Modelling of Reference Evapotranspiration Using Penman's Monteith (FAO-56) For Bauchi Metropolis

Peter J. Manga [*], Abdullazeez A. Mohammad [**], Ibrahim Maina [**]

[*] Giwo Science Academy, Km3 Ningi Road Bauchi, Bauchi State, Nigeria
[**] Department of Physics, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria

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Abstract- Limited information exists on reliable estimates of evapotranspiration (ET) for successful design of Irrigation planning , management practices , water resource and the effective uses of the water resources .The evaporating power of the atmosphere is expressed by the references crop evapotranspiration (ET_O) which represents the evapotranspiration from a standardized vegetated surface. It is a climatic parameter which can be computed from weather data. The data was collected from the Agro-weather station of Abubakar Tafawa Balewa University, Bauchi (2013-2016) and was estimated using penman's monteith (FAO-56). The result obtained shows that in the months of April, May and June expresses the optimal evaporative demand of the atmosphere with a value of (13.008, 11.0487 and 12.1778) $mmday^{-1}$ therefore much water is needed for crops growth and development. Whereas Mean temperature, solar radiation and wind speed are positively correlated with the estimated ET_O with a range of correlation coefficient of (+0.504 - +0.866) which implies that the soil surface is cover by grass and crops, transpiration takes place while relative humidity and atmospheric pressure are weakly correlated with (ET_O) with a range of correlation coefficient (+0.380 - +0.063) were recorded. These weak correlation described the semi-arid region of Bauchi Metropolis.

Index Terms- Climatic parameter, correlation coefficient, evapotranspiration, penman's monteith.

I. Introduction

Evapotranspiration greatly affects crops during planting and harvest for the past decade, large volume of water was lost from the soil by evaporation and from the crops by transpiration, it reduces water content around the crops root zone leading to low yield of crops production as well as water scarcity [14].

According to [2] defined water scarcity as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully. Water scarcity affects all social and economic sectors and threatens the sustainability of the natural resources base. The need of addressing water scarcity on crops requires an urgent need to develop a standard, precise and globally acceptable method of estimating reference evapotranspiration for accurate computation of crop water requirements has been stressed by many authours [8, 9, 4, 3, 18, 7]. Several models had been proposed by many authours and these include FAO-Penman, Penman, 1982-KinberlyPenman, FAO-Corrected–Penman, Penman-Monteith, Blanney-Criddle, Priestley-Taylor, FAO-Radiation, Hargreaves, and FAO-Blanney Criddle [3, 6, 17, 5, 7]. Many of these models are subject to local calibration thereby making them to have limited global acceptance. Due to the higher performance of FAO-56 Penman-Monteith (FAO-56 PM) model in different parts of the world when compared with other models, it has been accepted as the sole method of computing reference evapotranspiration from meteorological data [13, 3, 12, 16, 19, 10, 11].

In order to use FAO-56 PM model in computing daily evapotranspiration, specific meteorological data are required such as daily maximum and minimum air temperature, solar radiation, wind speed, and relative humidity. These data can be obtained directly from automatic weather stations. These automatic weather stations are unavailable in most developing countries due to their high cost acquisition and maintenances. Similarly analogue instrument are used in some meteorological stations in Nigeria leading to limited data due to their archaic equipment and lack of suitable facilities. These make it difficult for estimation reference evapotranspiration.

In this study, Penman's monteith (FAO-56) model was developed for the estimation of evaporation and transpiration using climatic parameter such as maximum and minimum temperature, relative humidity, sunshine hour and wind speed available at the Agro-weather station (ATBU) for predicting which climatic condition the estimation of references evapotranspiration could be accurate or inaccurate for optimal use of water resources and the effective application of water resource for Bauchi metropolis.

II. MATERIALS AND METHOD

3.1 Data collection

Maximum and minimum temperature, relative humidity, sunshine hour, solar radiation and wind speed for a period of four (4) years (2013 - 2016) for Bauchi latitudes 9° 3' and 12° 3' north and longitudes 8° 50' and 11° east. Table 1-6 was obtained from Agro-weather station, Abubakar Tafawa Balewa University, Bauchi.

