EVALUATION OF CLASS A PAN COEFFICIENT MODELS FOR ESTIMATION OF CROP REFERENCE EVAPOTRANSPIRATION FOR GERIYO IRRIGATION SCHEME, YOLA, NIGERIA

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Abstract: Evapotranspiration and evaporation measurements are vital parameters for many agricultural activities such as water resource management and environmental studies. There are several models which can determine pan coefficient K_p, using wind speed, relative humidity and fetch length conditions. This work analyzed three exiting pan models to estimate K_p values for the study area. The, K_{pan} estimated by the models were statistically compared with the Penman-Monteith – FAO estimates. Monthly mean reference crop evapotranspiration (ET_0) was calculated according to the pan-ET_o model. The monthly mean value of K_p, determined by PMF-56 standard model for the study area was approximately 0.73. Similarly, the monthly mean ET_o was 10.85 mm/month. The results showed that estimated pan coefficients by Raghuwanshi-Wallender and Snyder models were not statistically accepted to be used in the pan-ET_o conversion method in this study. However, Orang model was found to be best for estimating the pan coefficient with an average value of 0.67, which was close to pan coefficient value estimated by the PMF-56 model. The reference evapotranspiration estimated using pan coefficient obtained from Orang model showed highest coefficient of determination (R^2) = 0.80 and agreement Index (D)= 0.94,lowest Mean Absolute Error (MAE) = 0.81, Root Mean Square Error (RMSE), = 0.08, and coefficient of efficiency (E) =85%. The results from the analysis showed that for estimation of ET_o, the most appropriate pan coefficient is calculated using the Orang model for the study area, which give almost nearer estimates.

Keywords: Reference evapotranspiration, pan evaporation, pan coefficient, pan coefficient models

Introduction

Evapotranspiration (ET) is a combination of two processes whereby water is lost from the soil surface by evaporation and by transpiration. Evaporation and transpiration are only varied by meteorological condition and growing stage. ET is the net water loss caused by evaporation of moisture from the soil surface and transpiration by vegetation. Evapotranspiration from the plants depends upon the meteorological factors, such as temperature, wind, humidity and sunshine hours (Werner, 1996). However, Reference crop evapotranspiration (ET_o) is the rate of evapotranspiration from a hypothetic crop with an assumed crop height (12 cm) and a fixed canopy resistance (70 m^2), and albedo (0.23), closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Allen *et al.*, 1998).

Over the years, many methods have been developed, revised, and recommended for estimation of Evapotranspiration (ET_o) for different types of weather data and climatic conditions. Jensen and Allen (2000) gave a good overview of the evolution of practical ET_o estimation methods including theoretical and empirical equations. The theoretical methods in common use include the original Penman method and its variations such as the FAO-24 Penman (Doorenbos and Pruitt, 1977). The Penman methods combine an energy balance with expressions that describe heat fluxes to derive a method to estimate vapor flux from a vegetated surface.

Monteith (1965) introduced modifications to the original Penman equation by incorporating a stomata resistance term resulting in the well-known Penman-Monteith equation. For a number of years, the FAO-24 Penman method was used as a standard equation for estimating ET_o when all weather data (temperature, humidity, wind, and solar radiation) were available. However, recent studies have revealed the FAO-24 Penman method to lack proven global validity and interest has shifted to the Penman-Monteith equation (Jensen *et al*., 1990; Allen *et al*., 1994; Allen *et al*., 1998; Walter *et al*. 2001). The Penman-Monteith equation has been extensively evaluated and compared with measured lysimeter ET under different climatic conditions. Jensen *et al*. (1990) stated that the Penman-Monteith method ranked as the best method for all climatic conditions. Allen *et al*. (1994) also showed that ETo computed using the Penman-Monteith equation yielded estimates close to measured ET_o values.

Following these studies, Allen *et al*., (1998) stated that the FAO-56 Penman-Monteith method (PMF-56) was adopted as the standard method for definition and computation of ET_o from a grass reference surface (cool season grass). Several other works have confirmed the validity of the Penman-Monteith equation (De Souza and Yoder, 1994; Chiew *et al*., 1995; Howell *et al*., 1997, 2000; Oliveria and Yoder, 2000; Irmak *et al*., 2003; Itenfisu, 2003).

