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Comparison of evapotranspiration models

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सार - उत्तर प्रदेश के वाराणसी क्षेत्र में 1978-79 से 1992-93 तक के विभिन्न वर्षों के दौरान गेहूँ की फसल के वास्तविक वाष्पन वाष्पोत्सर्जन को प्रतिदिन लाइसीमीटर से मापा गया है। इस अध्ययन में वाष्पन - वाष्पोत्सर्जन का आंकलन करने वाले तीन निदर्शों नामतः डूरनबोस और प्रुट, थोर्नवेट और मृदा पादप वायुमंडल जल (एस. पी.ए.डब्ल्यू.) का उपयोग किया गया है। इन तीनों पद्धतियों की परस्पर तुलना करने से यह पता चलता है कि वाष्पन -वाष्पोत्सर्जन के परिकलन के लिए अन्य दो पद्धतियों की अपेक्षा मृदा पादप वायुमंडल जल निदर्श अधिक बेहतर है। इस शोध-पत्र में निदर्श के निष्पादन के अच्छे आकलन में सहायक एम.बी.ई. (माध्य अभिनत त्रुटि), आर.एम.एस.ई. (वर्ग माध्य मूल त्रुटि) तथा टी-साँख्यिकी का भी पता लगाया है।

ABSTRACT. Actual evapotranspiration of wheat crop during different year from 1978-79 to 1992-93 was measured daily in Varanasi, Uttar Pradesh using lysimeter. In this study three evapotranspiration computing models namely Doorenbos and Pruitt, Thornthwaite and Soil Plant Atmosphere Water (SPAW) have been used. Comparisons of these three methods show that the SPAW model is better than the other two methods for evapotraspiration estimation. In the present study the MBE (Mean-Bias-Error), RMSE (Root Mean Square Error) and *t*-statistic have also been obtained for better evaluations of a model performance.

Key words – SPAW, Model, Evapotranspiration, Lysimeter.

1. Introduction

For the growth and development of vegetation, heat and moisture are the two most important requirements. In tropical country like India, water is a limiting factor for agricultural production in general and semi arid areas in particular. Though the rainfall is the main source of water that is available to crops, the actual availability to crops does not depend on rainfall alone, as it should be balanced against the amount due to evapotranspiration and other loses. Evapotranspiration of a crop is an important factor in estimating water requirement and planning the irrigation systems.

Measurement of evapotranspiration (ET) through lysimeters is more accurate and dependable (Mishra and Ahmed, 1987). Based on the need and other objectives, several researchers designed various kinds and sizes of lysimeters to measure the ET rates of different crops (Mellroy and Summer, 1961; Denmead and Shaw 1962).

Many methods (Thornthwaite 1948; Penman 1956; Shaw 1963; Baier and Robertson 1966; Ritchie 1972; Doorenbos and Pruitt 1975; Mukammal and Neumann 1977) have been developed to estimate the evapotranspiration and used for various purposes related to water consumption of crops. The other related works to determine the ET of different crops and trees are reported by Doorenbos and Kassam (1979), Sepaskhah and Kashefipour (1995) Ma *et al*. (1999) and Fuqin and Lyons (1999).

The objective of this study was to compare the relative performance of SPAW, Doorenbos's and Thronthwaite's models for AET predictions, which is used in other studies *viz*., agricultural drought, irrigation scheduling and determination of water stress during crop growing season.

