

[Research Article]



Land Water Balance Analysis for Determining Potato Cropping Patterns and Planting Schedules in Pasuruan Region

Naufal Ilham Habibi*, Ania Maulidiah Nisa

Department of Climatology, Indonesia Meteorology, Climatology, and Geophysics, Indonesia

*Correspondence: naufalhabibi542@gmail.com

Article Info:	Abstract
<p>Received: 4 April 2026</p> <p>Accepted: 9 May 2026</p> <p>Published: 2 June 2026</p> <p>Keywords: land water balance; planting schedule; potatoe; Thornthwaite- Mather; Pasuruan.</p>	<p><i>Pasuruan Regency, with 213,686 farmers and a population growth rate of 0.4–1% annually, faces an urgent need for a stable food supply due to fluctuating potato prices and stock levels linked to unplanned planting. This study aims to identify optimal potato planting patterns and schedules using the Thornthwaite-Mather water balance method, based on monthly rainfall data. The Oldeman climate classification revealed five climate types in Pasuruan: C2, D2, D3, D4, and E, influenced by monsoon patterns affecting soil water availability. Soil moisture levels are suitable for potato planting from January to March, decrease from May to October, and increase again in November. The western region (Pasuruan city) tends to be drier, with a longer dry season. The resulting planting schedule recommendations are as follows: climate type C2 (first planting season: November–February; second planting season: March–June), D2 (first planting season: December–March), D3 (first planting season: January–April), and D4 and E (first planting season: February–May), to support the stability of potato production and food security in Pasuruan on a sustainable basis.</i></p>

Informasi Artikel:	Abstrak
<p>Diterima: 4 April 2026</p> <p>Disetujui: 9 Mei 2026</p> <p>Dipublikasi: 2 Juni 2026</p> <p>Kata kunci: keseimbangan air tanah; jadwal penanaman; kentang; Thornthwaite- Mather; Pasuruan.</p>	<p><i>Kabupaten Pasuruan, dengan 213.686 petani dan tingkat pertumbuhan penduduk sebesar 0,4–1% per tahun, menghadapi kebutuhan mendesak akan pasokan pangan yang stabil akibat fluktuasi harga dan persediaan kentang yang terkait dengan penanaman yang tidak terencana. Penelitian ini bertujuan untuk mengidentifikasi pola dan jadwal penanaman kentang yang optimal menggunakan metode keseimbangan air Thornthwaite-Mather, berdasarkan data curah hujan dekadal. Klasifikasi iklim Oldeman menunjukkan lima tipe iklim di Pasuruan: C2, D2, D3, D4, dan E, yang dipengaruhi oleh pola musim hujan yang memengaruhi ketersediaan air tanah. Tingkat kelembapan tanah cocok untuk penanaman kentang dari Januari hingga Maret, menurun dari Mei hingga Oktober, dan meningkat kembali pada November. Wilayah barat (Kota Pasuruan) cenderung lebih kering dengan musim kemarau yang lebih panjang. Rekomendasi jadwal penanaman yang dihasilkan adalah sebagai berikut: tipe iklim C2 (musim tanam pertama: November–Februari; musim tanam kedua: Maret–Juni), D2 (musim tanam pertama: Desember–Maret), D3 (musim tanam pertama: Januari–April), serta D4 dan E (musim tanam pertama: Februari–Mei), guna mendukung stabilitas produksi kentang dan ketahanan pangan di Pasuruan secara berkelanjutan.</i></p>

INTRODUCTION

The Pasuruan region has a variety of businesses, and one of them is agriculture, which is very important to the economy of the region. According to the BPS (2023a), Pasuruan Regency has one of the largest numbers of farmers, with 213,686 people. Pasuruan has a population of more than one million people. Most of them rely on farming to make a living, which is an important part of providing food and welfare for rural communities.

The population growth rate in each sub-district ranges from 0.5 to 1% per year (BPS, 2023b). This indicates that the Pasuruan region has been developing rapidly, with its population continuously increasing over time. The Pasuruan City BPS (2025b) states that the population growth rate in the Pasuruan City area ranges from 0.4 to 1% per year. To maintain the region's food security and prevent an imbalance between food demand and supply, this population growth must be balanced with the availability of food crop yields (Sumunar & Budiman, 2021).

Due to bad planning of planting times, prices and stocks of some important agricultural goods, like potatoes in East Java, have changed a lot in the last few years (Subardi, 2023). The Pasuruan region, where potatoes are a major crop, could also have similar conditions. Pasuruan Regency is East Java Province's biggest potato supplier. In 2024, it produced 2,015,433 quintals, which is a big jump from the 1,880,539 quintals it produced in 2023 (BPS, 2025). Because production is growing so quickly, planting times and crop choices need to be carefully planned. If you don't know when to plant, you might end up with too much stock and prices that drop in the market (Djazuli et al., 2025; Safitri et al., 2025). It can also make it more likely that crops will fail (Syaharuddin et al., 2023).

The complexity of crop scheduling in Pasuruan is further influenced by the region's diverse climatic and topographic conditions. Pasuruan features varied topography, ranging from highland mountainous areas on the slopes of Mount Bromo and Mount Arjuno to low-lying coastal zones along the northern coast of East Java (Sugiyanti, 2012). This topographic variation results in contrasting climatic conditions across the region: the highland areas of Pasuruan Regency generally receive higher rainfall and experience cooler temperatures,

while Pasuruan City, located in the low-lying coastal zone, tends to be drier and warmer (Ananta et al., 2024). Consequently, rainfall distribution, evapotranspiration rates, and groundwater availability vary significantly across sub-districts. These climatic differences directly influence when and how crops particularly potatoes, can be optimally planted in each area, making it crucial to understand the spatial variations in water availability throughout the region as a basis for determining the most appropriate planting schedule (Ananta et al., 2024; Park et al., 2025; Yulianti et al., 2023).

To address this complexity, a land water balance analysis is necessary to identify the most suitable planting seasons and cropping patterns for each area. The Thornthwaite-Mather method is particularly well-suited for this purpose, as it provides a systematic approach to calculating groundwater surpluses and deficits by accounting for potential evapotranspiration, precipitation, and soil water storage capacity (Lias et al., 2020; Maulida et al., 2022; Perwitasari et al., 2025; Sitanggang et al., 2022). Understanding the dynamics of soil water availability (SWA) is one of the most critical factors in determining crop performance, especially in regions with variable rainfall (Fadila, 2023). By quantifying how much water is stored in or lost from the soil across different periods, farmers can identify the optimal time to plant and select crop types that are best suited to local land and climate conditions (Uspessy et al., 2020).

There have been several studies on how to figure out when to plant potatoes. Lestantyo & Marandy (2022) used spatial rainfall data to guess when potatoes should be planted. The study's findings suggested that potatoes should be planted from January to April. However, the study was based solely on rainfall amounts without considering SWA, soil characteristics such as Field Capacity (FC) and Permanent Wilting Point (PWP), actual evapotranspiration, or soil water deficit and surplus. In the meantime, Yulianti et al. (2023) did research to find the best time to plant potatoes in the Solok region based on how much water was available on the land every ten days, using the Thornthwaite-Mather method in calculations. The result was a good schedule for planting potatoes, which was the third decade of March. This study only presented the potato planting schedule without

spatially mapping the amount of water availability or identifying which specific areas are suitable for potato cultivation according to the determined planting time.

Research on potato planting patterns and schedules in the Pasuruan region based on soil water balance using the Thornthwaite-Mather method, along with its temporal and spatial visualization, remains very limited and is rarely conducted. Information about the balance of water in the soil should help farmers figure out the best and most efficient ways to plant. So, the results of this analysis can be used as a starting point for efforts to keep potato production

steady all year long and help the Pasuruan region's food security in the long term.

METHOD

Study Area

This study covers the Pasuruan region, which consists of Pasuruan Regency and Pasuruan City (Figure 1). Pasuruan Regency and Pasuruan City are in East Java Province, with geographical coordinates ranging from 112°30' to 113°30' E and 7°30' to 8°30' S. The study area covers Pasuruan Regency, which has 24 subdistricts, and Pasuruan City, which consists of 4 subdistricts.