3.2 Estimation of reference evapotranspiration

The study was developed to estimate the reference evapotranspiration based on Penman-monteith method (FAO-56) by using of metrological data (2013-2016).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a+273} U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad \ldots(1)$$

Whereby ET_o is the reference evapotranspiration mmday^{-1}
From equation (1) we obtained the solution of Δ, R_n, G, T_a, U_2, e_s, e_a and γ respectively from empirical relation.

Table 1: Monthly Mean Daily Maximum Temperature (T_{max} ^0C)

Month	2013	2014	2015	2016
January	26.45	26.55	25.17	17.43
February	28.68	28.71	30.59	25.35
March	31.34	32.34	32.54	31.19
April	29.15	34.28	32.59	33.00
May	29.44	30.92	31.12	31.81
June	27.39	29.55	30.45	28.87
July	25.83	27.19	27.19	25.81
August	27.91	26.17	25.87	24.97
September	27.72	26.89	25.38	25.38
October	27.93	29.17	24.34	27.61
November	27.24	28.67	25.30	27.46
December	26.89	26.92	22.09	25.78

Table 2: Monthly Mean Minimum Temperature (T_{min} ^oC)

Month	2013	2014	2015	2016
January	23.87	23.95	21.68	16.72
February	25.78	25.88	28.62	25.53
March	28.98	29.86	29.58	31.18
April	29.00	30.61	30.44	32.99
May	29.44	28.62	31.09	31.80
June	25.08	29.49	29.56	28.85
July	23.57	25.23	25.23	25.80
August	25.39	24.37	23.56	24.96
September	25.86	24.47	25.35	25.35
October	26.29	24.77	24.11	27.59
November	24.35	26.36	25.29	27.44
December	23.55	26.84	22.08	25.76

Table 3: Monthly Mean Relative Humidity (Rh %)

Month	2013	2014	2015	2016
January	17.20	17.65	17.36	27.23
February	14.29	28.71	12.71	17.75
March	20.91	32.34	17.55	26.89
April	38.85	38.92	14.06	34.71
May	52.11	54.76	40.02	54.69
June	61.87	61.09	66.45	68.98
July	71.26	70.91	70.91	82.73
August	78.83	75.03	78.83	86.66
September	71.85	72.31	83.94	83.94
October	56.41	57.00	73.41	65.76
November	26.53	29.34	42.58	39.75
December	23.46	21.34	34.97	28.42

Table 4: Monthly Mean Solar Radiation$\left(MJm^{-2}day^{-1}\right)$.

Month	2013	2014	2015	2016
January	17.76	15.46	16.44	10.48
February	16.17	16.25	17.20	10.98
March	19.32	19.51	19.55	19.51
April	20.91	19.75	22.04	19.75
May	19.05	18.82	20.22	18.82
June	17.76	19.97	19.06	19.97
July	14.16	16.87	16.87	16.87
August	13.34	14.83	14.16	16.49
September	12.56	17.78	12.94	12.94
October	11.16	15.59	15.62	12.07
November	10.93	14.35	12.63	10.91
December	14.33	12.35	10.54	10.51

Table 5: Monthly Mean Wind Speed (m/s)

Month	2013	2014	2015	2016
January	0.790	0.538	0.790	1.118
February	0.714	0.731	0.714	1.018
March	0.784	0.687	0.784	1.235
April	0.814	0.929	0.814	1.563
May	0.962	0.789	0.924	1.760
June	0.804	0.861	0.870	1.619
July	0.680	0.675	0.675	1.242
August	0.550	0.641	0.550	1.159
September	0.593	0.637	1.063	1.663
October	0.519	0.547	0.899	0.845
November	0.529	0.539	0.961	0.901
December	0.578	0.568	1.096	0.983

Table 6: Saturated Pressure (P kp_a)

