Estimation of the Reference Evapotranspiration by Using Daily Meteorological Data and Cropwatt Model

Hammad Ali and Khansa Iftikhar

Department of Water Management, The University of Agriculture, Peshawar, Pakistan
Department of Physics, Hazara University, Manshera, Pakistan

Abstract: The main objective of the research paper was to modeled the daily actual reference evapotranspiration by estimating and comparing using pan evaporation method and CROPWAT model for Okra. The daily meteorological data was calculated from the Pakistan Forest Institute, Peshawar. The CROPWAT model was run for the specific weather condition of Peshawar region. The data obtained from the CLIMWAT and CROPWAT model was then compared with the daily observations. From the comparative analysis of the experiment it was concluded that the reference evapotranspiration values estimated by the daily recorded meteorological data were usually smaller than the modeled data of CROPWAT, the dissimilarity was in the range -1.5 to +0.2 mm/day. From the results it was observed that the ETo values estimated from the pan evaporation method (field observations) are quite similar and in a good correlation with the simulated values obtained by the CROPWAT model, with proportionate errors of 6% for whole growing season. The study reveals that the ETo estimation by using pan evaporation data could bring an important contribution for comparisons, validation and calibration of the model outputs for some parameters, like the crop daily evapotranspiration and crop reference evaporation.

Key words: CROPWAT - CLIMWAT - Reference evapotranspiration - Pan evaporation

INTRODUCTION

One third of the world’s population by 2025 will be affected by the severe water shortage situations because of limited resources and uplift water demand in industrial and other sectors. As agriculture uses a great amount of water, many people will have to take water from agriculture, distribute it to the other sectors and hence influencing the food and fiber production adversely. About 45% of the world’s population is living in under developed countries, which only escape from physical water scarcity by large and possibly environmental friendly investments for the development of water resources. Besides these there will be no easy way out for water scarcity problems. Indeed, one of the tasks of this paper is to save the each and every drop of water by irrigating the crops to its actual crop evapotranspiration [1].

CROPWAT model is an irrigation planning and management tool used for the simulation of the complex relationships of on-farm parameters the crop, climate and soil. The CROPWAT expedite the estimation of the crop evapotranspiration, irrigation scheduling and agricultural water requirements with different cropping patterns for irrigation planning. But for the actual evapotranspiration of the crop it is utmost important to calibrate the model with the field observations for the error calculation. For this purpose, the study was initiated in the water scarce region of the Pakistan to make the Cropwat model calibrated by using daily field observations.

The paper’s objectives are the following:
- Estimation of the metrological parameters by using Climwatt model
- Estimation of the reference evapotranspiration by using Cropwatt model
- Daily actual Reference evapotranspiration calculation by the daily pan evaporation method
- To test the performance of Cropwatt model by comparing the simulated results with the field data
MATERIALS AND METHODS

CLIMWAT Model Description: CLIMWAT 2.0 for CROPWAT is a model developed by the Environmental Development and Management Services and Water Resources and Natural Resources Services of the Food and Agriculture Organization of the UN [2]. CLIMWAT provides long-term monthly mean values of seven climatic parameters, namely:

- Mean daily maximum temperature in °C
- Mean wind speed in km/day
- Mean relative humidity in %
- Mean daily minimum temperature in °C
- Monthly effective rainfall in mm/month
- Mean solar radiation in MJ/m2/day
- Mean sunshine hours per day
- Monthly rainfall in mm/month
- Reference evapotranspiration calculated with the Penman-Monteith method in mm/day.

The data can be extracted for a single or multiple stations in the format suitable for their use in CROPWAT. The long-term monthly mean values for the Peshawar region with longitude 71.58°, latitude 34.01° and altitude of 360m was estimated by the CLIMWAT for CROPWAT.