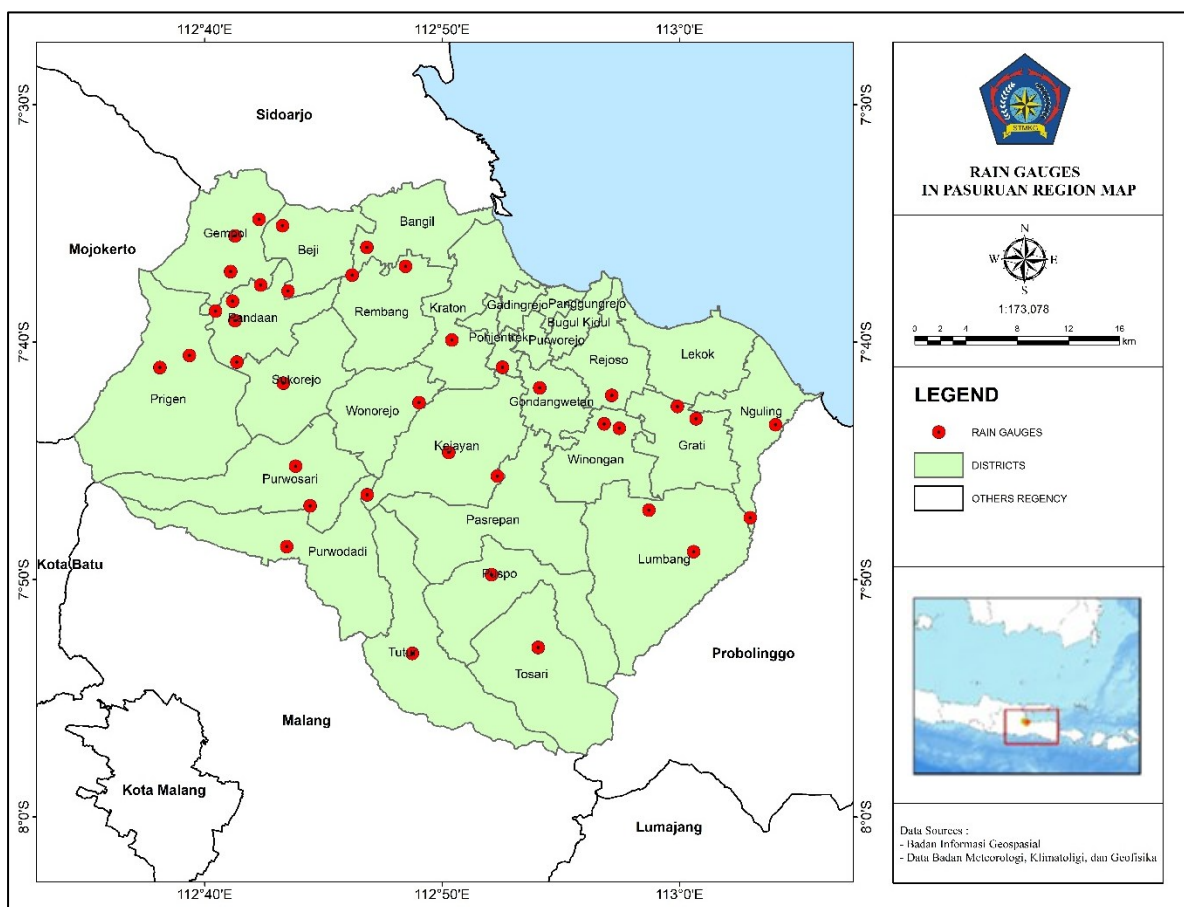


Figure 1. Study Area and Station Points in Pasuruan Region

Tools and Data Sources

This study used QGIS software for mapping to provide an overview and information on climate types and potato planting patterns and schedules in Pasuruan Regency and City. Microsoft Excel and Google Colab Python, with the main libraries including Pandas (data manipulation and tabular analysis), xarray (reading and processing multidimensional NetCDF data), netCDF4 (backend for reading .nc files), Matplotlib (data visualization

and plotting), NumPy (numerical array computation), Windrose (wind direction and speed diagram plotting), and Cartopy (geographic map visualization with coordinate projections), were used to calculate land water balance values.

Monthly average rainfall data for the period 1991-2020 from 39 rain gauges spread across the Pasuruan region, which can be accessed at <https://dataonline.bmkg.go.id/>. Monthly average temperature data for the period

1991-2020 obtained from Multi-Source Weather (MSWX), which can be accessed at <https://www.gloh2o.org/mswx/>. Coordinate data and complete data from 39 rain gauge

stations in the Pasuruan Region for determining evapotranspiration and soil water availability (Table 1).

Table 1. Rain Gauge in Pasuruan Region

No.	Rain Gauge	Latitude	Longitude	Data Completeness (%)
1	Baujeng/Tanggul	-7.63083	112.72530	96.67
2	Benerwojo/Kejayan	-7.76083	112.87220	56.67
3	Cukurguling/Lumbang	-7.78472	112.97860	85.03
4	Gading	-7.72417	112.94720	90.55
5	Gambiran/Jawi	-7.67611	112.65610	99.74
6	Gd. Wetan	-7.69889	112.90190	55.01
7	Gununggangsir/Banyulegi	-7.58500	112.72140	100
8	Jembrung	-7.59222	112.68810	99.82
9	Kademungan/Selowongko	-7.77389	112.78080	96.67
10	Kalursari/Bekacak	-7.61972	112.77030	99.72
11	Kepulungan	-7.61722	112.68500	100
12	Ketanireng/Wilo	-7.68083	112.68940	99.71
13	Kiduldalem/Bangil	-7.60028	112.78060	100
14	Mojoparon/Badong	-7.61361	112.80780	100
15	Mojotengah/Telebuk	-7.69556	112.72190	100
16	Ngempit	-7.66528	112.84030	41.10
17	Oro-Oro Pule	-7.74417	112.83810	51.92
18	Pandanrejo/Kawisrejo	-7.70417	112.95250	92.53
19	Panditan	-7.81389	113.01000	93.35
20	Parerejo/Purwodadi	-7.81028	112.72440	56.67
21	Petungasri/Kasri	-7.65167	112.68810	100
22	Poh Jentrek	-7.68444	112.87580	56.67
23	Prigen	-7.68458	112.63533	97.80
24	Puspo	-7.83000	112.86810	69.73
25	Randupitu	-7.62667	112.70610	99.73
26	Ranuklindungan I /Kwd.Grati	-7.71194	112.99860	96.39
27	Ranuklindungan Ii /Ranugrati	-7.72056	113.01170	93.91
28	Sanganom	-7.79000	113.04970	49.99
29	Sedarum/Nguling	-7.72472	113.06750	77.31
30	Sengonagung/Pager	-7.75389	112.73060	99.81
31	Sumbergadang/Winong	-7.64500	112.67440	93.89
32	Sumbersirah/Wonorejo	-7.70917	112.81720	89.27
33	Tawangrejo/Bareng	-7.63806	112.68640	92.22
34	Tejowangi/Purwosari	-7.78167	112.74080	60
35	Tosari	-7.88111	112.90080	54.75
36	Tutur	-7.88528	112.81250	100
37	Winong/Gempol	-7.58056	112.70500	100
38	Winongan Lor	-7.72722	112.95780	95.26
39	Stasiun Geofisika Pasuruan	-7.70460	112.63530	80

The physical properties of soil in the Pasuruan region, which are the FC and PWP values used in this study, were referenced from Pawitan et al. (1996), which provides soil physical properties classified by soil type and has been widely adopted in water balance

studies across Indonesian agricultural regions. Although Pasuruan encompasses varied topography, a spatially distributed soil type map with corresponding FC and PWP values for each soil type unit across the study area was unavailable. Therefore, the FC and PWP values

Table 2. The Field Capacity and Permanent Wilting Point Values for the Pasuruan Region

Province	Regency/City	FC	PWP
East Java	Pasuruan Regency	150	300
	Pasuruan City	150	300

Source: Pawitan, 1996.

from Pawitan et al. (1996) were applied based on the dominant soil type identified in the region, which represents a limitation of this study (Table 2).

Data Analysis

The study began with filling in the missing data at rainfall stations during the period 1991-2020 using the normal ratio method. This method takes into account rainfall data at other nearby rainfall stations to find the missing rainfall data at that station (Prawaka et al., 2016). The Normal Ratio Method formula is written through Equation 1 as follows (Wei & McGuiness, 1973).

$$P_{test} = \frac{1}{M} \left(\frac{N_{test}}{N_{base,1}} P_{base,1} + \frac{N_{test}}{N_{base,2}} P_{base,2} + \dots + \frac{N_{test}}{N_{base,M}} P_{base,M} \right) \quad (1)$$

where P_{test} is the rainfall data at station (x), which will be filled in with units of millimeters (mm). N_{test} represents the normal decadal rainfall at station (x) (mm). $N_{base,i}$ is the normal decadal rainfall from several nearby rain

stations with indices ($i = 1, \dots, M$) (mm). Meanwhile, $P_{base,i}$ is the rainfall data at nearby stations in the same period (mm). M indicates the number of nearby rain stations used in the calculation.

