Estimation of Daily Evaporation from Calculated Evapotranspiration in Iraq

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Abstract:

The knowledge of the evapotranspiration (ET) of natural ecosystems and plant populations is of fundamental importance in several branches of science, research and practical uses. Calculation of total daily Evaporation related to calculate the loss of water by daily evapotranspiration from FAO Penman-Monteith equation. Twenty two climatological stations are used in this work for the period 2004-2013 in Iraq. Estimating conversion constant in order to calculate Evaporation value and comparing it with measured value from Iraqi meteorological organization and seismology. The results show high correlation coefficient. We formulated method is proposed to for calculate the amount of evaporation for missing data of climatological Iraqi stations from calculated evapotranspiration value. GIS maps reflect distribution of evaporation, evapotranspiration and Kp in Iraq.

Keywords: Evapotranspiration, Evaporation, GIS, Iraq.

1. Introduction:

Evaporation in a soil-plant-atmosphere system occurs from each of the system component. Evaporation from the soil is affected by soil water content, type and tilth [1]. Evaporation occurs when liquid water is converted into water vapor. The rate is controlled by the availability of energy at the water surface, and the ease with which water vapor can mix into the atmosphere [2]. Evapotranspiration (ET) is the loss of water from vegetation surface through the combined processes of plant transpiration and soil evaporation. Both environment and biological factor affect ET. Important environmental factor include climate parameter. Biological factor affecting ET include type of vegetation, foliage geometry and foliage density [3]. The problem of measuring evaporation from open water surfaces, and transpiration from different types of vegetation, has been a central problem in hydrology for many years. In terms of the hydrological cycle and the water balance, evaporation and transpiration make up the second largest component. Many weather stations include measurements of the evaporation from a Class-A pan [4], as the basis for calculating the water loss from lakes or from crops [5, 6]. But most places are without such measurements, and, even where there is a pan, the measurements may be vitiated by poor maintenance, leading to errors due to leaks, the growth of algae in the water, an incorrect water level, weed-growth nearby, water scarcity, and so on. Also, it is hard to measure evaporation accurately during rainfall [8], perhaps because of splashing of water in or out of the pan. In view of these difficulties, it would be useful and cheaper to have some means of estimating pan evaporation with reasonable accuracy, from FAO Penman-Monteith method which demonstrate how the crop reference evapotranspiration which determined from meteorological data, such as temperatures, relative humidity, wind speed, sunshine duration. Pan coefficient (Kp) is away to calculate pan evaporation (mm/day)(Epan), or reference evapotranspiration (mm/day)(ETo) in indirectly method , there are different method used to predict pan coefficient value depending on climate data ,type of pan, ground cover in climate station, it's surrounding, the sitting of the pan and pan environment[9]. Many different equations for calculating pan coefficient was stated by Doorenbos and Pruitt's Table (Doorenbos & Pruitt, 1977)[9], Cuenca (1989)[10], Snyder (1992)[11], Pereira et al. (1995)[12], Raghuwanshi & Wallender (1998)[13], and FAO/56 (Allen et al.,(1998)[8]. Tthe selection of the best technique to use for a particular computation is largely a function of the data available , type or size of water body, and the required accuracy of the estimated evaporation.

2.Methodology:

2.1

Penman-Monteith equation:

In 1948, Penman [14] combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records. The Penman-Monteith form of the combination equation is:

$$ET = \frac{\Delta(R_n - G) + \rho_a C_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \quad (1)$$

where R_n is the net radiation, G is the soil heat flux, $(e_s - e_a)$ represents the vapor pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air, Δ represents the slope of the saturation vapor pressure temperature relationship, γ is the psychrometric constant, r_s and r_a are the (bulk) surface and aerodynamic resistances.

