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# MAIZE COEFFICIENT INFLUENCE ON REAL EVAPOTRANSPIRATION IN GARISSA COUNTY, KENYA

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**Abstract:** Agriculture in Kenya, with maize as staple food contributed to gross domestic potential of 35.1% in 2020. This sector is threatened by weather and climate extremes hence importance of adaptation strategies to cope with these uncertainties. Crop coefficients are essential for real evapotranspiration estimation and development of irrigation strategy. The study aims at examining the influence of maize coefficient on real evapotranspiration in Garissa County. This region experiences extremely high temperatures in August, while November is the peak of short rainy season. Quality controlled 10-year-long dataset was sought from Garissa synoptic station. Site specific soil parameters and maize coefficients were used in computations of estimates. Step-by-step daily basis computation of reference evapotranspiration was initially done based on the FAO56 standard methodology. The results were integrated with 1D Palmer-type soil model to estimate real evapotranspiration using soil parameters for the station at 1 m deep. Large annual mean differences were detected between reference (2231 ±81 mm) and real (306 ±113 mm) evapotranspiration. Results show that the daily mean real evapotranspiration without coefficient was 0.84±0.8 mm day$^{-1}$, while with coefficient led to slight increase of 0.86±0.8 mm day$^{-1}$. The mean annual precipitation was 303.2±146 mm, which was nearly similar to real evapotranspiration. Real evapotranspiration without coefficient ranged from 0 mm day$^{-1}$ in August and September to 4.8 mm day$^{-1}$ in November, while with maize coefficient ranged from 0 mm/day in August to 5.6 mm/day in November. Maize coefficient led to slight increase in daily real evapotranspiration, which would influence maize yield. The study is critical in investigating sensitivity of 1D Palmer-type soil model influence on reference evapotranspiration methodologies.

## 1. Introduction

Kenya's agriculture is primarily small-scale. Approximately 4.5 million farmers cultivate 90% of agricultural land, while an estimated 3 million work in smallholdings, accounting for 75% of all farms (GOK, 2018; Stiftung, 2019). Besides contributing to an estimated 52% of GDP, it is also a major source of employment for young people (Mumo et al., 2018). Kenya is a major producer of maize in the eastern and southern Africa region (FAOSTAT, 2002). Maize farming is critical because it is the primary source of food for millions of Kenyans and dominates food security in Sub-Saharan Africa (Onono et al., 2013; Rapsomanikis, 2015). Food security is anchored in SDG 2-Zero Hunger, as envisioned in the 2030 Agenda for Sustainable Development (UN, 2018), and Kenya is not an exception. Maize, as the main diet and staple food, is critical in determining food security. However, according to Conway (2009), temperature and rainfall have a significant impact on crop yield maximization. High temperatures reduce crop yields in the lowlands by increasing soil water stress, while precipitation variability contributes to water stress, limiting optimal crop growth (Barnabás et al., 2008). Evapotranspiration interlinkages and relationship drivers of climate change and variability is scanty and unexplored in Kenya. Hence, the present study seeks to examine influence of maize coefficient on evapotranspiration in Garissa County Kenya. Garissa, among other counties is arid and semi-arid and suffers from persistent climate variability, which highly impact on maize yields and food security (Omoyo et al., 2015). Our findings will enhance our understanding of water fluxes balance as well as a tool for proper planning and management of water resources for present and future agricultural processes across water and agricultural sectors.

## 2. Study area and data sources

Garissa County (*Fig. 1*) is located in Kenya's northeastern region and covers an area of 44,174.1 km$^2$. It is situated between latitude 1° 58'N and latitude 2° 1'S, and longitude 38° 34'E and 41° 32'E (Garissa CIDP*,* 2018). It is bounded to the east by the Republic of Somalia, to the south by Lamu County, to the west by Tana River County, to the northwest by Isiolo County, and to the north by Wajir County. It is divided into six sub-counties: Fafi, Garissa Township, Ijara, Lagdera, Balambala, and Dadaab. It is low-lying and flat, with elevations ranging from 70 m to 400 m above sea level. It characterized by little surface water, a few seasonal rivers that flow during rainy seasons, and the permanent Tana River (Climate Change Vulnerability and Adaptive Capacity, 2014). With an annual average precipitation of 275 mm, the climate varies from semi-arid to hot desert (Bwh). The rain falls in two phases: long rains from March to April and short rains from October to December. Its low elevation is characterized by high temperatures ranging from 20 °C to 38 °C (Okoti et al., 2014). The hottest months are September, January, February, and March, with moderate temperatures experienced from April to August.