Evaporation pan is an open pan of water that is subjected to the same climatic conditions with a growing plant, and from which water is evaporated because of the climatic conditions experienced (Smajastrla *et al*., 2000). Pan evaporation method usually gives reliable result if its calibration is made for different climatic regions (Jensen *et al*., 1990). Studies have revealed that pan evaporation method gives better results than other methods for estimation of ET_o. However, it is especially important to choose the pan coefficients with a high degree of accuracy concerning relative humidity and wind speed (Irmark *et al*., 2003).

Pan Coefficient (K_p) is the ratio of amount of evaporation from a large body of water to that measured in an evaporation pan. It depends on the exposure of the pan, wind speed, humidity and distance of the pan from homogeneous materials (Jensen, 1983). For computing pan coefficient (K_p), empirical methods are available, which is essentially a correction factor that depends on the prevailing upwind fetch distance, average daily wind speed and relative humidity conditions associated with the location of the pan evaporimeter (Doorenbos and Pruitt, 1977).

In earlier studies by Jensen *et al*. (1990), the ranking of these empirical methods varied depending on local calibration and conditions. Roderick *et al*. (2007) observed a decreasing trend for E_p mostly due to decreasing wind speed and some regional contributions from decreasing solar radiation. McVicar *et al*.

(2008) developed new grids for investigation of wind speed trend using an expanded anemometer network and stated that a negative trend of about -0.009 m s-1 per year was observed which resulted in declines in pan evaporation records. Roderick *et al.* (2009a, b) reported a decline in pan evaporation in terms of top-of atmosphere radiative forcing (−4.8 W m^2) due to doubled carbon dioxide (CO_2).

Doorenbos and Pruitt (1977) presented a table with K_p values ranging from 0.40 to 0.85 and for various ground cover types surrounding the pan. Sentelhas and Folegatti (2003) estimated ET_o values from class A Evaporation pan data using different models to determine pan coefficient(K_p) for a semi-arid region in Brazil and compared these values with those measured by a weighing lysimeter. They indicated that the best K_p models to estimate ET_o were Pereira *et al*. (1995) and Cuenca (1989) models. Gundekar *et al*. (2008) predicted ET_o values using K_p models for a semi-arid region in India. By comparing with ET_o calculated by the PMF-56 method, they found that the Snyder (1992) was the best K_p model for the semi-arid region. Thus, the aim of the study is to evaluate different class A pan coefficient models to ascertain the best pan coefficient model that may be adopted for optimum crop production in the study area.

Materials and Method

Area description and weather data

The Geriyo Irrigation Project is situated between 12º21' to 22º18' E and 9º16' to 19º19' N. The area is between 150 and 180 m above sea level within the savannah ecological zone of Nigeria.

The project area has two major seasons; the rainy and the dry season. The rainy season lasts from the beginning of May to the end of October, while the dry season lasts mainly from November to the end of April. The driest months are January and February when the average minimum relative humidity is 13%. This is mainly due to the prevalent dry and desiccating north-east trade winds. This season is favourable for the cultivation of many crops under irrigation as there is no rainfall during the period. The wettest months are August and September when depth of rainfall reaches up to 25% of total annual rainfall. The relative humidity of air rises in these months to about 81% from July to September. Temperatures in the area vary; the hottest month is April with monthly average maximum temperature of 39.7ºC, while the coldest months are December and January with minimum average temperatures of 16ºC (UBRBDA, 1977). Meteorological data which include: mean air temperature (T) in (°C), atmospheric relative humidity (RH) (%), pressure (P) (kPa), actual vapour pressure (Ea) in (kPa), net solar radiation (Rn) in (MJ m^{-2} day^{-1}), wind speed (U) in (m/s) and pan evaporation (Ep) (mm) for 15 years were collected from Upper Benue River Basin Development Authority (UBRDA) Meteorological station (Fig. 1) located in Yola, Adamawa state, Nigeria for the study.

