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RESPONSE OF THE FAO–PM–ETO MODEL TO VARIATIONS IN SELECTED CLIMATIC PARAMETERS: A CASE STUDY IN BENUE STATE, NIGERIA

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Abstract: This study evaluated the response of the FAO–PM–ETo model to variations in selected climatic parameters within the study area. Five years of historical climatic data were analyzed and compared with projected scenarios of 5–20% increases in climatic variables. The effects of each variable on reference evapotranspiration (ETo) and their sensitivity coefficients were determined. Results revealed that ETo exhibited the highest sensitivity to wind speed and the least sensitivity to relative humidity across all scenarios. Sensitivity was generally higher during the dry season compared to the wet season. On an annual scale, ETo sensitivity ranked in the order: wind speed > solar radiation > minimum temperature > maximum temperature > relative humidity. These findings highlight that climate change and variability can substantially influence evapotranspiration and crop water requirements in the study area
Keywords: FAO–PM–ETo model, climatic parameters, Benue State, Nigeria

1. INTRODUCTION

To meet the food demand of the projected human population of 9 billion by 2050, the world is expected to produce more than 60% more food relative to its 2005 production (Lal 2016). Water is an indispensable resource for food production. However, available water is under immense pressure as about 70% of the total available freshwater is used for agricultural purposes (Pimentel et al. 2004; Hertel & Liu 2016). This is further worsened by climate change, water scarcity, and other water-related problems (Hertel & Liu 2016; Sadow et al. 2017). This has necessitated the need for efficient and effective management of water resources. Sustainable water management in agriculture requires an accurate estimate of the reference crop evapotranspiration (ET_o). This is the first step to satisfying the water requirement of crops. ET_o is one of the most important components of the hydrologic cycle. It is a combined term of evaporation through the soil surface and transpiration, a process where water is lost through the stomatal openings in the leaves.

It has been referred to as the second most important hydrologic variable after precipitation (Goyal 2004; Alexandris et al. 2008) and the least understood hydrologic variable (Silva 2015). In a dry climate, it can constitute about 95% of the water balance (Wilcox et al.2003). ET_o is important in determining water use of crops, water balance studies, hydrologic modelling, irrigation scheduling, and irrigation management (Allen et al. 1998). The direct method of determining actual crop water use involves the use of a lysimeter, which is based on the principle of water balance. Although it is more accurate, it is time demanding, laborious, and expensive and requires skills and experience (Allen et al. 1998). The indirect method is simply by multiplying crop coefficient (K_c) and reference evapotranspiration (ET_o). K represents specific crop characteristics that differentiate a field crop from the reference grass, while ET_o is an indication of climatic demand (Allen et al. 1998). The FAO Penman-Monteith equation (FAO-PM) is the recommended standard equation for estimating ET_o because it has a high correlation with a lysimeter (Allen et al. 1998; Bakhtiari et al.2011). However, the FAO-PM equation is limited in application because its inputs (solar radiation, air temperature, air humidity, and wind speed) are not readily available in most weather stations, especially in developing countries. The FAO-PM equation combines the energy balance (radiative) and the mass transfer (aerodynamic) equations to compute ET_o using weather variables (Allen et al. 1998). The dominating component in the FAO-PM depends on the location. For example, the energy component is the controlling term in the humid climates, while the mass transfer component is dominant in semi-arid regions (Allen et al. 1998; Irmak et al. 2006; Vicente-Serrano et al. 2014).

Among the variables used for computing ET_o, some are more influential than others (Debnath et al. 2015), depending on the climate, location, and local conditions of the area. Under limiting conditions, Koudahe et al. (2018) argue that identifying the climatic variables most sensitive to ET_o becomes imperative, so that emphasis is placed on the measurements of those variables which could be used for developing simple empirical ET_o models. Identifying sensitive variables is also important in adapting and mitigating climate change impacts (Nouri et al.2017). Observations around the world have revealed that the earth's climate has changed and is still changing (IPCC 2013; USGCRP 2018). Between 1901 and 2016, global temperature has increased by about 1°C (USGCRP 2018), while rainfall variability and extreme rainfall events have also been on the rise (IPCC 2013; Alexander 2016). The African continent is most vulnerable to climate change because of its high dependence on rainfall for agriculture (IPCC 2013). Specifically, sub-Saharan Africa has been identified as the greatest food security risk region (Van Ittersum et al. 2016) since 96% of total crop production depends on rainfall (World Bank 2015). Nigeria has been singled out to receive a great deal of these impacts because of its burgeoning population and dominant rainfed agriculture (Ayinde et al. 2011). Understanding the impact of changes in climatic variables on ET_o is important to assess the possible implications of climate change on water resources, water management, and the overall hydrology of an area. ET_o, alongside other meteorological parameters, is an important variable that can be used to study climate change and examine its impacts on water use (Darshana et al. 2013; Wang et al.2013).

