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Prediction of Evaporation from Algardabiya Reservoir

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Abstract: Evaporation has crucial role in water resources management. Recently many forms of the equation have been applied for estimating daily and monthly evaporation around the world. This paper presents the results of modeling the evaporation from Algardabiya Reservoir, Sirte, Libya. Three evaporation models namely Penman, Priestley-Taylor and Linacre were selected in order to predict the evaporation from the reservoir. The meteorological data were used as input to those selected models. The data were collected from a weather station located at the reservoir site. Statistical analyses were conducted to check the accuracy of the models predictions and the tests showed significant difference among the three models. only.

Key words: Modeling · Evaporation · Algardabiya Reservoir · Semi arid region · Assessment

INTRODUCTION

Evaporation Is One of the Major: components of the hydrologic cycle and it describes the loss of water from water bodies to the air over a long period to elucidate its relationship with annual precipitation [1]. This process is very significant in design of various water resources and irrigation system [2]. Estimation of evaporation rate is important in the study of hydrology, climate, agricultural water system and design and operation of irrigation s ystems [3-7].

Moreover hydrologists have long been aware of the tremendous quantity of water lost each year by evaporation. Meyers [9] has estimated this loss to be over $20.910^{6}\times$ mega-liter per year from lakes, reservoirs and ponds in the 17 western states alone in USA. In addition, Bauwer [10] mentioned in his study that evaporation from lakes, reservoirs, or other water surfaces varies from about 2 meters per year for dry, hot climates to 1 meter per year or less for humid, cool climates.

The rapid increase in both world population and per capita consumption of water due to the rising standards of living and levels of economic activity, have greatly intensified the demand for water all over the world [11, 12]. However, in the arid and semi arid regions, water shortage would be faced because of the limited water resources and high evaporation rates. Water is stored in reservoirs in order to regulate its availability over the year in water resources are not distributed uniformly throughout all regions. Thus, impounding reservoirs can give flexibility to meet water demand at various time of the year.

Many researchers have been investigating the suitability of various evaporation methods to estimate evaporation rates from water body in many climatic settings, rarely of which were in an arid setting. For instance, Rosenberry *et al*. [13] compared fifteen evaporation methods applied to a small mountain lake in the northeastern USA. Singh and Xu [14] compared thirteen mass-transfer methods applied to four sites in Ontario, Canada. Mosner and Aulenbach [15] compared four empirical methods of evaporation estimation for Lake Seminole, South Western Georgia and North Western Florida. Finch [16] estimated evaporation from water temperature in a period from 1956 to 1962. Winter *et al*. [17] compared an early identical suite of evaporation methods applied to a medium-sized lake in the continental climate of northern Minnesota. Rasmussen *et al*. [18] used seven empirical methods to estimate evaporation from nine lakes in Minnesota. The two studies that used Bowen-Ratio-Energy Budget (BREB) as the standard [13, 17] found that empirical methods that emphasize on assessment of energy ?uxes provide the best estimates of water loss to the atmosphere. Rankings of alternative methods for estimating evaporation varied among the three above-mentioned studies. In some cases, the robustness of a particular empirical method depended on the ambient climate [13].

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In arid and semi arid regions, high evaporation rate from open water bodies is considered as a serious problem in water resources management. The situation in Libya is typical of arid climate, with average annual rainfall of less than 100 mm and average annual evaporation is estimated to be 2500 mm which is much higher than the rainfall [19]. This highlights the seriousness of water loss problem from open water bodies, such as the Algardabiya Reservoir. Thus, the objectives of this study are to assess the estimates of evaporation obtained using three models against observed evaporation values for Algardabiya Reservoir which is located in semi arid region, in Libya.

MATERIALS AND METHODS

Study Area: This case study is concerned with Algardabiya Reservoirlocated in Sirte-Libya (31° 09' 30.71" N; 16° 40' 58.02" E, 50 m.a.s.l). The location of the reservoir is depicted in Figure 1.

