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Analysis of water balance to determine cropping patterns of food crop in sub-watershed Tenggarong, Kutai Kartanegara regency

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Abstract

Sujalu, A. P., Hidayanto, M., Fiana, Y., & Pulihasih, A. Y. (2019). Analysis of water balance to determine cropping patterns of food crop in sub-watershed Tenggarong, Kutai Kartanegara regency. *Bulgarian Journal of Agricultural Science*, *25*(1), 214–220

Growing periods can be determined using water balance analysis to decrease harvest risk in certain area. Generally, there are two types of land use for crop, i.e. irrigated land and non-irrigated land. This research was aimed to determine water input, water use and water loss, consumptive use crop water balance and designing a cropping pattern on rainfed paddy field at Watershed Tenggarong.

Determination of field capacity and permanent wilting point using soil texture data was input through Bouyoucos hydrometer methods. The calculation of land water balance according to Thornthwaite and Mather (1957) was employed to determine the agro-climate condition, particularly the dynamics of soil moisture content to plan a general cropping patterns was used based on monthly data. The planting time period is the water holding capacity > 50% from available water. Water balance monthly indicated that this area has potential growing season about 9 months, water surplus 8 months (439.6 mm year^{-1}) and water deficits about 3 months (59.7 mm year^{-1}). In these area, paddy could be planted twice a year without irrigation. Whereas when there are climate anomalies, paddy fields can be cultivated on certain land (swamps or suburbs of lake/river).

Keywords: water balance; growing season; cropping patterns; watershed; rainfall

Introduction

Rainfall has a great impact on a system of farming, especially on dry land and rainwater. Rainfall determines the pattern and intensity of cultivation that is characterized by growing season in the area. Rainfall patterns changes in Indonesia have occurred since the last few decades. This change causes shifting season in some areas, therefore, the main constraint of agriculture in sub-watershed of Watershed Tenggarong areas is the water distribution. This is due to the existing irrigation facilities, which are inadequate, both in terms of technology and limited irrigation canals.

Although there are a lot of rains, plants can not directly utilize it from the river or the rain, but it should first be transformed so that it can be used by plants. By considering that the availability of water is very essential for agricultural planning, therefore the success of farming will also be determined by how much we can expect the availability of water for plants. Various attempts were made to reduce the risk of crop failure, one of them is to compile information about potential the time of planting, especially for crops. Method of Thornthwaite and Mather (1957) is one approach that is commonly used to determine the level of water availability to determine the potential growing season and planting crops.

The analysis of rainfall employing water balance technique is of immense help determining the growing season based on water surplus, water deficit and soil moisture recharge and utilization. Planting time play an important role in agricultural cultivation system especially on non-irrigated land and it can be determined based on the time of water surplus and soil moisture from decade or monthly water balance (Bhatt, 2017). On dry land, the selection of the proper planting time can minimize the risk of the plants experienced a water stress on the critical phase, quantify the volume of water that must be added to achieve the desired water needs index, as well as maximize cropping intensity. Influence of agricultural droughts on crop yields is studied by employing water balance techniques. However, agriculture of this area dissipate limited irrigation facilities, coarse, shallow and poor quality soil and precarious and erratic rainfall have given way to a verity of crop patterns to adjust with prevailing best possible alternative cropping system (Mardawilis et al., 2011; Bhagat, 2014; Rao and Bhaskara, 2015).

For this purpose, quantitative knowledge of water supply, loss and consumption is needed by performing water balance analysis. It is one of the greatest advances in understanding the response of plants in water-limited environment. Also, it is important to evaluate the difference of hydrologic parameters under different climate condition to find proper water balance such as in watersheds area (Ghandhari and Moghaddam, 2011; Bhatt, 2017). Preparation of the water balance is the basis of the development potential of climate, soil, and plants that are very useful for planning the development of agricultural production. It is intended to provide important information on the net amount of water that can be obtained, the value of the surplus water which can't be accommodated, and when the water balance occur. Therefore, these data can be used as a basis for planning and management of various activities, such as making a water dam (for water storage and distribution), and the possibility of natural water utilization for a variety of other activities (Mardawilis et al., 2011; Rao and Bhaskara, 2015).

