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Research Article

Irrigation and crop water requirement estimation for oil palms using soil moisture balance model in Peninsular Malaysia

Adesiji, Adeolu Richard [a,b*], Nik Daud, Nik Norsyahariati [a], Asogwa, Evarestus Osita [b], Mangey, Jarumi Akila [c], Musa, Hassan Hassan [b], Adaudu, Ignatius Idoko [b]

[a]*Department of Civil Engineering, Faculty of Engineering, Universiti Putra, Malaysia, 43400, UPM Serdang, Malaysia*
[b]*Department of Civil Engineering, Federal University of Technology, Minna, Niger State, Nigeria.*
[c]*Water Resources and Environmental Engineering Department, Ahmadu Bello University, Zaria, Nigeria*

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Abstract

This study presents the irrigation and crop water estimation in a Malaysian oil palm plantation for effective irrigation water management during water years 2013 and 2014. The study area was divided into four plots: 2000, 2002, 2006 and 2010, indicating years of peat swamp forest conversion to oil palm plantation. Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS) and Soil moisture balance hydrologic models were used to model the rainfall-runoff in the basin. Statistical analysis using coefficient of determination (R^2) and Nash–Sutcliffe efficiency coefficient (NSE) were used to evaluate the performance and correlation of the two hydrologic models. The result showed that R^2 and NSE were 0.94 and 0.90 respectively for calibration and 0.92 and 0.54 respectively, for monthly validation. This showed that the models performed well for simulation of the peatland hydrology. With the modelling of rainfall-runoff satisfied, the irrigation demand of the study plots was determined using the same soil moisture balance model. The irrigation demand ranged from 0.893 to 1.6 million cubic meters (MCM) in 2010 and 2000 study plots respectively. Irrigation demand is observed to be site specific which depends on the soil moisture deficit, readily available water in the oil palm root zone and oil palm rooting depth. Estimation of a future oil palm water requirement using the soil moisture balance model would be recommended for further studies for use as an advisory manual for the oil palm managers to enhance adequate water resources planning for oil palm productivity.

Introduction

Water resources management, especially in oil palm plantation, is of high significance considering the amount of moisture required for oil palm productivity. According to Harahap and Darmosarkovo (1999), oil palm is estimated to use water between 1.83 - 4.13 mm palm-1 day-1 for its production yield. This is far above the consumptive use of water by forest trees and annual crops (Schilling, 2007; Naderi et al. 2016). Cultivation of oil palms on formerly existing peat swamp forests in Malaysia and other oil palm producing Southeastern Asian countries has gained popularity owing to the high global demand for the oil palm products, especially palm oil bio diesel (Avinash et al. 2014). This high demand for the oil palm products thus led to conversion of peat swamp forests in those countries to oil palm plantations, especially in Indonesia and Malaysia. This conversion, however, did not come without its adverse effects as most of the trees in the peat swamp forest were felled in preparation for peatland agriculture (Kamlun et al. 2016; Adila et al. 2017). The peatlands thus became vulnerable to floods and eventual increase in surface runoff due to poor watershed management based on unreliable hydrological information along with rapid deforestation (Seo and Lee 2015; Kamlun et al, 2016). Due to deforestation and other anthropogenic activities in the peat swamp forests, peatland groundwater is lowered, which, in other words, enhance peatland agriculture for oil palm productivity (Querner et al. 2012; Katimon et al. 2013; Melling et al. 2014).

With lots of benefits derived from oil palm productions, sustaining these economic benefits is being threatened as best management practices (BMPs) to enhance its sustainability are not being practiced. The most important among these BMPs in the oil palm plantation is the soil water management, particularly of those oil palms cultivated on peat. According to Lim, et al., (2012), effective water management is the key to high oil palm yield on peat. To enhance oil palm productivity, therefore, adequate soil moisture at the root zones must be available as too little or too much of it will adversely affect nutrient uptake and fresh fruit bunches (FFB) yields of oil palms (May, 2012). This thus underscores the relationship between the surface runoff and soil moisture availability in the root zones. As water table depth (WTD) is being lowered due to peatland drainage, the crop water stress increases and the extraction of water from the root zones for crops use becomes more difficult. This explains why there is need for soil moisture availability in the root zones all year round which is only feasible when there is good water management put in place. Thus, according to Roundtable on Sustainable of Palm Oil (RSPO) (2012) and May (2012), a good water management system for oil palms on deep peat is one that can effectively maintain a water level of 50-75 cm from the peat surface for as long as possible. It should also be able to remove excess surface and sub-surface water quickly during wet season and retain water for as long as possible during dry spells.

