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Models Comparative Study for Estimating Crop Water Requirement and Irrigation Scheduling of Maize in Metekel Zone, Benishangul Gumuz Regional State, Ethiopia

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Abstract

This study was aimed to compare estimation methods of crop water requirement and irrigation scheduling for major crops using different models and compare the significance of models for adoption at different situations in Metekel zone. Crop water requirement and irrigation scheduling of maize in selected districts of Metekel zone were estimated using CropWat model based on soil, crop and meteorological data and AquaCrop based on soil, crop and meteorological data including Co_2, groundwater, field management, and fertility status. Model performance was evaluated using Normalized Root mean square errors (NRMSE), model by Nash-Sutcliffe efficiency (NSE), Prediction error (Pe), and Model efficiency (MF). It is observed that the maximum reference evapotranspiration in the study area was found to be 7.1 mm/day in Guba and minimum reference evapotranspiration was 2.9 mm/day in Bullen district. In all cases, the maximum ETo in all districts was fund to in March and the lowest in August. The maximum ETc of maize was found to be 702.4mm in Guba district and minimum ETc was found to be 572.6mm in Bullen district using CropWat but the effective rainfall (Pe) for maize were determined as 185mm respectively in Wembera district. However, using AquaCrop model the maximum ETc of 565 mm was recorded in Guba but 425 mm was recorded as minimum in Wembera district for irrigated maize in the study area. The study revealed that the irrigation scheduling with a fixed interval criterion for maize 10 days with 12 irrigation events has been determined. Moreover, furrow irrigation with 60 % irrigation application efficiency was adjusted during irrigation water applications for all districts. The performance of the irrigation schedule and crop response was evaluated by the analysis results in the simulation using different models. It has been observed that there was a strong relationship and a significant relation between the simulated and observed values for validation. Hence, Normalized Root mean square errors (NRMSE), model by Nash-Sutcliffe efficiency (NSE), Prediction error (Pe), and Model efficiency (MF) showed that AquaCrop model well simulated in all parameters considered. AquaCrop model is the most suitable soil-water-crop-environment management model, so future studies should suggest a focus on addressing deficit irrigation strategy with different field management conditions to improve agricultural water productivity under irrigated agriculture for the study area for major crops.

Keywords: Depilation, Irrigation events, AquaCrop, Fixed interval and Deficit Irrigation.
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1. INTRODUCTION

Irrigation implies the application of suitable water to crops in the right amount at the right time (FAO, 2005). Irrigation scheduling is important for developing best management practices for irrigated areas (Ali et al., 2011). There is considerable scope for improving water use efficiency of these crops by proper irrigation scheduling which governed by crop evapotranspiration (FAO., 1998) and (Allen et al., 1998) have suggested that the crop coefficient values need to be derived empirically for each crop based on lysimetric data and local climatic conditions.

Maize (*Zea mays L.*) is the world's third most important cereal crop after wheat and rice grown primarily for grain and secondly for fodder (Nelson, 2005). Seasonal maize water use varies according to the evaporative demand of the atmosphere, and hence according to climate, time of the season when the crop is grown, the life cycle length of the crop, and water availability (George *et al.* ,200). The typical seasonal ET of a cultivar of medium-season length grown in a temperate climate at the latitude of 35° to 40° being around 650 mm (USDA-NRCS, 2004).

The demand for water has been the main limiting factor for crop production in much of the world where rainfall is not ample. The ever increase in the human population is stimulating the rise in demand for a large quantity of crop yield (Lutaladio *et al.,* 2009). Sustaining this population will require increased production of all crops. There is also a limited amount of arable land and the resources to produce food are becoming scarcer. As population rises, less land will be devoted to agriculture, meaning increased production will have to come from increased yields (Milander, 2015). In Metekel zone, almost all farmers are poor in water resource management and lack of experience and knowledge about how much and when to irrigate efficiently for irrigation water saving-strategies to tackle the shortage of rainfall and dry spell (Dessalegn, 2015). This results in waterlogging, soil erosion, accumulation of salt, and loss of irrigation water resources. Therefore, there is a need to improve the water use efficiency to obtain more crop production per drop of water with declining irrigation resources and the uncertainty in the temporal and spatial distribution of rainfall. Among many, one of the mechanisms or strategies to improve crop productivity per unit of water under full irrigation is the employment of the aid of models to fill the gaps during dry spells (FAO, 1990). It has been reported by different scholars that the crop water requirement and irrigation scheduling determined using CropWat. However, the comparative study using the CropWat and AquaCrop model for the determination of crop water requirement and irrigation scheduling of major crops in the study area hasn't been done yet to the best of my knowledge.

The model simulation is a simplification of the field processes, but it attempts to account for the most important factors that influence the model performance. Determination of crop water requirement and irrigation scheduling will provide information that increases water use efficiency and increase the productivity of maize crops in the study area. However, the performance of models varies from one another based on various factors. Therefore, evaluation and identification of the best model for maximizing the efficiency of water use in crop production are unquestionable. Consequently, sustainable and effective utilization of scarce water resources may promote and contribute to poverty alleviation in the area and enhance food security through maximizing crop production of the farmers. The bjective of this study was to compare and evalauate ETo, crop water requirement and irrigation scheduling for maize using CropWat and AquCrop to improve water productivity for sustainable agricultural production under irrigated agriculture.