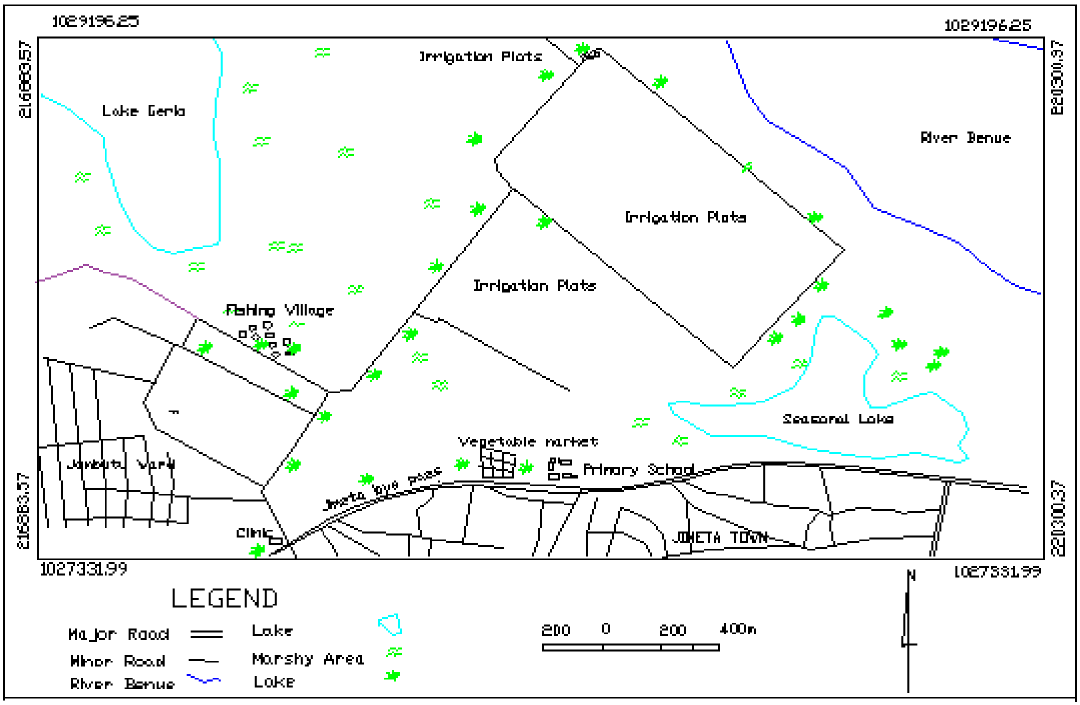

Fig. 1: Location of the study area

Pan coefficients and pan coefficient equations

One of the most popular methods for the indirect *ETo* estimation is through *Epan* measurements and *kp* coefficients adjusted to the surrounding environment and conditions (e.g. relative humidity, wind speed and windward side distance of green crop or a dry fallow).

The relationship between *ETo* and *Epan* is given by the following equation (Cuenca, 1989):

$$ET_o = K_p E_p \qquad 1$$

Where: E_{pan} is the pan evaporation (mm/day) and k_{pan} is the pan coefficient

Based on literature review, the values of k_{pan} cover a range between 0.3 and 1.1, and are proportional to relative humidity and inverse proportional to wind speed (Allen *et al.*, 1998; Gundekar *et al.*, 2008; Rahimikhoob, 2009). Significant efforts have been performed for the indirect estimation of *kp* by equations, that use meteorological data and the characteristics of the surrounding environment, for the case of Class-A pan evaporimeter (Pereira *et al.*, 1995)

There are several models for estimating pan coefficient (K_p), such as Cuenca model (1989), Allen and Pruitt (1991) model, Snyder (1992) model, modified Snyder model, Pereira model (1995), Raghuwanshi and Wallender (1998) model, Orang

(1998) model and Saswat (2017) model. In this study, Snyder (1992), Orang (1998) and Raghuwanshi and Wallender (1998) models were used.