This is where peatland hydrology and peat soil properties become very important. With adequate rainfall and minimum surface runoff, substantial percentage of rainfall known as

*Corresponding author email: ade.richard@futminna.edu.ng

effective rainfall would get to the root zones and become available soil moisture to the plants (Awulachew et al. 2009). Substantial part of this rainfall will also recharge the groundwater table thereby raising the water table depth and enhance adequate available soil moisture at the root zones (Rushton et al. 2006; de Siva and Rushton, 2007). Therefore, predicting water needs for irrigation is necessary for the development of an adequate water supply and the proper size of equipment. This is where crop irrigation design comes in which is mainly the estimation of crop water requirement (CWR) that would produce optimum crop yield. The focus of this paper is, therefore, to use Hydrologic Engineering Centre-Hydrological Modelling System (HEC-HMS) and soil moisture balance model to estimate surface runoff and irrigation water demand of oil palms in a Malaysian tropical peatland. Soil moisture balance model considers both the soil and crop properties of the study area being used in the soil moisture deficit estimation. Consumptive use of soil water by the oil palms compared to the available soil moisture known as total available water (TAW) during the period of no groundwater recharge was estimated on daily basis. This further helped in estimating the deficit in water balance in the soil and the precise irrigation need of the water-stressed oil palms.

Methodology

Study area

The study area is located in Sepang, the state of Selangor, Malaysia at Kuala Langat South Forest Reserve area, between latitude 02° 43’N and longitude 101° 39’E bounded to the West by Straits of Malacca (Figure 1). The study area experience tropical climate and high humidity with an annual rainfall between 2500 – 3000 mm. The monthly air temperature ranges between 32 °C and 36 °C, with the highest value recorded in May each year. For the 2014 water year under study, the lowest rainfall recorded was in February as 7.0 mm and highest in April as 437 mm. The average annual rainfall for the study year, 2014 was 2348 mm from the Malaysian Department of Irrigation and Drainage (DID) gaging station 2918101 in the study area. The study ran from June, 2014 to December, 2014 (both months inclusive). During this study period, the highest rainfall depth observed was in November as 399 mm. The vegetation of the study area is characterized with oil palms since the peat swamp forests were first converted to oil palm plantation in 1978.

Site selection

The study area located in Sepang with total area of 4,950 ha (49.5 km^2) was divided into four different sub-basins, each sub-basin named according to the years the peat swamp forests were converted to oil palm plantations, such as; 2000, 2002, 2006, and 1978/2010. The latter was first converted to oil palm plantation in 1978 before it was re-cleared for cultivation in the year 2010. All the sub-basins have the same hydrologic soil type and same vegetation but with different catchment areas. To establish an hydrological parameters for the ungauged study areas, a basin with a recorded daily and hourly flow and rainfall data from gaging stations 2918401 and 2918101 respectively located along Semenyih river which lies within latitudes of 2° 40’ 152”N to 3° 16’ 15”N and longitudes of 101° 19’ 20”E to 102° 1’ 10”E was used in the study. The use of Semenyih catchment as a proxy site for runoff estimation using HEC-HMS Model became necessary due to the lack of real-time runoff data in the study area. Semenyih basin was chosen as it has the similar vegetation and soil properties with Sepang basin.

Runoff estimation using recorded streamflow data and HEC-HMS

HEC-HMS, version 4.1 (USACE, 2000), was used in this study to simulate the runoff hydrographs resulting from a design storm on Sepang oil palm plantation basin. It was also used in this study to develop a hydrologic model for Semenyih basin with catchment area of 35.38 km^2. According to Chen *et al*., (2009), the model addresses the spatial distribution of catchment characteristics by subdividing a catchment into sub-catchments that are treated as homogenous in land-use, soil type, etc. The resulting runoff from the HEC-HMS was statistically compared with the recorded streamflow data by adjusting model parameter values of HEC-HMS such as curve number (CN) and lag time until the model results match acceptably the observed streamflow data. Having obtained the values of percent imperviousness, the values of CN and Lag-time were both inserted as input parameters in the HEC-HMS to obtain direct runoff which was then compared with the recorded flow.

