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COMPARISON STUDY OF PAN COEFFICIENT MODELS

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ABSTRACT

How much water should be applied is still the most important question to both farmers and engineers. Simple way to estimate water requirements is to predict crop evapotranspiration "ET". Thus, this study was conducted to help farmers in estimating water requirements according to reference evapotranspiration using simple measurement from pan. Reference evapotranspiration "ET_o" is often estimated from evaporation pan data as they recently are widely available than meteorologically-based "ET_o " estimates. Evaporation pan estimation of ET_o (= $K_p.E_{pan}$) reliant on determination of the pan coefficient "K_p" that depends on upwind fetch distance, wind run and relative humidity at the pan site. "K_p" estimation equations have been developed using regression techniques applied to either the table presented in FAO-56, or from the original data. The relative performance of the FAO-56 table and six different "K_p" equations are evaluated with respect to reproducing the original data table using the FAO-56 table as a standard. The study was conducted on Bostan region (West Nobaria sector, Egypt). In comparing the means, standard deviations, root mean squared errors and linear regression coefficients, four of the six equations reproduced the original data table with approximately the same accuracy as the FAO-56 table. A value of 0.679 could be used as pan coefficient for estimating of "ET_o" for Bostan area. As a conclusion, a map of "K_p" for different areas in Egypt could be created to help farmers in estimating the quantity of water that should be applied.

INTRODUCTION

The problem of food security is worsening by the rapid growth of population and therefore the demand for food. Irrigation can and should play an important role in raising and stabilizing food production especially in new areas due to lake of water quantities. Accurate reference vapotranspiration "ETo" data are essential to both water resources project planning and farm irrigation scheduling. As direct (i.e. lysimeter-based) field measurements of "ETo" are rarely available, "ETo" rates are generally estimated from theoretical predictive equations requiring meteorological data.About fifty methods are available for estimation of "ETo", those methods often yielding inconsistent results as their assumptions and meteorological data requirements differ **(Allen et al., 2001).** In many areas, the necessary meteorological data are lacking and simpler techniques are required. One of the most common and fairly reliable techniques for estimating "ETo" is from evaporation pan data when adjustments are made

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for the pan environment **(Kite and Droogers 2003)**. Evaporation rates from Class A pans are widely available throughout the world and can be used to estimate "ET_o" The ratio of "ET_o" to evaporation from class A pan is defined as the pan coefficient, "K_p", it's value ranges from 0.35 to 0.85 **(Ciolkosz and Albright 2000)**. A correction factor is essential that depends on the prevailing upwind fetch distance, average daily wind speed and relative humidity conditions associated with the sitting of the evaporation pan **(Doorenbos and Pruitt 1977)**. As well when developing their guideline "K_p" values in the FAO-24 publication from the lysimeter data, modified their original results by selecting ranges for the individual values of daily wind run and relative humidity while rounding all calculated "K_p" values up to the nearest 0.05 increment **(Allen and Pruitt 1991)**.

In Egypt, most of researchers estimated "ET_o" for different areas directly from models **(Abdel Hafez et al., 2001, Eid et al., 2001 and Hegazi et al., 2003)**.

Equations for "K_p" have been developed based on the FAO-56 table using linear and non-linear regression techniques. Thus this study aimed to modify those equations to estimate "K_p" values based on the field data rather than the FAO-56 data and compare them statistically. Also evaluate how evaporation pan estimates of "ET_o" compared with Penman-Monteith equations **(Snyder and Pruitt, 1992 and Ventura et al., 1999)**.

Nemours studies had been created to estimate "ET_o" using different techniques ranged from simple model to state of art ones like image processing, ANN, neurofuzzy… etc. **(De Silva et al., 2001, Bruton et al., 2000 and Odhiambo et al., 2001a,b)**.

MATERIALS AND METHODS

A hard copy of meteorological data (1995-2003) for the studied area Bostan region (West Nobaria sector, Egypt) was obtained from Central Metrology laboratory. Monthly average for needed data was used in calculations (9years×12months =108 point). As well field measurements were performed during 2003 season to test the devolved model. Figure 1 shows the metrology station and class "A" evaporation pan and schematic diagram for class A pan.