The reservoir is an earth embankment reservoir located 10 km south east of the City of Sirte and adjacent to the coastal highway. The reservoir has a crest diameter of 887.66 m and an operating depth of 12.5 m, giving it a maximum volume of 6.9 million cubic meters. Water seepage from the reservoir is controlled by a geomembrane, which covers the entire inner slope and floor of the reservoir. A 400 mm diameter UPVC slotted drain runs completely around the inner toe of the reservoir and drains at an outlet chamber located adjacent to the reservoir spillway. The reservoir has an apical diameter of 887.66 m, bottom diameter of 794.080 m and a surface area of 593860 m^2 [20].

Observation Data: The meteorological data used to estimate evaporation of Algardibyia Reservoir was acquired from the Meteorological Observatory of Manmade River Authority (MRA), Sirte, Libya. The meteorological data includes maximum and minimum air temperature, relative humidity, wind speed and evaporation from class A pan. The evaporation from the pan is multiplied by a factor of 0.69 to get the actual evaporation from Algardabiya Reservoir [21]. Two years of daily evaporation records from 2000 to 2001 were used to study the evaporation from Algardabiya Reservoir. Table 1 shows the various meteorological data and their descriptive statistics.

Evaporation Estimation

Penman Model: Penman [22, 23] presented a theory and formula for the estimation of evaporation from meteorological data. He derived an equation to estimate evaporation from open water surfaces. The Penman equation is based on the Daltonion law.

The Penman formula can be written as follows [24,25]:

$$E_{PEN} = \frac{\Delta}{\Delta+\gamma} \times R_n + \frac{\gamma}{\Delta+\gamma} \times f(u)\ D \tag{1}$$

Where:

E_{PEN} is open water-evaporation (mm/d); Δ is the slope of the saturation vapor pressure curve (kPa/°C); R_n is net radiation (MJ/m^2/d); Δ is psychrometric coefficient (kPa/°C); f(u) is wind function; D = (e_s-e_a) is vapor pressure deficit (kPa); e_s is saturation vapor pressure (kPa); e_a is actual vapor pressure (kPa).

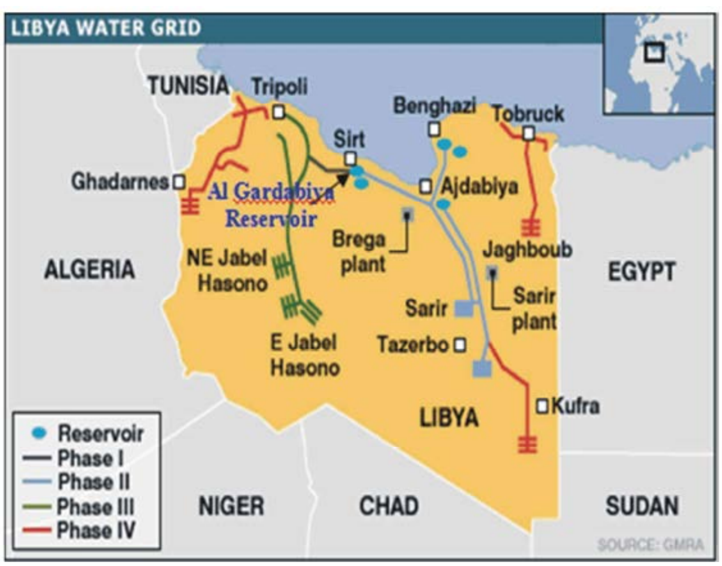

Fig. 1: Layout of Pipes and Algardabiya Reservoir for Manmade River Projects

The standardized calculation procedure for estimating the variables in Equation (1) from readily available data as recommended by Shuttleworth [26] and Allen *et al*. [2].

Priestly-Taylor model: Priestley and Taylor [27] proposed a simplified version of Penman's combination equation for use when surface areas are generally wet, which is a condition for evaporation. When the aerodynamic component is deleted and the energy component is multiplied by a coefficient (β =1.26) with either wet or under humid conditions in the surrounding area and for large bodies of water β was found to tend to 1.26 [28-30]. Therefore, it is possible to write Priestley and Taylor equation as:

$$E_{P-T} = \beta \left[\frac{\Delta}{\Delta + \gamma} \times \frac{R_n}{\lambda} \right] \tag{2}$$

where,

E_{P-T} is open water-evaporation (mm/d); β is Priestley- Taylor coefficient. Other notations have the same meaning and units as in Equation (1).

