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Study on Simplified Model for Estimating Evaporation from Reservoirs

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Abstract: In this study, the Linacre evaporation model was tested for its accuracy using daily, weekly and monthly records. The records were collected from class A evaporation pan installed at Algardabiya Reservoir, Sirt, Libya. The records for three years were used to calibrate and validate the model. Statistical tests show that the model gives a reasonable accuracy. The errors in the model prediction are 5.8%, 8% and 8.5% for weekly, monthly and daily prediction respectively. Thus, the Linacre model can be used when the available meteorological data is limited (air temperature only) and for all types of record such as daily, weekly and monthly.

Key words: Prediction, evaporation, model, Reservoir, Algardabiya, arid region, testing

INTRODUCTION

Humans have collected water and contained it in one location and thereby creating a more reliable and constant water supply despite its natural variation. Reservoirs are replenished by many sources including stream flow, groundwater, snow, and/or rainfall. They are diminished by multiple losses including consumption and evaporation. These inputs and outputs are characteristic of hydroclimatology of a region (Stahl and Hisdal, 2004). Water storage is designed to meet multiple objectives such as hydropower, irrigation, potable supplies, fishing and recreation, and to reduce the risk of floods and droughts (UNESCO, 2006). Climate change is increasing pressure on existing reservoirs; the effects include reduced flows and levels in rivers and lakes, declining groundwater levels, and higher water temperatures (Marsalek *et al*., 2004). For example, the rate of evaporation is in excess of 2 m per year over most of Australia's landmass while the mean rainfall is less than 500 mm per year (Erick, 2007). On such a hot dry continent, it has been estimated that up to 95% of the rain which falls in Australia is re-evaporated and does not contribute to runoff. Harvested water is commonly stored in small storages and dams, but it is estimated that up to half of this may be lost due to evaporation (Craig *et al*., 2005). WMO (World Meteorological Organization) reported that three quarters of total input (inflow and over-lake rainfall) to Lake Victoria in USA are lost from the lake by evaporation, which experiences relatively humid conditions (WMO, 1985). In Lake Nasser in Egypt, where the Nile's water is stored, water loss due to evaporation are 3 meters in depth, or double that of Lake Victoria. Lake Nasser is located in a very arid area that experiences hot desert conditions. Meyers (1962) has estimated this lost to be over 20.9×10^{6} mega-liter per year from lakes, reservoirs, and ponds in the 17 western states alone in USA. In addition, Bauwer (1988) 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. Many methods for estimation of evaporation losses from free water surfaces were reported and it can be divided into several categories including: empirical methods (e.g. Kohler *et al*., 1955), water budget methods (e.g. Shuttleworth, 1988), energy budget methods (e.g. Anderson, 1954), mass-transfer methods (e.g. Harbeck, 1962); and combination methods (e.g. Penman, 1948).

Accurate and reliable measurement of evaporation for a long term has been investigated by researchers, while using both the direct and indirect methods of measurements. In the direct method of measurement, the observation from Class A Pan evaporimeter and eddy correlation techniques were used (Linsley *et al*., 1982), whereas in indirect methods, the evaporation is estimated from other meteorological variables like temperature, wind speed, relative humidity, solar radiation, etc.

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Study Area:

Libya is considered as one of the countries having limited renewable water resources because most parts of the country are either semi-arid or arid, with average annual rainfall of less than 100 mm and average potential annual evaporation of 2500 mm which is much higher than the rainfall (IMB, 1980).

The case study is concerning Algardabiya Reservoir (Sirt-Libya, 31º 09' 30.71" N; 16º 40' 58.02" E, 50 m.a.s.l) which is a part of the Manmade River Project as shown in Figure 1.

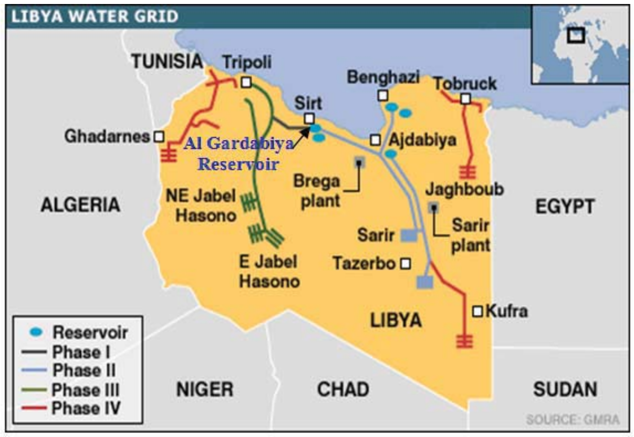

Fig. 1: Layout of Pipes and Algardabiya Reservoir for

Manmade River Project:

The reservoir is an earth embankment reservoir located 10 km south east of Sirt city 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 to 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 surface area is 593860 m^2 (McKenzie and Elsaleh, 1994).

