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EVAPORATION ESTIMATES IN FRONT OF HURGHADA CITY BY USING PENMAN-MONTEITH EQUATION, RED SEA, EGYPT

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Abstract:
Evaporation occurs simultaneously and this process depends on solar radiation, air temperature, relative humidity and wind speed. There is no any device for accurate direct measurement of evaporation from the sea surface, so many equations are used to estimate it from meteorological conditions. By using the Penman-Monteith equations, the daily evaporation rate of coastal water in front of Hurghada was estimated for four years (1999-2002). The result leading to the highest net evaporation occurred during the summers (June and July) and the lowest were in winters (January and December). The rates were fluctuating between 7.81-9.80 mm/day and net deposition occurred in winter months (January and November) and April, averaged between 2.48-5.05 mm/day. There is a direct proportion between net evaporation and air temperature and inversely proportional to the relative humidity. It is clear that the wind speed has affected on the evaporation rate. These consequences were similar to and conforms to previous researches, thereby the Penman-Monteith equations is desirable to estimate the evaporation rate of Hurghada coast.

Keyword: Evaporation Rate, Hurghada, Air Temperature, Relative Humidity, Wind Speed, Sun Radiation, Penman-Monteith Equation

1.0 Introduction:
Evaporation happens when liquid water converts to water vapor and the energy required is able to liberation of water molecules and converted it to steam energy of the surface of the water. The water evaporates from a variety of surfaces, such as lakes, rivers, land surface and oceans, and the last one is considered as the source which delivers 80% of the water that is delivered by the precipitation (Ab dulaziz, 2012). As for the evaporation, there is no any device, allowing carrying out accurate direct measurements of the evaporation from the sea surface The evaporation of ocean water is an important feature of the sea air interaction. It is observed that the evaporation is strongly influenced by many of coefficients such as air temperature, wind speed and humidity (Sofianos *et al*., 2002; YU, 2007; Xu and Singh, 1998 and Frank, 1992). Whereas, the evaporation rate from the ocean surface increased with increasing temperatures and wind velocity and decreased with increasing humidity (Güldal and Tongal, 2008; Filimonova and Trubetskova, 2005). There are seven types of estimating open water evaporation, these: pan evaporation, mass balance, energy budget models, bulk transfer models, combination models, the equilibrium temperature method and empirical factors (Finch and Hal, 2001). Different methods have been developed for its estimation. Some of them concern the evaporation as the remainder term in the water balance equation, but results cannot be accurate enough as the other terms in the equation may contain some error. Other methods are based on empirical and semi empirical formulas that associate evaporation with some meteorological elements.

The Red Sea has the most saline water of the world's oceans due to be losing the highest rate of water by the evaporation. This rate is changeable, where the greatest monthly evaporation rates were during the winter months in the southern Red Sea (Ab dulaziz, 2012; Privett, 1959). By using pan measurements aboard a ship and on the coast, Vercelli (2002) was recorded a doubtful value of 3.5 m yr − 1 and that were quite high. All later estimations are shown by Sofianos *et al*., 2002; Maiyza, 1988; Da Silva *et al*., 1994 and Tragou *et al*., 1999. The annual mean net evaporation (1.24 m yr^{-1}) estimated southern Red Sea (Ab dulaziz, 2012) is less; but can be considered as a nearly to 1.54 m yr^{-1} (Hastenrath and Lamb, 1979), 1.5 m yr^{-1} as estimated by Da Silva et al. 1994, 2.1 m yr^{-1} in the Aqaba Gulf (Ben-Sasson *et al*., 2009) and it is more than the value 1.1 m yr^{-1} (Clifford *et al*., 1997), Whereas Maiyza (1988) was estimated the maximum value from the coastal area in front of Hurghada during summer. The aim of this paper is an attempt to compute the evaporation rate based on daily meteorological data in the coastal area in front of Hurghada, using the form of the Penman- Monteith formula.