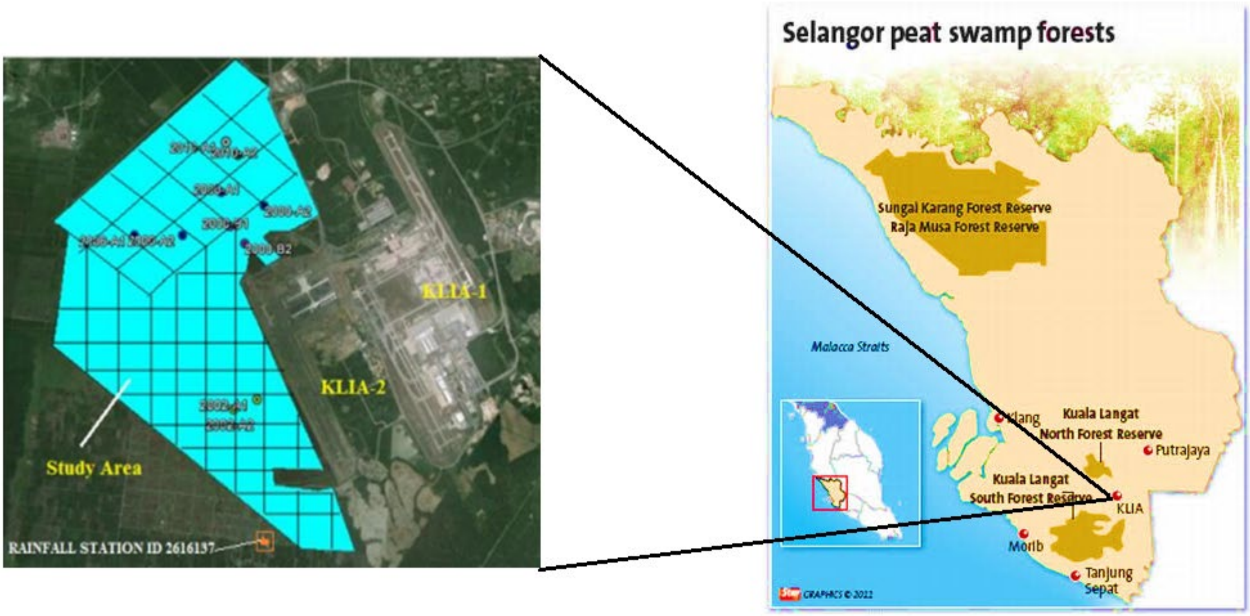

Figure 1. Location of study area with rainfall gauging station (*Source: Abdulkarim et al., 2017*)

Statistical relationship was established between the flow data from HEC-HMS and recorded flow data from gaging station ID 2918401. Both hourly and daily flow and rainfall data covering 2013 to 2015 were obtained from Malaysian Department of Irrigation and Drainages (DID) and used in the runoff estimation. Two highest rainfall depths with simple hydrographs were chosen for the calibration of the HEC-HMS model. Hourly rainfall depths of April 7th and November 23rd 2014 water year were chosen for the calibration of the model while the months of September and December were used for model validation. Having established the flow data for April 7th and November 23rd, the flow data from HEC-HMS and the recorded flow data from gaging station ID 2918401 were tested for model performance using both the coefficient of determination R^2 and Nash–Sutcliffe model efficiency coefficient (E_{NS}) (Dongquan *et al*. 2009; Karthikeyan *et al*. 2013).

The Nash–Sutcliffe model efficiency coefficient is used in assessing the predictive power of hydrological models, and it is defined as (1)

$$E = 1 - \frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \bar{Q_o}\right)^2} \quad (1)$$

Where;
Q_o = mean of observed discharges, and
Q_m = modeled discharge and
Q_o^t = observed discharge at time *t*.

Nash–Sutcliffe efficiency ranges from infinity to 1. The value of efficiency of 1 (when $E = 1$) means there is a perfect match of modeled discharge relative to the observed data. The value of efficiency equal to (when $E = 0$) shows that the predictions of model are as accurate as the mean of the observed data, whereas an efficiency below zero ($E < 0$) occurs when the observed mean is a better predictor than the model.

The soil moisture balance model and its computational method

In this study, a single layer soil water balance model that incorporates the physical processes such as: rainfall, surface runoff, evapotranspiration, crop transpiration, root growth, soil water distribution following rain event and potential recharge developed by Rushton (2006) is adopted. This soil moisture balance model with supporting input data listed has proved to be a strong and flexible method of potential surface runoff and crop water use estimation. The conceptual and computational models of this approach are as shown in Figure 2.