Although some works have been published on evaporation from lakes and reservoirs, it appears that evaporation from Algardabiya Reservoir has not been measured before. Thus, the major goal of the present research is to determine evaporation from the reservoir and to compare several determination approaches: standard class-A pan measurements and evaporation models based on the mass transfer approaches and energy balance method.

Data Acquisition:

The meteorological data used to estimate evaporation of Algardibyia Reservoir were acquired from the Meteorological Observatory of the Great Manmade River Authority (GMRA), Sirt, Libya. The meteorological data include maximum and minimum air temperature, relative humidity, wind speed, and pan evaporation. The Meteorological Observatory is situated approximately at 31.16 N latitude and 16.68 E longitudes. Altitude of the place is approximately 50 m above mean sea level. Obviously, the climate of the region is semi arid, with hot dry summers and mild-cold winters. The data set consisted of three years of daily records from 2004 to 2006. Table 1 shows the various meteorological data and their descriptive statistics.

Table1: Descriptive statistics of the daily meteorological data

Variables*	Units	Minimum	Maximum	Mean	SD	CV (SD/mean)	CR with EVP
MaxTemp	Cº	10	44	25.70	6.88	0.27	0.91
MinTemp	Cº	4	32	14.97	5.57	0.37	0.89
AvTemp	Cº	8.5	36	20.18	5.80	0.29	0.98
WS	Km/hr	5	50	14.63	7.78	0.53	0.16
RH	%	30	95	60.82	12.28	0.20	0.77
EVP	mm/d	3.7	15.2	7.66	2.29	0.30	1

* MaxTemp is maximum air temperature, MinTemp is minimum air temperature, AvTemp is average air temperature, WS wind speed, RH is relative humidity, EVP pan evaporation, CV is variation coefficient, and CR is correlation

Applied Model:

There are many models to estimate evaporation from an open water body, also known as lake evaporation and mentioned in this study as reservoir evaporation and some of these models are the water budget method, energy budget method, eddy correlation method, mass-transfer method, the Penman method, combination equation and the pan method (Dingman, 1994 and Brutsaert, 1982). The main disadvantage for most of these methods is that they require several meteorological data, such as air temperature, wind speed, humidity, and solar radiation to be measured or estimated at the reservoir. Mistake in the measurements of solar radiation and humidity will produce four time error in estimated value of the evaporation compared with same mistake made in the measurements of wind speed and temperature (Meyer *et al*., 1989; Linacre, 1993). For instance, a 30% error in the wind value creates an error of only 5% in the estimated evaporation depth (Linacre, 1993). So, accurate wind speed record may not be essential. Consequently, the pan method is the only existing method that does not require site specific measurements and is, therefore, commonly used to estimate evaporation from lake and reservoir (Doorenbos and Pruitt, 1977; Winter, 1981; Farnsworth *et al*., 1982; Linsley *et al*., 1982; Allen *et al*., 1998).

Many of the models are not applicable to the case study due to unavailable data. As a result, only one model, which is the Linacre model (Linacre, 1977) has been applied to the case study and the estimated value obtained using the model is compared with the measured data obtained from the Class A pan.

Pan Method:

Evaporation is regularly measured at a weather station nearby Algardabiya Reservoir using a class A evaporation pan during 2004 to 2006. Each day an observer fills the evaporation pan with water to a predefined level. The change in the water level observed the next day is due to both evaporation and rainfall. The evaporation rate is calculated by adjusting the change in water level considering recorded rainfall depth taken from rain gauge.

The method of determining the reservoir evaporation using the pan evaporation pan, E_p is commonly considered in regions where the input climate variables are not available. Annual lake evaporation estimates are obtained by multiplying the annual pan data by an appropriate coefficient, K_p as fallows:

$$E = K_P E_P \tag{1}$$

where E is the amount of evaporation from reservoir in unit of depth, K_P is a pan coefficient, and E_P is the amount of evaporation from class A pan in unit of depth.

