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Estimating and Validating Reference Evapotranspiration Using Weather Data over Northern India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Precise computation of evapotranspiration (ET) is essential for agricultural system modelling, hydrology, irrigation planning, including quantification and scheduling, and water resource management. Additionally, reliable estimations of ET might improve the accuracy of performance indicators related to the water balance in the assessment of irrigation projects. The study presents an estimation of daily reference evapotranspiration (ET_O) using the FAO-56 Penman Montheith model and daily weather data from the years 2020 to 2022 over SHUATS, Prayagraj (U.P.). The results obtained were validated with the output of CROPWAT 8.0. Statistical techniques viz. MAE, MBE, RMSE, MRE, Willmot index of agreement (d), ƞNS, PCC, and regression analysis were used to evaluate the performance of the simulation. The lesser values of MAE, MBE, RMSE, and MRE

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and the highest values of d, ηNS, PCC, and R2 reveal the closeness of the simulated reference evapotranspiration with that determined by the CROPWAT over the region. The results show the wide applicability to compute the daily ET_O using the FAO-56 P-M model for effective management of irrigation water in agriculture.

Keywords: Reference evapotranspiration; simulation; CROPWAT; statistical approach.

1. INTRODUCTION

Rapid growth in population, urbanization, and industrialization has led to increased demand for land and water for housing, infrastructure, and commercial development, reducing the availability of arable land and limited water resources for agriculture. Its fast expansion not only converts agricultural land and natural habitats into built-up land but also leads to overexploitation of water, causing water scarcity. Agriculture is the biggest sector where more than 80% of available water is used for crop production [1,2,3,4]. Human activities, especially the burning of fossil fuels, deforestation, and agricultural practices, have significantly increased the concentrations of greenhouse gases, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), in the atmosphere. These gases together contribute to the greenhouse gas effect by trapping heat into the atmosphere, causing climate change, which alters the components of the hydrological cycle, viz. precipitation, interception, evapotranspiration, runoff, infiltration, and water storage in interspaces between soil particles in the form of soil moisture [5,6]. Climate change intensifies water-related issues such as spatio-temporal changes in rainfall patterns, increased frequency and intensity of extreme weather events, rising temperatures, and melting glaciers, all of which have significant implications for the distribution and availability of water resources. Shifts in temperature and precipitation induced by climate change have altered the atmospheric demand for crop water, which has led to increased rates of evapotranspiration, potentially requiring more irrigation water to meet crop water demand. In such a scenario, the use of water management technologies such as quantifying the crop water requirement and irrigation scheduling may certainly be helpful for conserving, distributing, and using water resources judiciously.

The reliable and precise spatio-temporal computation of reference evapotranspiration is crucial, as crop water demands in irrigated agriculture are heavily determined by atmospheric demand. In many scientific applications such as irrigation scheduling, irrigation design, hydrology, agricultural systems modelling, and water resource management, precise estimate of evapotranspiration is essential [7]. The term "evapotranspiration" refers to a process that describes the combined loss of water from the Earth's surface through evaporation and transpiration. It is a key component of the hydrological cycle and is important for understanding water balance in various environments. The CROPWAT 8.0 software, a widely used model for managing and planning irrigation, simulates the complicated interactions between soil, crop, and climate characteristics on farms. It calculates crop evapotranspiration, irrigation schedules, reference evapotranspiration, forecasting of agricultural production, and agricultural water requirements using various irrigation planning patterns [8]. The computation of reference evapotranspiration requires minimum essential weather parameters like minimum and maximum air temperature, minimum and maximum relative humidity, wind speed, and solar radiation [9,10]. A drawback with this tool is the determination of daily reference evapotranspiration (ET_o), which is not determined for the 29^{th} day of February in a leap year, which may be misleading in the determination of the water requirement for a crop.

In the present study, daily reference evapotranspiration has been simulated for the period of three years from 2020 to 2022 over SHUATS, Prayagraj, and validated using CROPWAT using weather parameters. Additionally, the performance of the simulation has been evaluated using statistical analysis.