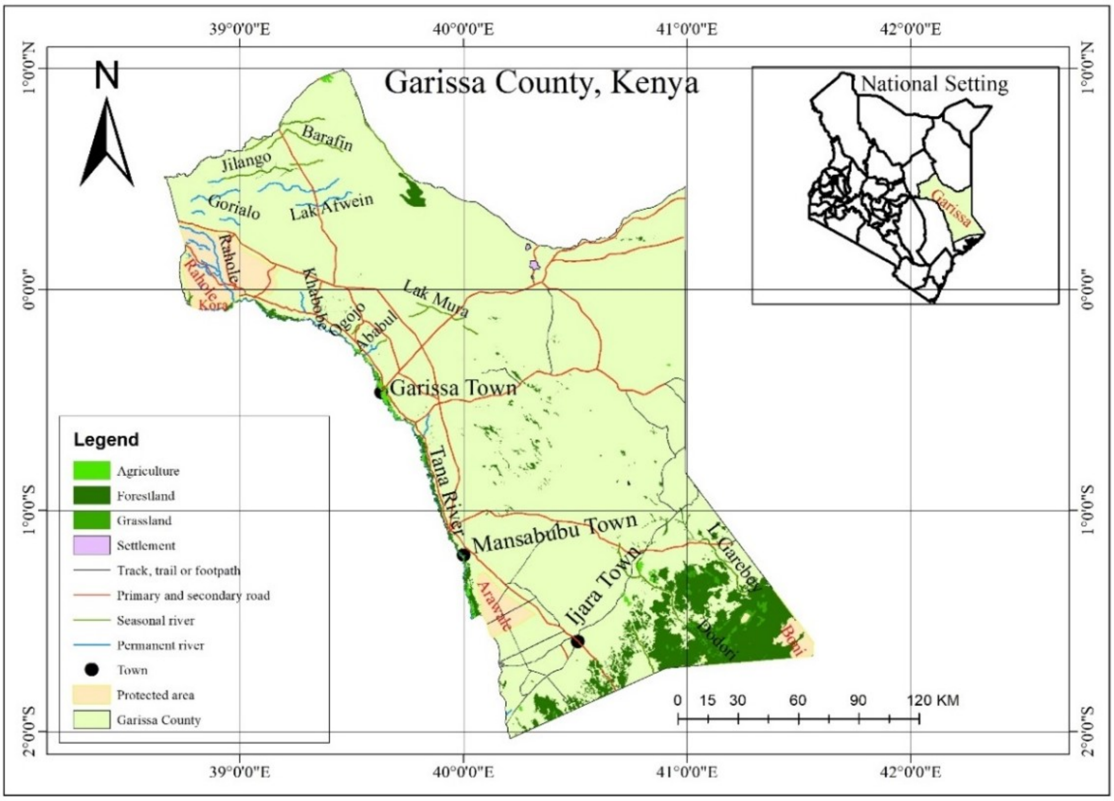


*Figure 1: Kenya and Garissa County.*

### 2.1 Quality control of dataset

Meteorological data with a 3-hour time resolution was downloaded from the Garissa synoptic weather station and organized into datasets spanning the years 2000 to 2009 [1 – Meteomanz.com]. A Visual Basic macro was used to filter errors in SYNOP messages (for example, bad digits) for temperature, relative humidity, pressure, wind speed, direction etc. Excel tables were used to organize the quality-assured database. The linear interpolation method was used to determine whether the missing measurement periods were less than 12 hours. Longer data shortages were replaced by data before and after the missing periods taking into account its mean daily course. After cleaning the data set, a step-by-step analysis of $ET_0$ (FAO 56 methodology by Zotarelli et al., 2010, and Lakatos et al., 2020), calculated evapotranspiration using soil parameters, $ET$, and extended with maize coefficient, $ET_{Kc}$ were undertaken using own Visual Basic Macro programmes developed in MS Excel.