2.2 Aerodynamic resistance (r_a):

The transfer of heat and water vapor from the evaporating surface into the air above the canopy is determined by the aerodynamic resistance:

$$r_a = \frac{\ln\left[\frac{z_m - d}{z_{om}}\right] \ln\left[\frac{z_h - d}{z_{oh}}\right]}{K^2 u_z} \quad (2)$$

Where

r_a aerodynamic resistance [s m^{-1}],

z_m height of wind measurements [m],

z_h height of humidity measurements [m],
d zero plane displacement height [m],
z_{om} roughness length governing momentum transfer [m],
z_{oh} roughness length governing transfer of heat and vapor [m],
k von Karman's constant, 0.41,
u_z wind speed at height z [m s^{-1}].

$$r_s = \frac{r_l}{\mathrm{LAI}_{active}} \qquad (3)$$

Where

r_s (bulk) surface resistance [s m^{-1}],
r_l bulk stomatal resistance of the well-illuminated leaf [s m^{-1}],
LAI_{active} active (sunlit) leaf area index [m^2 (leaf area) m^{-2} (soil surface)].

From combination of the original Penman-Monteith equation (Equation 1) and the equations of the aerodynamic (Equation 2) and surface resistance (Equation 3), given the FAO Penman-Monteith method to estimate ET_o, it is indicated below in equation(4):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (4)$$

Where

ET_o reference evapotranspiration [mm day^{-1}],
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],
T mean daily air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapor pressure [kPa],
e_a actual vapor pressure [kPa],
$e_s - e_a$ saturation vapor pressure deficit [kPa],
Δ slope vapor pressure curve [kPa $°C^{-1}$],
γ psychrometric constant [kPa $°C^{-1}$].

The reference evapotranspiration, ET_o, provides a standard to which evapotranspiration at different periods of the year or in other regions can be compared; evapotranspiration of other crops can be related. The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed. To ensure the integrity of computations, the weather measurements should be made at 2 m (or converted to that height) above an extensive surface of green grass, shading the ground and not short of water.

2.3 ET_o computed by CROPWAT:

CROPWAT 8.0 for Windows is a computer programme for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

2.4 Pan evaporation:

The evaporation rate from pans filled with water is easily obtained. In the absence of rain, the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period. Pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Although the pan responds in a similar fashion to the same climatic factors affecting crop transpiration, several factors produce significant differences in loss of water from a water surface and from a cropped surface. Reflection of solar radiation from water in the shallow pan might be different from the assumed 23% for the grass reference surface. Storage of heat within the pan can be appreciable and may cause significant evaporation during the night while most crops transpire only during the daytime. There are also differences in turbulence, temperature and humidity of the air immediately above the respective surfaces. Heat transfer through the sides of the pan occurs and affects the energy balance.

The pan evaporation is related to the reference evapotranspiration by an empirically derived pan coefficient:

$$ET_o = K_p E_{pan} \quad (5)$$

Where

ET_o reference evapotranspiration [mm/day],
K_p pan coefficient,
E_{pan} pan evaporation [mm/day].

2.6 Pan coefficient (K_p):

Pan types and environment:

In selecting the appropriate pan coefficient, not only the pan type, but also the ground cover in the station, its surroundings as well as the general wind and humidity conditions, should be checked. The sitting of the pan and the pan environment also influence the results. This is particularly so where the pan is placed in fallow rather than cropped fields. Two cases are commonly considered: Case A where the pan is sited on a short green (grass) cover and surrounded by fallow soil; and Case B where the pan is sited on fallow soil and surrounded by a green crop, we will use equation (6) to calculate pan coefficient for case A which stated as:

$$Kp = 0.108 - 0.0286\, u_2 + 0.0422 \ln(FET) + 0.1434 \ln(RHmean) - 0.000631 [\ln(FET)]2 \ln(RHmean) \quad (6)$$

K_p pan coefficient

u_2 average daily wind speed at 2 m height (m s^{-1})
RH_{mean} average daily relative humidity [%] = $(RH_{max} + RH_{min})/2$

FET fetch, or distance of the identified surface type (grass or short green agricultural crop for case A, dry crop or bare soil for case B upwind of the evaporation pan).

