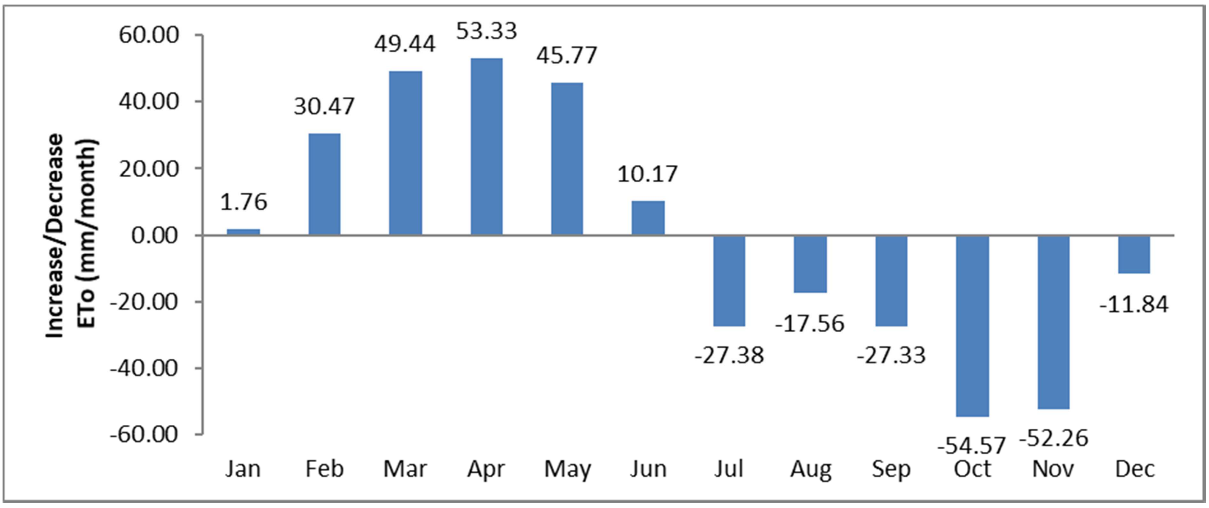

Fig. 5. Monthly temporal variations in potential evapotranspiration.

Similar conclusion was drawn in India by Goyal (2004), that temperature is most important parameter followed by radiation, wind speed and vapor pressure.

Analysis of Monthly evapotranspiration is more substantial to less variation in time and space as compared to daily observation (Shen *et al.,* 2001).

Aridity index variation

The temporal trend of monthly data for potential evapotranspiration, precipitation and aridity index had significant variation as shown in Fig. 6. Maximum value of ET_o and P was observed as 239.8 and 109.58 mm in the month of June and August respectively. Similarly, the minimum ET_o and P was observed as 48.9 and 6.9 mm in the colder month of December respectively. Aridity Index was observed higher than 0.75 over the year, while AI was lower than 0.55 in July and August only.

The maximum precipitation and lowest aridity index was observed for limited period of monsoon.

Lowest aridity index 0.43 also reflect that high precipitation during monsoon is not sufficient to meet crop water requirement. Maximum aridity index was observed 0.94 in month of November due to low precipitation.

Increasing trend of aridity index was observed from January to May due increase in ET_0 and hot weather whereas increasing trend of AI was observed from August to November due to low precipitation.