## 3. Methodology

FAO 56 standard methodology (Eq. 1) of the daily base was used to estimate reference evapotranspiration, $ET_0$ (Allen et al., 1988). Penman-Monteith reference evapotranspiration method is accepted as accurate, adopted, and recommended worldwide as a standardized method for $ET_0$ estimation. One-dimension Palmer-type soil model (Eqs. 2–7) was used for estimating evapotranspiration using site specific soil parameters, which included wilting point, field capacity and soil saturation point for each station at 1 m deep soil layer (Palmer, 1965; Ács and Breuer, 2006; Ács et al., 2007; Ferina et al., 2021). The soil types with the parameters were obtained from a soil map of Kenya with 5 km spatial resolution, which was taken using Weather Research and Forecasting (WRF) model due to scarcity of soil data parameters (Dy & Fung, 2016). The integration of the models in the methodology was applied because the use of evapotranspiration-driven models in agricultural studies is still in its initial stage due to data scarcity in Sub-Saharan Africa (Marshall et al., 2012). Application of the site-specific crop coefficients ($Kc$) were also applied in the model (Eq. 3). This study used maize coefficient as specified by FAO (Allen et al., 1998) because it is the staple food of Kenya. The parameters used in (Eq. 1) are for daily time step by step in which analysis of each station climate data was done using Visual Basic Macro programmes developed in MS Excel.

Consider the $i^{\text{th}}$ day of the year. The initial soil moisture in [mm] in the upper 1 m deep soil layer is the previous daily $(i-1)$ value, $\theta_{i-1}$. The reference evapotranspiration for the $i^{\text{th}}$ day is $ET_{0i}$ [mm day$^{-1}$]:

$$ET_{0i} = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}, \tag{1}$$

where the meteorological variables for the given day of the year (without the notation *i*) are: $R_n$ – 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$^{-1}$], calculated from the reference wind measurement in 10 m height (Zotarelli et al., 2010; Lakatos et al., 2020), $e_s$ – saturation vapour pressure [kPa], $e_a$ – actual vapour pressure [kPa], $e_s - e_a$ – saturation vapour pressure deficit [kPa], $\Delta$ – slope of the vapour pressure curve [kPa °C$^{-1}$], $\gamma$ – psychrometric constant [kPa °C$^{-1}$].

The evapotranspiration ($LE$ and $LE_{Kc}$) calculated by the 1D Palmer model for the $i^{\text{th}}$ day of the year is determined by the soil type, the plant constant ($Kc_i$) and the parameterization of $\beta_{i-1}$ function respectively. The latter is considered as a simple linear function of the available soil moisture ($\theta_{i-1}$– $WLT$), see in Eq. 4. During the test calculations, no significant differences were observed among the different methodologies, so we stayed with the linear approximation.

$$ET_i = \beta_{i-1} \cdot ET_{0i} \,, \tag{2}$$

$$(ET_{Kc})_i = Kc_i \cdot ET_i \,, \tag{3}$$

$$\beta_{i-1} = \begin{cases} 1 & if \;\; FC \leq \theta_{i-1} \\ \frac{\theta_{i-1} - WLT}{FC - WLT}) & if \; WLT \leq \theta_{i-1} \leq FC \,, \\ 0 & if \; \theta_{i-1} \leq WLT \end{cases} \tag{4}$$

where $ET_i$ – real evapotranspiration, $\beta_{i-1}$ – soil moisture availability parameter in a 1-m-deep layer of soil, $WLT$ – wilting point, $FC$ – field capacity and $Kc_i$ – specific crop coefficient for the given day. Parameterization knowing the amount of daily precipitation ($P_i$) and runoff ($R_i$) is provided on the basis of the daily water balance equation.

$$\mathrm{R_i} = \begin{cases} 0 & \text{if } (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) \leq \mathrm{SAT} \\ (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) - \mathrm{SAT} & \text{if } (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) > \mathrm{SAT} \end{cases} . \tag{5}$$