Linacre Model:

In an effort to overcome the difficulty of using the Penman formula, Linacre (1977) introduced a simplified Penman formula which requires only values of temperature, dew-point, elevation and latitude**.**

Computational Procedure:

The Penman formula for estimating the rate of evaporation from an open water surface is written as:

$$E = [R_n + \frac{\gamma}{\Delta}[0.35S(Z + u/100)]/[1 + \frac{\gamma}{\Delta}] \tag{2}$$

Where E is evaporation rate in mm/day, Δ is the slope of the curve of saturation vapour pressure with respect to temperature; γ is the psychrometric constant; S is the saturation deficit; Z is a surface parameter, being 0.5 for open water; u is the wind speed, R_n is the net radiation in evaporation units, and which may be expressed as:

$$R_n = \left[R_s(1-\alpha) - R_{nlw}\right]/L \tag{3}$$

where α is the albedo of the evaporating surface and L is the latent heat of evaporation. R_s and R_{nlw}, are the short and net long wave radiation respectively.

The aerodynamic component, E_a, has been evaluated from the following expression (Linacre, 1977):

$$LE = (R_n + \rho c\, S/\Delta r_a)/(1 + \gamma/\Delta) \tag{4}$$

where LE is the evaporation rate cal cm^{-2} s^{-1}, ρ is the density of air, c is the specific heat of air, S is the average saturation-deficit of the air in mbar, r_a is the diffusion resistance between water and air in $s.cm^{-1}$ and Δ is the slope of the curve of saturation vapour pressure with respect to temperature

Linacre (1977) used equivalent expression to replace R_n, S/Δ and $(1+\gamma/\Delta)$ in terms of temperature, latitude and elevation. Also, he introduced an intermediate value of 1.2 s. cm^{-1} as being representative of r_a. ρ and c are taken as constants. Rearranging these values, and assuming the albedo of an open water surface to be 0.05, he obtained the fallowing expression for the rate of evaporation in mm/day from a lake, (E) as:

$$E = \frac{700(T_a + 0.006h)/(100 - L) + 15(T_a - T_d)}{80 - T_a} \quad (5)$$

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

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

$$(T_a - T_d) = 0.0023\,h + 0.37\,T_a + 0.53\,R + 0.35\,R_{ann} - 10.9 \quad (6)$$

where R is monthly mean daily range of temperatures and R_{ann} is mean temperatures of hottest and coldest month

Model Testing:

Performance of the Linacre model was studied by evaluating its statistical performance. The statistical performances include the computation of the coefficient of determination (R^2), the mean square error (MSE) and the mean absolute relative error (MARE). The output of the model was compared with observed pan evaporation data. Coefficient of determination (R^2) measures the degree to which two variables are linearly related. MSE and MARE provide different types of information about the predictive capabilities of the model. The MSE measures the goodness-of-fit relevant to high evaporation values whereas the MARE yields a more balanced perspective of the goodness-of-fit at moderate evaporation (Kisi, 2006). The MSE and MARE are defined as:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(Ei_{observed} - Ei_{predicted})^2 \quad (7)$$

$$MARE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{Ei_{observed} - Ei_{predicted}}{Ei_{observed}}\right|100 \quad (8)$$

where, $Ei_{observed}$ is the observed pan evaporation, mm/day, $Ei_{predicted}$ is predicted evaporation, mm/day , and N is number of data used.

RESULT AND DISCUSSION

The Algardabiya Reservoir (Figure 1) is characterized by a Mediterranean semi-arid climate, with warm and dry summers and mild winter conditions. Typical value of annual rainfall at the reservoir site is about 170 mm. Most of the rainfalls occur during winter season. Generally, the recorded data for three years show the same yearly trend for E_p, (Figure 2). The highest monthly E_p is 11.2 mm it is occurred in August and September, 2006 whereas the lowest monthly E_p is 4.8 mm it is occurred in January, 2004. The highest E_p in 2006 was a result of the highest temperature (44°C) which was recorded in August. The last column of Table1 represents the correlation (CR) between the input variables such as air temperature (Ta), wind speed (WS), and relative humidity (RH) and the evaporation (EVP) from class A pan as an output variable. Based on coefficient between air temperature and evaporation was found to be 0.98 and this value is the highest among the tested input variables. Since the air temperature is the main variable in the Linacre model, so the model can be selected to predict the evaporation. This is supported by the above finding.

