

EVALUATION OF REFERENCE EVAPOTRANSPIRATION FOR GERIYO IRRIGATION PROJECT USING FAO-56 PENMAN MONTEITH MODEL IN YOLA, NIGERIA

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ABSTRACT

Estimates of reference crop evapotranspiration (ET_o) are widely used to define crop water requirements. These estimates are used in the planning process for irrigation schemes to be developed as well as to manage water distribution in existing schemes, thus accurate determination of reference evapotranspiration is very essential for precise computation of crop water use and productivity. This study was conducted to evaluate reference evapotranspiration for Geriyo Irrigation Project using FAO-56 Penman monteith model which is an effective tool for irrigation planning and management. Climatic data for the period of 15 years (2004-2019) were obtained from Upper Benue River Basin Development Authority metrological gauge station, Yola, Adamawa State, Nigeria for analysis. Climatic parameters such as solar radiation, slope of saturation vapour, Saturation vapour deficit, actual saturation vapour, and psychrometric constant were determined and used in the FAO-56 Penman monteith model. The model was validated using evapotranspiration obtained by Pan Evaporation method and had an R^2 value of 0.715. Results indicated that mean reference evapotranspiration value of 3.56 mm/day was obtained for the study area. The result revealed that solar radiation had the highest effect on evapotranspiration since it provide the energy needed for evapotranspiration to take place. The reference evapotranspiration determined using FAO56PM can be used for effective irrigation planning and management that will improve crop production and water productivity in the study aera.

Keywords: Evaluation, Evapotranspiration, FAO-56 PM Model, Geriyo, Irrigation, Meterological data

1. INTRODUCTION

Evapotranspiration is a combined process of both evaporation from soil and plant surfaces and transpiration through plant canopies [1]. Weather parameters, crop characteristics, management and environmental aspects affect evapotranspiration. The evapotranspiration rate from a reference surface is called the reference evapotranspiration denoted as ET_o [2]. Estimates of reference crop evapotranspiration (ET_o) are widely used in irrigation engineering to define crop water requirements. These estimates are used in the planning process for irrigation schemes to be developed as well as to manage water distribution in existing schemes. From the several existing ET_o equations, the FAO-56 application of the Penman-Monteith equation is widely used and can be considered as a sort of standard [3, 4]. The FAO-56 Penman-Monteith equation is predominately physically based approach, indicating that the method can be used globally without any need for additional parameter estimations and it is well documented, implemented in a wide range of software, and has been tested using a variety of lysimeters [2]. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. As water is abundantly available at the reference surface, soil factors do not affect evapotranspiration. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. Evapotranspiration values measured or

calculated at different locations or in different seasons are comparable as they refer to the evapotranspiration from the same reference surface. The only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data [2, 5]. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors [2]. Many models such as Blannet-Cridde, Priestley-Taylor, Hargreaves, and others are subject to sensitive analyses there by making them to have limited global acceptance. However, a reliable estimation of the reference evapotranspiration (ET_o) is of critical importance and required accurate estimates to study the water balance in an area [4]. FAO-56 Penman Monteith Model is standard, reliable and globally accepted for use in computation of reference evapotranspiration which will be used to define crop water requirement. FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration ET_o [4, 5]. FAO-56 Penman-Monteith equation is a predominately physically based approach, indicating that the method can be used globally without any need for additional parameter estimations [2]. The FAO-56 Penman-Monteith method was developed by defining the reference crop as a hypothetical crop with an assumed height of 0.12 m, with a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered [6]. The method overcomes the shortcomings of the previous FAO Penman method and provides values that are more consistent with actual crop water use data worldwide. FAO-56 Penman-Monteith method uses standard climatic data that can be easily measured or derived from commonly measured data [7]. All calculation procedures have been standardized according to the available weather data and the time scale of computation [8]. The FAO-56 Penman- method has a strong theoretical basis, including energy balances to model ET_o . It is based on fundamental physical principles, which guarantee the universal validity of the method. However, it needs four meteorological parameters: air temperature, relative humidity, wind and net radiation, which may not be everywhere available [7, 9]. Thus, the aim of this research work is to determine some climatic parameters of the study area and evaluate the reference crop evapotranspiration (ET_o) of Geriyo Irrigation Project using FAO-56 Penman Monteith model for effective irrigation and management in the scheme for optimum crop performance that will enhance increase in crop yield and water use productivity.