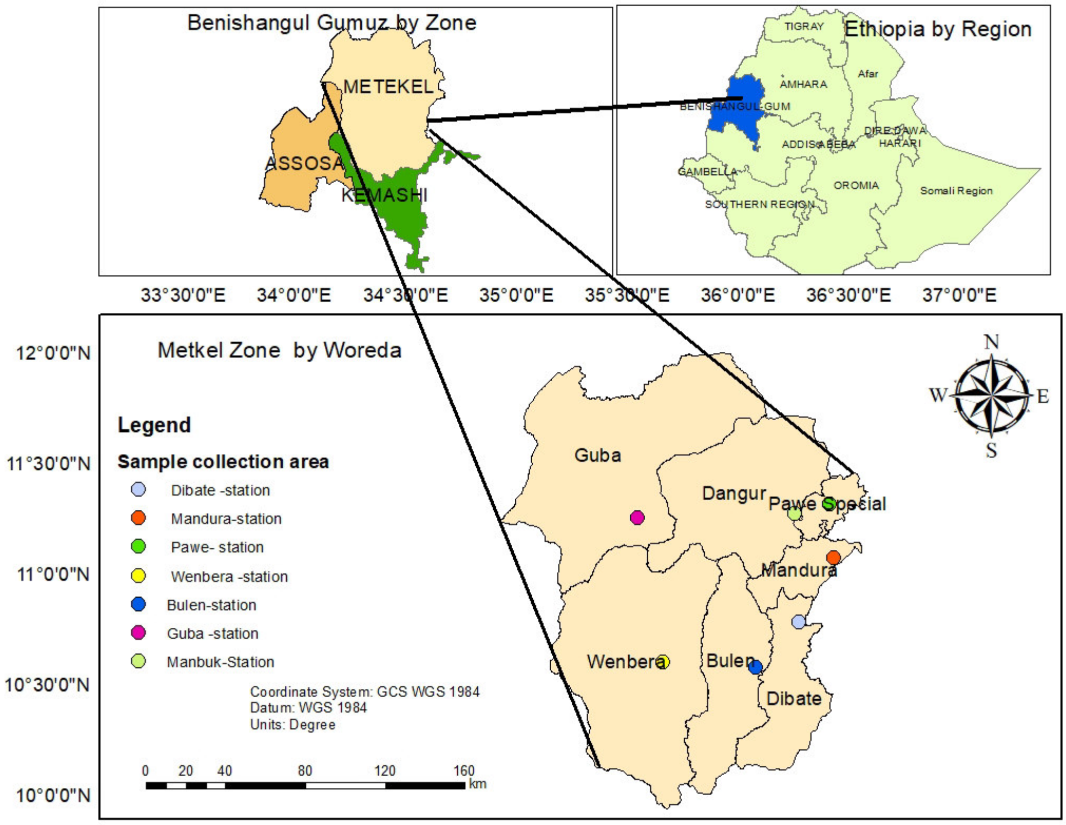
2. MATERIALS AND METHODS

2.1. Description of the study area

The study was conducted in Metekel zone of Benishangul Gumuz Regional State, North-West of Ethiopia. It is the largest zone of the region covering an area of 3,387,817 hectares consisting of seven 7 districts: Wombera, Bullen, Manbuk, Dibate, Mandura, Guba, and Pawe Woreda. The topography of the zone presents undulating hills slightly sloping down to low land Plateaus having varying altitudes from 600- 2800 m.a.s.l. and the annual rainfall of the area is 900-1580mm. About 80 % of the zone is characterized by having a sub-humid and humid tropical climate (Solomon et al., 2014). Its diverse agro-ecology provides the potential for the cultivation of different crops. Farmers practice a mixed crop-livestock production system. Cereals (maize, sorghum and finger millet) and oilseeds (soybean, sesame, and groundnut) are the most important food grains mainly cultivated in the zone. (Abebaw et al., 2015). According to the Ministry of Agriculture (MoA) and Agricultural Transformation Agency, the surrounding of Metekel Zone has a wide climatic range within hot to warm moist lowlands and hot to warm -sub-humid lowlands agroecological zones (MoA and ATA, 2013).

The annual minimum and maximum temperature of the study area is 20°C and 35°C respectively. The soil type of the study area is characterized by heavy clay soil with initial available soil moisture depletion level range 111-129 (mm/meter depth) and total available soil moisture level range 222-259 (mm/meter depth) varying with soil depth. a mean infiltration rate is 70 mm/day and the bulk density is varying from 1.12-1.31gm/cm3 across the depth of 1.2 meter (Ashebir and Demeke, 2017). Agricultural activities in the study area dominated by mixed crop-livestock production, which accounts 96.2% of the farmers and the rest 3.8% were involved only in livestock production (Solomon *et al.*, 2014). Figure 1: Location map of the study area

Figure1: loction of study area.



2.2. Crop Water Requirement

2.2.1. Crop and Irrigation Water Requirements using CropWat Model

CropWat 8.0 computed crop water requirement by feeding the computed monthly ETo values together with rainfall, crop type including cropping calendar together with the required soil characteristics of maize. The Kc for every growth stage was adapted from Allen *et al.* (1998) and then, ETc was calculated by euation (1). The irrigation requirement was calculated using the equation (2).

$$\mathbf{ETc = ETo * kc} \tag{1}$$

$$\mathbf{NIR = ETc - Pe} \tag{2}$$

Where, ETc = crop evapotranspiration (mm), ETo = reference evapotranspiration (mm), Kc = crop factor, NIR = net irrigation water requirement (mm), ETc = crop water requirement (crop evapotranspiration) (mm), Pe = effective rainfall (mm).

The amount of water applied during an irrigation event (gross irrigation) is equal to the net irrigation required between irrigation and that needed for efficiencies in the irrigation system. In this study, water was assumed to apply with precise measurements. As a result, there was no run-off and the only loss would be deep percolation and evaporation which are expected to be not much in a deficit irrigation practice. Therefore, a higher value of application efficiency (60%) was adopted.

$$\mathbf{GIR = NIR / Ea} \tag{3}$$

Where, GIR = gross irrigation requirement, NIR = net irrigation water requirement and Ea= water application efficiency=60%.

2.2.2. Crop and Irrigation Water Requirements using AquaCrop Model

Considering groundwater table, as no shallow groundwater table, all stress indicators, waterlogging stress, water shortage stress, air temperature stress, soil salinity stress have been considered as zero and considering no specific field management, net irrigation requirement and crop water requirement for furrow irrigation have been calculated. The simulation period has been adjusted and soil water profile at % of RAW considered as an initial condition with no field observation.

To all test crops, crop evapotranspiration has been calculated by multiplying the reference evapotranspiration (ETo) with the crop transpiration coefficient (KcTr) and a water stress coefficient (Ks) which is 1 when water stress does not induce stomatal closure.

Crop transpiration has been calculated by the concept of the following formula

$$\mathbf{Tr = Ks * K_{cT}r * ETo} \quad (4)$$

Where, ETo is the reference evapotranspiration, KcTr is the crop transpiration coefficient, Ks is a water stress coefficient which is 1 when water stress does not induce stomatal closure.

The crop transpiration coefficient K_{cTr} is proportional to the green canopy cover (CC):

$$\mathbf{K_{cTr} = K_{cTr,\,x} * K_c\, CC^{**}} \quad (5)$$

Where, $Kc_{Tr,\,x}$ is the crop coefficient for maximum crop transpiration (determined by the characteristics that distinguish the crop with a complete canopy cover from the reference grass), and CC* the canopy cover adjusted for micro-advective effects.

