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ESTIMATION OF EVAPOTRANSPIRATION AND CROP WATER REQUIREMENTS OF SOME SELECTED CROPS AT TONO IRRIGATION SCHEME IN THE UPPER EAST REGION OF GHANA

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Abstract
A research was conducted at Tono Irrigation area in the Upper East Region of Ghana to estimate evapotranspiration and crop water requirement of some selected crop. FAO Penman-Monteith and Surface Energy Balance System Algorithm methods were used to estimate Potential crop and actual crop evapotranspiration during 2008/2009 crop season. This was done using climatic parameters like temperature, rainfall, wind speed, relative humidity and sunshine hours and fourteen (14) Aster images acquired in November, December, January, February, March and April which were the period of irrigation in the study area. The test crops included rice, tomato, onion and cowpea which are part of the major crops cultivated in the study area. The research findings revealed that rice has the highest evapotranspiration and crop water requirement than tomato, cowpea and onion. Potential crop and actual crop evapotranspiration were 902 and 610, 787 and 588, 381 and 365, 496 and 466 respectively. Also reference crop evapotranspiration was the lowest at the peak of the rainy season which gave lowest temperature and irrigation water demand. The field study also revealed that infilteration was very prominent at the valley bottom area where rice was cultivated. The result from the study can serve as a guide by irrigation managers in quantifying irrigation performance and the amount of water needed by each crop daily, monthly and seasonally.

Keywords: Irrigation requirement, Evapotranspiration, Energy balance and Hydrological cycle

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1. INTRODUCTION

Evapotranspiration is the combination of soil evaporation and crop transpiration. Weather parameters, crop characteristics, management and environmental factors affect evapotranspiration. Reference, potential and actual evapotranspiration are distinguished. These terms are commonly used, although some differences of their definitions can be found among researchers. The potential crop evapotranspiration (ET_C) is the amount of water that is lost through the evaporation process from the disease-free and well-fertilized crop fields (FAO, 2005). The value of ET_C is different from different crops as the ground cover; canopy properties and aerodynamic resistance of crops are different from one another. Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface (FAO, 2005). This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process (FAO, 2005).
The penman-monteith method as modified by (Allen, 1998) was the most accurate method to estimate evapotranspiration.

Because of its accuracy, the Penman-Monteith method is used since temperature, relative humidity, wind speed sunshine hours data are available in the area. Before calculating ETc for every crop, reference crop evapotranspiration (ETo) has to be estimated in daily time step by using Penman-Monteith method (recommended by the FAO). The reference evapotranspiration(ETo) represents the potential evapotranspiration of a well-watered grass crop with an assumed height of 0.12m, a fixed surface resistance of 70s/m and an albedo of 0.23 (allen et al., 1998).

Actual evapotranspiration (ETa) is actually evapotranspired under the existing soil moisture supply. It is dependent on the unsaturated moisture storage properties of the soil (Allen, 1998) It is also affected by vegetated factors such as plant type and stage of growth (Allen, 1998).

The objective of this study was to evaluate the performance of the FAO Penman-Monteith, Geographical Information System (GIS) and Remote Sensing methods to estimate Potential Evapotranspiration, and Actual Evapotranspiration under climatic conditions of Tono irrigation area.

2. MATERIALS AND METHODS

2.1.Location and Climate

The study area lies in the Guinea Savannah Ecological Zone of Ghana and is located in the Upper East region and lying between latitude 10^o 45'N and longitude 1^o W. It has a potential area of about 3840ha with a developed area of about 3450ha (Adams et al., 2014). The project area comprises eight (8) command areas, namely Bonia, Gaani, Korania, Wuru, Yigania, Yigwania, and Chuchuliga zone a and b.

Tono area experiences a unimodal rainfall pattern with a total annual rainfall of around 950mm which normally starts in May, reaches its peak in August then there is a abrupt decline in October. Thereafter, there is a long drought period from November to the ending of April where only negligible amounts of rainfall are recorded (Adams et al., 2014). There are also considerable constant yearly rainfall variations. Previously, the onset of the rains maybe delayed until June whilst in others the rain comes earlier than normal. Exceptionally heavy rains occur periodically which are then hazardous to crops (Adams et al., 2014). The rains are usually at their peaks in late August or early September.

