# COMPREHENSIVE REVIEW OF CROP WATER REQUIREMENT ESTIMATION TECHNIQUES: APPROACHES, CHALLENGES, AND FUTURE DIRECTIONS

## ABSTRACT

In order to meet the growing demand for water, water scarcity is a significant issue that needs attention. Agriculture crops are not getting enough water because of this problem. Consequently, figuring out how much water a given crop needs requires using the right method. Accurate crop water requirements must be measured in order to schedule irrigation effectively, which in turn leads to efficient crop water management. To restore the lost moisture and promote the best possible growth for plants, irrigation is used. Water management and irrigation scheduling fundamentally depend on an accurate calculation of the crop's crop water requirements ($ET_c$). Accurate evapotranspiration measurements are necessary for effective irrigation water management. Evapotranspiration (ET), a process that measures the amount of water lost from soil and crops through transpiration and evaporation processes, respectively, is dependent on a variety of meteorological factors. A significant factor in determining crop water requirements and irrigation schedules is reference evapotranspiration. There exist multiple theories and methodologies for estimating reference evapotranspiration, ranging from empirical to physical based. Reference Evapotranspiration is referred to the idea behind ET is to calculate ET based on a reference surface that is comparable to a deep surface of green grass that is consistently growing, completely covering the surface with enough water, and looking stable. The goal of irrigation futures is to choose a suitable model for estimating reference crop evapotranspiration. In order to calculate the amount of water needed for a crop, multiply $ET_o$ by the crop coefficient ($K_c$), which is dependent on the phases and length of a crop's growth. Regression, fuzzy logic, Penman-Monteith, Blaney-Criddle, Hargreaves, ANN and WNN, and other conventional and non-traditional methods are used to estimate $ET_o$.

*Keyword: Crop water requirements; Evapotranspiration; Reference Evapotranspiration; Crop coefficient*

**INTRODUCTION**

Over the past few decades, irrigation has been the primary source of water usage for agriculture. To deal with the shortage of water, water-saving agriculture countermeasures must be adopted. The primary goal of irrigation is to apply water to the soil to meet crop evapotranspiration requirements when rainfall is insufficient, raising crop till harvesting (Memon & Jamsa, 2018). The process of applying the appropriate amount of water to the soil at the appropriate time to promote plant growth is known as irrigation. Therefore, determining the amount of water needed for irrigation is essential for water project design and management. The term crop water requirement refers to the amount of water needed by a crop to grow and reach maturity under optimal conditions. Accurately estimating CWR is important for ensuring food security, maximizing water use efficiency, and minimizing environmental impacts. The amount of water that crops require is provided by accessible soil moisture, irrigation water, and effective rainfall (Babu *et al.,* 2014). This review paper synthesizes the current state of knowledge on methods and approaches for estimating CWR.

**APPROACHES FOR ESTIMATING CROP WATER REQUIREMENTS**

1. **Empirical approaches:** These use statistical relationships between CWR and climatic variables, such as the Blaney-Criddle and Hargreaves-Samani equations.

   - **Blaney Criddle Method:** The Blaney Criddle approach is used to find the $ET_o$ over the agricultural field under consideration. By taking the mean temperature as an input, we may calculate the $ET_o$ rate using the Blaney Criddle method, which is a temperature-based approach. The Blaney-Criddle formula for estimating $ET_0$ is given (Blaney and Criddle, 1955):

     $ET_o = p\ (0.457 \cdot T_{mean} + 8.128)$

     Where,

     $ET_o$ - Reference evapotranspiration [mm day−1 ]

     $T_{mean}$ - Mean daily temperature [°C] given as $T_{mean} = (T_{max} + T_{min})\ /\ 2$

     p - Mean daily percentage of annual daytime hours.

   - **Hargreaves Method:** Hargreaves is one of the traditional techniques used to estimate $ET_o$. In this method of determining $ET_o$, temperature is the sole parameter that is employed. The Hargreaves formula for estimating $ET_o$ is given (Hargreaves, 1985):

$$ET_o = 0.0029\ R_a\ (TC+20)\ TR^{0.4}$$

$$T_R = T_{max} - T_{min}$$

Where,

$ET_o$ - Reference evapotranspiration

TR- Temperature range

$R_a$ - Extra-terrestrial radiation

TC -Temperature in degree Celsius

$T_{max}$ and $T_{min}$ - Daily maximum and minimum temperature.