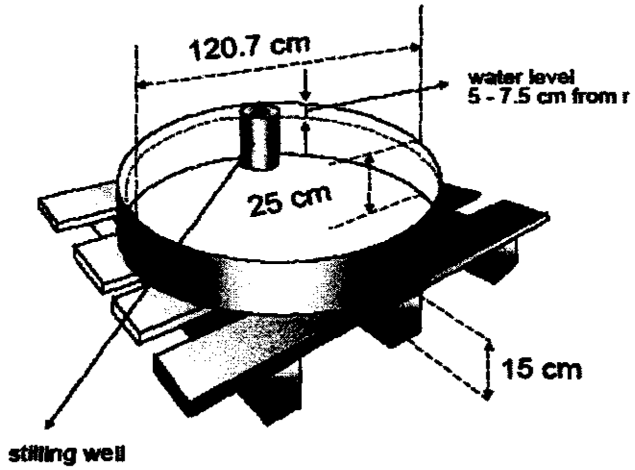

Figure (1): The metrology station and class "A" evaporation pan and schematic diagram for class A pan (after Allen et al., 1998).

Estimation of Pan Coefficient Equations

Several "K_p" equations have been developed in the past decades, including **Cuenca 1989, Allen and Pruitt 1991, Snyder 1992, Raghuwanshi and Wallender 1998 and Orang 1998.** The equations developed by Cuenca 1989, Snyder 1992, and Raghuwanshi and Wallender were based on the FAO-24 K_p table while those of Allen and Pruitt 1991 and Orang 1998 were developed using the original data table. **Orang 1998,** combined linear regression techniques similar to those used by Snyder with interpolation between fetch distances to develop a "K_p" equation which is also based on the original "K_p" table. The indicator regression approach used by Raghuwanshi and Wallender is not affected by the differences between the FAO-56 and original table values as it depends on categories rather than average, or particular values within a range.

The "K_p" equations are summarized below:

- Cuenca (1989):

$$K_p = 0.475 - 24\times10^{-4}\ U + 5.16\times 10^{-3}\ H + 1.18\times10^{-3}F - 1.6\times10^{-5}\ H^2 - 1.01\times10^{-6}\ F^2 - 8.0\times H^2U - 1.0\times10^{-8}H^2F \quad \textbf{(1)}$$

- Allen-Pruitt (1991):

$$K_p = 0.108 - 0.000331U + 0.0422\ln(F) + 0.1434\ln(H) - 0.00063\,[\ln(F)]^2\ln(H) \quad \textbf{(2)}$$

- Snyder (1992):

$$K_p = 0.482 - 0.000376\ U + 0.024\ \ln(F) + 0.0045\ H \quad \textbf{(3)}$$

- Modified Snyder (1992):

$$K_p = 0.5321 - 0.00030\ U + 0.0249\ \ln(F) + 0.0025\ H \quad \textbf{(4)}$$

- Orang (1998):

$$K_p = 0.51206 - 0.000321\ U + 0.002889\ H + 0.031886\ \ln(F) - 0.000107\ H \times \ln(F) \quad \textbf{(5)}$$

- Raghuwanshi and Wallender (R-W) (1998):

$$K_p = 0.5944 + 0.0242X1 - 0.0583X2 - 0.1333X3 - 0.2083X4 + 0.0812X5 + 0.1344X6 \quad \textbf{(6)}$$

Where:

- X1 = ln (F);
- X2,X3,X4 = 0 (if category is not present) or 1 (if present), corresponding to wind run categories of 175-425, 425-700 and >700 km/d, respectively,
- X5,X6 = 0 (if category is not present) or 1 (if present), corresponding to relative humidity categories of 40-70 and >70 %, respectively
- H = Daily mean Relative Humidity (%)
- U = Daily mean wind run, (km/day),and
- F = Fetch distance, (m). Defined by **Doorenbos and Pruitt 1977**.

According to ***Allen et al., 1998*** the FAO-56 equation is:

$$K_p = 0.87 + 1.119\ \ln(F) - 0.0157\ (\ln(86.4U))^2 - 0.0019\ (\ln(F))^2\ \ln(86.4U) + 0.013\ \ln(86.4U)\ \ln(H) - 0.000053\ \ln(864U)\ \ln(F)\ H \quad (7)$$

Where: U in (m/s)

A spread sheet was created to calculate "K_p" from the previous seven equations, then the relative performance evaluated for them in comparison to the published "K_p" equation based on their ability to reproduce the values in the original "K_p" table as well as their ability to estimate "ET_o" at studied area.

The performance of each equation is based on:

(a) mean and standard deviation of reproduced "K_p" values,
(b) comparison of linear coefficients of determination "R^2" and root mean squared errors (RMSE) between predicted "K_p" and meteorological data values, and
(c) comparison of predicted "ET_o" from reproduces "K_p" and published "ET_o" values for studied area.

Pan coefficient for published data was calculated from published "ET_o" and "ET_{pan}" for the same area (**FAO. Weather data 1992- 2003, Central Metrology Laboratory**).