We used data on average temperature and monthly rainfall during the study period to put Oldeman's climate types in the Pasuruan region into groups. To figure out when and how to plant, as well as which crops will grow best in a certain climate, you need to know what kind of climate it is (Fadholi & Supriatin, 2016; Agustin, 2022). Oldeman & Frere (1982) delineated agricultural patterns for food crops across the agroclimatic zones designated as A1, A2, B1, B2, C1, C2, C3, C4, D1, D2, D3, D4, and E. Oldeman's climate classification is based on the number of wet months (WM) and dry months (DM), where a wet month is defined as a month with average rainfall exceeding 200 mm for two consecutive months, while a dry month is defined as a month with average rainfall below 100 mm for two consecutive months. The main climate types (A, B, C, D, and E) are determined by the number of consecutive wet months, whereas the subdivisions (1, 2, 3, and 4) are determined by the number of consecutive dry months. Oldeman's climate classification is shown in Tables 3 and 4 below.

Table 3. Oldeman's climate classification

Main Type	Wet Months	Sub Division	Dry Months
A	> 9	1	< 2
B	7 – 9	2	2 – 3
C	5 – 6	3	4 – 6
D	3 – 4	4	> 6
E	< 3		< 2

Source: Oldeman, 1982.

Table 4. Agricultural Patterns in Each Agroclimatic Zone

Agroclimate Zone	Description
A1 and A2	Suitable for continuous rice cultivation, but production is low because solar radiation flux density is generally low throughout the year.
B1	Suitable for continuous rice cultivation with good early planting season planning. High production during the dry season harvest.
B2	Rice can be planted twice a year with short-maturing varieties, and the short dry season is sufficient for planting secondary crops.
C1	Rice can be planted once and secondary crops twice a year.

Agroclimate Zone	Description
C2, C3, and C4	Only one rice crop can be planted per year, and the second planting of secondary crops must be done carefully so as not to fall during the dry months.
D1	Short-season rice is planted once and usually has high yields due to high radiation flux density. The planting time for secondary crops is sufficient.
D2, D3, and D4	It is only possible to plant rice or secondary crops once a year, depending on the availability of irrigation water.
E	This area is generally too dry, so it may only be possible to plant secondary crops once, and even that depends on rainfall.

Source: Oldeman & Frere, 1982.

Rainfall and temperature data are used to calculate groundwater availability. These calculations employ the Thornthwaite & Mather (1957) method, which consists of two main steps: the calculation of evapotranspiration and the calculation of the land water balance. Both are explained as follows.

Evapotranspiration Calculation

The type of evapotranspiration used for the crop water balance is Crop Evapotranspiration (ET_c), which indicates the amount of water evaporation occurring in plants according to their age and species during the growing season. The formula used is shown in Equation 2 below.

$$ET_c = ET_p \times kc \quad (2)$$

where ET_c is crop evapotranspiration, ET_p is potential evapotranspiration, and kc is the potato crop coefficient of 0.74 (FAO, 1998).

Land Water Balance

The purpose of a land water balance calculation is to determine the availability of groundwater in each area. The steps involved are described below.

- After obtaining the rainfall and potato crop evapotranspiration ET_c values, the rainfall minus ET_c value is calculated. The rainfall minus ET_c value represents the difference between rainfall and potato crop evapotranspiration, which is necessary to determine periods of water surplus and deficit. Calculating the Accumulation of Potential Water Loss (APWL). The APWL is the cumulative deficit of rainfall relative to potential evapotranspiration, the negative result from the rainfall minus the potato ET_c are accumulated month by month.

- Calculating SWA preceded by determining the FC value. Filling in this column begins in the first month that APWL occurs, using the following Equation 3 by Sujalu et al. (2014, 2019).

$$SWA = FC \times k^{|APWL|} \quad (3)$$

where k is equal to $p_0 + p_1$ divided by FC , p_1 of -1.073807306, p_0 of 1.000412351, FC is field capacity, and $|APWL|$ = Absolute value of APWL.

The SWA column for the first month, where rainfall - ET_p is positive is filled with $(SWA = \text{Last SWA} + \text{rainfall} - ET_p)$. This continues until the value of SWA is equal to FC is reached. From that month onward, as long as rainfall remains in excess, the SWA value remains constant, equal to FC .

- Changes in Soil Water Availability (dSWA) value represent the difference in groundwater levels between one period and the previous period ($SWA_i - SWA_{i-1}$). A positive dSWA value indicates an increase in groundwater levels.
- Calculating actual evapotranspiration (ET_A) is determining if precipitation > ET_p , then ET_A is equal to ET_p . However, if precipitation is lower than potential evapotranspiration, the soil begins to dry out and ET_A is less than ET_p , so ET_A is equal to rainfall + dSWA.
- Calculating the deficit (D) obtained by knowing is the difference between ET_p and ET_A .
- The surplus (S) calculated by rainfall - ET_p - dSWA.
- Calculate the percentage of Available Groundwater (ATS) using the following equation.

$$ATS = \frac{SWA - PWP}{FC - PWP} \times 100\% \quad (4)$$

where ATS is the percentage of available groundwater, SWA is soil water availability, PWP is the permanent wilting point, and FC is field capacity.

ATS conditions align with groundwater availability analysis, previous deficits, and surpluses; when ATS is severely insufficient, and a groundwater deficit occurs, potato cultivation requires alternative water sources such as irrigation. Thus, ATS can be used as a reference to

determine whether a region has sufficient groundwater or requires additional irrigation in a specific month for regional planning purposes. The criteria for the ATS value are shown in Table 5. Proper irrigation management is then essential, as potato is a shallow-rooted crop that responds negatively to variations in water supply, and small errors in irrigation management can significantly reduce production profitability (Barung & Pattipeilohy, 2020; Shock et al., 2007). The overall methodological workflow is illustrated in Figure 2.

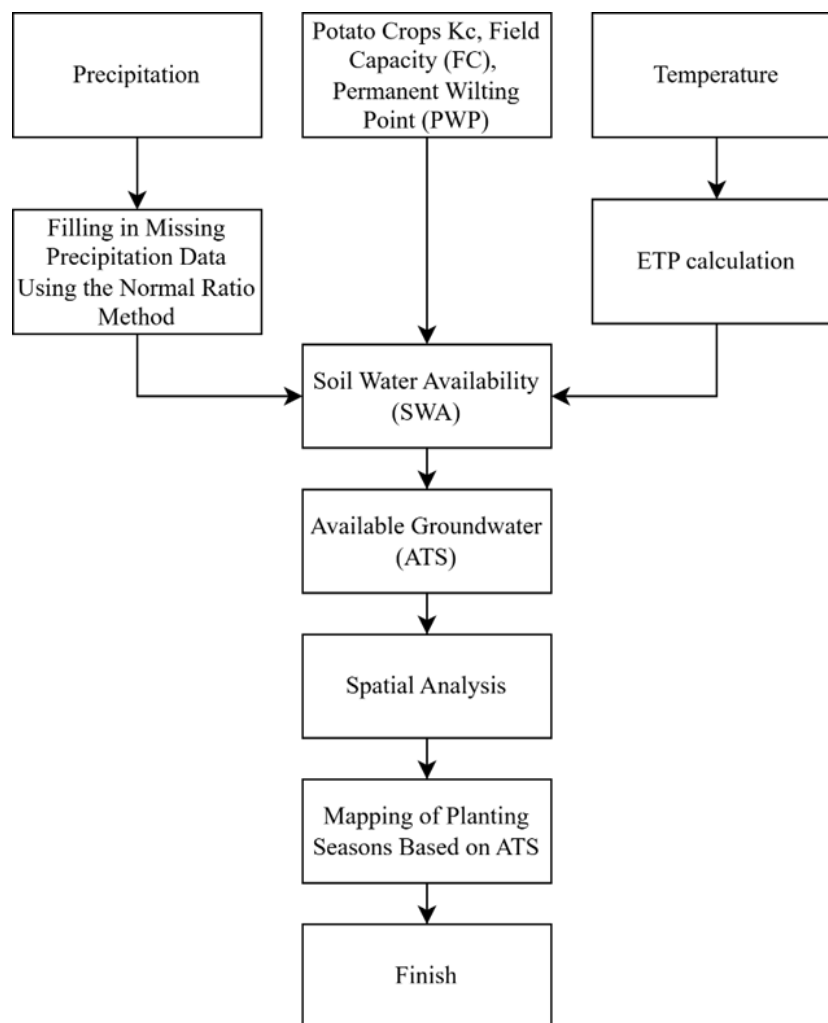


Figure 2. Flowchart of Methodology

Table 5. The Percentage of Available Groundwater

The Percentage of ATS	Description
<10	Very Low
10 – 40	Low
40 – 60	Moderate
60 – 90	Sufficient
>90	Highly Sufficient

Source: BMKG, 2010.