3. Result and discussion:

Evaporation is one of important element using in proper irrigation management although evapotranspiration, calculating of monthly average daily of evaporation through calculating the loss of water by monthly average daily evapotranspiration from FAO

Penman–Monteith equation(Equation 4). We applied this equation for 22 different climate station in Iraq using climate elements (max. temp., min temp., RH %, sunshine duration, wind speed). During the period 2004-2013, the lowest value was calculated in January for Mosel station 0.68 mm/day while highest value was calculated in June for Basrah station was 14.565 mm/day**.**

Figures (1), (2) and (3) Represent monthly distribution of evapotranspiration in Iraq.

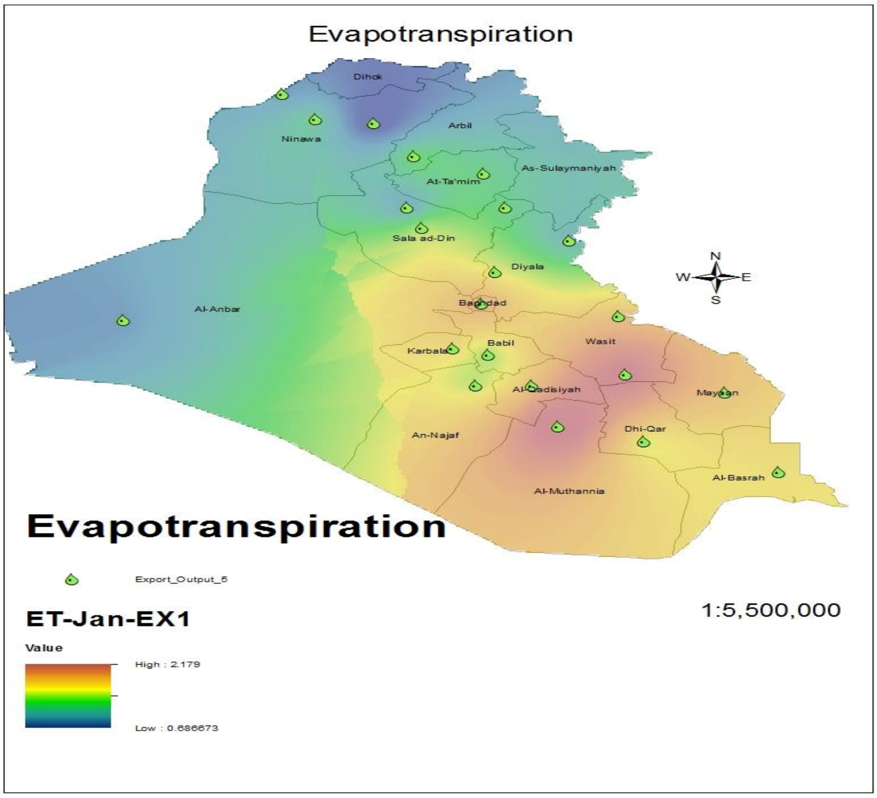

Figure (1): Evapotranspiration map for Iraq in January.