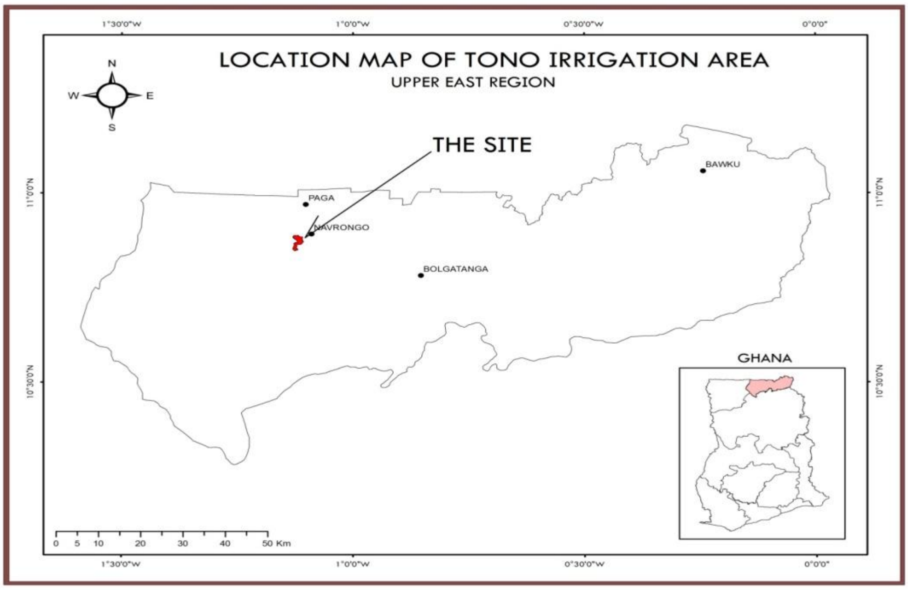

Figure 1. Map of upper east region showing the location of tono irrigation area(Adams et. al., 2014)

About 60% of the rainfall occurs within a period of three months (July to September), with torrential rains creating serious drainage problems. In most cases, absorptive capacity of the soil cannot withstand the intensity of the rain, thus creating high amounts of runoff, with erosion being one of the most significant agricultural constraints in the area. Precipitation, however, considerably outstrips evapotranspiration during the main period of the growing season (July-October) (Adams et al., 2014).

Mean monthly temperatures are high throughout the year only falling around 26^o C in August and September. The hottest temperatures records 32^{o}C in the months of March and April. December or January experiences an absolute minimum temperatures of around 16^{o}C with March and April recording an absolute maximum temperatures of about 35^{o}C (Adams et al., 2014).

Percentage relative humidity for the study area is high during wet season in particular, from July to September, and low in the dry harmattan period from January to February. Climatic data indicates low diurnal and monthly humidity readings between Noon and 1500 hours and high diurnal humidity readings between midnight and 0600 hours. Usually, humidity during the Noon to 1500 hours period may be 20 to 30 percent lower than at 0900 hours (Adams et al., 2014).

2.2. Estimation of Crop Water Requirement

The main objective of irrigation is to apply water to maintain crop evapotranspiration (ETc) when rainfall is insufficient. According to Hess, 2005, crop water requirement is defined as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. Mathematically, FAO, 2005 defined crop water requirement as:

$$CWR = \sum_{t=0}^{T} \left(K_{ci} * ET_{oi} - P_{eff} \right)$$

where Kci is the crop coefficient of the given crop i during the growth stage t and where T is the final growth stage, ETοi is reference evapotranspiration of crop i and Peff, effective rainfall from planting to harvest stage. CROPWAT software was used to estimate crop water requirement of each crop studied.

Smith et al., 1991 reported that CROPWAT is a practical tool to help agro- meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and the assessment of production under rain fed conditions or deficit irrigation.

