Techno-Science Research Journal 2 (2014) 5-11

I.T.C

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Techno-Science Research Journal

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Techno-Science Research Journal

Assessment of Rice Water Use in Chrey Bak River Catchment using CROPWAT Model

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Abstract: People are faced with shortages of freshwater for consumption and irrigation during the dry season and the early part of the wet season[1] as well as during the dry spell within the wet season. This paper assesses rice water use in Chrey Bak river catchment located in the Rolea B'ier district, Kompong Chhnang province - Cambodia using CROPWAT model. The study of rice crop water requirement is important not only for irrigation system design, irrigation scheduling but also for water resources management. The main purpose is to calculate rice water requirement by CROPWAT model, firstly in order to compute data into the CROPWAT to analyse crop evapotranspiration to understanding the consumption of water in the catchment and secondly to make maps of rice crop water requirement and rice irrigation requirement to provide information on water demand, land characteristic and land use change across the lower and upper regions of the Stung Chrey Bak catchment. Depend on the intensive study of the paper, monthly meteorological weather data recorded from 2010 to 2013 and soil characteristic data were used to obtain the results. The rice crop water requirement (CWR) data were calculated for each parameter and the obtained rice irrigation requirement (IR) data were compared. CWR and IR was calculated using CROPWAT model. The results of water requirement by model show that all dry season rice consume water corresponding to general rice (450 mm-700 mm) for the total growing period. However rainy season rice give outcomes of water use too much over the range. Thus, the result can be acceptable for rice cultivation.

Keywords: Chrey Bak river catchment; CROPWAT; Evapotranspiration (ETo); Rice crop water requirement (CWR); Rice irrigation requirement (IR).

1. INTRODUCTION

Water resources management in Cambodia relates to multiple sectors, including agriculture, water supply and sanitation, energy, industry, navigation, tourism and fisheries. The Royal Government of Cambodia (RGC) considers water as a key factor to poverty reduction, economic development, food security and environmental conservation (MOWRAM, 2004).

During periods of reduced or no rainfall, irrigation infrastructure plays a crucial role in providing supplementary irrigation to rice production.Agriculture plays an important role in improving food security and national economy because rice is the staple food and is targeted as an export commodity and more than 80 percent of the population live in rural areas and depend on largely rice-based agriculture for their livelihoods.

Almost every year, farmers in the lower part of Stung Chrey Bak catchment in Kompong Chhnang province face water shortages, flood and drought, which impose major constraints on agricultural production (Chann et al., 2011).
So the estimate of reference crop Evapotranspiration (ETo) is an important in irrigation and agriculture water research, management and development. The first step in this paper consider the effect of climate by calculating the ETo, crop water requirement and irrigation requirement which is define by (Doorenbos and Pruitt, 1977) in FAO-24 as the rate of Evapotranspiration. To estimate ETo from meteorological data require daily maximum and minimum temperature,

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relative humidity, wind speed, rain, solar radiation and sunshine duration.

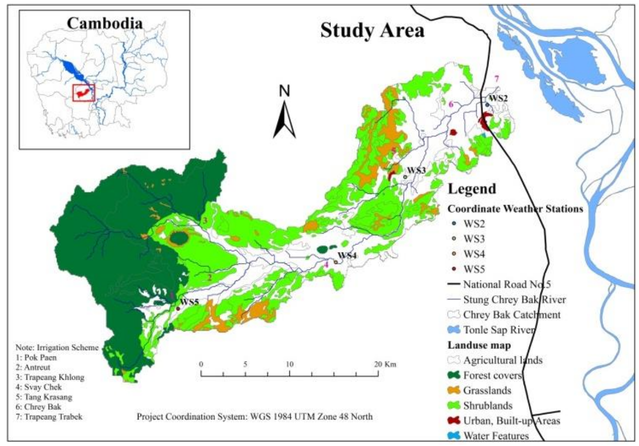
The objective of this study was to utilize climate data sets at Chrey Bak village, Kampong Chhnang province for the 2010-2013 periods to calculate reference crop Evapotranspiration by CROPWAT model. The study provided on two specific aims, firstly to compute the CROPWAT model to estimate water consumption at various locations in catchment and secondly to make maps of rice water use in Chrey Bak catchment in order to indicate information on water requirement, irrigated water demand, land characteristics and land use change across lower to upper regions of catchment.