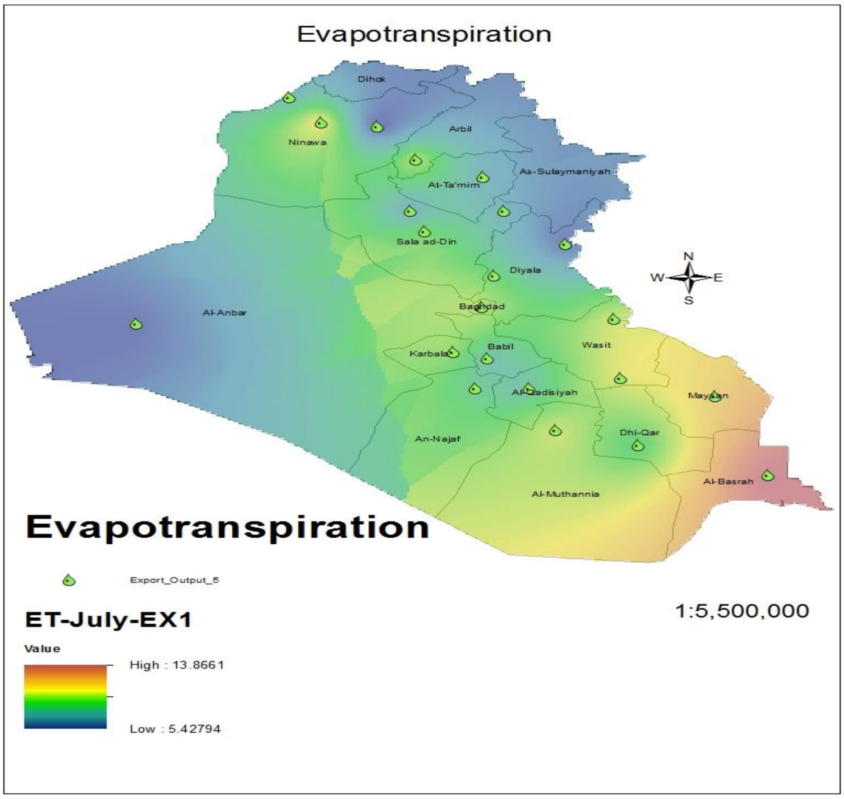

Figure (2): Evapotranspiration map for Iraq in July.

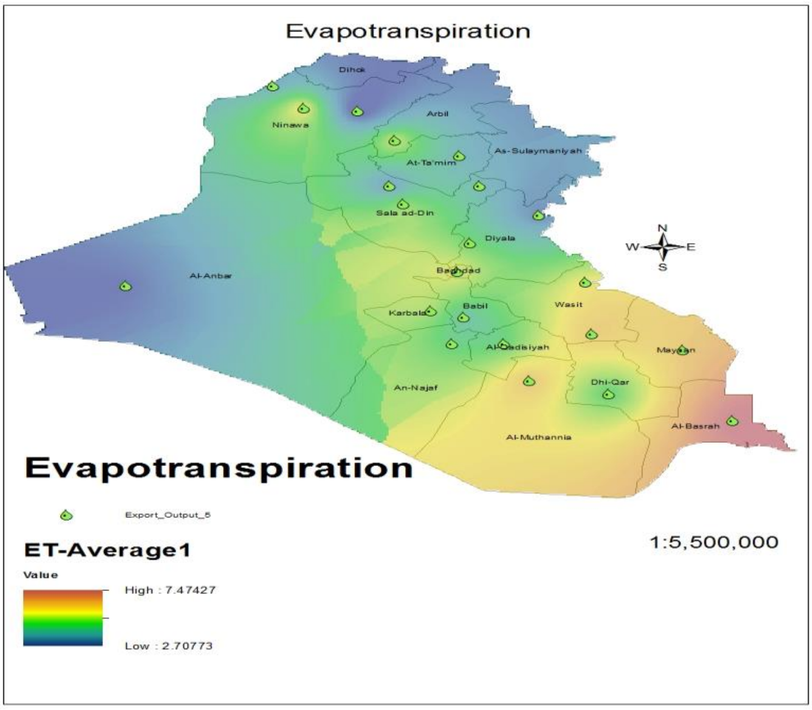

Figure (3): Average Evapotranspiration map for Iraq.

Mean monthly total evaporation measured for 15 climate stations for the period (2004 – 2013) in Iraqi meteorological organization and seismology which are less than 22 stations used in calculating evapotranspiration due to shortage in measuring evaporation data. Lowest mean monthly total evaporation was recorded in January in Mosel climate station was 34.9 mm while highest value recorded in Al Hai climate station in July was 651.4 mm. Fig (4) represent mean monthly total evaporation for Iraq which illustrate increasing in a mount of evaporation as we directed south.