CROPWAT Model Description and Management Variables: CROPWAT for Windows v.8.0 is applied model for irrigation planning and management, developed by several scientists [3,4]. This model is used for the calculation of reference Evapotranspiration (ETo), crop water evapotranspiration (ETc) and crop irrigation requirements; for developing irrigation schedules under different management conditions. CROPWAT model can be used as to support decision making for irrigation planning and management, by calculating the reference evapotranspiration, crop water evapotranspiration and irrigation requirements, to arrange different irrigation schedules, comprised on a daily soil-moisture balance using different options for the water supply and irrigation management conditions. The CROPWAT model was potentially calibrated validated from the previous studies reported by Marica [5] for six maize-growing seasons from 1995 to 2000, concerning the main components of soil water balance. The following climatic, crop and soil data is required as an input:

- Reference crop evapotranspiration (ETo): is calculated by using monthly climatic average data of the minimum and maximum air temperature, relative humidity (%) sunshine duration (h) and wind speed (m/s) as a input variables for FAO Penman-Monteith equation
- Rainfall data: (daily/monthly data); based on the average yearly data
- Cropping pattern: based on the crop type, planting date, length of the cropping stages, crop coefficient likes Kc values, root depth, depletion fraction, Ky values and the vegetation density; a set of typical crop coefficient for almost all the crops are available in the program;
- Soil type: soil moisture content present in the soil, maximum rain infiltration rate, maximum rooting depth and initial soil moisture depletion (% of the total available moisture);
- Scheduling program: different schedules can be selected from the program concerning the calculation of the irrigation application timing and application depth.

Suitable results which are convenient to the time steps (daily, weekly, decadal or monthly) are generated by the model. The output parameters from the model for a specific crop are as follow:

- Crop water evapotranspiration and requirements-CWR or ETc (mm/period);
- Irrigation water requirements- IWR (mm/period);
- Effective rain (mm/period) - the quantity of water efficiently used by the crops after entering into the soil; daily soil moisture depletion that is the amount of water daily depleted through the soil (mm);
- Yields reduction Estimation, because of the crop stress (when Etc/Etm goes below 100%).

The CROPWAT model can be operated by using two methods:

- Estimating the actual evapotranspiration (ETo) by the FAO Penman-Monteith equation;
- Using field observations of evapotranspiration through pan evaporation method.

Calculation of Reference Evapotranspiration by Field Observation: A pan evaporation method was used, which measures the evaporation from open water surface considering the cumulative effect of temperature, humidity, wind and radiation. The reference evapotranspiration was estimated by measuring the
change in water level, correcting it for precipitation and determining the amount of water evaporated from pan. The rainfall data was recorded by the rain gauge installed at PFI (Pakistan Forest Institute). The evapotranspiration \((ET_c)\) was then calculated by using equation;

\[
ET_c = K_p \times E_{pan}
\]

Where \(ET_c\) is Reference crop evapotranspiration (mm d\(^{-1}\)), \(E_{pan}\) is Pan evaporation (mm d\(^{-1}\)) and \(K_p\) is Pan Coefficient. The pan was placed in short green cropped area having relative humidity of 60% with wind speed of <175 km d\(^{-1}\). According to these conditions, the \(K_p\) factor becomes 0.75.

**RESULTS AND DISCUSSION**

In the present study, the daily reference evapotranspiration for the Okra was compared with the simulated results of the models. The \(ETo\) calculated by the model was monthly average, which were then converted to daily and decades (Table 2). During the first decade of the okra germination the error was 1.5%, but in the next decade it was -3.1%, which means that the model overestimate the irrigation depth for the first stages and underestimate for the next decade. However, we can under irrigate the Okra at its earlier stage because of its less \(Kc\) (Crop Coefficient) factor. The periods more sensitive to water shortage are flowering and fruit enlargement stages [6]. The third decade has 12.5% error which is overestimated by the model, so at this stage we can save the more water. Other decades also show the overestimated errors (3.8, 1.8, 4.2 and 9.1%) by the model (Table 1). The last decade shows the highest overestimated value of 21.9%. Here more water can be saved by applying the exact depth required by the crop. The total reference evapotranspiration depths during the whole season of Okra, by the pan evaporation method was 39mm less than that of the simulated values of CROPWAT model and encounters the error of 6.3% as shown in Fig.1.