2. STUDY AREA

The study site is located southwest of the provincial capital of Kompong Chhnang province, one of the six provinces surrounding the Tonle Sap Lake. The total land area of the province is approximately 5,500 km2 and the population is about 470,000 (NIS, 2008). Much of the province is located on ancient, low fertile soils which are characteristic of much of the lowland areas of Cambodia. However, there is a stretch of highly fertile soils which extends approximately five to ten kilometres inland from the network of streams that feed the Tonle Sap.Since rainfall gauges were first set up in the province about ten years ago, rainfall levels have been highly inconsistent, ranging from 800 mm per year to 1850 mm per year.

The main livelihood is rice farming, the majority of which is done in the wet season. Increasingly, however, dry season rice farming and vegetable and fruit crops are grown in paddy fields located close to major rivers, especially those surrounding the Tonle Sap.A land use map developed by the Japan International Cooperation Agency (JICA) in 2002 identified a small portion of remaining evergreen forest in the western region of the province, located where the Phnom Aural Wildlife Sanctuary shares borders with two other provinces - Pursat and Kompong Speu.

The Stung Chrey Bak approximate geographical coordinates are located at 12o 12' 00" N and 104o 40' 00" E in reference code WGS84 UTM_Zone_48N, catchment consists of approximately 790 km2 of land, and follows the Stung Chrey Bak River shown in Fig.1. Its headwater originates in the Chrieve Mountain in the west of the province. The river then flows eastward approximately 76 kms towards the Tonle Sap. The western part of the catchment is the steepest, with a slope up to 0.37 percent. The headwater of the river is within the Phnom Aural Wildlife Sanctuary. The sanctuary, located within a protected area of high conservation status, supposedly comprises large areas of primary evergreen forest.



Figgure 1. Study site map showing catchment boundaries, land use.

3. MATERIAL AND METHODS

3.1 Data sources

The main data sources are used in this study focusing on meteorological data and soil characteristic data. Chrey Bak catchment has four weather stations used to record meteorological data correctly used for the estimation of important components in this crop water need research. Meteorological stations have chosen to collect data locates at Chrey Bak catchment whose data will be shown in the map below. A total number of 4 rainfall stations exist in the Chrey Bak river basin, or on average 1 station per 177 km2. The World Meteorological Organization (WMO) recommends a minimum of 1 gauge for every 600-900 km2 of flat terrain and 1 gauge for every 100-250 km2 of mountainous area (WMO, 1995). The rainfall stations, however, are concentrated in middle and western part of the area, whereas fewer are available in the upper part of the basin. The availability of rainfall data is very limited.

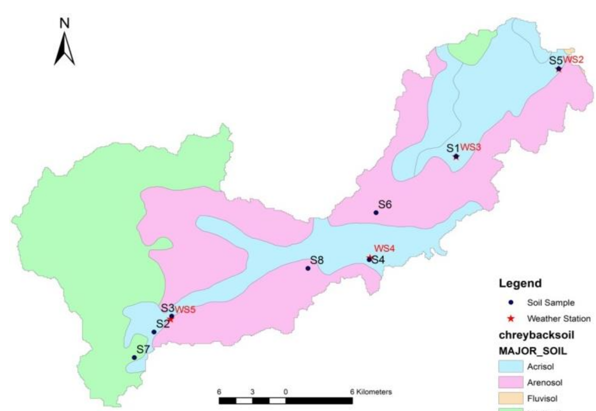


Figure 2. Soil samplings and weather stations in Chrey Bak catchment (Oeurng et al., 2012).