Linacre Model: In an effort to overcome the difficulty of using the Penman formula, Linacre [31] introduced a simplified Penman formula which requires only values of temperature, dew-point, elevation and latitude. The Linacre formula for estimating rate of evaporation in mm/day from a lake can be written as follows [31, 32]:

$$E = \frac{700(T_a + 0.006\,h)/(100 - L_a) + 15\,(T_a - T_d)}{80 - T_a} \tag{3}$$

where,

T_a, is the mean temperature of air (°C), h is the elevation (meters) above mean sea level, L_a is the latitude (degrees); and T_d is the mean dew-point temperature (°C).

Linacre [31] in his study presented an equation for estimating (T_a - T_d) and this equation can be written as,

$$(T_a - T_d) = 0.0023h + 0.37T_a + 0.53R + 0.35R_{ann} - 10.9 \tag{4}$$

where,

R is the monthly mean daily temperature (°C) and R_{ann} is the mean temperature of hottest and coldest months (°C).

Data Analyses: Performance of each model was tested by evaluating its statistical performance. Statistical tests were used in this study follow the suggestion by Willmott [33] and Jacovides and Kontoyiannis [35]. The statistical parameters used to test the statistical significance of the evaporation estimate, obtained using a given model are: Root Mean Square Error (RMSE), Mean Bias Error (MBE), the coefficient of determination (R^2) and t-statistic test (t). The following equations were used for the computation of the aforementioned parameters:

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} \left(E_{i,pred} - E_{i,obs} \right)^2 \right]^{1/2} \tag{5}$$

$$MBE = \frac{1}{n} \sum_{i=1}^{n} \left(E_{i,pred} - E_{i,obs} \right) \tag{6}$$

$$t = \left[\frac{(n-1)MBE^2}{RMSE^2 - MBE^2} \right]^{1/2} \tag{7}$$

where,

$Ei_{,obse}$ is observed evaporation, mm/day, $Ei_{,pred}$ is predicted evaporation, mm/day and n is number of data pairs.

RESULTS AND DISCUSSION

The Algardabiya Reservoir is characterized by a Mediterranean semi-arid climate, with warm and dry summers and mild winter conditions. In semi-arid zone the fluctuation of temperature is almost the same throughout the year (Figure 2). The maximum annual temperature at the reservoir site was 32.8°C in September, 2000 and 34.8°C in September, 2001 whereas the minimum annual was 7.5°C which occurred in January, 2000. The highest annual wind speed was 13.6 km/h occurred in April, 2000 and 14.1 km/h in April, 2001 whereas the lowest annual was 8.6 km/h which occurred in October, 2001. The humidity has been changed between 88 and 63%

Generally, the data collected and observed over the two years shows the same yearly trend in evaporation from the reservoir as show in Figure 2. The highest annual evaporation value from the reservoir is 9.4 mm/day which occurred in July, 2000 whereas the lowest annual value is 2.2 mm/day which occurred in January, 2000. In the absence of the solar radiation data for Algardabiya Reservoir, the temperature is taken as a measure for evaporation from the reservoir although the evaporation

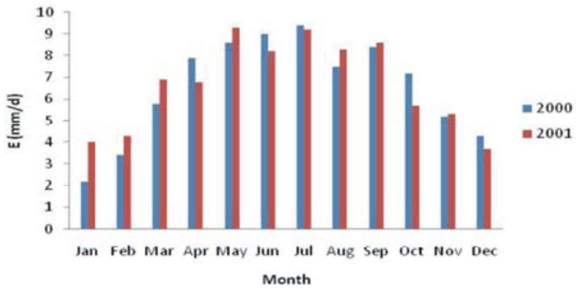

Fig. 2: Monthly average evaporation.