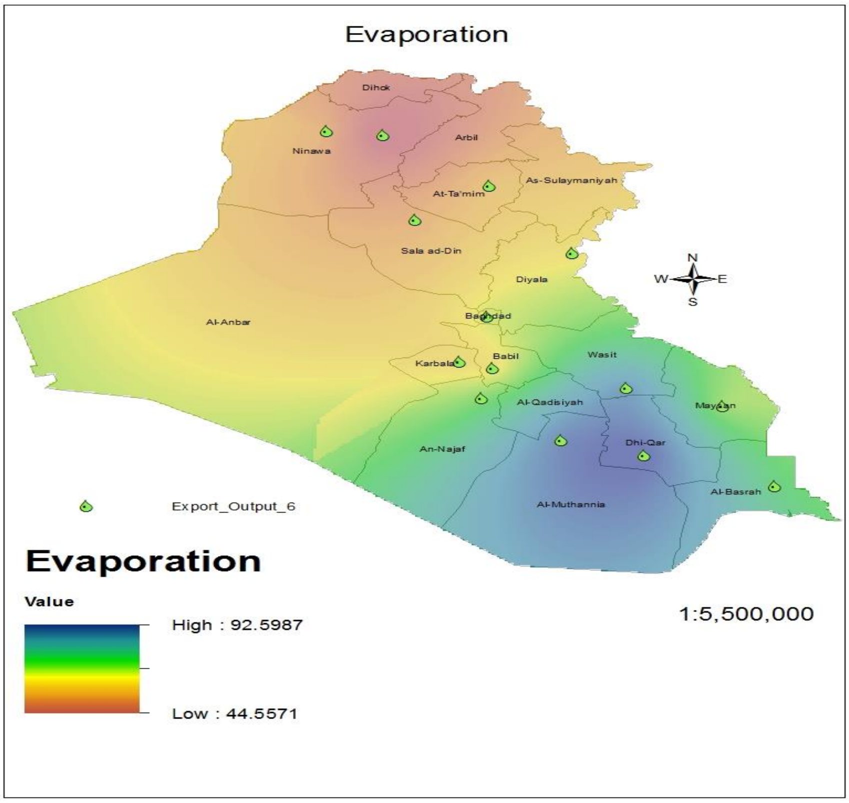

Figure (4): Average Evaporation map for Iraq.

From equation (5) we calculate pan coefficient (conversion constant) for 11 climate stations. Table (1) represent seasonal conversion constant Kp for some station in Iraq and the mean value equal to 0.67 in winter cooler time in the year and 0.59 in summer or warm period. These values were close to the recorded value 0.7 and 0.6 respectively for other cities [3].

Table (1): Kp for Iraqi stations.

	Conversion Constant			
	Winter	Spring	Summer	Autumn
Mousel	0.59	0.57	0.43	0.5
Kirkuk	0.61	0.7	0.54	0.47
Beji	0.56	0.53	0.54	0.52
Khanaqen	0.4	0.4	0.32	0.34
Baghdad	0.76	0.67	0.6	0.68
Karbala	0.81	0.75	0.69	0.74
Hilla	0.8	0.78	0.74	0.76
Hai	0.65	0.58	0.51	0.55
Najaf	0.6	0.57	0.53	0.53
Amara	0.83	0.81	0.77	0.79
Basrah	0.78	0.86	0.82	0.85
Average	0.67	0.66	0.59	0.61