Net irrigation requirement: The depletion (% RAW) below which the soil water content in the root zone may not drop (0 % RAW corresponds to Field Capacity). The total amount of irrigation water required to keep the water content in the soil profile above the specified threshold is the net irrigation water requirement for the period. The net requirement does not consider extra water that has to be applied to the field to account for conveyance losses or the uneven distribution of irrigation water on the field.

2.3. Irrigation scheduling

2.3.1. Irrigation Scheduling using CropWat model

Irrigation scheduling was worked out using CropWat 8.0 windows by selecting two scheduling criteria: fixing the interval and adjusting the depth to a constant value for no yield reduction and minimum water loss and the 100% readily available soil moisture depletion.

2.3.2. Irrigation schedules using AquaCrop model

Generation of irrigation schedules using AquaCrop have been computed by specify back to field capacity and fixed net application depth criterion and fixed interval and allowable depletion (% of RAW) time criteria.

By selecting the furrow irrigation method, irrigation events (when to irrigated and how much to irrigate have been specified by considering irrigation water quality for maximum dry yield production and water productivity and minimum labor cost (irrigation event). The electrical conductivity (EC) of the irrigation water was used as an input to irrigation scheduling.

2.4. Model Calibration and Simulations

After all, input data encoded - climatic, crop, management, and soil characteristics that described or defined the environment in which the crop was developed. Before the simulation, the simulation phase and the initial conditions at the beginning of the simulation were determined. The user can track changes in the soil water and corresponding changes in the crop development, soil evaporation, transpiration, (ET) rate, biomass production, and yield when running simulation results of the simulation were stored in output files in spreadsheet format to retrieve the data for further processing and analysis. Furthermore, program settings permit the user to change default settings and reset to an individual's default values once more.

Model Calibration for several crops was presented by Farahani *et al*., (2009); Garcia *et al*., (2009); Geerts *et al*., (2009) Hsiao *et al. (*2009) and Heng *et al.* (2009) shown the model performed well. The observed data set from the non-water stress conditions (that is full 100% ETc irrigation treatment) used for model calibration. The observed crop characteristics namely; time to emergence, time to attain maximum canopy cover, time to flowering, and senescence and physiological maturity (in calendar days) were used. After the calibration process, the model was validated from separated other treatment data except for 100% ETc (Yibrah *et al*., 2015).

2.5. Performance Evaluation of Models

The output of a model depends on the principle of the model itself and the accuracy of the input data. Evaluation of model performance should include both statistical criteria and graphical display. A model is a good representation of reality only if it predicts an observable phenomenon with acceptable accuracy and precision (League and Green, 1991).

Addicott and Whitmor (1987) concluded that any one method of measuring discrepancy between model output and observed data alone might be misleading, but several methods used together could summarize the closeness of a model's estimates and measurements with the observed values. The following statistics and model performance indicators were used to indicate overall model performance: average deviation, root mean square error (RMSE), relative error, model efficiency [Ali *et al*,2004, Dust *et al*., 2000; Lemma and Shimeles *et al*., 2003; Loague and Green, 1991].

Model performance was evaluated using the following statistical parameters: prediction error (Pe), Nash-Sutcliffe efficiency index (E), mean absolute error (MAE), root mean square error normalized (RMSEN).

$$\textbf{Prediction error (Pe): } \frac{(\mathbf{Si-Oi})}{\mathbf{Oi}} * \mathbf{100} \quad (6)$$

Where, Si the is predicted value, Oi is observed value.

Root mean square error normalized (RMSEN)

Because RMSE is expressed in the units of the studied variable, it does not allow model testing under a wide range of metro-climatic conditions (Jacovides and Kontoyiannis,1995). Therefore, RMSE can be normalized using the mean of the observed variable (Oi). The Normalized RMSE expressed in percent, will be calculated Loague and Green (1991).as illustrated in (Equation 7). A model can be considered excellent if NRMSE is smaller than 10%, good if between 10 and 20%, fair if between 20 and 30% and poor if larger than 30 (Ahmed, 2014; Yibrah, 2015).

$$\mathbf{RMSEN}=\frac{\mathbf{1}}{\boldsymbol{Oi}}\sqrt{\sum\frac{(\boldsymbol{Si}-\boldsymbol{Oi})^{\mathbf{2}}*\mathbf{100}}{\boldsymbol{N}}} \qquad \mathbf{(7)}$$

Where, Si is predicted value, Oi is observed value, and N is the number of observations.

Model efficiency

The robustness of the model was assessed with the model efficiency (ME) (Loague and Green 1991).

$$\mathbf{MF}=\frac{\sum_{i=1}^{N}(oi-\mathrm{mo})^{2}-\sum_{i=1}^{N}(si-oi)^{2}}{\sum_{i=1}^{N}(oi-mo)^{2}} \qquad \mathbf{(8)}$$

Where, Si is predicted value, oi is the observed value, N is a number of observations and MO is the average of the observed values.

ME acquires values from infinite negative to 1. The closer it gets to 1, the higher the robustness of the model. An ideal value of MF is the unit.

Nash-Sutcliffe efficiency index

The Nash-Sutcliffe coefficient of efficiency coefficient (NSE) determines the relative magnitude of the residual variance compared to the variance of the observations. A plot of observed data versus simulated data is that too fits the 1:1 line indicates a perfect match between the model and the observations. Nash-Sutcliffe was as accurate as of the average of the observed data. A negative NSE occurs when the mean of the observations is a better prediction than the model. (Ahmed, 2014; Yibrah, 2015) The Nash-Sutcliffe coefficient of efficiency coefficient (NSE) calculated as (Equation 9). Nash-Sutcliffe is very commonly used, which means that there are a large number of reported values available in the literature (Moriasi, *et.al*, 2007). However, like NSE is not very sensitive to systematic over-or underestimations by the model (Krause, *et.al*, 2005).

$$\mathbf{NSE}=1-\frac{\sum_{i=1}^{N}(si-oi)^{2}}{\sum_{i=1}^{N}(oi-mo)^{2}} \qquad \mathbf{(9)}$$

