Original Research Article

AVAILABILITY OF GROUNDWATER FOR RICE CULTIVATION UNDER OLDEMAN CLIMATE CLASSIFICATION IN TUBAN REGENCY, EAST JAVA PERIOD 2018-2022.

ABSTRACT

Tuban Regency, East Java is one of the agricultural sectors where the paddy rice system still relies on climate and weather. An important component for the agricultural sector is the availability of groundwater. The availability of groundwater can be known by using water balance analysis, with the calculation of crop water balance the community can know the deficit, surplus, and percentage of groundwater availability that can be used to determine the rice planting schedule, so that rice productivity can increase. The process to determine the availability of groundwater begins with the collection of data, namely rainfall, air temperature, coordinates and altitude of rain posts, and soil physical data throughout the Tuban Regency rain posts which are then calculated ETC (Plant Evapotranspiration) of rice, deficit, surplus, and ATS using the Thornthwait and Mather method. The results of data analysis obtained the smallest deficit value of 0.1 mm that occurred in Medalem in June and the largest deficit occurred in Ngimbang in November amounting to 279.6 mm. As for the smallest surplus of 0.9 mm that occurred in Sumurgung in April and the largest surplus of 313 mm that occurred in Jenu in January, with 100% groundwater availability that generally occurs during November-April and 0% ATS that occurs in June-September and Oldeman Climate types in Tuban Regency are C3, D3, D4, and E3, respectively.

***Keywords**: Rainfall, groundwater availability, water balance, Thorntwait and Mather methods, deficit and surplus.*

1. INTRODUCTION

The majority of the population in Indonesia works in the agricultural sector, which is the largest support sector for the country's economy. A crucial component of the agricultural sector is groundwater availability (Melviana). The condition of groundwater availability can be determined using water balance analysis, which is a balance between water inputs and outputs in a specific location over a certain period, allowing us to determine whether there is a surplus or deficit of water. Thorntwite and Mather (1957) developed a simple equation to calculate the water balance using input variables such as rainfall (CH), potential evapotranspiration (ETP), actual evapotranspiration (ETA), groundwater content (KAT), surplus, and deficit [1].

Java Island represents the largest distribution for the agricultural sector in Indonesia, including Tuban Regency in East Java. Tuban Regency is an agricultural center that heavily relies on rainfall, also known as rainfed agriculture. According to the Central Statistics Agency (BPS) of Tuban Regency, East Java, rice production in the period 2018-2019 in 20 sub-districts showed that 11 sub-districts experienced an increase in production, while 9 sub-districts experienced a decrease in production. For example, the sub-district of Jatirogo had a 1.5% increase in production, while the sub-district of Rengel experienced a significant decrease of 26.7% in rice production. Based on these statements, it is necessary to conduct a water balance analysis to assess groundwater availability in order to support the agricultural sector and anticipate the risks of crop failure or delays in rice cultivation.

1.1 Grounwater availability

Groundwater availability is an estimation of the groundwater condition in a specific area [2]. Groundwater availability (ATS) or the percentage of groundwater availability is divided into five categories as shown in Table 1.

Table 1. Percentage of groundwater availability

Groundwater availability (ATS)	Percentage (%)
Very Low	< 10
Low	10 ≤ ATS < 40
Moderate	40 ≤ ATS < 60
Sufficient	60 ≤ ATS < 90
Abudant	90 ≤ ATS < 100

1.2 Water Balance

Water balance is an explanation of the relationship between the equilibrium of inflow and outflow of water in a specific area of land over a certain period, considering the processes of water circulation, and its values change over time. The indirect estimation of water balance involves precipitation and evaporation as the main factors in the inflow and outflow of water to and from the soil [3]. Water balance is divided into three models:

1.2.1 General Water Balance This model utilizes climatological data and is useful for determining the occurrence of wet months or the amount of rainfall exceeding the water loss due to evaporation from the soil surface, as well as evaporation from the plant system (transpiration), and their combination (evapotranspiration) [4].

1.2.2 Land Water Balance This model combines climatological data with soil data, especially data on the field capacity (FC), the wilting point (WP), and available water [4].

1.2.3 Crop Water Balance Crop water balance is a model that combines climatological data, soil data, and crop data. This water balance is specifically designed for certain types of crops. The crop data used includes crop coefficient in the output component of the water balance [4].

1.3 Water Balance Components

The components of the water balance are as follows:

1.3.1 Precipitation

Precipitation refers to the process of liquid (in the form of rain or frozen) falling from the atmosphere to the Earth's surface. Precipitation can be in the form of rain, dew, snow, or hail. In tropical regions, including Indonesia, precipitation is commonly in the form of rainfall.