From the expression above, provided there is readily available water, RAW for the oil palm, actual evapotranspiration, AE becomes potential evapotranspiration, PE. From Figure 2, when the soil moisture falls below the threshold of RAW, the crops are under stress and the rate of transpiration is reduced except the rate of inflow into the soil exceeds the PE. If the soil moisture drops further to the level of TAW which corresponds to permanent wilting point, it then becomes difficult for plant roots to further extract soil water.

Reference evapotranspiration *ETo*

With the available maximum, minimum and mean temperature data with radiation, *Ra*, the Hargreaves method of evapotranspiration estimation was used in this study. According to Droogers and Allen (2002), Hargreaves *ETo* equation can be expressed as:

$$ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}Ra \quad (2)$$

Where;
ET_o = the daily reference evapotranspiration (mm/day)
T_{max} = maximum daily temperatures respectively (°C)
T_{min} = minimum daily temperatures respectively (°C)
T_{mean} = Mean Temperature (°C)
Ra = Extraterrestrial radiation as 16.4 MJm²/day (Shavalipour et al. 2013)

Results

Table 1 presents the crop and soil parameters for the soil moisture balance of oil palms. All the oil palms in the study area were already mature at the time of study and hence the use of maximum root depth of 0.9 m and crop stress coefficient K_c of 1.0.

Runoff estimation from the HEC-HMS

Curve number value of 40 and Lag-time of 60 minutes, with estimated impervious value of 17.64 % were chosen after series of trials and these were further used in the validation processes. CN value of 40 and Lag-time of 60 minutes gave the $\mathbf{E_{NS}}$ of 0.794 and R^2 value of 0.853 for April 23rd calibration which showed a good fit and as well above 0.5 thresholds. This also showed that the two-flow data were not significantly different and that the model predictions are as accurate as the mean of the observed data (Dongquan *et al*. 2009). Figures 3 shows the hydrographs of the calibrations carried out from the two flood events of April 7th and August 23rd 2014 water year. The two hydrographs indicate that the simulated flows reasonably predicted the recorded flow.

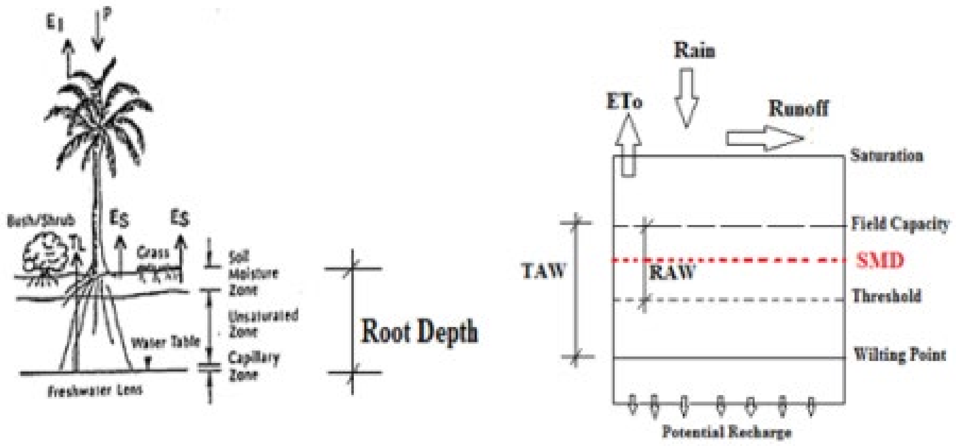

Figure 2. Conceptual and computational models of soil moisture balance

Table 1. Crop and soil parameters for the soil moisture balance of oil palms study plots

Parameters/Year of cultivation	2000	2002	2006	2010
CROP PARAMETERS:				
Maximum root depth (m)	0.9	0.9	0.9	0.9
*Depletion factor	0.70	0.70	0.70	0.70
Kc (initial)	1.00	1.00	0.7	1.00
Kc (development)	1.00	1.00	1.00	1.00
Kc (mild stage)	1.00	1.00	1.00	1.00
Kc (late)	1.00	1.00	1.00	1.00
SOIL PARAMETERS:				
Bulk density (gcm^{-3})	0.302	0.217	0.276	0.397
VMC @ Saturation (m^3 m^{-3}) θ_{sat}	0.53	0.51	0.52	0.52
VMC @ Field capacity (m^3 m^{-3}) [θ_{sat} x $\frac{\gamma_b}{\gamma_w}$]	0.16	0.11	0.14	0.206
VMC @ Wilting Point (m^3 m^{-3}) [FC/2.4]	0.067	0.05	0.06	0.086
Maximum TAW (mm)[FC-WP]/900	84	54	72	108.4
Maximum RAW (mm) [TAW*0.7]	59	37.8	50.4	75.9
Soil Moisture Deficit (mm)	83.9	54	72	108.4
*NSS Factor	0.45	0.45	0.45	0.45