RESULT AND DISCUSSION

Classification of Seasonal Zones and Monthly Precipitation

The classification of seasonal zone types (ZOM) in the Pasuruan region is based on the analysis of monthly decadal rainfall data for the period 1991–2020 at rainfall stations. The ZOM types were derived from data processed by the BMKG Central Office, as shown in Figure 3.

The Pasuruan region as a whole has a ZOM Monsunal-2 climate type, which means that rainfall follows a monsoon pattern and there are two seasons: the rainy season and the dry season. In the Monsunal-2 ZOM type, there is one peak in the rainy season and one peak in the

dry season. These conditions make it easier to identify months with high rainfall and months with low rainfall, as well as to determine the planting season schedule (Figure 4).

The 30-year (1991–2020) climatological average rainfall pattern shows a monsoon or U-shaped pattern. Rainfall increases in October, peaking in January at 369.3 mm/month, and remains high through March. This is consistent with research by Aini et al. (2021) showing that rainfall increases in November and December. During this period, the Pasuruan region experiences the rainy season. Rainfall decreases until it peaks in August. In other words, the Pasuruan region experiences a dry season.

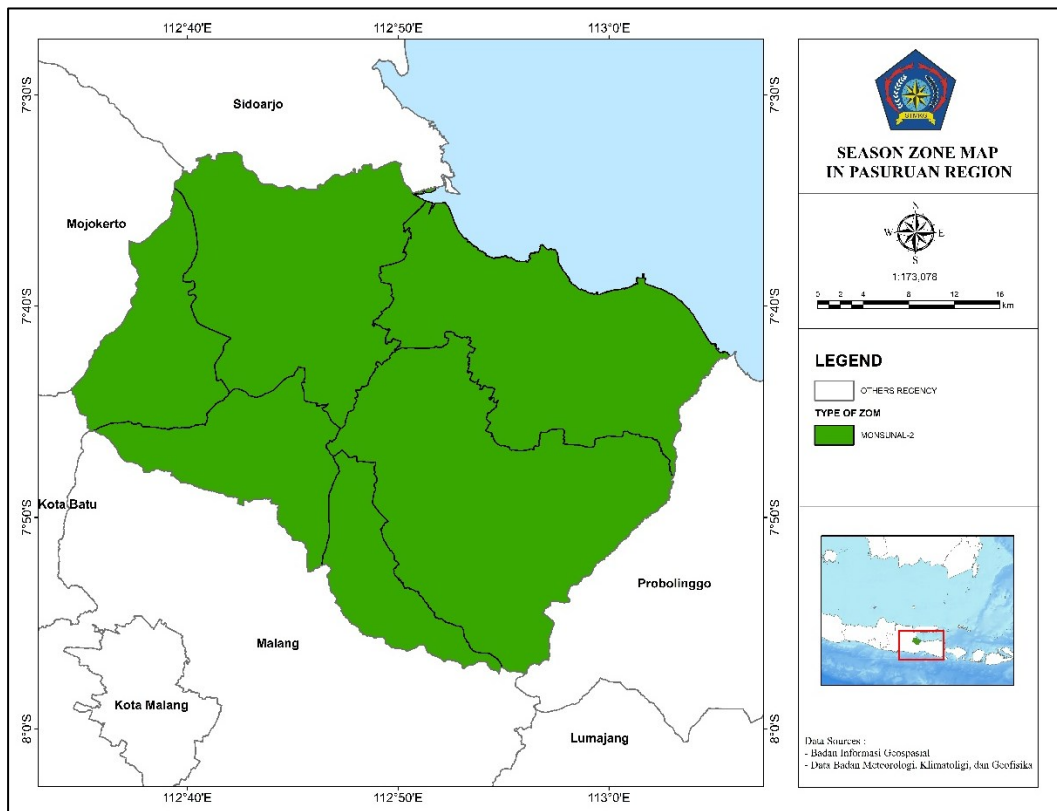


Figure 3. Map of Seasonal Zone Types

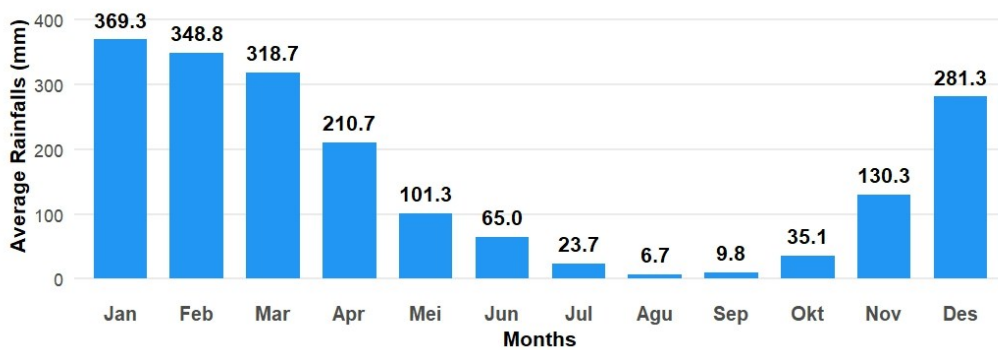


Figure 4. Monthly rainfall in Pasuruan Region for Thirty Years

Oldeman's Climate Classification

The Oldeman climate classification for the Pasuruan region was determined based on the analysis of monthly rainfall data from 1991 to 2020 at 39 observation stations distributed throughout the Pasuruan region. The results of the analysis show that Pasuruan Region has five Oldeman climate types, namely C2, D2, D3, D4, and E. The spatial classification of Oldeman climate types in Pasuruan Region can be seen in Figure 5.

The Pasuruan region has mostly climate type D4, but northern Pasuruan has climate types D2 and D3. Climate type E is found near the city of Pasuruan, and climate type C2 is only

found in a small part of the Pasuruan region. In climate types D2 to E, there can only be planted potatoes once a year. In climate type C2, there can be potatoes planted twice a year. An analysis of groundwater availability at each representative station for the Oldeman climate types is used to figure out when and where to plant rice.

Using monthly rainfall and air temperature data from 1991 to 2020, we figured out the best planting patterns and schedules for normal conditions. The following seven stations were used to figure out how much water was available in the soil for potato crops using the Thornthwaite-Mather method (Table 6).

