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Assessment of Crop Water Requirement for Various Crops in Peshawar, Pakistan Using CROPWAT Model

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Abstract

Water is an important input for agriculture so that this valuable resource is designed properly and deliverable. Reasonable information on evapotranspiration, crop water requirements, and net irrigation requirements is required for effective planning of this resource. Present research intentions to calculate the Crop Water Requirement for the various crop in the Peshawar district using CROPWAT 8.0 model. Crops in the area of study comprise wheat, sorghum, and millet. The climate data (rainfall, maximum temperature, minimum temperature, hours of sunshine, wind speed, and humidity) was obtained from Regional Meteorological Center, Peshawar. The soil and crop data were obtained from Food and Agriculture Organization for the above-mentioned crops. The reference evapotranspiration, crop water requirement, effective rainfall, and irrigation water requirement were calculated via the CROPWAT model. The study evident that for crops grown in the area the irrigation water requirement is desired to fulfill crop water requirements since effective rainfall is not enough to encounter the crop water requirement.

Keywords: CROPWAT • Crop water requirement • Evapo-transpiration • Irrigation • Water requirement

Introduction

Background

Water is becoming valuable and rare owing to its growing demand in agricultural activities [1]. Water demand is rising gradually as the crop yield is a serious problem throughout the world, particularly in developing countries, owing to population growth, rapid urbanization, and irrigation activities. The causes for this are the lack of adequate water management and water resources conservation. It is compulsory to apply significant approaches that help rise water efficiency [2]. Water is an important input for agriculture so that this valuable resource is designed properly and deliverable. Reasonable information on evapotranspiration, crop water requirements, and net irrigation requirements is required for effective planning of this resource. The water demand for crops differs significantly between crops and crops, even during the entire growing season of a single crop [1]. A major part of a hydrological cycle is evapotranspiration. It is also the transport of water from crop and soil surface to the environment through evaporation. Type of vegetation under various weather conditions vary in evapotranspiration. In Pakistan, although many crops require irrigation and a major portion of water is wasted in the environment because of the greater rate of evapotranspiration. As the ETo rises, the need for crop water will also significantly raise, eventually affecting the production of a crop. It is quite tough to achieve this issue owing to a restricted resource of water [3]. The water requirement can be calculated by the estimated process, where the calculation of the water requirement of the crop (ETc) is equivalent to the ETo value multiplied by the crop coefficient (Kc). Globally, the Penman-Monteith equation is one of the most accurate and detailed techniques for calculating evapotranspiration and crop water requirements [4]. In CROPWAT 8.0, the Penman-Monteith equation is used to evaluate the potential evapotranspiration. Temperature, wind speed, humidity, solar radiation, and ambient temperature are the main determiners of the potential evapotranspiration rate in the Penman-Monteith equation. With model CROPWAT 8.0 we can detect crop water requirements throughout the growing period by rainwater and irrigation on the field [5]. Crop Water Requirements (CWR) relates to the quantity of water needed to cover losses of evapotranspiration from the cultivated field over a certain period. The requirements of crop water are normally expressed in mm/day, mm/month, or mm/season [6].

The only way to improve agriculture is through the provision of modern, adequate irrigation strategies and improved water management practices. Taking into consideration the current water situation throughout the world is an important technique for choosing proper water use. CROPWAT is an FAO-developed window-based model for determining the ETo for accurate irrigation scheduling and design. The Penman-Monteith Equation of FAO is the basis of this application to determine ETo, which will also be useful for increasing crop production [7]. This research aims to estimate the Crop Water Requirement for the various crops in the Peshawar district using CROPWAT 8.0.

Research problem

The CROPWAT model is preferred for use in this study in the determination of the reference evapotranspiration (ETo) as it is reported to deliver very reliable values on actual crop water use data worldwide. Systematic crop water requirements are essential ensuring efficient scheduling of irrigation and water management, design of canal capacities, planning of water resources, regional drainage, and research in reservoir operation. Adequate information on crop water and irrigation requirements is lacking among the farmers practicing irrigation for most of the crops grown in the area. This research is thus an attempt to calculate the crop water needs of the main crops grown in the study area using the FAO CROPWAT model [8].

Objectives

To determine the Crop Water Requirement and Irrigation water Requirement for various crops in Peshawar district.

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Literature Review

A summary of evapotranspiration (ET)

Water is supplied to crops by rain and surface moisture if it is not sufficient to supply them, we have directly converted it into irrigation. The irrigated water should not exceed the water used by plants by ET. It is also termed as consumptive use actual ET. It is a physical process in which gaseous water molecules move from the plant and the soil surface to the atmosphere [9]. ET is the combined evaporation and transpiration, so an approximation or measured combination must be made because often they are in nature. The depletion of moisture from the cultivation fields is called crop ET, which helps in planning irrigation. Solar radiation, temperature, wind speed, relative moisture, soil, and plant parameters influence crop [6].