RESULTS AND DISCUSSION

Using available meteorological data for studied area, "K_p" was reproduced from the previous equations. In addition, using published data for the same area (**Central Metrology Laboratory 1995-2002, Khalil 1997**) "K_p" was estimated.

Statistical description (mean, standard deviation SD, and coefficient of variance (CV%) were preformed for the reproduced "K_p" from all used equations and published one. Table 1 summarizes the statistics associated with the "K_p" values.

Table (1): K_p statistical description for different equations (n=108).

Equation	Mean	SD	CV%
1	0.729	0.017	2.264
2	0.779	0.016	2.103
3	0.657	0.012	1.831
4	0.576	0.011	1.897
5	0.696	0.011	1.552
6	0.634	0.0003	0.006
7	0.754	0.016	2.168
Published Data	0.679	0.011	1.627

Mean values of reproduced " K_p" ranged between 0.576±0.011 for eq. (4) to 0.779 ±0.016 for eq. (2). Although eq. (4) is a non linear as the others, the mean value was relatively smaller than the others, thus due to the wide range of data which it came from **(Snyder, 1992).** Also, the variation in reproduced "K_p" was small due to the small variation in used data.

The results of linear relations between reproduced "K_p" from the previous equations with published one are shown in figure (2).

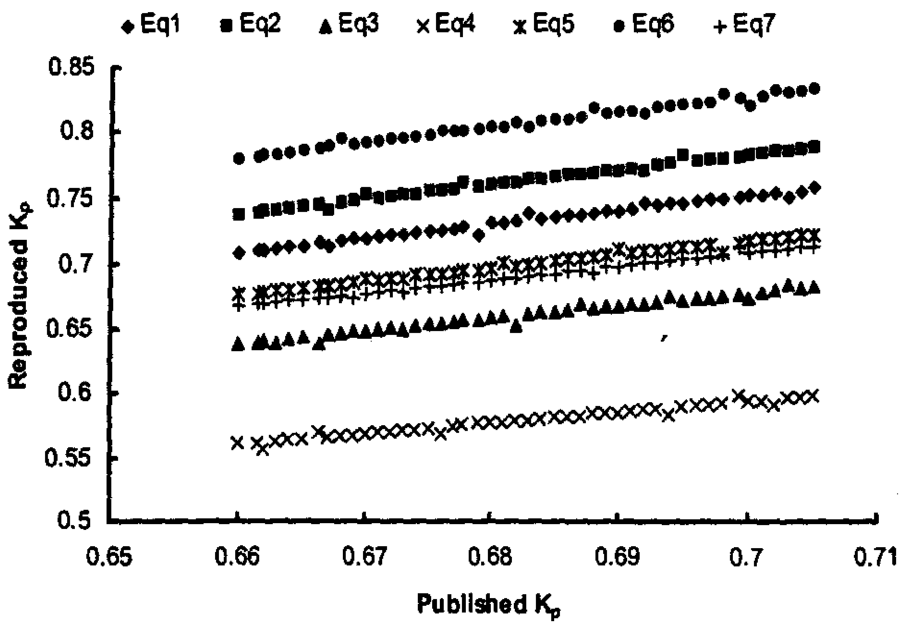

Figure (2): Linear relation between published "K_p" and reproduced "K_p".

To get the best related equation to published data, the coefficient of determination "R^2" and root means square error RMES were estimated from figure 2 assuming zero intercept. Reproduced K_p = Constant × Published K_p. The results are shown in table 2.

All equations had good relation with published data, the best reproduced "K_p " was from eq. (7).

Finally, reproduced "K_p" from all equations were used to estimate the reference evapotranspiration "ET_o " and compared with measured one for season 2003. Figure 3 shows "ET_o " for Bostan area during year 2003.It was noticed that values of "ET_o " in September for all equations had values greater than those in August, thus may be due to the values of wind speed and humidity.

Table 2: Linear coefficient, "R^2" and RMSE for reproduced "K_p".