* Depletion factor (Allen *et al*. 1998)
**NSS factor (Rushton *et al*. 2006)

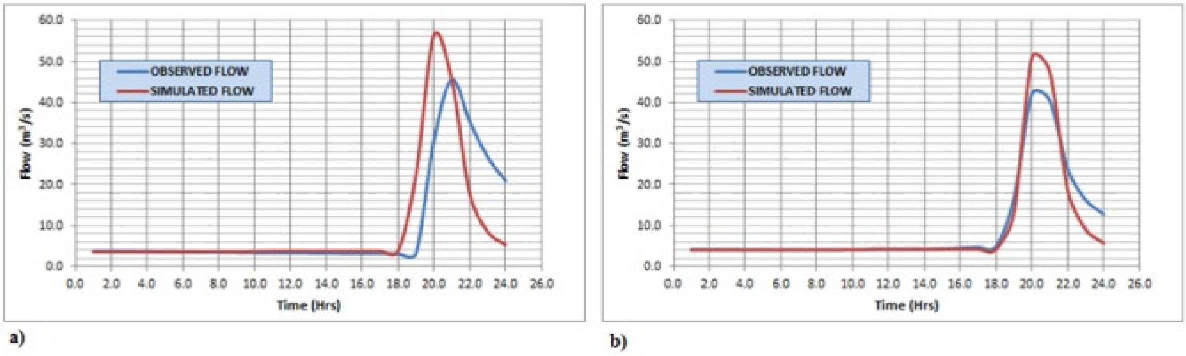

Figure 3. Comparison of simulated and observed hydrographs for semenyih basin. a) April 7th 2014 flood event and b) August 23rd 2014 flood event

Soil moisture balance model validation

The adopted runoff coefficients from the previous sections were inserted into the model and the model was run for each of the study plots. Similar runoff hydrographs were observed from all the other plots, since the same rainfall pattern was used in all the sub-basins with similar soil and oil palm properties, though with different initial soil moisture deficit. Therefore, the values of E_{NS} and coefficient of determination R^2 for all the study plots (for 20 % increase in runoff coefficients) between the SMB Model and HEC-HMS Model flows gave acceptable values. This means the predicted discharge for the sub-basins fit the observed data well with Nash–Sutcliffe model efficiency of 0.54 and R^2 ranging from 0.92 to 0.928 at the sub-watershed outlets (Tilahun *et al*. 2015).

Interpretation of soil moisture balance model output parameters

Graphical relationship among some important output parameters of the soil moisture balance model for study plot 2000 is presented in Figure 4. The most important among the parameters in the figures are the relationships between groundwater recharge, soil moisture deficit (SMD), reference evapotranspiration (ETo), total available water (TAW), readily available water (RAW) and surface runoff. In the figure, the shaded parts represent the periods of higher soil moisture dificits (SMD), where SMD > RAW.

The model recorded annual groundwater recharge which varied from 5 mm in 2010 study plot to 27 mm in 2002 study plot. Annual rainfall depth was 2135 mm while the annual runoff ranged from 1114 mm in 2006 to 1195 mm in 2002. Actual evapotranspiration, AE ranged from 881 mm in 2002 to 989 mm in 2006. Parts of this moisture are held up in the root zones which are readily available for crops use. They are termed readily available water (RAW). It is defined as the amount of water readily available for crop for extraction from its root zone (Steduto, 2012) and depends on soil types, depth and distribution of roots within the soil mass (Carr, 2011). Since it became evident that the peatlands in all the study plots experienced groundwater recharge late in the year, availability of soil moisture for oil palms' productivity in the root zone and avoiding peatland degradation became very crucial.

Monthly soil moisture balance estimation

The equation for the estimation of monthly water balance (Δs) for all the study plots is as represented in [3]. This helps to estimate the monthly water balance status for each of the study plots in order to appraise the need to supplement rainfall in the event of any deficit in soil moisture to avoid water stress.