2. **Analytical approaches:** These apply physical principles of water balance, energy balance, and plant physiology to model the CWR, such as the Penman-Monteith equation.

   **Penman-Monteith Method:** A common technique for predicting $ET_o$ in any place at any time of year is the Penman-Monteith approach. The Penman-Monteith method's input parameters include solar radiation, air temperature at minimum and maximum values, pressure, wind speed, and soil heat flow. The formula used for estimating $ET_o$ using Penman-Montieth method is given (Monteith, 1965):

$$ET_0 = \frac{0.4.8\Delta(R_n-G)+\gamma\frac{900}{T+273}u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)}$$

Where

$ET_0$ = reference evapotranspiration (mm/day)

$\Delta$ = slope of the saturation vapor pressure curve (kP$_a$/°C)

$R_n$ = net radiation at the surface (MJ/m$^2$/day)

$G$ = soil heat flux density (MJ/m^2/day)

$\gamma$ = psychrometric constant (kP$_a$/°C)

$T$ = air temperature at 2 m height (°C)

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

$e_s$ = saturation vapor pressure (kP$_a$)

$e_a$ = actual vapor pressure (kP$_a$)

3. **Remote sensing-based approaches:** These utilize satellite data on vegetation indices, soil moisture, and evapotranspiration to estimate CWR at larger spatial scales.

   - Satellite remote sensing (RS) data have been widely used for a variety of practical applications and research issues. Meteorology, soil and canopy investigations,

agriculture and crop production, water, ice, and ocean research and management, geology, mapping, land use and environmental monitoring, reconnaissance and defense, etc. are among the most significant application disciplines (Ferencz *et al.*2004).

- **Crop Evapotranspiration ($ET_c$):** Crop water requirement is the total amount of water needed by the crop for the duration of the growing season. The Crop Coefficient Approach determines $ET_c$ by factoring in the crop features into the Crop Coefficient and the effect of different weather conditions into ET (Memon & Jamsa, 2018):

  $ET_c = K_c * ET_o$

  Where,

  $K_c$ is the crop coefficient, which varies according to the crop and stage of growth

  $ET_o$ is the reference crop evapotranspiration (Dadhwal and Ray, 2001).

- **Crop coefficient ($K_c$):** The crop coefficient, or $K_c$, is essentially the ratio of the crop $ET_c$ to the reference $ET_o$. It shows how the influence of the four main factors that set the crop apart from the reference grass, i.e., Height of crop. Albedo of the crop-soil surface, resistance to canopy, and soil evaporation, particularly in exposed areas . Four growth stages—initial, developmental, mid-season, and late-season—were identified within the overall crop growing cycle in order to calculate the $K_c$ values for various crops (Memon & Jamsa, 2018).

- **Reference evapotranspiration:** In irrigation engineering, the estimation of reference evapotranspiration ($ET_0$) is commonly utilized to determine crop water requirements. Both the planning process for newly designed irrigation schemes and the management of water distribution in already-existing schemes make use of these estimates. The FAO-56 application of the Penman-Monteith equation (Allen et al. 1998) is the most extensively utilized of the various $ET_0$ equations now in use and can be regarded as a kind of standard (Walter et al. 2000). Hereafter, the Penman-Monteith equation, FAO-56, will be referred to as PM. Compared to many other approaches, the PM has two advantages. Firstly, the method is primarily based on physical principles, meaning that it may be applied worldwide without requiring further parameter estimations. Second, the technique has been verified with an assortment of lysimeters and is thoroughly documented, integrated into a broad spectrum of software, and tested (Droogers and Allen, 2002).

4. **Simulation modeling:** Crop growth simulation models, such as CROPWAT and AquaCrop, integrate various biophysical processes to estimate CWR.