The monthly climatic data estimated from the CLIMWAT using test sites parameters was used as an input in the CROPWAT model, a simulation for the year 2011 with Okra was carried out and the modelled daily actual reference evapotranspiration was compared with those derived from the pan evaporation method. Ordinarily, the satellite information used for the CROPWAT model is restricted to rainfall, sunshine duration and evapotranspiration estimation. Pan evaporation method is not applicable for direct use of measuring evapotranspiration, whilst it only estimates the daily transpiration rate. As CROPWAT model can also be used for the estimation of the reference evapotranspiration from both monthly climatic data and from the direct use of evapotranspiration measurements. Therefore, one possible use of Metrological Station data is to replace the measured evapotranspiration by estimations made from pan evaporation information. Fig.1 presents the comparison between daily crop evapotranspiration values computed by the CROPWAT model and those computed through the pan evaporation method. Analysis of model results showed that \(ETo\) observations obtained from the pan evaporation method are generally lower than that of simulated by the CROPWAT model, the differences being range from -1.5 to +0.2 mm/day. Preceding results showed a fruitful correlation between the field observations.

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**Fig. 1:** Comparison between daily reference evapotranspiration values computed by the CROPWAT model and by pan evaporation method at Peshawar region.
Table 1: Reference evapotranspiration computed from the pan evaporation method and percent error estimation with CROPWAT simulation

<table>
<thead>
<tr>
<th>Dates</th>
<th>From</th>
<th>To</th>
<th>Epan (mm) /decade</th>
<th>Kp</th>
<th>ET₀,pan (mm) /decade</th>
<th>ET₀,CROPWAT (mm) /decade</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14-May-11</td>
<td>23-May-11</td>
<td>96.9</td>
<td>0.75</td>
<td>72.7</td>
<td>73.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>24-May-11</td>
<td>2-Jun-11</td>
<td>104.1</td>
<td>0.75</td>
<td>78.1</td>
<td>75.7</td>
<td>-3.1</td>
</tr>
<tr>
<td></td>
<td>3-Jun-11</td>
<td>12-Jun-11</td>
<td>97.4</td>
<td>0.75</td>
<td>73.1</td>
<td>83.5</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>13-Jun-11</td>
<td>22-Jun-11</td>
<td>107.2</td>
<td>0.75</td>
<td>80.4</td>
<td>83.5</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>23-Jun-11</td>
<td>2-Jul-11</td>
<td>106.2</td>
<td>0.75</td>
<td>79.7</td>
<td>81.1</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>3-Jul-11</td>
<td>12-Jul-11</td>
<td>91.4</td>
<td>0.75</td>
<td>68.6</td>
<td>71.6</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>13-Jul-11</td>
<td>22-Jul-11</td>
<td>86.7</td>
<td>0.75</td>
<td>65.0</td>
<td>71.6</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>23-Jul-11</td>
<td>1-Aug-11</td>
<td>73.6</td>
<td>0.75</td>
<td>55.2</td>
<td>70.7</td>
<td>21.9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>763.5</td>
<td></td>
<td>572.6</td>
<td>611.4</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Table 2: Reference evapotranspiration computed from the CROPWAT model