1.3.2 Temperature

Temperature variation in the Indonesian archipelago depends on the altitude or elevation. Temperature decreases with increasing altitude from sea level, with a decrease of approximately 0.6 ºC per 100-meter increase in elevation. In the absence of temperature observation data, estimation can be done by considering the elevation factor from the nearest weather station using the following formula [5].

$$Th = Th_0 - 0{,}6\left(\frac{h_1 - h_0}{100}\right) \tag{2.1}$$

Explanation:

Th : Temperature at a height of h m above sea level (°C)

Tho : Temperature at sea level (0 m) (°C)

h0 : Reference point elevation (m)

h1 : Elevation of the location (m)

1.3.1 Evapotranspiration

The process of water changing into vapor and moving from the soil surface to the air is called evaporation, while the process of water vaporization from plants is called transpiration. In practice, it is difficult to determine the separate water loss through these processes, so the measurement of total water loss through evaporation and transpiration is calculated as evapotranspiration.

1.3.2 Soil Moisture Content

Soil moisture content refers to the amount of water present in the soil, which serves as a supporting system for plants to regulate their water balance. In determining soil moisture content, there are several terms that need to be understood:

a. Field capacity

Field capacity (FC) is the condition of the soil when it is saturated with water and is considered the upper limit of water availability for plants. The upper limit represents the soil's maximum water absorption capacity. When the soil receives more water than its capacity, it becomes waterlogged. The field capacity of a particular soil type depends on its texture and structure [6].

b. Permanent wilting point

The permanent wilting point (PWP) is the lower limit of water availability in the soil for plants, beyond which plants can no longer absorb water for their growth. The lower limit represents the minimum water content in the soil, and when the water reaches this minimum content, plants cannot absorb water for their growth.

c. Available water

Available water refers to the water in the soil that falls within the range between field capacity and permanent wilting point [7].

1.4 Thornthwaite Mather Method

Thornthwaite and Mather developed a simple formula to calculate the availability of groundwater using the water balance approach. The first step in calculating the water balance is to determine the Potential Evapotranspiration (ETP). The calculation steps for ETP are as follows:

a. Calculate the monthly heat index (i):

$$i = \left(\frac{t}{5}\right)^{1{,}514} \tag{2.2}$$

Where t: air mean temperature (^{o}C)

1. Yang selanjutnya dilakukan penjumlahan i total selama setahun dengan rumus

$$I = \sum_{i=1}^{12} i\left(\frac{t}{5}\right)^{1{,}514} \tag{2.3}$$

2. Calculate $ETP_{standard}$ using formula:

3. $$ETP_{Standard} = 1,6\left(10\frac{t}{I}\right)^{a} \quad (2.4)$$

Where a equals to 0,000000675 I³ – 0,0000771 I² + 0,01792 I + 0,49239

4. Considering the location is at the equator (latitude 0), it is necessary to correct the standard ETP by using the daylight hours (for latitude 0, 1 day = 12.1 daylight hours) and the number of days per month = 30 days. Therefore:

$$ETP = \left(\frac{X}{30}\right)\left(\frac{Y}{12.1}\right)ETP_{Standard} \quad (2.5)$$

Where
X: Total days of the month
Y: days in hours

5. The conversion of evapotranspiration to millimeters (mm) can be calculated using the following formula:.
ETP (mm)=ETP (cm)×10 (2.6)

6. For the plant water balance, the evapotranspiration used is the crop evapotranspiration (ETC), which represents the amount of water evaporation that occurs in the plants according to their age and crop type during the growth period. Therefore [8]:
ETC = ETP × kc (2.7)
kc is the crop coefficient, which depends on the type of crop. In this study, rice is the crop being used, and the value of kc for rice is 1.13.

Next, calculations are performed for the plant water balance, which include APWL (Accumulated Potential Water Loss), KAT (Soil Water Content), ETA (Actual Evapotranspiration), and ATS (Available Groundwater). The calculation steps and data processing are as follows:

a. Accumulated potential water loss for evaporation:
Accumulated potential water loss is necessary to determine the potential water loss during dry months. When CH > ETC, APWL = 0 as there is no water deficit. Conversely, if CH < ETC, APWL can be calculated using the following formula:
APWL = Previous month's APWL + (CH - ETC)

b. Soil Water Content (KAT):
To calculate KAT for the current month, APWL can be determined using the following formula.
Please note that the above information is a translation of the provided text and may require further context or clarification for accurate interpretation.