2. METHODOLOGY

2.1 Study Area and Weather Data Used

The study area, the research farm of Sam Higginbottom University of Agriculture, Technology, and Science (SHUATS), Prayagraj district (Fig. 1) of Uttar Pradesh, is located at a latitude of 25° 34' 12" N, a longitude of 87° 11' 24" E, and an altitude of 98.0 m above mean sea level. The region has a hot and dry summer, a chilly and severing winter, and a warm, humid rainy seasons. It receives an annual normal rainfall of 1207.0 mm. The maximum temperature in the region varies from 40 °C to 45 °C during the summer. The weather data, such as daily maximum and minimum temperature, daily maximum and minimum relative humidity, daily wind speed, and bright sunshine of duration three years from 2020 to 2022, were collected from the meteorological observatory located in the campus of SHUATS, Prayagraj, Uttar Pradesh, and used for ET_O computation and validation.

2.2 FAO-56 Penman-Monteith Model

The FAO-56 Penman-Monteith equation was used to compute daily, 10-day and monthly ETo. The equation is written as [11]:

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \frac{900}{(T+273)}\,\gamma\,(e_s - e_a)u_2}{\Delta + \gamma(1 + 0.34\,u_2)} \quad (1)$$

Where, ET_o is the grass reference evapotranspiration (mm/day), R_n is the net radiation available on surface (MJ/m^2/day), G is the soil heat flux (MJ/m^2/day) taken zero for daily simulation, T is the daily mean temperature at 2 m height (ºC), γ is the Psychrometric constant (kPa/ºC), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), (e_s - e_a) is the vapour pressure deficit (kPa), and u_2 is the wind speed at 2 m height (m).

2.3 Validation Using Statistical Approach

Statistical analysis based on residual and association between the simulated and CROPWAT estimated reference evapotranspiration was used to test the goodness-of-fit. Mean absolute error (MAE), mean bias error (MBE), root mean square error (RMSE), Willmot index of agreement (d), Nash-Sutcliffe efficiency (NSE), and Pearson correlation coefficient (PCC) were used to quantify the error between them. Moreover, following the suggestions of Krause et al. (2005), the slope (*m*) and the intercept (*c*) of the straight line fitted to the observed and the simulated series of reference evapotranspiration were used as evidence of closeness between them. For perfect agreement, the values of m and c near unity and zero, respectively, represent the line of perfect fit drawn on a 1:1 slope and a zero intercept.

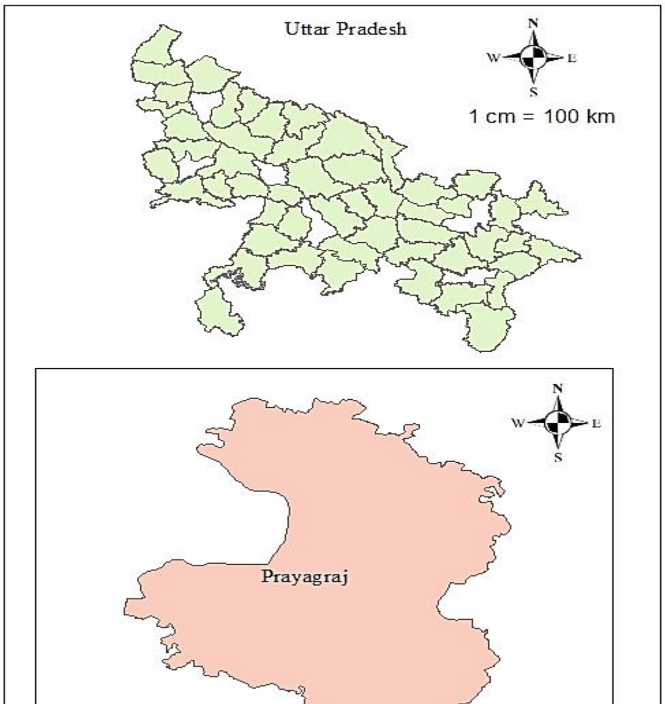

Fig. 1. Location map of study area

3. RESULTS AND DISCUSSION

The daily estimates of reference evapotranspiration (ET_O) were simulated using weather data over the SHUATS, Prayagraj (UP), and the performance of the simulation was evaluated by comparing the results with the reference evapotranspiration estimated by CROPWAT version 8.0, a computer program developed by the Land and Water Development Division of the Food and Agriculture Organization, Rome (Italy).