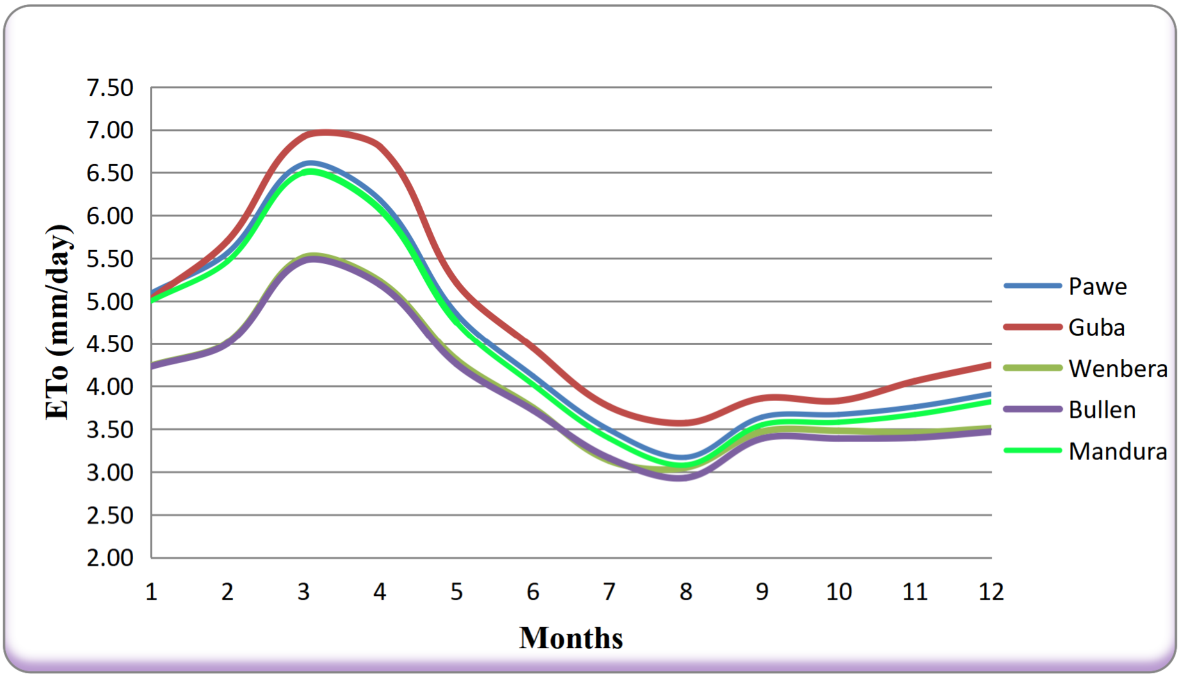
Where, Si is predicted value, oi is the observed value, N is the number of observations and Mo is the average of the observed values.

3. RESULTS AND DISCUSSION

3.1. Climate Characteristics of the Study Area

Long -term climatic data of the study area were analyzed and reference evapotranspiration (ETo) was calculated based on the FAO Penman-Monteith method (Allen *et al*., 1998) and the results are given in the following figure 1.

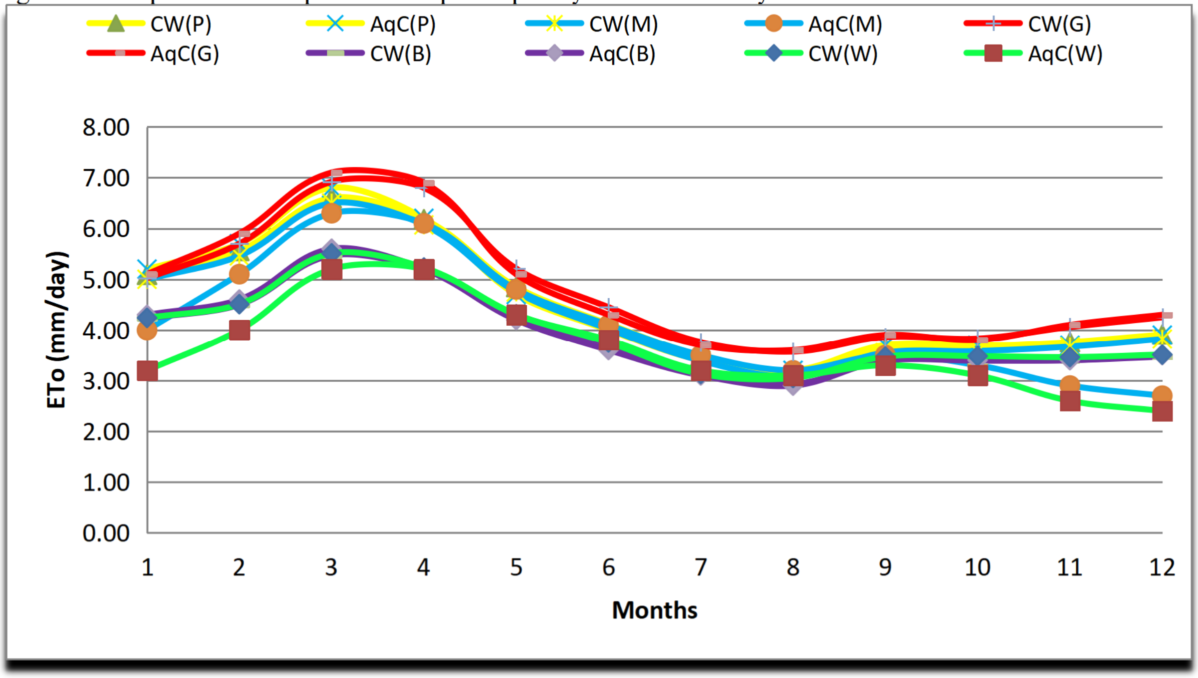
Figure 2: Long term evapotranspiration (ETo) of the study areas (1987-2011).



As shown in Figure 2, the average ET_O value simulated using CropWat in *Pawe* district was found to be 4.50 mm/day. The maximum value of ET_O was found to be 6.60 mm/day in March and the minimum ET_O was 3.17mm/day in August. The average ET_O value simulated using CropWat in *Mandura* district was 4.51 mm/day. The average ET_O value simulated using aqua crops in *Mandura* district was 4.13 mm/day.The average ET_O value simulated using CropWat in *Guba* district was found to be 4.79 mm/day. The maximum value of ET_O was found to be 6.92 mm/day in March and the minimum ET_O was 3.57 mm/day in August.

The average ET_O values simulated using CropWat in *Bullen* district were found to be 3.93mm/day. The maximum values of ET_O were 5.47 mm/day in March and the minimum was 2.93 mm/day in August using CropWat.The average ET_O value simulated using CropWat in *Wembera* district was found to be 3.97 mm/day. The maximum value of ET_O was found to be 5.51 mm/day in March and the minimum was 3.05 mm /day in August.

Figure 3: Comparison of CropWat and AquaCrop daily ETo of the study areas.



