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STUDY AND ANALYSIS OF EVAPOTRANSPIRATION IN ERBIL CITY

The research

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Dedication:

This research project is the work of one academic year. It is decated to :

- My beloved family
- To all my teachers, who taught me throughout my life, especially assistant professor Dr. Mohammed Azeez Saeed who supervised this research work.

Acknowledgments:

I would like to send my warm and endless thanks and gratitude to my family who supported me during all the years of the study without which I was not able to continue my education. Also my special thanks is extended to Assistant Professor Dr. Mohammed Azeez Saeed for supervision of the study. Appreciations are due to the Department of General Science and the College of Basic Education for their support during the four years of the study.

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Abstract/Summary

In this work, hourly values of atmospheric parameters needed for the calculation of evapotranspiration from Penman – Monteith equation recorded by automatic weather station installed at Grdarasha Agriculture field are collected and analyzed.

The parameters, together with detailed calculation procedure are shown in forms of tables and graphs, only the data of five months are used , namely (February , March , June , July and September), 2008 . Because those are the only months were no missing values noticed.

It is found that modified Penman – Monteith method is the most accurate and widely used among all other methods available in the literature.

It is concluded that at Erbil, the calculated daily values of evapotranspiration varies from ($1.73 mm.day^{-1}$) in the month of February to ($9.74 mm.day^{-1}$) in the month of July while monthly total evapotranspiration varies from ($48.44 mm .month^{-1}$) in the month of February to ($301.94 mm. month^{-1}$) in the month of July.

Chapter One

1.0 Introduction:

In this chapter, definitions and scientific knowledge of Evaporation, Transpiration and Evapotranspiration are stated.

Different types of evapotranspiration and meteorological factors affecting the rate of evapotranspiration are also outlined, the hydrological cycle of water and the energy balance equation is also shown.

1.1 The Aim:

One of the most important factor in physical climatology and meteorology in energy balance equation is the process of Evapotranspiration (Evaporation+Transpiration).This process is the key factor in the availability of the amount of water vapor in the atmosphere, which intern controls the amount of rainfall in any region under consideration.

Evapotranspiration is also the sole of knowledge and calculation of crop water requirements, irrigation requirements, and irrigation schedule for any type of strategic agriculture crop in any region, which also intern controlling the infrastructure of the agriculture economy of country.

For these reasons, it was decided here to study the evapotranspiration in Erbil using the most universally recognized modified Penman – Monteith method.

1.2 Evaporation:

Evaporation is the physical change of state of water from solid and liquid to vapor and its diffusion into the atmosphere, it plays a major role in the redistribution of thermal energy between the earth and the atmosphere and is an essential part of the hydrological cycle. The process involves the supply of energy for latent heat of vaporization and the transfer process and it is a continuous process as long as there is a supply of energy [1].

The evaporation of one gram of water requires (597.3) calories at (0 ^{0}C) [2], and it is important in all water resource studies [3, 4].

There are three necessary conditions for evaporation to occur and persist [5]:-

1. There must be a continual supply of heat to meet the latent heat.

2. The vapor pressure in the atmosphere over the evaporating body must remain lower than vapor pressure at the surface of that body.

3. There must be a continual supply of water from or through the interior of the body to the site of the evaporation.

The rate of evaporation depends on many factors, the most important are [6]:-

1. The difference between the saturation vapor pressure at the water surface and the vapor pressure of the air, and the existence of continual supply of energy to the surface.

2. Wind velocity can also affect the evaporation rate because the wind is generally associated with the importation of fresh, unsaturated air which will absorb the available moisture.

3- Temperature, the rate of emission of molecules from liquid water is a function of its temperature, and evaporation increase with increasing temperature.

4- The atmospheric pressure, and also quality of water.

5- Relative humidity, the humidity of the air and also solar radiation.

The process of evaporation of water is shown in figure (1-1) from website [7].