The soil has been collected in 8 locations within the Chrey Bak catchment with regard to the accessibility to the sampling location (Fig.2). However, we made an effort to conduct soil sampling so that the results could represent the soil characteristics of the catchment.In each location, three soil layers have been excavated. Each layer varies from 10 to 30 cm .The collected soil samples were brought the laboratory for further analysis.

We use SPAW model (Fig.3)to determine soil characteristics. SPAW model developed by Dr. Keith Saxton, USDA-ARS is the graphic computer program used for estimating the soil characteristics (Texture Class, Wilting Point, Field Capacity, Saturation, Available Water, Saturation Hydraulic Cond and Matric Bulk Density). The result of the soil characteristics calculated from this model is presented in Table 1.

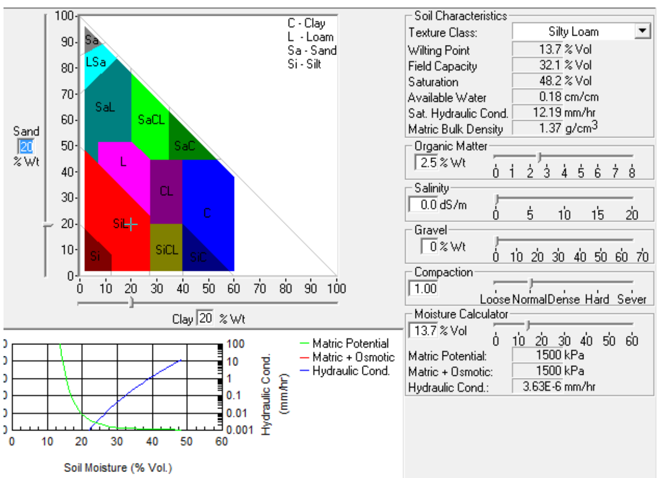


Figure 3. Main window of SPAW model.

Table 1. Soil characteristics generated by SPAW model from 4 different locations nearby weather station (Oeurng et al., 2012).

Location	Wilting Point (% Vol)	Field Capacity (% Vol)	Saturation (% Vol)	Available Water (cm/m)	Sat. Hydraulic Cond (mm/hr)	Matric Bulk Density (g/cm3)
S1	30.9	43	46.4	0.12	0.1	1.42
S3	4.9	11	39.1	0.06	55.77	1.61
S4	19.2	30.3	40.9	0.11	3.04	1.57
S5	13.7	22.3	38.7	0.09	10.62	1.63

3.2 CROPWAT model

CROPWAT model allows the standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It is a system developed by the Land and Water Development Division of FAO for planning and management of irrigation (Smith et al., 2009).

Although,procedures of calculation of the crop water requirements and irrigation requirements are based on Penman-Monteith method and methodologies presenting in FAO Irrigation and Drainage Papers No. 24 "Crop water requirements" (Doorenbos and Pruit, 1977) and No. 33 "Yield response to water" (Doorenbos and Kassam, 1979). CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions.

3.3 Reference crop evapotranspiration

In order to calculate ETo, CROPWAT is required to have adequate meteorological data which are recorded daily. These data consist of rain, temperature, humidity, solar radiation, wind and evaporation.
Defined as that part of the rainfall which Rainreducesirrigation wateron the ground sothat water issaved.For agricultural production, effective precipitationrefersto the portion ofrainfall thatcan be effectively usedby plants.That is tosaythat allrain isavailable for cropsas someis lost byrunoff (RO) anddeep percolation(DP).There are differentmethods for calculating theeffective rainfallforCROPWAT:

- Fixedpercentage

$$P_{eff} = 80\% \times P \quad \text{(Eq.1)}$$

Where P: monthly rainfall in mm

- Dependable rain (FAO/AGLW formula)

$$P_{eff} = 0.6P - 10 \quad \text{If } P_{month} \le 70\,mm \quad \text{(Eq.2)}$$

$$P_{eff} = 0.6P - 24 \quad \text{If } P_{month} > 70\,mm \quad \text{(Eq.3)}$$

- Empirical formula

$$P_{eff} = 0.5P - 5 \quad \text{If } P \le 50\,mm \quad \text{(Eq.4)}$$

$$P_{eff} = 0.7P + 20 \quad \text{If } P > 50\,mm \quad \text{(Eq.5)}$$

- USDA soil conservation service

$$P_{eff} = \frac{P(125 - 0.2P)}{125} \quad \text{If } P \le 250\,mm \quad \text{(Eq.6)}$$

$$P_{eff} = 125 - 0.1P \quad \text{If } P > 250\,mm \quad \text{(Eq.7)}$$

4. RESULTS AND DISCUSSIONS

4.1 Rainy season crop

In the case study ofrice water use, Pka Rumdourl rice wassowndirectly with thegrowth period of160 daysfrom June 14 toNovember 30 every year from 2010 to 2013.After the computing the climate data, precipitation, soil data and the crop characteristic data, crop water requirement result is shown in Fig.4.

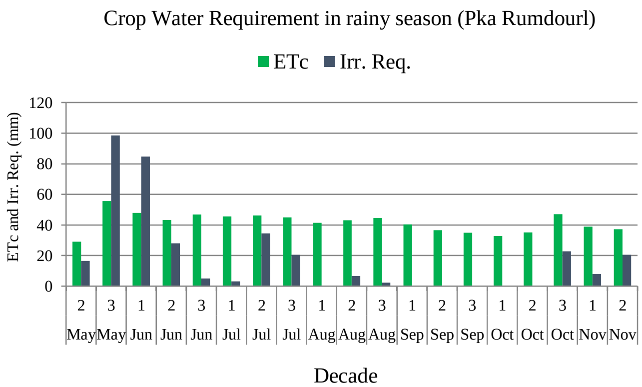


Figure 4. Graph of water requirement and crop needs irrigation (CROPWAT Data).

According to Fig.4,thericeevapotranspiration(ETc) is equal to 792.30mm (withsoil preparationstage 30 days) during the growth periodof 160 days.In the stage of land preparation, the irrigated water is needed up maximum to 98.45 mm per decade which is essential for land soaking and producing organics in the field before the sowing.
The difference between crop water requirement and irrigation requirement, irrigation requirement is smaller than crop water requirement, it indicates that in that period there are rains, and otherwise, when crop water and irrigation requirement are the same, it means that there is no rain in that time Fig.4.

4.2 Dry season crop

For the dry season, IR-66 rice was planted to represent the crop pattern in the Chrey Bak catchment which was reference by CDRI (Chem et al., 2011). IR-66 rice was used to study of crop water requirement in the dry season that its period is 110 days from December 12 to March 31 every year in 2010 to 2013.

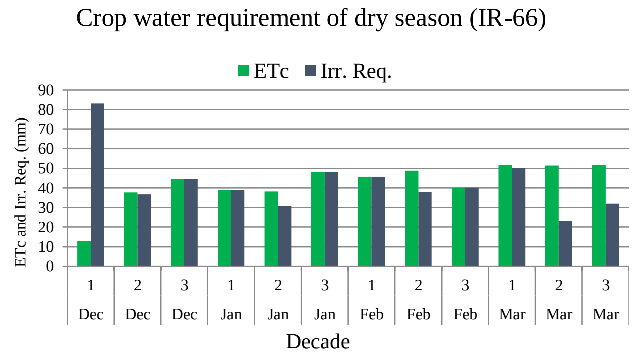


Figure 5. Graph of water requirement and crop needs irrigation (CROPWAT Data).

Depend onthe Fig.5, the water needs of crops IR-66 is 509.65 mm (with land preparation only 5 days) for all phases of the period of 110 days. In the stage of land preparation, the irrigated water is needed up maximum to 83.15 mm per decade which is essential for land soaking in the field in first period before the sowing. Fig.5shows that the need for irrigation is almost equal to the water requirements of crops in each decade since it is the dry season and there is not much rain. Thus, the culture uses only water for irrigation.