Broner and Schneekloth, 2003 reported that water requirements of crops depend mainly on environmental conditions. Plant use water for cooling purposes and the driving force of this process is the prevailing weather conditions. Under the same weather conditions, different crops have different water use requirements(Broner and Schneekloth, 2003).

The Surface Energy Balance System (SEBS) by Su et al., (2001) was used to estimate actual evapotranspiration (ET_a) and other energy fluxes in daily, monthly and seasonal time steps.

Estimation of ET_a is the most crucial part in the study of irrigation performance. Because the process uses satellite images of different dates, the major advantage of the process is that ET_a can be computed over large areas in different times. Daily ET_a values for the land cover or seasonal crops like rice, tomato, onion and cowpea that were growing in the field during the image date were selected.

Remote sensing methods are very crucial in the estimation of ET_a as they cover large areas and can provide estimates at a very high spatial resolution. Intensive field monitoring is also not required, although some ground-truth measurements can be useful in interpreting the satellite images.

Daily actual evapotranspiration according to Su, 2002, is given by:

$$E_{daily} = 8.64 \times 10^7 \times \Lambda \times \frac{R_{n*} - G_*}{\lambda \rho_\omega} \quad 2$$

Where E_{daily} is the daily actual evaporation (mmd^{-1}), Λ is the daily average evaporation fraction which can be approximated by SEBS estimate since the evaporative fraction is conservative R_{n*} and G_* are the daily net radiation flux and soil heat flux and ρ_w is the density of water.

The daily soil heat flux is close to zero because of the downward flux in daytime and upward flux at night balance each other approximately; the daily evaporation only depends on the net radiation flux given by:

$$R_{n*} = (1-\alpha)R \downarrow + \varepsilon L$$

Aster images (Path-194 Row-053), covering the whole of the study area was acquired in 4th, 8th, 12th, 16th, 20th, 24th, 28th November and December 2008, and 4th, 8th, 12th, 16th, 20th 24th, 28th January, February and March, 2009 which is the irrigation period (dry season) of the study area and downloaded from the website (http://earthexplorer.usgs.gov).

The remote sensing input used for this study is Aster data having the following description (table 1).

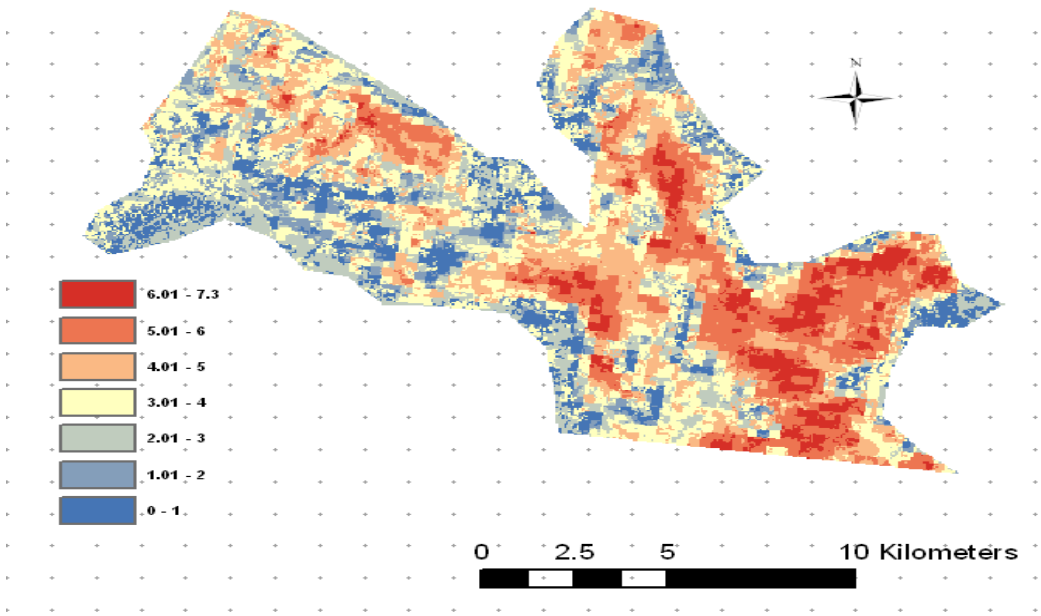

Figure 2. Daily actual evapotranspiration (mm/day) map of the command area

Table 1: Description of imageries used in the study

Aster	Bands	Resolution
Visible	2	15
Near infrared	7+1	30
Thermal infrared	5	60

Penman-Monteith method was used to estimate Potential Evapotranspiration as (Allen et al., 1998):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T} + 273\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2}$$