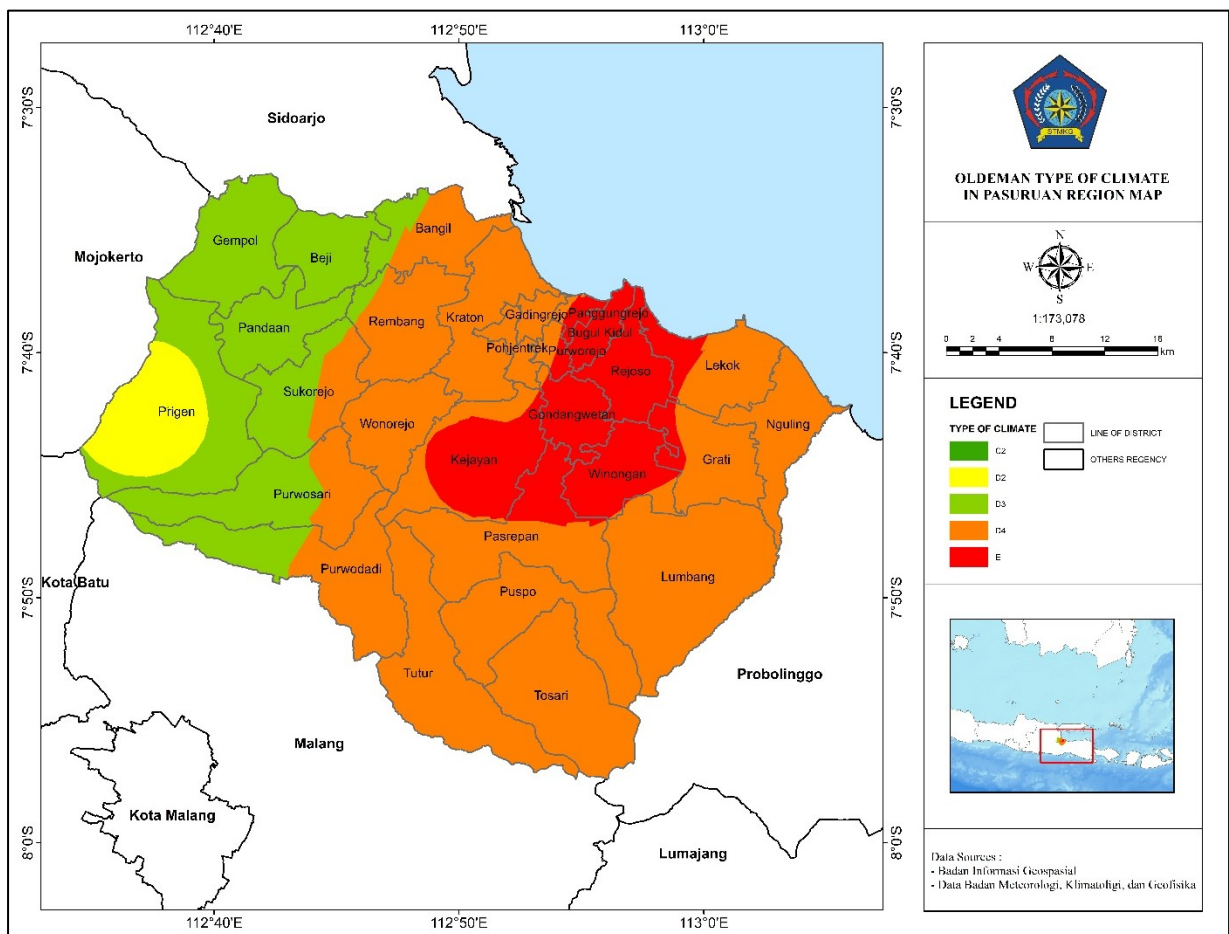


Figure 5. Oldeman Climate Classification Map

Table 6. The Percentage of Available Groundwater

Type Climate	Station
C2	Prigen
D2	Gambiran
D3	Gununggangsir/Banyulegi
D4	Ranuklindungan li/Ranugrati
E	Winongan Lor

Land Water Balance

The land water balance is a model that combines climate data with soil data, such as FC, PWP, and ATS. The difference between FC and PWP tells us how much water is available.

Figure 6 shows the results of the soil water balance calculations for each rainfall station that represents a different climate type in the Pasuruan region.

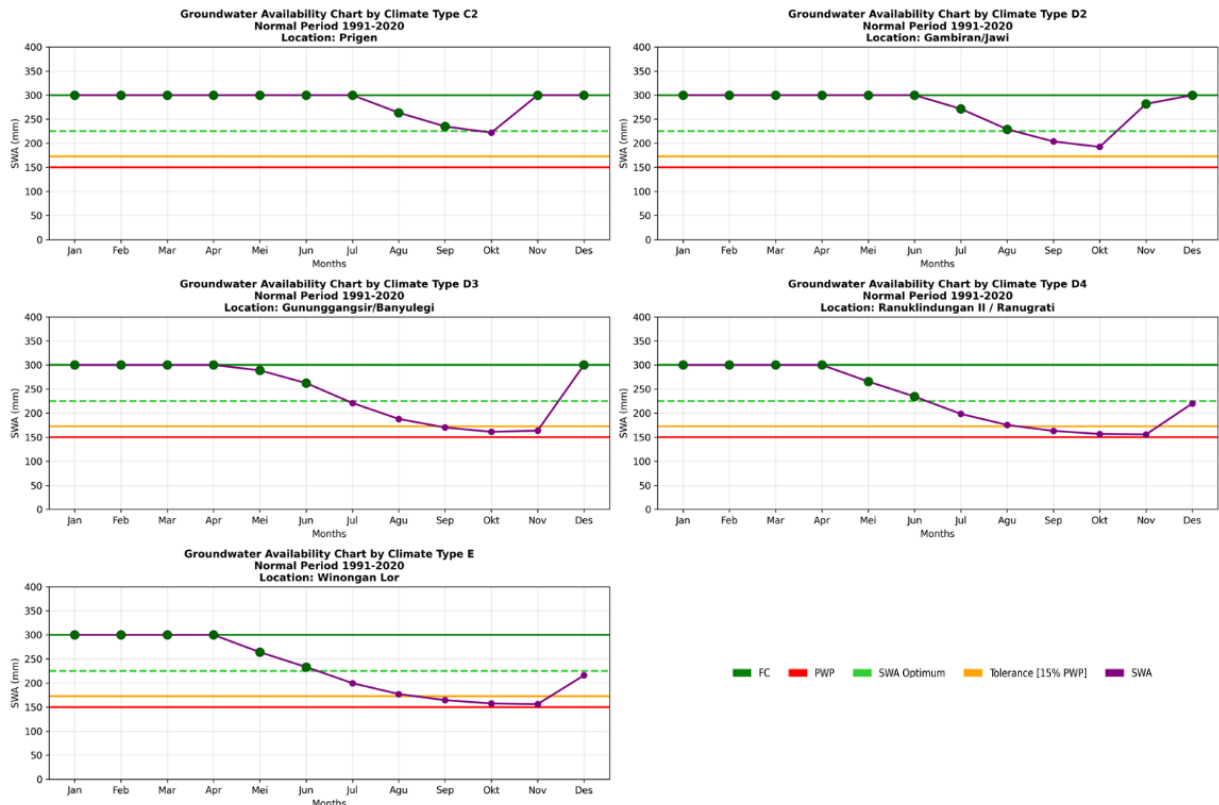


Figure 6. Graph of Groundwater Availability at Each Climate-Type Observation Station in Normal Period 1991-2020

As shown in Figure 6, the C2 climate type in the Pasuruan region experiences a dry period from August to October, characterized by negative APWL values. This occurs because evapotranspiration exceeds rainfall, causing soil water reserves to begin to decline. Field capacity is reached nine times a year, specifically from November through July, indicating that groundwater recharge occurs nearly year-round. Even during the dry season, groundwater availability from August through October remains above the optimum moisture level because the water reserves formed during the wet season are still substantial. Under these conditions, the C2 climate type remains highly conducive to agricultural activities because the groundwater supply is well-maintained almost year-round.

The D2 climate type in the Pasuruan region experiences a longer dry season compared to the C2 climate type, specifically

from July through October, as indicated by negative APWL values. Field capacity is reached eight times a year, from November through June. The reduced frequency of reaching field capacity suggests that the period for replenishing groundwater reserves is becoming more limited. In July and August, groundwater availability begins to decline, though it remains above the optimum water level, so crops have not yet experienced significant water stress. From September through October, groundwater availability exceeds the optimum level but has not yet crossed the tolerance threshold, so crops begin to feel drought stress, though conditions have not yet reached a level threatening their survival.

More critical conditions were observed in the D3 climate type in the Pasuruan region, where the dry season lasts from May to October, characterized by negative APWL values. Field capacity is only reached five times a year, from

January to April, meaning the period for replenishing groundwater reserves is shorter compared to the previous climate type. In June, groundwater availability remained above the optimum level even though the APWL value was already negative. From September through November, groundwater availability fell below the tolerance limit, causing crop growth and productivity to be disrupted, particularly for crops vulnerable to drought stress. Conditions began to improve in December as rainfall increased again and groundwater reserves gradually replenished.

The D4 climate type in the Pasuruan region has a dry season from May to November, characterized by negative APWL values. Field capacity is only reached four times a year, from January to April, so the water reserves formed during the wet season are very limited. In May and June, groundwater availability remains above the optimum level, although it continues to decline. Conditions worsen from August through November when groundwater availability falls below the tolerance threshold, putting crops without irrigation at risk of damage due to prolonged water shortages. These conditions improve in December with the onset of the rainy season, and groundwater reserves begin to recover.