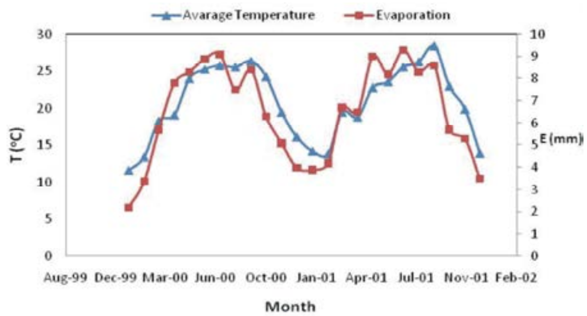

Fig. 3: Comparison Evaporation and air temperature during study period

is largely driven by solar radiation and the air temperature is considered as a secondary variable that governs the evaporation. However, the variation of air temperature and evaporation are not exactly the same as showen in Figure 2 shows but in most months the data showed that decreasing and increasing of air temperature has direct proportion on decreasing and increasing of evaporation.

The daily observed evaporations from the reservoir were accumulated to produce monthly averages for two consecutive years, 2000 and 2001 (Figure 3). The evaporation values indicate the E increased from January to July, in both years and then the values decreased exhibiting a bell-shape response with time of the year. During both years, the E increased from about 70 mm per month in January, to about 285 mm per month in July. In general, the evaporation in each month between May and September of 2001 was about 45 mm higher than the corresponding values in 2000, suggesting that 2001 was drier/warmer than 2000.

The three models coundered in this paper, expressed by Equations 1, 2 and 3 namely Penman, Priestley-Taylor and Linacre and all the models estimated the values of daily evaporation for 2000 and 2001. Another set of daily evaporation values was the observed evaporation for Algardabiya Reservoir for comparison. Various statistical parameters and a comparison of the results for 2000 and 2001 are presented in Table 1.

Monthly estimates of evaporation using the Penman model range from 4.1 to 12.1 mm, averaging 9 mm and total 6611 mm (Table 2) for the study period. The total difference in evaporation estimation between the Penman model and the observed evaporation was 1855 mm. This accumulated error between the Penman model and the observed evaporation was the highest of all the models, while, monthly estimates of evaporation using the Priestly- Taylor model range from 3.4 to 10.9 mm, averaging 7.9 mm and total 5784 mm for the study period. Difference in evaporation estimation, when compared with observed evaporation was 1028 mm. Monthly estimates of evaporation using the Linacre model range from 2 to 8.6 mm, averaging 5.6 mm and total 4079 mm for the study period. The Linacre model most closely agrees with the observed evaporation from reservoir; the total difference in evaporation was - 677 mm. Table 3 shows that the lowest annual error of evaporation estimates was by the Linacre model. This error was 11.3 and 17.1 percent annually for 2000 and 2001 respectively.

The average monthly evaporation is calculated by the selected models with the corresponding the observed evaporation in study area and the results are presented in Table 3 together with the percentage error of the estimates. The average monthly differences between the observed evaporation and the predicted models range from 11.3 to 33.9 percent in year 2000 and range from 17.1 to 44.1 percent in year 2001, with the best estimates obtained by Linacre model and the worst estimates by the Penman model for both years.

The performances of Penman, Priestley-Taylor and Linacre models against observed data were evaluated using RMSE, MBE, t-test and R^2 statistical parameters and the results are presented in Table 4. The RMSE values ranged from 1.15 to 2.95 mm/day and the smaller the RMSE value indicates a better the model performance according to Willmott [33] and Jacovides and Kontoyiannis [34]. The magnitudes of RMSE values were useful to identify model performance, but not the degree of under-or overestimation by individual model. From Table 4 RMSE values indicate that Linacre model consistently produced the most appropriate evaporation estimates for Algardabiya Reservoir. The Priestley-Taylor model follows in model performance with respect to RMSE values followed by the Penman model.

Table 1: Descriptive statistics of the evaporation models.

