Irrigation water requirements of rice using Cropwat model in Northern Benin

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Abstract: Understanding crop water requirements (CWR) in semi-arid region is essential for better irrigation practices, scheduling and efficient use of water since the water supply through rainfall is limited. This paper estimated the crop reference and actual evapotranspiration (Et_o and ET_c) respectively and the irrigation water requirement of rice (*Oryza sativa L.*) in Benin's sub-basin of Niger River (BSBNR) of west Africa, using CROPWAT model. The long recorded climatic data, crop and soil data from 1942 to 2012 were computed with the Cropwat model which is based on the United Nations' Food and Agriculture Organization (FAO) paper number 56 (FAO56). The Penman-Monteith method was used to estimate ET_o. Crop coefficients (Kc) from the phenomenological stages of rice were applied to adjust and estimate the actual evapotranspiration ET_c through a water balance of the irrigation water requirements (IR). The results showed the BSBNR annual reference evapotranspiration (ET_o) was estimated at 1 967 mm. The lowest monthly value of ET_o of 123 mm, was observed in August month, middle of the rainy season while the highest value 210 mm was observed in March within dry season. The crop evapotranspiration ET_c and the crop irrigation requirements were estimated at 651 mm and 383 mm, respectively in rainy season and 920 mm and 1 148 mm, respectively within a dry season. Irrigation projects of these seasons can then be scheduled for water use efficiency based on these findings.

Keywords: crop evapotranspiration, irrigation water requirement, rice, CROPWAT, model, Benin
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1 Introduction

Water for agriculture is becoming increasingly scarce in the light of growing water demands from different sectors (IWMI 2010)[1]. Water supply matters in the world that will soon have to grow food for billions more people[2] as world population is projected to peak at 9.3 billion in 2050, an increase of 28%. Analysis showed that the total crop water requirement of all major crops increased with the rising temperature thereby increasing the simulated irrigation water demand[3]. In the future, food and livelihood security may be challenged due to global environmental changes, particularly global climatic changes that evidence has gradually shown to be appearing[4]. In January 2011, world food prices surged to a new historic peak, for the seventh consecutive month, since Food and Agriculture Organization (FAO) started measuring food prices in 1990[5]. In Benin the price of a 25 kg package of rice, have reached $70 from $30 (US Dollar) during the 2007-2008 crises and we do know that rice is becoming the most important staple all over the world. In Asia for instance, rice provides on average 32% of the total calorie uptake annually[6]. Mainly because of a fast growing population, demand for rice is expected to keep increasing in the coming decades[7]. About 75% of the global rice volume is produced in the

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irrigated lowlands[6]. Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem[8]. As many scientists are skeptical of the role of genetic engineering and biotechnology in improving water use efficiency[9] due to the fact that manipulation of single of few genes is unlikely to significantly contribute to the improvement of such complex trait[10,11], ways must be sought to save water and increase the water use efficiency for irrigated rice productivity[8]. In Benin sub basin of Niger River (BSBNR) a semi-arid area with a seven months dry season, farmers are limited by water availability in their activities. The dependence on water for food production has become a critical constraint to enhance food production. The rainy season (5 months) is the only period for farming as much precipitation falling in this short time. The month of August only, record more than 30% of an annual rainfall. Therefore in other periods of year, the great challenge faced by the agricultural sector is to produce more food from less water by increasing crop water productivity[13]. In Benin only 5% of agriculture lands are irrigated. Therefore, farmers face unemployment during dry season consequently they may not keep pace with the rapid increase demand for food production for the coming decades to ensure food security for the steadily growing world population, particularly in countries with limited water and land resources[14]. As a result, unemployed young men are often engaged in illegal hunting of wild animals, logging of forest trees and harvesting of fallen down trees (stems and branches) for firewood within natural resources reserves (the "upper Alibori", the "three rivers" and the "W" Pendjari National Park). This ultimately becomes an environment problem and threat to biodiversity conservation. Recently in response to 2008 and 2009 food price rises, the Benin government has provided farmers water pump machines and financial credit to promote paddy field irrigation during the long dry season cropping. Intensified irrigation may increase the rate of environmental degradation[15], water availability and its saving can increase crop yield. Understanding crop water needs is essential for irrigation scheduling and water efficient use in an arid region[11]. Further, with increasing scarcity and growing competition for water, judicious use of water in agricultural sector will be necessary[16]. Predicting water needs for irrigation is necessary for the development of an adequate water supply and the proper size of equipment. In our study area consistent information on irrigation water use is still lacking. The objective of this study was to estimate irrigation water requirement of rice (*Oryza sativa*) using the Cropwat model. Cropwat is a FAO model for irrigation management designed by Smith[17] which integrates data on climate, crop and soil to assess reference evapotranspiration (ETo), crop evapotranspiration (ETc) and irrigation water requirements.

