Assessment of Groundwater Availability for Rice Farming in Tuban Regency, East Java in 2018-2022

Abstract

A study has been carried out on deficit, surplus, percentage of groundwater availability and Oldeman climate type classification in Tuban Regency, East Java in 2018-2022 with the aim of increasing the productivity of rice plants in the area. This process begins with data collection, including rainfall, air temperature, coordinates and height of rain posts, as well as physical soil data which is used to calculate rice ETC (EvapotranspirasiTanaman/Plant Evapotranspiration), deficit, surplus and ATS (Air Tanah Tersedia/Groundwater Available). The method used in this calculation is the Thornthwaite and Mather method. From data analysis, it was found that the smallest deficit of 0.1 mm occurred in Medalem in June, while the largest deficit occurred in Ngimbang in November amounting to 279.6 mm. The smallest surplus of 0.9 mm was recorded in Sumurgung in April, while the largest surplus of 313 mm occurred in Jenu in January. Groundwater availability reaching 100% generally occurs in November-April, while 0% ATS occurs in June-September. and the Oldeman climate patterns in Tuban Regency are C3, D3, D4, and E3 respectively.

Keywords: groundwater availability, Oldeman climate, Thornthwaite and Mather method, deficit, surplus.

1. Introduction

Many Indonesians work in the agricultural sector, that's why Indonesia is called an agricultural country. Agriculture is the main pillar in the Indonesian economy. Water management systems are a very important part of the agricultural sector. With a water management system, we can prevent water shortages on agricultural land. Can understand this water management system by analyzing groundwater availability [1]. The availability of groundwater on agricultural land can be understood through the water balance analysis process. To carry out water balance calculations, you can use simple equations such as the Thornthwaite method, which requires input data such as rainfall. In this approach, we use the soil water storage capacity of a particular area that has a particular type of plant to determine soil water levels, surpluses, and deficits. The data used in this technique includes rainfall or CH, potential evapotranspiration (ETP), actual evapotranspiration (ETA), soil water content (KAT), surplus, and deficit [2].

Agriculture in Tuban Regency, East Java, is an important part of the agricultural sector in Indonesia, which is dominated by the island of Java. Tuban Regency is an area that is very dependent on rainfall for agriculture, or what is known as rain-fed agriculture. This makes it a very important agricultural center. Based on data from the Central Statistics Agency (BPS) of Tuban Regency, East Java, rice production during 2018-2019 in 20 sub-districts shows that 11 sub-districts experienced an increase in production, while 9 sub-districts experienced a decrease in production. production. For example, production in Jatirogo District increased by 1.5%, while rice production in Rengel District experienced a significant decline of 26.7% [3].

In 1948, Thornhwaite proposed in "The Evapotranspiration in Climate Classification" by Cunha and Schoffel [4] to calculate the water balance using monthly average air temperature, rainfall, and soil water storage capacity. It is assumed that the soil acts as a reservoir, and all the water available in it undergoes evapotranspiration. To monitor fluctuations in water storage throughout the year, data on groundwater supplies such as rainfall, potential evapotranspiration, available water capacity, estimated actual evapotranspiration, deficit, surplus, and soil water content have been obtained. Thornthwaite and Mather further developed monthly water balance calculations in 1955. If there is no potential evapotranspiration (ETP) data for an area, then ETP estimates can be made using monthly average temperature data in that area.

2. Research method

This study took place at the BMKG Class III Meteorological Station in Tuban, East Java. The Figure 1 below displays the map of the research area.

Figure 1. Map of the distribution of rain posts in Tuban Regency [5]

Groundwater availability refers to the amount of water per unit of time that is projected to be accessible in a specific location over a specific period [6]. Table 1 divides groundwater availability (ATS) or the percentage of groundwater availability into five categories.

Table 1. Percentage of groundwater availability [6]

Groundwater availability (ATS)	Percentage (%)
Very Low	< 10

Low	$10 \leq ATS < 40$
Moderate	$40 \leq ATS < 60$
Sufficient	$60 \leq ATS < 90$
Abudant	$90 \leq ATS < 100$

The water balance of a land involves analyzing the inputs, outputs, and changes in water storage to calculate the amount of water present in the soil[7]. The water balance is categorized into three models:

a. General Water Balance. This model makes use of climatological data and is helpful in identifying when wet months occur or when the amount of rainfall surpasses the water lost from evaporation on the soil surface, as well as evaporation from the plant system (transpiration), and their combined effect (evapotranspiration) [8].
b. The Balance of Land Water. This model integrates climate data and soil data, specifically information on field capacity (KL), the wilting point (TLP), and available water [8].
c. The crop water balance is a model which integrates data on climate, soil, and crops to calculate the water needs of crops. This water balance is specially tailored for specific crop types. The crop data utilized contains the crop coefficient in the water balance output component [8].

