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Review of Estimation Methods for Crop Evapotranspiration and Irrigation Water Requirement of Different Crops

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Abstract:- Water stands as a vital input with a pivotal role in global agricultural production. Its significance transcends ecosystems, particularly in the context of agricultural systems that lay the foundation for wetland and marine ecosystems. Accurate irrigation scheduling and accurate crop water requirement measurement are both necessary for effective water management of crops. For the best plant growth, irrigation is used to replenish the moisture that has been lost. The reference evapotranspiration is crucial in determining the water requirements for crops and the timing of irrigation. For irrigation planning and water management, an accurate calculation of the crop water requirements (ETc) is important. Accurate irrigation scheduling and accurate crop water requirement measurement are both necessary for effective water management of crops. For the best plant growth, irrigation is used to replenish the moisture that has been lost. The reference evapotranspiration is crucial in determining the water requirements for crops and the timing of irrigation. Accurate calculation of any crop's ETc. This paper conducts an assessment and analysis of crop evapotranspiration estimation and the corresponding irrigation water requirement for various crops. It delves into the utilization of diverse evapotranspiration models and data within the context of geographical ecology studies. Additionally, the paper employs these methodologies to estimate daily water needs for agricultural crops cultivated in different climatic zones, both in India and globally.

I. INTRODUCTION

Water stands as one of the most vital resources, playing a pivotal role in agricultural production across virtually every region worldwide. Its presence ensures the growth and sustenance of crops and livestock, which are essential for ensuring food security and supporting livelihoods. The availability and efficient management of water emerge as critical factors in achieving both agricultural productivity and environmental sustainability. This importance extends to all ecosystems, with a particular focus on agricultural ecosystems that form the foundation of wetland and marine ecosystems. Globally, agricultural ecosystems are the predominant consumers of water resources, accounting for 80% of water usage. This percentage varies across regions due to economic development and climatic differences (Juan et al., 2018). The success of quality seeds and fertilizers is often hindered if plants are not optimally irrigated. The central challenge faced by the agricultural sector is to increase food production while using less water. As the demand for water continues to rise and water scarcity becomes more pronounced, the efficient and economic utilization of available water resources becomes imperative. Understanding crop evapotranspiration (ET) holds paramount importance for calculating soil water balance and determining irrigation water requirements. This knowledge is instrumental in optimizing irrigation scheduling and water management, taking into account factors such as irrigation system efficiency and rainfall patterns. The daily water needs of crops are significantly influenced by local weather conditions, highlighting the necessity for region-specific studies that examine the parameters affecting irrigation water depth. Direct measurement of crop evapotranspiration can be achieved through methods such as lysimeters or water balance approaches. However, indirect methods that rely on climatic data are often preferred due to the challenges associated with obtaining accurate field measurements and the limited availability of lysimeters. Crop evapotranspiration (ETc) is derived from reference crop evapotranspiration (ETo) using a crop coefficient. ETo serves as a crucial hydrological parameter for irrigation scheduling, water resource planning, and the computation of actual evapotranspiration. The concept of reference evapotranspiration was introduced to measure atmospheric evaporative demand independently of crop types, growth stages, or management practices (Allen et al., 1998). ETo serves as the foundation for computing ETc by employing a suitable empirical crop coefficient. This approach enables the estimation of crop water requirements and facilitates hydrological water-balance modeling for specific regions or basins.

II. REVIEW

- *Estimation of Reference Crop Evapotranspiration (ETo)*

There are two methods for measurement or estimation of reference evapotranspiration (ETo); direct and indirect methods. The direct methods involve directly measuring weather parameters like temperature and humidity, while indirect methods rely on empirical equations utilizing factors like solar radiation and wind speed.

III. DIRECT METHODS

Crop evapotranspiration (ETc) can be directly measured using a lysimeter, which isolates a volume of soil with or without crops from the surrounding hydrological environment. However, this method has limitations such as the need for proper construction, skilled manpower, instrumentation, and higher costs. It is also time-consuming and requires precise planning and execution.

Due to the constraints associated with lysimeter measurements, alternative indirect methods are used to estimate ETc. These methods involve estimating the reference crop evapotranspiration (ETo) using various ETo estimation techniques based on weather data (Pandey et al., 2014; George and Raghuvanshi, 2012). Once ETo is determined, it is multiplied by the crop coefficient (Kc) to obtain ETc.