2 Material and methods

2.1 Site description

The BSBNR (10°40'N 1°E/12°30'N 3°32'E) in Alibori province, Northern Benin is located within a wide West African Niger River basin (Figure 1) characterized by a tropical continental climate with two seasons a year[18]. It covers an area of 46 000 km^2, about 40% of Benin total area (112 622 km^2). The mean monthly temperature varies between 32.5°C in April to 25.2°C in December and the average annual rainfall is 849 mm. A Five-month rainy season is from April to October and following by a dry season of seven-month (November-March). The months from June to September are the wettest with 90% cumulative annual rainfall, or an average 731 mm. In fact, in August alone accounts for about 30%, or an average of 257 mm of the total annual rainfall. The annual humidity varies from 25% to 80% and average 60%. Daily sunshine length varies between 5 h to 11 h averaging 3 000 h/a. Two distinct and powerful winds: Alize maritime (monsoon) and Alize continental (harmattan) vary over time with different speeds: The monsoon wind blows from April to November in the SW direction with speed ranging from 3 m/s in April to 2 m/s in mid-October. The harmattan blows from November to March in the N or NE direction. The study area is characterized by tropical ferruginous soils developed on granito-gneissic formations and hydromorphic soils found in the valleys. Soils are characterized by high portion of clay and silts. Clay accumulation is about 3 m thick[19].

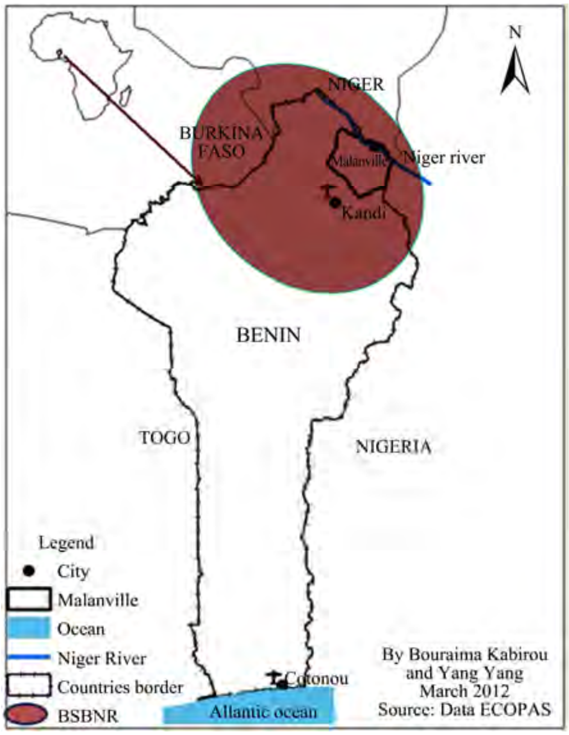

Figure 1 Location of Benin Sub Basin of Niger River (BSBNR)

2.2 Calculate reference evapotranspiration

The reference evapotranspiration ET_o was calculated by FAO Penman-Monteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 named FAO56[20]. FAO56 adopted the P-M (Penman-Montieth) method as global standard to estimate ET_o from meteorological data. The Penman–Monteith equation integrated in the CROPWAT program is expressed by Equation (1).