By studying the sensitivity of ET_o in dry (arid and semi-arid) climates, Liu et al. (2010), Hou et al. (2013), and Gao et al. (2016) observed that $ET_o$is most sensitive to solar radiation and temperature (Goyal 2004; Patle and Singh 2015). Irmak et al. (2006) attributed the influential role of temperature under dry climate to the exponential relationship between temperature and saturation vapor deficit and the linear relationship between vapor pressure deficit (VPD) and ET_o. In contrast, under humid climate, Irmak et al. (2006), Tabari and Talaee (2014), and Koudahe et al. (2018) reported that ET_o is highly influenced by solar radiation and sunshine hours. The dominance of solar radiation under wet climate is attributed to the lower influence of other climatic variables (Hupet and Vanclooster 2001).

Moreover, Zhao et al. (2015) reported that under arid climate, ET_o is most sensitive to relative humidity. From the literature, even under similar climates, we observed diverging results and no clear pattern of the climate variable influencing ET_o. This shows that ET_o sensitivity is location-specific (Liu et al. 2010). This may be due to non-climate related factors (Gao et al. 2016; Jerszurki et al.2019) and the complexity of the FAO-PM ET_o equation (Vicente-Serrano et al. 2014). Previous studies have also examined the impacts of more than one variable on ET_o. Under arid and semi-arid climate, Sharif and Dinpashoh (2014) reported that by increasing mean temperature and wind speed at 20%, while decreasing actual vapor pressure, ET_o increased by 36.4%. The subject on sensitivity analysis and sensitivity coefficient has continued to be studied under different locations and climates, while there are no general conclusions regarding the most sensitive weather variable to ET_o.

2. MATERIALS AND METHOD

The study was conducted under a tropical savannah climate (Benue state). Benue lies roughly in the middle of the country and shares boundaries with six other states: Nasarawa to the North, Taraba to the East, Kogi and Enugu states to the West and Ebonyi and Cross-River states to the South. The relief is it neural purate forest, savannah. However, it has a landmass of 33,955 square kilometers and lies between Latitudes 6.5° and 8.5° North and Longitudes 7.47° N and 10 East. (Mahjongjp88, 2026). Benue State lies within the AW Climate and experiences two distinct seasons, the wet/rainy season and the dry/summer season. The rainy season lasts from April to October with annual rainfall in the range of 100–200mm. The dry season begins in
November and ends in March. Temperatures fluctuate between 23 to 37 degrees Celsius during the year. The vegetation of the State consists of rain forests which have tall trees, tall grasses and oil palm trees that occupy the state's western and southern fringes while the Guinea savanna is found in the eastern and northern parts with mixed grasses and trees that are generally of average height. Benue being the food basket of the nation has its major economic scale as agriculture, with crops such as maize, cassava, yams, and rice being grown extensively, particularly in the floodplain areas (Ladipo, 1998)

Data Set description

Meteorological data was accessed from NASA prediction of worldwide energy resources (NASA Power, 2019) from 2019 to 2023 (5yrs) and also from Nigeria metrological Agency (NINET) for the same study period. Obtained from the study are; solar radiation, minimum and maximum temperature, relative humidity and wind speed. The data was screened and checked for inconsistency.

Sensitivity Analysis and sensitivity coefficient

Sensitivity analysis was performed, to determine the most sensitive climate variable to ET_0 for each of the given location to determine the extent to which changes in a weather variable affects ET_0. There are various methods of sensitivity analysis and there is a single universally accepted method. However, this study adopts a simple technique which involves plotting the relative change with dependent variables ET_0 against the relative change in independent variable (solar radiation, minimum and maximum temperature, wind speed and relative humidity).

Partial derivatives was used to conclude the sensitivity coefficient following the procedure of (Irmak, et al. 2006). The sensitivity coefficient (SC) is simply defined as the ratio of the changes in ET_0 with respect to changes in a climatic variable. SC is expressed as follows:

$$SC_i = \lim_{\Delta x \to 0}\left(\frac{\Delta ET_0/ET_0}{\Delta X_i/X_i}\right) = \frac{\partial ET_0}{\partial X_i}\cdot\frac{X_i}{ET_0}$$

where SC_i is the sensitivity coefficient and X_i is the climate variable. Firstly, the average daily value of each climatic variable and location for a period of 34yrs
(1990–2023) was calculated. This was used to calculate the ET_0 using the FAO-PM equation. Then a ±5 to ±25% increase and decrease will be applied to each climate variable to produce new sets of daily ET_0 values.

A plot as shown in Figure 1, the response of ET_0 to relative increase and decrease of the climate variable will be obtained. Monthly and annual changes in ET_0 will be obtained by averaging daily changes. By simply dividing daily changes in ET_0 by daily changes in climatic variable gives the daily SC. Similarly, monthly seasonal and annual SC will be obtained by averaging the corresponding daily SC.