Indirect methods provide a practical approach to estimate ETc, especially in situations where direct lysimeter measurements are not feasible or practical. These methods rely on weather data and crop coefficients to approximate crop water requirements and are widely used in agricultural water management and irrigation scheduling.

Crop evapotranspiration (ETc) can be measured directly using a device called a lysimeter. A lysimeter consists of a container that holds a volume of soil, either with or without crops, and is designed to isolate the soil and plants from the surrounding hydrological environment. This method has many constraints like proper construction, installation and operation of lysimeter, requires skilled manpower, instrumentation and higher cost (Allen *et al*., 1998). Many times, it is not always possible to measure ET using lysimeter since it is time consuming and requires precise and well-planned experiments. Considering these constraints in accurate field measurements of ET, the alternative indirect methods are being used for estimation of ETc in which ETo is estimated by different ETo estimation methods using weather data (Pandey *et al*., 2014; George and Raghuvanshi, 2012) and then multiplying it by crop coefficient (Kc).

IV. INDIRECT METHODS

In this method to estimate crop evapotranspiration (ETc) firstly, the reference crop evapotranspiration (ETo) from a well-watered agricultural crop from a standard surface is estimated and it is multiplied by appropriately developed empirical crop coefficients (Kc). Considering the limitations of direct measurement of crop evapotranspiration for a given crop using lysimeter, indirect methods of ETo estimation are being used depending on availability of climatic data. These methods can be grouped into combination methods (Penman VPD#1, Penman VPD#3, Penman-Monteith, FAO-24 Penman (c=1), 1982 Kimberly-Penman, 1972 Kimberly-Penman, FAO-24 Corrected Penman) and empirical formulations based on radiation (Turc, Jensen-Haise, Priestley-Taylor and FAO-24 Radiation), temperature (Thornthwaite, SCS

Several methods exist for estimating reference crop evapotranspiration (ETo), including Blaney-Criddle, FAO-24 Blaney-Criddle, Hargreaves, and pan evaporation techniques (such as Christiansen Pan, FAO-24 Pan, and George et al., 2002). The relationship between net radiant energy received by irrigated crops and evapotranspiration rate has been well established (Nikam, 2008). The two primary estimation approaches are the aerodynamic and energy balance methods (Dehghanisanij et al., 2004). The energy balance method, known for its reliability, is especially useful when sensible heat storage is limited or net heat energy storage is minor. Accurate irrigation planning hinges on understanding soil energy balance factors. Global models utilizing meteorological data aid in ETo prediction. However

The FAO-56 Penman-Monteith method, as outlined by Allen et al. (1998), has been advocated as the primary standard for defining and computing reference evapotranspiration (ETo) by expert consultation groups. Among various approaches, the energy balance method for estimating reference evapotranspiration has demonstrated a higher degree of consistency with actual crop water usage data on a global scale. This approach, as detailed by Allen et al. (1998), has displayed enhanced precision in estimating evapotranspiration rates compared to alternative methods, establishing it as a valuable tool for water management and irrigation planning. In this method, a theoretical grass reference crop with distinct characteristics serves as the reference surface, enabling comparability of ETo estimates across different locations and seasons. Requiring meteorological data including radiation, air temperature, air humidity, and wind speed, this approach boasts a high likelihood of accurately predicting ETo across a wide range of geographical locations and climatic conditions. The procedure for estimating missing meteorological variables is also provided, enhancing its practical applicability. Moreover, numerous studies have underscored the relatively accurate and consistent performance of the Penman-Monteith method across both arid and humid climates.