3.1 Validation of Simulated ET_O with CROPWAT

The minimum and maximum values of daily ET_O estimates during simulation were observed to be 0.940 mm/day and 6.490 mm/day with a normal daily value of 3.508 mm/day over the region, while those values computed using the CROPWAT were found to be 0.960 mm/day and 6.450 mm/day with a normal value of 3.546 mm/day, respectively, indicating the good performance of the simulation. The lowest values of SE for simulated and CROPWAT determined ET_O over the region were estimated to be 0.039 mm/day for both, showing minimum dispersion of sample mean of reference evapotranspiration with that of population mean and thus, high accuracy in simulation (Table 1).

The scatter points between the simulated ET_O and the CROPWAT estimated ET_O were plotted and shown in Fig. 2. The trend line fitted between the simulated and the CROPWAT estimated ET_O was observed to be parallel to the line of best for the ET_O estimates (Fig. 2).

The highest value of R^2 of 0.9998, which is almost equal to the maximum correlation coefficient of 1.0 between the simulated and CROPWAT estimated ET_O was seen, pointing out the perfect goodness-of-fit and very strong correlation between them. The slope value of linear trend line (0.9908) fitted between them was observed to be almost near 1.0 which is the slope of the best line of fit (Fig. 2).

Table 1. Basic statistics of reference evapotranspiration obtained by simulation and CROPWAT over SHUATS, Prayagraj (UP)

General Statistics	SHUATS, Prayagraj	
	Simulated ET_O	CROPWAT ET_O
Minimum (mm/day)	0.940	0.960
Maximum (mm/day)	6.490	6.450
Mean (mm/day)	3.508	3.546
SD (mm/day)	1.284	1.281
CV	0.366	0.361
SE (mm/day)	0.039	0.039

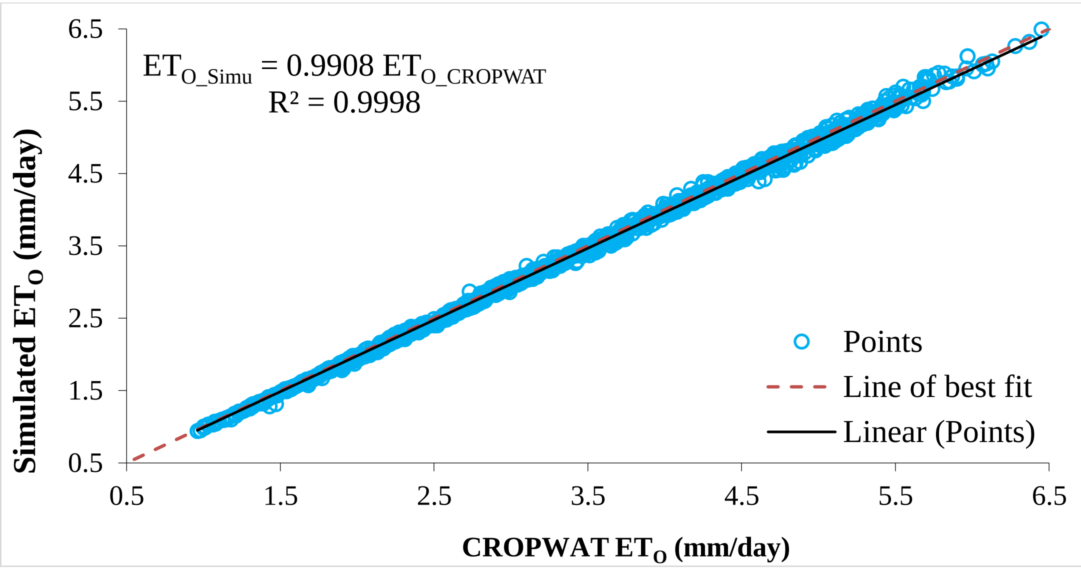

Fig. 2. Scatter plot of simulated and CROPWAT estimated daily ETo estimates during the years from 2020 to 2022 over SHUATS, Prayagraj