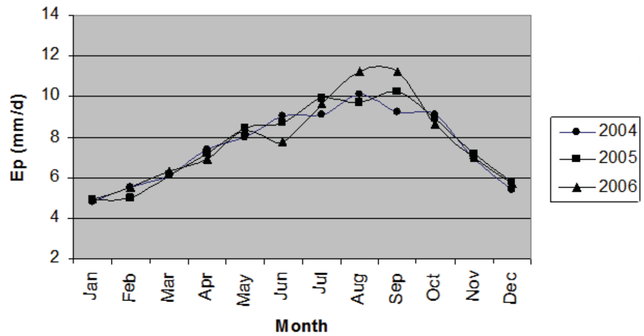

Fig. 2: Monthly evolution of the observed monthly pan evaporation, E_p, at the site of Algardabiya reservoir over the period 2004-2006

The performance of Linacre model was tested using MSE, MARE and R^2 for the daily, weekly and monthly values and the results are shown in Table 2. The results show that the Linacre model gave the best performance in weekly prediction test. The second best performance is monthly prediction. For Linacre weekly prediction the MSE is 0.21 $mm^2\ d^{-1}$, MARE is 6.3 % and coefficient of determination (R^2) is 0.996. For monthly prediction using the Linacre model the MSE is 0.44 $mm^2\ d^{-1}$, MARE is 8.89 % and coefficient of determination (R^2) is 0.992. However, the Linacre daily prediction has higher values of MSE and MARE which are 0.53 $mm^2\ d^{-1}$ and 9.11 % respectively and Coefficient of determination (R^2) is 0.979. Although the Linacre model needs only air temperature data to run the model, the model output is found to be in good agreement with historical record in all periods (daily, weekly and monthly). This finding can help to overcome the shortage of data and facilitate the model application.

Table 2: Statistic Analysis for the Model

Duration	MSE (mm^2d^{-1})	MARE (%)	R^2
Daily	0.53	9.1	0.979
Weekly	0.21	6.30	0.996
Monthly	0.44	8.9	0.992

The evaporation estimates of all duration are shown in Figures 3 to 5 in the form of scatter plots. Scattered plots of Linacre model (daily, weekly and monthly) are plotted against observed pan evaporation. It is obviously confirmed that prediction obtained from Linacre model is in agreement with the observed evaporation.