Materials and Methods

Time and place of research

The study was conducted at sub-watershed Tenggarong located in the west of the city of Tenggarong-Kutai, Kartanegara district, that include 6 main rivers, i.e. river Bensamar (watershed Tenggarong Hulu), river Tenggarong (watershed Tenggarong), river Saka Kanan (watershed Saka Kanan), river Sempak (watershed Terban), river Saka Kiri (watershed Saka Kiri) dan river Maluhu (watershed Maluhu) and cover an area of approximately ± 314.73 km². The area
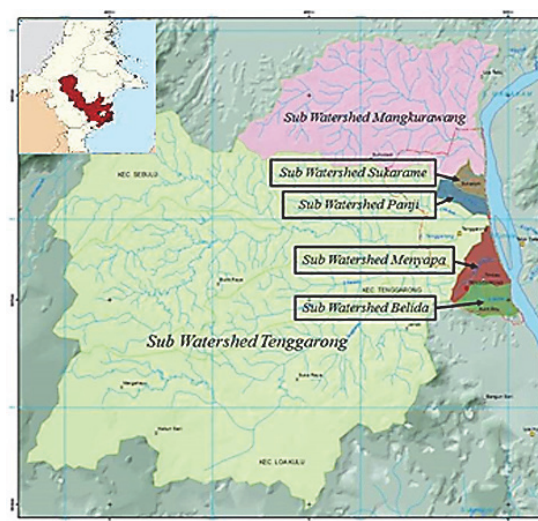
Fig. 1. Map of the watersheds in Kutai Kartanegara
Source: The Regional Development Planning Board, 2015

located at coordinates between 116°49' EL-116°57' EL and 0°24' SL-0°28' SL. The type of soil in the watershed Tenggarong was dominated by red-yellow podzolic. Climate categorized as a Type B in climate classification of Schmidt and Ferguson (Sayid et al., 2011).

Data collection

Data collected from both primary and secondary data related to the research, include:
– climate data, particularly rainfall and evaporation, over the period of year 2001 to 2014;
– physiographic data, particularly land slope;
– soil conditions, those related to soil water status.

Water balance analysis

The analysis of water balance was carried out with integral equations by simplifying some similarities, according to the method of Thornthwaite and Mather (Karim, 2012; Rao and Bhaskara, 2015). So that, the water balance of a land area can be expressed in the form of the equation:

R = ETA ± ΔWCS ± Li

where:

R = rainfall (mm months^{-1})

ETA = actual evapotranspiration (mm months^{-1})

ΔWCS = soil water content changes (mm months^{-1})

Li = runoff (surplus or deficit depending on its value) (mm months^{-1})

The analysis of evapotranspiration potential was carried out according to the equation of Buckman and Braddy (1969) quoted by Sujalu (2011) as follow:

$$PETi = 616 \times \left(10 \times \frac{Ti}{I}\right)^{a1}$$

$$I = \sum_{jan}^{des}\left(\frac{Ti}{5}\right)^{1.514}$$

$$a = 6.75 \times 10^{-7}I^3 - 7.71 \times 10^{-5}I^2 + 1.792 \times 10^{-2}I + 0.492$$

where:

PET = Potential evapotranspiration
Ti = Temperature of the month to the first monthly
I = Index of monthly heat
a = Constant

Changes in water content of soil (WCS) is the difference in soil moisture content on a period to prior periods between sequential. For each change in soil water content, it can be calculated with the formula R-ETP and if it is with negative value, there will be a deficit (lack) of water for (ETp = ETa). Conversely, if (R-ETP) is positive, then there will be a surplus/excess of water (R-ETp-DWCS), so that soil water availability decreases water exponentially and expressed by the equation (Hidayat et al., 2006; Sujalu, 2011; Karim, 2012; Rao and Bhaskara, 2015):