Figure (5) illustrate the relation between ETo calculated from Penman-Montieth equation and evaporation measured by Iraqi meteorological organization and seismology for Basrah climate station (2004-2013). We found that the relation was linear as indicated by the relation:

$$Y=0.918+0.239x$$

with $R^2=0.9615$

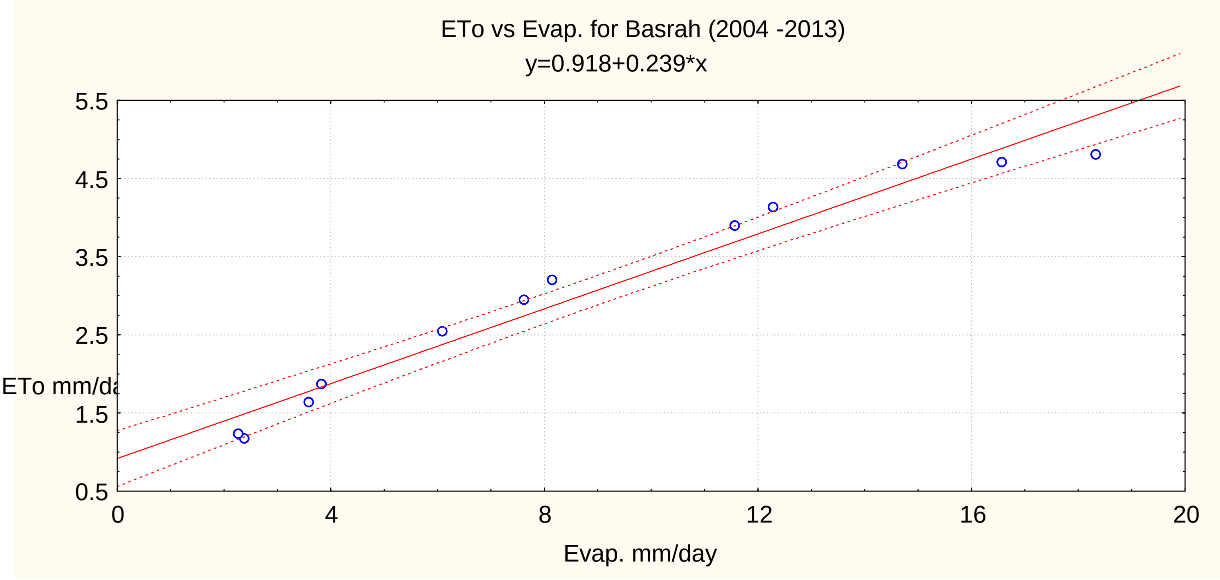

Figure (5): Relation between ET0 and Evaporation (Basrah).

Figure (6) illustrate relation between ETo calculated from Penman–Monteith equation and evaporation Measured by IMO for Baghdad climate station.

We find R^2=0.9955.