2.0 Data Collection:

To estimate the evaporation in Hurghada by using Penman- Monteith formulas, the variables that used from the weather station was fixed in the National Institute of Oceanography and Fishery (Red Sea branch) at 10m height about the sea level (Fig. 1). Where it collected the data every one hour from January 1999 untill December 2002, these variables as following:

1) Maximum and minimum air temperature.
2) Maximum and minimum wind speed and its directions.
3) Maximum and minimum relative humidity.
4) The incident solar radiation values

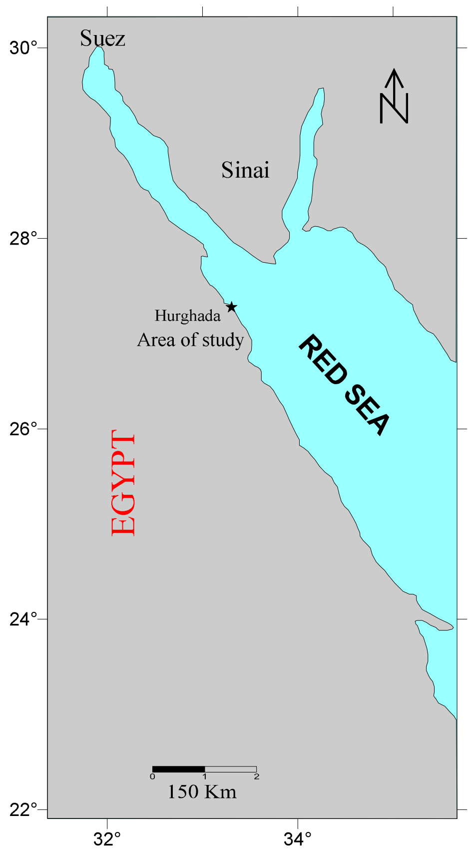

Fig. 1: Study Area

3.0 Result and Discussion:

There are many methods to estimate of evaporation losses from sea water as empirical methods (e.g. Kohler *et al*., 1955), and combination methods (Penman, 1948). In addition to the direct method of measurement depend on 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 meteorological variables like temperature, wind speed, relative humidity and solar radiation. Jensen *et al*. (1990) clearly showed Penman- evaporation estimates to be the most reliable of all estimation methods, although there were seven variations used. Penman combined the mass transfer and energy budget approaches and eliminated the requirement for surface temperature to obtain his expression for the evaporation in mm per day from open water (Zotarelli *et al.,* 2013):

$$\lambda ET_o = \frac{\Delta(\, R_n - G) + [86.400\,\frac{\rho_a\, c_p\,(e_s^o - e_a)}{r_{av}}]}{\Delta + \,\gamma(1 + \frac{r_s}{r_{av}})}$$

Where ρ_a = air density (kg m^{-3}), C_p = specific heat of dry air, e_s^o = mean saturated vapor pressure (kPa) computed as the mean e_o at the daily minimum and maximum air temperature (°C), r_{av} = bulk surface aerodynamic resistance for water vapor (s m^{-1}), e_a = mean daily ambient vapor pressure (kPa) and r_s = the canopy surface resistance (s m^{-1}).

The highest average air temperature values in Hurghada were during summer (in July) all the times of the investigation period and the lowest average values were during winter (in January) as shown in figure (2) and table (1) agreement with Maiyza (1988) and Saman (2000). During four-year duration of this research, the highest value of the temperature (31.37^{o}C) in July 2002 while the lowest value (14.87^{o}C) in January of the same year. The relative humidity change with change the amount of water vapour available, so the relative humidity increases by evaporation from the surface of the Red sea, this is because with the increase in water vapour, the humidity increases (Moustafa *et al*., 2015). Generally, the less relative humidity values have been recorded during the summer months, while the highest values have been recorded during the winter months during the four years of the study, so the relative humidity annual cycle was opposite to air temperature cycle, it increased when temperature decreased and vice versa (Moustafa *et al*., 2015). The lowest value of relative humidity was 41.0% during July 2000 (Fig.2), while the highest value was 70.3% during October 2002.