The value of soil moisture $\theta_i$ and corrected evaporation $ET_i$ (practically near zero) can also be easily calculated at the end of the $i^{\text{th}}$ day, when the soil moisture is near the wilting point, as we know that $WLT \leq \theta_{i-1} \leq SAT$:

$$\theta_\mathrm{i} = \begin{cases} \mathrm{WLT} & \text{if} \quad (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) \leq \mathrm{WLT} \\ (\theta_{i-1} + \mathrm{ET_i} + \mathrm{P_i}) & \text{if} \quad \mathrm{WLT} > (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) \leq \mathrm{SAT} \\ \mathrm{SAT} & \text{if} \quad (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) > \mathrm{SAT} \end{cases} , \tag{6}$$

$$\mathrm{ET_i} = \begin{cases} \mathrm{ET_i} & \text{if } (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) \geq \mathrm{WLT} \\ (\theta_{i-1} + \mathrm{P_i} - \mathrm{WLT}) & \text{if } (\theta_{i-1} - \mathrm{ET_i} + \mathrm{P_i}) < \mathrm{WLT} \end{cases} \tag{7}$$

## 4. Results and discussion

### 4.1 Temperature (°C) and precipitation (mm) variability in Garissa County

Results indicated that temperature ranged from 26.7 °C to 31.6 °C in Garissa County. Mean annual precipitation was 303.2 ±146 mm, while absolute minimum and maximum were 114.2 mm and 552.2 mm, respectively. Temperature and precipitation showed variation (*Fig. 2*) throughout the period of analysis. Arid and semi-arid regions, which cover 80% of land mass are highly affected by extreme weather events (Marigi et al., 2016). Further, in Arid and Semi-arid Lands (ASALs), most inhabitants have insufficient financial ability to respond to these extreme weather events such as recurring and persistent droughts (Ng'ang'a et al., 2016). Therefore, research on drought and other extreme weather events are imperative to provide cushion against effects associated to them like water scarcity, failed agricultural production, maize in our context, as well as their whole livelihood systems.

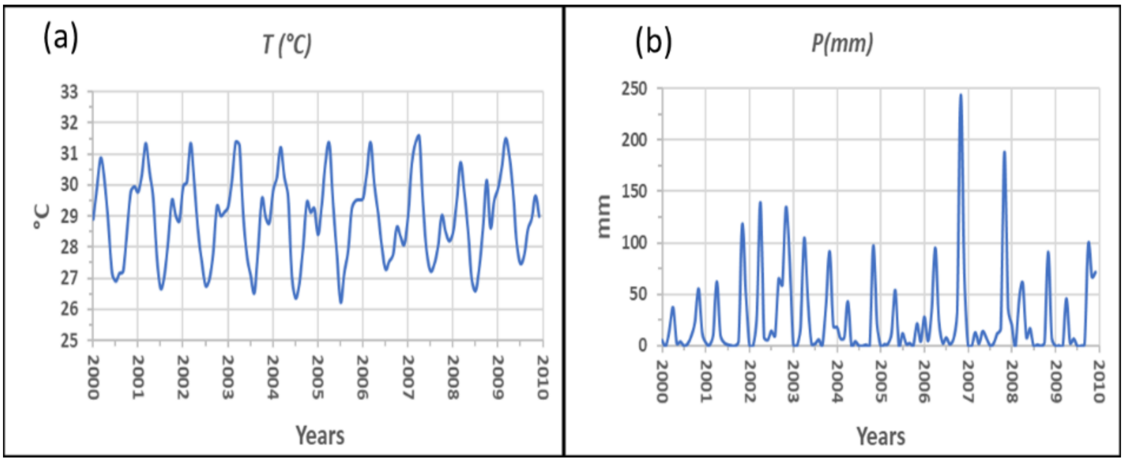


*Figure 2: Monthly mean temperature and precipitation variability in Garissa County (2000–2009).*

### 4.2 Daily reference evapotranspiration ($ET_0$) and real evapotranspiration ($ET$)

Daily results (*Fig. 3*) in Garissa County indicated that daily averages of $ET_0$ and $ET$ are 6.1 ±0.86 mm day$^{-1}$ and 0.84 ±0.8 mm day$^{-1}$, respectively. The daily maximum value of $ET_0$ was 9.6 mm day$^{-1}$, while daily minimum absolute estimate was 1.9 mm day$^{-1}$. The maximum absolute daily ET was 4.8 mm day$^{-1}$, while the minimum absolute value was zero (0 mm day$^{-1}$).