	2000						2001					
Method	Min (mm/d)	Max(mm/d)	Mean (mm/d)	SD	Skewness	Kutosis	Min (mm/d)	Max(mm/d)	Mean (mm/d)	SD	Skewness	Kutosis
Observed	1.0	14.5	6.4	3.0	0.3	-0.3	1.2	16.	6.6	3.0	0.66	0.30
Penman	2.1	16.0	8.6	3.2	0.1	-0.7	3.5	17.5	9.5	2.86	0.28	0.34
Priestly-Taylor	2.4	15.3	7.9	3.1	0.10	-0.8	3.0	16.9	7.9	2.9	0.65	0.28
Linacre	1.1	13.0	5.7	2.7	0.3	-0.5	1.3	13.0	5.5	2.3	0.65	0.24

Table 2: Comparison of observed evaporation rate to evaporation rate from predicted models

	Penman	Priestley-Taylor	Linacre	Observed
Monthly minimum average (mm/d)	4.1	3.4	2	2.2
Monthly maximum average (mm/d)	12.1	10.9	8.5	9.1
Monthly average (mm/d)	9.0	7.9	5.6	6.5
Total evaporation (mm)2000-2001	6611	5784	4079	4756
Total evaporation difference with observed (mm)	1855	1028	-677	n/a
Annual evaporation (mm/year) 2000-2001	3305.5	2892.0	2039.5	2378.0

Note: n/a, not applicable

Table 3: Monthly average predicted evaporation and errors between observed and models

Month	E_{obs} average Evap.(mm/d)	E_{Pen} average Evap.(mm/d)	Error (%)	$E_{P\text{-}T}$ average Evap.(mm/d)	Error (%)	E_{lic} average Evap.(mm/d)	Error (%)
January	2.2	4.1	86.4	3.4	54.5	2	-9.1
February	3.4	4.8	41.2	4.7	38.2	3	-11.8
March	5.7	7	22.8	6.8	19.3	4.9	-14.0
April	7.8	9.3	19.2	10.1	29.5	6.7	-14.1
May	8.3	10.5	26.5	10.5	26.5	7.6	-8.4
June	8.9	11	23.6	10.9	22.5	8.1	-9.0
July	9.1	11.4	25.3	10.5	15.4	8.5	-6.6
August	7.5	12.1	61.3	9.2	22.7	6.7	-10.7
September	8.4	11.3	34.5	10.3	22.6	7.3	-13.1
October	6.3	8.2	30.2	7.3	15.9	5.7	-9.5
November	5.1	7.1	39.2	6.2	21.6	4.3	-15.7
December	4	5.9	47.5	4.5	12.5	3.2	-20.0
Average annual, 2000	6.4	8.6	33.9	7.9	23.1	5.7	-11.3
January	3.9	6	53.8	5	28.2	3.6	-7.7
February	4.2	5.9	40.5	5.2	23.8	3.5	-16.7
March	6.7	8.9	32.8	8	19.4	6.2	-7.5
April	6.5	9.2	41.5	7.4	13.8	5.5	-15.4
May	9	11.4	26.7	10.8	20.0	7.3	-18.9
June	8.2	11.4	39.0	9.5	15.9	6.7	-18.3
July	9.1	11.9	30.8	10	9.9	7.2	-20.9
August	8.3	11.9	43.4	10.2	22.9	6.5	-21.7
September	8.6	11.6	34.9	10.3	19.8	6.8	-20.9
October	5.7	10	75.4	7.3	28.1	4.6	-19.3
November	5.3	9.4	77.4	6.6	24.5	4.3	-18.9
December	3.5	6.2	77.1	4.8	37.1	3.3	-5.7
Average annual, 2001	6.6	9.5	44.1	7.9	20.4	5.5	-17.1

Subscripts: Obs, Observed evaporation; Pen, Penman model; P-T, Priestley-Taylor model; Lic, Linacre model

Table 4: Statistic Analysis for the Model

Model	RMSE (mm/d)	MBE (mm/d)	R^2	t
Penman	2.95	2.54	0.75	45.8
Priestley-Taylor	1.68	1.41	0.9	41.2
Linacre	1.15	-0.93	0.96	36.5

The MBE values ranged from - 0.93 to 2.54 mm/day (Table 4). Positive values indicate overestimation of evaporation from the reservoir and vice versa and the absolute value is an indicator of model performance, i.e. the smaller the value the better is the performance. One out of the three MBE values was negative. The MBE values indicate that the overall evaporation estimates by Linacre model was under predictions while Penman and Priestley-Taylor models overestimate the evaporation from reservoir during study period. Based on the MBE values (Table 4) the Linacre model performed best since the MBE value is the lowest. This is followed by the Priestley-Taylor and Penman models.