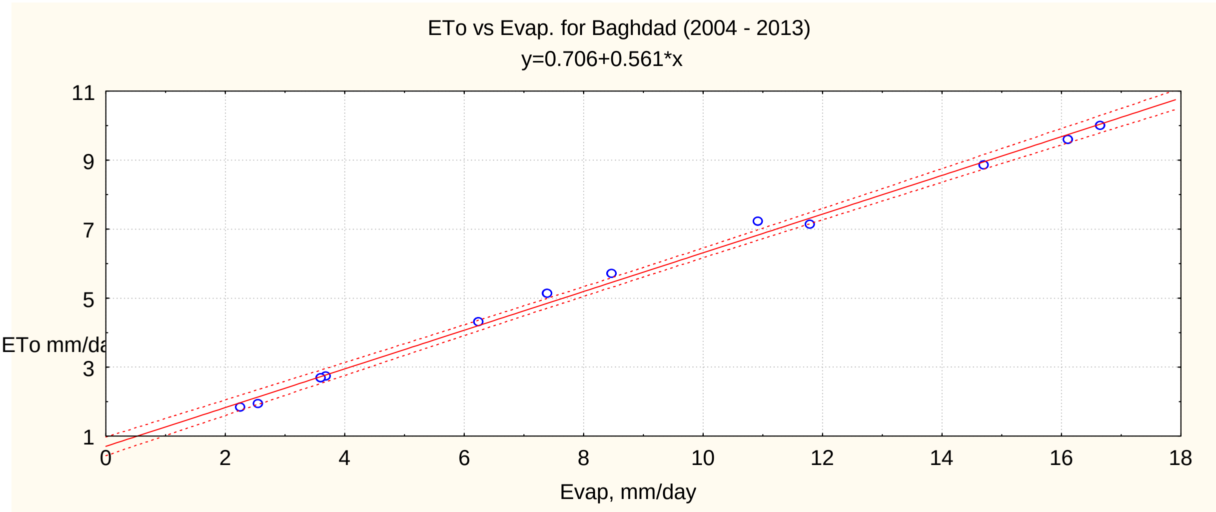

Figure (6): Relation between ET0 and Evaporation (Baghdad).

Figure (7) represent a degree of a comparison between evaporation calculated by appling equation (5) and evaporation measured for Baghdad climate station for 2013.

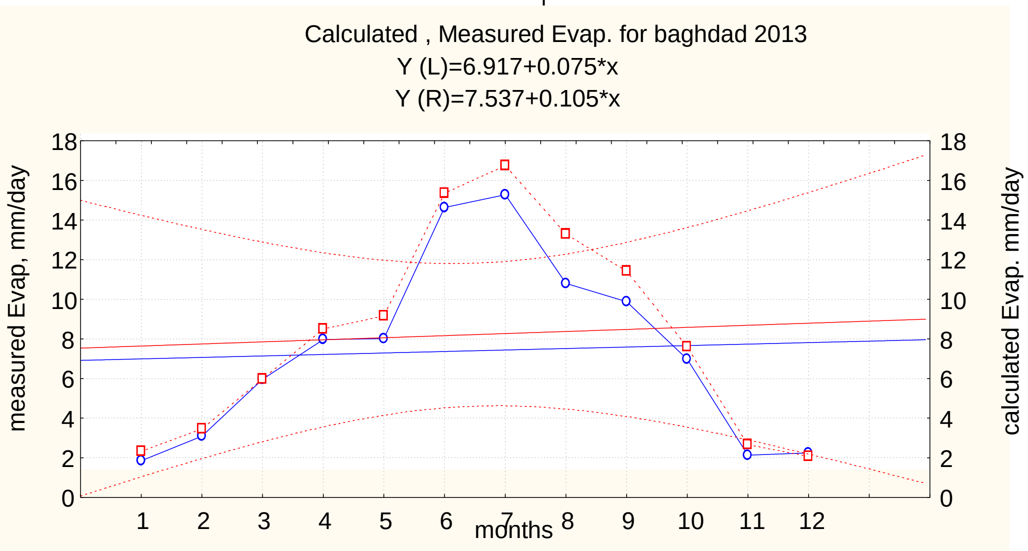

Figure (7): Comparison between measured and calculated evaporation.

4. Conclusion:

We notice from the distribution map for evapotranspioration and evaporation climate elements that its values were less than the values of its records in Nassirya, Ammara, Simawa as that's related to Basrah city were it is surrounded by water area be a source of water vapor in the atmosphere increasing humidity decreasing evapotranspiration and evaporation process. Evaporation affected by relative humidity and wind speed surrounding station like Nassirya having higher speed of air than Basrah also prevailing wind in Basrah was SE for some month which mean that the blowing air on Basrah city comes from Arab Gulf saturated by water vapor decrease evaporation and evapotranspioration. Evaporation is very important element in irrigation process , the amount of water evaporated during time affected by more than one parameters complicated the measurement accuracy, our procedure aimed to calculate amount of evaporation from calculating evapotranspiration and pan coefficient using cropwat v 8.0, from Figure(7) we found a similarity between calculated and measured evaporation giving high reliability to adopt this method to find missing data for evaporation element for different places in Iraq.

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