2. Material and methods

2.1. *Study site and climate description*

Varanasi district is situated in the Indo-gangetic plain of India at an elevation of 75 m amsl and 25° 20′ latitude and 83° 03′ longitude having subtropical climate. The mean

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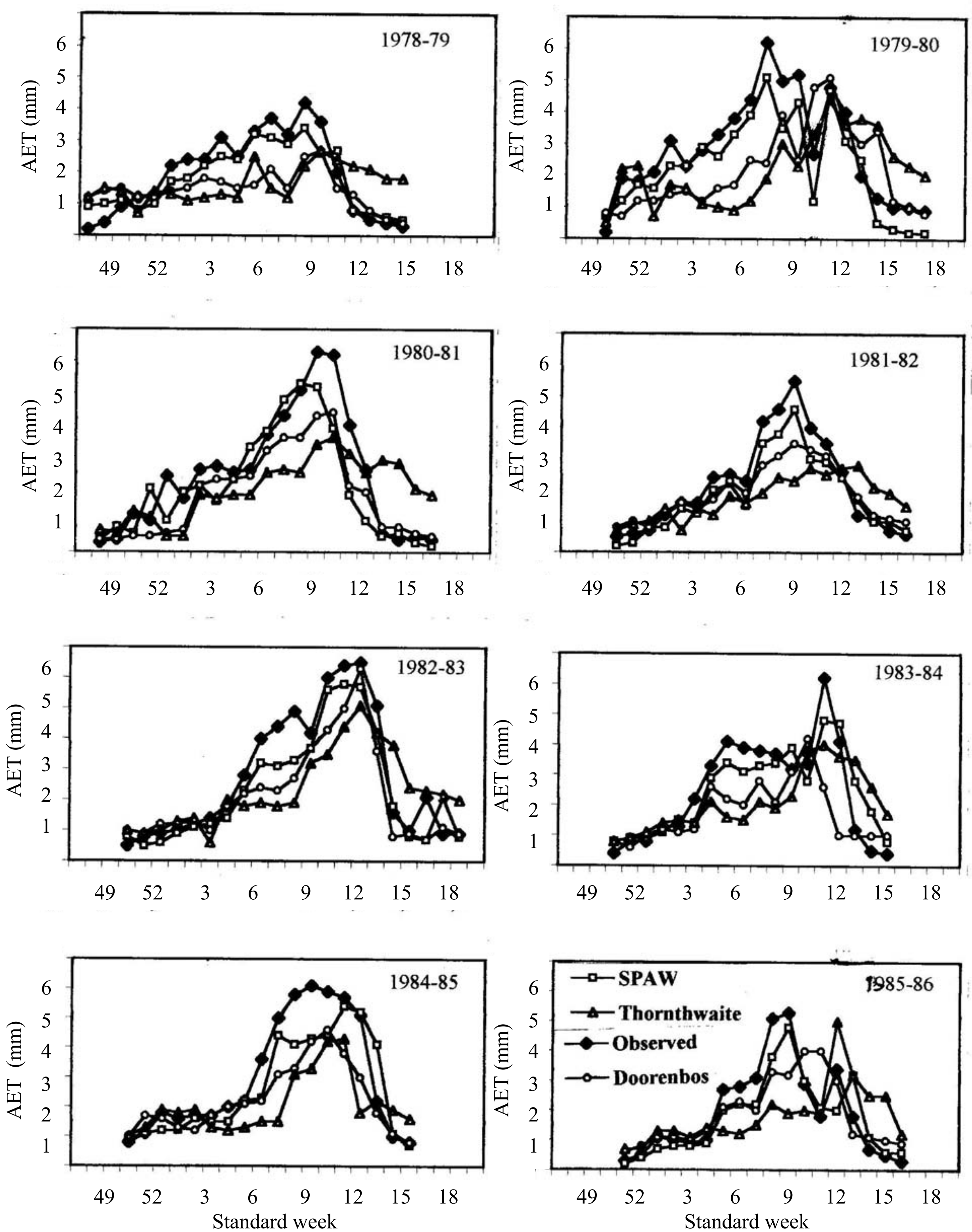

Fig 1. Weekly observed *vs.* estimated actual evapotranspiration during the different crop growth seasons (1978-79 to 1992-93)