The quantity of water that descends onto the earth's surface within a specific timeframe is referred to as rainfall. A rainfall amount of 1 mm indicates that 1 liter of rainwater is deposited on a 1 m^2 surface [7].

The temperature difference in the Indonesian archipelago is influenced by the height or elevation of the land. The temperature drops as altitude increases from sea level, decreasing by around 0.6 ºC for every 100 meters gained in elevation. If there is no temperature observation data available, you can estimate it by taking into account the elevation from the nearest weather station using the formula [1].

$$Th = Th_0 - 0.6\left[\frac{h_1 - h_0}{100}\right] \quad (1)$$

with:
Th = Temperature at a height of h m above sea level (°C)
Th_o = Temperature at sea level (0 m) (°C)
h_0 = Reference point elevation (m)
h_1 = Elevation of the location (m)

As forEvapotranspiration refers to the joint evaporation of both soil and plants [9].

Soil moisture content is the measure of water in the soil that provides a supportive environment for plants to manage their water levels. When it comes to evaluating soil moisture content, there are various terms that must be comprehended:

a. Field capacity

Field capacity refers to the soil's saturated state, indicating the highest amount of water it can retain[5].

b. Permanent wilting point
The permanent wilting point is the minimum amount of water in the soil that is available to plants, beyond which plant roots are unable to take in water for their growth [5].

c. Availability water
Water that is accessible in the soil is defined as the water that falls within the range of field capacity and permanent wilting point [5].

In 1948, Thornhwaite suggested in the article "The Evapotranspiration in Climate Classification" by Cunha and Schoffel [4] the idea of computing water balance by using monthly average air temperature, precipitation, and soil water storage capacity. It was assumed that the soil functions as a storage system, and that all the water present in the soil is subject to evapotranspiration. Throughout the year, the variation in water storage was monitored by considering factors such as groundwater supply from precipitation, potential evapotranspiration, available water capacity, estimates of actual evapotranspiration, deficit, surplus, and soil water content. In 1955, Thorthwaite and Mather expanded on the water balance calculation for every month. In the absence of ETP data for a particular area, ETP can be estimated by utilizing monthly average temperature data. This method [10] can be utilized to derive ETP using the following calculation:

$$ETP = \left[\frac{X}{30}\right]\left[\frac{Y}{12.1}\right] ETP_{standard} \qquad (2)$$

with:

X =total days of the month

Y = days in hours

The Oldeman climate types in Tuban Regency, East Java, were determined by analyzing the average monthly rainfall data from rain gauge and BMKG stations, taking into account the sequence of Wet Months (WM) and Dry Months (DM). The Wet Months and Dry Months categories in the Oldeman climate type are outlined as follows:

a. Wet Months (WM) refer to months that have an average rainfall > 200 mm.

b. Dry Months (DM) refer tomonths that have an average rainfall < 100 mm.

Oldeman classified climate into five types, A, B, C, D, and E, based on the frequency of Wet Months and Dry Months in a year, using the mentioned values [11]. Table 2 displays the categorization of Oldeman climate types.

Table 2. Classification of Oldeman's Climate Types [11]

Oldeman Climate Type	Sub Type	Number ofWM	Number of DM

A	A1	>9	<2
	A2	>9	2 ≤ DM ≤ 3
B	B1	7≤ WM ≤ 9	>2
	B2	7≤ WM ≤ 9	2 ≤ DM ≤3
C	C1	5≤ WM ≤ 6	<2
	C2	5≤ WM ≤ 6	2 ≤ DM ≤3
	C3	5≤ WM ≤ 6	4≤ DM ≤ 6
	C4	5≤ WM ≤ 6	7
D	D1	3≤ WM ≤ 4	<2
	D2	5≤ WM ≤ 6	2 ≤ DM ≤3
	D3	5≤ WM ≤ 6	4≤ DM ≤ 6
	D4	5≤ WM ≤ 6	7≤ DM ≤ 9
E	E1	<3	<2
	E2	<3	2 ≤ DM ≤3
	E3	<3	4≤ DM ≤ 6
	E4	<3	>6