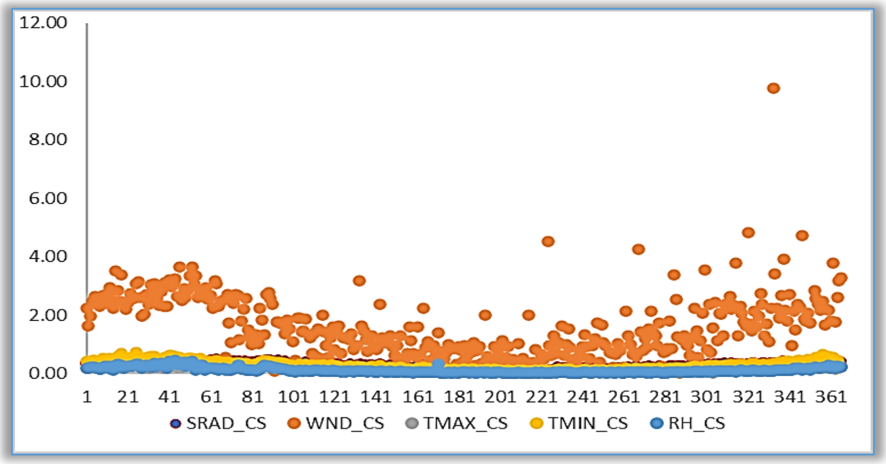

Figure 1: Sensitivity coefficient of ETo to (a) maximum temperature (Tmax), (b) wind speed (U_2), (c) minimum temperature (Tmin), (d) solar radiation (Rs), and (e) relative humidity (RH).

A positive SC will imply that an increase in climate variable will result in an increase in ET_0 while a negative SC will indicate a decrease in climate variable will result in a decrease in ET_0. The magnitude of the absolute value of the SC is an indication of the magnitude the climate variable has on ET_0 for instance, a SC of 0.1 for a variable implies that a 50% increase in the variable will increase ET_0 by 0.5% as other observed variable are held constant. According to Irmak et al. (2006) they attributed the changes to the sensitivity of ET_0 to errors of the variables with the assumption that other variables were accurately measured and held constant and their mean values during the period of analysis for each location.

3. RESULT AND DISCUSSSION

MONTH AND ANNUAL SENSITIVITY COEFFICIENTS FOR THE STUDY AREA

Dry season months (Nov and Mar):

- Rs (0.33–0.42): Solar radiation sensitivity is highest in Feb-Mar (0.41–0.42), reflecting clear skies and strong sunshine during harmattan and late dry season.
- U_2 (2.04–2.88): Wind speed sensitivity peaks in Feb (2.88) and Jan (2.54), showing that in the dry season, wind speed strongly influences ET due to low humidity and high atmospheric demand.
- T_{max} & T_{min} (0.22–0.49): Maximum and minimum temperatures both have moderate-to-high influence; T_{min} sensitivity is very high in Jan (0.49) because cold nights during harmattan cause big temperature swings.

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- RH (0.17-0.29): Relative humidity plays a greater role in Feb (0.29) and Jan (0.23) due to very dry air. During the dry season, wind speed and solar radiation are dominant drivers of ET, with temperature also contributing significantly

During the dry season, wind speed and solar radiation are dominant drivers of ET, with temperature also contributing significantly

Transition months (Apr-May, Oct-Nov):

- Rs (0.24-0.34): Still moderately high, indicating sunshine is important before/after the peak rains.
- U_2 (1.08-2.39): Wind influence drops in Apr-May but rises again in Nov harmattan begins.
- T_{max}/T_{min} (0.13-0.29): Lower than in peak dry season but still notable.
- RH (0.05-0.09): Lower influence than in dry months, since humidity levels begin to rise. Transition months see reduced wind sensitivity (except in Nov) and more balanced influence of all parameter, meaning ET is less extreme than in dry season.

Rainy season months (Jun-Sep):

- Rs (0.14-0.20): Solar radiation sensitivity is lowest due to frequent cloud cover.
- U_2 (0.61-1.04): Wind speed sensitivity also lowest, as humid, stable air reduces evaporation.
- T_{max}/T_{min} (0.07-0.13): Temperature influence is minimal because temperatures are moderated by cloud cover and rains.
- RH (0.03-0.05): Very low sensitivity.

High humidity means ET is less responsive to small RH changes. In the rainy season, ET is least sensitive to all parameters, especially RH and temperature. Water loss is low, which is good for crops but limits natural drying

ANNUAL SENSITIVITY COEFFICIENT

Wind speed (U_2) is the most influential factor annually (1.59) meaning ET in Benue is especially sensitive to wind variations. This aligns with harmattan effects in dry months. Solar radiation (0.28) is the second most important driver, reflecting Benue's position in the tropical belt with high insolation year-round. Temperature ($T_{min} > T_{max}$): Nighttime minimum temperatures (0.26) actually have slightly more annual influence than daytime maximum (0.15), possibly due to their effect on daily temperature range. Relative Humidity has the least annual effect (0.11) though its seasonal role is more significant in the dry months.