Where:
ET_o= Reference crop evaporation ($mmday^{-1}$)
R_n=Net radiation at the crop surface($MJm^{-2}day^{-1}$)
G = Soil heat flux density ($MJm^{-2}day^{-1}$)
T = Mean daily air temperature at 2m height (°C)
U_2= Wind speed at 2m height (ms^{-1})
$e_s =$ Saturated vapor pressure (kPa)
$e_a =$ Actual vapor pressure (kPa)
$e_s - e_a =$ Saturated vapor pressure deficit (kPa)
$\Delta =$ Slope vapor pressure curve (kPa°C^{-1})
$\gamma =$ Psychrometric constant (kPa°C^{-1})
In this study, Tono meteorological station is selected for this purpose because it is situated in the irrigation command area. Once the ET_o value is calculated, the potential crop evapotranspiration is calculated by the product of ET_o and Crop coefficient (Kc).
Mathematically, ETc is given by:

$$ET_c = ET_o \times K_c$$

Kc is specific for a particular crop and varies as local climatic condition varies. The single crop coefficient approach is used here to determine Kc. The double crop coefficient approach is impossible here because of lack of daily water balance data for the surface soil layer.
The standard crop coefficient (K_c) values of each growing stage for each crop was selected from FAO-56 document, table 12. Single crop coefficient approach was used in this study and K_c values of all the growing stages have to be adjusted but unfortunately information about wetting frequency which is used to adjust initial K_c value was not available hence, standard K_c values for initial stage was used.

The adjusted K_c values of the mid and late stages were computed based on climatic conditions. Meteorological data such as wind speed at 2m and minimum relative humidity was taken from Tono station and minimum height of each crop was also taken from FAO-56 document, table 12.The equations for computing the adjusted K_c values are shown below.
Standard crop coefficient (K_c) values of every growing stage such as initial, mid and late stage of each crop was taken from FAO-56 document table 12. The equation for adjusting K_c values in the mid-stage is expressed as:

$$K_{c\_mid} = K_{c\_mid(Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3}$$

Where $K_{\_mid(Tab)}$ is standard K_c values for mid growing stage which was taken from FAO-56 document table 12, u_2 and RH_{min} are mean wind speed at 2m and mean minimum relative humidity and h is the height of the plant during the mid- growing stage.
The K_c value for end-growing stage is also expressed as:

$$K_{c\_end} = K_{c\_end(Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3}$$

3. RESULTS AND DISCUSSION

The results obtained when a 11-year period of climatic data was used with the FAO-Penman Monteith method to estimate the reference crop evapotranspiration (ETo) for the study area showed that ETo varied from a minimum value of 4.43mm/day in July to the highest value of 6.47mm/day in April (Table 2). The results showed that ETo was lowest during the peak of the rainy season to the highest during the peak of the dry season.
The results also showed that for paddy rice, crop evapotranspiration (ET_c) and crop water requirement varied from 0.57 to 6.84mm/day and 0.0 to 26.78mm/day respectively (Table 3).

Table 2. Reference Crop Evapotranspiration

Country : Ghana					**Meteorological Station: Tono**		
Coordinates: Lat. 10° 5' N Lon. 1°W					**Altitude : 172m**		
Month	Max. T (° C)	Min. T (° C)	Humidity (%)	Wind (km/day)	Sunshine Hours	Radiation (MJ/m²/day)	ET_o (mm/day)
January	38.5	16.7	33	145	9.1	20.6	5.75
February	41.4	18.9	31	145	9.2	22.1	6.40
March	42.7	21.3	43	113	9.0	23.0	6.27
April	42.0	21.2	52	141	8.3	22.3	6.47
May	40.2	21.7	62	149	8.3	21.9	6.12
June	36.7	20.1	68	161	8.2	21.3	5.53
July	35.0	20.6	72	113	5.9	18.0	4.43
August	33.4	20.2	77	129	6.6	19.4	4.46
September	35.5	19.9	74	133	7.8	21.2	4.94
October	37.9	20.6	63	141	9.0	22.0	5.58
November	39.6	17.0	50	129	9.1	20.8	5.52
December	38.8	17.2	34	129	9.1	20.0	5.43
Year	38.5	19.6	55	136	8.3	21.1	5.58

