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Application of FAO-CROPWAT Modelling on Estimation of Irrigation Scheduling for Paddy Cultivation in Batticaloa District, Sri Lanka

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ABSTRACT

Agriculture sector is one of the main sources of income in the North eastern and some of the North western parts of Sri Lanka. Over the past decade, many countries around the world have witnessed a growing scarcity and competition for water among different users. Since Agriculture is the major user of water, improving agricultural water management is essential to any irrigation management approach specially to apply the exact amount of water to the field in order to meet crop water requirement. This study aims to estimate water requirement of rice by using the model CROPWAT. According to the study, effective rainfall was found to be 601mm and 133 mm in *Maha* and *Yala* season respectively. Total crop water requirements are 349 mm and 436 mm in *Maha* and *Yala* season respectively. Irrigation scheduling carried out by CROPWAT revealed that, the gross irrigation requirement is 473 mm and net irrigation requirement is 331 mm. Net scheme irrigation requirements are 40, 106, 100 and 22 mm per month in May, June, July and August respectively. Further, flow of net scheme irrigation requirements is found to be 0.15, 0.41, 0.37 and 0.08 l/s/ha in May, June, July and August respectively. Therefore, the model for planning of irrigation water requirements of rice is very important for efficient utilization of water and to meet the possible change of climate in agricultural sector.

Key words: CROPWAT, Water requirement, Effective rainfall, Irrigation scheduling, Rice.

INTRODUCTION

Rice, the staple food of Sri Lanka, is the most important source of employment and income of the rural population (Tao *et al*., 2008). Sri Lanka's rice sector has achieved spectacular results in the last 5 decades. The total paddy production increased rapidly and reached 4.18 million Mt in 2010 (Central Bank of Sri Lanka, 2010). The per capita consumption of rice is 105 kg/year (average of 2004-2008) or about 300 grams per day, which provides about 1,000 calories or almost half of the average total daily calorie intake (Department of Census and Statistics, Agriculture Census, 2010). Global population is expected to increase by about 30% by the year 2030 and as a result, demand for food will increase (FAO, 2000). Major constrains to meet the increasing food demands of the population are scarcity of irrigation water and land availability for crop production (Ali, 2008). Water is important for plant growth and food production. Since, there is competition between municipal, industry users and agriculture for the finite amount of available water, estimating irrigation water requirements accurately is important for water project planning and management (Michael, 1999). Severe water scarcities are the major problem in many countries particularly in Sri Lanka. The uneven distribution and pattern of rainfall and low water holding capacity of soils, soil moisture stress during dry season are some of the major limiting factors for higher productivity in the nation.

In Sri Lanka, so many strategies have been developed and being executed with the aim of developing the agriculture sector which is one of the main sources of income. The traditional methods have been practiced in agriculture by farmers for a long period. With the emergence of new technologies and its widespread use, the use of those technologies in Agriculture sector will probably create a positive effect on the growth and development of agriculture (Singh *et al*., 2015). A possible approach to overcome constraints could be through improving performance of adopted irrigation systems or introductions of better ones. Further, efficient use of irrigation water based on the crop water requirement is essential to save water in the agricultural field. Therefore, field measurements are needed to measure the crop water requirement of a particular crop. Owing to practical difficulties in obtaining accurate field measurements for ET_C, prediction methods are commonly used. However, these methods often need to be applied under climatic and agronomic conditions different from those

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under which they were originally developed. Testing the accuracy of the methods under a new set of conditions is laborious, time consuming and costly. To overcome such difficulties, guidelines were formulated by FAO to calculate ET_C of crops under different climatic and agronomic conditions (Teare and Peet, 1983).

Many advanced and novel scientific irrigation scheduling techniques have been developed in the past three decades. However, the adoption by farmers is low, especially in developing countries (Annandale *et al*., 2011). The major reasons for low adoption are reported to be lack of soil water parameters and weather conditions and complexity of the techniques such that farmers are confused by choice and do not understand the difference between the different scheduling techniques (Stirzaker, 2006), failure of the scientist to understand the situation of farmers and the constraints under which they operate (Vanclay, 2003).