Table 1. Monthly and annual sensitivity coefficients for the study area

Period	Rs	U_2	T_{max}	T_{min}	RH
Jan	0.39	2.54	0.22	0.49	0.23
Feb	0.41	2.88	0.24	0.48	0.29
Mar	0.42	2.04	0.22	0.35	0.17
Apr	0.34	1.22	0.18	0.28	0.11
May	0.27	1.08	0.13	0.20	0.06
Jun	0.20	0.81	0.09	0.13	0.05
Jul	0.15	0.61	0.07	0.09	0.03
Aug	0.14	0.86	0.07	0.10	0.03
Sep	0.17	1.04	0.08	0.12	0.03
Oct	0.24	1.38	0.12	0.18	0.05
Nov	0.33	2.39	0.17	0.29	0.09
Dec	0.37	2.32	0.21	0.44	0.17
Annual	0.28	1.59	0.15	0.26	0.11

SEASONAL COEFFICIENT FOR THE STUDY AREA

Dry season (Nov-Apr):

- U_2 (2.43): Wind speed is the dominant driver of ET. Strong harmattan winds and low humidity greatly increase water loss from soil and crops.
- Rs (0.38): Solar radiation is high due to cloudless skies, increasing ET.
- T_{min} (0.41): Nighttime temperatures have a large effect because of wide day-night temperature swings during harmattan.
- T_{max} (0.21): Daytime temperatures have moderate influence.
- RH (0.19): Even small humidity changes impact ET due to the very dry air

Wet season (May-Oct):

- U_2 (0.96): Wind speed still influences ET but far less than in dry season, as air is more humid and winds weaker.
- Rs (0.19): Solar radiation's influence drops due to cloud cover.
- T_{min} (0.14) & T_{max} (0.09) Temperature sensitivity is low because clouds and rains stabilize daily temperatures.
- RH (0.04): Humidity has very little effect on ET since it remains high throughout the season.

Seasonal comparism:

- Rs is higher in dry season: U2 is the strongest driver in both, especially dry season.
- T_{max} Moderate drop in wet season. T_{min} has big drop in wet season. Rh is the lowest which much less important in wet season
- Dry season: Wind speed and sunshine dominate ET, with large night-day temperature differences boosting evaporation.
- Wet season: ET sensitivity is reduced due to high humidity, cloud cover, and lower wind speed.

Table 2. Seasonal sensitivity coefficients for the study area

Period	Rs	U_2	T_{max}	T_{min}	RH
Dry season (Nov-Apr)	0.38	2.43	0.21	0.41	0.19
Wet season (May-Oct)	0.19	0.96	0.09	0.14	0.04

COMPARISION OF MONTHLY AND ANNUAL PERCENT CHANGE IN ET (mm) for 2029-2023

From 2019 to 2023, mean annual ET for the study area was 1,877.80 mm, with notable fluctuations between years. The highest annual ET occurred in 2023 (1,975.76 mm), while the lowest was in 2019 (1,751.28 mm). This variation suggests year-to-year changes in climatic conditions likely linked to differences in solar radiation, wind speed, and rainfall distribution.

Dry season (Nov-Mar):

Highest ET values occur in Jan to Mar, with peak mean ET in March (213.44 mm) followed closely by February (204.28 mm) and January (199.01 mm). Between years, February 2020 (221.37 mm) and March 2021 (220.52 mm) stand out as especially high, indicating particularly hot/dry conditions in those months.

Transition months (Apr, Oct, Nov)

- April (189.25 mm) marks the shift from dry to wet season. ET still relatively high but lower than in February–March.
- October (126.37 mm) shows a sharp rebound in ET as rains subside, skies clear, and temperatures rise.
- November (154.43 mm) sees a further increase as harmattan sets in.

Inter-Annual Variability

Dry season peaks vary more sharply than wet season lows, suggesting that annual differences in ET are largely driven by dry-season climatic extremes. For example: February 2020 had the highest dry–season monthly ET (221.37 mm). June 2022 had one of the lowest wet-season ET values (110.63 mm). Years like 2023 show consistently higher ET across both seasons, possibly due to warmer conditions and slightly reduced rainfall/cloudiness

Table 3. Comparison of Monthly and annual percent change in ET (mm) for 2019 – 2023 for the study area