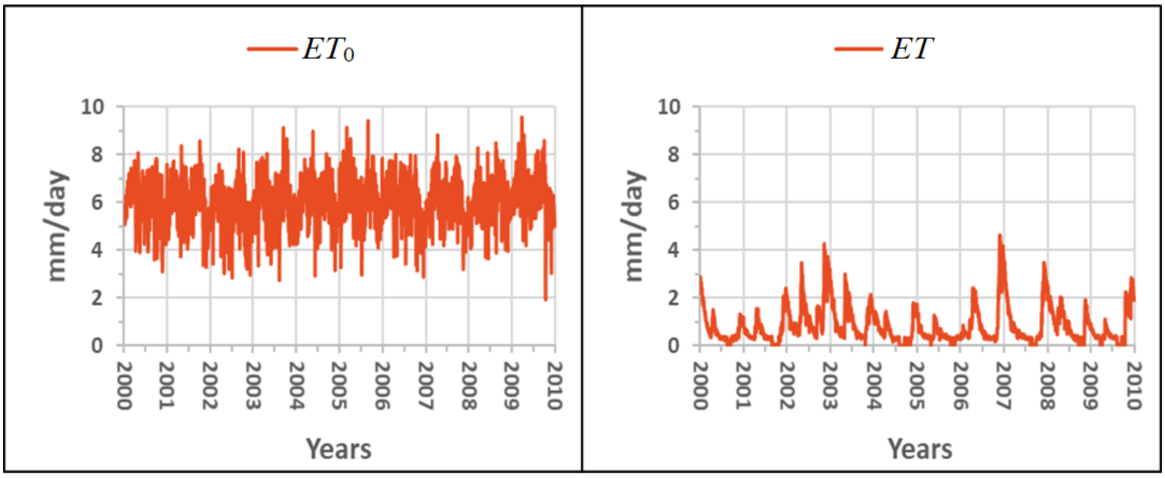


*Figure 3: Daily variability of $ET_0$ and ET in Garissa County, Kenya (2000–2009).*

### 4.3 Maize coefficient influence on Real evapotranspiration

Application of maize crop coefficient led to slight increase of ET. As stated by Guerra et al. (2011), crop coefficients are fundamentally vital for estimating evapotranspiration of crops. In situations of zero runoff, the amount of annual precipitation will not change practically since surface runoff is a function of precipitation as well as retention potential of the soil (Mohamed et al., 2019), hence the daily precipitation will depend on the coefficient. In Garissa County, zero runoff was experienced because by the time when rainy season starts, the soils are absolutely dry. Ndegwa et al. (2022) established that maize coefficient in Kenya varies as per four growth stages that is $Kc_{ini}$ of 0.4 , $Kc_{dev}$ of 0.8 , $Kc_{mid}$ of 1.15 and $Kc_{end}$ of 0.7. Moisture use also varies from one growth stage to another as well as one region to the other (Ndegwa et al., 2022). For instance, maize moisture utilization peaks at flowering and grain filling stages, and declines as the plant reaches physiological maturity. A study by Critchley et al. (1991) established that maize crop requires 500 mm to 800 mm of precipitation for optimal yield during growing period that is 90 to 125 days for early maturity and around 180 days for late maturity maize varieties. In our study, 1D Palmer-type soil model established a zero runoff, hence soil stress in Garissa County. Soil moisture distress highly influences real evapotranspiration since if there is deficiency in moisture, evapotranspiration requirements are not satisfied. Ndegwa et al. (2022) demonstrated that moisture deficit has a negative impact at any growth stage from germination to gain filling. Stegman (1982) also noted that a 1% decrease in seasonal real evapotranspiration led to an average loss of 1.5% in maize yield, whereas water stress more so during the reproductive stages, more so blister stage (10-14 days after silking) led to a 2.6% decline in maize crop yield.