Estimation of pan coefficient (K_p) using Raghuwanshi and Wallender model

Raghuwanshi and Wallender (1998) presented an equation for pan coefficient (K_p) using indicator regression approach. In this approach, the wind speed, relative humidity, and quantitative fetch length data were used. The equation can be expressed as;

$K_p = 0.5944 + 0.0242X_1 – 0.0583 X_2 – 0.1333 X_3 – 0.2083 X_4 + 0.0812 X_5 + 0.1344 X_6$ 2

Where:

X_1= In (F); X_2, X_3, X_4 = 0 if U < 175; X_2 =1 if 175 < U < 425; X_3 =1 if 425 < U < 700; X_4 =1 if U > 700; X_5, X_6 = 0 if RH < 40%; X_5 =1 if 40% < RH < 70%; X_6 =1 if RH > 70%;

U = Wind speed at a height of 2 m, (km/day), RH = Relative humidity (%); F = Fetch distance (m); X_{1-6} = Data variables

Estimation of pan coefficient (K_p) using Snyder model

Snyder (1992) stated that the equation recommended by Frevert *et al.* (1983) is composite for estimation of pan coefficient (K_p), and under the same climate and methods, the result is different by considering Allen and Pruitt (1991) approach. A simpler equation, which is a function of average daily relative humidity (RH), wind speed (U) at a height of 2 m and also the fetch distance from the pan in the direction of the wind blows (F) was considered as given below;

$K_p = 0.482 + (0.024 \text{ In } F) – (3.76 \times 0.00001 \times U) + (0.0045 \times RH)$ 3

Estimation of pan coefficient (K_p) using Orang model

Orang (1998) developed an equation for pan coefficient (K_p) using average daily relative humidity (RH), wind speed (U) at a height of 2 m, and fetch distance from the pan in the direction of the wind blows (F) expressed as;

$K_p = 0.51206 – (0.000321 \times U) + (0.002889 \times RH) + (0.031886 \times \text{In } F) – (0.000107 \times RH \times \text{In } F)$ 4

Estimation of reference crop evapotranspiration using standard PMF-56 Model

In this present study, the PMF-56 standard method (Allen *et al*. 1998) was used to test the accuracy of the ET_o estimated from K_p models given as;

$K_p = ET_oE_p$ 5

Where: $ET_o = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(Es-Ea)}{\Delta+\gamma(1+0.34U2)}$ 6

Where: ET_o = Reference crop evapotranspiration [mm/day]; R_n = Net radiation at the crop surface [MJ.m^2/day]; G = Soil heat flux density [MJ.m^2/day]; T =Mean of daily air temperature [°C]; U =Wind speed at 2 m height [m/s]; E_s = Saturation vapour pressure [kPa]; E_a = Actual vapour pressur, [kPa]; Δ = Slope of vapour pressure curve [Kpa.°C-1]; γ = Psychometric constant [Kpa.°C-1]; E_p = USWB class-A pan evaporation data [mm/day]

Estimation of reference crop evapotranspiration (ET_o)

Reference crop evapotranspiration (ET_o) was estimated usingthe pan evaporation method expressed as (Snyder 1992);

$ET_o = E_p \times K_p$ (mm/day) 7

Where: ET_o = the reference crop evapotranspiration (mm/day); E_p = the measured class A pan evaporation (mm/day); K_p = the pan coefficient obtained from the three models

The values of ET_o estimated by using each model was recorded and compared with the ET_o values obtained from PMF-56 model.

Statistical analysis

To evaluate the performance of the K_{pan} models in evapotranspiration estimates, using the class A pan method, several performance criteria were used including coefficient of determination (R^2), Mean Absolute Error (MAE). Root Mean Square Error (RMSE), Coefficient of Efficiency (E)and Agreement Index (D). The R^2 measures the degree to which two variables are linearly related and should optimally be one. The RMSE and Eare criteria of the residual standard deviation and should be as small as possible. These performance parameters were determined in line with Sree and Aruna (2017) expressed as;

$$R^2 = \frac{\{\sum_{i=1}^{n}(Xi-X)(Yi-Y)\}2}{\sum_{i=1}^{n}(Xi-X)2\sum_{i=1}^{n}Yi-Y)2} \quad 8$$

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n}(Xi-Yi)2}}{n} \quad 9$$

$$E = 1-\left[\frac{\sum_{i=1}^{n}(Xi-Y)2}{\sum_{i=1}^{n}(Xi-X)2}\right] \quad 10$$

$$MAE = \frac{\sum_{i=1}^{in}|Xi-Yi|}{n} \quad 11$$

$$D = 1-\left[\frac{\sum_{i=1}^{n}(Xi-Yi)2}{\sum_{i=1}^{n}(|Xi-X|+|Yi-X|)2}\right] \quad 12$$

Where: Xi and Yi are the ith observed and estimated values, respectively; $\bar{X}$and$\bar{Y}$are the average of Xi and Yi, and n is the total numbers of data

Results and Discussion

Estimation of monthly pan coefficient (K_{pan})

For calculating the monthly average of pan coefficient at first, the average of monthly ET_o and monthly average of pan evaporation were calculated. Then, by dividing these two values, the pan coefficient was obtained for PMF-56 which was used as the observed values. For Kpan models, these were obtained directly by averaging monthly values. The monthly Kpan values calculated using the three different pan models were compared with PMF-56 values for the study area and are presented in Table 1.