Period	2019_ET	2020_ETo	2021_ETo	2022_ETo	2023_ETo	Mean ET
Jan	188.41	214.04	204.07	203.45	185.11	199.01
Feb	180.49	221.37	214.05	208.78	196.69	204.28
Mar	208.86	212.45	220.52	219.14	206.26	213.44
Apr	171.11	196.86	203.16	160.37	214.75	189.25
May	139.65	146.57	158.08	145.35	195.50	157.03
Jun	118.37	116.75	128.44	110.63	120.31	118.90
Jul	105.84	110.62	111.31	98.30	135.90	112.39
Aug	106.10	130.75	111.48	96.02	118.56	112.58
Sep	108.96	98.00	107.94	96.32	123.56	106.95
Oct	106.75	128.31	122.18	126.55	148.07	126.37
Nov	136.17	172.50	140.43	170.88	152.17	154.43
Dec	180.60	176.80	189.25	190.31	178.89	183.17
Annual	1751.28	1924.99	1910.90	1826.08	1975.76	1877.80

Table 4. Monthly and annual variations in ET (mm) for 5% change in climatic variables for the study area

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	2019												
Rs	0.94	0.96	0.95	0.92	0.78	0.69	0.63	0.66	0.70	0.66	0.82	0.98	0.81
U_2	0.15	0.16	0.19	0.21	0.17	0.17	0.15	0.16	0.13	0.13	0.13	0.14	0.16
T_{max}	1.78	1.79	1.88	1.74	1.66	1.56	1.53	1.50	1.54	1.53	1.66	1.73	1.66
T_{min}	0.99	1.08	1.26	1.22	1.18	1.17	1.18	1.18	1.16	1.12	1.05	0.67	1.10
RH	2.05	2.12	2.82	3.44	3.68	3.72	3.97	4.08	4.03	4.04	3.55	2.28	3.32
ET	9.88	11.86	13.21	7.85	6.33	5.01	3.23	2.89	4.52	4.30	7.15	12.09	88.32
	2020												
Rs	1.04	1.12	0.98	0.92	0.78	0.70	0.66	0.75	0.63	0.77	0.95	0.93	0.85
U_2	0.18	0.17	0.18	0.24	0.20	0.18	0.16	0.19	0.14	0.13	0.14	0.13	0.17
T_{max}	1.73	1.85	1.91	1.84	1.68	1.60	1.54	1.55	1.53	1.58	1.73	1.81	1.69
T_{min}	0.76	0.96	1.21	1.22	1.20	1.22	1.19	1.16	1.12	1.13	1.06	0.96	1.10
RH	1.66	1.28	2.55	3.01	3.63	3.84	4.00	3.73	4.10	3.88	2.72	2.49	3.08
ET	11.28	12.86	13.35	9.55	5.49	4.14	3.47	4.58	2.99	5.30	9.17	9.26	92.18
	2021												
Rs	1.01	1.10	1.02	1.01	0.88	0.79	0.69	0.69	0.70	0.80	0.86	0.99	0.88
U_2	0.15	0.15	0.20	0.19	0.19	0.15	0.17	0.15	0.14	0.13	0.13	0.15	0.16
T_{max}	1.85	1.90	1.88	1.88	1.68	1.59	1.52	1.53	1.55	1.64	1.71	1.75	1.71
T_{min}	0.85	0.93	1.14	1.15	1.20	1.06	1.04	1.04	1.04	1.05	1.08	0.95	1.04
RH	2.08	1.58	2.41	2.85	3.56	3.87	3.97	3.96	4.10	4.50	3.94	2.29	3.27
ET	13.13	10.02	12.96	11.35	7.01	5.12	3.25	3.87	3.97	4.88	6.69	10.74	92.99
	2022												
Rs	2.05	2.27	2.11	1.80	1.73	1.46	1.24	1.21	1.28	1.55	1.97	1.99	1.72
U_2	0.32	0.30	0.36	0.41	0.35	0.30	0.34	0.35	0.28	0.24	0.27	0.31	0.32
T_{max}	3.47	3.74	3.87	3.45	3.33	3.15	3.09	3.00	3.05	3.21	3.54	3.52	3.37
T_{min}	1.98	2.00	2.67	2.53	2.44	2.36	2.31	2.28	2.26	2.23	2.03	1.81	2.24
RH	3.76	3.72	6.19	7.36	7.91	8.28	8.46	8.39	8.61	8.14	6.22	4.72	6.83
ET	24.28	25.21	26.07	14.58	12.59	8.44	4.32	3.36	5.61	11.66	20.36	22.80	179.28
	2023												
Rs	1.02	1.10	0.96	1.00	0.90	0.65	0.73	0.66	0.73	0.79	0.82	0.98	0.86
U_2	0.17	0.16	0.27	0.25	0.16	0.12	0.19	0.15	0.12	0.13	0.12	0.15	0.17
T_{max}	1.66	1.76	1.95	2.03	2.05	1.76	1.75	1.68	1.71	1.87	1.89	1.70	1.82
T_{min}	0.71	0.79	1.03	1.21	1.25	1.17	1.35	1.24	1.23	1.09	1.05	0.94	1.09
RH	2.10	2.25	3.06	3.17	3.52	4.03	3.97	4.03	4.03	4.00	3.57	2.26	3.34
ET	11.33	13.14	11.65	13.42	11.24	4.58	5.76	4.09	5.41	8.20	8.71	10.07	107.60