2 DESCRIPTION OF STUDY AREA

The study area is Lake Geriyo Irrigation project located at the north western part of Jimeta, Yola North local government area of Adamawa state. Lake Geriyo lies between Longitude $12^\circ 00'$ and $12^\circ 28'$ E Greenwich and Latitude $9^\circ 16'$ and $9^\circ 19'$ N of the equator [10]. It covers an area of 850 ha with 320ha currently under cultivation. The area has two major seasons, the rainy and dry season. The rainy season last from the beginning of May to end of October, and the dry season last from November to the end of April. The driest months are January and February where the average minimum relative humidity is 13%. The wettest months are August and September where rainfall depth reaches up to 25% of the total annual rainfall. The hottest month is April with monthly average temperature of 39.9°C while the coldest months are December and January with minimum average temperature of 16°C [11]. The map of the study area is as shown in Figure 1.

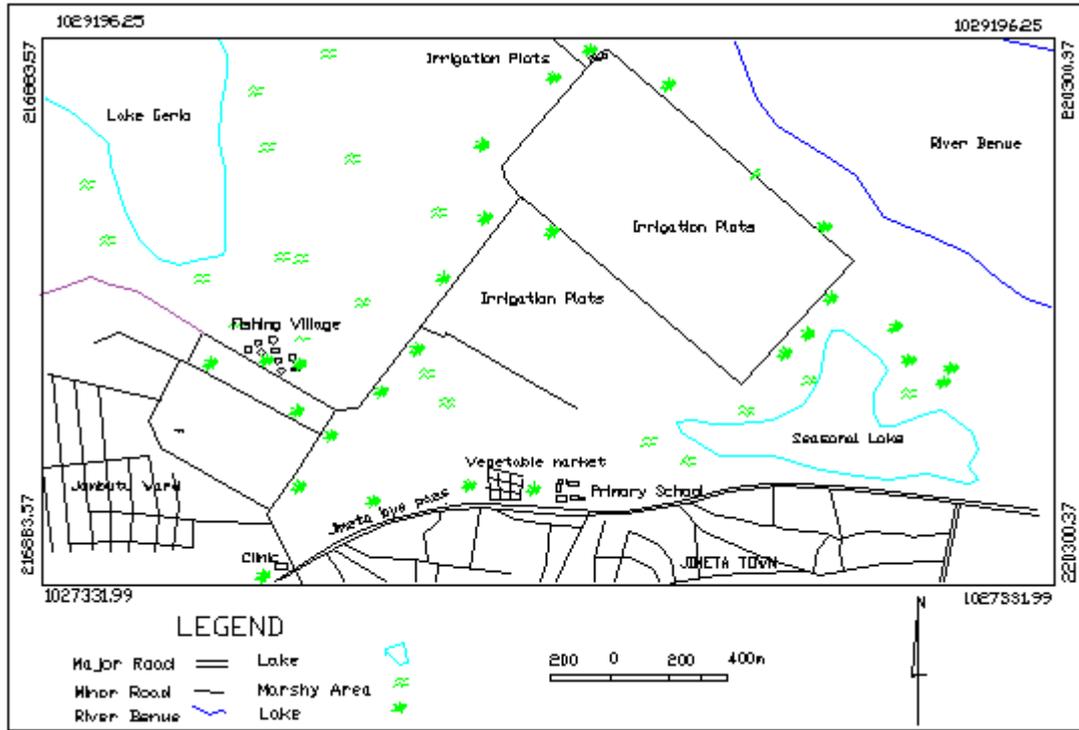


Figure 1. Map of Gerio Irrigation Project

3 MATERIALS AND METHOD

3.1 Data collection

Data for 15 years were collected from Upper Benue River Basin Development Authority Metrological gauge station Yola, Adamawa State, Nigeria. The data included; Temperature, Relative humidity, Rain fall and Wind speed. The data collected were used to determine the required parameters that was used in the FAO-56 PM model.