Table 1: Mean monthly pan coefficients obtained from empirical models

Month	Observed Values	Estimated Values		
	PMF-56 Model	Snyder Model	Orang Model	Ranghuwanshi-Wallender Model
January	0.75± 0.02	0.58± 0.01	0.72± 0,01	0.69± 0.03
February	0.76± 0.01	0.57± 0.06	0.68± 0.01	0.56± 0.04
March	0.70± 0.03	0.57± 0.04	0.67± 0.02	0.56± 0.06
April	0.71± 0.05	0.56± 0.08	0.61± 0.04	0.57± 0.02
May	0.69± 0.02	0.56± 0.06	0.60± 0.02	0.55± 0.09
June	0.73± 0.05	0.58± 0.08	0.70± 0.03	0.49± 0.08
July	0.77± 0.01	0.57± 1.03	0.63± 0.02	0.65± 2.05
August	0.75±0.02	0.58± 2.03	0.65± 0.02	0.58± 0.05
September	0.78± 0.03	0.58± 0.08	0.76± 0.03	0.56± 1.02
October	0.72± 0.04	0.58± 0.09	0.68± 0.05	0.63± 1.23
November	0.71± 0.02	0.58± 0.12	0.65± 0.01	0.57± 0.08
December	0.72± 0.02	0.58± 0.11	0.63± 0.02	0.60± 0.09
Mean	**0.73**	**0.57**	**0.67**	**0.58**

± Standard deviation

Table 1 indicates that k_p values vary in all the models. It is evident that there was a significant variation of the pan coefficient values among different months. From visual observation on the mean value of $K_p$estimated, a value of 0.67 was obtained from Orang model which gave the best agreement to the PMF-56, followed by Ranghuwanshi and Walleder and then Snyder model. However, it was observed that the $K_p$values estimated by Orang (1998) model were closewith the K_p values estimated by PMF-56. The equation given by Orang (1998) estimated near pan coefficient values followed by Ranghuwanshi and Wallender and Snydermodels, respectively even though they gave under estimated value of K_p.

The value of Pan Coefficient estimated bySnyder and Ranghuwanshi and Wallender modelsdid not agree with the standard PMF-56 model. The possible reason for this might be that the models used indicator regression approach in which the wind speed, relative humidity, and quantitative fetch length data were used which may not necessarily represent the factor affecting the pan coefficientvalue which is in line with Saswat *et al.* (2017).

Estimation of monthly evapotranspiration (ET_o)

Table 2 shows the values of the monthly ET_o values estimated using the E_{pan} data measured by USWB class-A pan evaporimeter and the K_p values estimated from the three models. The result shows that evapotranspiration vary throughout the months in all the models. It was observed that ET_o values are higher from the months of November to April in the dry season when the prevailing weather condition change due to increases in temperature and low relative humidity in the atmosphere. The values of the mean monthly ET_o estimated by PMF-56 with the corresponding values determined by pan models were compared. The results indicate that the mean monthly value of ET_o estimated by the Orang model was 10.64 mm/month which was closely matched with that of PMF-56 which had a value of 10.85 mm/month.