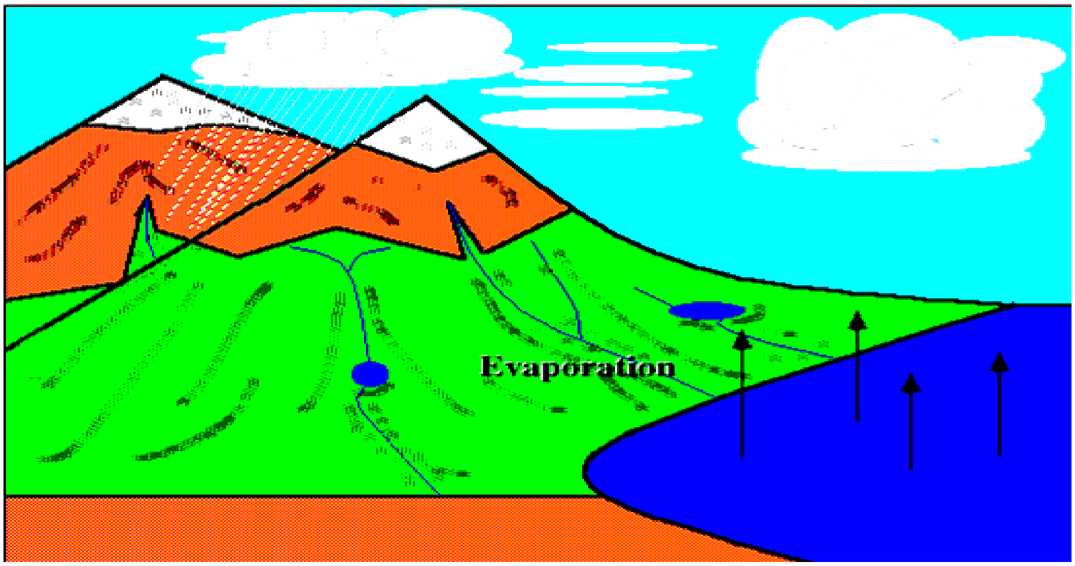

Fig (1-1): The evaporation processes [7]

It has been documented that about 80% of atmosphere water vapor comes by the process of evaporation [8].

1.4 Transpiration:

The transpiration is a physical process that loss of water from living plants, involves flow of liquid water from the soil to the surface of leaves.The conversion of liquid water from the plant tissue into water vapors in the atmosphere is not an essential or an active physiological function of plant but a passive response to the atmosphere environment.Transpiration occurs when the vapor pressure in the leaf cells is greater than the atmospheric vapor pressure [2, 5].

Transpiration is evaporation of water through the stomata plants which has been absorbed water from the soil through minute root [9].In addition to the factors affecting evaporation, transpiration is controlled by some other factors of plant such as [2]:-

1. The stage of plant growth.
2. Leaf area and leaf temperature.
3. The amount of soil moisture.

Transpiration in leaves occurs in stomata opening in light and closing in the dark and the opening of stomata during day leads to transpiration. Stomata are small openings on the plant leaf through which gases and water vapor pass, by the roots the water transfer to the plant.The process of transpiration increases by increasing the difference between atmosphere and leaf humidity [1].

The process of vaporization which occurs within the leaf is shown figure (1-2).

Fig (1-2): The vaporization process in the leaf [10]

In figure (1-3) the process of transfer of water from plants to the atmosphere (transpiration) is well explained from web site [11].