3.2 Determination of climatic parameters

Climatic parameters used for the work include the following; Net radiation (R_n), Saturation vapour as a function of air Temperature ($e^\circ(T)$), Relative humidity (RH_{mean}), Saturation vapour pressure (e_s), Actual vapour pressure (e_a), Saturation vapour deficit ($e_s - e_a$), Solar radiation (R_s) and Wind speed (u_2).

3.3 Determination of saturation vapour pressure

As saturation vapour pressure is related to air temperature, it was calculated from the air temperature. The relationship is expressed by [6] as;

$$e^\circ(T) = 0.6108 \exp\left[\frac{17.27T}{T+237.3}\right] \quad (1)$$

3.4 Determination of relative humidity

RH_{mean} , was estimated as detailed by [2] as;

$$e_a = e^\circ(T_{mean}) \frac{RH_{mean}}{100} \quad (2)$$

$$e_s = \left[\frac{e^\circ(T_{max}) + e^\circ(T_{mean})}{2} \right] \quad (3)$$

3.5 Determination of saturation vapour pressure deficit ($e_s - e_a$)

The saturation vapour pressure deficit was calculated using [6]:

$$(e_s - e_a) = \left[\frac{e^\circ(T_{max}) + e^\circ(T_{mean})}{2} \right] - e^\circ(T_{mean}) \frac{RH_{mean}}{100} \quad (4)$$

3.6 Slope

Slope of saturation vapour pressure curve (Δ) was estimated as detailed by [2] expressed as;

$$\Delta = \frac{4098 e^{\circ(T)}}{(T+237.3)^2} \quad (5)$$

Where; Δ = slope of saturation vapour pressure curve at air temperature T [$k_{pa}/^{\circ}C$], T = average air temperature [$^{\circ}C$]. Psychrometric constant (Υ): The psychrometric constant in the Penman and Penman-Monteith (PM) was calculated from [2] expressed as:

$$\Upsilon = \frac{c_p P}{\epsilon \lambda} = 0.664742 \times 10^{-3} \times p \quad (6)$$

Where; (Υ) = psychrometric constant [$KPa/^{\circ}C$], P = mean atmospheric pressure [KPa], λ = latent heat of vaporization, 2.45 , c_p = specific heat at constant pressure, 1.013×10^{-3} [$MJ/kg/^{\circ}C$], ϵ = ratio molecular weight of water vapour/dry air = 0.622 .

$$p = 101.3 \left(\frac{293 - 0.0065z}{293} \right)^{5.26} \quad (7)$$

where; z = elevation above sea level, $z = 180m$ for Adamawa state.

3.7 Determination of solar radiation (R_s)

Solar radiation, (R_s) was calculated with the Angstrom formula, which relates solar radiation to extra-terrestrial radiation and relative sunshine duration [2]:

$$R_s = a_s + b_s \left[\frac{R_a}{N} \right] \quad (8)$$

$$R_a = \frac{24(60)}{3.142} G_{sc} \times Dr [Ws \times \sin Q \sin U + \cos Q \cos U \times \sin Ws] \quad (9)$$

where; G_{sc} = solar constant = $0.0820 MJ/m^2/min$

$$Dr = 1 + 0.033 \cos \left[\frac{2 \times 3.142}{365} \times J \right] \quad (10)$$

Dr = inverse relative distance Earth to Sun

$$U = 0.409 \times \sin \left[\frac{2 \times 3.142}{365} \times J - 1.39 \right] \quad (11)$$

U = Solar inclination angle, J = number of days in a year = 8035.5 for 22 years including leap year, Q = latitude of the area [rad].

$$Ws = \frac{3.142}{2} - \arctan \left[\frac{-\tan Q \times \tan U}{0.00001} \right] \quad (12)$$

Where; Ws = Sunset angle.