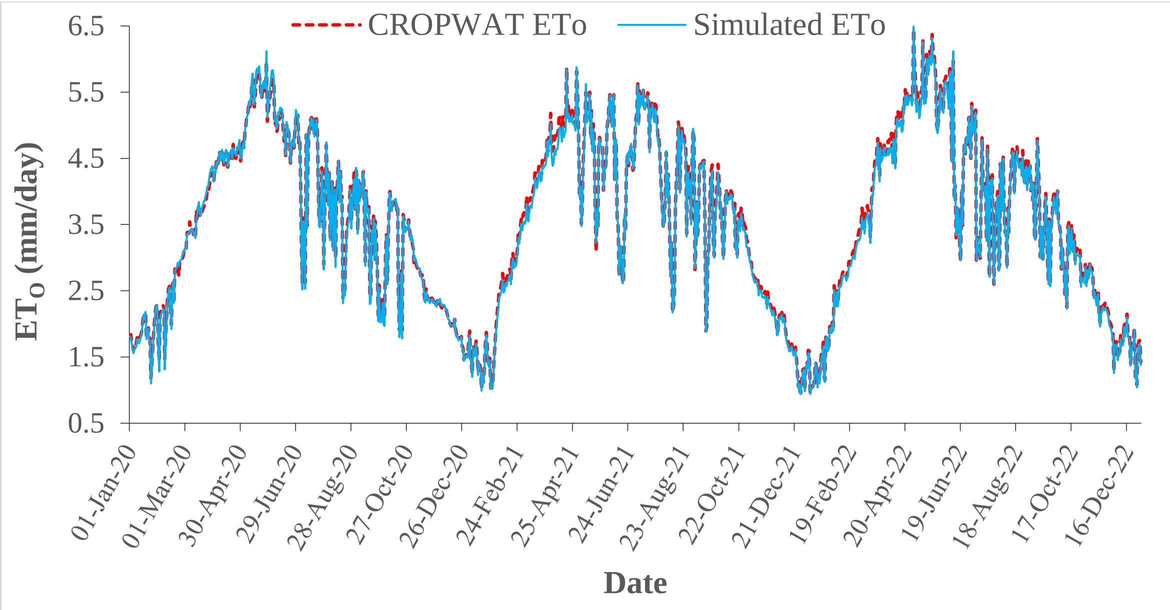

Fig. 3. Daily time series of simulated and CROPWAT determined ETo estimates during the years from 2020 to 2022 over SHUATS, Prayagraj

Table 2. Errors between simulated and CROPWAT determined reference evapotranspiration during the years from 2020 to 2022 over the region

MAE (mm/day)	MBE (mm/day)	MRE (mm/day)	RMSE (mm/day)	d	η_{NS}	PCC
0.052	0.037	-0.013	0.065	0.999	0.997	0.999

The close agreement between the simulated and CROPWAT estimated reference evapotranspiration can be seen in Fig. 3. The Fig. 3 showed the peak value of reference evapotranspiration in the month of May of each year from 2020 to 2022, during the study period reflecting that the region has highest atmospheric demand in this month due to the maximum amount of bright sunshine duration, air temperature, and solar radiation.

The perfection in simulation to compute reference evapotranspiration was analyzed by analysing the errors quantified between simulated and CROPWAT determined ET_O in terms of MAE, MBE, MRE, RMSE and correlation between them in the form of d, η_{NS} and PCC which were computed and presented in Table 2. Table 2 depicts the values of MAE, MBE, MRE, and RMSE, which were observed to be 0.052 mm/day, 0.037 mm/day, -0.013 mm/day, and 0.065 mm/day, respectively, which are the lowest and almost unity, indicating the simulated values of ET_O are very close to the values of ET_O determined by using CROPWAT. The highest values of d, η_{NS} and PCC obtained to be 0.999, 0.997, and 0.999, respectively show the very strong correlation between the simulated ET_O estimates and that estimated by using the CROPWAT (Table 2).