$$ET_o = \frac{0.408\,\Delta(R_n - G) + \gamma \dfrac{900}{T+273} U_2(e_a - e_d)}{\Delta + \gamma(1+0.34U_2)} \tag{1}$$

where, ET_o: reference crop evapotranspiration, mm/d; R_n: net radiation at the crop surface, MJ/(m^2·d); G: soil heat flux, MJ/(m^2·d); T: average air temperature, °C; U_2 : wind speed measured at 2 m height, m/s; $(e_a–e_d)$: vapor pressure deficit, kPa; Δ: slope of the vapor pressure curve, kPa/°C; γ: psychrometric constant, kPa/°C; 900: conversion factor.

The FAO CROPWAT program[21] incorporates procedures for reference crop evapotranspiration and crop water requirements and allow the simulation of crop water use under various climate, crop and soil conditions. In our study a long recorded 1942 to 2012 meteorological data[22] collected from two stations (Kandi and Malanville, Figure 1) used in. Meteorological parameters used for calculation of ET_o were latitude, longitude and altitude of the station, maximum and minimum temperature (^{o}C), maximum and minimum relative humidity (%), wind speed (km/day) and sunshine hours. ET_o was calculated for every ten days (defined as "decade" by FAO) and then cumulated to monthly data. Soil characteristics considered for estimation of crop water requirement are available water content (mm/m) and depth of soil (cm).

2.3 Crop data

The major cultivated crops in study area are rice, maize, tomato, pepper, groundnut, sorghum, cotton etc. We focus on rice in this study for its importance in this region. Even, it is the most important staple food for a large part of the world's human population[23]. Crop coefficient values (K_c) are taken from available published data[20,24]. K_c values for initial, mid and late growth stages of rice are used for the sole rainy and dry seasons months.

2.4 Crop evapotranspiration (ET_c)

ET_o is multiplied by an empirical crop coefficient (K_c) to produce an estimate of crop evapotranspiration (ET_c), as in Equation (2).

$$ET_c = K_c \cdot ET_o \tag{2}$$

where, ET_c is a crop evapotranspiration; K_c a crop coefficient; ET_o a reference crop evapotranspiration.

3 Results and discussion

3.1 Calculation of reference evapotranspiration

The BSBNR mean annual reference evapotranspiration (ET_o) is estimated at 1 967 mm. Table 1 and Figure 2 show ET_o by month. The months December to May have a relatively high values, more than 160 mm per month and the months June to November showed lowest ET_o, those periods coincide with the dry and rainy season respectively. This indicates the differences observed in the meteorological parameters within a year. In dry season, the resulting low relative humidity combined with high temperatures led to increased evapotranspiration over this period of a year. Inversely the low values of ET_o in rainy season may be due to the high frequencies of rainfall combined with high relative humidity and relative low temperatures. In Guixi, Jiangxi Province, China Nahla et al.[25] found low ET_o due to high humidity in the study area. As the trend of ET_o affecting by climatic factors such as temperatures, solar radiation, and rainfall as well as wind, relative humidity of the air consequently ET_o is a climatic parameter. With the variations of these parameters ET_o will vary greatly within and between seasons. The results are in accordance with Adeniran et al.[26], which showed that ET_o was lowest during the peak of the rainy season to highest during the peak of the dry season.

Table 1 Printouts Climate/ET_o Data of BSBNR

Month	Temperature mini/°C	Temperature maxi/°C	Humidity/%	Wind/km·d^{-1}	Sunshine/h	Radiation/MJ·m^{-2}·d^{-1}	ET_o/mm·month^{-1}
January	16.6	33.9	31	179	8.6	19.6	176.30
February	19.8	36.5	28	179	8.5	20.9	177.53
March	24.0	38.7	35	186	7.6	20.8	210.69
April	26.2	38.8	49	200	8.0	21.9	207.43
May	25.0	36.1	62	196	8.3	22.0	190.61
June	23.4	33.1	72	176	8.1	21.3	155.92
July	22.4	30.9	78	120	6.7	19.3	132.52
August	22.1	30.0	80	107	6.1	18.7	123.73
September	21.9	31.1	78	103	6.9	19.7	125.56
October	22.1	34.1	68	117	8.5	21.1	149.63
November	18.6	35.5	49	130	9.2	20.7	154.42
December	16.4	34.2	37	155	9.0	19.6	163.35
Average	**21.5**	**34.4**	**56**	**154**	**8.0**	**20.5**	**1967.69**