$$N = \frac{24}{3.142} Ws \quad (13)$$

N = number of day light hours

3.8 Determination of net radiation (R_n)

Net radiation (R_n) was determined by subtracting the net incoming short-wave radiation (R_{ns}) from the net outgoing long wave radiation (R_{nl}) [12] expressed as;

$$R_n = R_{ns} - R_{nl} \quad (14)$$

$$R_{ns} = (1 - \alpha) R_s \quad (15)$$

$$R_{nl} = \left[\frac{T_{max,K}^4 + T_{min,K}^4}{2} \right] (0.34 - 0.14 \sqrt{e_a}) (1.35 \frac{R_s}{R_{so}} - 0.35) \quad (16)$$

$$R_{so} = (0.75 + 2 \times 10^{-5} Z) R_a \quad (17)$$

Where; R_s = The incoming solar radiation, [MJ/m²/day], α = Albedo or canopy reflection coefficient, which is 0.23 for the hypothetical, grass reference crop, dimensionless, R_{ns} = Net solar or short-wave radiation [MJ/m²/day], R_{nl} = Net outgoing long wave radiation [MJ/m²/day], σ = Stefan-Boltzman constant [4.903×10⁻⁹ MJ/k⁴/m²/day], R_{so} = Clear sky radiation [MJ/m²/day], Z = Elevation above sea level, e_a = Actual air vapour pressure [kpa], $T_{max,k}^4$ = Daily maximum absolute temperature [°k], $T_{min,k}^4$ = Daily absolute minimum temperature [°k].

$$G_{monthi} = 0.07[T_{monthi+1} - T_{thimoni-1}] \quad (18)$$

Where; G_{monthi} = mean air temperature, $T_{monthi+1}$ = mean air temperature of next month = 37.26°C, $T_{thimoni-1}$ = mean air temperature of previous month = 20.65°C.

3.9 Determination of evapotranspiration using Pan Evaporation Model

The principal weather parameters which includes; maximum and minimum air temperature, air humidity, wind speed, and solar Radiation were determined and using Equation (19) in line with [13] was used to calculate the evapotranspiration of the study area:

$$ET_o = K_p \times E_{pan} \quad (19)$$

Where ET_o is the reference evapotranspiration (mm/day), K_p is pan coefficient, and E_{pan} is the pan evaporation (mm/day).

3.10 Determination of Evapotranspiration using FAO56 Penman Montieth Model

The calculated climatic parameters determined were used in the FAO-56 Penman Montieth model to estimate the reference evapotranspiration in line with [14] as;

$$T_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (20)$$

Where; ET_o = reference evapotranspiration[mm/day], R_n = net radiation at the crop surface [MJ/m²/day], G =soil heat flux density [MJ/m²/day], T =average temperature [°C], u_2 = wind speed at 2 m height [m/s], e_s =saturation vapour pressure [KPa], e_a =actual vapour pressure [KPa], $(e_s - e_a)$ =saturation vapour pressure deficit [KPa], Δ =slope vapour pressure curve [KPa/°C], γ =psychrometric constant [KPa/°C].

4 RESULTS AND DISCUSSION

4.1 Model validation

The evapotranspiration values calculated by the FAO-56 Penman Montieth model for Gerio Irrigation Project was compared with the pan evaporation evapotranspiration values. The results are presented in Figure 2. The figure shows that the ET_o values calculated by the FAO-56 PM model are in the range of those obtained by pan evaporation for the 15 year data obtained for the study. The relationship between ET_o estimated from the FAO-56 PM model and ET_o observed from the pan is linear with R^2 value of 0.715 which revealed that there was correlation between the evapotranspiration obtained from the FAO-56 PM model and corresponding values observed using pan evaporation.