Batticaloa district has many agriculture activities such as paddy, vegetables, chilies and other crop cultivation. Paddy is the major crop under cultivation by the farmers in this district. Their basic economy and food are mainly depending on rice production. The study area's paddy cultivation is also affected by the rainfall fluctuation and the scarcity of irrigation water which lead to number of problems in paddy production and human life. It is also a major problem in primary economic activities. Therefore, improved practices on cultivation and the adoption of new technology against water scarcity are important to get optimum yield of the crop. In this view, efficient application of water based on the crop water requirement is identified as one of the adoptable techniques to solve the water scarcity problem in the study area. There is lack of information with respect to Batticaloa district on crop water requirements and the shortfall of data at a regional scale. Hence, this study made an attempt to compute the crop water requirements of rice in Batticaloa district in Sri Lanka using CROPWAT 8.0 (FAO, 2009).

Keeping all these points in view the study was carried to determine irrigation scheduling for paddy cultivation for the efficient use of water to increase the paddy production in sustainable manner.

MATERIALS AND METHODS

Study location

This study is conducted in Batticaloa district that belongs to eastern province of Sri Lanka. The geographical coordinates of the Batticaloa district are 7°34′ N and 81°41′ E.

Selection of model

In this study, CROPWAT model was selected for the computation of crop water requirement and irrigation scheduling for rice in Batticaloa district. CROPWAT 8.0 was used to calculate reference evapotranspiration using climatic variables such as maximum and minimum temperature, sunshine hour, rainfall, relative humidity and wind speed.

CROPWAT model input data

The basic input data for CROPWAT model are the climatic parameters which are required for calculating Reference Evapotranspiration. Researchers proposed several methods to determine evapotranspiration out of which the Penman-Monteith Method (FAO, 1998) has been recommended as the appropriate combination method to determine the crop water requirements using climatic data such as temperature, humidity, sunshine and wind speed.

FAO Penman-Monteith method (FAO, 1998) was used in the present study for determining reference crop evapotranspiration (ET_O) since it has been reported to provide values that are very consistent with actual crop water use data worldwide (Allen *et al*., 2006). Secondary data such as station data (Table 1), climate data (Table 2), rainfall data (Table 3), crop data (Table 4) and soil data (Table 5) were

Table 1: Coordinates of study area.

Country	Sri Lanka
Station	Batticaloa
Altitude	8.53 m
Latitude	7.34°N
Longitude	81.41°E

Table 2: Batticaloa district climate data (Average of last 30 years).

Month	Maximum temperature (°C)	Minimum temperature (°C)	Mean RH (%)	Wind speed (km/h)	Sunshine hours (Hours)
January	27.53	23.21	81	14.3	6.4
February	28.20	23.22	80	13	7.9
March	29.70	23.90	79	10.9	8.8
April	31.11	24.90	78	9.5	8.6
May	32.40	22.50	73	9.2	8.4
June	33.60	25.40	68	9.3	8.4
July	33.20	25.00	69	9.8	8
August	32.50	24.80	71	9.7	8.3
September	32.10	24.60	73	9.7	8.3
October	30.60	24.10	79	9.5	7.5
November	29.00	23.50	82	10.4	6.7
December	27.81	23.20	83	12.9	5.6

Source: Meteorological Department, Sri Lanka.

Table 3: Average monthly rainfall data (Last 30 years).

Month	Rainfall (mm)
January	279.1
February	178.3
March	84.8
April	72.4
May	31.2
June	18.5
July	37.0
August	61.7
September	61.7
October	178.1
November	285.2
December	429.8

Source: Meteorological Department, Sri Lanka.

Table 4: Crop data.

Particulars	Stages				
	Initial	Development	Mid	Late	Total
Kc value	0.5	-	1.05	0.7	-
Stages (days)	20	25	35	25	105
Rooting depth (m)	0.10	-	0.60	0.60	-
Critical depletion (fraction)	0.20	-	0.20	0.20	-
Yield response	1.00	1.09	1.32	0.50	1.10

Source: (Sahindomi *et al.,* 2013) and (Doorenbos and Kassam, 1979)

Table 5: Soil data.

Soil texture	Sandy regosol
Total available soil moisture (FC- WP)	100 mm/m
Maximum rain infiltration rate	30 mm/day
Maximum rooting depth	90 cm
Initial soil moisture depletion (as % TAM)	0 %
Initial available moisture	100 mm/meter

Source: FAO CROPWAT 8.0, 2009.

collected in the present study and used as input data for CROPWAT model for further analysis.