Khodke and Gundekar (2009) reported the classification of different ETo estimation methods in four major groups as under:

Table 1 The Classification of Different ETo Estimation Methods in Four Major Groups

Sr. No.	Classifications	Methods	References
1	Temperature	1) Thornthwaite	Thornthwaite (1948); Thornthwaite and Mather (1955)
		(2) SCS Blaney-Criddle	USDA (1970)
		(3) FAO-24 Blaney-Criddle	Doorenbos and Pruitt (1977); Allen and Pruitt (1986)
		(4) Hargreaves	Hargreaves *et al.* (1985); Hargreaves and Samani (1985)
2	Radiation	(1) Turc	Turc (1961); Jensen (1966b)
		(2) Jensen- Haise	Jensen and Haise (1963); Jensen *et al.* (1971)
		(3) Priestly-Taylor	Priestly and Taylor (1972)
		(4) FAO-24 Radiation	Doorenbos and Pruitt (1977)
3	Evaporation	(1) Christiansen Pan	Christiansen (1968); Christiansen and Hargreaves(1969)
		(2) FAO-24 Pan*	Doorenbos and Pruitt (1977)
		(3) Pan Evaporation	---
4	Combination	(1) Penman VPD#1	Penman (1948, 1963)
		(2) Businger-van Bavel	Businger (1956); Van Bavel (1966)
		(3) Penman VPD #3 (4) Penman-Monteith	Penman (1963) Monteith (1965); Allen (1986); Allen *et al.* (1989)
		(5) 1972 Kimberly-Penman	Wright and Jensen (1972)
		(6) FAO-24 Penman (c =1)	Doorenbos and Pruitt (1975, 1977)
		(7)FAO-24 Corrected Penman	Doorenbos and Pruitt (1977)
		(8) FAO-PPP-17 Penman	Frere and Popov (1979)

Chavan *et al.* (2009) studied several reference evapotranspiration methods for hot and humid regions in Maharashtra and reported that the accurate estimation of reference crop evapotranspiration (ET_0) in the water balance or irrigation scheduling allows us to improve the crop water management practices.

Chavan and Khodke (2010) estimated ETo with various methods (Pan Evaporation, Blaney-Criddle, Hargreaves- Samani and Priestly-Taylor) and compared them with FAO Penman- Monteith (FAO-56) to test their capabilities to predict daily ETo under the southern hot and humid region of *Konkan* platue in Maharashtra state. Based on the statistical parameters Blaney- Criddle was found to be the most reliable and accurate method for estimation of ETo followed by Hargreaves-Samani, Pan Evaporation and Priestley-Taylor.

Daniel (2013) conducted research in the humid Mississippi region of the USA to assess substitute approaches for estimating reference evapotranspiration (ETo) when complete weather data, as needed by the FAO-56 Penman-Monteith method, were absent. The study evaluated three alternatives: FAO-56 Reduced Set, Hargreaves, and Turc methods, relying solely on air temperature measurements. In the study, the Turc formula, initially dependent on temperature and solar radiation, was modified to use estimated radiation data. Results revealed the Turc method as more precise in estimating FAO-56 ETo compared to other methods. This suggests the viability of the Turc approach for ETo estimation in regions with limited weather data availability.

Awari *et al.*(2018) compared performance of different ETo estimation methods and showed that as compared to PM-56 method, the 1982 Kimberly-Penman and FAO-24 Penman (c=1) method over- estimated ETo by about 31.76 and 39.28 %, respectively for all months, except during the peak month. These methods yielded mean absolute error of 2.2 and 2.5 mm/day) The coefficient of determination of 0.78 and 0.79 indicates a strong correlation between the variables, explaining approximately 78% and 79% of the total variation in the data, respectively. respectively whereas the Priestley-Taylor and Turc radiation methods under-predicted ETo when compared to PM-56 method by 61.51 and 63.07%, respectively whereas Hargreaves method under estimated ETo by 13.31%. They reported that among all the methods considered for their study, Hargreaves temperature method showed very close agreement with PM-56 method and ranked first in estimating ETo based on statistical parameters viz., MAE, MSE, RMSE and Model efficiency. The rank of other methods in estimating ETo in decreasing order is 1982 Kimberly -Penman, FAO-24 Penman (c=1),FAO-24 Epan, PriestleyTaylor and Turc method.