<table>
<thead>
<tr>
<th>Month</th>
<th>Min Temp°C</th>
<th>Max Temp°C</th>
<th>Humidity</th>
<th>Wind km/day</th>
<th>Sun hours</th>
<th>Rad MJ/m²/day</th>
<th>ETo mm/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>4.6</td>
<td>17.1</td>
<td>57</td>
<td>121</td>
<td>6.5</td>
<td>10.9</td>
<td>53.62</td>
</tr>
<tr>
<td>February</td>
<td>6.6</td>
<td>19</td>
<td>57</td>
<td>138</td>
<td>6.9</td>
<td>13.5</td>
<td>64.09</td>
</tr>
<tr>
<td>March</td>
<td>11.2</td>
<td>23.7</td>
<td>57</td>
<td>156</td>
<td>7.1</td>
<td>16.5</td>
<td>102.05</td>
</tr>
<tr>
<td>April</td>
<td>15.7</td>
<td>29.5</td>
<td>47</td>
<td>121</td>
<td>9.1</td>
<td>21.8</td>
<td>138.34</td>
</tr>
<tr>
<td>May</td>
<td>21.2</td>
<td>36</td>
<td>36</td>
<td>216</td>
<td>10.4</td>
<td>25.1</td>
<td>228.68</td>
</tr>
<tr>
<td>June</td>
<td>25</td>
<td>40.5</td>
<td>32</td>
<td>216</td>
<td>10</td>
<td>24.9</td>
<td>250.53</td>
</tr>
<tr>
<td>July</td>
<td>26.7</td>
<td>39.1</td>
<td>54</td>
<td>216</td>
<td>8.7</td>
<td>22.7</td>
<td>221.87</td>
</tr>
<tr>
<td>August</td>
<td>26</td>
<td>36.7</td>
<td>61</td>
<td>190</td>
<td>8.2</td>
<td>20.8</td>
<td>187.31</td>
</tr>
<tr>
<td>September</td>
<td>22</td>
<td>35</td>
<td>55</td>
<td>147</td>
<td>8.2</td>
<td>18.7</td>
<td>153.33</td>
</tr>
<tr>
<td>October</td>
<td>15.7</td>
<td>31</td>
<td>47</td>
<td>121</td>
<td>7.7</td>
<td>15.2</td>
<td>118.23</td>
</tr>
<tr>
<td>November</td>
<td>9.3</td>
<td>24.8</td>
<td>46</td>
<td>112</td>
<td>7.4</td>
<td>12.1</td>
<td>77.69</td>
</tr>
<tr>
<td>December</td>
<td>4.8</td>
<td>19.2</td>
<td>54</td>
<td>112</td>
<td>7.1</td>
<td>10.7</td>
<td>55.84</td>
</tr>
<tr>
<td>Average</td>
<td>15.7</td>
<td>29.3</td>
<td>50</td>
<td>156</td>
<td>8.1</td>
<td>17.7</td>
<td>137.63</td>
</tr>
</tbody>
</table>

Comparison (pan evaporation) and the modeled results (CROPWAT), with relative errors from 3.1% to 21%. Fig. shows a between ET₀ modeled results of daily CROPWAT simulation over the whole Okra-growing season and by the pan evaporation method respectively. Thus ET₀ measured by the model is very identical to the estimated ones. The results from the experiment can constitute the hypothesis of an ET₀ data validation process, determined by the CROPWAT model. Similar results were obtained by George et al. [7], who reported that by using earth observation data and CROPWAT model to estimate the actual crop evapotranspiration.

CONCLUSION

From the present study it can be concluded that the use of the classical methods can be used for ensuring the improvement of the modern methods for determining the agro-meteorological parameters, like evapotranspiration. The preceding results of the study have proved that for validation and comparison of the evapotranspiration and other output parameters the pan evaporation data play an important role. From the study it was observed that the CROPWAT model results for evapotranspiration (ET₀) are generally higher than that calculated by the pan evaporation method. Preliminary results emphasized a good correlation between the simulated values (CROPWAT) and those derived from the pan evaporation data, with relative errors of ±2-20%. Generally, the CROPWAT model overestimates the actual reference evapotranspiration with respect to the calculated values. Moreover, 38mm of water could be saved if the model is calibrated for the errors for the whole growing season of the Okra.

REFERENCES