$$KAT = TLP + \left(1,00041 - \left(\frac{1,07381}{AT}\right)\right)^{|APWL|} \times AT \quad (2.10)$$

Where:
TLP : Permanent wilting point (mm) (TLP Tuban Regency: 210 mm)
KL : Field capacity (mm) (KL Tuban Regency: 350 mm)
AT : Available water (mm), calculated as AT = KL - TLP
|APWL| : Absolute value of APWL

Then, for months where APWL does not occur, KAT is calculated using the following formula.
Please provide the specific formula for calculating KAT in order to assist you further.
KAT = KAT final + CH – ETP (2.11)

a. Changes in groundwater level (dKAT)
Changes in groundwater level can be determined using the following formula:
dKAT = dKAT of that month – dKAT the month before (2.12)

a. Positive values indicate changes in groundwater content that occur when CH > ETC (rainy season). If dKAT = 0, it means that KL is reached. Conversely, if CH < ETC or dKAT is negative, then the entire CH and dKAT will be evaporated.

b. Actual Evapotranspiration (ETA)

If CH > ETC, ETA = ETC because ETA reaches its maximum value. However, if CH < ETC, ETA = CH + |dKAT| because the entire CH and dKAT will be evaporated.

c. Deficit (D)

Deficit refers to the reduction in water available for evapotranspiration, so D = ETC - ETA, which occurs during the dry season.

d. Surplus (S)

Surplus refers to the excess water when CH > ETC, so S = CH - ETC - dKAT, which occurs during the rainy season.

e. Available Groundwater (ATS)

$$ATS = \frac{KAT - TLP}{KL - TLP} \times 100\%$$

Explanation:

KAT: Groundwater content (mm)

TLP: Permanent wilting point (mm)

KL: Field capacity (mm)

1.5 Oldeman Climate Classification

The classification criteria of the Oldeman climate type are based on the number of consecutive Wet Months (BB) and Dry Months (BK) within a year, taking into account rainfall probability, effective rainfall, and plant water requirements. The categories for Wet Months and Dry Months in the Oldeman climate type are as follows:

a. Wet Months (BB): Months with an average rainfall of > 200 mm.

b. Dry Months (BK): Months with an average rainfall of < 100 mm.

Based on these values, Oldeman established 5 (five) types of climate: A, B, C, D, and E, depending on the number of consecutive Wet Months and Dry Months that occur within a year. The classification of Oldeman climate types is shown in Table 2.

Table 2. Oldeman Climate Type Classification

Tipe Iklim Oldeman	Sub Tipe	Jumlah Bulan Basah (BB) Berturut-turut (bulan)	Jumlah Bulan Kering (BK) Berturut-turut (bulan)
A	A1	> 9	< 2
	A2	> 9	$2 \leq BK \leq 3$
B	B1	$7 \leq BB \leq 9$	> 2
	B2	$7 \leq BB \leq 9$	$2 \leq BK \leq 3$
C	C1	$5 \leq BB \leq 6$	< 2
	C2	$5 \leq BB \leq 6$	$2 \leq BK \leq 3$
	C3	$5 \leq BB \leq 6$	$4 \leq BK \leq 6$
	C4	$5 \leq BB \leq 6$	7
D	D1	$3 \leq BB \leq 4$	< 2
	D2	$5 \leq BB \leq 6$	$2 \leq BK \leq 3$

	D3	$5 \leq$ BB ≤ 6	$4 \leq$ BK ≤ 6
	D4	$5 \leq$ BB ≤ 6	$7 \leq$ BK ≤ 9
E	E1	< 3	< 2
	E2	< 3	$2 \leq$ BK ≤ 3
	E3	< 3	$4 \leq$ BK ≤ 6
	E4	< 3	> 6

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2. RESEARCH METHOD

This research was conducted at the BMKG Class III Meteorological Station in Tuban, East Java. The map of the research area is shown in the following image.

Figure 1 Rainfall Station Map of Tuban Regency.

2.1 Data Collection Method

The following data were collected for this research:

a. Rainfall data: The rainfall data used in this study were obtained from 28 rain gauge stations in the Tuban Regency, East Java, for the period of 2018-2022.

b. Temperature data: Monthly temperature data were collected from the Meteorology Station III in Tuban, East Java, which has observation data. For rain gauge stations without temperature observation data, estimates were made based on the nearest station, using temperature calculation formulas based on the altitude of the location according to [4].

c. Soil physical data: Field capacity (FC) and permanent wilting point (PWP) data for Tuban Regency, East Java, were obtained from secondary data in the book "Pemanfaatan Sumberdaya Air" [10].

d. Coordinate and elevation data: Coordinate and elevation data for the 28 BMKG rain gauge stations in Tuban Regency were obtained from the BMKG Meteorology Station Class III in Tuban, East Java.