Table 5. Monthly and annual variations in ET (mm) for 10% change in climatic variables for the study area

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	2019												
Rs	1.89	1.92	1.89	1.83	1.56	1.39	1.26	1.32	1.40	1.31	1.64	1.96	1.61
U_2	0.30	0.32	0.37	0.42	0.35	0.35	0.30	0.32	0.26	0.25	0.25	0.28	0.31
T_{max}	3.57	3.59	3.75	3.49	3.31	3.12	3.06	3.00	3.07	3.07	3.32	3.45	3.31
T_{min}	1.97	2.15	2.52	2.43	2.35	2.33	2.36	2.36	2.33	2.24	2.10	1.33	2.21
RH	4.11	4.25	5.64	6.88	7.37	7.45	7.95	8.15	8.07	8.09	7.10	4.56	6.64
ET	21.25	22.09	25.06	16.21	12.30	9.13	6.41	5.76	8.77	8.20	14.56	23.36	173.10
	2020												
Rs	2.09	2.23	1.96	1.84	1.56	1.39	1.31	1.51	1.26	1.54	1.91	1.86	1.70
U_2	0.36	0.34	0.35	0.48	0.39	0.37	0.32	0.38	0.28	0.25	0.29	0.26	0.34
T_{max}	3.46	3.71	3.83	3.68	3.36	3.20	3.08	3.09	3.05	3.17	3.46	3.62	3.39
T_{min}	1.51	1.92	2.43	2.43	2.40	2.45	2.38	2.32	2.24	2.25	2.13	1.92	2.20
RH	3.33	2.56	5.10	6.02	7.26	7.69	7.99	7.46	8.19	7.75	5.44	4.97	6.16
ET	24.75	26.30	25.90	19.75	11.52	8.14	6.71	8.99	5.85	11.09	19.39	20.45	189.98
	2021												
Rs	2.03	2.20	2.03	2.02	1.76	1.59	1.39	1.37	1.39	1.61	1.72	1.98	1.75
U_2	0.30	0.31	0.39	0.39	0.38	0.31	0.33	0.30	0.27	0.26	0.27	0.30	0.32
T_{max}	3.71	3.80	3.75	3.76	3.36	3.18	3.03	3.07	3.10	3.28	3.43	3.50	3.41
T_{min}	1.70	1.85	2.28	2.31	2.39	2.12	2.09	2.09	2.07	2.10	2.16	1.90	2.09
RH	4.16	3.16	4.82	5.70	7.11	7.73	7.94	7.91	8.20	9.00	7.88	4.57	6.53
ET	26.24	23.34	25.72	23.10	14.32	10.68	6.92	7.65	7.75	10.90	14.33	22.59	193.54
	2022												
Rs	2.05	2.27	2.11	1.80	1.73	1.46	1.24	1.21	1.28	1.55	1.97	1.99	1.72
U_2	0.32	0.30	0.36	0.41	0.35	0.30	0.34	0.35	0.28	0.24	0.27	0.31	0.32

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T_{max}	3.47	3.74	3.87	3.45	3.33	3.15	3.09	3.00	3.05	3.21	3.54	3.52	3.37
T_{min}	1.98	2.00	2.67	2.53	2.44	2.36	2.31	2.28	2.26	2.23	2.03	1.81	2.24
RH	3.76	3.72	6.19	7.36	7.91	8.28	8.46	8.39	8.61	8.14	6.22	4.72	6.83
ET	24.28	25.21	26.07	14.58	12.59	8.44	4.32	3.36	5.61	11.66	20.36	22.80	179.28
	2023												
Rs	2.04	2.20	1.92	1.98	1.80	1.31	1.46	1.32	1.46	1.58	1.64	1.98	1.72
U_2	0.31	0.33	0.43	0.46	0.34	0.28	0.34	0.31	0.27	0.25	0.26	0.29	0.31
T_{max}	3.31	3.52	3.90	4.07	4.11	3.53	3.50	3.35	3.42	3.74	3.78	3.39	3.63
T_{min}	1.41	1.58	2.06	2.41	2.49	2.33	2.69	2.48	2.47	2.19	2.11	1.88	2.17
RH	4.39	4.43	5.74	6.27	7.10	7.87	7.71	8.06	8.13	7.74	7.13	4.55	6.58
ET	22.34	24.95	24.39	26.28	22.63	9.48	11.97	7.81	10.51	16.77	17.60	21.08	215.81

Table 6. Monthly and annual variations in ET (mm) for 15% change in climatic variables for the study area