- **CROPWAT:** The software CROPWAT 8.0 calculates reference crop evapotranspiration using the Smith (1992), Penman (1948), and Monteith (1965) methodologies. Calculations for agricultural water requirements and irrigation schedule make use of these predictions. CROPWAT 8.0 determines how much irrigation water a cropping pattern in an irrigated area needs at different phases of crop development over the course of the growing season. This water can be needed either monthly, weekly, or as needed (Babu *et al.,* 2014).

- **Aqua Crop:** The FAO created Aqua Crop, a crop growth model, to divide the $ET_a$ into $T_r$ and non-beneficial soil evaporation $E_a$. It is a simulation model that focuses on the unique relationship between water and crop productivity. AquaCrop is widely used for many diverse applications, including assisting in irrigation management decision-making, analyzing the effects of climate change on agricultural output, and determining which crop cultivation techniques are most productive. Numerous nations across the globe have effectively used the approach to enhance sustainable agriculture productivity and water-use efficiency (Salemi *et al.,* 2011).

## CHALLENGES AND FUTURE DIRECTIONS

1. Improving the accuracy and applicability of CWR models across diverse agroclimatic conditions.
2. Integrating remote sensing data and simulation models for large-scale, real-time CWR monitoring.
3. Addressing the impacts of climate change and variability on CWR.
4. Assessing the role of precision agriculture technologies in optimizing CWR estimation and irrigation management.
5. Developing decision support tools to help farmers and water managers plan and allocate water resources effectively.

## RESULTS AND DISCUSSION

Allen et al. (1998) highlight that the FAO Penman-Monteith equation consistently produces the most accurate crop water requirement (CWR) estimates, affirming its status as the standard method recommended by the Food and Agriculture Organization. Trajkovic (2005) notes that while empirical methods can facilitate rapid assessments, they often lack the precision necessary for diverse and variable climates, leading to potential inaccuracies in estimating water needs. Singh and Irmak (2009) emphasize the growing importance of remote sensing technologies, which provide large-scale estimates of evapotranspiration and CWR by utilizing satellite imagery to monitor crop health and moisture status; however, they stress that these methods require rigorous calibration with ground data to ensure reliability. Steduto et al. (2009) discuss the advantages of simulation models like AquaCrop, which offer detailed insights into crop growth and water response, modeling complex interactions among various environmental factors. Nevertheless, they point out that these models often demand extensive input data, which can be a significant limitation in regions with limited data availability. The review underscores the critical role of local environmental factors—such as soil type and specific crop characteristics—in accurately estimating CWR; ignoring these factors can result in ineffective water management strategies. Furthermore, the review identifies significant research gaps, particularly in integrating climate change projections into existing CWR models and adopting precision agriculture technologies to optimize irrigation scheduling. Collectively, these insights emphasize the need for ongoing advancements in CWR estimation methods to support sustainable agricultural practices, especially in the context of increasing water scarcity and climate variability.

## CONCLUSION

Water management in agriculture cannot be sustained unless crop water requirements are accurately estimated. This review emphasizes the different methods, their approaches, and the further study required to enhance CWR estimation. There are several methods for estimating CWR: analytical, empirical, remote sensing-based, and simulation modeling techniques. Comparing analytical methods with field measurements, like the FAO Penman-Monteith method, usually yields the most accurate estimations of CWR. While empirical approaches might be helpful for quick judgments, their accuracy may be compromised in areas with diverse climates. Although they need thorough calibration and validation, remote sensing-based

techniques offer promise for regional-scale CWR estimation. Though they need a lot of input data and parameterization, crop growth simulation models can produce precise CWR estimates. Improving the precision and applicability of CWR models under a range of agroclimatic conditions, integrating remote sensing data and simulation models for large-scale, real-time CWR monitoring, addressing the effects of climate variability and change on CWR, evaluating the role of precision agriculture technologies in optimizing CWR estimation and irrigation management, and creating decision support tools to assist farmers and water managers in effective planning and resource allocation are some of the ongoing challenges in this field. The increasing need for sustainable agricultural water management and the need to provide food security in the face of escalating water shortages and climate change issues necessitate ongoing study and innovation in CWR estimate techniques.

## REFERENCES

Allen R.G., Pereira L.S., Raes D. & Smith M. 1998. Crop evapotranspiration: Guidelines for computing crop requirements. Irrigation and Drainage Paper No. 56, FAO, Rome, Italy.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome.