The data listed below was gathered for this study:

a. Data on rainfall: The study collected rainfall data from 28 rain gauge stations in the Tuban Regency, East Java, for the years 2018-2022.
b. Monthly temperature data was obtained from the Meteorology Station III in Tuban, East Java, which has recorded observation data. Rain gauge stations without temperature observation data used estimates based on the nearest station, using temperature calculation formulas based on the altitude of the location.
c. The data on Field Capacity (FC) and Permanent Wilting Point (PWP) for Tuban Regency, East Java, were collected from secondary sources found in the book "PemanfaatanSumberdaya Air" [12].
d. Coordination and elevation information: The coordination and elevation information for the 28 BMKG rain gauge stations in Tuban Regency were acquired from the BMKG Meteorology Station Class III in Tuban, East Java.

Deficit, surplus, and groundwater availability levels were calculated using the Thorntwaite method in Microsoft Excel. The Available Groundwater (ATS) results were grouped into 5 categories based on the percentage of groundwater availability.

The results of data processing were analyzed using the descriptive analysis method. This involved describing the data in the form of Oldeman climate type classification results, calculating the percentage of groundwater availability (ATS), and determining surplus and deficit to establish the planting schedule in Tuban Regency, East Java.

The flow chart of this research can be seen in Figure 2,

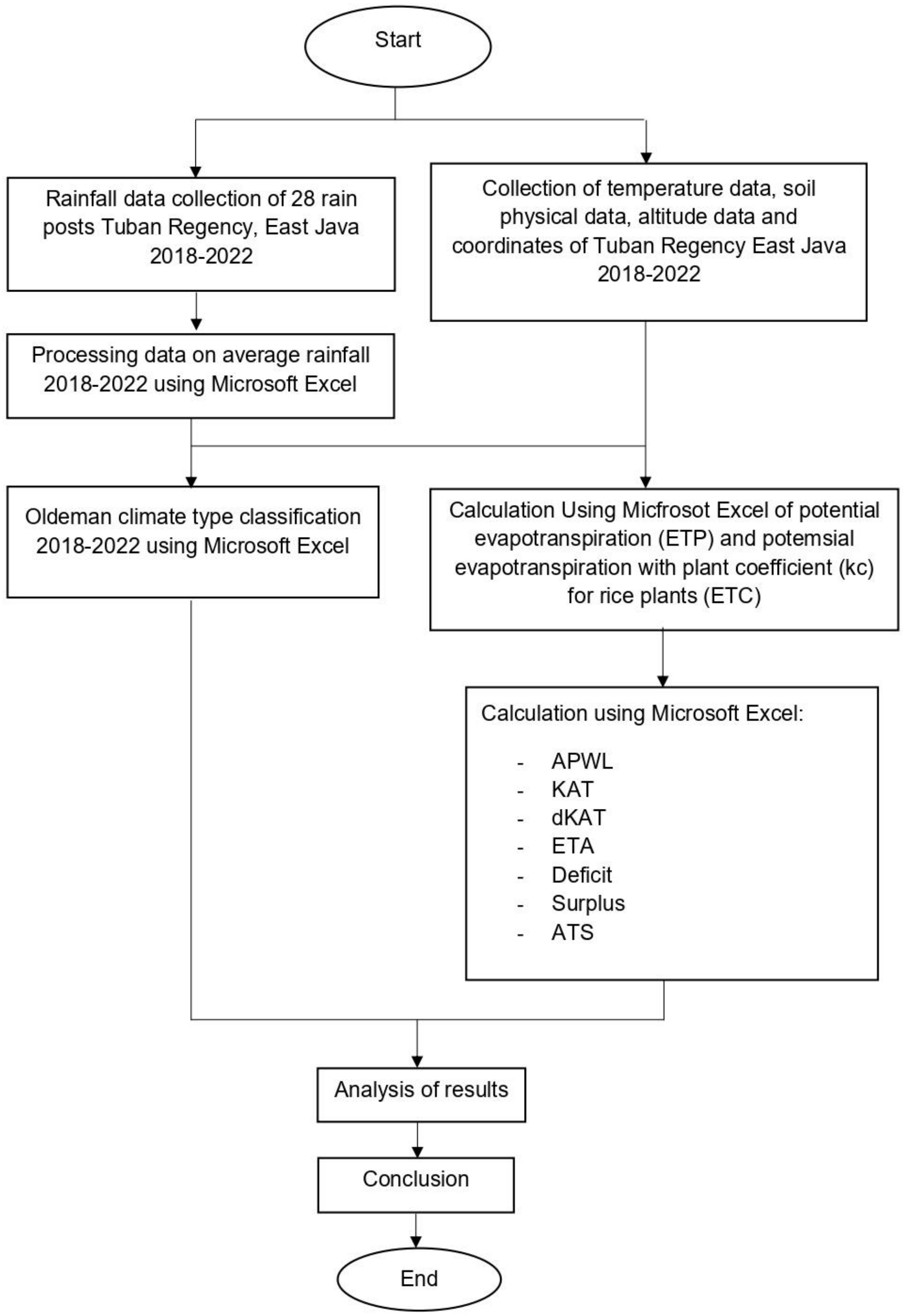

Figure 2. Research Flow Chart

3. Result and discussion

3.1 Rainfall analysis

According to the rainfall data collected from the Class III Tuban Meteorological Station, it is evident that Tuban Regency experiences a monsoonal rainfall pattern. The monsoonal rainfall pattern in Tuban Regency is characterized by distinct rainy and dry seasons. The west monsoon or Asian winds bring heavy rainfall from November to March, while the east monsoon or Australian winds result in dry conditions from June to September. The graph below shows the average rainfall at a rain gauge in Tuban Regency, as shown in Figure 3.

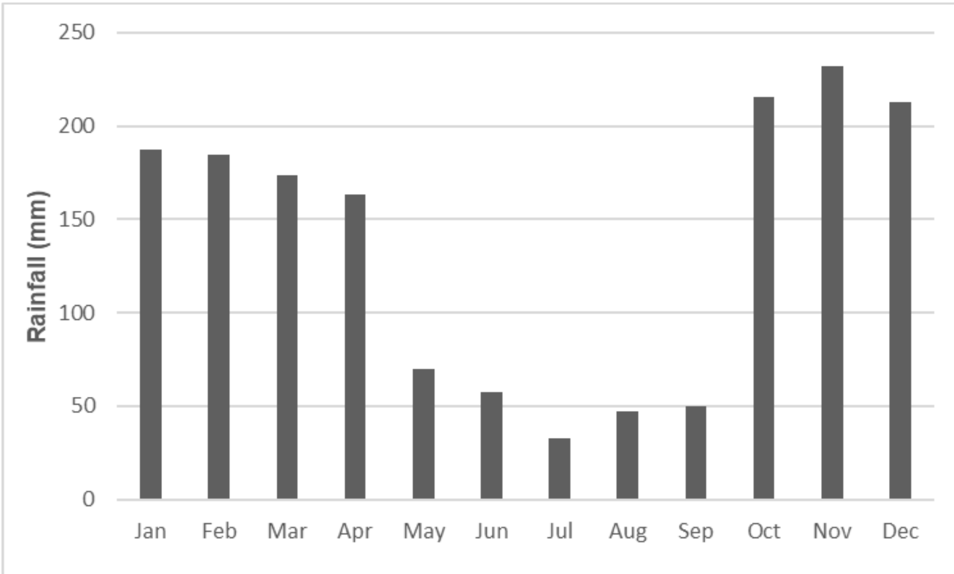

Figure 3. Mundri Rainfall 2018-2022

3.2 Oldeman Climate Type Analysis

The Tuban Regency has the Oldeman climate types C3, D3, D4, and E3, as shown in the following Table 3.

Table 3. Climate Type OldemanTuban Regency [11]

No.	Climate Type	Rain Station
1	C3	Mundri, Laju Kidul, Sendang, Jojogan, medalem, Ngabongan, Kerek, Tegalrejo, widang
2	D3	Bangilan, Kejuron, Montong, Sumurgung, Kebonharjo, Kepet, Bogorejo, Soko, Rengel, Maibit, Klotok, Parengan
3	D4	Jenu
4	E3	Belikanget, Simo, Tuban, Silowo, Palang, Ngimbang