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	2019												
Rs	2.83	2.87	2.84	2.75	2.34	2.08	1.89	1.98	2.10	1.97	2.46	2.95	2.42
U_2	0.46	0.47	0.56	0.63	0.52	0.52	0.45	0.48	0.39	0.38	0.38	0.41	0.47
T_{max}	5.35	5.38	5.63	5.23	4.97	4.67	4.58	4.50	4.61	4.60	4.97	5.18	4.97
T_{min}	2.96	3.23	3.78	3.65	3.53	3.50	3.54	3.54	3.49	3.35	3.16	2.00	3.31
RH	6.16	6.37	8.45	10.33	11.05	11.17	11.92	12.23	12.10	12.13	10.66	6.84	9.97
ET	33.28	32.80	37.50	25.00	18.56	13.28	9.54	8.67	13.25	12.15	22.46	35.27	261.76
	2020												
Rs	3.13	3.35	2.94	2.77	2.34	2.09	1.97	2.26	1.88	2.32	2.86	2.80	2.56
U_2	0.53	0.51	0.53	0.72	0.59	0.55	0.48	0.57	0.41	0.38	0.43	0.39	0.51
T_{max}	5.18	5.56	5.74	5.51	5.04	4.79	4.62	4.64	4.58	4.75	5.18	5.43	5.08
T_{min}	2.27	2.89	3.64	3.65	3.59	3.67	3.58	3.48	3.36	3.38	3.19	2.88	3.30
RH	23.10	10.17	34.40	44.97	59.55	63.95	68.09	62.67	71.80	66.63	41.26	38.02	48.92
ET	39.04	40.61	39.29	30.52	17.70	11.99	10.12	13.57	8.82	17.59	30.47	32.37	293.66
	2021												
Rs	3.04	3.30	3.05	3.03	2.65	2.38	2.08	2.06	2.09	2.41	2.57	2.96	2.63
U_2	0.46	0.46	0.59	0.58	0.58	0.46	0.50	0.45	0.41	0.39	0.40	0.45	0.48
T_{max}	5.56	5.70	5.63	5.64	5.05	4.78	4.55	4.60	4.66	4.93	5.14	5.25	5.12
T_{min}	2.55	2.78	3.42	3.46	3.59	3.18	3.13	3.13	3.11	3.15	3.24	2.85	3.13
RH	6.24	4.74	7.22	8.55	10.67	11.60	11.91	11.87	12.31	13.50	11.82	6.86	9.80
ET	40.24	37.49	39.35	35.46	22.24	16.45	10.37	11.48	11.80	16.48	22.69	34.98	299.03
	2022												
Rs	3.07	3.40	3.17	2.69	2.60	2.19	1.86	1.82	1.92	2.33	2.96	2.98	2.58
U_2	0.48	0.45	0.53	0.62	0.52	0.45	0.50	0.53	0.42	0.36	0.41	0.46	0.48
T_{max}	5.21	5.61	5.80	5.17	5.00	4.73	4.64	4.51	4.57	4.80	5.30	5.29	5.05
T_{min}	2.97	3.00	4.00	3.79	3.65	3.54	3.47	3.42	3.39	3.35	3.04	2.72	3.36
RH	5.64	5.58	9.29	11.05	11.87	12.42	12.69	12.59	12.91	12.21	9.33	7.07	10.24
ET	37.55	39.21	40.78	22.44	19.48	12.82	6.28	4.79	8.24	18.05	31.76	35.38	276.78
	2023												
Rs	3.05	3.31	2.89	2.97	2.70	1.97	2.19	1.97	2.18	2.37	2.45	2.97	2.58
U_2	0.47	0.49	0.60	0.67	0.52	0.44	0.50	0.47	0.41	0.36	0.40	0.43	0.47
T_{max}	4.96	5.28	5.86	6.10	6.16	5.29	5.26	5.03	5.14	5.61	5.68	5.09	5.44
T_{min}	2.11	2.37	3.10	3.62	3.73	3.50	4.04	3.71	3.70	3.28	3.16	2.83	3.26
RH	6.52	6.79	8.61	9.40	10.61	11.70	11.42	11.97	12.07	11.52	10.67	6.74	9.82
ET	34.12	37.35	37.80	39.99	35.08	14.59	18.71	11.77	16.18	26.09	27.22	32.84	331.74

Table 7. Monthly and annual variations in ET (mm) for 20% change in climatic variables for the study area