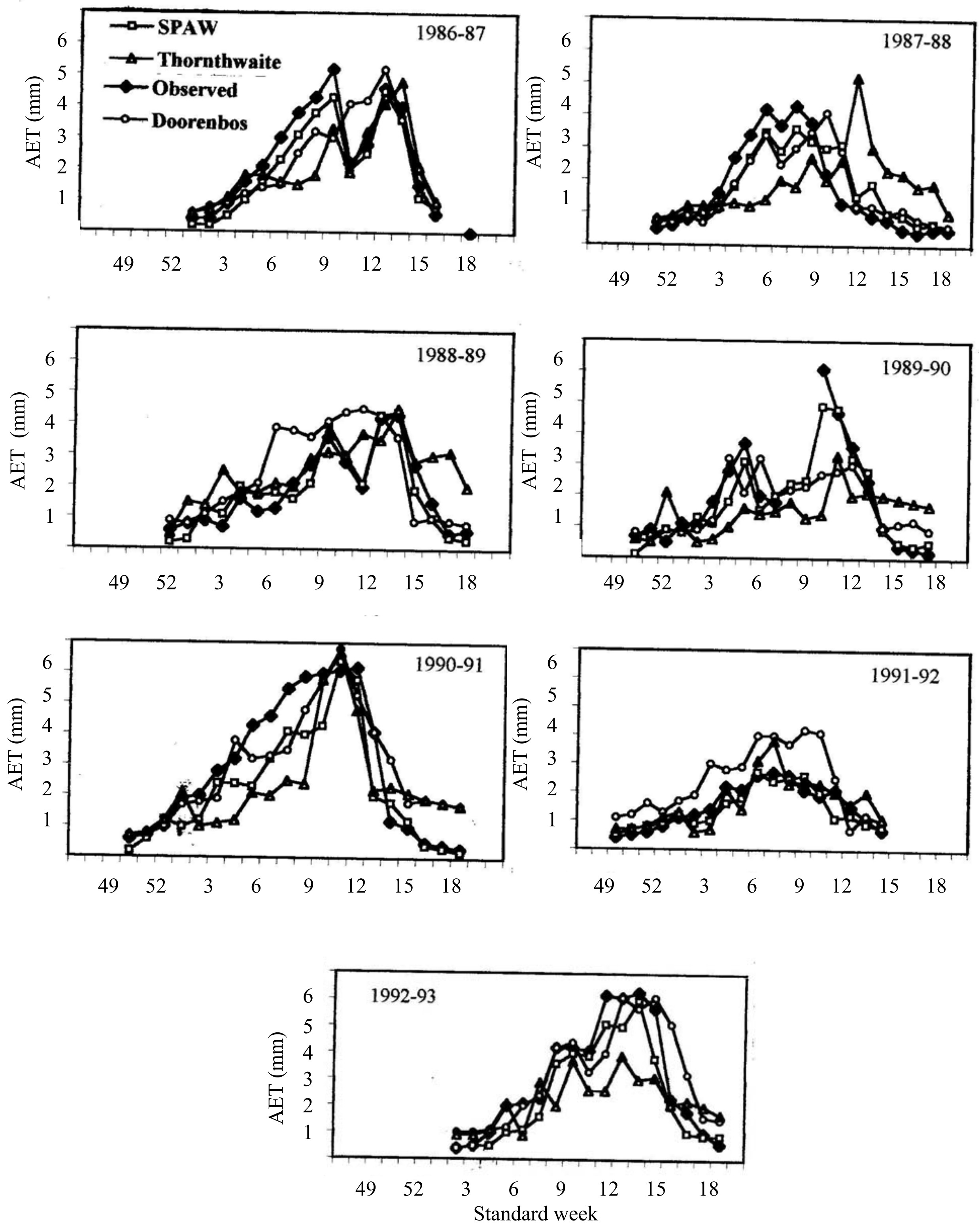

Fig. 1(*contd*). Weekly observed *vs.* estimated actual evapotranspiration during the different crop growth seasons (1978-79 to 1992-93) annual rainfall is about 1056 mm/year (± 172 SD) and the estimated annual potential evapotranspiration (PET) is approximately 1525 mm/year (Rao *et al*., 1971). The percentage distribution of annual rainfall is 88 percent from June to September (monsoon season) and 7.7 percent from October to February (winter season) 4.3 percent from March to May (summer season). The temperature begins to rise from February and reaches maximum by the end of May or early June. The average mean maximum temperature is 39.4° C during May-June. The coldest period of the year is in between the last week of December and first week of January. The average minimum temperature during December-January is 9.3° C. Wheat are planted in this region during November-December and harvested in April to May.