As the driest climate type in the Pasuruan region, Climate Type E experiences a dry season from May to November, characterized by negative APWL values. Although the duration of the dry season is the same as that of Climate Type D4, the intensity of drought in Climate Type E is significantly higher, as reflected by lower groundwater availability levels throughout the dry season. Field capacity is reached four times a year, from January through April. From May through July, groundwater availability remains above the optimum moisture level, although it continues to decline. The most critical conditions occur from August through November, when groundwater availability drops below the tolerance limit, though it has not yet reached the point of permanent wilting. In December, groundwater availability begins to increase again, though it only approaches the optimum moisture level, reflecting that the recovery of water reserves in climate type E occurs more slowly compared to other climate types in the Pasuruan region. These conditions indicate that Climate Type E has the highest vulnerability to prolonged

drought among all climate types in the Pasuruan region. Consequently, effective water resource management and adaptive agricultural practices are essential to minimize the impacts of seasonal water deficits in this climate type.

Mapping Water Availability

To support the determination of potato planting schedules, spatial maps of water availability from January through December were used. The average ATS maps for potato crops in the Pasuruan region were derived from data spanning the 1991–2020 period. The results of the monthly average ATS maps for potato crops are shown in Figures 7 and 8.

From January to April, the entire Pasuruan region is suitable for potato cultivation, indicated by a light blue color, which signifies an ATS value of 100%. In May, the entire Pasuruan region remains suitable for potato cultivation because it meets the requirement of an ATS value exceeding 65%. However, in June, the areas around Pasuruan City with climate type E are no longer suitable for potato cultivation, indicated by a white color. In July–August, potato cultivation is not possible because the ATS value for the Pasuruan City area and its surroundings is below 65%. For September–October, parts of the Pasuruan region, including the city and regency, cannot be used for potato cultivation. Then, in November–December, some areas can once again be used for potato cultivation, indicated by the color blue, which signifies an ATS value above 65%. This means that potatoes can be planted again after they could not be planted in the preceding months.

Potato Planting Patterns and Schedules

Potato planting patterns and schedules are determined based on soil moisture availability in each climate type in Pasuruan. In general, when determining the growing period for potatoes intended for consumption, the harvest time depends on the variety or cultivar (100–110 days), which typically falls between mid-April and mid-May (Diwa et al., 2015; Wahyuni et al., 2018). The planting patterns and schedules are shown in Figure 9 as follows.

There are two growing seasons in climate type C2. From November to February, soil water availability in climate type C2 areas for potato crops starts to reach field capacity. This means that the first growing season is from November

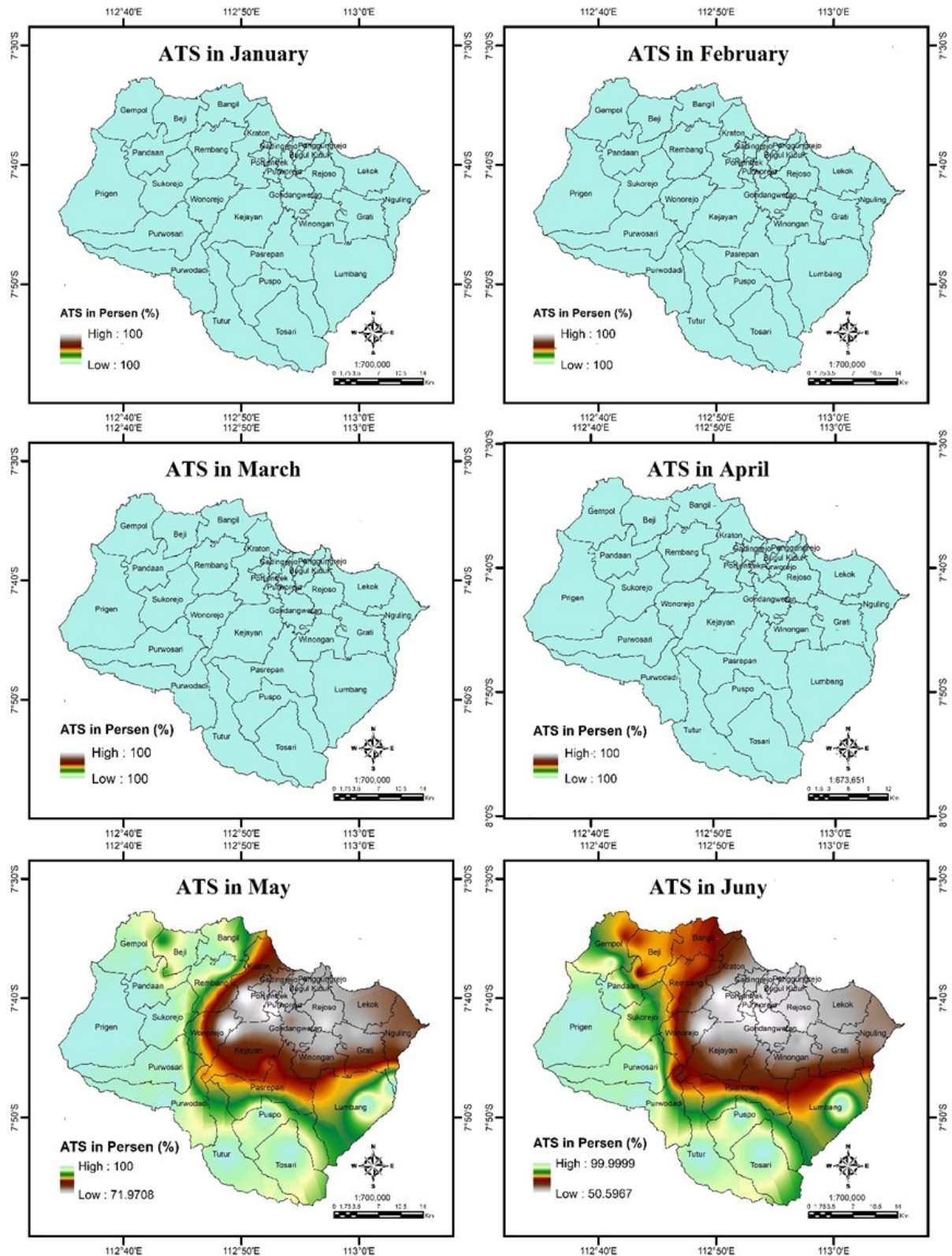


Figure 7. ATS Map for January to June

to February, as shown in red. The soil still has enough water from March to June to reach field capacity, so the second growing season is from March to June, as shown in green. The Pasuruan region has a climate type D2, and the soil water

availability for potato crops starts to reach field capacity from December to March. This means that the growing season is from December to March, which is shown in green. Climate type D2 regions only have one growing season