ASW = WHC x k^a,
WHC = FC – PWP,
WCS = PWP + ASW
K = (Po + P$_1$)/WHC

where:

WCS = Actual Soil Water Content (mm)
ASW = Availability of Soil Water (mm)
WHC = water holding capacity or availability of Maximum Soil Water (mm)
FC = Field Capacity (mm)
PWP = Permanent Wilt Point (mm)
a = Accumulate Potential Water Loss (APWL)
Po = 1.000412351 (constant)
P$_1$ = -1.07380730 (constant)

Cropping periods

Status and patterns of water availability is a major factor in determining the pattern of planting annuals that are largely determined by the availability of water for the plant. Time of planting or growing season (GS) especially in rainwater land depends on whether or not there is rainfall and its distribution during a certain period. Generally drilling program at the planting season and cropping pattern assignment in each region are determined based on the pattern of rainfall monthly average or based on potential and supply patterns from nearest water source. It is the pattern of crops for a given piece of land or cropping pattern means the proportion of area under various crops at a point of time in a unit area or it indicated the yearly sequence and spatial arrangements of crops. According to relative average of various crops or of crops and fallow in a district or a group of districts in an area. Factors such as type of soil, climatic conditions, irrigations, irrigation facilities, etc., determine the cropping pattern in an area (Ghosh, 2011; Bhatt, 2017). Cropping pattern also was determined by spread of crops expressed as a percentage of total area of important crops. It includes the identification of most efficient crops of the region which is considered as a homogeneous of soils and climatic belt (Coughlan and Huda, 2008).

Growing season, also called Frost-free Season, is the period of the year during which growing conditions for indigenous vegetation and cultivated crops are most favorable. It is the period of the year categorize as the rainy or wet season, the length of which varies spatially, temporally, and with crop type. Length of growing season is measured in enumerates the days of the year when average temperature is above the threshold at which crops will germinate and continue to grow (along with native vegetation). The length of growing season in rain fed fields directly related to the amount and distribution of rain and soil properties in water holding (Coughlan and Huda, 2008; Odekunle, 2014). The amount of water required of the plants (water consumptive) or water absorbed by plant roots is almost equal to the amount of water lost by evapotranspiration of plants. Determining the length of cropping period (the length of growing season) can be done based on the ratio P/PE (ratio precipitation and potential evapotranspiration), defined as the time interval in a year that have a ratio P/PE > 0.5 plus the time it takes to evapotranspiration as much as 100 mm of ground water is considered available in the soil (FAO, 1978; Hidayat et al., 2006; Sujalu, 2011).

Results and Discussion

Watershed Tenggarong is one of the agricultural development areas in Kutai Kartanegara regency. Land use planning in this region produced ten groups of land consisted seven groups of land had to be remained as before, namely forest, dry land farming, mix farming/agroforestry, scrub, coal mining, wet land (paddy field) and settlements, and other three groups of land for allocation of development agriculture, animal husbandry, and addition of forest area (Sayid et al., 2011).

Table 1. The land use types at the area studied

No.	Land use types	Area	
		(ha)	(%)
01.	Farm (dry land farming)	403.13	0.65
02.	Forest	292.15	0.46
03.	Shrub	2,996.25	22.23
04.	Mixed Garden	6,473.44	15.21
05.	Bush	8,501.36	40.07
06.	Wetland	1,248.99	2.06
07.	Garden	2,106.64	3.52
08.	Settlements	4,267.78	7.21
09.	Settlement expansion	415.61	0.69
10.	Slough/swamp area	1,815.63	2.91
11.	Coal mining	834.26	1.38
	Amount	31,520.98	100.00

Source: (Sayid et al., 2012)

Rainfall

Based on rainfall data from 12 climate observation stations in the watershed Tenggarong for the year period from 2001 to 2016, the results showed that monthly rainfall average ranged from 97-220 mm month^{-1} or an average of 168 mm month^{-1}, whereas the average rainfall ranged from 1,500-2,850 mm year^{-1} or average of 2,018 mm year^{-1}. Rainfall occurred on rainy days (rd) monthly rates ranging from 10 to 15 rd with an average rainfall 13 rd month^{-1}.