Saman, (2000) pointed to the rad- flux in front of Hurghada was higher during summer and autumn seasons, reaching to (279.29 w/m²) , whereas it is lower during winter and spring seasons. The rad – flux during the period of the investigation fluctuated between 145.17 w/m^2 (average during 2001) and 254.14 w/m^2 (average during 1999). The change of wind speed curve can be divided into two parts, the first part is starting from January 1999 until May 2000 and be confined to the wind speed between 15.53 (January 1999) and 21.34 m/s (March 2000). The second part of the curve shall be the average wind speed is low and the highest value is up close to the speed of the wind to July 2002 (9.89 m/s) while being less valued in April 2001 (4.31m/s). The prevailing wind due to its direction and the geographic nature of the Red Sea varies according to the wind coming from the land or from the sea or from the northern or the southern Red Sea which accelerated or jumped evaporation from the coastal water (Maiyza, 1988). So, the wind rose for the investigated period (1999 – 2002) were plotted in figure 3, illustrated the prevailing wind in the four years were N-NNE, similar to and conforms with Maiyza (1988) and Moussa (2000).

A recent revision of the some publications (Doorenbos and Pruitt, 1977; Hess, 1996) were recommending the Penman-Monteith formula as the idealistic approach, recognizes that the simplest variety of the Penman equation, particularly with local calibration will provide most satisfactory estimates of evaporation. This equation should give the best estimate of reference evaporation and can be reliable in a wide range of environments (Allen *et al*., 1994). Evaporation rise in June and July, at the rate were fluctuating between 7.81–9.80 mm/day, and net deposition occurred in the winter months (January and December) and April, averaged between 2.48 – 5.05 mm/day. These results are nearly similar to results of evaporation which estimated from Aswan dam reservoir (Badawy, 2009 and Ben Sasson *et al*., 2009).