** CW(P)=CropWat of Pawe, AqC(P)=AquCrop of Pawe, CW(M)=CropWat of Mandura, AqC(M) = AquCrop of Mandura, CW(G)=CropWat of Guba, AqC(G)=AquCrop of Guba, CW(B)=CropWat of Bullen, AqC(B)=AquCrop of Bullen and CW(W)=CropWat of Wombera, AqC(W)=AquCrop of Wombera.*

As shown in Figure 3, the average ET_O value simulated using aqua crops *in Pawe* was found to be 4.52 mm/day. The maximum value of ET_O was found to be 6.80 mm/day in March and the minimum ET_O was 3.2 mm/day in August. The relative difference between average ETo values simulated using CropWat and AquaCrop was found to be small which was 0.02 mm/day. The climate parameters were collected from the Pawe agricultural research center metrology station that was located at a longitude of 36.05^0 East, the latitude of 11.15^0 North, an altitude of 1120 meters above sea level.

The maximum value of ET_O in *Mandura* using AquaCrop, was 6.30 mm/day in March and the minimum ET_O was 3.20 mm/day in August. The relative difference between average ETo values simulated using Cropwat and AquaCrop was found to be 0.38 mm/day. The climate parameters were collected from *Mandura* district metrology station that was located at a longitude of 36.32^0 East, the latitude of 11.06^0 North, an altitude of 1161 meters above sea level.

The average ET_O value simulated using AquaCrop was found to be in the *Guba* district was found to be 4.82 mm/day. The maximum value of ET_O was 7.1 mm/day in March and the minimum ET_O was 3.6 mm/day in August. The relative difference between average ETo values simulated using CropWat and AquaCrop was found to be small which was 0.03 mm/day. The climate parameters were collected from the *Guba* distric*t* metrology station that was located at a longitude of 35.40^0 East, the latitude of 11.05^0 North, an altitude of 977 meters above sea level in the Guba district.

The average ET_O values simulated aqua crops in *Bullen* district were found to be 3.93 mm/day. There was no difference between ET_O average values simulated using CropWat and Aqua Crops. The maximum values of ET_O using aqua crop the maximum values of ET_O was 5.6 mm/day in March and minimum was 2.9mm /day in August, The climate parameters were collected from *Bullen* district metrology station that was located at the longitude of 36.96^0 East, the latitude of 10.50^0 North, an altitude of 1323 meter above sea level.

The average ET_O value simulated using aqua crops in the *Wembera* district was found to be 3.62 mm/day. The maximum values of ET_O were 5.2 mm/day in March and the minimum was 3.10 mm /day in August. The relative difference between average ETo values simulated using CropWat and AquaCrop was found to be 0.35 mm/day. The climate parameters were collected from Debre-zeyite metrology station that was located at a longitude of 36.96^0 East, the latitude of 10.50^0 North, and altitude of 1323 meters above sea level in *Wembera* district.

As General, the maximum reference evapotranspiration in the study area estimated using CropWat was found to be 6.92 mm/day in *Guba*, and minimum reference evapotranspiration was found to be 2.93 mm/day in *Bullen* district. The maximum reference evapotranspiration in the study areas simulating using aqua crops was found to be 7.1 mm/day in Guba and minimum reference evapotranspiration was found to be 2.9 mm/day in Bullen district.

3.2. Crop and Irrigation Water Requirements of maize in project area

3.2.1. Crop and Irrigation Water Requirements of maize using CropWat model

The crop water requirement (ETc) throughout the growing season was then determined based on equation 8.

Table 1: Crop characteristics and input data used for CropWat

Crop characteristics	**Growing stages**				**Total**
	Initial	**Development**	**Mid**	**Late**	
Kc	0.45		1.2	0.85	
Stages	20	35	40	30	125
Rooting depth	0.3		1		
Critical depletion (fraction)	0.55	0.55		0.8	
Yield response factor	0.4	0.4	1.3	0.5	1.25
Crop height		2 (optional)			

As shown in Table 1, Since there was no determined crop coefficient, rooting depth, critical depletion, and yield response factor, so far for this area, the FAO recommended values for growth stages are used to calculate CWR and to made irrigation scheduling. The local planting date of the crops had been used for the computation.

Table 2: Simulated ETc and IR of crops in the study areas using CropWat

District	**ETC (mm)**	**ER (mm)**	**IR (mm)**
Pawe	680.4	12.4	667.5
Mandura	680.3	15.2	664.3
Guba	702.4	10.3	690.8
Bullen	572.6	21.3	539.9
Wembera	576.5	185	393

* ETC=Crop water requirement, ER =Effective rainfall, IR= Irrigation requirement

As shown in Table 2, the maximum seasonal irrigation requirement of maize, was found to be 690mm in

Guba district and minimum irrigation requirement of 393mm in Wombera district. Relatively height amount of the required water was satisfied by rain that occurred in December, January, February and march in *Wembera* district since this area is located in height altitude and height rainfall area. Seasonal effective rain (Pe) was185mm respectively in *Wembera* district. In Abshege Woreda, Gurage Zone, Ethiopia, the Crop water requirement of maize estimated using CROPWAT 8.0 for a window with a growing period of 140 days to maturity would require 423 mm depth of water, while 101 mm would be required as supplementary irrigation depth (Solomon Abirdew *et al,* 2018). The total crop water requirement of maize was 535.60 mm in Tepi, Southwest of Ethiopia (BiniamYaziz and Tesfaye Tefera, 2016).

3.2.2. Crop and Irrigation Water Requirements of maize using the aquacrop model

Table 3: Crop characteristics & input parameters used as input for AquaCrop

Crop characteristics	Discriptions	Input Parameter
Initial canopy	Initial canopy cover (%)	0.29
	Canopy size seedling (c.m2/plant)	6.5
	Plant density (plants/ha)	44,444
Development	Maximum canopy cover (%)	90
	From day 1 after sowing to emergence (day)	8
	Maximum canopy(day)	50
	Senescence (day)	95
	Maturity (day)	125
Flowering and yield formation (root/tuber formation)	Length building up of harvest index (day)	52
	Duration of flowering (day)	13
	From day 1 after sowing to flowering(day), yield formation	68
Root deepening	Maximum effective root depth (m)	1.2
	From day 1 after sowing to maximum root depth (day)	97
	Average root zone expansion (cm/day)	1.1

As shown in Table 3, Some maize characteristics used as input for aqua crop model have been taken with minimum calibration from the reference manual developed by (Dirk *et al.*, 2009) with contributions of the AquaCrop network in January 2009, the experiments used for calibration and validation crops including maize were generally conducted under high levels of management, with the control treatments aimed at production levels close to the maximum potential achievable in that location. Most of the pepper characteristics have been taken with minimum calibration (JOHN B., 2015). Most of the onion characteristics have been also taken with minimum calibration (MARTA P., 2013).