ET_o = Reference crop Evapotranspiration computed using FAO Penman-Monteith Method.

Table 3: Evapotranspiration and Irrigation Requirement for Paddy Rice (2008/2009)

Station: Tono								
Month	**Decade**	**Stage**	**Kc coeff**	**ETc mm/day**	**ETc mm/dec**	**Eff rain mm/dec**	**Irr. Req. mm/dec**	**Irr. Req mm/day**
Sep	1	N	1.2	0.57	4	32.4	0	0
Sep	2	N/L	1.11	3.86	38.6	44.7	117.6	11.76
Sep	3	N/L	1.06	5.49	54.9	31	267.8	26.78
Oct	1	Init	1.09	5.85	58.5	10.5	245.2	24.52
Oct	2	Init	1.1	6.14	61.4	0	61.4	6.14
Oct	3	Dev	1.11	6.2	68.2	0.2	67.9	6.17
Nov	1	Dev	1.16	6.43	64.3	1.6	62.6	6.26
Nov	2	Dev	1.21	6.65	66.5	0.7	65.8	6.58
Nov	3	Mid	1.23	6.77	67.7	0.5	67.3	6.73
Dec	1	Mid	1.23	6.74	67.4	0.1	67.3	6.73
Dec	2	Mid	1.23	6.71	67.1	0	67.1	6.71
Dec	3	Mid	1.23	6.84	75.2	0	75.2	6.84
Jan	1	Late	1.21	6.84	68.4	0	68.4	6.84
Jan	2	Late	1.16	6.7	67	0	67	6.70
Jan	3	Late	1.11	6.65	73.1	0.1	73	6.64
					902.3	122	1373.6	135.40

where N= Nursery, N/L= Nursery/Land preparation, Init= Initial stage, Development stage, Mid= Mid-Season stage, Late= Late season stage, IR= Irrigation Requirement (mm/day), IR= Irrigation Requirement (mm/dec), K_c= Crop Coefficient, ET_c= Crop Evapotranspiration (mm/day), ET_c= Crop Evapotranspiration (mm/dec).

For tomato, crop evapotranspiration and crop water requirement ranged from 3.22 to 7.01mm/day and 2.16 to 7.00mm/day respectively (Table 4). For onion crop evapotranspiration and crop water requirement ranged from 3.16 to 4.83mm/day in both cases respectively (Table 5). For cowpea crop evapotranspiration and crop water requirement ranged from 1.75 to 5.22mm/day also in both cases respectively (Table 6).

Table 5: Evapotranspiration and Irrigation Requirement for Onion in 2008/9

Station: Tono, Area: 119.4ha									
Month	**Decade**	**Stage**	**K_c**	**ET_c**	**ET_c**	**Eff.**	**IR**	**Period**	**IR**
			Coeff.	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**		**mm/day**
Nov	2	A	0.7	3.25	22.7	0	22.7	7	3.24
Nov	3	A	0.7	3.16	31.6	0	31.6	10	3.16
Dec	1	D	0.72	3.16	31.6	0	31.6	10	3.16
Dec	2	D	0.79	3.35	33.5	0	33.5	10	3.35
Dec	3	D	0.86	3.8	41.8	0	41.8	11	3.80
Jan	1	D	0.94	4.27	42.7	0	42.7	10	4.27
Jan	2	M	1	4.72	47.2	0	47.2	10	4.72
Jan	3	M	1.02	4.8	52.8	0	52.8	11	4.80
Feb	1	L	1.02	4.81	48.1	0	48.1	10	4.81
Feb	2	L	1.02	4.83	29	0	29	6	4.83
					381			95	40