Measurement of evapotranspiration

Depending on different approaches/precepts, there are many techniques to measure evapotranspiration:

Direct methods

a) Field Water Balance method

b) Soil Moisture Depletion method

Indirect methods

a) Empirical/ Statistical Methods

- Thornthwaite method
- Hamon method
- Papadakis method
- Modified Jensen and Haise method
- Blaney-Criddle method

b) Micrometeorological methods

- Energy balance
- Penman-Monteith equation
- Aerodynamic resistance

c) Remote Sensing Methods

- Energy balance-regression model
- Bartholic, Namken end Wiegand model
- Brown and Rosenberg Resistance model [10,11].

Factors that affect Evapotranspiration

The factors affecting evaporation and transpiration are crop characteristics, weather conditions, and environmental and management factors.

Weather parameters: Air temperature, Radiation, wind speeds, and air humidity are the major weather variables affecting evapotranspiration. A reference crop evapotranspiration (ETc) describes the evaporative power of the environment. The ETc reflects standardized vegetated surface evapotranspiration.

Crop factors: When evaluating the evapotranspiration by crops cultivated in wide, well-maintained fields, the crop type, variety, and growth phase must be recognized. Differences in transpiration resistance, crop roughness, reflection, crop height, soil cover, and rooting aspects of crops influence the effects of ET in various crop varieties in the same environmental circumstances.

Management and environmental conditions: The existence of hard and impervious soil horizons as well as the absence of pest and disease control, and impoverished soil managing, like soil salinity, poor soil fertility, and reduced fertilizer application,could limit crop growth and lower evapotranspiration. The plant density, ground cover, and groundwater content are other aspects to consider in the assessment of ETo. ETo is mainly influenced in the extent of the water stress also the soil type that the soil contains [10].

Reference and Potential Evapotranspiration

Reference ETo is the removal of water from the hypothesized plant of 0.12 m, surface tension of 70 s/m, at an albedo of 23% with no water deficit similar to evaporation from ordinary grasses and covering the soil and watering it appropriately [12,13]. The loss of water from small green grasses that are shaded by normal height is potential evapotranspiration. The ETo rate is not linked in this definition to a particular crop. Many plants are like short green grasses, but ETo is the correct definition of short green vegetation, free from stress or disease. The two reference surfaces proposed by FAO are Alfalfa and short cuts of grass owing to the accessibility of data [14]. Several authors proposed that the Penman-Monteith equation of FAO is the finest of all diverse authors' models, although needs a lot of climatic parameters. FAO has modeled CROPWAT to compute ETo easily for this intent [12]. Various models were related by [15] and the FAO Penman-Monteith showed reliable and meaningful ETo results.

Crop Evapotranspiration Calculation

Crop evapotranspiration (ETC) needs reference evapotranspiration (ETo) for determination using the subsequent equation;

$$ETC = ET_0 \times K_c$$

We will consider the ETo and multiply it constantly with the crop coefficient [6].

CROPWAT model review

CROPWAT is FAO's "Land and Water Development Division" decision-making tool. In command to guesstimate “reference evapotranspiration”, “crop water requirement” (CWR), and to provision “Irrigation water requirement” (IWR). The CWR and IWR calculation algorithm for the model is built on the ETo calculation, which is counted according to Penman-Monteith and other crop parameters. CROPWAT may become a suitable tool to improve irrigation scheduling under various systems and schemes, to assess productivity in irrigation applications, rain-fed productivity, and the impact of drought. As inputs for CROPWAT, climatic and crop data is necessary. The development of irrigation plans and rainfed farming assessment as well as all irrigation practices are based on a regular approach to the soil balance employing numerous supply also irrigation management alternatives [16].

Assessment of crop water requirement

Faisal Basiri explain Water Requirement for Crop as the total water provided by irrigation or rainfall to satisfy the demand for evapotranspiration of crops, therefore, does not decline production. Crop evapotranspiration involves the amount of water waste by evapotranspiration. To fully understand the irrigation requirement, it is necessary to ensure crop water requirements. Irrigation water requirement essentially understands the changes in the demand for crop water and the effective amount of rainfall existing. We must consider providing water for soil leaching and its correction to water non-uniformity concerns irrigation water requirements [14].

The following equations can be used to assess the "crop water needs" (CWR), which in ordinary conditions are practically equivalent to crop evapotranspiration. With this in mind, crop growth like crop density, disease, insects, weeds, water scarcity, and salinity pressures are not subject to any restrictions. For actual crop evapotranspiration (ET_c) to be measured effectiveness, first, it needs an assessment of reference or potential Evapotranspiration, and then it needs the appropriate crop constants (Kc).

$$ET_c = ET_0 \times K_c$$

ET_c = Crop evapotranspiration in mm/day

K_c = coefficient for crop, with no dimension

ET_o = evapotranspiration (Reference) in mm/day

Irrigation water requirement

Irrigation and the amount of rainfall must be adequate to fulfill the ET needs to sustain crop water tension in the drier climate. This means that the irrigation water requirement (IWR) is, for any particular time during the crop growth period, the amount of water not supplied effectively in the rainfall.