Phad *et al.* (2019) The estimated reference crop evapotranspiration and crop water requirement for major kharif cereals in the Marathwada region, Maharashtra, are essential to optimize irrigation practices and ensure sustainable agricultural productivity during the monsoon season. Precise information on these factors helps farmers make informed decisions on water management and crop selection for efficient water usage and higher yields. They used FAO-56 Kc values for kharif sorghum, maize and pearl millet to calculate the daily crop water requirement (ETc). They reported that ETo reaches to its peak value during 28th April to 18th May in all the districts of Marathwada region. Among the districts, Parbhani had the higthest ETo and Aurangabad had the lowest ETo followed by Nanded, Latur, Osmanabad, Beed and Jalna. The mean water requirement (ETc) of kharif sorghum during initial stage was found to be lower (1.83 to 2.0 mm day^{-1}), increased during developmental stage (3.34 to 3.70 mm day^{-1}) and during mid-season stage (4.70 to 5.10 mm day^{-1}) The evapotranspiration rate decreased during the late season stage, specifically from 4.64 mm per day to a range of 1.29 to 1.38 mm per day. The total water requirement of kharif pearlmillet varies between 291.69 mm for Parbhani to 265.02 mm for Aurangabad.

- *Estimation of Crop Evapotranspiration and Irrigation Water Requirement*

Tyagi *et al*. (2000a) reported that the maximum evapotranspiration rate (ETc) for wheat was 4.2 mm per day, occurring in the 16th week after planting. Recorded total ETc values for different crops in Karnal, India were: wheat (337 mm), rice (587 mm), maize (335 mm), sorghum (495 mm), sunflower (655 mm), and berseem (480 mm).

Mishra *et al.* (2000) conducted a study to evaluate the applicability of utilizing standard crop factors in a range of equations for predicting daily crop coefficient (Kc). This prediction was essential for computing actual crop evapotranspiration (ETa) and implementing the WATERMAN computerized simulation model, used for irrigation scheduling and water management. Among 25 tested functions, the study demonstrated a close match between observed and fitted Kc values for all crops. Polynomial equations of varying degrees provided accurate data fitting in most cases. Predicted daily Kc values were then employed to estimate ETa for six distinct crops namely wheat, rice, mustard, potato, jute, and tea in the Lower Assam region of India.

Dutta and Das (2001) conducted research in the Lunkaransar region of the Indira Gandhi canal command, focusing on estimating crop water requirements through the Modified Penman and Pan Evaporation methods. The findings indicated varying crop evapotranspiration (ETc) values across different crops and growth seasons. Among Kharif crops, Pigeon pea exhibited the highest ETc at 503 mm, followed by Pearl millet with values of 488 and 491 mm, and Groundnut with values of 430 and 452 mm. For Rabi crops, Gram displayed the highest ETc with values of 239 and 260 mm, followed by Wheat with values of 213 and 227 mm, and Mustard with values of 129 and 142 mm. The study also noted phenological differences in crop ETc, with peak values aligning with flowering, pod development, and grain-filling stages.

Kuoa *et al.* (2006) conducted field experiment at the HsuehChia Experiment Station, ChiaNan Irrigation Association, Taiwan during 1993 to 2001 to calculate the reference and actual crop evapotranspiration, derived the crop coefficient and collected required input data for the CROPWAT irrigation management model. They estimated irrigation water requirements of paddy and upland crops for Nan Irrigation Association, Taiwan.

Chavan and Khodke (2009) conducted a study to assess crop water requirements for irrigation planning in a semi-arid region using 16 years of daily meteorological data from five locations in the Marathwada region: Aurangabad, Beed, Nanded, Parbhani, and Osmanabad (from 1984 to 2001). Employing the FAO 56 Penman-Monteith technique, they calculated reference crop evapotranspiration (ETo) and derived crop coefficients to estimate water needs for eight primary crops. Effective rainfall was used to identify weeks of surplus or deficit relative to agricultural water demands. Notably, Cotton, groundnuts, and sugarcane demonstrated higher water needs in Parbhani, while kharif sorghum, rabi sorghum, wheat, and soybean had elevated water requirements in Osmanabad. Kharif sorghum and soybean needs were met by effective rainfall.

Gadge et al. (2010) estimated crop water requirements under a micro-irrigation system, utilizing Penman-Monteith method. Climatic data were sourced from a meteorological observatory located at All India Co-ordinated Research Project on Water Management, MPKV, Rahuri. This comprehensive data spanned from 1975 to 2005, enabling a thorough analysis of climatic conditions during that period. For the purpose of the research.