4.3 Mapping of rice crop water requirement

After computing all data at each different weather station point in catchment, so we calculate by CROPWAT model at each year from 2010 to 2013.Thiessen Polygons generated from a set of WS points. Each Thiessen polygon defines an area of influence around its WS points, so that any location inside the polygon is closer to that point than any of the other WS points. The mapping below shows paddy fields in catchment by consumption of water use during whole cultivation all wet and dry rice season.

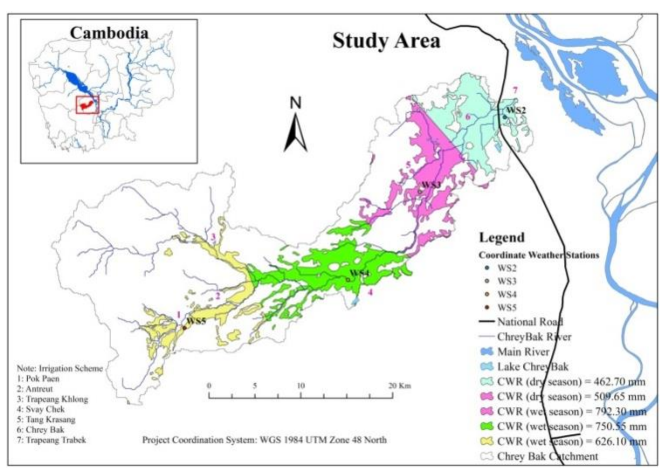


Figure 6. Crop water requirement of rice in Chrey Bak catchment.

As shown inFig.6, we see that it has 4 different colors in representative 4 Thiessen Polygons by each weather station. Regarding WS2 covers area of paddy field at bottom of catchment which farmers located in the area cultivate only dry season rice 3 to 4 months (IR-66), and it consumes water use 462.70 mm for period of planting. Likely in WS4 and WS5 is planted only wet season rice 6 months period (Pka Romdourl) with respectively consumption 750.55 mm and 626.10 mm in completed cultivation. However, except the cultivation of rice in WS3, it cultivates rice twice per annum rainy and dry season rice in crop water need in whole cultivation excluding land preparation periods with respectively 792.30 mm and 509.65 mm per period of planting.

4.4 Mapping of rice irrigation requirement

After knowing the crop water requirement (CWR), it is important to estimate the rice crop irrigation requirement (IR). Regarding the map below Fig.7shows IR in Chrey Bak catchment for dry and rainy season rice at each color representative, existing lake, existed irrigation by each scheme and so on. As we see that IR in dry season, WS2 has value of IR equal 662.10 mm bigger than WS3 equal 511.30 mm because WS2 located in soil characteristic of sandy clay loam with great percolation than clay soil in WS3. Like while wet season rice, IR in WS3 is 351.50 mm in which clay soil has small percolation than upper land at WS5 (sandy loam) 856.80 mm, cause of sandy loam is not easily saturation water retaining on land field. So in land preparation stage, soils absorb too much water to sustain rice water requirement during planting period.

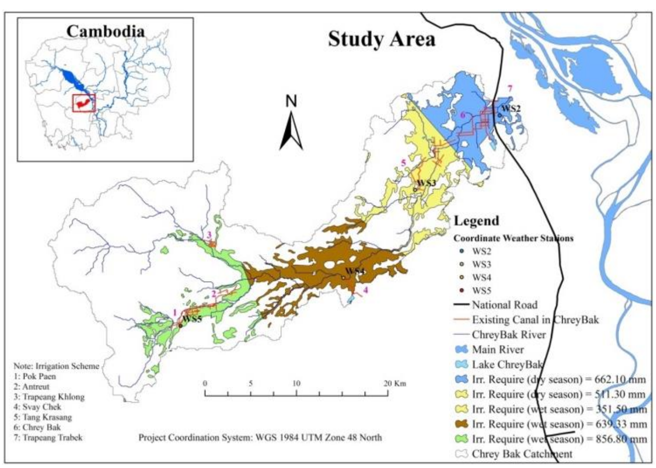


Figure 7. Irrigation requirement of rice in Chrey Bak catchment.