IWR= (ET – ER)

IWR= Irrigation Water required to fulfill crop water requirement, (mm)

ET= Evapotranspiration (mm)

ER = Effective Rainfall (mm)

Methodology

Study area

Geographical location is between lengths 71°22' 0" -71° 42' 0" East and latitudes |33° 44' 0" – 34° 15' 0" North. It is the head quarter of Khyber Pakhtunkhwa province. The Peshawar area is 1.257 square kilometers and about 358 m above sea level. The district has extreme climatic conditions. The average monthly temperature for the Peshawar district varies from at least 2.60 °C in January up to 42.70 °C in June (Ullah & Khan, 2019). The average Relative humidity varies from 46 to 76 correspondingly in June and August [17] (Figure 1).

Input data for CROPWAT

Water and irrigation measurements use inputs from climate, soil, and crop data, along with irrigation and rain data. The climate input data needed are rainfall (day/decade/monthly) and reference evapotranspiration (decade/monthly). The FAO Penman-Monteith technique provides a measure of reference evapotranspiration from minimum and maximum temperature, wind speed, sunshine hours, and humidity [18].

Input meteorological data : Meteorological data included the minimum, and maximum temperature, wind speed (Km/day), air humidity (%), and sunshine duration (hr.) for the Peshawar District, the latitude, longitude, and elevation value. Data have been gathered from the meteorology department for 13 years (2005-2017), ETo value can be obtained ETo per day or per month. The attained ETo values are founded on the method of Penman-Monteith (Figure 2).

Input rainfall data: Data of Rainfall develops one of the variables deciding the importance of the need for crop water. Data for the thirteen years from 2005 to 2017 has been used for rainfall. USDA Soil Conservation Services (SCS) formula has been used to calculate effective rainfall [1] (Figure 3).

$$P_{eff} = \frac{P_{total} * (125 - 0.26 P_{total})}{125} \quad for\ P_{total} \le \left(\frac{250}{3}\right) mm$$

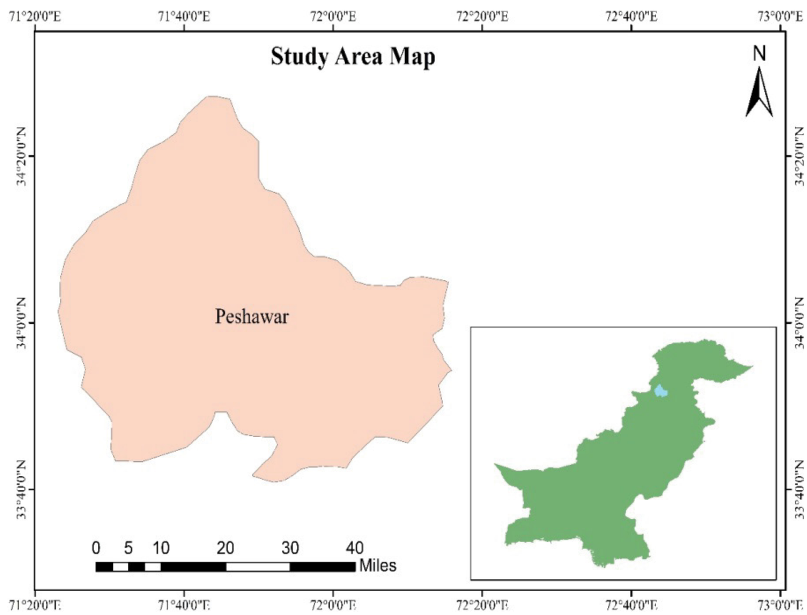


Figure 1. Map of the study area.

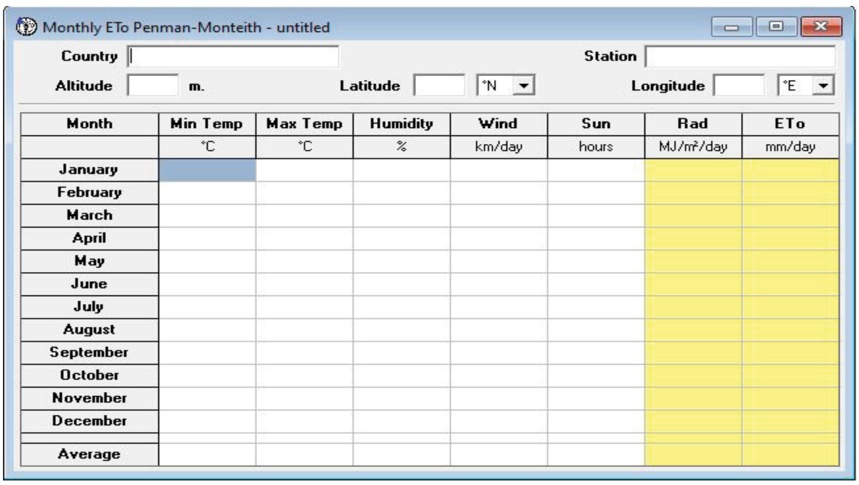


Figure 2. Monthly ETo penman-monteith calculation.

$$P_{eff} = \frac{125}{3} + 0.1 * P_{total} \quad for\ P_{total} > \left(\frac{250}{3}\right) mm$$

Input crop data: The input crop characteristics data includes the total number of days at each stage of growth, Kc value for each phase of growth, critical depletion, depth of root, and crop yield response parameter. The yield response factor (K_y) is the proportion of the reduction of comparative yield to the deficits in comparative evapotranspiration that combines temperature, soil, and crop conditions that reduce crop yields from evapotranspiration in comparison with their potential yield (Figure 4).