The crops considered in this particular study were papaya, banana, sugarcane, pomegranate, lime, grapes, kharif soybean, rabi tomato, kharif groundnut, rabi onion, cotton, gram, potato, kharif brinjal, cabbage, summer brinjal, summer cucumber, summer onion, summer okra, summer groundnut and summer chilli. The study revealed that there is a saving of at least 50% of water if drip irrigation method is used instead of surface irrigation method. Also crop water requirement under micro irrigation methods is less than surface irrigation methods

Raut *et al.* (2010) estimated irrigation water requirements of wheat and mustard crops grown in Western Yamuna Canal Command area CROPWAT model with the help of agrometeorological and remote sensing data (1986-1998 and 2008). The variations in irrigation water requirements of these two crops were judged by calculating coefficient of variations (CVs) of yearly data. Crop coefficient values were obtained through FAO (1993) method. Supervised maximum likelihood classification (MXL of IRS 1B image) was done to estimate area under wheat and mustard in the canal command. Water need was calculated from amount of supply and water requirement for the whole area. Results showed that ETc of both wheat and mustard varied very little over different years (CVs 4.7 and 5.6 per cent) whereas irrigation water requirements of both crops had relatively large variations (CVs 14.1 and 22.6 per cent), respectively) which were mainly because of high variations of their effective rainfall (CVs 61.1 and 69.2 per cent).

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In a study spanning nine chosen districts within Madhya Pradesh, Singh et al. (2014) employed the Penman-Monteith technique to establish the water requirements for soybean and wheat crops. The outcomes unveiled a seasonal water necessity of 401.6 mm for soybeans and 352.2 mm for wheat. These measurements signify the water quantities essential to sustain optimal growth and yield for these crops throughout their complete growth phases.

Masum *et al.* (2014) carried out from 2002 to 2011 in nine Upazillas of Barind area under Rajshahi district. Reference Evapotranspiration was estimated using FAO Penman-Monteith method. Reference Evapotranspiration and crop coefficient of wheat crops were used for estimating crop water requirement. By using estimated effective rainfall and crop water requirement, the irrigation water requirement was determined. The irrigation water requirement for Wheat was higher in the vegetative and midseason stage from December to January and comparatively less irrigation water was required in initial and maturity stage. IWR decreases in the month of March as wheat was in maturity stage. The crop water requirement varied from 121.9 mm/month to 96.7 mm/month.

Desta *et al.* (2015) conducted research at Ethiopia's DebreZeit Agricultural Research Center in the central highlands, employing the FAO CROPWAT 8.1 software and long-term weather data to evaluate chickpea's crop water demands. Using a simulated planning date of December 24, the researchers assessed irrigation needs across different growth phases. The study outlined chickpea's net irrigation requirements: 37.2 mm for the seedling stage, 114.4 mm during vegetation, 205.2 mm in late (maturity) growth, and 79.8 mm in the final growth stages. The total irrigation requirement for a single growing season, calculated via the CROPWAT software, was estimated at 436.7 mm.

In a study conducted by Khandelwal et al. (2015), the authors aimed to estimate reference crop evapotranspiration (ETo), crop evapotranspiration (ETc), and net irrigation water requirements for various crops in the Limbasi branch canal command area of the Mahi Right Bank Canal (MRBC) project situated in Gujarat, India. The Hargreaves-Samani approach was employed to calculate reference crop evapotranspiration (ETo) using thirteen years' worth of available data. The research findings revealed significant insights into the net irrigation water requirements for different crops: For kharif paddy, the net irrigation water requirement (NIR) was calculated to be 166.8 mm. In the case of rabi sorghum, tobacco, and wheat, the corresponding NIR values were 404.3 mm, 504.2 mm, and 564.7 mm, respectively. For summer paddy and pearl millet, the calculated NIR values were 851.1 mm and 619 mm, respectively.

These results offer valuable information regarding the specific irrigation water requirements for different crops across distinct seasons in the mentioned geographical area. The utilization of the Hargreaves-Samani approach for ETo estimation provides a useful framework for understanding and managing irrigation water resources effectively in agricultural practices.