Equation	Constant	R^2 (%)	RMSE
1	1.0744	88.44	0.012
2	1.1179	94.42	0.012
3	0.9688	98.61	0.0134
4	0.8493	95.42	0.012
5	1.0256	98.81	0.013
6	1.1812	92.53	0.001
7	1.0124	99.21	0.012

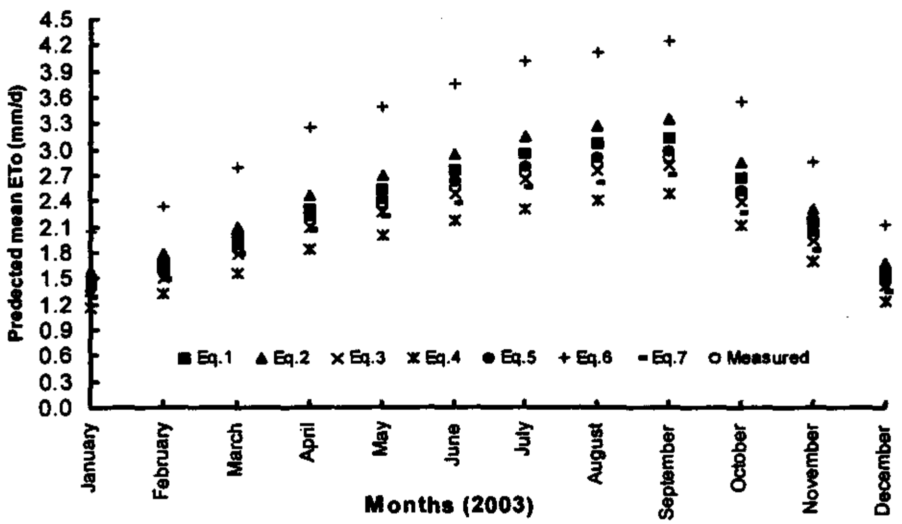

Figure 3: Predicted mean "ET_0" from different "K_p" and measured data for year 2003.

Form figure 3, eq. 6 gave over estimated result and eq. 4 under estimated result, thus due to the constants in table 2. To see the importance of good estimation of "K_p", for one feddan and cultivation season equal to 150 day, using eq. 2 or eq. 6 gave 204.5 and 647.3 m^3 more water than published respectively. In other side, using eq. 4 gave approximately 208.1 m^3 less water. Using eqs. 3, 5 and 7 gave almost the same amount of published data (±60m^3).

CONCLUSION AND RECOMMENDATIONS

The relative performance of commonly used non-linear and regression equations for prediction of evaporation pan coefficients, "K_p", needed for estimation of "ET_0" from evaporation pan data. Means, standard deviations, and coefficients of variation were determined for each model. With the exception of the R-W (Eq.6) and Modified Snyder (Eq.4) models, the predicted "ET_o" is approximately similar to measured data for Bostan area.

Satisfying, the value of 0.679 could be used for estimating "ET_o" for Bostan area from multiplication of this value by pan measurement. As a conclusion, a map of "K_p" for different areas in Egypt could be created to help farmers in estimating the quantity of water should be applied.

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الملخص العربى

دراسة مقارنة لعدة نماذج رياضية لحساب معامل وعاء البخر

د/محمد عادل السعداوي*

يعتمد تطوير منظومة الري على تقدير كمية مياه الري المفترض إضافتها الي التربة و كيفية حسابها، ويعتبرهذا هو السؤال الأكثر أهمية سواء للمزارعين أو المهندسين الزراعيين ، ولهذا الغرض قدمت هذه الدراسة طرق بسيطة لمساعدة شباب الخريجين حائزي الأراضي الجديدة بمنطقة البستان – غرب النوبارية- حيث يمكن تحديد كمية البخر نتح المرجعية باستخدام أجهزة قياس البخر فى منطقة الدراسة، وعادة ما تحدد كمية البخر نتح المرجعي من البيانات المناخية وقياس الأنخفاض فى وعاء البخر، حيث يقدر بحاصل ضرب الأنخفاض فى وعاء البخر مضروبا فى معامل الوعاء ويعتمد هذا المعامل على نوع ووضع الوعاء مع البيانات المناخيةوقد استخدمت في هذه الدراسة عدة نماذج رياضية تربط معامل الوعاء ببعض البيانات المناخية وقورنت النتائج المتحصل عليها من القيم المقاسة فى نفس المنطقة ،وقد تمت مقارنة تلك النتائج مع بعض النتائج السابقة لنفس منطقة الدراسة باستخدام الدلائل الإحصائية (المتوسط الحسابي، الانحراف المعياري، معامل الارتباط و الخطأ القياسي). أسفرت الدراسة على أن استخدام ٠,٦٧٩ كمعامل وعاء لمنطقة البستان يعطي نتائج متقاربة مع النتائج السابقة والنتائج القياسية. ونتيجة لهذه الدراسة يوصى بعمل خريطة لمعامل الوعاء لمصر للمساعدة في حسابات البخر نتح المرجعي وبالتالي حساب كميات مياة الري المطلوبة للمحصول بطريقة بسيطة.

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