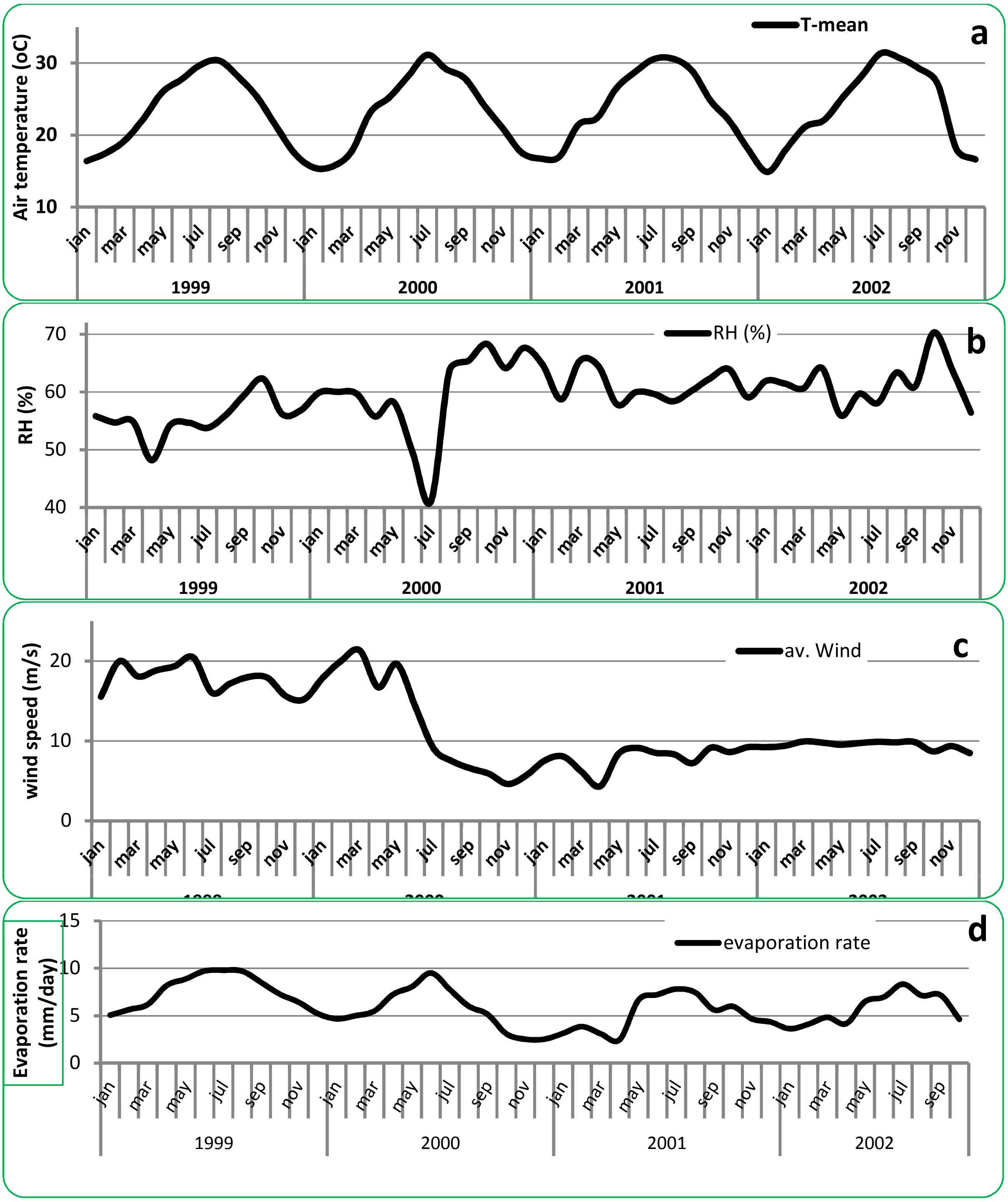

Fig. 2: Time series of meteorological variables from January 1999 to December 2002. The variables plotted are a) Mean air temperature, b) Relative humidity, c) Wind speed and d) Calculated evaporation rate at a height of 10 m in Hurghada (National Institute of Oceanography and Fishery).