Furthermore, Table 4 shows the coefficient of determination R^2 for the three models. For example the value of R^2 between the measured evaporation from the reservoir and the predicted evaporation using Penman, Priestley-Taylor and Linacre models are 0.75, 0.90 and 0.96 respectively. The results of the present study were found to be in agreement with the findings of Warnaka and Pochop [35]; Anyadike [36]; Andersen and Jobson [7]. So the Linacre model is the best predicted evaporation among selected models.

The result from the t-test (Table 4) shows the level of confidence between the above models. In the present study the level of significance was chosen to be $\alpha = 0.05$, so that the corresponding critical t value, as obtained from the statistical tables, is t = 2.576, for n-1 degrees of freedom [37]. For a model's estimates to be judged statistically significant at the 1-α confidence level, the calculated t value must be less than the critical t value. It is noted that there is no significant difference between these models. The Linacre model needed only the air temperature data to run the model, thus the model output is found in agreement with the measured evaporation from the reservoir and the predicted evaporations obtained from the application of other models (Penman, Priestley-Taylor) which require more data. This finding can help to overcome the shortage of data and make model application relatively easy. Several authors have pointed out that a disadvantage of Penman’s formula is the need for climate data which are not always available [38-41]. One way round this problem is to estimate the missing information, as discussed by Linacre, [32] ; or Penman's formula can be adapted for use where input data are scarce. Anyadike [36] in his study in West Africa reported that Linacre model is superior to Thornthwaite and Penman models in ease of use and accuracy. This supported the selection of using Linacre and other models to be tested for their accuracy in this study.

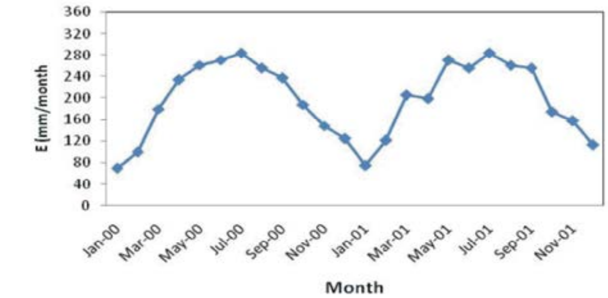

Fig. 4: The monthly observed evaporation values during study period.

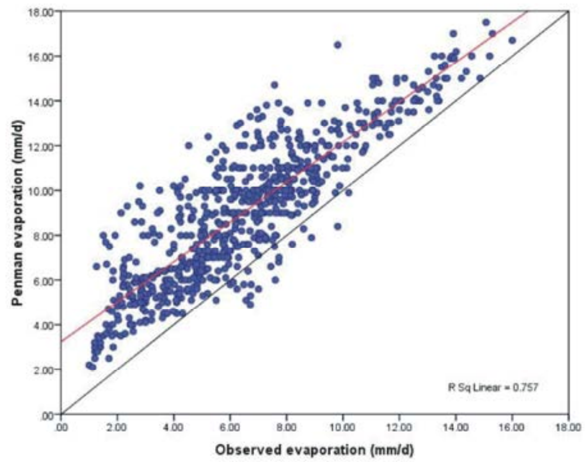

Fig. 5: Comparison of the Penman model and the observed evaporation

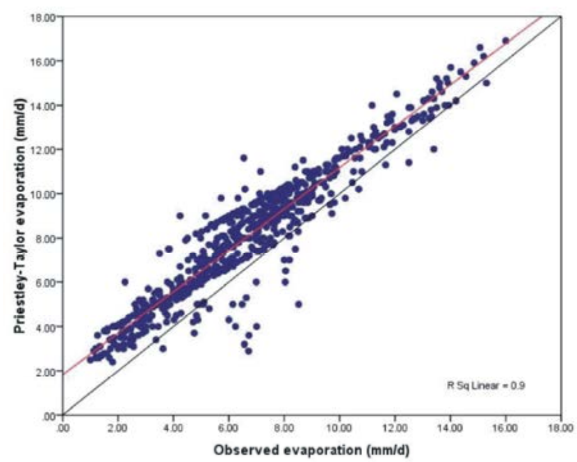

Fig. 6: Comparison of the Priestley-Taylor model and the observed evaporation

In order to examine the performance of the selected models, their estimation results are plotted versus the observed evaporation in Figures 4, 5 and 6. The scatter diagrams indicate that the model comparison plots are around 45° straight lines, thus implying that there are no