Station data
Source

Geospatial data from survey department and https://www.distancesto.com/coordinates/lk/batticaloa-latitude longitude/history/15542.html

Climate data

Following long-term meteorological data were collected from meteorological department.

- Maximum Temperature and Minimum Temperature (degree Celsius).
- Maximum Relative Humidity and Minimum Relative Humidity (%).
- Wind Speed (km/h).
- Sunshine Hours (Hours).

Rainfall data

Average monthly rainfall data were collected from meteorological department to find out the effective rainfall to calculate the crop water requirement and irrigation scheduling.

Determination of effective rainfall

Many water studies have used the CROPWAT 8.0 model to estimate monthly effective rainfall. Although the software offers several alternative methods, the method referred to as the "USDA SCS method" (USDA Soil Conservation Service method) has generally been used due to its simplicity; being only a function of monthly precipitation and not requiring local calibration. The original USDA SCS method estimates monthly effective rainfall from gross rainfall, soil water holding capacity and crop evapotranspiration. A similar study was carried out to determine the water requirement of main crops in the perumal tank irrigation command area in Cuddalore district of Tamilnadu. In the method reference crop evapotranspiration (Reference Evapotranspiration) was determined using the FAO Penman - Monteith method and the effective rainfall was calculated using USDA S.C method (Saravanan and Saravanan, 2014). Monthly rainfall data are required to calculate the effective rainfall (Allen *et al*., 1998 and Smith, 1991). For this study, the USDA SCS method provided in the CROPWAT model was used to calculate the effective rainfall on monthly basis using the following criteria.

- When total rainfall is <250 mm, effective rainfall (ER) is given by the following equation;

$$ER=Total\ R*(125-0.2*TR)/125 \quad .....Eq.\ 1$$

- When total rainfall is >250 mm, effective rainfall is given by the following equation;

$$ER=125+0.1*Total\ Rainfall \quad .....Eq.\ 2$$

Crop data

The crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Crop coefficient values (Kc) were taken from available published data and FAO CROPWAT 8.0 default value. Based on the published information following crop data were collected.

Soil data

The soil module is essential data input, requiring the general soil data like total available water (TAW), maximum infiltration rate, maximum rooting depth, initial soil moisture depletion. In case of calculation of rice water requirement, additional soil data are required such as drainable porosity, critical depletion for puddle cracking, water availability at planting, maximum water depth. In Batticaloa, the coastal belt of eastern province of Sri Lanka, the predominant soil group is sandy Regosols, which contain 95-98% sand with no confining horizons in its soil profile (Bawatharani *et al*., 2004).

Sandy regosols soil predominating the coastal belt of Batticaloa district is very low in plant nutrients especially nitrogen and poor in other soil fertility components due to its poor retention capacity (Premanandarajah and Prapagar, 2009). They are largely dominant in the cultivated area in this narrow strip along the sea (Heerthihah *et al*., 2010).

Default value for sandy soil by FAO in the model was used in calculation of irrigation scheduling and related publications (Central Environmental Authority, 1992) and (Wickramasinghe and Wijewardena, 2000).

RESULTS AND DISCUSSION

Effective rainfall

Table 6 shows the average monthly rainfall and effective rainfall in mm. Effective rainfall was calculated by USDA method in CROPWAT 8.0. Batticaloa district receives around 1060.1mm effective rainfall per year. Highest value of effective rainfall is observed in December (168 mm) and lowest value of effective rainfall is observed in June (18 mm). Rainfall reduces irrigation water requirement on the ground. Therefore, there are chances for water saving. For agricultural production, effective precipitation refers to the portion of rainfall that can be effectively stored in the root zone after the losses such as runoff and deep percolation (Layheang *et al*., 2015). Therefore, paddy cultivation needs irrigation water in mid of the year (April to August) but rain water is sufficient in November to February for paddy cultivation in Batticaloa district. During the dry period higher percentage of available rainfall is effectively stored in the root zone because, the absorbance capacity of soil is high due to dry nature of the soil. During rainy season, especially during December and January soil reached its saturation capacity very often, therefore there is a chance for runoff losses. Therefore, percentage of effective rainfall in relation to the receiving rainfall is less during this period compared to the dry season months.