Table 6: Evapotranspiration and Irrigation Requirement for Cowpea in 2008/2009

Station: Tono, Area: 103.8ha									
Month	**Decade**	**Stage**	**K_c** **Coeff.**	**ET_c** **mm/day**	**ET_c** **mm/dec**	**Eff.** **mm/dec**	**IR** **mm/dec**	**Period**	**IR** **mm/day**
Nov	2	A	0.4	1.86	9.3	0	9.3	5	1.86
Nov	3	A	0.4	1.8	18	0	18	10	1.8
Dec	1	A	0.4	1.75	17.5	0	17.5	10	1.75
Dec	2	D	0.51	2.15	21.5	0	21.5	10	2.15
Dec	3	D	0.71	3.11	34.3	0	34.3	11	3.11
Jan	1	D	0.91	4.14	41.4	0	41.4	10	4.14
Jan	2	M	1.06	4.99	49.9	0	49.9	10	4.99
Jan	3	M	1.07	5.05	55.6	0	55.6	11	5.05
Feb	1	M	1.07	5.06	50.6	0	50.6	10	5.06
Feb	2	M	1.07	5.06	50.6	0	50.6	10	5.06
Feb	3	M	1.07	5.22	41.8	0.1	41.6	8	5.2
Mar	1	L	0.97	4.87	48.7	0.1	48.6	10	4.86
Mar	2	L	0.78	4.06	40.6	0.2	40.4	10	4.04
Mar	3	L	0.65	3.38	16.9	0.4	12.5	5	2.5
					496			130	52

The irrigation requirement of rice is higher than tomato, onion and cowpea (figure 3).
During the fieldwork it was revealed that rice at Tono irrigation area was cultivated on the valley bottom soil and other major crops on the upland soils. It was also observed that infiltration process was prominent at the valley bottom soil area and high demand of evapotranspiration due to high temperatures; this could contribute to the high demand of irrigation water.
The daily ET_a values of the selected crops and map of the command area were estimated and created from equation 2 and figure 2 above. The ET_a values of rice, tomato, onion and cowpea for the growing periods were 610, 588, 365 and 466. Rice has the highest ETa value and onion has the lowest ETa value.
This is due to the fact that crop water requirement of rice is higher than onion. This also depends on daily temperature. According to Valor et al., 1996, if there is abundant moisture in the soil; the actual evapotranspiration rate is equal to potential evapotranspiration. When the moisture content in the soil is limited as a result of high temperature and other climatic parameters, and the crop unable to abstract enough water from the soil, then actual evapotranspiration becomes less than the potential evapotranspiration.

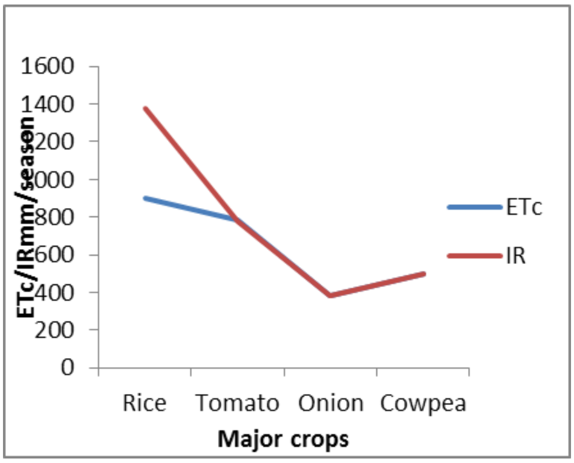

Figure 3. ETc and IR of major crops

Thus the relationship between ET_a and ET_o depends upon the soil moisture content. If there is no rain to replenish the water supply, the soil moisture gradually become depleted by the demands of the vegetation to produce a soil moisture deficit. As soil moisture deficit increases, the ETa becomes increasingly less than ET_o. The value of soil moisture deficit and ET_a vary with soil type and vegetation (Shaw, 1988).
Figure 4 below illustrates that rice and tomato have highest ETc and ETa values than onion and cowpea. These values differ in different environments as these depend on weather characteristics, soil type and the level of the water table (Shaw, 1988).