Analysis of rainfall characterization includes four main components (ICSAR, 1995), namely:

1. Annual rainfall spread of this area falls within Class Region III (rainfall between 1,500-2,000 mm year^{-1}).

2. Type rainfall has a period of dry months (months with rainfall of < 100 mm month^{-1}). Thus, obtained value of Q = ± 9.8%, or rain type A (which may imply that the watershed Tenggarong is very wet areas with dense vegetation of tropical rain forest).

3. Rainfall patterns or Bimodal Dual (Double Wave) with the notation Pattern C, periods of high rainfall occurred in December and April, while periods of low rainfall occurred in September and November.

4. Agro-climate zones, the basin has not dry months (DM). In watershed Tenggarong there are 8 humid months (HM) and 3 wet months (WM), including agro-climate zones E1.

Water balance

Watershed Tenggarong in general has not been irrigated that is highly dependent on rain water. The results of water balance analysis (Table 1) was used as a reference in determining the initial forecasts of alternative commodities and time of planting on land that does not have irrigation. The calculation results of soil water status were obtained from analysis of soil physical properties of soil in the laboratory. Assessment in Institute for Agricultural Technology (BPTP), East Kalimantan Province (Heriansyah, 2004) showed that soil available water content (WCS) is in the range 245-301 mm or average 271 mm.

Analysis of water balance in implementation is tailored to the needs and availability of climatological data. In this study because of data limitations (only data of rainfall and air temperature), the calculation of water balance using the method of Thornthwaite and Mather (1957) which has been modified (ICSAR, 1995) and in determining the value of potential evapotranspiration (PE) is done with a system of the book (Bookkeeping). Water balance calculation contains six major components, namely precipitation, potential evapotranspiration, actual evapotranspiration, soil water availability as well as surplus and deficit (Hidayat, 2006; Mardawilis, 2011; Rao et al., 2015). Water balance implies about the details of the input and outputs of water in one place at a certain time period, compiled in the form of quantitative equations, which provide information in the form of quantitative values of each component of input and output water (Karim, 2012) (Fig. 2).

Monthly water balance analysis of the results mentioned above shows that these areas have a surplus during the eight
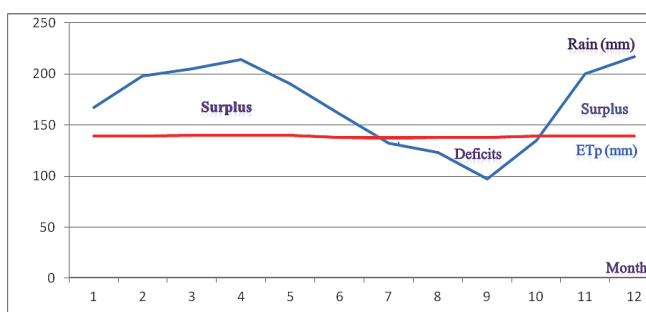
Fig. 2. Water balance

Table 2. Climate data at watershed Tenggarong (average monthly)

Climate elements	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Rainfall (mm month^{-1})	167	198	205	214	190	161	132	123	97	135	200	217
Temperature (°C)	26.8	26.7	27.0	27.2	27.0	26.6	26.2	26.5	26.6	26.9	26.9	26.9
Humidity (%)	87.7	86.8	89.7	90.7	89.1	87.0	86.1	86.7	83.9	86.4	87.6	86.8