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	2019												
Rs	3.78	3.83	3.78	3.67	3.12	2.78	2.51	2.64	2.80	2.62	3.28	3.93	3.23
U_2	0.61	0.63	0.75	0.84	0.70	0.69	0.60	0.64	0.52	0.51	0.50	0.55	0.63
T_{max}	7.13	7.18	7.50	6.97	6.63	6.23	6.11	6.01	6.14	6.14	6.63	6.90	6.63
T_{min}	3.95	4.31	5.03	4.86	4.70	4.66	4.73	4.72	4.66	4.47	4.21	2.67	4.41
RH	8.21	8.49	11.27	13.77	14.74	14.89	15.89	16.30	16.13	16.17	14.21	9.12	13.29
ET	46.35	45.07	51.06	34.21	25.07	17.63	12.84	11.43	17.86	16.35	31.00	48.47	357.34
	2020												
Rs	4.18	4.47	3.92	3.69	3.12	2.79	2.62	3.02	2.51	3.09	3.82	3.73	3.41
U_2	0.71	0.68	0.70	0.96	0.78	0.73	0.64	0.76	0.55	0.51	0.57	0.53	0.68
T_{max}	6.91	7.42	7.65	7.35	6.73	6.39	6.17	6.18	6.10	6.34	6.91	7.24	6.78
T_{min}	3.03	3.85	4.85	4.86	4.79	4.89	4.77	4.63	4.48	4.50	4.25	3.84	4.39
RH	6.65	5.11	10.20	12.05	14.52	15.37	15.99	14.93	16.39	15.50	10.87	9.95	12.33

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ET	55.43	57.53	53.79	41.73	24.18	15.84	13.54	18.15	11.87	24.27	42.39	45.30	406.04
	2021												
Rs	4.05	4.41	4.07	4.04	3.53	3.18	2.78	2.75	2.78	3.21	3.43	3.95	3.51
U_2	0.61	0.62	0.79	0.77	0.77	0.61	0.67	0.60	0.55	0.52	0.53	0.60	0.64
T_{max}	7.41	7.59	7.50	7.52	6.73	6.37	6.06	6.14	6.21	6.57	6.86	7.00	6.82
T_{min}	3.39	3.70	4.56	4.61	4.78	4.24	4.17	4.18	4.15	4.20	4.33	3.80	4.18
RH	8.32	6.32	9.63	11.39	14.23	15.47	15.88	15.83	16.41	18.00	15.75	9.15	13.07
ET	56.06	53.64	54.45	49.02	30.69	22.54	13.89	15.44	16.02	23.30	31.69	48.81	415.55
	2022												
Rs	4.09	4.54	4.23	3.59	3.47	2.91	2.48	2.43	2.56	3.11	3.94	3.98	3.44
U_2	0.64	0.59	0.71	0.83	0.69	0.60	0.67	0.71	0.55	0.48	0.54	0.62	0.64
T_{max}	6.95	7.48	7.74	6.90	6.67	6.30	6.18	6.01	6.10	6.42	7.07	7.05	6.73
T_{min}	3.96	4.00	5.34	5.05	4.87	4.71	4.62	4.56	4.52	4.46	4.05	3.62	4.48
RH	7.52	7.44	12.38	14.73	15.83	16.56	16.92	16.79	17.21	16.28	12.43	9.43	13.66
ET	53.15	56.34	56.89	30.81	26.95	17.46	8.31	6.03	11.01	24.98	44.36	49.61	385.90
	2023												
Rs	4.07	4.41	3.85	3.96	3.61	2.63	2.93	2.63	2.91	3.16	3.27	3.96	3.43
U_2	0.63	0.66	0.77	0.87	0.71	0.59	0.66	0.64	0.56	0.48	0.53	0.56	0.63
T_{max}	6.61	7.04	7.80	8.13	8.21	7.05	7.01	6.71	6.85	7.47	7.57	6.79	7.25
T_{min}	2.81	3.16	4.13	4.82	4.97	4.66	5.39	4.95	4.93	4.38	4.22	3.77	4.34
RH	8.52	8.93	11.32	12.50	13.97	15.57	15.23	15.97	16.17	15.32	14.27	9.03	13.05
ET	47.67	51.94	52.24	54.85	48.71	19.98	25.76	15.79	21.92	36.12	37.61	46.00	458.59

The sensitivity coefficients provided are from a climate evapotranspiration sensitivity analysis (from the FAO Penman–Monteith method), showing how evapotranspiration responds to changes in: Rs (Solar radiation), U_2 (Windspeed at 2m height), T_{max} (Maximum temperature), T_{min} (Minimum temperature), RH (Relative humidity).

4. CONCLUSION

This report has tried to analyze the response of FAO–PM–Eto to changes in selected climatic parameters of location. The sensitivity of FAO-PM-Eto model was carefully observed after analyzing five years of the selected climatic variables past data and comparing with a future 5%–20% increase in those climatic parameters over the study area. The effects of the change of each variable on Eto and the sensitivity coefficients were determined. The result showed changes in Eto sensitivities with respect to changes in climatic variables in the study area. From the result, Eto was most sensitive to wind speed in the study area. In all scenarios, Eto showed the least sensitivity to relative humidity and most sensitive to wind speed in the study area. In general, the sensitivity coefficient of the selected climatic parameters were higher in the dry season than the wet season. From the annual sensitivity coefficients, Eto was most sensitive to wind speed followed by solar radiation, minimum temperature, maximum temperature and relative humidity. Therefore, the result of this study have indicated that climatic change and climatic variability could have significant effects on Evapotranspiration and consumptive crop water use in the study area.

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