Table 6: Rainfall and effective rainfall.

	Rainfall mm	Effective rainfall mm
January	279.1	152.9
February	178.3	127.4
March	84.8	73.3
April	72.4	64
May	31.2	29.6
June	18.5	18
July	37	34.8
August	61.7	55.6
September	61.7	55.6
October	178.1	127.3
November	285.2	153.5
December	429.8	168
Total	1717.8	1060.1

Crop water requirement in *Yala* season

Table 7 shows the crop water requirement during planting to harvesting period (May to August). ET_C value recorded as the range in between 2.18 to 4.5 mm/day during the period of May to July. In the initial stage, the rice needs only about 2.18 mm per day as the water requirements. Crop water requirement increase from 2.18 to 4.38 mm/day during initial stage to mid stage respectively. Then, it further increases from 4.45 mm to 4.47 mm/day during the entire period of the mid-season stage where the rice consumes much water for growing and reaches its maximum height. Finally, the water requirement of rice decreases from 4.5 to 3.19 mm per day in the late-season, the period of ripening. This is also the time for draining water for the harvest. Similar data was also recorded by Layheang *et al*., 2015.

Irrigation Scheduling

Irrigation scheduling in *Yala* season

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. Table 8 and 9 shows the computation of net irrigation requirement, gross irrigation requirement and irrigation flow rate for irrigation scheduling from planting date to harvesting date during *Yala* season. As per irrigation scheduling carried out by CROPWAT it shows that gross irrigation requirement is 472.5 mm and net irrigation requirement is 330.7 mm.

Table 7: Crop water requirement in *Yala* season.

Month	Decade	Stage	Kc Crop coefficient	ETc mm/day	ETc mm/decade	Effective rain mm/decade	Irrigation Requirement mm/decade
May	1	Initial	0.50	2.18	19.6	11.7	6.6
May	2	Initial	0.50	2.13	21.3	8.8	12.5
May	3	Development	0.61	2.60	28.6	7.9	20.7
June	1	Development	0.84	3.58	35.8	6.4	29.4
June	2	Mid	1.03	4.38	43.8	4.7	39.2
June	3	Mid	1.05	4.47	44.7	7.0	37.7
July	1	Mid	1.05	4.46	44.6	9.6	34.9
July	2	Mid	1.05	4.45	44.5	11.5	33.0
July	3	Late	0.97	4.15	45.7	13.8	31.8
August	1	Late	0.82	3.57	35.7	16.9	18.8
August	2	Late	0.72	3.19	12.7	7.8	3.0
					Total	**106.1**	**267.7**

Table 8: Summary of Irrigation scheduling in *Yala* season.

Total gross irrigation	472.5mm	Total rainfall	116.5 mm
Total net irrigation	330.7mm	Effective rainfall	39.9 mm
Total irrigation losses	0.0 mm	Total rain loss	76.6 mm
Actual water use by crop	373.8mm	Moist deficit at harvest	3.2 mm
Potential water use by crop	373.8mm	Actual irrigation requirement	333.9 mm
Efficiency irrigation schedule	100%	Efficiency rain	34.20%
Deficiency irrigation schedule	0%		

Table 9: Irrigation scheduling in *Yala* season.