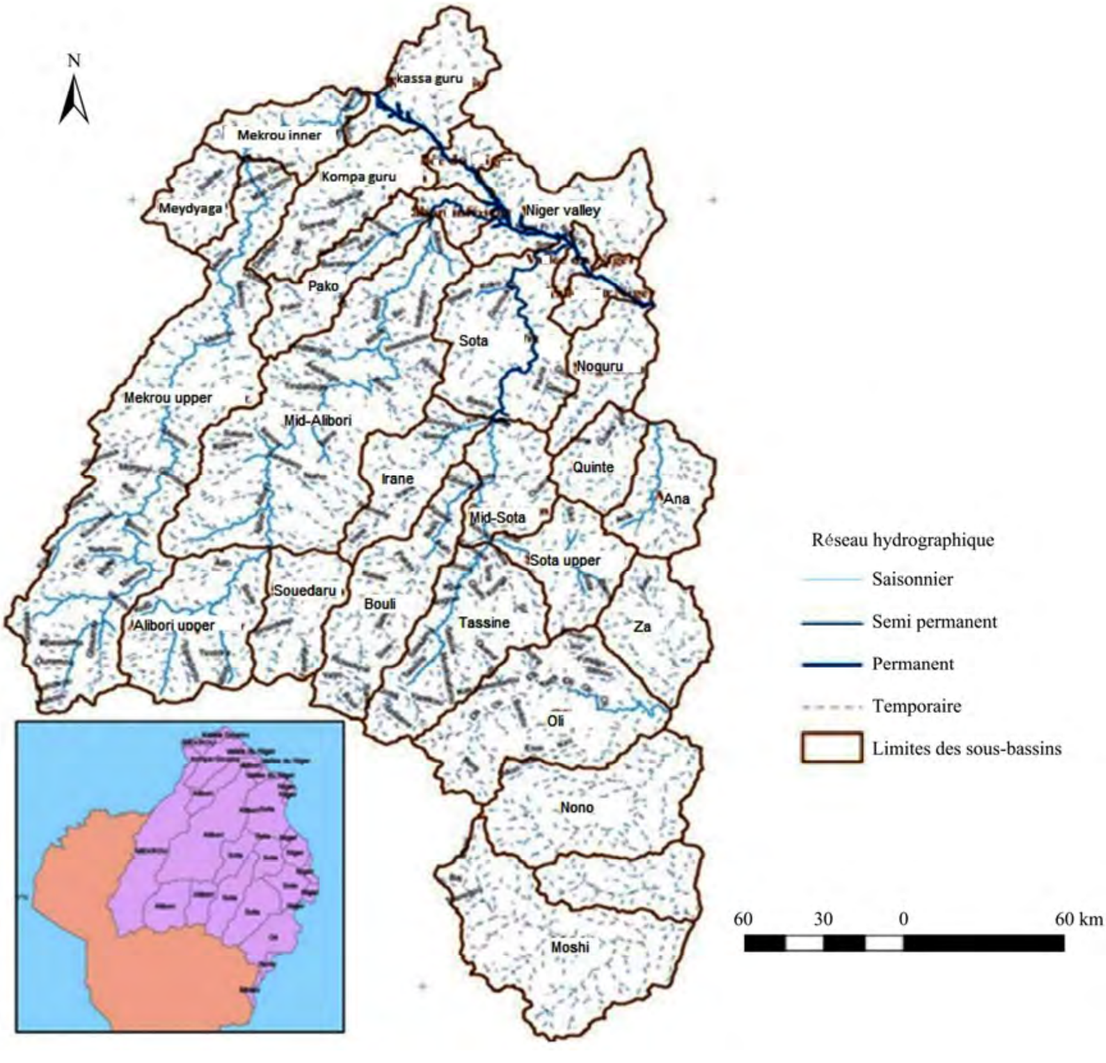

Figure 2 BSBNR watershed catchments representation

Pofagi et al.[18] have estimated ET_o of 1 738 mm the using P-M method from 1921 to 1960 data for the same area. Compared to our results increase of Evapotranspiration may be explained by the differences in inputs data, the accuracy of the model or a global warming else.

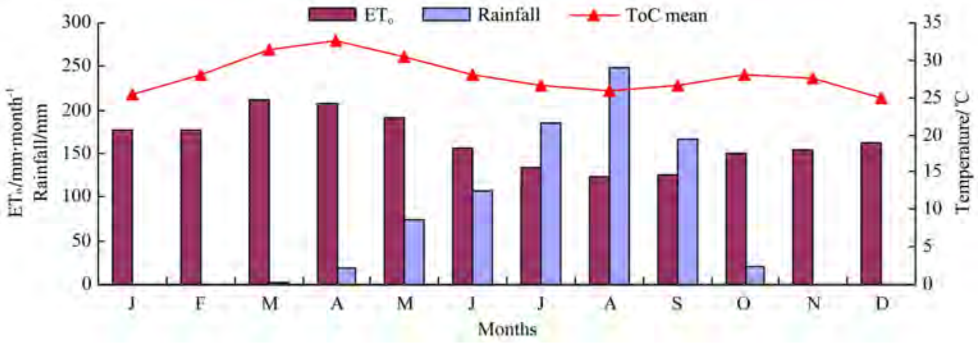

Figure 3 Combined ET_o, rainfall and temperature trends in BSBNR (1942-2012)

3.2 Actual evapotranspiration ET_c

The crop evapotranspiration (ET_c) of rice was found to be around 651 mm in the rainy season cropping where as in the dry season cropping it was estimated to be around 920 mm (Table 2). ET_c was more during the dry season than the rainy season. This is similar to the FAO[21] report, in that crops grown in the dry season needs more water than those grown during the rainy season. This phenomenon is partly due to the meteorological factor. For example, more rainy days and shorter sunshine duration are experienced in rainy season. The ET_c is a function of the amount of rainfall and varies greatly within and between seasons[27] considering the crop development cycle, growth stages.