Table 4: Simulated NIR, WP, and DY of maize in the study areas using AquaCrop

Parameters	Districts				
	Pawe	*Mandura*	*Guba*	*Bullen*	*Wombera*
NIR (mm)	673.1	569	618	548.8	309
ET_C (mm)	593.9	502.1	565	484.6	425
DY (ton/ha)	11.349	12.013	12.013	11.738	12.167
WP (kg/m^3)	1.97	2.47	2.18	2.51	2.98
P (%)	23	23	21	26	32
ETo (mm)	678.4	570.8	705.3	565.5	467.8
Rain (mm)	12.3	15	12.5	23.5	196.7

**Net=net irrigation requirement, ETc=cropwater requirement, DR=dry yield, Wp=water productivity, p=allowable root zone depletion for actual production, ETo=reference evapotranspiration,*

As shown in Table 4, the maximum net requirement of maize was found to be 673 mm in *Pawe* district and the minimum net irrigation requirement was found to be 309 mm in *Wembera* district.

3.3. Irrigation Scheduling of maize under different districts

3.3.1. Irrigation scheduling of maize using CropWat model

To carry out irrigation scheduling for selected crops using CropWat model has different options. These are irritating at fixed intervals per stage time, irrigate at 100% critical depletion and the refill soil to 100% field capacity depth criteria. However, based on the research evidence and field data available in the study area irrigate at fixed interval per stage time criteria was used. Irrigation efficiency of 60% was selected since main irrigation application methods for the area is surface irrigation especially furrow irrigation.

Table 5: Irrigation scheduling of maize in *Pawe* using irrigate at a fixed interval

Date	Stage	NIR (mm)	GIR (mm)	Date	Stage	NIR (mm)	GIR (mm)
10 December	Initial	40.2	67	8 February	Mid	65.6	109.3
20 December	Initial	28.3	47.2	18 February	Mid	67.7	112.8
30 December	Dev	35.4	59	28 February	Mid	70.8	118
9 January	Dev	46.1	76.8	10 March	End	74.8	124.7
19 January	Dev	58.6	97.7	20 March	End	71.8	119.6
29 January	Mid	64.8	108	30 March	End	59.5	99.1

*NIR=net irrigation requirement, GIR= Gross irrigation requirement

As shown in Table 5, irrigation scheduling of maize in *Pawe* using fixed interval (10 days) per stage time criteria and refill soil to field capacity depth criteria had 12 irrigation events. The total gross and net irrigation requirements were 1123.7 mm and 674.2 mm respectively with a yield reduction of 0.0%.

Table 6: Irrigation scheduling of maize in *Mandura* using irrigate at a fixed interval

Date	Stage	NIR (mm)	GIR (mm)	Date	Stage	NIR (mm)	GIR (mm)
10 December	Initial	33.6	56	8 February	Mid	65.2	108.6
20 December	Initial	26.6	44.3	18 February	Mid	67.2	112
30 December	Dev	33.6	56	28 February	Mid	70.3	117.2
9 January	Dev	44.1	73.4	10 March	End	75.2	125.3
19 January	Dev	56.6	94.3	20 March	End	72.6	120.9
29 January	Mid	63.7	106.2	30 March	End	58.9	98.1

* NIR=Net irrigation requirement, GIR=gross irrigation requirement, Dev=Development

As shown in Table 6, irrigation scheduling of maize in *Mandura* using the fixed interval (10 days) per stage time criteria and refill soil to field capacity depth criteria had 12 irrigation event. The total gross and net irrigation requirements were found to be 1112.4 mm and 667.4 mm respectively with yield reduction of 0.1%.

Table 7 : Irrigation scheduling of maize in *Guba* using irrigate at fixed interval

Date	Stage	NIR (mm)	GIR (mm)	Date	Stage	NIR (mm)	GIR (mm)
10 December	Initial	29.7	49.5	8 February	Mid	63.8	106.3
20 December	Initial	27.9	46.6	18 February	Mid	65.8	109.7
30 December	Dev	34.2	57.1	28 February	Mid	68.5	114.2
9 January	Dev	43.8	73	10 March	End	72.7	121.1
19 January	Dev	54.4	90.6	20 March	End	74.2	123.7
29 January	Mid	61.9	103.1	30 March	End	63.6	105.9

* NIR=Net irrigation requirement, GIR=gross irrigation requirement, Dev=Development

Irrigation scheduling of maize in *Guba* using the fixed interval (10 days) per stage time criteria and refill soil to field capacity depth criteria had 12 irrigation events and had the total gross and net irrigation requirement of 1100.7 mm and 660.4 mm respectively as shown in table 23.

The yield reduction was high (4.4%) since soil texture of *Guba* district was sandy as shown in table 7, that need irrigation schedule using short irrigation intervals and small amount of water. So irrigation interval less than 10 days can be use by considering labor cost to reduce yield reduction.

Table 8 : Irrigation scheduling of maize in *Bullen* using irrigate at a fixed interval

Date	Stage	NIR (mm)	GIR (mm)	Date	Stage	NIR (mm)	GIR (mm)
10 December	Initial	32.4	53.9	8 February	Mid	52.3	87.1
20 December	Initial	24.1	40.2	18 February	Mid	53.6	89.3
30 December	Dev	29.5	49.1	28 February	Mid	56.7	94.4
9 January	Dev	37.4	62.4	10 March	End	62.1	103.5
19 January	Dev	47.2	78.6	20 March	End	60.8	101.4
29 January	Mid	51.9	86.5	30 March	End	48.4	80.7

* NIR=Net irrigation requirement, GIR=gross irrigation requirement, Dev=Development

As indicated in Table 8, irrigation scheduling of maize in *Bullen* using the interval (10 days) per stage time criteria and refill soil to field capacity depth criteria had 12 irrigation events and had the total gross and net irrigation requirements of 927.2 mm and 556.3 mm respectively with no yield reduction.