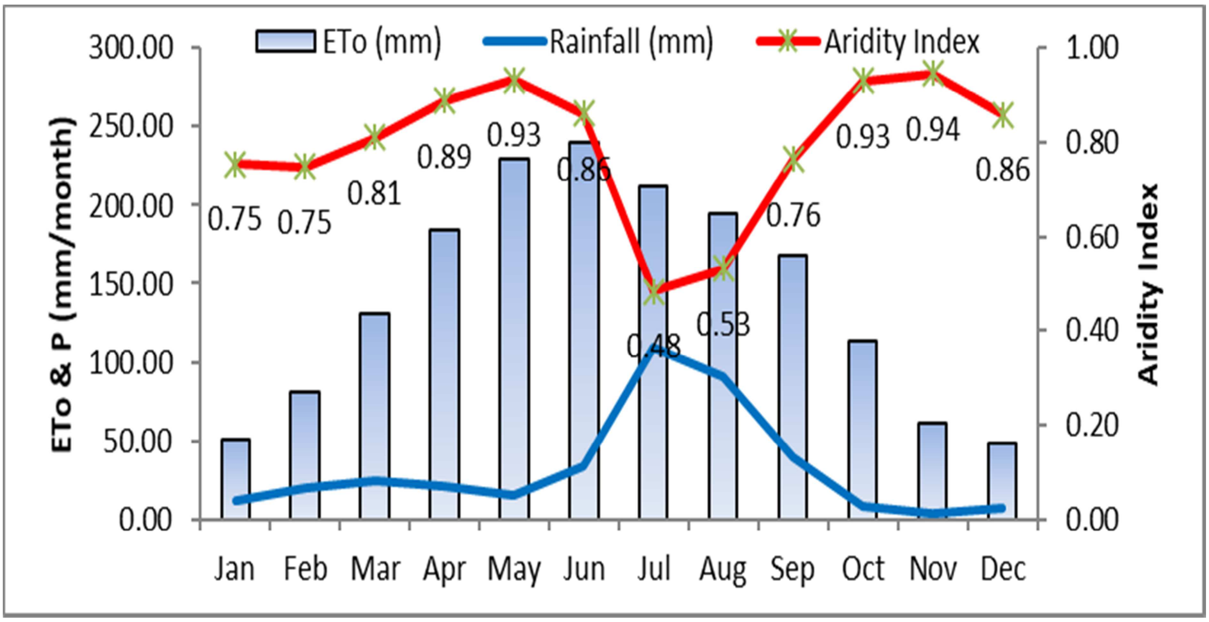

Fig. 6. Monthly variation of ET_0, Precipitation and Aridity Index.

The trend of monthly aridity index was observed opposite to precipitation pattern. Many researcher (Frich *et al.*, 2002; Li *et al.*, 2012) studied the aridity and humidness variation and also examine the influence of different climatic factors like temperature, precipitation and evaporation. Aridity Index also refers to the change in evapotranspiration and precipitation.

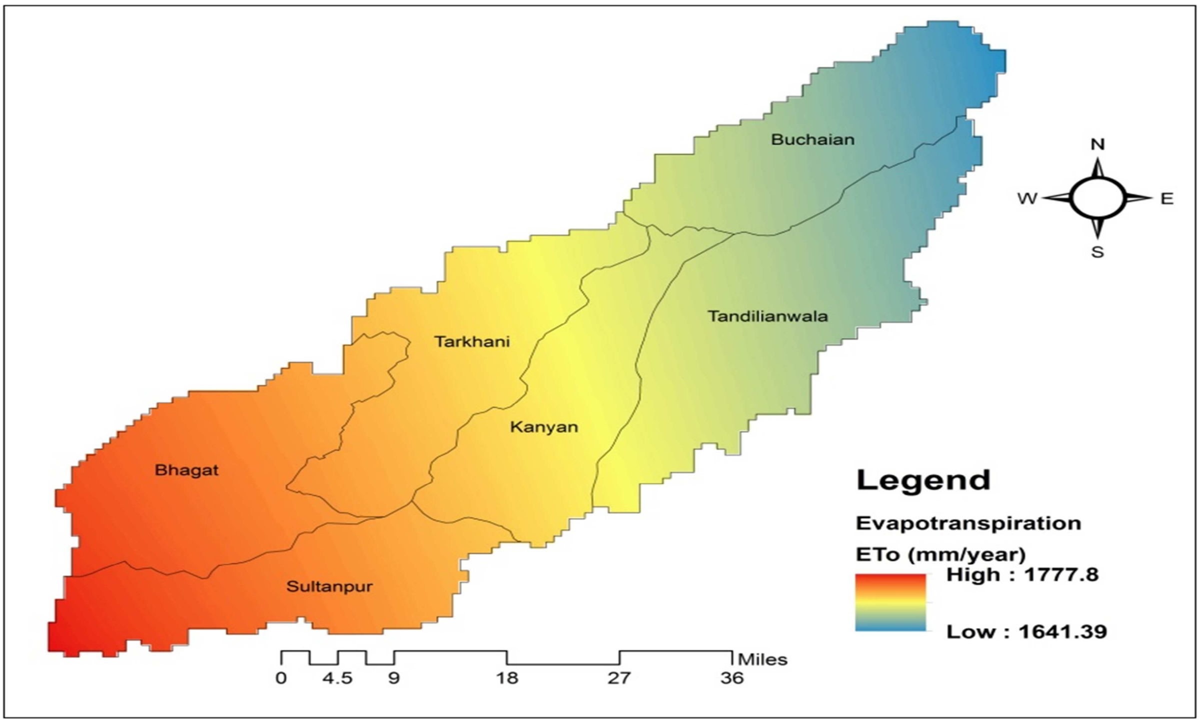

Fig. 7-A. Spatial variation of the average annual ET_0 over canal command.

Spatial variation

Fig. 7-A illustrates the spatial pattern of 30-year mean annual potential evapotranspiration over the canal command. The figure illustrates a gradual increase of potential evapotranspiration from north-east to south-west, with the highest value in the upper part of canal command. The range of annual ET_0 varies from 1641 to 1777 mm and average value of 1709 mm was observed for entire area. The results are almost supported by Khan *et al.* (2003) for potential evapotranspiration and crop water requirement in Rechna doab. These variations along length of canal command represent high water demand at tail end as compare to head end. Irrigation system in Pakistan is supply driven instead of demand based. Therefore, rise in potential water demand toward tail-enders reflects more severe condition for agriculture sector in the days to come. Song *et al.* (2010) examine spatial and temporal variations of ET_0 in North China Plain. They reported maximum annual ET_0 in the central and western areas and minimum ET_0 occurred in east of North China Plain.