Input soil data: The CROPWAT software needs certain basic data on the soil, such as total soil moisture available, the maximum infiltration rate of rainfall, maximum depth of root, initial depletion of soil moisture content, and initially soil moisture available(Figure 5).

Output data obtained from CROPWAT

Crop water requirement : After receiving the crop, the number of days for various phases of crop such as (initial, mid-season, development, and late season), crop coefficient values, yield response fraction values, and the date of transplantation from the user, the crop water requirements of various crops were measured by the model. The outputs encompass various crop stages, crop coefficient (K_c), effective precipitation, crop reference evapotranspiration, and irrigation demands as below (Figure 6).

Irrigation schedule: The irrigation schedule specifies the right irrigation calculation and the proper irrigation time. The CROPWAT model estimates the irrigation schedules of ET_o, CWR, and IWR to be drawn upon various management conditions and water supply plans. The model generated Gross Irrigation, Net irrigation, and rate of flow in liter/sec/hectare (l/s/ha). The model also balances soil moisture on daily basis (Figure 7 and Figure 8).

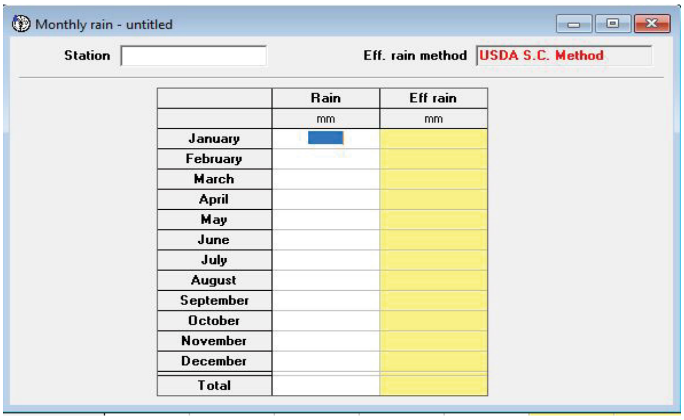


Figure 3. CROPWAT input for calculation of effective rainfall.

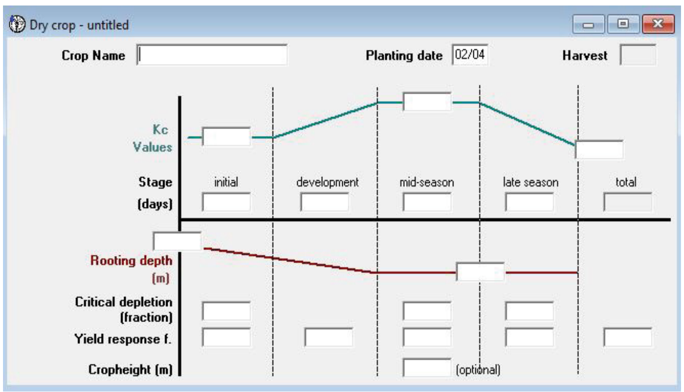


Figure 4. Input module of CROPWAT for crop data.

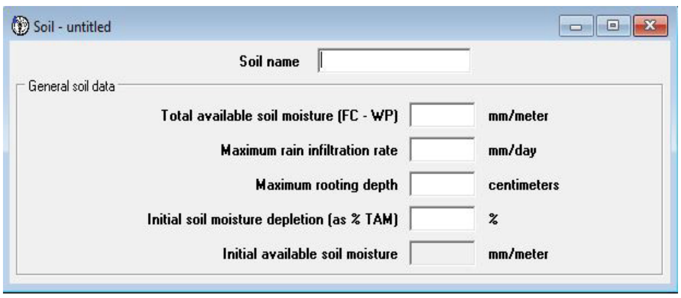


Figure 5. Input module of CROPWAT for soil data.

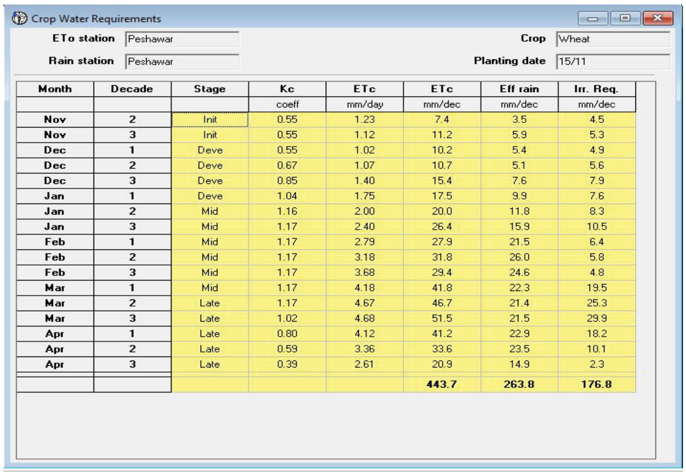
Results and Discussions

Meteorological Data

The climate data from 2005-2017 on a mean monthly basis has been collected from Regional Meteorological Center Peshawar. **Rainfall Data:** The rainfall data is taken on a mean monthly basis. The maximum average monthly rainfall has been reported in August whereas the minimum average monthly rainfall has been reported in November.