Month	2013	2014	2015	2016
January	942.55	942.62	945.39	945.93
February	941.49	941.59	941	943.94
March	939.78	939.91	940.27	941.58
April	941.19	939.64	941.03	940.45
May	942.18	940.80	940.2	718.19
June	943.39	942.14	941.95	944.03
July	942.86	944.06	944.06	943.73
August	943.24	943.41	942.86	943.58
September	942.78	943.18	943.33	943.33
October	941.39	942.61	942.93	941.89
November	943	942.40	943.72	942.29
December	943.48	943.68	942.16	943.2

III. RESULT AND DISCUSSION

Figure (1-3) shows the statistical Analysis in testing the penman's model with climatic parameters. (wind speed, sunshine hour, air temperature, solar radiation, relative humidity)for Bauchi metropolis. According to [1], correlation coefficient, r and coefficient of determination, R^2 are related by $r = \sqrt{R^2}$ and a correlation greater than 0.8 is generally described as strong. In this case plant loss their water inform of transpiration whereas a correlation less than 0.5 are generally described as weak, soil loss its water in form of evaporation.

Table 7 shows the estimated ET_O based on Penman's Monteith (FAO-56) Method in other to determine how much water is needed for healthy growth of plant.

The analysis evaluation was conducted for monthly observed base line (January – December) and the correlation coefficient in finding their degree of linear relationship between climatic parameters and estimated ET_O was also observed. In figure (1-3) presents the correlation of monthly mean wind speed, relative humidity and solar radiation plotted with estimated ET_O. It could be observed that

ET_O has a strong correlation coefficient with the climatic parameters respectively, which indicates that much water is needed for crops production while weak correlation coefficient of relative humidity and atmosphere pressure shows it semi-arid region.

Table 7 shows that in the months of April, May and June for optimum irrigation planning, management practices and for effective use of water resources, application of water on crops is highly advised due to the high rate of evapotranspiration as (13.008, 12.1163 and 10.2327) $mmday^{-1}$ for 2013, (10.5799, 9.8797 and 11.0487) $mmday^{-1}$ for 2014, (10.5799, 9.5797 and 11.0487) $mmday^{-1}$ for 2015 and (9.0024, 12.1778 and 9.5543) $mmday^{-1}$ for 2016. The estimated ET_O has a range value (9.0024 – 13.008) for Bauchi metropolis.

Table 7: Estimated Reference Evapotranspiration Rate (ET_o mm day^{-1})

Month	2013	2014	2015	2016
January	3.8647	2.1452	2.1452	0.3687
February	3.5566	3.9524	3.9524	0.9734
March	8.5134	8.6166	8.6166	6.7066
April	13.008	10.5799	10.5799	9.0024
May	12.1163	9.8797	9.8797	12.1778
June	10.2327	11.0487	11.0487	9.5543
July	6.3219	7.7665	7.7665	6.3918
August	7.2503	5.1264	5.1264	5.8757
September	5.9744	6.5942	6.5942	3.2290
October	3.8537	7.4206	7.4206	3.4764
November	1.9722	3.9672	3.9672	1.8029
December	3.4059	2.4746	2.4746	1.0542

Table 8: correlation coefficient for (2013-2016)

Year	$T_{av}(^oC)$	Ws (m/s)	(SR $Mjm^{-2}day^{-1}$)	Rh($^o/_o$)	P (Kp_a)
2013	0.521	0.526	0.594	0.246	0.063
2014	0.504	0.614	0.857	0.245	0.280
2015	0.526	0.566	0.866	0.115	0.349
2016	0.531	0.566	0.866	0115	0.349