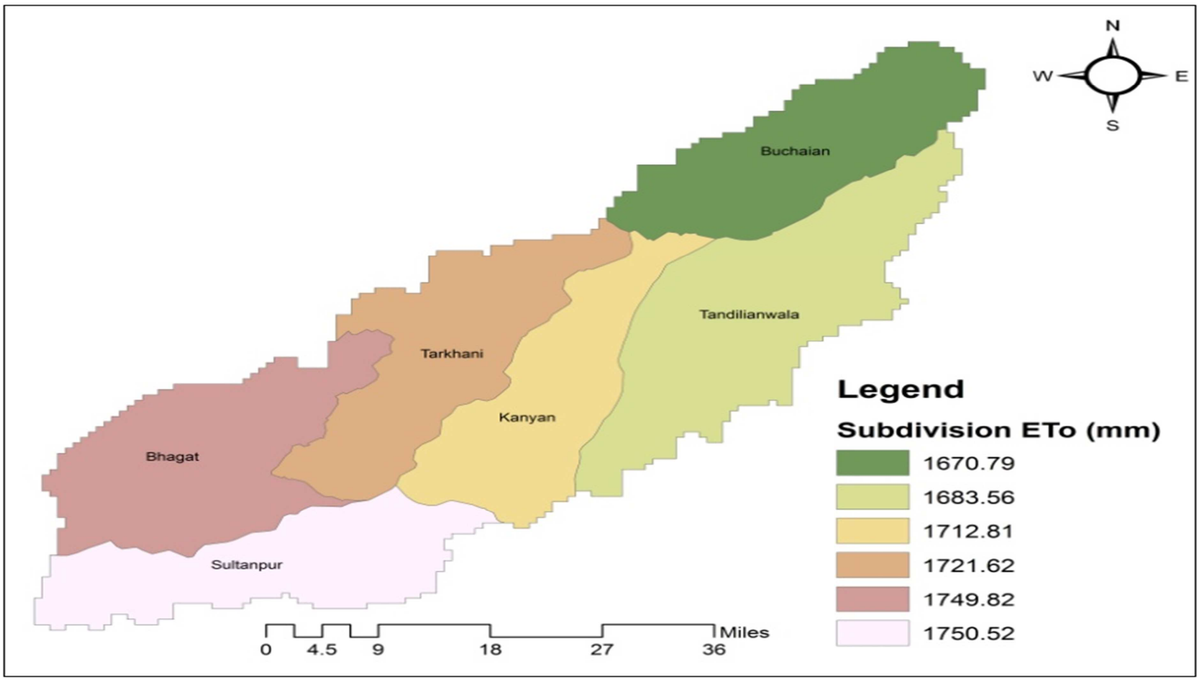

Fig. 7-B. ET_0 of different Irrigation Administrative Units (Subdivision Level).

Average annual ET_0 for six irrigation administrative units is presented in Fig 7-B. Potential evapotranspiration can classify into three groups as head, middle and tail because two subdivisions at each location have approximately same values with location-wise difference. Maximum ET_0 was observed for Bhagat and Sultanpur Subdivision and minimum ET_0 was noticed for Buchiana and Tandilianwala Subdivision. High ET_0 at tail subdivision demands more irrigation supply for healthy growth of crops. High evapotranspiration, low precipitation and high aridity index at tail of canal command may exert adverse effects on agriculture output in the wake of low or non-availability of canal supply. Therefore, canal supply at distributary channel may be altered to adjust these variations.

Groundwater pumping is an alternate option for tail farmers if subsidized by government else they failed to get good profit due to input cost. Rephrase.

Conclusion

Comprehensive analysis for spatial and temporal variation in potential evapotranspiration revealed significant results. Increasing trend in monthly ET_0 was observed from January to June and decreasing trend was observed from June to January. An extend of potential evapotranspiration was observed ranging from 7.95 to 1.55 mm/day in hottest month June to coldest month of January respectively. A maximum increase of 53 mm/month and maximum decrease of 54.5 mm/month was observed in April and October respectively.

Major chunk of potential evapotranspiration i.e. 72% occurred during kharif cropping season, whereas remaining 28% was contributed during rabi season. Difference of 136 mm was observed with minimum ET_0 of 1641 mm/yr at head and maximum ET_0 of 1777 mm/yr at tail of canal command. Aridity Index was observed higher than 0.75 over the whole year expect in month of July and August due to more rainfall. Temperature and sunshine durations were observed as most influencing parameters for variation in ET_0 at monthly time scale as well as spatially along canal command.

Temporal analysis confirmed high water demand/losses in terms of evapotranspiration during kharif season (hot months) and monthly variations were more significant for transitional months. The spatial variation in ET_0 demonstrated declining trend from northeast to southwest along the canal length and established resemblance to local and regional climatic condition. However, lowest aridity index also reflected that high precipitation during monsoon were not sufficient to meet crop water requirement. Spatial variation indicate that an additional irrigation is required at tail of canal command and significant temporal variation demands more at least twofold water supply during kharif season to meet high evapotranspiration. Future work could be performed by employing advanced techniques and it should be linked to new realities of climate change.

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