3.2 Discussion

Results showed the highest value of correlation between simulated and CROPWAT determined reference evapotranspiration resembling the perfect simulation of reference evapotranspiration. The strong simulation can also be seen with the high value of Willmot index of agreement, Nash-Sutcliffe efficiency, and Pearson correlation coefficient determined between them. The figures and tables shown above depict the usefulness of the simulation to determine the reference evapotranspiration over the region during the period of study. The simulated value of the reference evapotranspiration is useful in determining the crop water requirement, irrigation scheduling, demand for the canal command area, and agricultural water management as a whole. The analysis of the results presents the worldwide applicability of the simulation to compute the reference evapotranspiration for effective management of irrigation water.

4. CONCLUSION

In this paper, the reference evapotranspiration has been simulated on a daily time scale using weather data over SHUATS, Prayagraj, and validated with that obtained with CROPWAT. Very low average value of MAE, MBE, RMSE and MRE, and very high values of d, ∏NS, PCC and R^2 between the simulated and CROPWAT estimated ET_O were observed ensuring the close simulation of reference evapotranspiration to that computed by CROPWAT using weather data over the area. Hence, wide application of the FAO-56 Penman Monteith method for the computation of reference evapotranspiration using weather data is recommended for agricultural planning.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Jury WA, Vaux H. The role of science in solving the world's emerging water problems. The Proceedings of the National Academy of Sciences, USA. 2005;102(44): 15715–20.
2. Doungmanee P. The nexus of agricultural water use and economic development level. Journal of social sciences. 2016;37: 38e45.
Available:http://dx.doi.org/10.1016/j.kjss.2016.01.008
3. Tzanakakis VA, Paranychianakis NV, Angelakis AN. Water Supply and Water Scarcity. Water. 2020;12: 2347.
Available:https://doi.org/10.3390/w12092347
4. Nasr P, Sewilam H. Fertilizer drawn forward osmosis for irrigation. Emerging Technologies for Sustainable Desalination Handbook; 2018.
Available: https://doi.org/10.1016/B978-0-12-815818-0.00013-8
5. Nilawar AP, Waikar ML. Impacts of climate change on streamflow and sediment concentration under RCP 4.5 and 8.5: A case study in Purna river basin, India. Science of the Total Environment. 2019;650:2685–2696.
Available:https://doi.org/10.1016/J.SCITOTENV.2018.09.334
6. El-Jeitany J, Pacetti T, Caporali E. Evaluating climate change effects on hydrological functionality and water-related ecosystem services. Ecohydrology. 2023; 1–19.
Available:https://doi.org/10.1002/eco.2557.
7. Patel A, Sharda R, Patel S, Meena P. Reference evapotranspiration estimation using CROPWAT model at Ludhiana district (Punjab). International Journal of Science, Environment and Technology. 2017;6(1):620 – 629.
8. Nazeer M. Simulation of maize crop under irrigated and rainfed conditions with CROPWAT model. ARPN Journal of Agricultural and Biological Science. 2009; 4(2). ISBN- 1990-6145.
DOI:www.arpnjournals.com.
9. Raja P, Sona F, Surendran U, Srinivas CV, Kannan K, Madhu M, Mahesh P, Annepu SK et al. Performance evaluation of different empirical models for reference evapotranspiration estimation over Udhagamandalm, The Nilgiris, India. Scientific Reports. 2024;14: 12429.
Available:https://doi.org/10.1038/s41598-024-60952-4.
10. Zhang R, Zhu M, Mady AY, Huang M, Yan X, Guo T. Effects of different long-term fertilization and cropping systems on crop yield, water balance components and water productivity in dryland farming.

Agricultural Water Management. 2024;292: 108689.
Availavle:https://doi.org/10.1016/j.agwat.2024.108689

11. Allen RG, Pereira LS, Raes D, Smith M. Crop. Evapotranspiration: FAO Irrigation and Drainage Paper 56. FAO : Rome, Italy; 1998.

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