The soil of this area is alluvial in origin. The majority of soils in six-category system of USDA soil Taxonomy *i.e.* group Ustochrepts and other belongs to group Ustifluvents (Singh *et al*., 1989). Texture commonly are 15-30% Clay and 30 - 70% Sand. The profile are 1.2 meter deep (Jha, 1994).

2.2. *Data*

Gravimetric Lysimeter (Mechanical weighing) employed for daily ET data collection from Agricultural Farm of Institute of Agricultural Sciences, B.H.U., Varanasi. The lysimeters are designed, fabricated and installed by India Meteorological Department.

Lysimetric data are available from 1978-79 to 1992-93 crop season. Evapotranspiration of wheat crop was measured daily at 0730 hrs and weekly average were worked out. Since the crop was grown under irrigated conditions input data on irrigation type, date and amount are used. Input data on crop (canopy percentage, greenness, phenology *etc*.), soil (wilting point, field capacity, saturation limit, available water, sand, clay and silt percentage) and weather (temperature, rainfall and evaporation) were collected from the study site (Mall, 1996).

2.3. *SPAW model*

The Soil Plant Atmosphere Water (SPAW) model previously developed and reported (Sexton, 1994), is calibrated and validated at crop reporting district Varanasi by Mall (1996), is used in the present study. The SPAW model has been found to adequately describe, integrate and relate the plant-soil-atmosphere process as demonstrated by several research applications (De Jong and Zentner, 1985; Saxton *et al*., 1992; and Rathore *et al*., 1994).

The model computes a daily soil water profile budget by considering climatic input, crop growth characteristics and water-holding characteristics of the soil. Daily potential evapotranspiration (PET) value estimated by daily pan evaporation data reduced by pan coefficient is sequentially applied to relationships to separately consider intercepted water evaporation, soil water evaporation and plant transpiration. These components combine to provide an estimate of daily actual evapotranspiration (AET), which is withdrawn from the multilayered soil profile depending on the specified root pattern and water availability at that time. Infiltration (daily precipitation minus runoff) wets the soil profile layer's and soil water in all layers is redistributed according to tension and conductivity relationships uniquely specified for each layer.

2.4. *Doorenbos and Pruitt method*

The guidelines and methodology given by Doorenbos and Pruitt (1977) were followed for estimating AET. The reference crop ET is also known as potential evapotranspiration (PET), the Pan evaporation method was used to calculate PET in the present analysis.

The crop coefficient (K_c) relates the predicted PET to AET of a disease free and well-watered crop as

$$\text{AET} = K_c * \text{PET}$$

The values of K_c for the stages of crop development were taken from Doorenbos and Pruitt (1977).

2.5. *Thornthwaite's method*

The AET were computed using water balance procedure developed by Thornthwaite and Mather (1955). The soil moisture storage (SM) is determined by the following equation as suggested by Krishnan (1980)

$$\text{SM} = \text{AWHC} * e^{\text{Acc PWL / AWHC}}$$

Where AWHC is available water holding capacity, defined as amount of water present in the soil between field capacity and wilting point. Depending upon the soil characteristics the AWHC assumes different values. Accumulated PWL is the numerical values of potential water loss. It is determined by accumulating the negative differences of rainfall and PET, 'e' is the exponential term. The PET computed by Pan evaporation method has been used in the present study. After computing soil moisture storage during different periods, the AET is calculated.