Table 2: Mean monthly estimated evapotranspiration (ET_o)

Month	Observed Values	Estimated Values		
	PMF-56 Model	**Snyder Model**	**Orang Model**	**Ranghuwanshi-Wallender Model**
January	13.85± 1.02	13.35± 2.05	13.35± 1.04	15.89± 2.06
February	17.12± 0.05	9.93± 1.09	10.98± 0.04	12.02± 1.06
March	18.57± 1.08	12.56± 2.55	11.68± 1.02	14.99± 2.96
April	18.08± 0.09	11.77± 1.08	12.87± 1.00	14.35± 1.44
May	11.42± 1,23	9.23± 0.06	9.89± 1.20	12.36± 2.00
June	7.12± 1.34	8.21± 1.22	8.78± 1.40	12.60± 1.08
July	5.90± 2.02	6.16± 1.05	6.70± 2.00	9.73± 2.05
August	4.48± 1.12	5.10± 1.08	5.46± 1.10	7.74± 1.08
Sept	4.47± 0.90	11.01± 0.09	11.96± 1.00	17.09± 0.07
October	5.72± 0.34	6.81± 2.09	7.40± 0.50	10.53± 0.97
Nov	11.00± 0.25	10.52± 9.05	11.42± 0.35	13.96± 2.04
Dec	12.43± 0.45	15.85± 0.08	17.21± 0.25	18.55± 0.99
Mean	**10.85**	**10.00**	**10.64**	**12.29**

± Standard deviation

Table 3: Comparison of ET_o estimated from the models using statiscal parameters

Statistical parameters	Snyder Model	Orang Model	Ranghuwanshi-Wallender Model
MAE	1.90	0.81	1.78
RMSE	0.16	0.08	0.15
R^2	0.43	0.80	0.32
E (%)	98.0	85.0	97.0
D	0.93	0.94	0.93

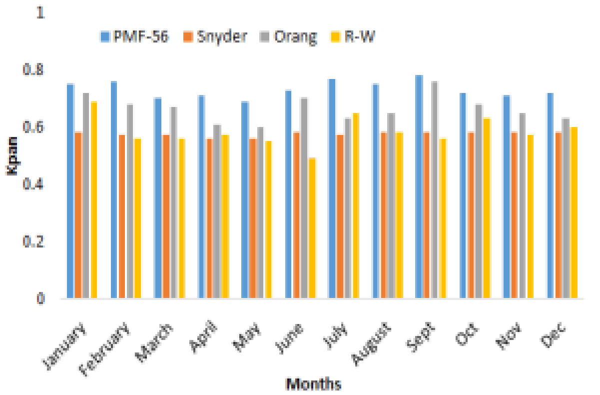

Fig. 2: Mean monthly K_{pan} calculated by PMF-56 and using the K_{pan} models

Performance evaluation of K_{pan}

To evaluate the performance of K_{pan} models in evapotranspiration estimates, using the class A pan method, performance criteria were used includingcoefficient of determination (R^2), Mean Absolute Error (MAE). Root Mean Square Error (RMSE), Coefficient of Efficiency (E) and Agreement Index (D) and this was done by using (Eq.8-12).The relatively high values of R^2 and least values of RMSE, MAE and E indicate that a strong correlation exists between PMF-56 and that particular pan model. Hence from Table 3, it was observed that Orang model gave the least value of error fits as the best model which is giving the estimation of evapotranspiration with reasonable degree of accuracy in the study area.The Orang model indicated the best adaptation to the PMF-56 model compared to the other models and optimum performance for the estimation of ET_o under the climatic environmental conditions of the study area (Fig. 2). Different predictive accuracy is observed among the K_p models, which may be due to different climatic-environmental conditions which is in line with Vassilis *et al.* (2012).

Conclusions

This study was conducted to evaluate three existing pan models, which are Snyder (1992), Raghuwanshi–Wallender (1998) and Orang (1998) Models. Using a 15 year class A pan daily evaporation data (E_{pan}) for Upper Benue River Basin Development Authority, meteorological station, Yola. K_{pan} values and calculation of reference evapotranspiration was carried out. K_{pan} values were calculated using the three pan models and are compared with K_{pan} values obtained from the Penman–MonteithFAO-56 Method. Thus, from the study, it can be concluded that;

i. K_{pan}values,and reference evapotranspiration (ET_o) values of the three different models were lower compared to PMF-56 reference evapotranspiration obtained.
ii. Based on visual observation and statically performance evaluation criteria, Orang (1998) model showed the best adaptation to PMF-56 method compared to the other models.
iii. For adequate performance for the estimation of reference evapotranspiration (ET_o), the most appropriate pan coefficient is calculated using the Orang model under the climatic conditions for Geriyo Irrigation Project.

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Conflict of Interest
Authors have declared that there is no conflict of interest reported in this work.

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