Date	Day	Stage	Rainfall mm	Ks fraction	Depletion %	Net Irrigation mm	Gross Irrigation mm	Flow l/s/ha
4-May	3	Initial	0	1	33	4.4	6.2	0.24
6-May	5	Initial	0	1	28	4.4	6.2	0.36
8-May	7	Initial	0	1	25	4.4	6.2	0.36
10-May	9	Initial	0	1	22	4.4	6.2	0.36
15-May	14	Initial	0	1	25	6.4	9.1	0.21
19-May	18	Initial	0	1	21	6.4	9.1	0.26
22-May	21	Development	0	1	22	7.3	10.5	0.4
25-May	24	Development	0	1	21	7.8	11.1	0.43
30-May	29	Development	0	1	25	10.4	14.8	0.34
2-June	32	Development	0	1	21	9.8	14	0.54
5-June	35	Development	0	1	22	10.8	15.4	0.59
9-June	39	Development	0	1	21	11	15.8	0.46
12-June	42	Development	0	1	22	12.4	17.6	0.68
15-June	45	Development	0	1	22	13.2	18.8	0.72
19-June	49	Mid	0	1	25	15.2	21.7	0.63
22-June	52	Mid	0	1	22	13.3	19	0.73
25-June	55	Mid	0	1	22	13.4	19.1	0.74
29-June	59	Mid	0	1	24	14.2	20.3	0.59
2-July	62	Mid	0	1	22	13.4	19.1	0.74
5-July	65	Mid	0	1	22	13.4	19.1	0.74
9-July	69	Mid	0	1	22	13.4	19.1	0.55
12-July	72	Mid	0	1	22	13.4	19.1	0.74
15-July	75	Mid	0	1	22	13.3	19.1	0.74
19-July	79	Mid	0	1	22	13.3	19.1	0.55
22-July	82	End	0	1	21	12.7	18.2	0.7
25-July	85	End	0	1	21	12.5	17.8	0.69
29-July	89	End	0	1	21	12.5	17.8	0.51
2-August	93	End	0	1	26	15.4	22.1	0.64
6-August	97	End	0	1	24	14.3	20.4	0.59
10-August	101	End	0	1	24	14.3	20.4	0.59
14-August	End	End	0	1	5			

Table 10: Irrigation scheme in *Yala* season.

Precipitation deficit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. Rice	0	0	0	0	39.8	106.3	99.8	21.8	0	0	0	0
Net scheme irrigation requirement												
in mm/day	0	0	0	0	1.3	3.5	3.2	0.7	0	0	0	0
in mm/month	0	0	0	0	39.8	106.3	99.8	21.8	0	0	0	0
in l/s/h	0	0	0	0	0.15	0.41	0.37	0.08	0	0	0	0
Irrigated area	0	0	0	0	100	100	100	100	0	0	0	0
Irrigation requirement for actual area (l/s/h)	0	0	0	0	0.15	0.41	0.37	0.08	0	0	0	0

Table 11: Summary of Crop water requirement in Maha season.

Month	ETc (mm)	Effective rainfall (mm)
November	56.4	153.4
December	91.3	167.8
January	108.7	152.7
February	92.8	127.4
Total	349.2	601.4

Table 12: Summary of crop water requirement in Yala season.

Month	ETc (mm)	Effective rainfall (mm)	Irrigation requirement (mm)
May	71.7	29.7	42.0
June	120.9	18.1	102.8
July	138.6	34.9	103.6
August	105.7	50.3	50.1
Total	436.7	133	298.5

Irrigation scheme in *Yala* season

Table 10 shows computation of irrigation scheme for paddy cultivation in *Yala* season. Irrigation scheme includes precipitation deficit, net scheme irrigation requirement, irrigated area and irrigation requirement for actual area. Net scheme irrigation requirements are 39.8, 106.3, 99.8 and 21.8 mm per month in May, June, July and August respectively. Flow of net scheme irrigation requirements are 0.15, 0.41, 0.37 and 0.08 l/s/ha in May, June, July and August respectively.

Comparison of crop water requirement in *Maha* and *Yala* season

According to the analyzed data effective rainfall is 601.4 and 298.5 mm/ decade in *Maha* and *Yala* season respectively and total crop water requirement are 349.2 and 436.7 mm/ decade in *Maha* and *Yala* season respectively (Table 11 and 12). According to the ET_C and effective rainfall calculations, irrigation requirement in *Yala* season is 298.5 mm to complete the paddy production (Table 12). This data shows that, in *Yala* season (dry season), the crop water requirement is higher than *Maha* season (rainy season). The (FAO, 2009) also reported that, crops grown in the dry season needs more water than those grown during the rainy season.

CONCLUSION

This study concluded that the model for planning of irrigation scheduling of rice is very important for efficient utilization of water and to meet the possible change of climate in agricultural sector. Therefore, one of the best strategies to achieve this is the application and utilization of the rapid growing technologies in information and communication technology. Therefore, introduction and use of this CROPWAT software is very useful in water management of paddy as well as other crops cultivated in the dry zone of Sri Lanka. It is also suggested to study further on the water requirement of different varieties of the paddy as well as vegetable crops at different zones or districts.

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