2.6. *Statistical procedure for the evaluation of the models*

Root Mean Square Error (RMSE) and the Mean Bias Error (MBE) have been used to evaluate the model

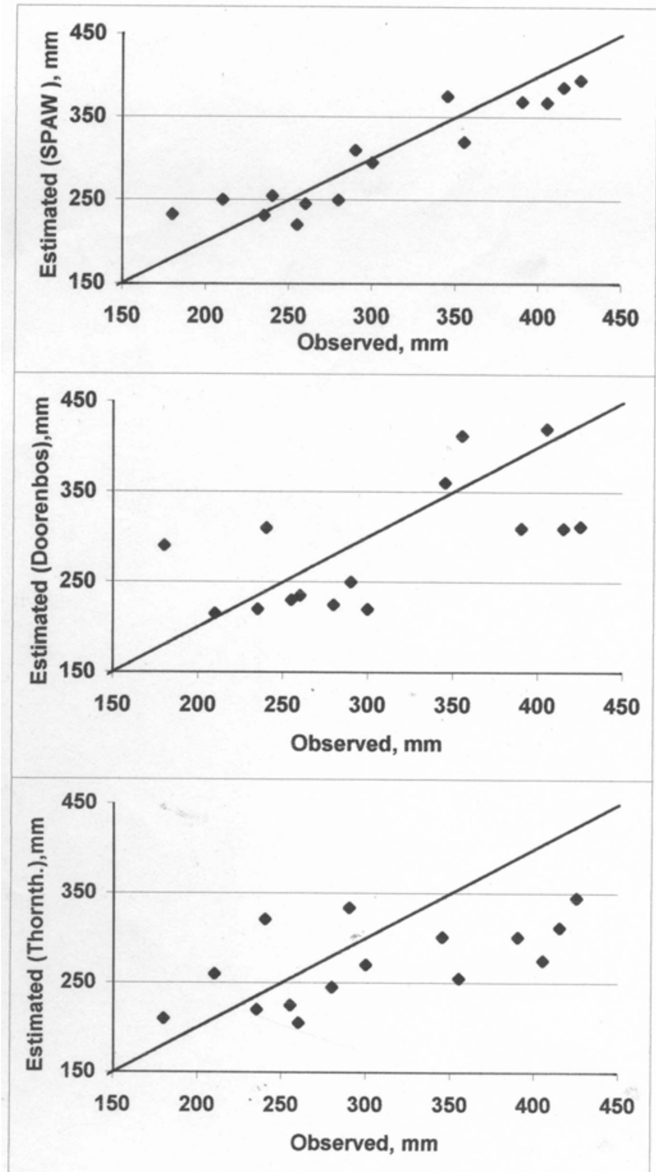

Fig. 2. Seasonal total observed *vs*. estimated actual evapotranspiration

performance. Jacovides and Kontoyiannis (1995) studied and concluded that the use of the RMSE and MBE in evaporation is not an adequate indicator of model performance. However, the *t*-statistic should be used in conjunction with these two indicators for better evaluation of a model's performance. The RMSE and MBE are defined as:

$$\text{RMSE} = \left(\frac{1}{N}\sum_{i=1}^{N} d_i^2\right)^{1/2}$$

$$\text{MBE} = \frac{1}{N} * \sum_{i=1}^{N} d_i$$

TABLE 1

Performance of models using regression constant a and b, R^2, RMSE and MBE errors and *t*-statistic

Model	a	b	R^2	MBE (mm)	RMSE (mm)	*t*-statistic	*t*-critical
SPAW	67.70	0.76	0.87	-5.6	29	0.72	2.98
Doorenbos	121.9	0.54	0.38	-17.7	65	1.06	2.98
Thornthwaite	164.1	0.35	0.37	-33.7	69	2.08	2.98

Where N is the number of data pairs and d_i is the difference between i^{th} predicted and i^{th} measured values.