In their study, Mehta and Pandey (2016) focused on estimating the crop water requirements (ETc) for ten major crops cultivated in different seasons within the middle Gujarat region. The selected crops included rice, wheat, maize, pearl millet, chickpea, green gram, soybean, groundnut, mustard, and cotton. The authors employed the FAO Penman-Monteith method to estimate daily reference evapotranspiration (ETo) based on a dataset spanning 20 years (1993 to 2013) of mean meteorological data from Anand, Gujarat. The results revealed a pattern of changing daily ETo values over the course of the year: ETo started at 4.2 mm per day in January and gradually increased. It reached its peak at 10.1 mm per day during May 25th to 30th. ETo then decreased sharply in June, remained low in July and August, slightly increased in September and October, and eventually decreased to a minimum of 4.0 mm per day by the end of the year. The study also provided insights into the seasonal crop water requirements (ETc) for different crops: Among summer crops, groundnut had the highest ETc value at 849.0 mm, followed by pearl millet (499.2 mm) and green gram (476.5 mm). In the kharif (monsoon) season, cotton (848.0 mm) and rice (729.3 mm) had the highest crop water requirements, while pearl millet (323.6 mm) and green gram (324.6 mm) had the lowest. For winter season crops, wheat exhibited the highest ETc at 501.2 mm, whereas mustard had the lowest at 411.7 mm. This comprehensive analysis sheds light on the varying water requirements of different crops across distinct seasons in the middle Gujarat region, aiding in better resource management and crop selection decisions for sustainable agriculture.

Mehanuddin *et al.* (2018) In their research conducted in Shimoga Taluk, Karnataka, India, the study aimed to assess the crop water requirement for cotton, maize, and sugarcane, utilizing a 10-year climatic dataset. The researchers utilized CROPWAT 8.0 software to determine the reference crop evapotranspiration (ETo) and crop evapotranspiration (ETc) for each crop. The findings indicated that during the rabi season, both cotton and maize experienced insufficient effective rainfall to meet their water requirements, necessitating irrigation to fulfill the crops' water needs adequately. However, during the kharif season, the effective rainfall was found to be sufficient, adequately satisfying the water requirements of cotton and maize without the need for additional irrigation. Notably, the study did not explicitly mention the water requirement status of sugarcane concerning effective rainfall. Further investigation is required to understand the water demands of sugarcane and its reliance on effective rainfall during various seasons. These research findings hold significant importance for local farmers and policymakers to implement suitable irrigation and water management strategies. By considering the water needs of these crops, sustainable agricultural practices can be promoted, contributing to increased productivity and ensuring food security in the region.

Memon and Jamsa (2018) A study was conducted in Godhra Taluka, Gujarat, India, to determine the water needs of soybean and tomato crops. Researchers used the widely-used FAO Cropwat 8.0 software, developed by the Food and Agriculture Organization (FAO), to analyze climatic and crop-related parameters. Valuable insights were gained into the crop water requirements, with soybean needing 426.0 mm/dec and tomato requiring 1180.7 mm/dec. Additionally, irrigation requirements were found to be 381.0 mm/dec for soybean and 1135.7 mm/dec for tomato, with minimal yield reduction. These findings can help farmers and policymakers optimize irrigation and water management practices for these crops in the region.

Yadav *et al*. (2018) estimated the study conducted in Madhya Pradesh aimed to determine the crop water requirement of Rabi and kharif season crops grown under paired row planting in various agro-climatic conditions. They used an already developed crop coefficient and reference evapotranspiration to calculate the water requirements. Over 35 years of daily weather data from twenty districts was collected to determine the reference evapotranspiration using the Aqua crop model. The results showed that daily ETo peaked during the 21st-22nd SMW and decreased afterward. The highest ETo was observed in Datia (11.0 mm/day) during the 21st SMW, while the lowest was in Betul (2.2 mm/day) during the 32nd SMW. The study revealed varying water requirements for different crops in different districts, such as the highest water requirement for chickpea, wheat, and lentil in Jabalpur and for sugarcane in Narsinghpur during mid-season. Among kharif crops, cotton had the highest water requirement in Harda, followed by sesame and groundnut in Datia.