Table 2 Cropwat outputs on Crop cooeficient (K_c), mean (mm/d) cumulative value (mm) of crop evapotranspiration (ET_c), effective rain (mm) and irrigation requirement for each phenological stage of rice crop.

	Growth stages	Length/d	Kc	ET_c/mm·d^{-1}	∑ ET_c/mm	Eff Rain/mm	IR/mm·10 d^{-1}
Rainy season	Nurs	30	1.13±0.07	2.98±2.28	89.50	85.20	75.90±89.23
	Init	0-15	1.10	4.65±0.06	50.40	42.70	7.70
	Deve	15-50	1.11±0.02	4.73±0.18	144.30	169.40	0
	Mid	50-100	1.14	4.89±0.26	241.20	267.50	3.58±7.57
	Late	100-120	1.09±0.05	4.22±0.08	126.30	16.10	43.37±7.83
	TOTAL				651.70	580.90	383.50
Dry season	Nurs	30	1.13±0.07	3.06±2.46	91.80	0.20	100.77±106.90
	Init	0-15	1.10	5.78±0.03	57.50	0	57.75
	Deve	15-50	1.14±0.03	6.16±0.35	191.10	0	63.70±4.92
	Mid	50-100	1.22	7.50±0.46	444.90	0.40	74.07±6.83
	Late	100-120	1.14±0.06	6.75±0.36	134.90	1.10	76.85±4.45
	TOTAL				920.20	1.80	1148.90

Note: Init= Initial phase of rice cycle , Deve=Developement phase, Mid=Middle phase, Late=Late phase, ∑=cumulative, Eff= Effective, IR= Irrigation requirement.

