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Evaporation Rate at Wadi El-Rayan Lake, Egypt

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Abstract: Wadi El-Rayan Lake, a shallow lake with an elevation 40 m below mean sea level is located in the western desert of Egypt. It is important for agricultural water supply, fish production and tourism. Three approaches were used to calculate the evaporation rate of Wadi El-Rayan Lake: the energy budget method, the Dalton formula and the Penman equation. The monthly variation in the calculated evaporation rates by the three methods is substantial, but the annual pattern of evaporation is consistent among these methods. Minimum evaporation rates occur in December, while the maximum occurs in June. The temporal variation in evaporation is explained by variation in temperature and largely driven by changes in the net radiation, although evaporation rates reach their highest levels with high wind. The relative humidity and air pressure are negatively correlated with evaporation.

Key words: Dalton formula · Energy budget · Evaporation · Penman equation · Wadi El-Rayan Lake

INTRODUCTION

Evaporation rates are of great importance to study the heat, water and salt budgets of a lake [1-3] and are particularly true for shallow lakes. Increased efforts have been directed toward a better understanding and a more accurate evaluation of the different methods to calculate the rate of evaporation [4], including energy budget and mass transfer (bulk aerodynamic) approaches. These methods require meteorological input parameters that must be measured or estimated to generate reliable results. Some of the meteorological data are measured directly in weather stations, while others are related to commonly calculated data and can be derived with the help of a direct or empirical relationship [5]. Despite the importance of Wadi El-Rayan Lake, evaporation rates have rarely been investigated. The objectives of the present work are to calculate the evaporation rate using three methods and to evaluate the relationship between the calculated results and meteorological features of the Wadi El-Rayan Lake area. Monthly means of the available meteorological data (1996-2006) were used.

Site Description: Wadi El-Rayan is a very important Lake in Egypt, as a reservoir for agricultural drainage water, fisheries and tourism. Wadi El-Rayan, 40 meters below mean sea level, is a man-made lake. It lies in the western desert of Egypt at 29° N and 30° E, with an area of 99.40 million m^2 (Fig. 1). The Lake is divided into two ponds, receives agricultural drainage water through El-Wadi Drain and has no outlets; water is pumped to new projects for agricultural land reclamation. The mean water discharge is estimated to be 221.42 million m^3 [6].

The Evaporation Estimates Methods: Since the first investigations were published, almost a countless number of employed empirical equations on evaporation have been written. Due to this profusion of equations, the formulas have been taken from the literature and indiscriminately employed without criteria to several applications around the world [7]. Thus, a large scattering of evaporation rates has been found and the initial results suggested that it might be impossible to determine a generally applicable equation for evaporation. In general there are two ways of the heat and mass transfer processes by evaporation from a free water surface diffusion and advection as shown by investigator [8].

The Energy Budget Method: The energy budget method is currently simplified for use in Pale climatic and pale hydrological studies [9-11]. The energy equations stated that the heating and cooling processes must balance each other in water mass. Evaporation deprives the water heat that is transferred to the atmosphere as latent heat of water vapor and is liberated when the water vapor is condensed. A general expression of the energy budget of

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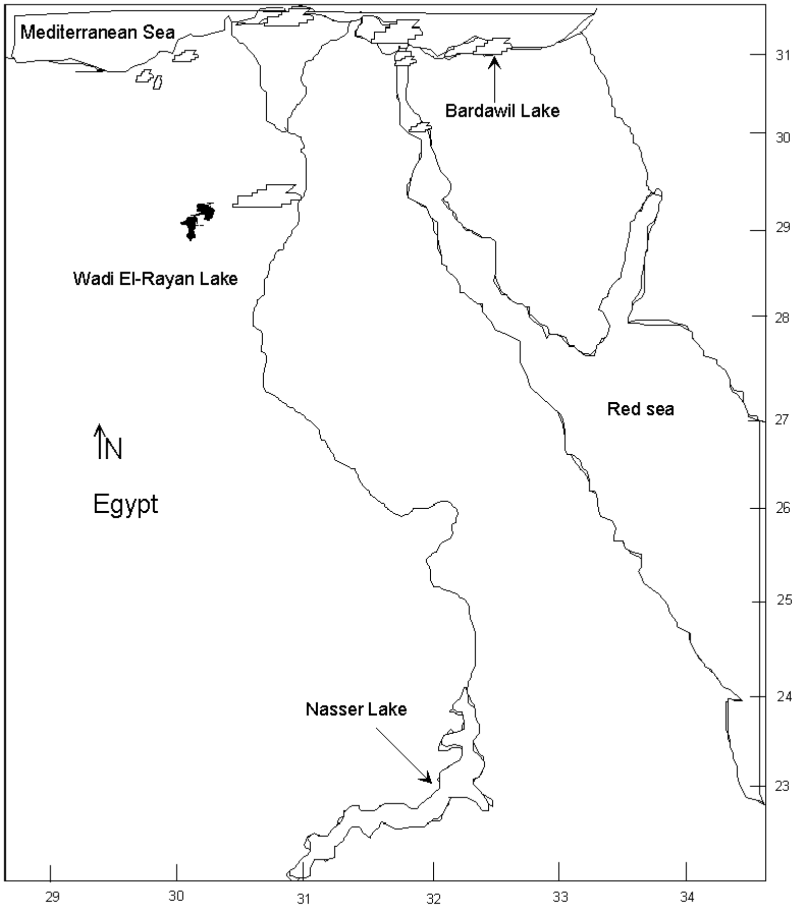