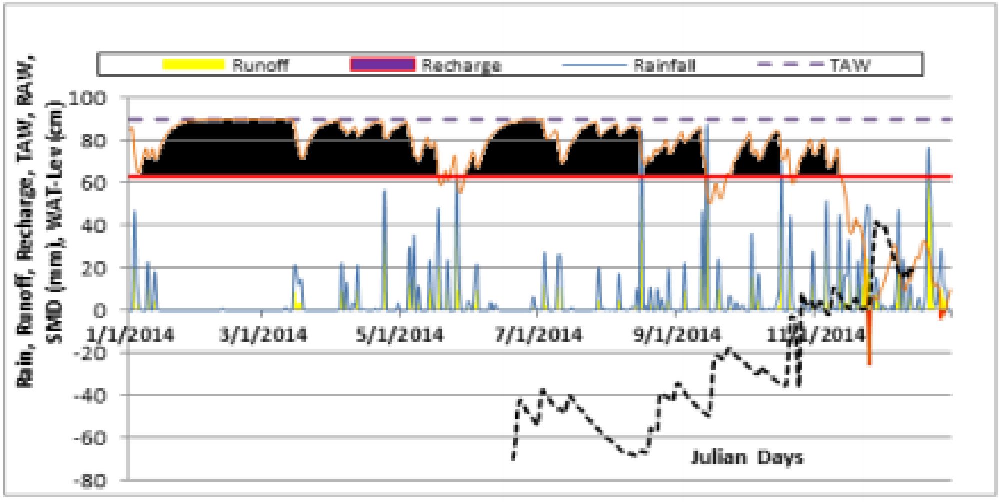

Figure 4. Soil moisture components for 2000-SITE representing 2014 water year

$$\Delta s = [P + RAW] - [ET_o + Q + Re] \qquad (3)$$

Using Water Balance Equation to estimate the existing storage in the month of January for 2000 study plot;

$\Delta s = [P + RAW] - [ET_o + Q + Re]$
$\Delta s = [106 + 59] - [164.91 + 44.52 + 0] = -44.43$ mm for January
$\Delta s = [1 + 59] - [156.78 + 0.42] = -97.2$ for February

Using this equation for all the study plots as presented in the tables, February recorded the highest water deficit in all the study periods and this could be attributed to the low total monthly rainfall depth of 1.0 mm. 2002 study plot recorded the highest soil water deficit of – 118.2 mm because of low readily available water recorded as 38 mm followed by -106.2 mm in 2006 study plot which recorded 50 mm as RAW. Peat fires recorded in 2006 study plot during this period was attributed to the excessive lowering of water table depth which was occasioned by low rainfall depth that resulted in high water deficit in the month of February.

Peatland irrigation design and planning for study area

For oil palm optimum productivity, required quantity of soil water depth from where crop roots extract soil water must be maintained (Michael, 2008). If the consumptive water use of crops exceed the rate at which soil is receiving water, then this will lead to water stress which would have serious implications on the crops productivity. According to Gleick and Palaniappan (2010), 'Such consumptive water uses include water that has been evaporated, transpired, incorporated into products or crops, heavily contaminated, or consumed by humans or animals.

Oil palm's consumptive water use and irrigation designs

In order to estimates the oil palms' consumptive water use for each study plot, days where SMD is greater than RAW are checked to examine the consumptive water use by the crops and comparing it with permissible withdrawal for the study plot. Once the oil palms' consumptive water use exceeds the field permissible withdrawal, there will be soil water deficit within the soil root zone which must be replenished (through irrigation) to avoid adverse effects of soil water stress on oil palms. Irrigation needs of the 2000 study plot is therefore estimated in the section below.

Irrigation water design for 2000 Study plot

From Figure 4, there are **Four** occasions when SMD > RAW; these are;
i. CASE I: Jan 1 -May 18 (138 days)
ii. CASE II: May 30 – Sept 13 (107 days)
iii. CASE III: Sept 22 – Oct. 22 (31 days)
iv. CASE IV: Oct 24 – Nov. 12 (20 days)

CASE I with longer number of days was chosen for irrigation design

<u>Consumptive crop water use for CASE I</u>

ET_o = (5.13 * 3) + (5.34 * 34) + (5.67 * 22) + (5.46* 79) = 753.03 mm
ET_{ocrop} == 1.0 * 753.03 = 753.03 mm

Rainfall = 476.5 mm
Runoff = 217.08 mm
Recharge = 0
Effective rainfall = Rainfall – Runoff – Recharge
= 476.5 – 217.08 – 0
= 259.52 mm
Effective rainfall can also be expressed by;
Effective rainfall = 0.8 * Rainfall (with rainfall above 75 mm/month) (Dastane, 1978).