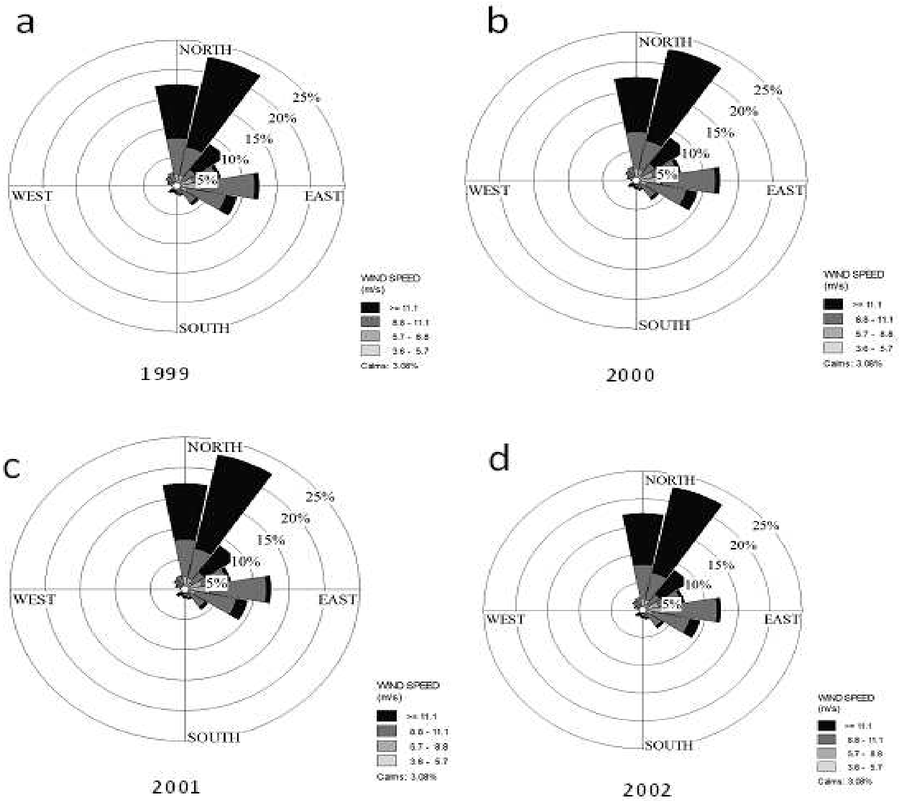

Fig. 3: Wind Rose for Wind Direction through the Years 1999-2002

Table 1: Maximum, Minimum and Average Levels of Air Temperature, Relative Humidity, Wind Speed and Evaporation Rate during 1999- 2002 from Coastal Water in Front of Hurghada

		Air temperature °C	Relative humidity %	Wind speed m/s	Evaporation mm/day
1999	**Max.**	30.36	62.26	20.45	9.80
	Min.	16.39	48.17	15.23	5.05
	Average	23.45	55.59	17.69	7.55
2000	**Max.**	31.15	68.32	21.34	9.51
	Min.	15.48	41.04	4.61	2.52
	Average	23.03	59.46	12.43	5.58
2001	**Max.**	30.62	65.42	9.22	7.81
	Min.	16.73	57.80	4.32	2.48
	Average	23.97	61.21	7.88	5.19
2002	**Max.**	31.37	70.28	9.94	8.34
	Min.	14.87	55.95	8.47	3.63
	Average	23.58	61.38	9.48	5.74

Table 2: The Correlation Coefficient between Evaporation Rate, Air Temperature, RH and Wind Speed

	Evaporation rate	Air temperature	Relative humidity	Wind speed
Evaporation rate	1			
Air temperature	0.68	1		
Relative humidity	-0.65	-0.17	1	
Wind speed	0.55	-0.11	-0.50	1

Comparing the following figures of time series of meteorological variables of mean air temperature, relative humidity, wind speed and the calculated evaporation rate at a height of 10 m in Hurghada from January 1999 through December 2002 (figs.2), It is evident through the changes of temperatures and evaporation during the summer and winter seasons. The lower rates of evaporation were in the months of November 2000 and April 2001, it considered abnormal changes. These abnormal decreases result from increased humidity and lowering wind speed (fig. 2) and table 2. Clearly, there is a relation between the evaporation rate and the wind speed that is highest in the 1999 and 2000 also the evaporation rate in the same two years is highest (table 2) (Maiyza, 1988; Yegorov 1950).

The results reveal many interpretations consistent to some extent with previous estimations. For instance the results of monthly evaporation rates in the Red Sea as showed in Figure (2), it is clear that the greatest monthly evaporation rates are during the summer months. This result is similar to and confirms with Meshal *et al.* (1984) results. The evaporation rate and air temperature curves are conformable, where the highest values were in summer while the lowest values were in winter.

4.0 Conclusion:

Penman combined the mass transfer and energy budget approaches and eliminated the requirement for surface temperature to obtain his expression for the evaporation in mm per day from open water. Net evaporation occurred in June and July, at the rate was fluctuating between 7.81-9.80 mm/day, and net deposition occurred in the winter months (January and November) and April, averaged between 2.48-5.05 mm/day. The corresponding values of air temperature ranged between 14.87 (in winter) - 31.37^{o}C (in summer). The wind speed confined between 21.34 m/s (March 2000) and 4.31m/s (April 2001), prevailing from NNE-NNW during the four years. The less relative humidity values have been recorded during the summer months, while the highest values have been recorded during the winter months. The first year recorded the highest average of Rad –flux value whereas the third year recorded the lower value. The net evaporation has direct proportion to the air temperature and inversely proportional with the relative humidity. These consequences were similar to and confirms with the previous researches, thereby the Penman-Monteith equations is desirable to estimate the evaporation rate of Hurghada coast.

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