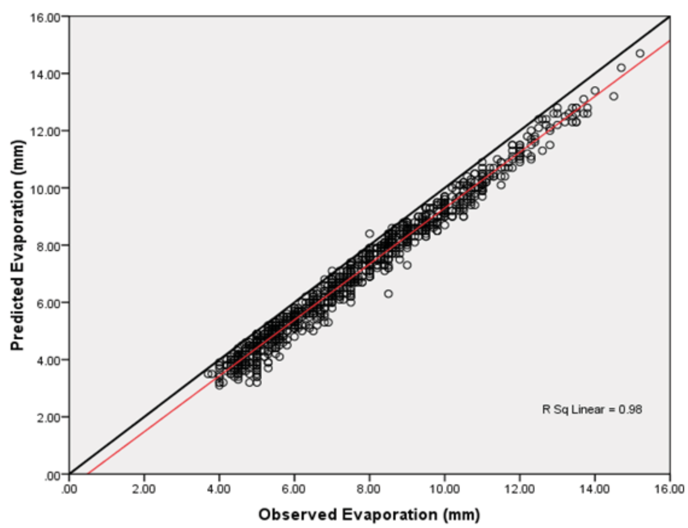

Fig. 3: Scattering for Linacre daily model prediction

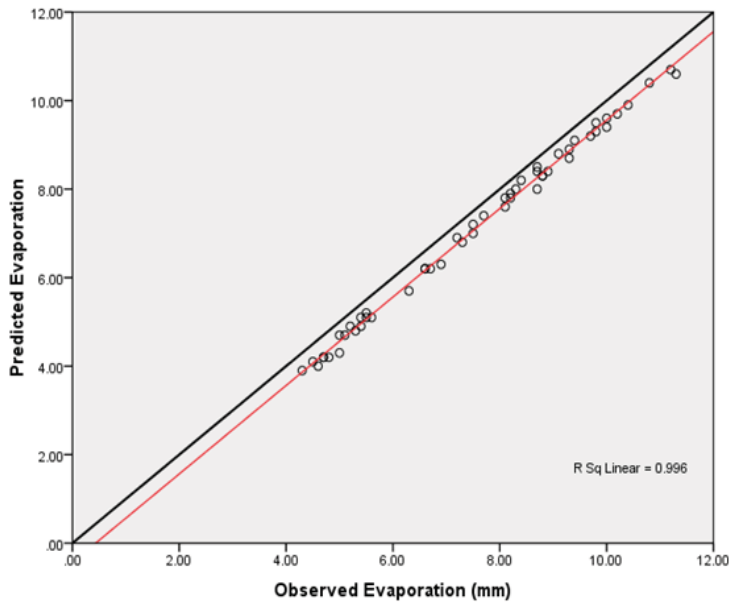

Fig. 4: Scattering for Linacre weekly model prediction

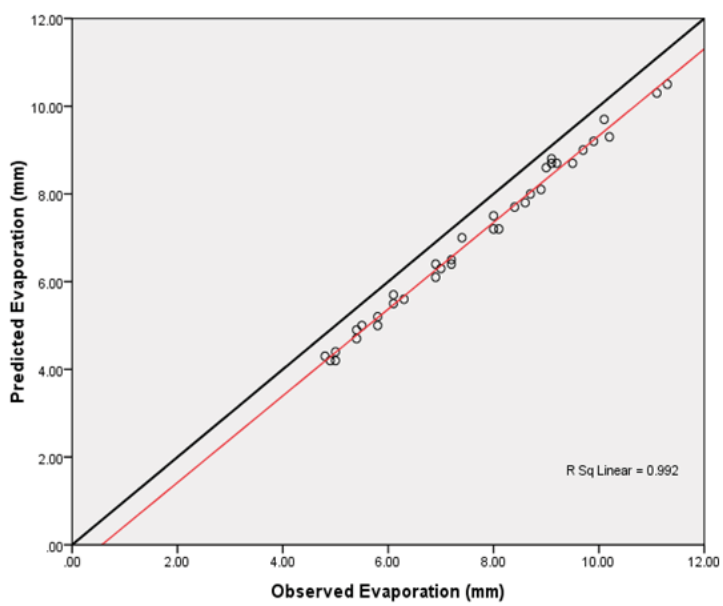

Fig. 5: Scattering for Linacre monthly model prediction

The model predictions were compared with ± 10% error and most of the predictions were found within the above range and only 3.5%, 5.8% and 25% of the predicted evaporation in daily, weekly and monthly were found outside -10% error as shown in Figures 6, 7 and 8.

To confirm the overall performance of the tested Linacre model, the time series for the observed and predicted evaporation (daily, weekly and monthly) were plotted together as shown in Figures 9, 10 and 11.