2.2 Data Processing Method

The data were processed as follows:

a. Determination of Oldeman climate types: The determination of Oldeman climate types in Tuban Regency, East Java, was based on the average monthly rainfall data from the rain gauge stations and BMKG stations, considering the number of wet months (WM) and dry months (DM) in sequence. The classification of wet months and dry months is based on the Oldeman climate theory.

Wet Month (WM): Months with an average rainfall of more than 200 mm.

Dry Month (DM): Months with an average rainfall of less than 100 mm.

The number of wet months and dry months is classified based on the Oldeman climate types.

b. Calculation of deficit, surplus, and groundwater availability for rice cultivation: The calculation of deficit, surplus, and groundwater availability was performed using Microsoft Excel with the Thornthwaite & Mather method (1957). The ATS (Available Groundwater) results were divided into 5 classes representing the percentage of groundwater availability.

2.3 Analysis Method

The analysis of the processed data was conducted using descriptive analysis, which involved describing the data in terms of the calculated percentage of groundwater availability (ATS) and the values of surplus and deficit. This analysis helps determine the planting patterns and planting calendar for rice cultivation in Tuban Regency, East Java.

2.4 Thinking Framework

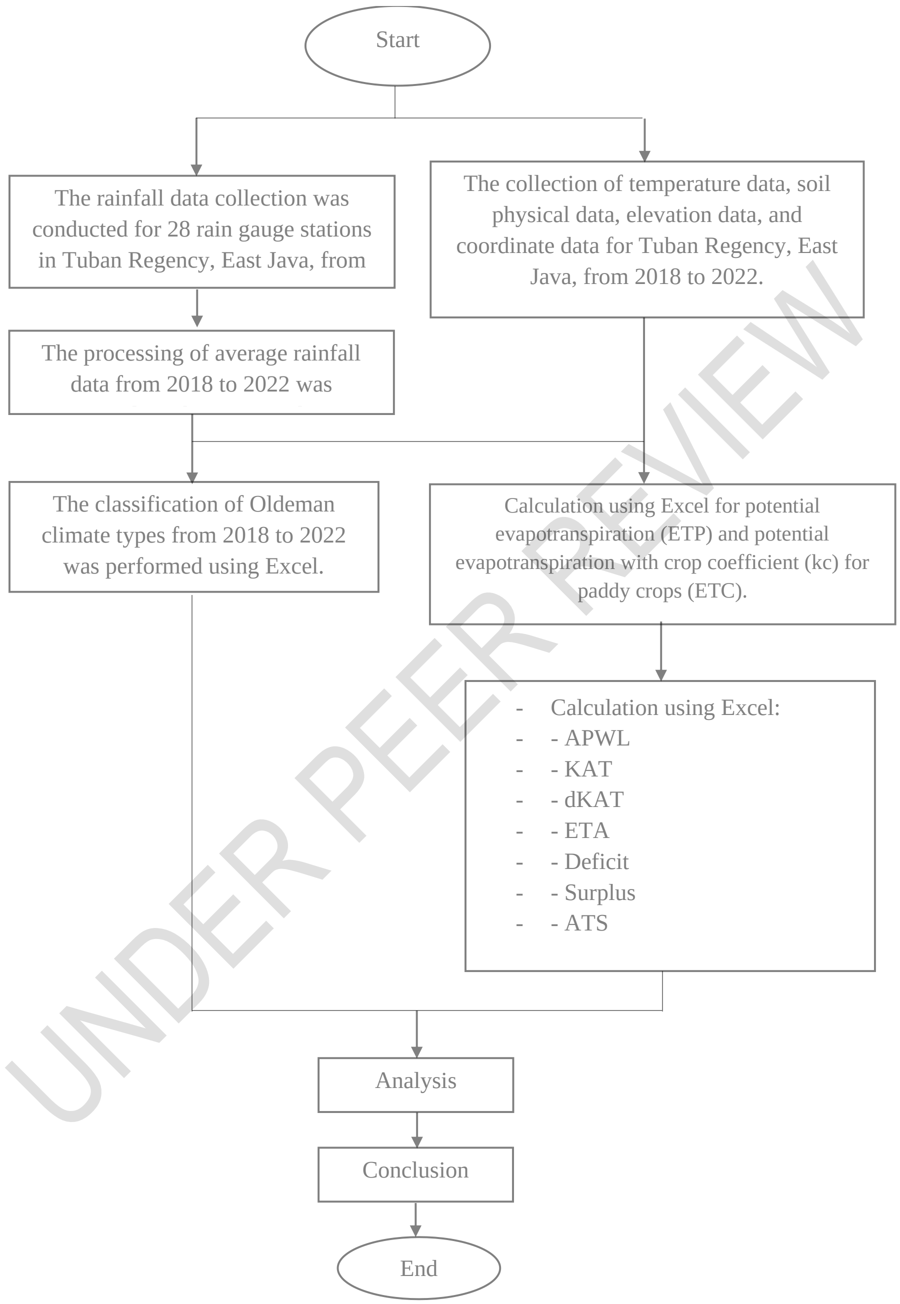

Fig 2.Research Flow Chart

3. RESULT AND DISCUSSION

3.1 Oldeman Climate Types in Tuban Regency, East Java

In this research, climate classification was conducted using the Oldeman and Frere (1982) method for rice crops in Tuban Regency, covering 28 regions. Rainfall data from 28 rainfall stations scattered throughout Tuban Regency from 2018 to 2022 were used. The Oldeman climate classification conducted in Tuban Regency resulted in the following successive climate types: C3, D3, D4, and E3. The C3 Oldeman climate type occurs in the Mundri, Laju Kidul, Sendang, Jojogan, Medalem, Ngabongan, Kerek, Tegalrejo, and Widang regions, indicating that these areas can only have one rice planting season per year based on the agroclimate zone. The D3 Oldeman climate type is found in the Bangilan, Kejuron, Montong, Sumurgung, Kebonharjo, Kepet, Bogorejo, Soko, Rengel, Maibit, Klotok, and Parengan regions, indicating that these areas can have one rice planting season depending on the availability of irrigation water. The D4 Oldeman climate type occurs in the Jenu region, indicating that in Jenu, only one rice planting season is possible per year depending on the availability of irrigation water, with a dry period of 7-9 months. The E3 Oldeman climate type occurs in the Belikanget, Simo, Tuban, Silowo, Palang, and Ngimbang regions, indicating that these areas are generally too dry for rice cultivation, but they can have one planting season for other crops (palawija) depending on rainfall availability.