<u>To estimate whether there is deficit;</u>

Consumptive water use – Effective rainfall = 753.03 - 259.52
= 493.51 mm

This is far greater than the permissible withdrawal of 27.18 mm for 2000-Study plot, hence the need for irrigation.
493.51 > 27.18

Having confirmed the need for irrigation for CASE I, Field Irrigation Requirement (FIR), frequency of irrigation and the water depth required for irrigation between the periods in question.

Water Holding Capacity of Soil = TAW = 84 mm
Rooting depth = 0.9 m
Moisture Holding Capacity of root zone
$$\frac{84 * 0.9}{1000} = 0.0756 = 76\ mm$$
Allowable depletion (Allen *et al*. 1998) = 35 %

STEP 1. Allowable depletion depth between irrigations

$= 0.35 * 76 = 26.6 \text{ mm} = 2.7 \text{ cm}$

The daily consumptive use of water between Jan 1 to May 18 = 5.45 mm/day

STEP 2. Duration of irrigation (in days) between Jan 1 to May 18;

$$\frac{Available\ moisture}{Daily\ consumption} = \frac{2.7}{0.55} = 5\ days$$

This means irrigation will be needed after every 5 days from Jan 1 to May 18.

STEP 3. Net Water depth required for irrigation each time after 6 days

5 * 0.55 = 2.75 = 3.0 cm

This means 3.0 cm (30 mm) depth or equivalence of 5.45 mm/day (165 mm/month) of irrigation water will be needed for 5 days at every irrigation period.

STEP 4: Field Irrigation Requirement (FIR)

Using the Irrigation Efficiency of 40 % (Allen *et al*. 1998)

$$FIR = \frac{Net\ Irrigation\ Requirement}{Efficiency\ of\ Irrigation} = \frac{3.0}{0.4} = 7.5\ cm$$

This means 7.5 cm (75 mm) depth of irrigation water will be needed per Area of field.

i.e. 7.5 cm per *hectare*
for 2000 study plot with 19.31 km^2, the quantity of water required in the study plot;

Quantity of irrigation = 7.5 * Area of field = 0.075 (m) * 19.31 (km^2)
0.075 * 19310000 = $\mathbf{1.45 * 10^6\ m^3}$

Hence volume of water required to irrigate 1,931 ha of 2000 study plot at 16 days interval;

= $\mathbf{1.45 * 10^6\ m^3}$

This is the amount of irrigation water needed in 6 days i.e

$$\mathbf{1.45 * 106\ m^3} / 6 \text{ days} = \frac{1{,}450{,}000}{6 * 24 * 3600} = 2.79\ m^3/\text{s}$$

Table 2 shows the summary of irrigation requirements in all the study plots with the peatland properties. Study plot 2000 required the highest irrigation needs as a result of its size (19.31 km^2). This is followed by study plot 2002 with 12.34 km^2 as the area of the peatland. From Table 3, 7.63 m^3/s represents the total irrigation need of the study area with days varying from 4 to 7 days depending on the study plot.

Discussion

Soil moisture balance model has been used in this study to establish the water balance of the study area and to determine the irrigation need of the oil palms. Most prominent in the model application is the rainfall-runoff relationship of the study area being used. The major model input parameters are rainfall, crop evapotranspiration, available water for evaporation (AWE), crop rooting depth, depletion factor and near surface storage. The output parameters include surface runoff, soil moisture deficit, total available water, readily available water and groundwater recharge. Groundwater recharge and soil moisture deficit estimation became important in a bid to appraise the influence insufficient rainfall on the crop survival and production yield. In all the study plots groundwater recharge did not occur until late November. The first recharge in study 2000 was experienced on 25th November 2014 with annual recharge varying from 5 mm in 2010 study plot to 27 mm in 2002 study plot. It was observed that most of the precipitation was lost to runoff as annual runoff from the study varied from 1114 mm in 2010 study plot which is about 53 % of annual rainfall to 1195 mm in 2000 study plot (56 % of annual rainfall). The effects of not having enough water in the soil storage was observed particularly during the period of no recharge and the steps to follow in estimating the required irrigation needs in the event of high soil moisture deficit noted. Difficulty in applying the model is of great concerns. First, lack of real time measured data in the study area could not allow the rainfall-runoff relationship to be measured directly. Thus in this study, a nearby catchment (with gaging stations for both streamflow and rainfall) having similar vegetation and land use pattern with the study area was used in establishing rainfall-runoff relationship for the study area. The flow and rainfall data from this adopted catchment were used to calibrate and validate HEC-HMS rainfall-runoff model using a statistical analysis.