months that occurred in a period of months from January to June, and November – December. The monthly water surplus in detail is in January amounted to 27.0 mm, in February – 57.3 mm, in March – 78.3 mm (the highest monthly surplus), in April – 72.8 mm, in May – 48.4 mm, in June – 19.6 mm (the lowest monthly surplus), the month of November amounted to 58.7 months and in December amounted to 75.3 mm in overall water surplus reached 478.8 mm/year[-1]. The excess water is absorbed from the soil in the form of deposits of soil into a run-off. Surface flow (run-off) is that part of precipitation that flows over the ground surface towards the river. The excess rain water (surplus) after the land's capacities to store water are met will flow as run-off. Most water run-off occurs when rain and the others released the land gradually in the form of spring. As has been previously communicated its position Tenggarong river divides the city of Tenggarong, and considering the amount of potential run-off that occurred in the region and also by considering the conditions Tenggarong area topography, the Watershed Tenggarong is very possible to build dams or reservoirs, which have various functions. Although the main function is to accommodate the construction of the dam monthly surplus water run-off resulting in the potential is big enough in this area, as well as water reserves in the period in the months of water deficit that can be utilized by a variety of purposes including drinking water.

In addition to having monthly water surpluses, the region normally monthly cumulative water deficit in a period of 3 months from August to October as a whole as much as 44.5 mm year^{-1}, with details of the deficit in June amounted to 0.4 mm month[-1], in July – 0.3 mm month[-1], in August – to 3.9 mm month[-1], in September – to 13.6 mm month[-1] and in October – 26.7 mm month[-1]. Changes of store of water (APWL) is the difference between the value of the previous month with water deposits of the month compared to the number of entries in ground water is very small. Changes of store of water is utilized for evapotranspiration (ETA) and the absence of rain water supply led to the deficit (Fig. 3). The influence of this water deficit depends on the ability of soil binding of water (water holding capacity) which is different for each type of soil that is affected by clay content (textures), organic material and topography. The results of the analysis indicate a drastic change occurred in July until October because in June the majority of research is entering a transitional season. That period is the dry season which is characterized by the presence of water deficit in the area of research, and the dry season occurs evenly throughout the region in June, and the impact of the drought that is strengthened to reach a peak in August to September. The lack of precipitation during the July to August followed by a relatively high air temperature leading to a water deficit in active root zone causing disturbance of soil water balance.
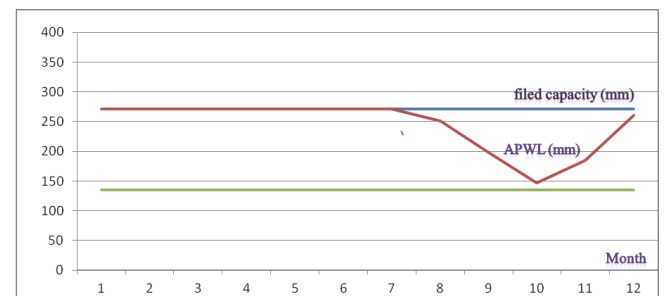

Fig. 3. Water balance (soil water status)

Analysis of cropping periods (growing season)

Growing seasons define the period of time when temperature and moisture conditions are suitable for crop growth. Understanding when these periods of growth occur helps researchers, policymakers, and farmers to better manage their land and water resources and to better understand how variability in climate affects the ability of farmers to plant, grow, and harvest specific crops. The concept of growing seasons takes into account the seasonality and length of potential growing periods during the year. The growing periods are determined based on the start of the rainy season, potential evapotranspiration, and temperature. Climate and weather influence crop production in different ways. If a weather event that is fatal to crops takes place during the crop growth period, an indicator of the impact of the fatal event may be more relevant than that of growing-season mean climate to explain variations in crop production in that year (Coughlan and Huda, 2008; Odekunle, 2014).