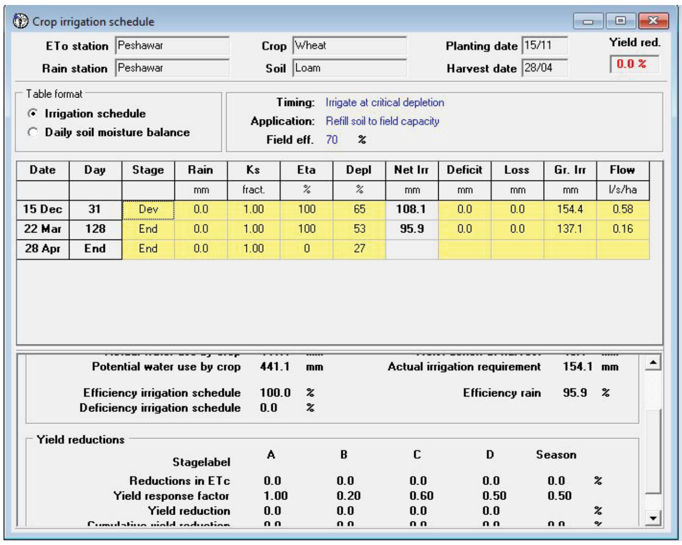
Temperature: The temperature data both maximum and minimum is needed as an input in the CROPWAT model. The mean minimum temperature has been recorded in January while meaning the maximum temperature is recorded in June i.e., 5.1 ºC and 39.2 ºC respectively.

Humidity: A relative humidity parameter is also needed for the



Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.55	1.23	7.4	3.5	4.5
Nov	3	Init	0.55	1.12	11.2	5.9	5.3
Dec	1	Deve	0.55	1.02	10.2	5.4	4.9
Dec	2	Deve	0.67	1.07	10.7	5.1	5.6
Dec	3	Deve	0.85	1.40	15.4	7.6	7.9
Jan	1	Deve	1.04	1.75	17.5	9.9	7.6
Jan	2	Mid	1.16	2.00	20.0	11.8	8.3
Jan	3	Mid	1.17	2.40	26.4	15.9	10.5
Feb	1	Mid	1.17	2.79	27.9	21.5	6.4
Feb	2	Mid	1.17	3.18	31.8	26.0	5.8
Feb	3	Mid	1.17	3.68	29.4	24.6	4.8
Mar	1	Mid	1.17	4.18	41.8	22.3	19.5
Mar	2	Late	1.17	4.67	46.7	21.4	25.3
Mar	3	Late	1.02	4.68	51.5	21.5	29.9
Apr	1	Late	0.80	4.12	41.2	22.9	18.2
Apr	2	Late	0.59	3.36	33.6	23.5	10.1
Apr	3	Late	0.39	2.61	20.9	14.9	2.3
					443.7	**263.8**	**176.8**

Figure 6. Output module for crop water requirement.



Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
15 Dec	31	Dev	0.0	1.00	100	65	108.1	0.0	0.0	154.4	0.58
22 Mar	128	End	0.0	1.00	100	53	95.9	0.0	0.0	137.1	0.16
28 Apr	End	End	0.0	1.00	0	27					

Figure 7. Crop irrigation scheduling.

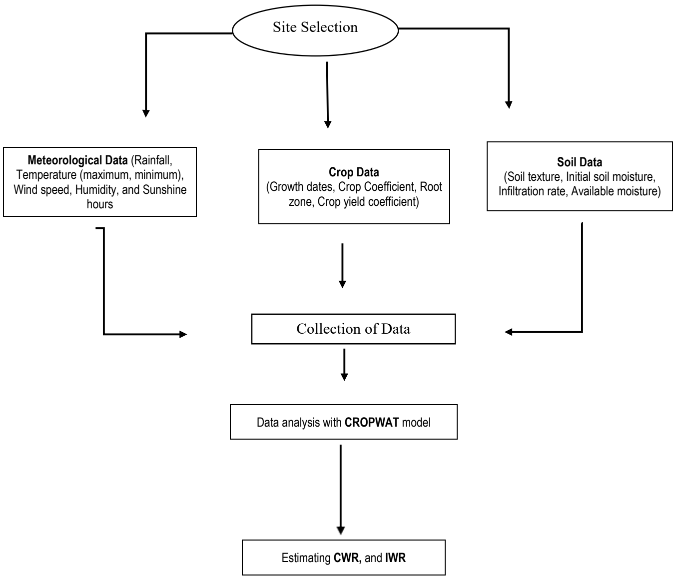


Figure 8. Flow chart of the methodology.

CROPWAT model. Mean monthly relative humidity data from 2005-2017 has been collected from the meteorological department. The average minimum humidity of 44.1 percent is noted in May whereas the average maximum humidity of 68.1 percent is noted in August. Wind Speed: Wind speed data is necessary for the CROPWAT model. The data on a mean monthly basis has been obtained from the meteorological department. The mean minimum wind speed was detected in December (4.3 Km/hr) whereas the maximum was detected in July (16.9 Km/hr.)