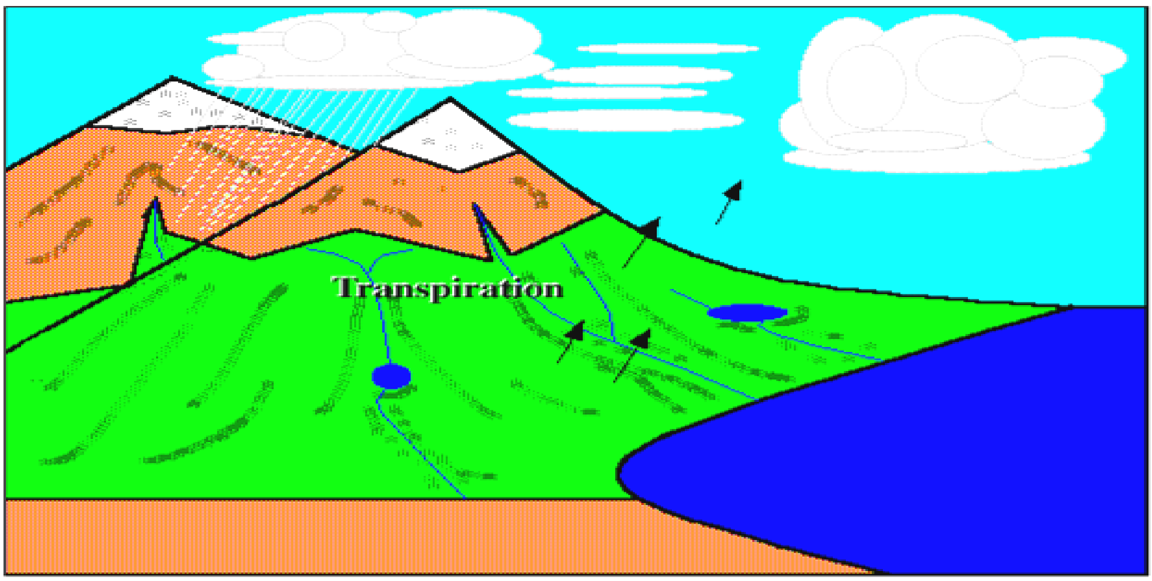

Fig (1-3): The transpiration process in the plant [11]

It has been documented that transpiration contributes about 20% of the atmosphere water vapor [8].

1.5 Evapotranspiration:

Evapotranspiration is the sum of water evaporation from land surface and transpiration from leave surface to the atmosphere, its energetic equivalent is latent heat flux, which is the energy required to evaporation water, it is a crucial component for energy, and is a key mediator of ecosystem water status along the soil-vegetation – atmosphere continuum. Evapotranspiration is the concurrent occurrence of evaporation and transpiration, they influence each other. Soil evaporation is reduced by occurrence of transpiration [9, 12].

Evaporation and Transpiration are two components of evapotranspiration, Allen et. al. (1998) Defined reference evapotranspiration as " the rate of evapotransipration from hypothetically crop with an assumed crop height (12cm) and fixed canopy resistance (70 s m^{-1}) and Albedo (0.23) which would closely resemble evapotransipartion from an extensive surface of green grass cover of uniform height , actively growing, completely shading the ground and not short of water [13].

It is one of the important components in studies involving hydrology specifically in studies related to irrigation planning, evapotranspiration is a term often used to describe water loss to the atmosphere from the combined water, soil and plant surfaces of an area[14] .