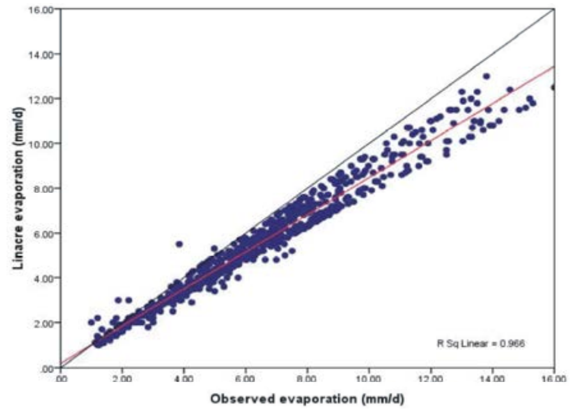

Fig. 7: Comparison of the Linacre model and the observed evaporation

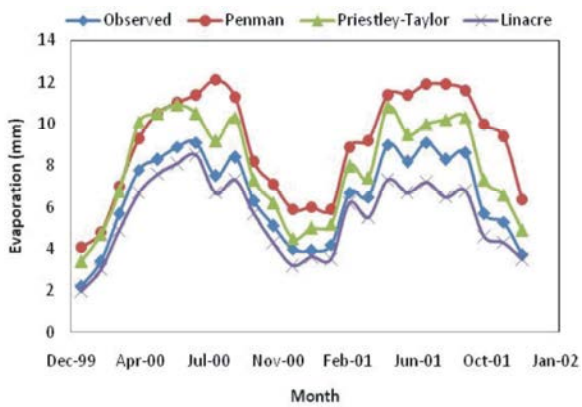

Fig. 8: Observed and predicted monthly evaporation for Algardabiya Reservoir

bias effects in the selected models in this paper. This obviously confirms that the prediction obtained from Linacre model is reasonable.

Figure 7 shows the monthly observed and predicted evaporation for Algardabiya Reservoir for the period from 2000 to 2001. Penman and Priestley-Taylor models overestimated the evaporation and their positive MBE confirms the overestimation. On the other hand, the Linacre model underestimated the evaporation and its negative MBE confirmed the underestimation (Table 4). Also, Figure 7 presented the behavior of the models including time lag and model accuracy where the total evaporation from reservoir for the studied period was found to be 4756 mm while the estimated evaporation using the Linacre model was 4079 mm. This shows that the Linacre model was underestimating the evaporation from Algardabiya Reservoir, while the other models are over estimated the evaporation from Algardabiya Reservoir, 6611 and 5784 mm using Penman and Priestley-Taylor models respectively. Penman estimates are higher than measured evaporation probably due to the slope of the wind coefficient which is the same as Penman derived for a rougher grass surface and not for a water surface.

CONCLUSIONS

The evaporation estimates obtained from three commonly used evaporation estimation models are compared to the observed evaporation, for Algardabiya Reservoir (Sirte-Libya). The selected models were the Penman, Priestley-Taylor and Linacre. Statistical measures such as the Root Mean Square error (RMSE), the Mean Bias Error (MBE) and coefficient of determination (R^2) were used to evaluate the performance of the three selected models. Based on the tests, the Linacre model produced the most reliable estimates, compared to the other models (Penman and Priestley-Taylor). Furthermore, the Linacre model is used whenever there is shortage of data with reference to air temperature such as for study area. Linacre model estimated the evaporation from Algardabiya Reservoir with a 14.2% in accuracy during the study period.

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