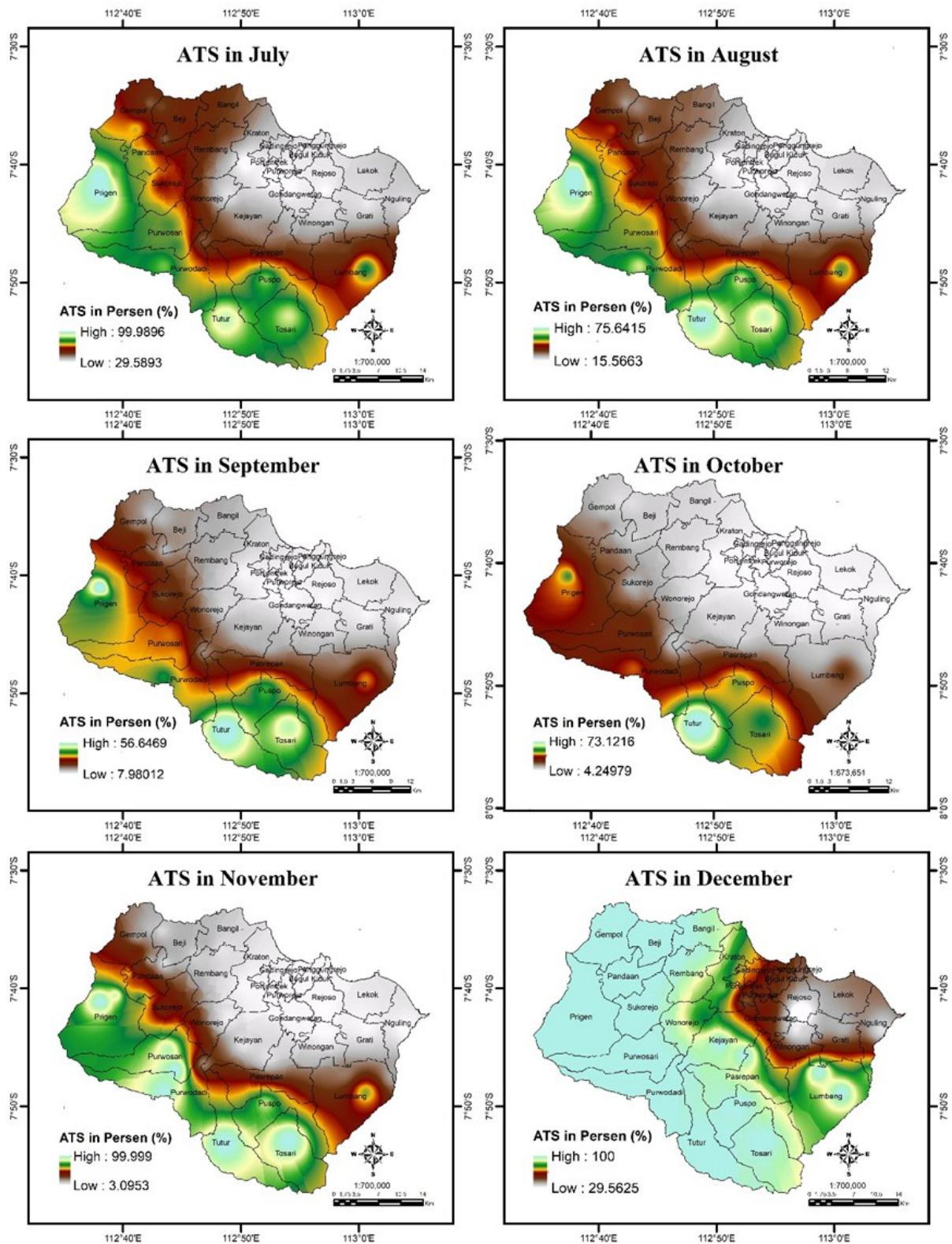


Figure 8. ATS Map for July to December

because the soil doesn't have enough water to reach field capacity in the months that follow. So, it is not possible to plant potatoes.

In the Pasuruan region, which has a D3 climate, groundwater becomes available for potato crops from January to April. This is when

the planting season starts, which is marked in yellow. There is only one planting season in areas with climate type D3 because they don't reach field capacity in the months that follow. Because of this, it is not possible to plant potatoes. In the Pasuruan region (climate type

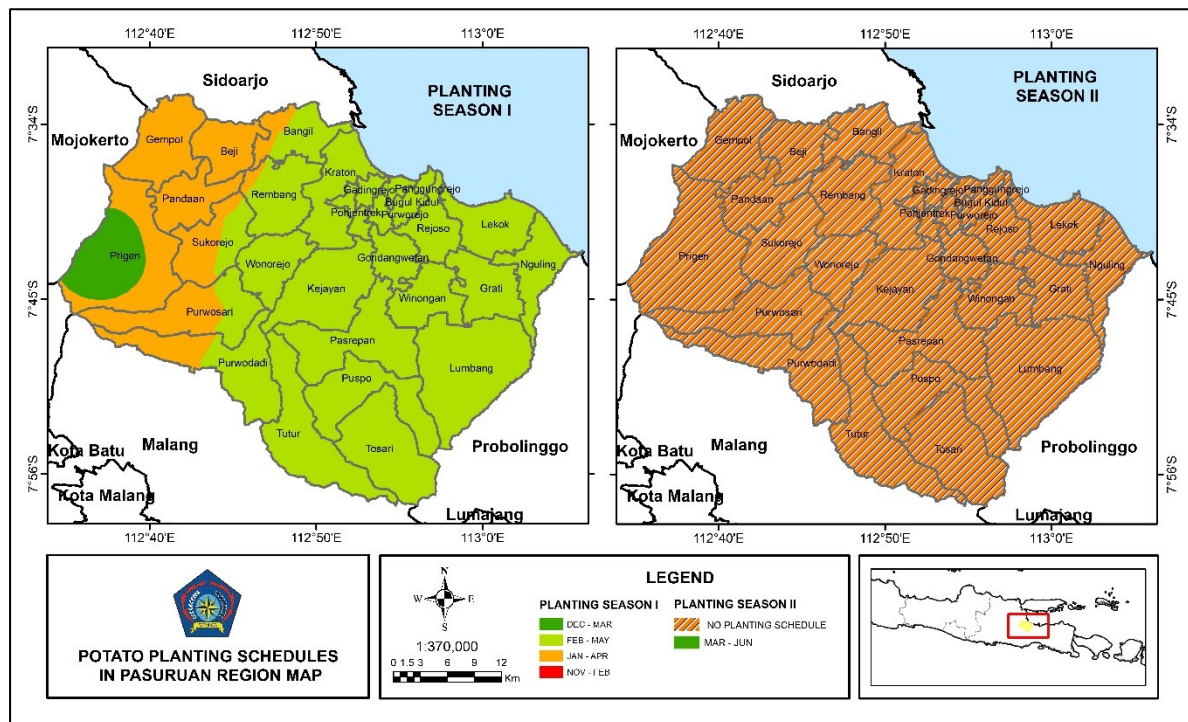


Figure 9. Potato Planting Patterns and Schedules in the Pasuruan Region

D4), on the other hand, groundwater for potato crops starts to reach field capacity from February to May. This is why the planting season is shown in light green. In areas with climate type D4, there is only one planting season because the field capacity is not reached in the months that follow. So, you can't plant potatoes right now.

The planting schedule for climate type E is the same as for climate type D4. The Pasuruan region's groundwater for potato crops reaches field capacity from February to May, which is when the planting season is. The color yellow shows this. In climate type E areas, there is only one planting season because the soil moisture doesn't reach field capacity in the months that follow. So, potatoes can't be planted. The overall outcomes of the potato planting schedule in the Pasuruan region, especially for Season 1, correspond with the results of the research conducted by Lestantyo & Marandy (2022).

Limitation of Study

This study has several limitations that should be considered when interpreting the results. First, the data used in the land water balance calculations were derived from daily climate data that were subsequently converted into monthly data. As a result, the analysis of groundwater availability and the resulting potato planting schedules are presented monthly.

This temporal resolution may not fully capture short-term fluctuations in rainfall and soil moisture conditions that can influence agricultural activities. To obtain more detailed and operational planting recommendations, future studies should apply calculations on a decadal scale so that the planting schedules can also be generated more precisely on a ten-day basis.

Second, the values of field capacity and permanent wilting point used in this study were based on available soil data that may no longer fully represent the current physical characteristics of soils in the Pasuruan region. Changes in land use, cultivation practices, and soil degradation over time can alter soil water retention properties. Therefore, updated soil surveys and recalculations of these parameters are necessary to improve the accuracy of groundwater availability estimations and land water balance analyses.

Third, this study mainly focuses on general climatic conditions and has not specifically incorporated the influence of large-scale climate anomalies that significantly affect rainfall variability in Indonesia. Phenomena such as the El Niño–Southern Oscillation and the Indian Ocean Dipole (IOD) can substantially alter precipitation patterns, dry season duration, and groundwater recharge processes in the Pasuruan region. Consequently, further studies

are needed to evaluate groundwater availability and agricultural planting schedules under different ENSO and IOD phases to develop more adaptive and climate-resilient agricultural planning strategies.

CONCLUSION

Based on research and analysis, the Pasuruan region has five climate types: C2, D2, D3, D4, and E. The monsoon rainfall pattern directly affects the amount of groundwater available each month. In general, the amount of groundwater is good for growing potatoes from January to March. It starts to go down in some places from May to October and then goes back up in November. The western part of Pasuruan, especially Pasuruan City and the area around it, is usually drier and has a longer dry season than other parts. For climate type C2, the best time to plant is from November to February for the first season and from March to June for the second season. For climate type D2, the best time to plant is from December to March for the first season; for climate type D3, the best time to plant is from January to April; and for climate types D4 and E, the best time to plant is from February to May.

ACKNOWLEDGMENT

The author expresses gratitude to the Indonesian Agency for Meteorology, Climatology, and Geophysics for the facilities and data used in this study, including the editors and reviewers of the Journal of Geography and Education, who have contributed to improving the quality of this manuscript.