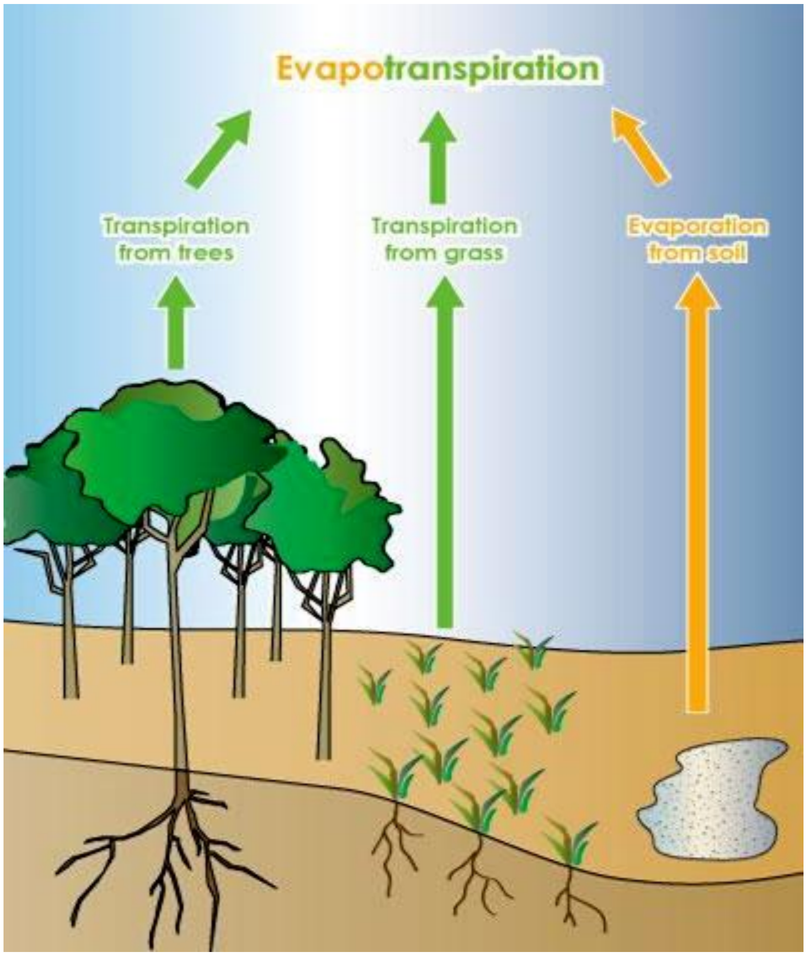

Fig (1-4): The Evapotraspirartion process [15]

In Figure (1-4) from website [15]. It is clear that the loss of water from a vegetated surface through the combined processes of soil evaporation and plant transpiration, the difference between the two processes is in the technique, where the water lost by transpiration must enter the plant via the root , then pass to the foliage where it is vaporized and lost to the atmosphere through tiny pores in the leaves(stomata) ,while water lost through soil evaporation passes directly from the soil to the atmosphere, these two interdependent processes are generally difficult to separate [16].

The Evapotranspiration increases with [17]:-

1. Higher air temperature.
2. More solar (light) energy.
3. Lower humidity.
4. Fast wind speed.

Evapotranspiration is an important process of the hydrologic cycle, returning approximately (75%) of the total rainfall on continental basis to the atmosphere [18].The level of the evapotranspiration is controlled mainly by the factors which are [19, 20]:-

1. Plant characteristics.
2. Extent of ground cover and stage of growth of plants.
3. Water availability in soil.
4. Meteorological parameters.
5. Reflection coefficient of sunlight (Albedo).
6. Stomata resistance.

In the literature, two terminologies of evapotranspiration have been defined, as follow:

The indirect measurement is based on the moisture balance equation [20]:-

Precipitation = Runoff+ Evapotranspiration+ the change in ground and Soil moisture storage change …..(1.1)

The moisture balance equation (eq.1.1) is well explained in figure (1-5) from web site [20].

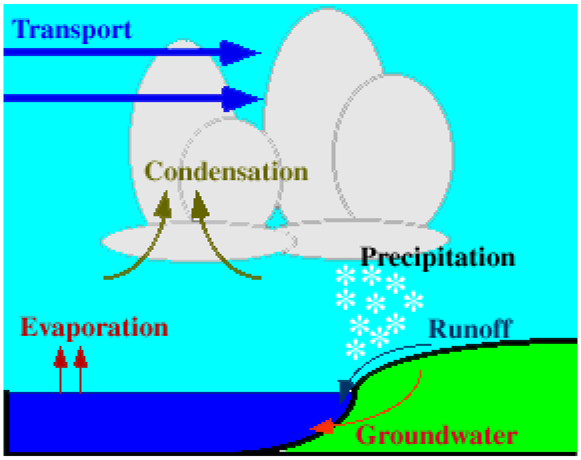

Fig (1-5): The balance equation [20]

1.6 Units of Evapotranspiration:

The evapotranspiration rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from surface in units of water depth, the time unit be an hour, day, decade, month or even an entire growing period or year. It is usually measured in mm/ day.