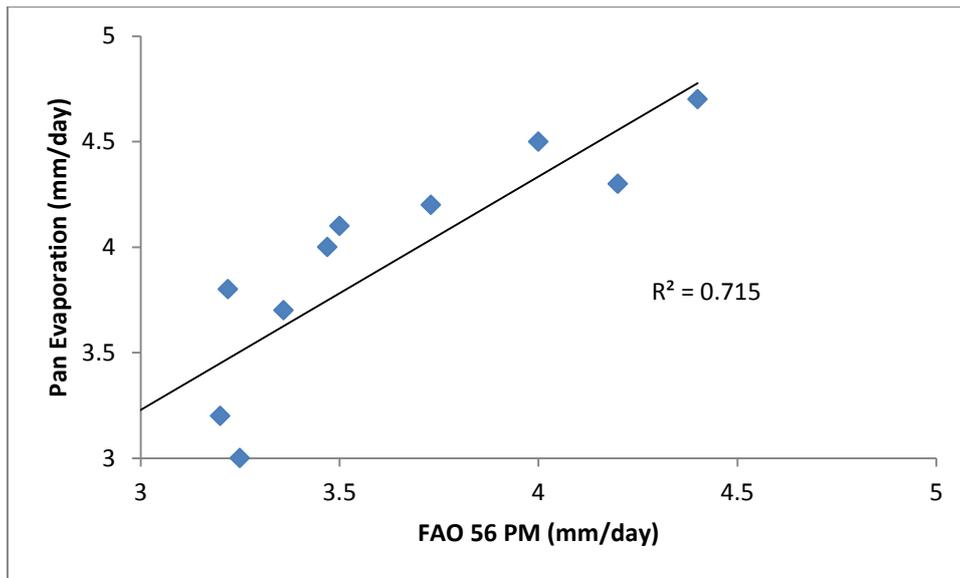


Figure 2. Relationship between FAO-56 PM and Pan Evapotration Model

3.2 Reference evapotranspiration

Table 1 shows the reference evapotranspiration and other parameters for the study area. The result indicates that evapotranspiration varied through out the year. It was observed that evapotranspiration was high during dry season especially between the months of December to April and the highest mean evapotranspiration value of 4.40 and 4.70 mm/day was observed in March for the FAO-56 PM and Pan evaporation models, respectively. During the rainy season between the months of May to November, low values of evapotranspiration were recorded with the lowest mean evapotranspiration value of 2.95 mm/day attained in the month of September and 2.8 mm/day recorded in the month of August for FAO-56 PM and Pan Evaporation models, respectively. The result revealed that the over roll mean reference evapotranspiration value of 3.56 mm/day was obtained for the study area which is lower than the value of 3.86 mm/day recorded by pan evaporation. It was observed that evapotranspiration demand is high in hot dry conditions due to the dryness of the air and the amount of energy available as direct solar radiation with latent heat of vaporization. Under these circumstances, much water vapour was stored in the air while wind aid in the transport of water allowing more water vapour to be taken up. On the other hand, under humid weather conditions during the rainy season when the relative humidity of the air is high with low solar radiation due to the presence of clouds cause the evapotranspiration to be lower as observed in the month of September and presented in Figure 3.

Table 1. Mean Climatic Parameters and Evapotranspirations for Gerio Irrigation Project

	Jan	Feb	Mar	Apr	May	Jun	Jul	Agus t	Sep	Oct	Nov	Dec	Mean
FAO-56 PM													
ET _o (mm/day)	4.00	4.20	4.40	3.50	3.36	3.20	3.25	3.10	2.95	3.22	3.47	3.73	3.56
Pan E													
ET _o (mm/day)	4.50	4.30	4.70	4.10	3.70	3.20	3.00	2.80	3.50	3.80	4.00	4.20	3.82
Tmax mean.	28.5	31.2	38.7	36.7.	34.2	30.7	28.7	25.9	29.3	28.7	30.7	25.7	30.75
Temp.(° C)													
Tmin. mean	15.3	22.4	22.8	25.4	23.4	20.5	15.7	18.5	13.4	15.7	16.8	20.1	19.17
Temp. (° C)													
RH. (%)	61	60	53	45	47	52	70	73	70	65	63	62	55.25
WindSpeed	2.63	2.75	3.72	3.45	2.32	2.31	2.22	2.25	2.30	2.62	2.74	2.52	2.65
(m/s)													
Rn(MJm ⁻² day ⁻¹)	15.22	15.71	16.32	16.02	16.22	16.20	10.72	8.73	10.70	10.53	12.88	13.02	13.54

Table 1 also reveals that both the maximum and minimum temperatures varied throughout the years. It was observed that highest maximum mean temperatures of 38.7°C was recorded in March during the dry season while the lowest mean minimum temperature of 13.4°C was obtained in