Dhokle *et al.* (2019) Utilizing the FAO-CROPWAT model and meteorological data, the study estimated the agricultural water requirements in Ahmednagar district. With an average yearly rainfall of 597 mm, 492.9 mm was considered useful for agriculture. The irrigation requirements (in mm) for sorghum, wheat, Bajra, and cotton crops were reported as 221.2, 358.8, 39.1, and 302.5, respectively, providing valuable insights for water management strategies and sustainable agricultural development in the region.

Bharteey *et al.* (2020) The study conducted in the semi-arid conditions of Mirzapur district, Uttar Pradesh, used the FAO Penman-Monteith approach to estimate reference crop evapotranspiration (ET0) and determine water requirements for six commonly cultivated crops. Rice exhibited the highest total water requirement throughout its life cycle, amounting to 729.97 mm, followed by groundnut (396.45 mm), wheat (345.33 mm), mustard (274.31 mm), potato (250.92 mm), and pea (198.75 mm). On a per-plant basis, potato had the highest water requirement of 30.11 liters, followed by rice (23.95 liters), mustard (18.52 liters), pea (17.89 liters), groundnut (17.84 liters), and wheat (6.91 liters). Effective rainfall played a vital role in significantly reducing the water requirements for all crops, providing valuable insights for sustainable water management practices in the region.

Dingre and Gorantiwar (2020) conducted a study over 2015 and 2016 in semiarid regions of India, focusing on sugarcane evapotranspiration and crop coefficients (Kc) on clay soils. They utilized drip irrigation with intervals of 7 to 10 days between watering, supplemented by natural rainfall. The irrigation schedule relied on the field water balance method. Evapotranspiration was calculated using this approach, and reference evapotranspiration (ETo) was determined using the Penman-Monteith method. Standard FAO-56 methodology was employed to compute crop coefficients. The study aimed to enhance irrigation practices and water management for sugarcane cultivation in comparable settings. The average sugarcane crop evapotranspiration over two years, assessed using the field water balance method, was found to be 1339 mm per year. The irrigation water requirement amounted to 991 mm per year, while effective rainfall was 424 mm per year. The findings exhibited a distinct similarity between Kc values derived from field water balance measurements and those reported by FAO-56. Notably, Kc values of 0.70, 1.20, and 0.78 were determined for the tillering, grand growth, and maturity stages of sugarcane, respectively. These Kc values were notably lower by 25.5%, 4%, and 20.4% during the respective stages when compared to FAO-56 Kc values. Furthermore, the study formulated a second-order polynomial equation correlating the crop coefficient as the dependent variable and the ratio of days after transplanting to the total crop period as the independent variable. This equation proved highly valuable for effective irrigation water management. Its applications encompassed the creation of Decision Support Systems, crop yield models based on soil moisture, computer programs, mobile applications, and the automation of irrigation systems. These applications were particularly beneficial for major sugarcane-producing countries in semi-arid regions.

V. CONCLUSION

Agricultural water resource planning, management, and regulation rely heavily on accurate estimates of water usage in agricultural regions. Inadequate water allocations can negatively impact crop growth, harvests, and ultimately contribute to food scarcity. The largest source of water loss in agricultural areas is through evapotranspiration (ET). To address this, adopting more effective strategies to reduce ET is crucial for achieving sustainable and efficient water management in agriculture. Furthermore, the ongoing effects of climate change are projected to lead to increased atmospheric temperatures, resulting in higher energy levels that drive more evaporation. Given these challenges, it becomes imperative to enhance water-use efficiency and sustainable water management in agriculture by improving the accuracy of ET estimation. This comprehensive review delves into the technical advancements of methodologies, tools, and approaches for estimating ET, all aimed at enhancing agricultural water management. Existing literature highlights two primary approaches: first, the identification of more effective strategies to reduce ET without compromising crop growth, and second, the development of precise tools and methods to measure ET accurately. The accuracy of ET estimation plays a pivotal role in achieving precise agricultural water management. The integration of precision and digital agricultural technologies has shown promise in elevating the accuracy of ET estimation. Notably, the incorporation of advanced techniques like remote sensing and satellite technology, coupled with the application of machine learning algorithms for data analysis, has demonstrated the potential to significantly enhance accuracy and revolutionize agricultural water management.

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