The rate of evaporanspiration is expressed as a volume of water evaporated per unit area per unit time, as follow:-

$= mm^3\ mm^{-2}\ day^{-1} = mm\ day^{-1}$

Thus it is measured in the same units as rainfall.

1.7 Meteorological factors affecting Evapotranspiration :

As mentioned before, the rate of evapotranspiration at any location on the earth's surface is controlled by several factors. These factors can be summarized as follow [20]:

1. Energy availability: the more energy available, the greater the rate of evapotranspiration. It takes about (597.3) calories of heat energy to change (1) gram of liquid water into a gas.
2. The humidity gradient away from the surface, the rate and quantity of water vapor entering into the atmosphere both become higher in drier air.
3. The wind speed above the surface, the process of evapotranspiration moves water vapor from ground or water surfaces to an adjacent shallow layer that is only a few centimeters thick, when this layer becomes saturated evapotranspiration stops, wind can remove this layer replacing it with drier air which increases the potential for evapotranspiration.
4. Winds also affect evapotranspiration by bringing heat energy into an area, an 8 km per hour wind will increase still-air evapotranspiration by 20 percent and 24 km per hour wind will increase still-air evapotranspiration by 50 percent.
5. Water availability, evapotranspiration cannot occur if water is not available.
6. Physical attributes of the vegetation. Such factors as vegetative cover, plant height, the leaf area index and shape and the reflectivity of plant surfaces can affect rates of evapotranspiration.
7. Stomatal resistance, Plants regulate transpiration through adjustment of small openings in the leaves called stomata. As stomata close, the resistance of the leaf to loss of water vapor increases, decreasing to the diffusion of water vapor from plant to the atmosphere.
8. Soil characteristics, soil characteristics that can affect evapotranspiration include its heat capacity, and soil physical properties.
9. Type of plant, plants transpires water at different rates. Some plants which grow in arid regions conserve precious water by transpiring less water than other plants.

Chapter Two : Methods of Measurement of Evapotranspiration

2.1 Direct method:

2.1.1 Piche evapormeters:

A piche evapormeter consists of an inverted graduated tube filled with water and a filter paper clamped over its mouth, the instrument is kept in a Stevenson's screen, the piche evapormeter is not very reliable, it overestimates the effects of wind and underestimates the effects of solar radiation [1].

2.1.2 Evaporation pan:

Are very useful field method , the amount of evaporation from the pan must be adjusted to take any rainfall into account, the evaporation varies considerably with pan size, depth, material , exposure and water level , and we known the change of the water by scalar ruler which is inside the pan and gives the amount of evaporation , the size of the pan is important to know, the height is (h= 25 cm) and the diameter is (R=125 cm) , the general effect of the various factors is to make pan evaporation usually greater than that of a large open-water surface[19] .

2.1.3 Lysimeter:

Lysimeter is defined as the calculation of the vertical output fluxes using the volume and concentration of leached water over a period of time from a defined volume of soil (Muller, 1995) [1], the lysimeters are tanks, filled with soil and buried in the ground, to measure the loss of water from the soil, they are commonly used for measuring evapotranspiration from a crop, Lysimeters are of the drainage and weighing types, with the latter the most commonly used instrument.

2.2: Indirect Method: Empirical Method:

The concept of reference evapotranspiration was introduced to avoid need to calibrate a separate evapotranspiration equation for each crop and stage of growth , there are six internationally accepted equation for estimating Evapotranspiration based on temperature and radiation[13] , they are :

2.2.1 Thornthwaite (1948):-
2.2.2 Hargreaves equation:
2.2.3 Priestley-Taylor model (Priestley and Taylor, 1972):
2.2.4 Adjusted Hargreaves (Trajkovic, 2007):
2.2.5 Stanghellini equation:
2.2.6 Penman–Monteith method (Monteith1965, Allen et al, 1998):

The Penman- Monteith equation is used for computing water evaporation from vegetated surface, and developed by John Monteith in (1965) [14]. Monteith’s derivation was built upon that of Howard Penman (penman. 1948). This equation is used universally for the measurement of the evapotranspiration because of very high precision in the calculations and depends on the physical factors of the climate, such as temperature, humidity, reflection coefficient (Albedo) and the solar radiation.