Sunshine Hours: The CROPWAT model needs the data of sunshine hours. The maximum sun hours (11.9hr) have been recorded in June whereas the minimum sun duration hours in January (5.9hr). Timation and Analysis of Reference Evapotranspiration (ET_o).

Estimation of ET_o: The average monthly values of the ET_o at the beginning and end of the year were recorded at minimum and maximum in mid-year as shown in Table 1. The peak ET_o was reported in June (10 mm/day) and the least ETo was reported in December (1.61mm/day).

Analysis of ET_o: The increased ET_o values were due to the increased temperature, maximum sunshine time, and high wind speed from May to August. Wind speed was observed in July at an average peak value of 16.9 km/hr. For maximum sunshine hours which have accelerated ET_o, high values of radiation were observed. Incoherent patterns with ET_o resulted in differing months in the monthly averaged values of humidity. At the beginning and end of the year, the lower values for ET_o were due to reduced temperatures, limited sunshine, and lower wind speeds. In December, the average minimum wind speed was 4.3 km/hr. Minimum sunlight duration, which contributed to minimum ETo as shown in Figure 9, was responsible for low radiation values. (Table 1 and Figure 9)

Effective rainfall

Effective rainfall is that fraction of the overall rainfall that substitutes or possibly reduces the respective net amount of irrigation water needed. The total mean rainfall in the area of study is 588 mm per annum whereas the mean effective rainfall in the area of study is 528 mm per annum. The mean rainfall is maximum in August which is 88.1 mm whereas the rainfall is minimum in November and December which is 18.4 and 18.6 mm respectively as shown in (Table 2).

Crop data

Crop data required to oblige the purposes allocated to this research are shown in the tables below for cultivated crops in the research area [14]. (Table 3.) Table 3 shows the crop coefficient values and their corresponding crop height for various crops i.e wheat, millet, sorghum, and cotton crop. (Table 4)

Table 4 demonstrates the total length of growing crop periods, the length of each stage (initial, mid-season, development, and late-season) periods as well as their month of plantation for wheat, millet, sorghum, and cotton crops in the study area.

The Yield Response Factor (Ky) values for each growing phase (emergency, flowering stage, vegetative stage, ripening, and yield formation), rooting depth and depletion fraction for wheat, millet, sorghum, and cotton are given in (Table 5) [19].

A mathematical guesstimate for correcting **p** for ETc rate is **p = pTable 22 + 0.04 (5 - ETc)** wherever the adjusted p is restricted to 0.1 <= p <= 0.8 and ETc is in millimeter (mm)/day.

Table 1. Mean monthly climatic parameter values and ET_o values for 2005-2017.

Month	Minimum Temperature	Maximum Temperature	Humidity	Wind Speed	Sun hours	Solar Radiation	ET_o
	°C	°C	%	Km/hr.	Hr.	MJ/m²/day	mm/day
January	5.1	18.1	66	6.3	5.9	10.3	1.72
February	8.3	21.6	65	9.6	5.9	12.4	2.72
March	13.1	25.1	62	10.5	8.3	18.1	4
April	18	30.8	54	11.9	8	20.2	5.74
May	23.1	36.5	44	14.1	10	24.5	8.37
June	26.3	39.2	44	15.6	11.9	27.7	10
July	27.4	36.8	62	16.9	11.3	26.5	8.32
August	26.2	35.5	68	15.4	10.1	23.6	6.88
September	23.6	34.7	63	12.2	9.6	20.6	6.07
October	18	31.3	61	7.9	7.5	14.9	4.14
November	11.1	25	67	5.3	7	11.8	2.35
December	5.8	20.8	66	4.3	6.6	10.2	1.61

Table 2. Average monthly effective rainfall in the study area.

Month	Rainfall (mm)	Effective rainfall (mm)
January	40	37.4
February	83.4	72.3
March	73.9	65.2
April	73.9	65.2
May	27.3	26.1
June	29.8	28.4
July	81.8	71.1
August	88.1	75.7
September	33.5	31.7
October	19.7	19.1
November	18.4	17.9
December	18.6	18
Total	588.4	528

Table 3. Crop Coefficient values and respective crop height.

Crop	Kc Initial	Kc mid	Kc end	Crop Height h (m)
Wheat	0.55	1.15	0.32	1
Millet	0.3	1	0.3	1.5
Sorghum	0.3	1.1	0.55	1-2.

Table 4. Measurements of crop growth phases for numerous planting periods.

Crop	Length					Plant Date
	Initial	Development	Mid	Late	Total	
Wheat	25	35	65	40	165	Oct/Nov
Millet	15	25	40	25	105	June
Sorghum	20	30	40	30	120	June

Soil data

According to different researchers, the area of research is covered by loam-type soils; the table below shows the fundamental infiltration rate and water existing in various soil textures, essential as data of soil in a CROPWAT model. The loam soil has available water vary from 100-175 mm/mm whereas its fundamental infiltration rate varies from 10-20 mm/hr. A value of 100 mm/m and 240 mm/day is selected for the analysis [20] (Table 6 and 7).