The C3 Oldeman climate type is found in the Mundri, Laju Kidul, Sendang, Jojogan, Medalem, Ngabongan, Kerek, Tegalrejo, and Widang regions, meaning that these areas are only suitable for one rice planting season per year according to the agroclimate zone. The D3 Oldeman climate type is present in the Bangilan, Kejuron, Montong, Sumurgung, Kebonharjo, Kepet, Bogorejo, Soko, Rengel, Maibit, Klotok, and Parengan regions, suggesting that these areas may only have one rice planting season depending on the presence of irrigation water. In the Jenu region, the climate is classified as D4 Oldeman, which means only one rice planting season is possible per year depending on the availability of irrigation water, with a dry period lasting 7-9 months. The E3 Oldeman climate type is found in the Belikanget, Simo, Tuban, Silowo, Palang, and Ngimbang regions, suggesting that these areas are typically not suitable for growing rice due to dry conditions. However, they may be able to support one crop planting season for other crops if there is enough rainfall [13].

3.3 Analysis of Groundwater Availability

The groundwater availability in Tuban Regency typically peaks from November to April, with the KAT (Soil Water Content) value matching KL (Field capacity) when groundwater availability reaches maximum values at 350 mm. This indicates that there is a rainy season during these months, resulting in an abundance of water and a surplus.

ATS (Available Groundwater)in Tuban Regency, East Java 2018-2022 shown in Table 4, and Groundwater Availability in Mundri shown in Figure 4, as well as Groundwater Availability in Bogorejo shown in Figure 5.

Table 4. ATS in Tuban Regency, East Java 2018-2022 [5]

Rain Statiom	ATS (%)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Bangilan	100	100	100	100	58	30	24	13	0	100	100	100
Mundri	100	100	100	100	37	0	0	0	0	100	100	100
Kejuron	100	100	100	100	36	1	0	0	0	0	100	100
Laju Kidul	100	100	100	100	61	0	0	0	0	0	100	100
Sendang	100	100	100	100	34	0	0	0	0	0	100	100
Jojogan	100	100	100	100	63	11	0	0	0	0	100	100
Montong	100	100	100	100	68	15	0	0	0	0	100	100
Sumurgung	100	100	100	100	38	0	0	0	0	0	100	100
Banyu Urip	100	100	100	100	46	46	8	0	0	0	100	100
Ngabongan	100	100	100	76	100	49	5	0	0	0	100	100
Kebonharjo	100	100	96	100	49	8	0	0	0	0	100	100
Belikanget	100	100	100	100	49	0	0	0	0	0	0	100
Kerek	100	100	100	100	60	0	0	0	0	0	100	100
Simo	100	100	86	100	25	0	0	0	0	0	0	100
Kepet	100	100	100	92	21	0	0	0	0	0	100	100
Tuban	100	100	100	88	7	0	0	0	0	0	100	97
Bogorejo	100	100	100	100	100	100	100	100	100	100	100	100
Tegalrejo	100	100	100	100	15	0	0	0	0	0	0	100
Silowo	100	100	100	100	22	0	0	0	0	0	100	100
Jenu	100	100	100	100	35	0	0	0	0	0	0	0
Soko	100	100	100	85	44	0	0	0	0	0	100	100

Rangel	100	100	100	100	30	0	0	0	0	0	100	100
Maibit	100	100	100	91	23	0	0	0	0	0	100	100
Klotok	100	100	100	88	16	0	0	0	0	0	100	100
Widang	100	100	100	100	37	0	0	0	0	0	100	100
Palang	100	100	78	34	0	0	0	0	0	0	0	0
Ngimbang	100	100	89	76	9	0	0	0	0	0	100	100
Parengan	100	100	100	69	44	0	0	0	0	0	100	100