Among all the models mentioned above, Penman- Monteith method is the best reliable method for evapotranspiration calculation in arid and humid locations of the world as compared to the performance of various other evapotranspiration models. The Penman-Monteith equation is simple representation for the physical and physiological factors which are governing evapotranspiration process. This equation requires the air temperature, humidity, radiation and wind speed for daily, weekly and monthly calculation. This equation is physically based on a combination of the energy balance and aerodynamic transport consideration is a major contribution to the field of agricultural and environmental physics.

Food and Agriculture Organization of the United Nations (FAO) standard method for modeling evaporanspiration use Penman-Monteith equation. Penman–Monteith equation from the energy balance equation we get [30]:-

$$ET_0 = \frac{1}{\lambda} \times \frac{\Delta(R_n - G) + K_t \times \frac{VPD \times \rho \times C_p}{r_a}}{\Delta + \gamma(1 + \frac{r_c}{r_a})} \qquad (2.6a)$$

Where r_c is the canopy resistance (s m^{-1}), r_a is the aerodynamic resistance (s m^{-1}).

From the original Penman – Monteith equation (2.6a) and the equations of the aerodynamic and surface resistance , the FAO Penman- Monteith method to estimate evapotranspiration can be derived and get this formula by (Allen et al., 1998) [20] :-

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T_a + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (2.6b)$$

And also for reference evapotranspiration for short grass or a tall reference crop which is also defined by Penman (1947) as " the amount of water transpired in unit time by a short green crop, completely shading the ground , of uniform height and never short of water , the equation :-

$$ET_0 = \frac{\Delta(R_n - G)}{\lambda\{\Delta + \gamma(1 + C_d U_2)\}} + \frac{\gamma \frac{C_n}{T_a + 273.16} U_2(e_s - e_a)}{\Delta + \gamma(1 + C_d U_2)} \qquad (2.6c)$$

Equation (2.6c) is very important because it depends on all elements of the climate and atmosphere.

ET_0- hourly reference evapotranspiration (mmh^{-1}).

R_n- net radiation at the crop surface ($MJ\ m^{-2}\ h^{-1}$).

G- Soil heat flux density ($MJ\ m^{-2}\ h^{-1}$).

T_a- Mean hourly air temperature at 2 m height (°C).

U_2- wind speed at 2 m height ($m\ s^{-1}$)

e_s- Saturation vapour pressure (kP_a) at the mean hourly air temperature (T) in (^0C).

e_a- actual vapor pressure (kP_a)at the mean hourly air temperature (T) in ^0C

$e_s - e_a$- saturation vapor pressure deficit (kP_a),

Δ - Slope of saturation vapor pressure curve ($kP_a\ °C^{-1}$), at the mean hourly air temperature (T)

γ- Psychometric constant ($kP_a\ °C^{-1}$)

C_d- Bulk surface resistance and aerodynamic resistance coefficient or denominator constant change with reference type.

λ - Latent heat of vaporization in ($MJ\ kg^{-1}$)

C_n-numerator constant that changes with reference type and calculation time step which for hourly during day time is equal = 37

The method proposed by Penman (1948) is physically based and hence inherently more meaningful, his equation based on a combination of the energy balance and aerodynamic transport consideration, is a major contribution in the field of agricultural and environmental physics [6].

Chapter Three
3.0 Results and Discussion

In order to organize the results of the calculations of evapotranspiration shown in columns of tables (1).