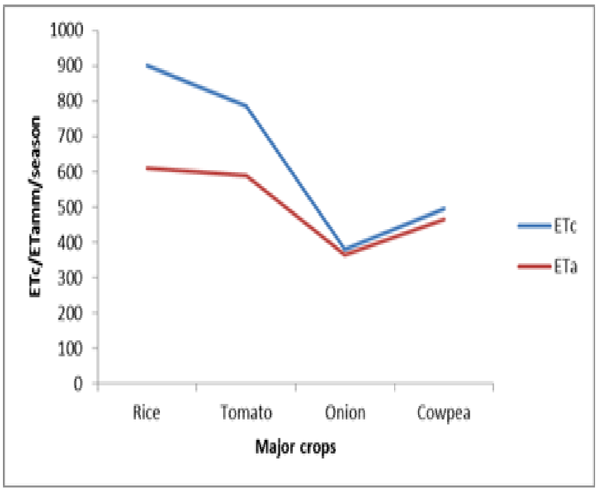

Figure 4: ETc and ETa of major crops at Tono irrigation scheme

4. CONCLUSIONS

Evapotranspiration is a major controlling factor of hydrological processes. Climate variability will affect the hydrological processes mainly through evapotranspiration.
FAO Penman-Monteith method coupled with GIS and remote sensing was used to estimate reference, potential and actual evapotranspiration at Tono irrigation area.
Climatic parameters like temperature, relative humidity, rainfall, wind speed and sunshine hours for a period of 11-years. Rice has the highest evapotranspiration and crop water requirement than tomato, cowpea and onion.

5. REFERENCES

[1]. Adams S, Issaka R. N. , Quansah G. W., Amfo-Otu R. , and Bagna S. 2014. Assessment of Irrigation Water Quality of Tono Irrigation Dam in Navrongo, Ghana. Journal of Biodiversity and Environmental Science Vol.4 (3): p. 187-195

[2]. Adams S, Issaka R. N. , Quansah G. W. , Amfo-Otu R. , Asamoah E. A, Nketia K. A 2014. Water requirements of some crops at Tono irrigation area, Navrongo, Ghana. Journal of Biodiversity and Environmental Science Vol.4 (3): p. 246-257

[3]. Allen R. G., Pereira L. S., Raes D., and Smith M, 1998. Crop evapotranspiration, guidelines for computing crop water requirements, FAO irrigation and Drainage paper 56, pp. 300, Rome, Italy

[4]. Broner I, Schneekloth J. 2003. Seasonal Water Needs and Opportunities for Limited Irrigation for Colorado Crops, Newsletter of the Extension Irrigation Services, Dept. of Civil Engineering, Colorado State University. No. 4.718.

[5]. FAO. 2005. Irrigation water requirement, In: Irrigation potential in Africa: A basin approach, Chapter 5, FAO corporate document repository, Rome, Italy.

[6]. Hess T. 2005. Crop Water Requirements, Water and Agriculture, Water for Agriculture, WCA infoNET, http:// silsoe.cranfield.ac.uk/iwe/dailyet.htm

[7]. Smith M. , Allen R. G., Monteith J. L. , Perrier A. , Pereira L. S. and Segeren A. 1991. Report of the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements. UN-FAO, Rome, Italy, pp. 54

[8]. Su Z and Jacobs C. 2001. ENVISAT: actual evaporation. BCRS Report 2001: USP-2 report 2001. Publication of National Remote Sensing Board, Delft, pp. 57.

[9]. Su Z. 2002. The surface energy balance system for estimation of turbulent heat flux. Hydrological and Earth System Sciences, 6(1): 85-89

[10]. Shaw E. M. 1998. Hydrology in practice. Second edition, Chapman and Hall, New York, pp. 539

[11]. Valor E. and Caselles V. 1996. Mapping land surface emissivity from NDVI: Application to European, African and South American areas. Remote Sensing of Environment 57(3): 167-184