In all the study plots, February, March, April, May, June, July, August and some parts of October and November were observed to represents the periods with high irrigation needs as SMD > RAW throughout these periods. This has been attributed to many factors, among which are: low monthly rainfall depth, high runoff, high evapotranspiration and high surface temperature. Since the major parts of the water year requires no irrigation by the virtue of soil moisture availability and adequate storm events, deficit irrigation was recommended. Volume of water expected as irrigation requirements for the study plots ranged from 0.607 $*10^6\ m^3$ in 2006 study plot to 1.6 $*10^6\ m^3$ in 2000 study plot. Permissible withdrawal in each of the study plots also varied from 11.7 mm in 2002 study plot to 42.87 mm in 2000 study plot. In order to ensure adequate supply of water for irrigation purposes, the need to locate the source of such irrigation water is of high importance. There were two options available; the first is diverting water from Semenyih reservoir which have been tested for its irrigation potentials (Juahir *et al.* 2009) and the other option which was preferable due to its proximity to the study area was chosen.

Table 2. Irrigation requirement of oil palm plantation with peatland soil properties

Study Plot	Area (km^2)	ETo. (mm)	Permissible Withdrawal (mm)	Freq of Irrigation (day)	Monthly Irrigation Depth (mm)	Field Irrigation Required ($10^6\ m^3$)	Field Irrigation Required (m^3/s)
2000	19.31	753.03	27.18	5	165	1.45	2.79
2002	12.34	753.03	11.7	4	164	0.68	1.96
2006	0.893	769.41	19.87	5	163.8	0.607	1.4
2010	0.893	802.17	42.87	7	165	0.893	1.48
TOTAL							**7.63 m^3/s**

Conclusion

Irrigation and crop water requirement (CWR) estimation in a tropical peatland in oil palm plantation has been estimated for the 2014 water year. The need to ensure the adequate and constant soil moisture availability in the peatland for oil palm use in the absence of groundwater recharge is the basis behind this study. The study was able to estimate when and how much water is recharging the peatland water table. The study also examined the need for rainfall supplement in case of inadequacy of soil moisture in the root zones and thus estimate the irrigation need of the crops. Each study plot was examined separately and the periods when SMD > RAW was noted as the periods where the irrigation is required in the fields. In all the study plots, the thresholds of 50-75 cm water table depth below the peat surface as best management practice (BMP) for tropical peatland area was obtainable. The total amount of recharge estimated is site specific. In all the study plots, recharge occurred when the SMD ≤ 0. This occurred when the field capacity was reached and there was free draining of soil water into the deep sub-surface causing a rise in water table depth. The use of nearby river Semenyih catchment (35.38 km^2) and HEC-HMS software proved suitable for the study catchment. Establishing relationship between the two helped in adopting the HEC-HMS software in the study area along with the soil moisture balance model. This therefore, enabled the appropriate runoff coefficients to be used in soil-moisture balance model for reliable estimates of groundwater recharge and runoff for the study areas. And in conclusion, for proper water management practice, early detection of oil palm evapotranspiration demand will help in observing irrigation need and in controlling irrigation scheduling, effective irrigation planning and savings of water resources. HEC-HMS and SMB models have been used successfully for on-point and immediate oil palm water deficit estimation. However, the application of soil moisture balance model for future oil palm water deficit estimation to forestall oil palm water stress and for adequate oil palm plantation water resources planning would be recommended for future studies. On-site oil palm plantation management would also help in reducing costs associated with plantation irrigation. From the study, it would be observed that in the months of February, March, June, July, August and September, all in 2014, peatlands in the study area and indirectly, the oil palms experienced water deficit. This means, during these months in the subsequent water years, adequate water availability to all the oil palms in the plantation must be a priority to prevent oil palm water stress.

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Author contributions

Adesiji, Adeolu Richard, Asogwa, Evarestus Osita and Adaudu, Ignatius Idoko carried out the literature review and performed the main writing part. Nik Norsyahariati Nik Daud supported the study by providing the concept and structure of the manuscript, proof-read the whole manuscript and supervised the study as well as giving her advice on the manuscript. Musa, Hassan Hassan And Mangey, Jarumi Akila also edited the final manuscript and were involved in the statistical aspect of the study.

Conflict of interests

The authors declare that there is no conflict of interests to disclose that might be perceived as affecting the objectivity of this study.

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