Table (1) The monthly mean hourly Evapotranspiration /mm h^{-1}

Time/h	February/ET_0	March/ET_0	June/ET_0	July/ET_0	September/ET_0
0	0.01	0.02	0.03	0.09	0.03
1	0.01	0.02	0.04	0.08	0.02
2	0.01	0.02	0.05	0.08	0.02
3	0.01	0.02	0.04	0.09	0.03
4	0.01	0.02	0.03	0.09	0.04
5	0.01	0.02	0.05	0.11	0.04
6	0.01	0.03	0.08	0.12	0.03
7	0.01	0.01	0.31	0.33	0.16
8	0.05	0.10	0.47	0.51	0.28
9	0.11	0.18	0.60	0.66	0.38
10	0.14	0.21	0.75	0.81	0.46
11	0.19	0.22	0.82	0.91	0.61
12	0.22	0.22	0.84	0.99	0.66
13	0.22	0.25	0.88	0.93	0.62
14	0.19	0.25	0.94	0.99	0.73
15	0.22	0.28	0.82	0.93	0.75
16	0.14	0.20	0.81	0.90	0.33
17	0.08	0.13	0.32	0.44	0.26
18	0.02	0.05	0.23	0.37	0.12
19	0.02	0.03	0.18	0.16	0.08
20	0.01	0.02	0.14	0.07	0.07
21	0.02	0.01	0.04	0.03	0.05
22	0.02	0.02	0.03	0.00	0.04
23	0.01	0.02	0.02	0.05	0.04
Sum,mmday^{-1}	**1.73**	**2.35**	**8.52**	**9.74**	**5.85**

From table (1) it can be seen that the maximum hourly value of (0.22mmh^{-1}) were occurred at (12 and 13 h) in the month of February,(0.28 mmh^{-1}) at (15 h) in March, (0.94 mmh^{-1}) at (14 h) in June, (0.99 mmh^{-1}) at (12 and 14 h) in July, and (0.75 mmh^{-1}) at (15h) in month of September, the values of daily evapotranspiration shown in table (1) is plotted in figure (1).

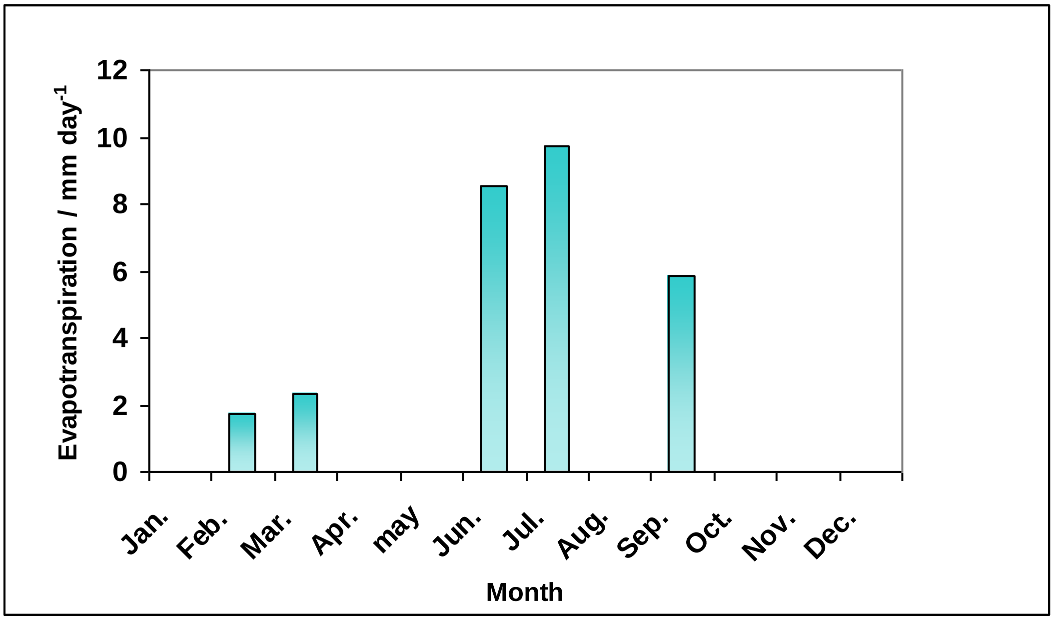

Fig (1): Daily mean Evapotranspiration/mm day^{-1} with five months

During the course of the day, hourly values of evapotranspiration starts to increase from sunrise to the afternoon then decrease to the minimum at midnight , this variation are caused by increase of air temperature and net radiation during the day , while the rest of the parameters can be considered almost constant or very slowly varied during the night time.