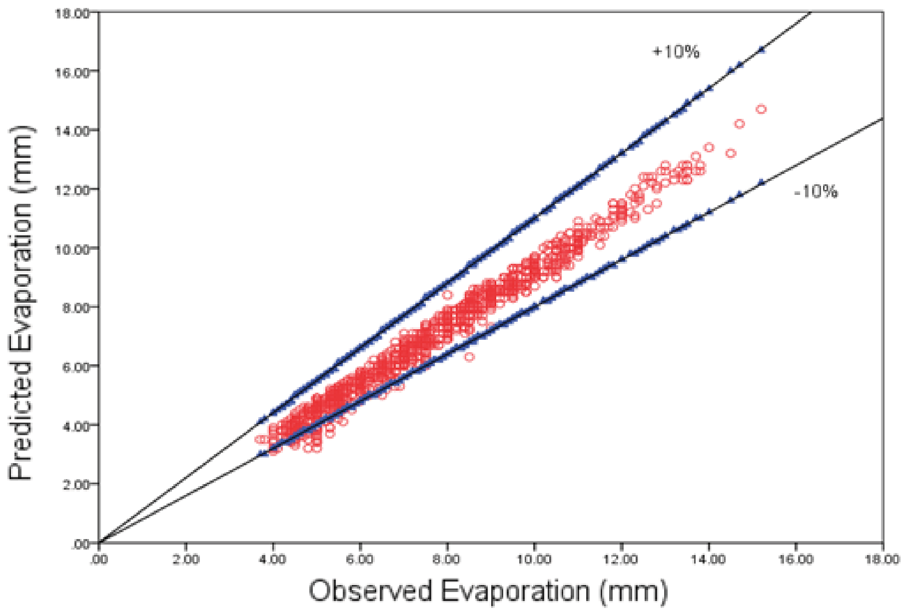

Fig. 6: Comparison between predicted and observed daily evaporation

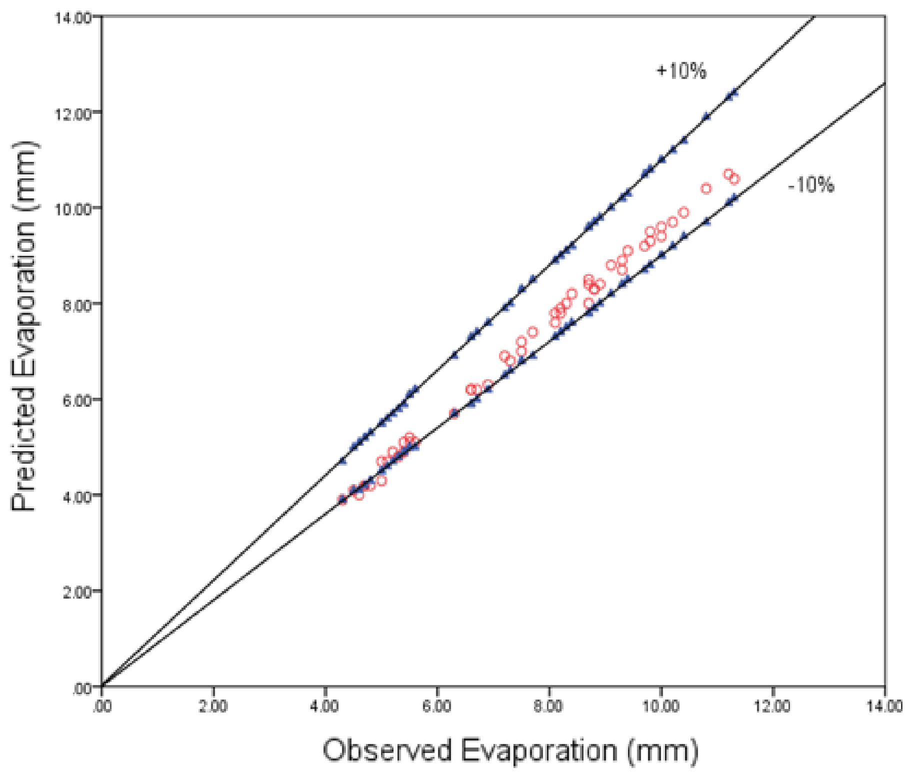

Fig. 7: Comparison between predicted and observed weekly evaporation

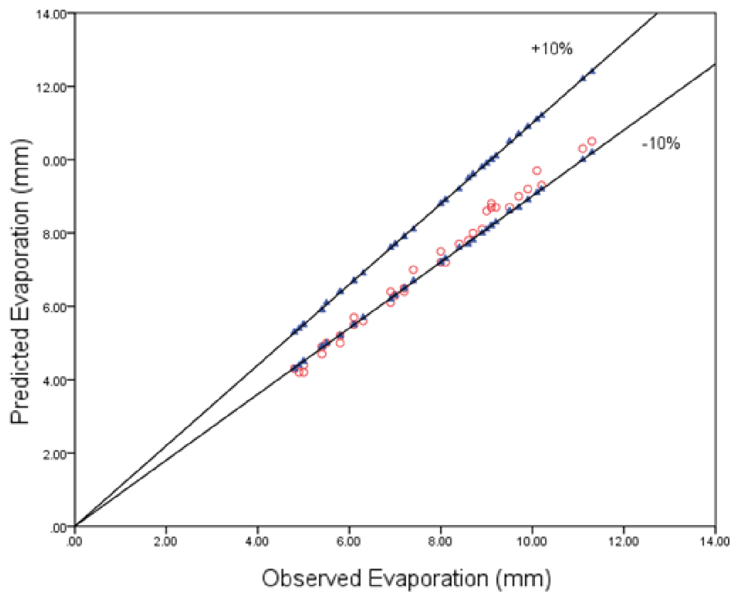

Fig. 8: Comparison between predicted and observed monthly evaporation

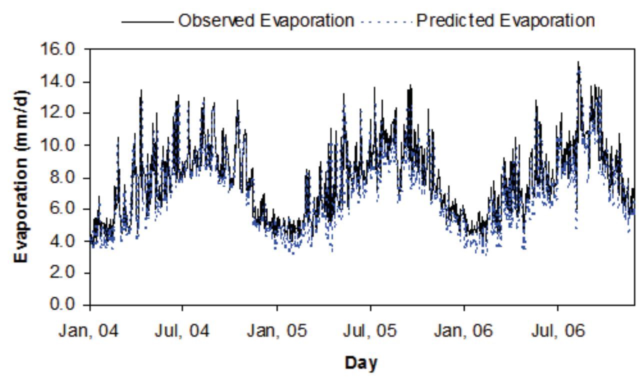

Fig. 9: Observed and Predicted evaporation for Algardabiya reservoir using Linacre daily model

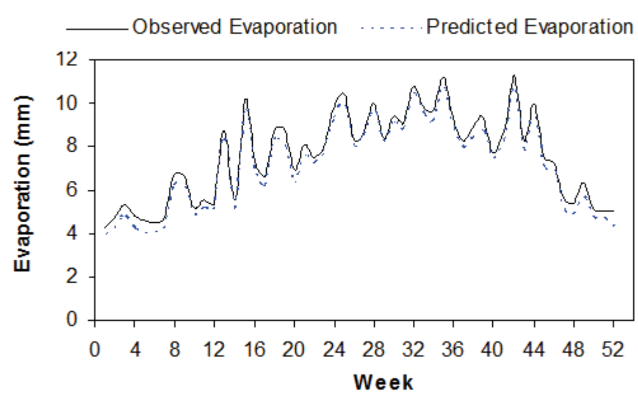

Fig. 10: Observed and Predicted evaporation for Algardabiya reservoir using Linacre weekly model

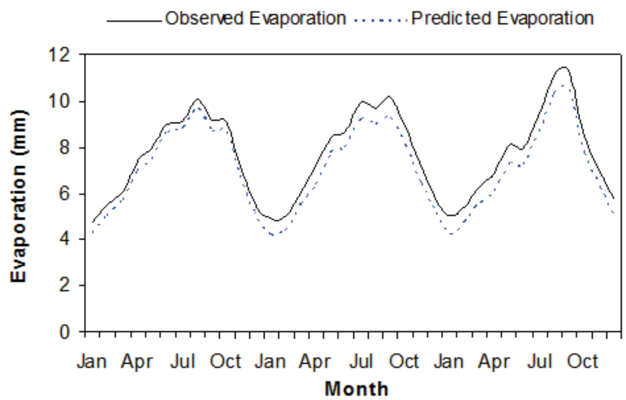

Fig. 11: Observed and Predicted evaporation for Algardabiya reservoir using Linacre monthly model

Although it clears that Linacre model slightly underestimated the pan evaporation. It is obvious from Figures 9 to 11 that Linacre model (using three years field data) gives the same trend of results compared with the observed evaporation. From observed evaporation data, the total evaporation for the studied period was found to be 8407.3 mm while, the predicted evaporation is 7692.7 mm. This shows that the Linacre model under estimated the evaporation from Algardabiya by 8.5% (daily prediction), 5.8% (weekly prediction) and 8% (monthly prediction).

Conclusion:

Evaporation rates from Algardabiya Reservoir (Sirt-Libya) were predicted using the Linacre model and compared the evaporation value obtained by direct measurement (class A pan). Various statistical measures (MSE, MARE and R^2) were used to test the computed daily, weekly and monthly evaporation rates by using Linacre model. Compared with the observed evaporation, the weekly predicted evaporation is found with R^2 equals to 0.996 while the R^2 for monthly and daily were found to be 0.992 and 0.979 respectively. For Linacre model the inputs data was air temperature only but it is found that the model gave reasonable prediction compared with historical records. Since, in most of developing countries, the lack of data is a common problem the Linacre model can be recommended to be used for estimation of evaporation from open surface. The model predictions were compared with ± 10% error and majority of the predictions were found within the above errors. For Algardabiya Reservoir, Libya, the model gave about 8.5%, 5.8%, and 8% underestimation in predicting daily, weekly and monthly evaporation respectively.

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