Babu, R. G., Veeranna, J., Kumar, K. R., & Rao, I. B. (2014). Estimation of water requirement for different crops using CROPWAT model in Anantapur region. *J. Environ. Sci*, *9*, 75-79.

Blaney, W. D., & Criddle, W. E. (1955). "Determining Water Needs in Planting Irrigation." U.S. Department of Agriculture, Agricultural Research Service.

Droogers, P., & Allen, R. G. (2002). Estimating reference evapotranspiration under inaccurate data conditions. *Irrigation and drainage systems*, *16*, 33-45.

Ferencz, C., Bognár, P., Lichtenberger, J., Hamar, D., Tarcsai, G., Timár, G., ... & Ferencz-Árkos, I. (2004). Crop yield estimation by satellite remote sensing. *International Journal of Remote Sensing*, *25*(20), 4113-4149.

Hargreaves, G. H. (1985). "Evapotranspiration." Journal of Irrigation and Drainage Engineering, 111(3), 225-230.

Kumar, R., Jat, M. K., & Shankar, V. (2012). Methods to estimate irrigated reference crop evapotranspiration–a review. *Water Science and Technology*, *66*(3), 525-535.

Kumar, R., Shankar, V., & Kumar, M. (2011). Modelling of Crop Reference Evapotranspiration: A Review. *Universal Journal of Environmental Research & Technology*, *1*(3).

Mehta, R., & Pandey, V. (2016). Crop water requirement (ETc) of different crops of middle Gujarat. *Journal of agrometeorology*, *18*(1), 83-87.

Memon, A. V., & Jamsa, S. (2018). Crop water requirement and irrigation scheduling of soybean and tomato crop using CROPWAT 8.0. *International Research Journal of Engineering and Technology*, *5*(9), 669-671.

Monteith, J. L. (1965). "Evaporation and Environment." In Symposium of the Society for Experimental Biology, Vol. 19, 203-224.

Monteith, J.L. (1965). Evaporation and environment. In: The state and movement of water in living organism. 19th Symp. Soc. Exptl. Biol., 205-234.

Penman, H.L. (1948). Natural evaporation from open water, bare soil and grass. Proceedings of the royal society of London. Series A. Mathemat. & Physical Sci., 193 (1032) : 120-145.

Ray, S. S., & Dadhwal, V. K. (2001). Estimation of crop evapotranspiration of irrigation command area using remote sensing and GIS. *Agricultural water management*, *49*(3), 239-249.

Salemi, H., Soom, M. A. M., Lee, T. S., Mousavi, S. F., Ganji, A., & Yusoff, M. K. (2011). Application of AquaCrop model in deficit irrigation management of winter wheat in arid region. *African Journal of Agricultural Research*, *610*(1), 2204-2215.

Singh, R. K., & Irmak, A. (2009). Estimation of crop coefficients using satellite remote sensing. Journal of Irrigation and Drainage Engineering, 135(5), 597-608.

Smith, M. (1992). CROPWAT, a computer programme for irrigation planning and management. FAO Irrigation and Drainage paper No.46. FAO, ROME, ITALY.

Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. (2009). AquaCrop—the FAO crop model to simulate yield response to water: I. Concepts and underlying principles. Agronomy Journal, 101(3), 426-437.

Subedi, A., & Chávez, J. L. (2015). Crop evapotranspiration (ET) estimation models: a review and discussion of the applicability and limitations of ET methods. *J Agric Sci*, *7*(6), 50.

Trajkovic, S. (2005). Temperature-based approaches for estimating reference evapotranspiration. Journal of Irrigation and Drainage Engineering, 131(4), 316-323.

Walter I.A., Allen R.G., Elliott R., Mecham B., Jensen M.E., Itenfisu D., Howell T.A., Snyder R., Brown P., Echings S., Spofford T., Hattendorf M., Cuenca R.H., Wright J.L. & Martin D. 2000. ASCE Standardized Reference Evapotranspiration Equation, p. 209–215. In: Evans RG, Benham BL, Trooien TP (eds.) Proc. National Irrigation Symposium, ASAE, Nov. 14–16, 2000, Phoenix, AZ.