Table 3. Ratio of rainfall (R) and potential evapotranspiration (PE) monthly

Climate elements	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Rainfall (mm/month)	167	198	205	214	190	161	132	123	97	135	200	217
Evapotr.Pot. / ETP (mm)	139.0	138.7	139.6	140.2	139.6	138.4	137.2	138.1	138.4	139.3	139.3	138.7
Ratio P/PE	1.4	0.9	1.7	2.4	1.3	0.8	1.3	0.9	0.8	0.9	1.4	1.5

Table 4. Pattern of cropping

Subject	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Ratio P/PE	1.4	0.9	1.7	2.4	1.3	0.8	1.3	0.9	0.8	0.9	1.4	1.5
Pattern of cropping[1]	Paddy II		Second crop				Paddy I				Paddy II	
Pattern of cropping[2]	Paddy I		Second crop				Fallowed				Paddy I	
Pattern of cropping[3]	Paddy field		Fallowed								Paddy field	

Note: [1]Pattern of cropping at wet season; [2]Pattern of cropping at dry season; [3]Pattern of cropping at climate anomalies (influence of El Nino)

Based on this, analysis of the P/PE ratio, with the above in mind, shows that the P/PE in the rainfall average monthly cumulative throughout 12 months is always > 0.5. Therefore, the watershed Tenggarong areas have planting period (the length of growing season) for 12 months or all year round. Results of analysis of P/PE ratio can be seen in Table 3. However, agriculture of this area dissipate limited irrigation facilities, coarse, shallow and poor quality soil and precarious and erratic rainfall has given way to a verity of crop patterns to adjust with prevailing best possible alternative cropping system. Agriculture land use refers the proportion of area used to grow different crops during the agriculture enter year.

Cropping patterns

Table 1 shows that this type of land use has the potential for considerable length of time of planting is about 270-330 days as paddy fields will be planted with paddy twice a year. The results of water balance analysis showed that both the use of land for irrigated land and non-irrigated land at Watershed Tenggarong (generally) in East Kalimantan Province still has the potential to grow paddy at least once a year. In Watershed Tenggarong, the area of irrigated paddy can be planted with paddy twice a year. So for the region paddy can be planted twice a year if just relying on rainfall. Thus as long as farmers can grow paddy twice a year because of the additional water from rain. This region does not have irrigation but can still grow paddy twice a year (Table 4), due to adequate rainfall with planting time might be started from October 1 until December 1, with sequence of paddy-paddy or paddy-paddy-other food crop. During the dry season paddy still has the potential to grow at least once per year. Further for non-irrigation land with monthly high rainfall, the result showed that the area had potency of growing periods of 182 days through the year.

The cropping pattern of the area is essentially characterized by dry land. In dry land, diversion cropping pattern exist and no single crop claims a large share of the gross cropped area. Dry cultivation which characterizes this area is also basically rice fields and second crops cultivation. Even in dry land wherever water is available, it is the paddy crop that is sown by the farmers. Paddy varieties IR 64 and Ciherang are widely used in the area, while the Mayas (traditional rice) is always on the field. In general, the planting of rice monoculture dominated on the planting season-1 and only a fraction is planting rice with second crop. Plants on planting season-2 are more varied, because in general farmers are already understand the difficulties of irrigation for rice. Although for a small portion of the region there is effort to grow rice on planting season-3. Rice production in the area of Watershed Tenggarong varied from 3-4 tons (paddy fields) and 6-8 ton/ha (paddy rice fields).

Based on conditions the elements of the climate and the results of analysis of water balance, Watershed Tenggarong has the potential to grow paddy at least once a year. In rainy season (wet season) there can be 2 periods of cultivation of paddy and second crop by 1 period for a year. Whereas during the dry season there can be 1 period of cultivation of paddy and second crop by 1 period for a year, with one period (July-September) of fallowed land. The cropping pattern 3 performed on abnormal climatic conditions (influence of El Nino) is generally done in the area of the marshes or the edge of the lake with paddy fields in spite of the high level of risk to crops. The abnormal weather caused by this event had seriously disturbed the fundamental modes of crop cultivation and damaged the production of food and other commodities in the affected areas (Nugroho and Nuraini, 2016).

Conclusion

Based on the description as a whole, it can be concluded that watershed Tenggarong is well provided with rainfall, but there are some periods with drought occurrence. The region has 3-months rainfall deficits and 8-months rainfall surplus, at irrigated or non-irrigated land area all year round (12 months) there is potential planting period (growing season). Irrigation system of investment is essential in order to obtain stable and high crop yields.

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