Table 9: Irrigation scheduling of maize in *Wembera* using irrigate at a fixed interval

Date	Stage	NIR (mm)	GIR (mm)	Date	Stage	NIR (mm)	GIR (mm)
10 December	Initial	26	43.4	8 February	Mid	37.2	62.1
20 December	Initial	13.6	22.7	18 February	Mid	37.5	62.5
30 December	Dev	18	30.1	28 February	Mid	41.6	69.3
9 January	Dev	26	43.3	10 March	End	47.6	79.3
19 January	Dev	36.9	61.5	20 March	End	47.2	78.6
29 January	Mid	39.4	65.6	30 March	End	38.4	64.1

* NIR=Net irrigation requirement, GIR=gross irrigation requirement, Dev=Development

As shown in Table 9, Irrigation scheduling of maize in *Wembera* using the fixed interval (10 days) per stage time criteria and refill soil to field capacity depth criteria had 12 irrigation event and had the total gross and net irrigation requirement of 655.8 mm and 393.5 mm respectively with no yield reduction.

Research conducted in Vertisol in Metekel Zone, North-West of Ethiopia during the summer seasonal (January first to May fifth) indicated that CWR, IR, NIR and GIR requirements of maize with total growth stages of 125 days were found to be 502 mm,486.8 mm 478.5 mm and 651.1 mm respectively and relatively high yield was recorded using irrigating at fixed interval 14 days per stage time criteria and refill soil to field capacity depth criteria. (Ashebir and Demeke, 2017).

3.3.2. Irrigation Scheduling of maize using the AquaCrop model.

Generating irrigation schedules is a practical mode for planning or evaluating a potential irrigation strategy. In this mode, AquaCrop will generate at run time irrigations according to the specified time and a depth criterion.

Table 10: Irrigation scheduling of maize in the study area at a fixed interval

Irrigation event	DAP	NAD (mm)					EC_W (ds/m)
		Pawe	*Mandura*	*Guba*	*Bullen*	*Wembera*	
1	10December	27.6	43.2	32.8	46.2	38.2	0.4
2	20 December	25.5	32.2	21.7	35.3	21.2	0.4
3	30 December	25.2	29.4	25.2	36.3	18.9	0.4
4	9 January	46.3	43.9	43.8	46.7	23.8	0.4
5	19 January	54.4	49.5	56.6	50.9	26.9	0.4
6	29 January	55.8	52.6	60.2	52.1	30.3	0.4
7	8 February	55.8	54.7	61.6	52.2	30.4	0.4
8	18 February	56.7	56.7	62.9	52.8	31.1	0.4
9	28 February	57.5	58.7	64.5	53.8	30.5	0.4
10	10 March	61.8	60.6	66.9	56.5	36.3	0.4
11	20 March	51.9	46.6	51	41.7	32.1	0.4
12	30 March	26.6	24.1	20.3	19.3	17.5	0.4
IR (mm)		655.1	552.3	567.5	534.8	337	
Rain (mm)		12.3	15	12.5	23.5	196.7	
ET_O (mm)		678.4	570.8	705.3	565.5	467.8	
DY (T/ha)		11.883	11.858	11.803	11.635	11.736	
Wp (kg. /m^3)		2.21	2.65	2.43	2.69	2.94	

*DAP=Days After Planting, NAD=Net application depth, IR=Irrigation requirement, ET_O =Reference evapotranspiration, DY= Dry yield, WP= water productivity, EC_{W}=Electrical conductivity of irrigation water.

As shown in Table 10, to generate irrigation scheduling of maize, a fixed interval of 10 days' time criterion and refill soil to field capacity depth criteria which had 12 irrigation events. The simulation indicated CWR of 655.1, 552.3, 567.5, 534.8 and 337 mm, 11.643, 11.858,11.803, 11.635, and 11.736 t/ha of maize can be produced in *Pawe, Mandura, Guba, Bullen, and Wembera* respectively. In Bushland the study that was conducted in 1989 shows that crop water requirement of maize simulated using AquaCrop was 598.0 mm in areas where measured crop water requirement of maize was 625.0 mm and in 1990 crop water requirement of maize simulated using AquaCrop was 730.8 mm in areas where the measured value was 778.3 mm. (Lee kheng Heng *et al*., 2009). During the 'driest' year, seasonal (March to mid-September) rainfall (138 mm) and ETo (682 mm) resulted in irrigation needs of onion in were found to be 286 mm and 360 mm for the sandy and sandy loam soils, respectively (MARTA P., 2013).

3.4. Performance Evaluation of Models

Considering the districts as a number of observations RMSE values of maize when simulating crop water requirement was fund to be 133.5. Considering the number of irrigation events as a number of observations, the magnitude of root means square errors when simulating irrigation scheduling for maize in each irrigation event was found to be 4.09, 4.39, 4.26, 5.17, 3.12 in *Pawe, Mandura Guba Bullen,* and *Wembera* respectively annex tanble 1 and 2.

Considering the districts as a number of observations RMSEN values of maize when simulating crop water requirement were found to be 20.74% and lied between 20% and 30 % and the simulation was reasonable. The magnitude of all RMSEN values of maize when simulating irrigation scheduling for maize in each irrigation events were found to 7.18%, 7.88%, 7.74%, 9.08%, 9.13% *in Pawe, Mandura, Guba, Bullen, and Wembera* respectively and all values lied than 10%, so the simulation is excellent in each district annexed table 2. The simulation is considered excellent if RMSEN is less than 10%; it is good if it comes between 10% and 20%; reasonable when it comes between 20% and 30%, and poor when it is greater than 30% (Jamieson, Porter and Wilson,1991).

Nash-Sutcliffe efficiency index (NSE) values of maize, when simulating crop water requirements was found to be 0.98 closed to one, which means the model simulation was in the acceptable range. The relative magnitude of the residual variance compared to the variance of the observations was small. The magnitude of NSE when simulating irrigation scheduling for Maize in each irrigation event was found to 0.1,0.12, 0.16, -0.44, -0.08 in *Pawe, Mandura, Guba, Bullen, and Wembera* respectively as annexed in table 1 and 2. All vales were close to one and the simulation was accurate.

The magnitude of model efficiency (MF) values when simulating irrigation scheduling for maize in each irrigation event was found to 0.1,0.12, 0.16, -0.44, -0.08 in *Pawe, Mandura, Guba, Bullen*,and *Wembera* respectively. The negative value of Model efficiency indicates overestimation. And positive values indicate underestimation. Ideally, model efficiency (MF) will be zero. The model efficiency of maize when simulating crop water requirements was 0.98. When Pe, approaches zero, they represent positive indicators of model performance and used to evaluate the model prediction error. Pe used to define the robustness of the model as well as to predict the values. Pe values of maize when simulating total crop water requirements were found to be -0.13, -0.26, -0.19, -0.15, and -0.26 in *Pawe, Mandura, Guba, Bullen,and Wembera* respectively. But Pe values when simulating irrigation scheduling maize in each irrigation event were found to be -0.2, -0.17, -0.14, -0.2, and -0.17 in *Pawe, Mandura Guba Bullen, and Wembera* respective and annexed in teble 1 and 2.