4.5 Comparison of irrigation demand and scheme

Following (Chem et al., 2011) said that the monthly discharges in each river reach were calculated for Stung Sre Bak,Stung Chaktuem and Stung Chrey Bak main stream by formulae sluice gate discharge (McCuen, 1989) and spillway discharge (Garg, 1999) and are shown in Table 2.

Estimation of irrigation water demand by CROPWAT model in the current account is calculated based on all paddy field area in the catchment. The monthly variation in irrigation water demand was estimatedbased on the rice crop factor and rice crop cultivation.The current account simulation found that irrigation demand is 140.93 million m3 per annum. There are unmet demands; however, the demand in June and December aretooover shortage to supply.This means that if there is no improvement program in the future and if the command areais increased, there will be much water shortages in June and December.

Table 2. Stream flow in river 2007 (Chem et al., 2011).

Month	**Stung Srae Bak (106 m^3)**	**Stung Chaktuem (106 m^3)**	**Stung Chrey Bak main stream (106 m^3)**
January	5.50	3.40	8.90
February	5.10	0.50	5.60
March	1.50	2.50	4.00
April	1.40	4.40	5.80
May	4.30	17.50	21.80
June	6.40	6.50	12.90
July	9.00	13.70	22.70
August	16.10	18.10	34.20
September	14.90	41.20	56.10
October	24.40	38.70	63.00
November	2.10	34.30	46.40
December	0.80	6.30	7.10
Annual Flow	91.00	197.00	289.00

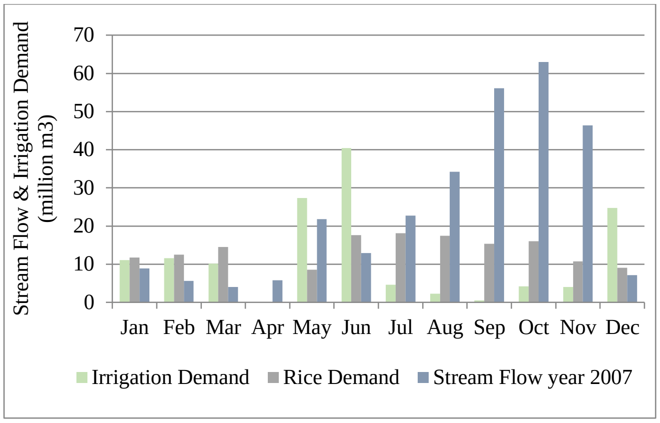


Figure 8. Comparison of monthly stream flow, rice demand &irrigation demand.

5. CONCLUSIONS

CROPWAT can be used to compute the CWR in all seasons and gives the acceptable results of different types of rice plant. Irrigation requirement, irrigation scheduled and scheme can also be calculated in this model.After computing all meteorological data, soils data and rice parameters inmodel, the results of water requirement of IR-66 rice in the two stations for period of 110 days in dry season show the values in-between consumptive uses, and the results of water requirement of Pka Romdourl rice in the other three stations for 160-day period in rainy season give the outcomes over consumption values. Generally, the rice consumes water from 450 mm to 700 mm for the total growing period (Brouwer and Heibloem, 1986). Thus, the result can be acceptable for rice cultivation.

Annual stream flow is 289 million m3 per annum. Stream flow varies from wet to dry season. A five month (December, January, February, March and April) total low stream flow was about 31.4 million m3. This study concludes that this water supply in the catchment is not enough to grow all areas in dry season rice in WS2 and WS3 only supply around 45 percent of need. During start up of rainy season in May and June, we found that much amount of water consumption uses for land preparation period at that time soils need soaking to increase organics and becoming soft mud to ease for rice start to grow its root in initial season stage. Finally from development to late season stage of rice cultivation, rice need too much of water even though in stream flow and too much of rain at that time.

ACKNOWLEDGEMENTS

This work was conducted under the sediment project financially supported by Commission Universitaire pour le Développement (CUD), Belgium. Thanks given to intern students of the Rural Engineering Department for their kind assistance during the fieldworks in data collection.

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