Total crop water requirement

The overall water needed for various crops in the area of study is existing in table 11. The average water needed for the wheat crop was 443.7 mm/period. The average water needed for millet was 578.1 mm/period. The average water needed for sorghum was 690.2 mm/period. From this, it is concluded that CWR for

Wheat < Millet < Sorghum

The results have shown that for crops with long growing seasons, the crop and reference evaporations (ET_c and ET_O) were higher than those with shorter growing seasons. Throughout the dry season, ET_c was greater than during the rainy season [21].

Table 5. Factor of Yield Response, Depth of Root, and Depletion Fraction.

Crop	Depth of Root (m)	Yield Response factor (Ky)					Depletion Fraction (P)
Wheat	1.5-1.8	1	0.2	0.6	0.5	0.5	0.55
Millet	1.0-2.0	1	0.2	0.6	0.5	0.5	0.55
Sorghum	1.0-2.0	1.25	0.4	1.5	0.5	0.2	0.55

Table 6. Soil texture and their corresponding available water.

Soil Texture	Available Water (AW) (mm/m)
Coarse Sands	20-65
Fine Sands	60-85
Loam	100-175
Sandy Loams	90-130
Fine Sandy Loam	100-170
Loamy Sands	65-110
Silty Clay Loam	130-160
Silty Clay	125-170
Silt Loams	150-230
Clay	110-150
Peats and Mucks	160-240

Table 7. Basic Infiltration rates for various soil types.

Soil type	Basic infiltration rate (mm/hr)
Sand	< 30
sandy loam	20 - 30
Loam	10-20
clay loam	5-10
Clay	1-5

Table 8. *Crop Water requirement for Wheat crop.*

Month	Decade	Stage	Kc (coefficient)	ETc (mm/day)	ETc (mm/decade)	Eff. Rainfall (mm/decade)	Irrigation Req. (mm/decade)
Nov	2	Initial	0.55	1.23	7.4	3.5	4.5
Nov	3	Initial	0.55	1.12	11.2	5.9	5.3
Dec	1	Develop	0.55	1.02	10.2	5.4	4.9
Dec	2	Develop	0.67	1.07	10.7	5.1	5.6
Dec	3	Develop	0.85	1.4	15.4	7.6	7.9
Jan	1	Develop	1.04	1.75	17.5	9.9	7.6
Jan	2	Mid	1.16	2	20	11.8	8.3
Jan	3	Mid	1.17	2.4	26.4	15.9	10.5
Feb	1	Mid	1.17	2.79	27.9	21.5	6.4
Feb	2	Mid	1.17	3.18	31.8	26	5.8
Feb	3	Mid	1.17	3.68	29.4	24.6	4.8
Mar	1	Mid	1.17	4.18	41.8	22.3	19.5
Mar	2	Late	1.17	4.67	46.7	21.4	25.3
Mar	3	Late	1.02	4.68	51.5	21.5	29.9
Apr	1	Late	0.8	4.12	41.2	22.9	18.2
Apr	2	Late	0.59	3.36	33.6	23.5	10.1
Apr	3	Late	0.39	2.61	20.9	14.9	2.3
					443.7	**263.8**	**176.8**

Net irrigation requirement

It is distinct from the CWR. NIR is the irrigation water provided to a field to ensure the crop receives its entire CWR and no water losses in the irrigation process. The NIR for various crops is presented in the table. The NIR for wheat, millet, and sorghum crops are 177, 383, and 484 mm per season respectively. The NIR for

Sorghum > Millet > Wheat.

The greater value of NIR illustrates that the effective rainfall availability is small (Table 8 and Figure 10).

Figure 10 shows Sorghum has the maximum consumption of water than the wheat and millet crop. This is due to less effective rainfall during their growth periods. The Crop Water Requirement for crops grown in summer is maximum due to high evapotranspiration. With the increase in CWR, an increase in IWR occurs [22].

Table 9. *Crop Water requirement for Millet crop.*

Month	Decade	Stage	Kc (coefficient)	ETc (mm/day)	ETc (mm/decade)	Eff. Rainfall (mm/decade)	Irrigation Req. (mm/decade)
June	2	Initial	0.3	3.12	18.7	4.5	14.9
June	3	Develop	0.3	2.94	29.4	12.9	16.5
July	1	Develop	0.49	4.34	43.4	20.2	23.3
July	2	Develop	0.78	6.49	64.9	25.5	39.4
July	3	Mid	1.01	7.93	87.3	25.4	61.9
Aug	1	Mid	1.03	7.56	75.6	26.2	49.4
Aug	2	Mid	1.03	7.07	70.7	27.5	43.2
Aug	3	Mid	1.03	6.79	74.7	21.8	52.9
Sep	1	Late	0.92	5.91	59.1	14.5	44.7
Sep	2	Late	0.63	3.92	39.2	9.1	30.1
Sep	3	Late	0.39	2.13	14.9	5.7	6.7
					578.1	**193.4**	**382.9**

Table 10. Crop Water requirement for Sorghum crop.