Daily $ET$ ranged from zero (0 mm day$^{-1}$) to 4.8 mm day$^{-1}$, while on application of maize coefficient; daily maximum estimate of $ET_{Kc}$ was 5.4 mm day$^{-1}$, while the daily absolute minimum estimate was 0 mm day$^{-1}$ (*Fig. 4*). The daily mean was 0.86 ±0.86 mm day$^{-1}$. This concurs with Marshall et al. (2012), who indicated that deficits in estimated real evapotranspiration are a direct measure of crop stress and can be integrated into agricultural drought monitoring systems to determine crop water requirement and water resource management (Wu, 1997).

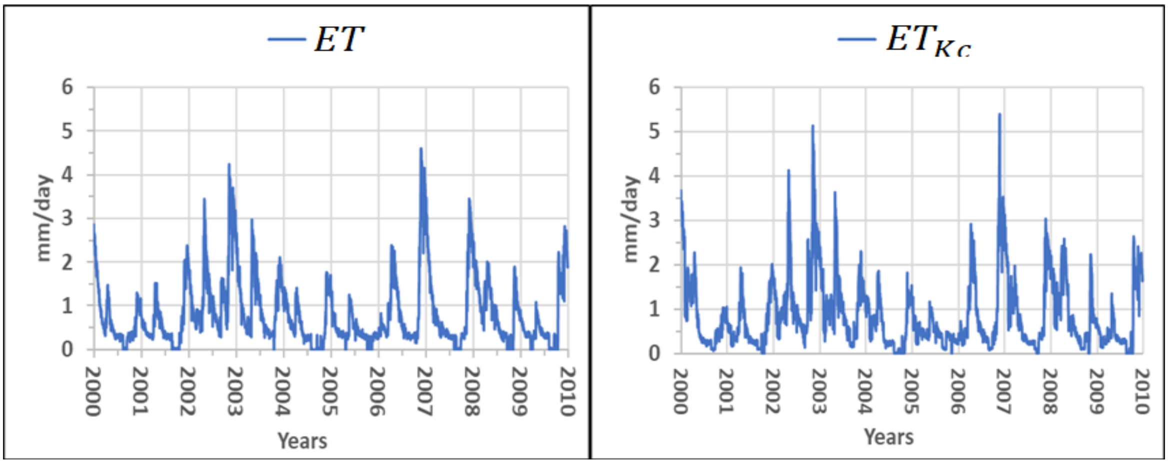


*Figure 4: Influence of Maize coefficient on daily variability of ET in Garissa County.*

### 4.4 Annual $ET_0$, $ET$ and $ET_{Kc}$ (maize coefficient)

Analysis also shows annual variation of $ET_0$ with a range of 2102 mm year$^{-1}$ to 2317 mm year$^{-1}$ in Garissa County. These results agree with Djaman et al. (2018), who observed that across Madagascar, annual $ET_0$ varied from 1081 mm year$^{-1}$ to 2239 mm year$^{-1}$ and averaged 1620 mm year$^{-1}$. The mean reference evapotranspiration was 2211 ±55 mm year$^{-1}$ a concurrence with Djaman et al. (2018), who observed long-term average annual $ET_0$ between 1891 mm year$^{-1}$ and 2111 mm year$^{-1}$ in western coast and northwestern coast. $ET$ ranged from 159 mm year$^{-1}$ to 522 mm year$^{-1}$ with a mean annual value of 306 ±111 mm year$^{-1}$. The variation of real evapotranspiration is attributable to the variation of precipitation, which conforms with Yang et al. (2021), who mentioned that the decrease in $ET$ is attributed to decrease in precipitation amounts and regions with less annual precipitation depicts less $ET$. $ET_{Kc}$ ranged from 164 mm year$^{-1}$ to 520 mm year$^{-1}$, while the mean annual value was 313 ±109 mm year$^{-1}$. The effect of maize coefficient on evapotranspiration was evaluated to provide basis for maize crop yield monitoring and modelling.

## 5. Conclusion

$ET$ (daily, monthly, and annual) increases slightly upon application of maize coefficient. Application of 1D Palmer-type soil model is sensitive and suitable in modelling $ET$ estimates even though the variation is small with the application of maize coefficient. Soil parameters studies should be given an in-depth insight to aid in operationalizing water management decisions in agricultural and hydrological processes. These findings are imperative in planning appropriate adjustment mechanisms in bolster of improving resilience of maize farming and food security in Garissa County and larger ASALs counties.

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