4. CONCLUSIONS AND RECOMMENDATION

This study was aimed to compare estimation methods of crop water requirement and irrigation scheduling for major crops using different models and compare the significance of models for adoption at different situations in Metekel zone. It is observed that the maximum reference evapotranspiration in the study area was found to be 7.1 mm/day in *Guba* and minimum reference evapotranspiration was 2.9 mm/day in *Bullen* district. In all cases, the maximum ETo in all districts was fund to in March and the lowest in August. The maximum ETc was found to be 702.4mm respectively in *Guba* district and minimum ETc was found to be 572.6mm in *Bullen* district respectively using CropWat but the effective rainfall (Pe) were determined as 185mm in *Wembera* district. However, using AquaCrop model the maximum ETc was recorded for maize 565 mm in *Guba* but minimum 425 mm, was recorded in *Wembera* district. The study revealed that the irrigation scheduling with a fixed interval criterion for maize 10 days with 12 irrigation events has been determined. Moreover, furrow irrigation with 60 % irrigation application efficiency was adjusted during irrigation water applications for all districts. It has been observed that there was a strong relationship and a significant relation between the simulated and observed values for validation. Hence, Normalized Root mean square errors (NRMSE), model by Nash-Sutcliffe efficiency (NSE), Prediction error (Pe), and Model efficiency (MF) showed that the model well simulated in all parameters considered.

AquaCrop model is very useful and well simulate for the study area under different climatic conditions. Therefore, this model is recommended due to its merit that a user friendly, easy for an application, accuracy, and robustness and address the conditions where water is a key limiting factor for crop production, climate change, and different field management options to enhance water productivity. Scheduling irrigation water using the AquaCrop model is found to improve water productivity. It is thus advisable to use the AquaCrop model in to the development action at scale through developing appropriate pakcages and extension quidelines.It is recommended that farmers and end-users should adopt fixed irrigation intervals for irrigated maize in the study area to save water, time, labor, and energy during irrigation water application.

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6. APPENDICES

Table 1. Performance Evaluation of Models to Simulate CWR for maize in different districts.

District	Si	Oi	(Si-Oi)	(Si-Oi)/Oi	$(Si-Oi)^2$	$(Oi- O\bar{i})$	$(Oi- O\bar{i})^2$
Pawe	593.9	680.4	-86.5	-0.12713	7482.25	37.96	1440.962
Mandura	502.1	680.3	-178.2	-0.26194	31755.24	37.86	1433.38
Guba	565	702.4	-137.4	-0.19562	18878.76	59.96	3595.202
Bullen	484.6	572.6	-88	-0.15368	7744	-69.84	4877.626
Wenbera	425	576.5	-151.5	-0.26279	22952.25	-65.94	4348.084
Sum	2570.6	3212.2	-641.6	-1.00116	88812.5	37.96	6603666
Mean	514.12	642.44	-128.32	-0.20023	17762.5	37.86	1440.962
RMSE			**133.5**				
NRMSE (%)			**20.7**				
NSE			**0.98**				
MF			**0.99**				
Pe			**-0.2**				

Teable 2. Performance Evaluation of Models to Simulate Irrigation Scheduling of maize under different districts of study areas.

Maize	Pawe			Mandura			Guba			Bullen			Wombera		
DAP	**Oi**	**Si**	**(Si-Oi)^2**	**Oi**	**Si**	**(Si-Oi)^2**	**Oi**	**Si**	**(Si-Oi)^2**	**Oi**	**Si**	**(Si-Oi)^2**	**Oi**	**Si**	**(Si-Oi)^2**
10-Dec	40.20	27.60	158.76	33.60	43.20	92.16	29.70	32.80	9.61	40.20	46.20	36.00	26.00	38.20	148.84
20-Dec	28.30	25.50	7.84	26.60	32.20	31.36	27.90	21.70	38.44	28.30	35.30	49.00	13.60	21.20	57.76
30-Dec	35.40	25.20	104.04	33.60	29.40	17.64	34.20	25.20	81.00	35.40	36.30	0.81	18.00	18.90	0.81
9-Jan	46.10	46.30	0.04	44.10	43.90	0.04	43.80	43.80	0.00	46.10	46.70	0.36	26.00	23.80	4.84
19-Jan	58.60	54.40	17.64	56.60	49.50	50.41	54.40	56.60	4.84	58.60	50.90	59.29	36.90	26.90	100.00
29-Jan	64.80	55.80	81.00	63.70	52.60	123.21	61.90	60.20	2.89	64.80	52.10	161.29	39.40	30.30	82.81
8-Feb	65.60	55.80	96.04	65.20	54.70	110.25	63.80	61.60	4.84	65.60	52.20	179.56	37.20	30.40	46.24
18-Feb	67.70	56.70	121.00	67.20	56.70	110.25	65.80	62.90	8.41	67.70	52.80	222.01	37.50	31.10	40.96
28-Feb	70.80	57.50	176.89	70.30	58.70	134.56	68.50	64.50	16.00	70.80	53.80	289.00	41.60	30.50	123.21
10-Mar	74.80	61.80	169.00	75.20	60.60	213.16	72.70	66.90	33.64	74.80	56.50	334.89	47.60	36.30	127.69
20-Mar	71.80	51.90	396.01	72.60	46.60	676.00	74.20	51.00	538.24	71.80	41.70	906.01	47.20	32.10	228.01
30-Mar	59.50	26.60	1082.41	58.90	24.10	1211.04	63.60	20.30	1874.89	59.50	19.30	1616.04	38.40	17.50	436.81
Sum	683.60	545.10	2410.67	667.60	552.20	2770.08	660.50	567.50	2612.80	683.60	543.80	3854.26	409.40	337.20	1397.98
Mean	56.97	45.43	200.88	55.63	46.02	230.84	55.04	47.29	217.73	56.97	45.32	321.18	34.12	28.1	116.49
N	12	12		12	12		12	12		12	12		12	12	
RMSE			4.09			4.39			4.26			5.17			3.12
NRMSE (%)			7.18			7.88			7.74			9.08			9.13
NSE			0.10			0.12			0.16			-0.44			-0.08
MF			0.10			0.12			0.16			-0.44			-0.08
Pe			-0.2			-0.17			-0.14			-0.2			-0.17