As shown in Table 2 over a rainy season ET_c increased from 2.98±2.28 mm/d to 4.22±0.08 mm/d while in dry season it increased from 3.06±2.46 mm/d to 6.75±0.36 mm/d. Those variations may be explained by the crop coefficient K_c given in Equation (2), basically the ratio of ET_c to ET_o. Although the K_c varied little, it was not constant in any phenological stage[28] and it expresses the crop water requirement for a given season. For the accuracy of analysis the study considered the cumulative ET_c (∑ET_c) using the crop development stages. During the initial stage of crop growth, which is the period from sowing through 15 d, the cumulative ET_c (∑ET_c) values was very low; 50 mm and 57 mm for rainy and dry season respectively. ∑ET_c values increase during the crop development stage (16-50 d) and reach its peak during the mid-season stage (51-100 d). The ∑ET_c values decline rapidly during the last crop growth stage, the period from 101 d to 120 d. The values of ET_c were lower in the beginning and end of the productive cycle and higher in the middle of the observations period. On the overall, the ET_c throughout the rice crop development cycle was too much variable, mainly because of the dominant climatic conditions and the crop development of each phenological stage.

3.3 Irrigation Requirement

Table 2 shows the mean value of the irrigation requirement (IR). It is important to mention here that the 10-day (decade) mean IR was run to have an idea of how much water to irrigate. The total IR was estimated at 383 mm for the rainy season and 1 148 mm for dry season. The high irrigation requirements during the months of dry season may be explained by the severe drought conditions and the resulting low relative humidity due to the lack of rain combined with high temperatures which led to increased evapotranspiration. Zhong et al.[29] observed, when the hottest period with highest temperature, high evaporation occur and soil moisture decrease rapidly implying highest agricultural water requirement. From Figure 3 it can be see that there were no rainfall in the months of November to April, the dry season period and the Table 2 showed the given period with no or very low effective rain that may meet the crop water needs. Surendran[3] have come to the same result that, difference in irrigation requirements might be due to the combined effect of the changes in temperature, sunshine hour percentage and wind and the decrease in effective rainfall. The total effective rainfall of 1.8 mm versus 580 mm was recorded in the months of dry season cropping. Then much water should be needed to compensate the rice ET_c and the change in soil moisture during the crop growth of this season. The changes in IR indicate the differences in water requirement even within a same season hence it shows the significance of requirement of scientific planning for irrigation. In Taiwan, Kuo et al.[30] have estimated, in the paddy field, the irrigation water requirements at 962 mm and 1 114 mm for rainy and dry season respectively while it has been estimated by Hargreaves et al.[31] at 1 788 mm for rainy and 2 030 mm for dry season within Senegal river basin for rice. Difference may be explained by the weather, seasons and soil types. In Taiwan the annual rainfall is about 2 500 mm and the effective rainfall within Senegal river basin is estimated at 157 mm for the rainy season with a total cumulative rainfall 274 mm which represents the only August rainfall in BSBNR.

4 Conclusions

The FAO-Penman-Montieth equation is recommended as the standard method for estimating reference and crop evapotranspiration as well as crop irrigation water requirement through the FAO CROPWAT model. The annual reference evapotranspiration (Et_o) for rice was estimated at 1 967 mm. The total crop evapotranspiration (ET_c) for rainy season is about 651 mm and 920 mm for dry season.

Rice consumes more water in dry season than in rainy season. For the whole crop development cycle, the irrigation water requirements reached 383 mm and 1 148 mm for rainy season and dry season, respectively. The mean values of these parameters, ET_c and IR, fluctuate throughout rice crop development cycle and between Seasons depending on weather and soil conditions. It showed the significance of requirement of scientific planning for irrigation. Results on ET_c and IR provided practical assessment for irrigation scheduling of rice grown in this tropical semi-arid environments. These results can be used for a most efficient water use and to optimize production of the rice in BSBNR.

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