September during the raining seasons. The same trend was observed for relative humidity, wind speed and solar radiation which had mean values of 55.25%, 2.65 m/s and 13.54 MJ/m²/day, respectively. Figure 4, present the relations between the mean temperatures and months in the year for the study area. Higher temperatures were observed during the dry season compared to raining season. In addition, Figure 5 shows the relations of reference evapotranspirations, wind speed, relative humidity and solar radiations verses the months in the year. It was observed that all the parameters varied throuhout the months of the year. The figure revealed that wind speed had relatively small effect on evapotranspiration followed by relative humidity. However, solar radiation was observed to be high during dry season, but low during rainy season which had mean value of 13.54 MJ/m²/day and mean reference evapotranspiration of 3.56 mm/day for the study area which is in line with [5, 15]. This implies that the rate of evapotranspiration is directly related to the solar radiation. This is because for evapotranspiration to take place, energy is required to change the state of the molecules of water from liquid to vapour. This energy is provided by solar radiation. From the study, it was observed that solar radiation and temperature are the most important factors affecting evapotranspiration. The results of the analyses comparing FAO-56 PM model ET_o estimate with pan evaporation demonstrated that the model could be used well in estimating daily ET_o from meteorological data. The model gives accurate estimates based on a daily basis which can lead to improved accuracy in evapotranspiration estimation. The model performance was more accurate based on daily calibration between ET_o estimated from the FAO-56 PM model versus ET_o obtained from the evaporation pan. Thus, the FAO Penman Montieith model could be a useful tool for calculating reference evapotranspiration, which is required for accurate determination of irrigation water requirements.