Fig. 1: Geographic location of Wadi El-Rayan Lake, Egypt

lake water [12, 13] is: $Q_s = Q_r + Q_e + Q_c$. Where, Q_s is the change of energy storage in the lake, Q_r is the rate of effective radiation, Q_c is the sensible heat flux and Q_e is the rate of exchange of heat with the atmosphere through processes of evaporation, Q_e can be expressed by: $Q_e = \lambda E$. Where, λ is the latent heat of evaporation and E is the evaporation rate. Assuming $Q_s=0$, the Bowen ratio, defined by $\beta=Q_c/\lambda E$, to compute evaporation from radiation estimates [14], as follows:

$$E = Q_r / \lambda (1+ \beta) \qquad (1)$$

The Dalton Formula: Evaporation rate has been estimated by the mass transfer, bulk-aerodynamic method, using convenient parameters routinely measured at weather stations. The approach is based on measurements of the factors affecting the actual removal of water vapor from a water surface by processes of turbulent diffusion and transport. The evaporation rate, as a vertical flux of water vapor, was estimated using the Dalton formula [8, 15], as:

$$E = CU (e_0-e_a) \qquad (2)$$

Where, C is an empirical mass transfer coefficient dependent on the elements of weather, U is the wind velocity, e_0 is the saturation vapor pressure and e_a is the actual vapor pressure.

The Penman Equation: Combining the energy budget and aerodynamic methods [16], the approach is formed as follows:

$$E = Q_r (\Delta / \Delta+\nu) + E_a (\nu / \Delta+ \nu) \qquad (3)$$

Where, Δ is the slop of the saturated vapor pressure curve at the air temperature, ν is the Psychrometric constant and E_a is the drying power of the air, $E_a= f(u) (e_0-e_a)$, f(u) is the Penman's function of wind.

RESULTS

Wadi El-Rayan Lake is a Warm Subtropical Basin located in the arid zone (Table 1). The air and surface water temperatures are low in winter and high in summer (the air: 12.5- 28.2 Celsius and the water 14.8- 28.2 Celsius). The water is warmer than the air during the period from November to March, while it is cooler during the rest times. The net radiation ranged between 34.0 W/m^2 in December and 199.7 W/m^2 in July. As Wadi El-Rayan Lake located in about -40 m altitude, the air pressure is relatively high and has small amplitude (1009.0 mb in July -1018.6 mb in January). Winds are from all directions, but are often from the north, north-northeast, north-northwest and southerly east and west in most time. The recorded wind shows great variability from month-to-month (minimum value 2.1 m/s in December and maximum value 5.4 m/s in June). The relative humidity varied between 36.8% in June and 57.7% in November.

The monthly means evaporation calculates (mm/day) of Wadi El-Rayan Lake are shown in Table (2). The energy budget results ranged between 1.72 and 6.97 mm/day; with an average of 4.65 mm/day. The Dalton equation results ranged between 1.25 and 9.54 mm/day, with an average of 5.66 mm/day. The Penman equation results ranged between 1.29 and 7.28 mm/day, with an average of 4.72 mm/day. The minimum and the maximum evaporation values, calculated by the three equations, were recorded in December and June respectively.

Table 1: The combined effect of weather factors affecting evaporation rate for Wadi El-Rayan Lake