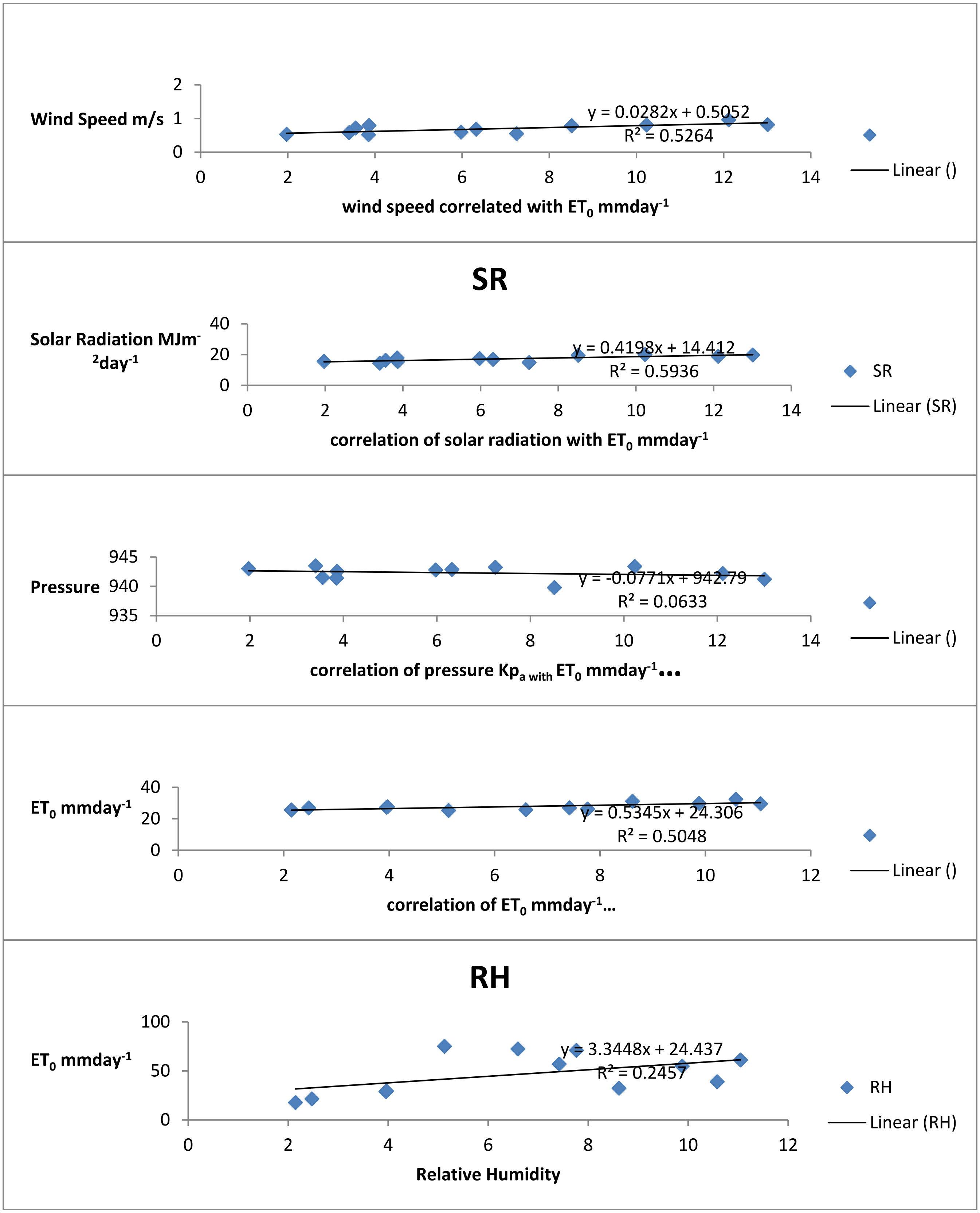

Figure 1: Plot of estimated ET_0 with Climatic parameter for 2013

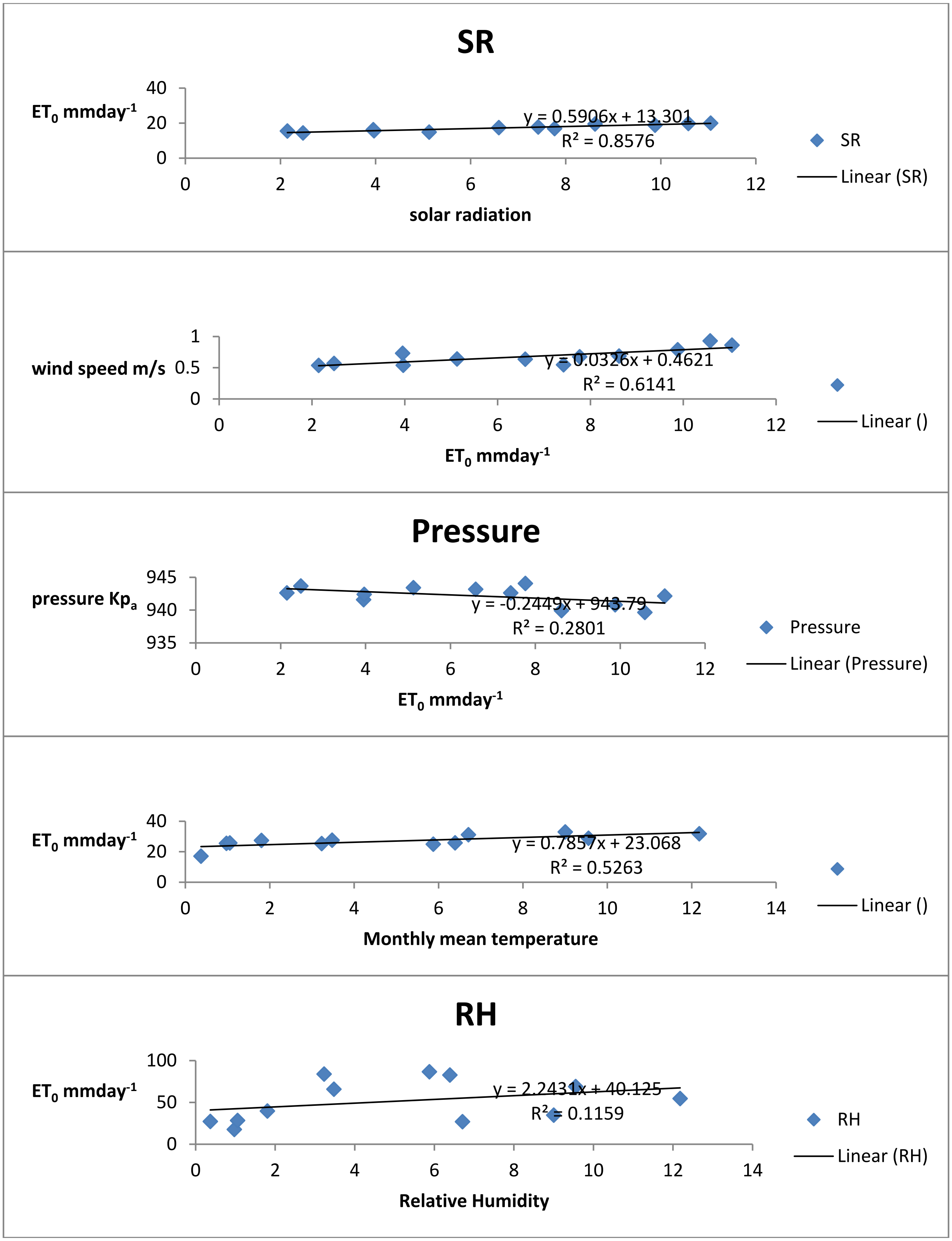

Figure 2: Plot of estimated ET_O with climatic parameter for 2014

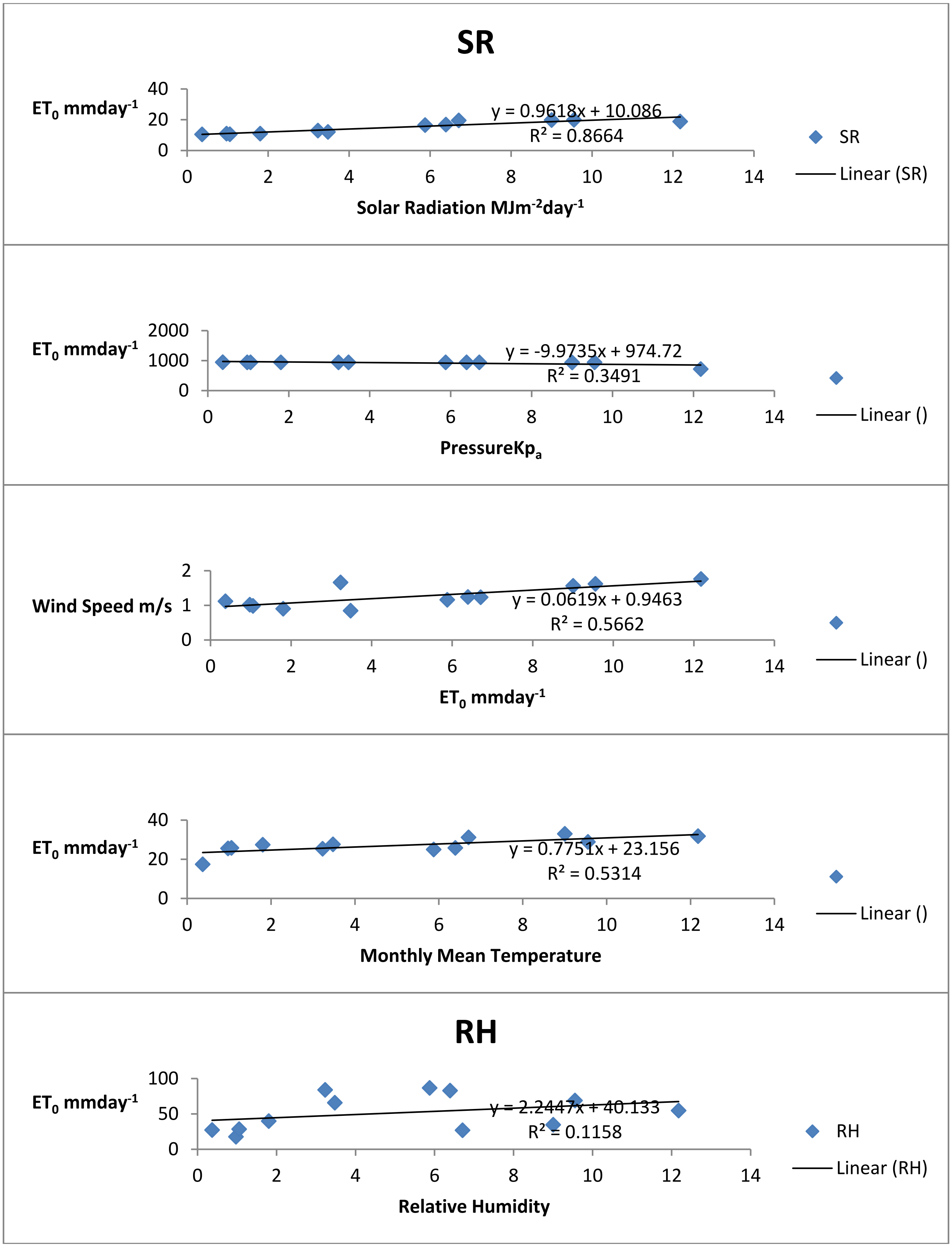

Figure 3: Plot of estimated ET_O with climatic parameter for 2015

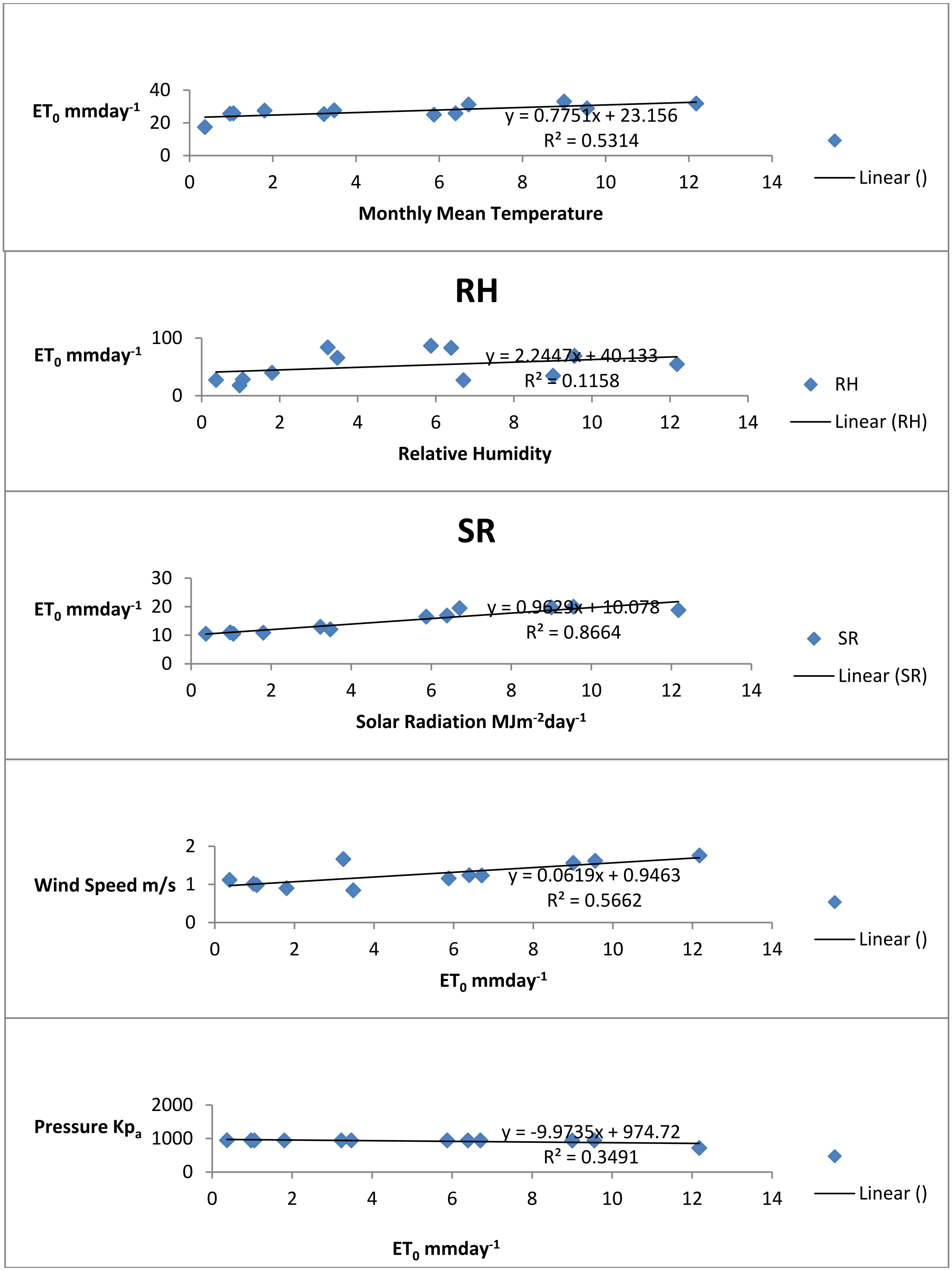

Figure 4: plot of estimated ETo and climatic parameter for 2016

IV. CONCLUSION

The model was developed for the estimation of reference crops evapotranspiration ET_O base on penman's monteith FAO-56 and from the result obtained we can conclude that in Bauchi from (2013-2016) in the months of April, May and June crops lost water and it nutrient by transpiration with high range value from (13.008 – 9.0024) mmday^{-1}. Therefore irrigation activities is highly advised. Climatic parameters were correlated to test whether there is agreement between estimated $ET_{O.}$ It has shown that air temperature, solar radiation and wind speed are strongly positively correlated with $ET_{O,.}$ that is increase in atmospheric temperature, solar radiation and wind speed will increase the rate of transpiration and evaporation processes which expresses the evaporative power of the atmosphere.

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AUTHORS

First Author – Peter J. Manga, Giwo Science Academy, Km3 Ningi Road Bauchi, Bauchi State, Nigeria
Second Author – Abdullazeez A. Mohammad, Department of Physics, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria
Third Author – Ibrahim Maina, Department of Physics, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria

Corresponding author E-Mail: 2016petermanga@gmail.com