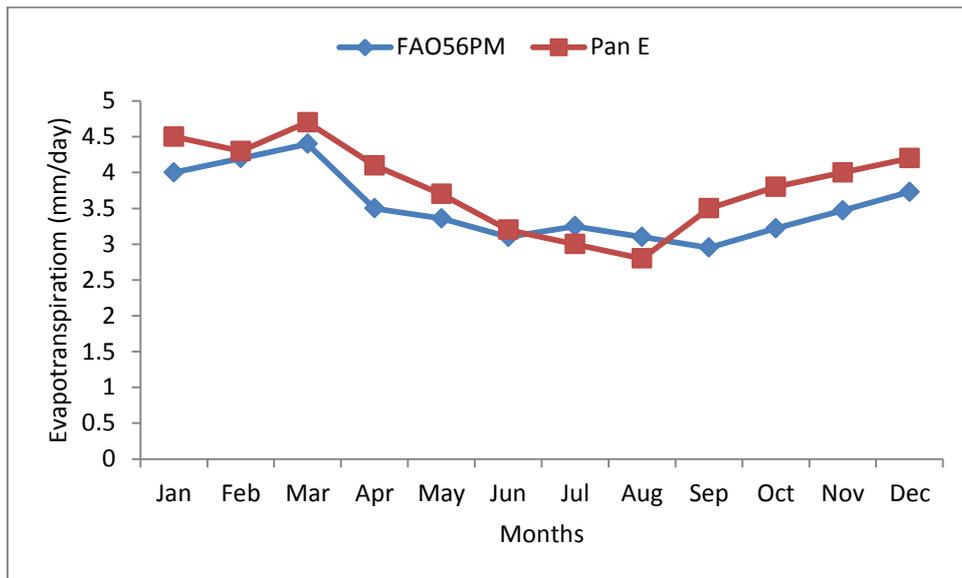


Figure 3. Reference Evapotranspirations verses Months

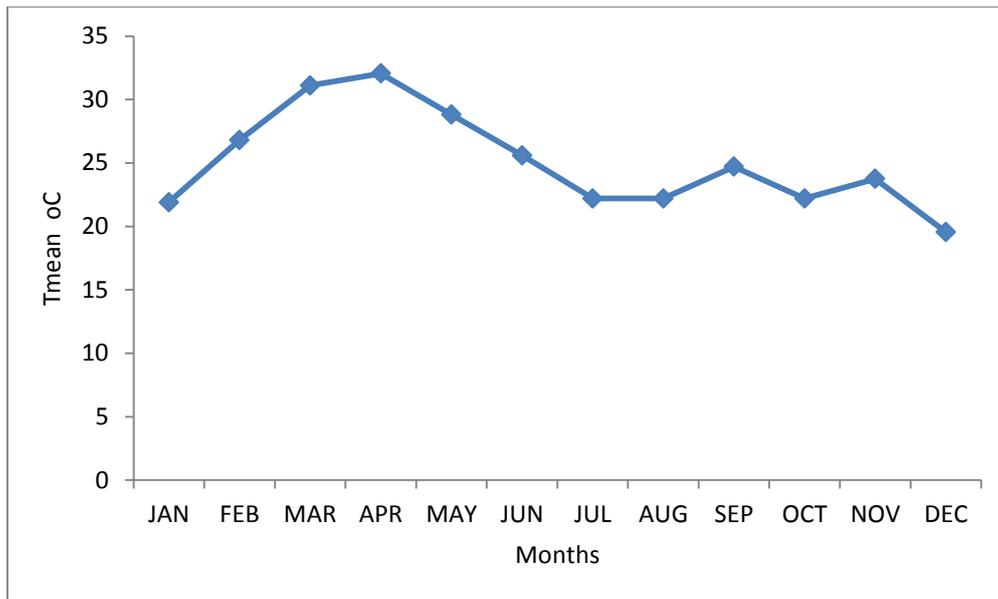


Figure 4. Relations Mean Temperature verses Months

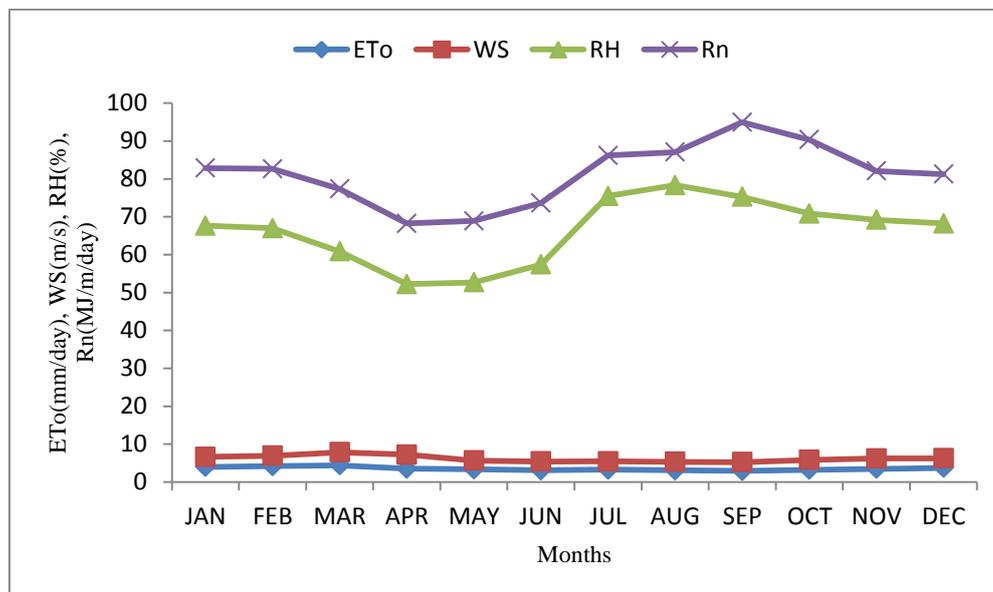


Figure 5. Relations of Evapotranspirations, Wind speed, Relative humidity and Solar radiation verses Months in the year

4 CONCLUSIONS

The climatic parameters of the study area were determined and used in the FAO-56 Penman-Monteith model to evaluate the reference evapotranspiration for Geriyo irrigation project. Estimated reference evapotranspiration using FAO-56 Penman Monteith model was compared with pan evaporation model values for validation. Comparing FAO-56 PM model ET₀ estimate with Pan Evaporation ET₀ demonstrated that the model could be used well in estimating daily ET₀ from meteorological data. Reference evapotranspiration value of 3.56 mm/day was obtained for the study area which can be used as a tool for effective irrigation planning and management in the scheme. Lower values of reference evapotranspirations were observed during rainy season due to the high relative humidity and low solar radiation, while higher values of evapotranspirations were recoded during the dry season as a result of hot dry air and high solar radiation. Among all the climatic parameters, solar radiation had the highest effect on reference evapotranspiration in the study area.

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