	The meteorologiclaparameters which are directly measured							The meteorologiclaparameters which are derived by the empirical relationships						
	Ta	Tw	Qr	P	U	Ud	RH	eo	ea	β	L	C	v	Ea
Jan	12.5	14.8	048.6	1018.6	2.6	NE, NNW	56.1	10.78	06.05	0.2404	587.35	0.012	0.0677	02.96
Feb	13.7	16.6	085.4	1017.5	4.0	NE, NNW	48.4	11.65	05.64	0.2390	586.42	0.011	0.0677	04.94
Mar	16.1	18.7	127.1	1013.2	3.6	N, NW	48.1	13.60	06.54	0.1833	885.34	0.011	0.0674	05.40
Apr	22.0	20.2	167.7	1012.1	4.6	N, NNE	40.3	19.63	07.91	-0.0752	584.60	0.011	0.0673	10.62
May	25.9	24.4	191.1	1011.1	4.8	NEN	38.2	24.81	09.48	-0.0482	582.46	0.011	0.0672	14.32
Jun	26.3	25.8	199.3	1009.9	5.4	SE, SSW	36.8	25.40	09.35	-0.0146	581.73	0.011	0.0672	16.34
Jul	27.9	26.4	199.7	1009.0	4.7	SW, E	40.3	27.90	11.24	-0.0442	581.44	0.011	0.0671	15.32
Aug	28.2	28.2	169.9	1010.3	5.3	SE, SW	43.2	28.39	12.26	-0.0015	580.54	0.011	0.0672	16.19
Sep	26.3	26.2	147.2	1012.2	4.8	NNE, NE	43.4	25.40	11.02	-0.0051	581.56	0.011	0.0673	13.43
Oct	25.0	23.0	108.7	1014.2	4.9	NE, NW	47.8	23.52	11.24	-0.0795	583.16	0.011	0.0674	11.64
Nov	19.8	20.5	070.4	1015.0	5.0	NNE, NW	57.7	17.15	09.90	0.0169	584.67	0.011	0.0675	06.98
Dec	13.0	17.4	034.0	1016.3	2.1	NEN	55.4	11.14	06.17	0.4372	586.02	0.012	0.0676	02.76

Ta; Air temperature (Celsius), Tw: water temperature (Celsius), Qr: Net radiation (W/m^2), P: Air pressure (mb), U: Wind speed (m/s) , Ud: Wind direction, RH: Relative humidity (%), eo; Saturation vapor pressure (mb), ea; Actual vapor pressure (mb), β: Bowen ratio, L: Latent heat (cal.cm^3), C; the empirical mass transfer coefficient (W/m^2), ν: the Psychrometric constant (mb/Celsius) and Ea: the drying power of the air.

Table 2: Monthly mean evaporation rats (mm/day) of Wadi El-Rayan Lake estimated with the three methods.

Month	Energy budget	Dalan equation	Penman equation	Standard deviation	Variance
Jan	2.12	1.48	1.79	0.452548	0.102
Feb	3.72	2.65	3.11	0.756604	0.288
Mar	5.30	2.80	4.50	1.767767	1.630
Apr	5.47	5.93	6.06	0.325269	0.096
May	6.44	8.10	6.94	1.173797	0.725
Jun	6.97	9.54	7.28	1.817264	1.968
Jul	6.78	8.61	7.24	1.294005	0.906
Aug	6.03	9.40	6.25	2.382950	3.555
Sep	5.20	7.59	5.42	1.689985	1.745
Oct	3.54	6.62	4.07	2.177889	2.712
Nov	2.53	2.99	2.67	1.032376	0.649
Dec	1.72	1.25	1.29	0.332340	0.068

DISCUSSION

The interpretation of the current equations shows that, the similarity indexes are of 95.34%. The highest similarity is between the energy budget and the Penman equation results (99.1%). Although the highly similarity between the equations results, however, there is a highly significant variance from month to another (Table 2). The lowest monthly variance was measured in December, while the highest one was in August.

There are different relationships between the meteorological elements and the calculating results of evaporation rate in Wadi El-Rayan Lake. The distinct evaporation variations, using the three methods in Wadi El-Rayan Lake, could be explained by similar variations in temperature. As the water and air temperature difference is partly responsible for the change in evaporation rate calculates and the effects of temperature are complex [17, 18]. However, monthly changes in evaporation show a strong negative relationship with lake's water -air temperature difference [19]. As well as the monthly evaporation variation is largely driven by changes in the net radiation, particularly short wave radiation [16]. Through the non-linear effect of temperatures on vapor pressure, monthly changes in water and air temperatures lead to a vapor pressure difference (e_0-e_a) curve that is similar to that of the evaporation rate estimations [4]. The correspondence between evaporation and vapor pressure difference helps to corroborate the results of the more rigorous three evaporation calculation methods [19]. Other meteorological factors are likely to affect monthly evaporation rates; these include wind velocity, air mass humidity and atmospheric pressure. When water temperature increases, in response to the warm conditions and humidity drops with high winds, then the evaporation rates reach high levels [20]. On the geographical basis, as Wadi El-Rayan Lake, northerly currents (atmospheric depression) are prevailing in winter and southerly (atmospheric height) in summer. Northern, northeastern and northwestern winds (wet air mass in cold months) lead to decrease evaporation rate. On the contrary, southeastern and southwestern winds (dry air mass in warm months) lead to increase the evaporation rate from the Lake surface. Wind speed has positive correlation with evaporation results, this agrees with the previous results [21-23]. Inversely, relative humidity and air pressure are negatively correlated with evaporation estimates results. When relative humidity and air pressure increased the water-air vapor pressures difference would be reduced and consequently evaporation rate decreased [24].

It could be concluded that the monthly variation in the estimated evaporation rates is obvious, with high similarity between methods results. The evaporation variations explained by the effect of variations in temperature and largely driven by changes in the net radiation. The evaporation rates reach high levels with high wind. The relative humidity and air pressure are negatively correlated with evaporation calculates results.

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