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3.2 Groundwater Availability in Tuban Regency, East Java

Groundwater availability is divided into 5 categories as shown in Table 2: very scarce with a percentage < 10%, scarce with a percentage of 10% ≤ ATS < 40%, moderate groundwater availability with a percentage of 40% ≤ ATS < 60%, sufficient groundwater availability with a percentage of 60% ≤ ATS < 90%, and very sufficient groundwater availability with a percentage of 90% ≤ ATS < 100%. Groundwater availability is an important component for the agricultural sector as it regulates planting and harvesting schedules in a particular place or region, considering the suitability of farmers with rainfed land based on its groundwater content. The water balance analysis using the Thornthwait and Mather method utilizes air temperature as a heat index, and the calculated heat index is used to determine the Potential Evapotranspiration (ETP), where meteorological factors, including temperature, influence evapotranspiration. In this study, temperature estimation calculations for the 28 regions from 2018 to 2022 were performed using the formula [4], taking into account the altitude factor with reference to the Class III Meteorological Station in Tuban. The results of ETP (Potential Evapotranspiration) and Crop Evapotranspiration (ETC) calculations for rice show that higher air temperatures correspond to higher values of ETP and ETC for rice. Groundwater availability reaches its maximum value from November to April when the Water Content in the Soil (KAT) is equal to the Field Capacity (KL), which indicates the rainy season with abundant water supply and surplus. The obtained deficit and surplus values indicate that when Tuban Regency experiences a deficit, the surplus value is 0 mm, and vice versa, when there is a surplus, the deficit value is 0 mm. This indicates that the deficit and surplus values are influenced by rainfall. When the rainfall is low or during the dry months, a deficit occurs.

4. CONCLUSION

Based on the discussion, the conclusions that can be drawn are as follows:

a. ATS (Available Soil Moisture) in Tuban Regency, East Java, has a value of 100% which generally occurs during the months of November-April, and ATS 0% which indicates very low availability of soil moisture, typically happening during the months of June-September. The Oldeman Climate Types in Tuban Regency are C3, D3, D4, and E3 in sequential order.

b. The smallest deficit value is 0.1 mm, occurring in Medalem during the month of June, while the largest deficit occurs in Ngimbang in November, amounting to 279.6

mm. As for the smallest surplus, it is 0.9 mm, occurring in Sumurgung in April, and the largest surplus is 313 mm, occurring in Jenu in January.

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