Month	Decade	Stage	Kc (coefficient)	ETc (mm/day)	ETc (mm/decade)	Eff. Rainfall (mm/decade)	Irrigation Req. (mm/decade)
June	2	Initial	0.3	3.12	31.2	7.6	23.6
June	3	Initial	0.3	2.91	29.1	12.9	16.2
July	1	Develop	0.45	4.01	40.1	20.2	19.9
July	2	Develop	0.73	6.04	60.4	25.5	34.9
July	3	Mid	1.01	7.93	87.2	25.4	61.8
Aug	1	Mid	1.12	8.27	82.7	26.2	56.5
Aug	2	Mid	1.12	7.73	77.3	27.5	49.9
Aug	3	Mid	1.12	7.43	81.7	21.8	59.9
Sep	1	Late	1.12	7.17	71.7	14.5	57.2
Sep	2	Late	0.98	6.07	60.7	9.1	51.6
Sep	3	Late	0.8	4.38	43.8	8.2	35.7
Oct	1	Late	0.63	3.02	24.1	5.9	16.7
					690.2	**204.8**	**483.8**

***Table 11**. CWR and IWR for various Crops.*

Crops Name	Wheat	Millet	Sorghum
Planting Date	15-Nov	15-Jun	11-Jun
Harvesting Date	28-Apr	27-Sep	08-Oct
Period days	165	105	120
Eto (mm)/Period	501.71	795.09	886.42
Max, Kc	1.17	1.03	1.12
CWR (mm)/ Period	443.7	578.1	690.2
Rainfall (mm)/Period	299.2	221.4	232.9
Effective Rainfall (mm)/Period	263.8	193.4	204.8
NIR (mm) / period	176.8	382.9	483.8
Gross NIR (mm/period) 70% Eff	252.57	547	691.14

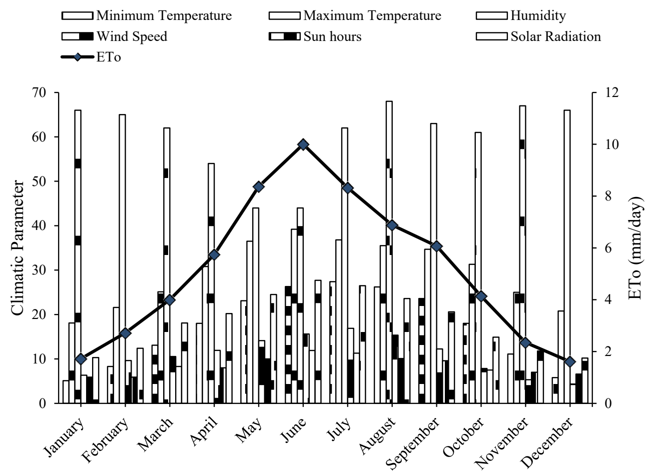


Figure 9. Effect of climate parameters on ET0.

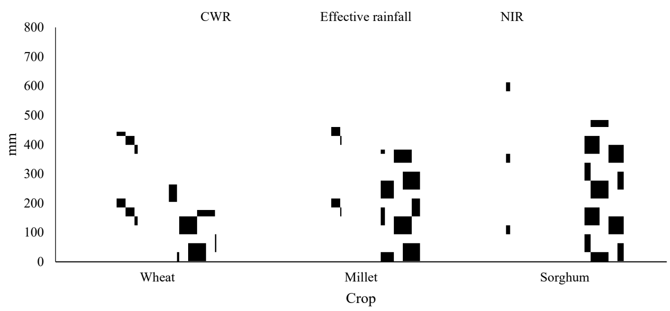


Figure 10. The contrast of effective rainfall, IWR, and CWR for various crops.

Conclusions and Recommendations

Conclusions

It has been concluded from the study that by putting the meteorological data like Temperature (maximum and minimum), rainfall, wind speed, relative humidity, and sunshine hours into the CROPWAT model the Effective rainfall, Reference evapotranspiration, Irrigation water requirement, and Crop water requirement can be determined. CROPWAT is an easy, meaningful, and workable model for the assessment of Effective rainfall, Reference evapotranspiration, Irrigation water requirement, and Crop Water Requirement. The texture of soil from the research was loam. The available water was 100 mm/m whereas the infiltration rate of the study area was 10 mm/hr. Mean reference evapotranspiration for Peshawar was 5.16 mm/day. The maximum ETo was in June which was 10.0 mm/day whereas the minimum value of ETo in December was 1.62 mm/day. Effective rainfall of 75.7 mm was maximum in August while a minimum of 17.9 mm in November. The average water needed for the wheat, millet, and sorghum crop was 443.7, 578.1, and 690.2 mm/period respectively. The irrigation water requirement for wheat, millet, and sorghum crops is 177, 383, and 484 mm per season respectively. From this, it is concluded the CWR and IWR for Sorghum > Millet > Wheat. CWR and IWR for crops grown in summer are greater than that for crops grown in the winter season. This increase in demand is due to the higher evapotranspiration in summer and less effective rainfall.

Recommendations

- Since this analysis is focused on 17 years of meteorological data. It is suggested that greater accuracy and reliability be achieved for a minimum of 30 years.
- Identical research can be conducted using the different models in several climactic locations.
- The results of this research can be correlated with evaluation models.
- While the CROPWAT model provides a sensible approximation for CWR and IWR, it will be assessed in the research area for even more reliable results.

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