The RMSE provides information on the short-term performance of a model by allowing a term by term comparison of the actual difference between the predicted value and the measured value. The smaller the RMSE value the better the model's performance. However, this test does not differentiate between under - and over - estimation.

The MBE provides information on the long-term performance of a model. A positive value gives the average amount of over-estimation in the estimated values and *vice versa*. The smaller the absolute value, the better the model performance. It is obvious that the RMSE and MBE statistical indicators, if not used in combination with one another, may not be adequate indicator of a model's performance.

In order to indicate whether the model's estimates are statistically significant at a particular confidence level, *t*-test was performed with RMSE and MBE. The *t*-statistic is defined (Kennedy and Neville, 1986; Walpole and Myers, 1989) through the MBE and RMSE errors, as:

$$t = \left[\frac{(N-1)MBE^2}{(RMSE^2 - MBE^2)} \right]^{1/2}$$

The *t*-statistic is chosen as an indicator for hypothesis testing *vs*. the coefficient of determination R^2 because it is more informative, as it combines both the MBE and RMSE values.

In the present study the level of significance is chosen to be α=0.005, so that the corresponding critical t value, as obtained from the statistical tables, is t=2.98, for N-1 degrees of freedom.

3. Results and discussion

Weekly estimated AET values are compared with weekly observed AET. It is apparent from the Fig. 1 that the observed AET values are comparable with estimated AET computed from SPAW, Doorenbos's and Thornthwaite's methods. From Fig. 1 it is clear that AET estimated by SPAW model is in good agreement with observed AET in all years' than other two methods namely Doorenbos's and Thornthwaite's. In early stage of the wheat crop, estimated AET from Doorenbos's and Thornthwaite models overestimate the observed values, but in flowering phase of crop observed values of AET always higher than the computed value by Doorenbos's and Thornthwaite's model.

Comparison between observed and estimated AET by Doorenbos's method shows nearly the same trend as Thornthwaite's method except in early and later stages of the wheat crop. In early and later stages, Doorenbos's method shows good agreement with observed AET values, but in crop development and flowering stage estimates from Doorenbos method is higher than the observed AET values except in few cases.

There is a good agreement between observed and estimated AET values by SPAW model from sowing to maturity of the wheat crop. The trend of the weekly-observed and estimated AET values by SPAW is nearly same during all the study years (1977-78 to 1992-93).

The seasonal total (from sowing to maturity) of observed and estimated AET values by three methods were also worked out. Fig. 2, present the comparison of observed and predicted AET values for the models of SPAW, Doorenbos's and Thornthwaite's respectively. The 1:1 line is also shown in Fig. 2, the relative performance of the models can also be observed from the scatter diagrams.

Furthermore, Table 1, shows the regression constants a and b, the coefficient of determination (R^2), MBE and RMSE errors, and the *t*-statistics, for the three models. Table 1, leads to conclusion in respect to the regression constants a and b and R^2 . Reviewing Fig. 2, in respects to scatter of points, it is clear that the SPAW model performed the best. From Table 1, it may be seen that the SPAW model performed better, as MBE and RMSE values are lower. The Doorenbos's model follows in model performance with respect to MBE and RMSE values while the Thornthwaite's model performance is poor.

SPAW model is based on detailed information on soil and crop, due to this model performance is better than other methods. The result shows that in the present time when fast computer and crop growth simulation models are available, the old models *viz*. Doorenbos and Thornthwaite may not be useful. A good calibrated and validated model, which estimates the daily values of different water balance components can be used for irrigation scheduling and water management.

4. Conclusion

The study has brought out useful features regarding evapotranspiration of wheat crop at Varanasi. SPAW model is better than other two methods of Doorenbos and Pruitt and Thornthwaite for AET estimation and also for water balance studies of wheat crop. The method has been tried in the present study only for wheat crop at Varanasi. However, the study has lot of potential and could be extended over other crops and regions where relevant data are available or could be gathered in future.

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