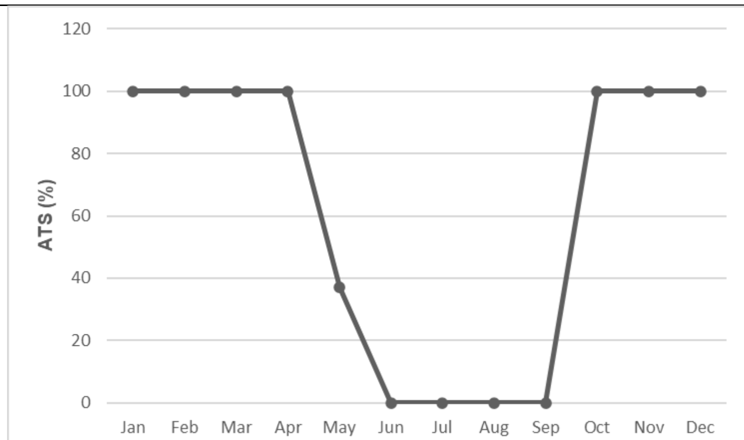

Figure 4. Groundwater Availability in Mundri

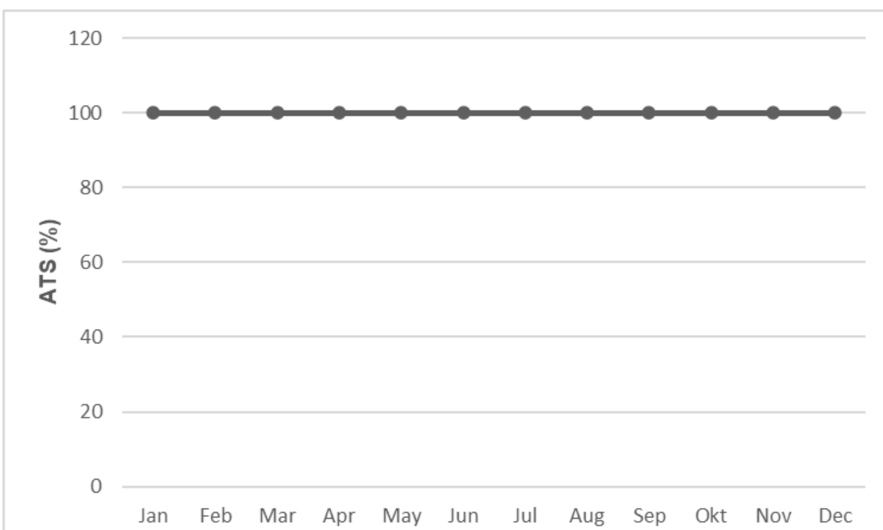

Figure 5. Groundwater Availability in Bogorejo

Using Table 4 and Figure 4 as an illustration, we can see that Tuban District in East Java has consistently high levels of groundwater, reaching 100% from November to April. This suggests that the district experiences a rainy season during those months, resulting in more rainfall than what is lost through evapotranspiration in rice plants. From June to October, typically, the Tuban Regency experiences a dry season with very little groundwater availability, at 0%. As a result, the availability of groundwater for rice plants is minimal and may even lead to drought, indicating that the rainfall during this period is also less than the evapotranspiration of rice plants, which means there is a dry season. In May, the Tuban Regency experiences a moderate level of groundwater availability, signifying a transition from the rainy season to the dry season. Jenu has no ATS from June to December and Palang from May to December. By examining the ATS percentage, which indicates ample groundwater availability in Tuban Regency from November to April, we can establish the best time to start planting rice. Accordingly, the ideal time to begin rice planting in Tuban Regency is in November, with a total planting and harvest period of 4 months. In the Bogorejo area in Figure 5, the ATS percentage is consistently 100% throughout the year, allowing for rice planting to occur three times with a four-month period for planting and harvesting. The calculation of groundwater availability also reveals deficits and surpluses in the Regency. The data shows that when Tuban Regency experiences a deficit, there is a surplus of 0 mm, and vice versa. This indicates that deficits and surpluses are influenced by rainfall. Low rainfall or dry months result in deficits, while higher rainfall leads to surpluses [13].

4. Conclusion

The conclusions that can be drawn from the discussion are as follows:

a. In Tuban Regency, East Java, the ATS (Available Soil Moisture) ranges from 100% during November-April to 0% during June-September, indicating high and low availability of soil moisture, respectively. The Oldeman Climate Types in Tuban Regency are, in order, C3(can only get one rice and second crop planting a year,with dry months 4 – 6 months), D3 (only maybe one rice crop or one crop per year, with dry months 4 – 6 months), D4 (only maybe one rice crop or one crop per year,with dry months of 7 – 9 months), and E3 (this area is generally too dry, can only get secondary crops once,with dry months of 4 – 6 months).

b. The tiniest shortfall is 0.1 mm, observed in Medalem in June, whereas the greatest deficit of 279.6 mm is observed in Ngimbang in November. The smallest excess is 0.9 mm, happening in Sumurgung in April, and the largest excess is 313 mm, occurring in Jenu in January.

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