The values of hourly evapotranspiration shown in table (1) are plotted in figure (2) for the months (February, March, June, July and September), respectively.

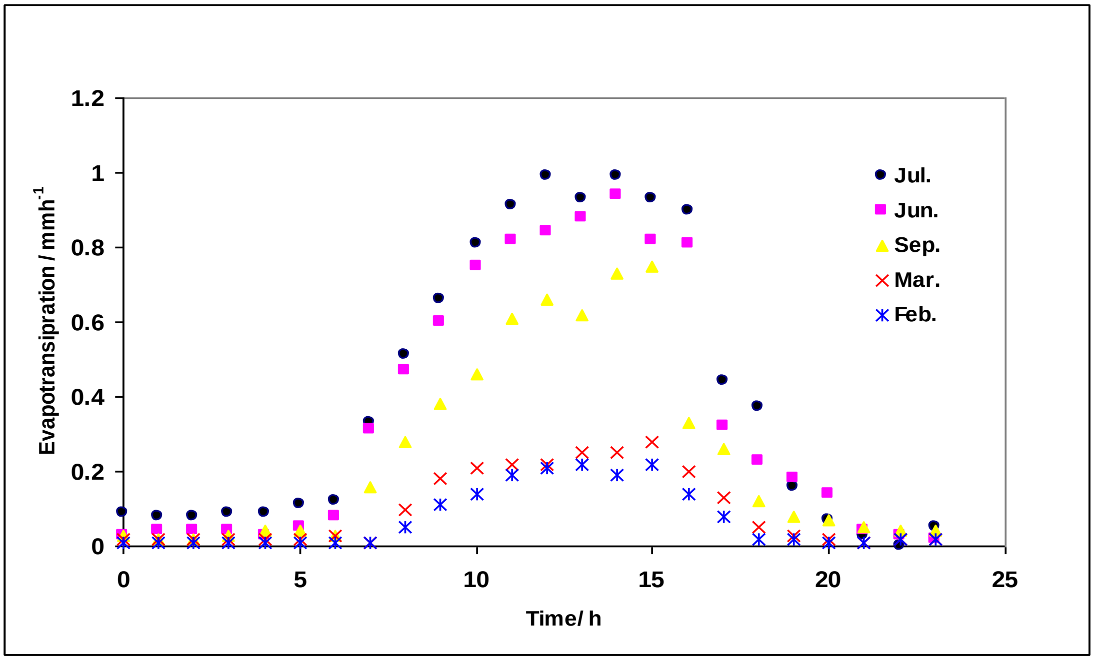

Fig (2): Hourly mean Evapotranspiration/mm h^{-1} for the five months with time

Chapter four:

4.1 Conclusions:

From the results and analysis carried out in this research work, the following conclusions can be made:

1. Modified Penman – Monteith method is the easiest equation in calculation of hourly, daily and monthly evapotranspiration.
2. Monthly mean daily total evapotranspiration at Erbil varies from the minimum value (1.73 $mmday^{-1}$) in the month of February to the maximum value (9.74 $mmday^{-1}$) in the month of July.
3. Monthly total evapotranspiration at Erbil varies from the minimum value of (48.44 mm $month^{-1}$) in the month of February to the maximum value of (301.94 mm $month^{-1}$) in the month of July.

4.2 Suggestions for future work:

1. Determination the Evapotranspiration /mm h^{-1} by using other method and comparing the results with the evapotranspiration by using Penman – Montieth equation for the same place, in Erbil.
2. Data record from other places of Kurdistan region (Dhouk, Suleimanyiah) for the same five months by using Penman – Monteith equation and study the difference in the values of evapotranspiration , hourly , daily and monthly
3. Study the evapotranspiration in the agriculture field which are near the rivers, lakes or dams in order to see their effects.

4. Study evapotranspiration at different altitudes to see the effect of height variation on it.

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