REFERENCE

- Agustin, A. (2022). *Analisis Zona Klasifikasi Iklim Oldeman untuk Kesesuaian Tanaman Padi (Oryza sativa L.) di Kabupaten Lampung Timur* (Skripsi [Bandar Lampung]: Jurusan Teknik Pertanian, Fakultas Pertanian, Universitas Lampung).
- Aini, A. N., Intan, P. K., & Ulinnuha, N. (2021). Prediksi Rata-Rata Curah Hujan Bulanan di Pasuruan Menggunakan Metode Holt-Winters Exponential Smoothing. *JRST (Jurnal Riset Sains dan Teknologi)*, 5(2) 117–122. <https://doi.org/10.30595/jrst.v5i2.9702>
- Ananta, M. I., Limantara, L. M., & Soetopo, W. (2024). The Impact of Climate Change on Air Temperature in the Rainy and Dry Seasons in East Java, Indonesia: A Case Study of Climate Change in the Wlingi Dam Area. *International Journal of Environmental Impacts*, 7(2), 169–180. <https://doi.org/10.18280/ije.070202>
- Badan Pusat Statistik [BPS]. (2023). *Hasil Pencacahan Lengkap Sensus Pertanian 2023 – Tahap I Kabupaten Pasuruan*. <https://pasuruankab.bps.go.id>
- Badan Pusat Statistik [BPS]. (2025a). *Produksi Tanaman Sayuran Menurut Kecamatan dan Jenis Tanaman di Kabupaten Pasuruan, 2024*. <https://pasuruankab.bps.go.id>
- Badan Pusat Statistik [BPS]. (2025b). *Jumlah Penduduk, Laju Pertumbuhan Penduduk, Distribusi Persentase Penduduk, Kepadatan Penduduk, Rasio Jenis Kelamin Penduduk Menurut Kecamatan di Kabupaten Pasuruan, 2024*. <https://pasuruankab.bps.go.id>
- Badan Meteorologi Klimatologi Geofisika [BMKG]. (2010). *Atlas Rawan Kekeringan Provinsi Jawa Barat*. Jakarta: Badan Meteorologi Klimatologi dan Geofisika.
- Barung, F. M., & Pattipeilohy, W. J. (2020). Neraca Air Lahan dan Tanaman Padi di Kabupaten Manokwari Selatan, Papua Barat pada Tahun 2019. *Buletin GAW Bariri*, 1(1), 29–36.
- Diwa, A. T., Dianawati, M., & Sinaga, A. (2015). *Petunjuk Teknis Budidaya Kentang*. BPTP Jawa Barat: Lembang.
- Djazuli, R. A., Noor Rizkiyah, S. P., Laily, D. W., Roidah, I. S., SP, M. M. A., Setiawan, R. F., Fitriana, N. H. I., & Rozci, F. (2025). *Manajemen Pemasaran Pertanian*. UMG Press.
- Fadholi, A., & Supriatin, D. (2016). Sistem Pola Tanam di Wilayah Priangan Berdasarkan Klasifikasi Iklim Oldeman. *Jurnal Geografi Gea*, 12(2), 61-70. <https://doi.org/10.17509/gea.v12i2.1788>
- Fadila, N. (2023). *Perbandingan Usaha Tani Padi Sawah dengan Berbagai Sumber Irigasi di Kecamatan Manyak Payed Kabupaten Aceh Tamiang* (Tesis, [Medan]: Universitas Medan Area). <https://repositori.uma.ac.id/handle/123456789/20345>
- FAO. (1998). *Crop Evapotranspiration: Guidelines for Computing Crop Water*

- Requirements* (FAO Irrigation and Drainage Paper 56). Food and Agriculture Organization of the United Nations.
- Lestantyo, P., & Marandy, Y. S. (2022). Prediksi Waktu Tanam Kentang Sesuai Curah Hujan Menggunakan Analisis Spasial. *Experiment: Journal of Science Education*, 2(2), 41–50. <https://doi.org/10.18860/experiment.v2i2.24971>
- Lias, S., Amirullah, I., & Laban, S. (2020). The Potential of Water Availability in Maros Watershed using Thornthwaite-Mather water balance method. *IOP Conference Series: Earth and Environmental Science*, 486, 12135. <https://doi.org/10.1088/1755-1315/486/1/012135>
- Maulida, Y. N., Anisarida, A. A., & Hafudiansyah, E. (2022). Kajian Neraca Air Daerah Irigasi Ciherang Kabupaten Bandung Provinsi Jawa Barat. *Jurnal Teknik Sipil Cendekia*, 3(1), 1–13. <https://doi.org/10.51988/jtsc.v3i1.47>
- Oldeman, L. R., & Frere, M. (1982). *A Study of The Agrometeorology of The Humid Tropics of South East Asia* (WMO Technical Note No. 179; WMO No. 597). World Meteorological Organization.
- Park, H. H., Ei, E., & Kuk, Y. I. (2025). Effects of Climate Variation on Spring Potato Growth, Yield, and Quality in South Korea. *Agronomy*, 15(1), 149. <https://doi.org/10.3390/agronomy15010149>
- Pawitan, H., Irsal, L., Heny, S., Rizaldi, B., Handoko, & Baharsjah, J. S. (1996). *Implementasi Pendekatan Strategis dan Taktis Gerakan Hemat Air*. Seminar Nasional Pemantapan Gerakan Hemat Air untuk Mengoptimalkan Pemanfaatan Sumberdaya Air, Jakarta.
- Perwitasari, S. N., Situmorang, Y., Asdak, C., & Pithaloka, N. (2025). Water Balance Analysis Using the Thornthwaite-Mather Method as a Basis for Cropping Pattern Development in Dry Land. *Journal of Agricultural Engineering*, 14, 547. <https://doi.org/10.23960/jtep-l.v14i2.547-559>
- Prawaka, F., Zakaria, A., & Tugiono, S. (2016). Analisis Data Curah Hujan yang Hilang dengan Menggunakan Metode Normal Ratio, Inversed Square Distance, dan Rata-rata Aljabar. *Jurnal Rekayasa Sipil dan Desain*, 4(3), 397–406.
- Safitri, U. R., Mahdalena, O., Annisa, N., Aisyah, D., Aini, Q., & Eka, S. (2025). Analisis Tantangan Musiman yang Berdampak pada Ketersediaan Stok Bisnis Durian di Tamansari. *Jurnal Ekonomi, Sosial & Humaniora*, 7(1), 31–36.
- Shock, C. C., Pereira, A. B., & Eldredge, E. P. (2007). Irrigation best management practices for potato. *American Journal of Potato Research*, 84(1), 29–37. <https://doi.org/10.1007/BF02986296>
- Sitanggang, W. R., Amaru, K., & Sampurno, R. M. (2022). Analisis Neraca Air Metode Thornthwaite-Mather pada Budidaya Tanaman Jagung Manis Menggunakan Sistem Irigasi dan Mulsa. *Seminar Nasional Penelitian dan Pengabdian kepada Masyarakat Universitas Muhammadiyah Metro*, 4(1), 84–96.
- Subardi. (2023, February 22). *Atasi Harga Jatuh, Kementan Susun Jadwal Tanam Berbasis Kebutuhan Riil*. Kementerian Pertanian Republik Indonesia. <https://hortikultura.pertanian.go.id/atasi-harga-jatuh-kementan-susun-jadwal-tanam-berbasis-kebutuhan-riil/>
- Sugiyanti, S. (2012). *Analisis Tingkat Bahaya Longsorlahan di Kecamatan Tosari Kabupaten Pasuruan Provinsi Jawa Timur* (Skripsi, [Surakarta]: Universitas Muhammadiyah Surakarta).
- 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.
- Sujalu, A. P., Ismail, I., Hardwinarto, S., Boer, C., & Sumaryono, S. (2014). *Analysis of water balance for determine cropping patterns for food crops in watershed Karangmumusthe province of East Kalimantan*. *AgroLife Scientific Journal*, 3(2), 68-74.
- Sumunar, A. A. K., & Budiman, S. (2021). Proyeksi Ketahanan Pangan Provinsi Nusa Tenggara Timur Tahun 2015-2045 Ditinjau dari Ketersediaan, Kebutuhan, dan Persediaan Beras. *Sepa: Jurnal Sosial Ekonomi Pertanian dan Agribisnis*, 18(1), 80–91.

- <https://doi.org/10.20961/sepa.v18i1.47131>
- Syahrudin., Fatmawati., & Suprajitno, H. (2023). Long-Term Forecasting of Crop Water Requirement with BP-RVM Algorithm for Food Security and Harvest Risk Reduction. *International Journal of Safety & Security Engineering*, 13(3), 565-575.
<https://doi.org/10.18280/ijssse.130319>
- Thornthwaite, C. W., & Mather, J. R. (1957). *Instructions and Tables for Computing Potential Evapotranspiration and The Water Balance*. Drexel Institute of Technology, Laboratory of Climatology.
- Uspessy, J. F., Laimheheriwa, S., & Patty, J. R. (2020). Penentuan Musim Tanam Berdasarkan Perhitungan Neraca Air Lahan di Daerah Saumlaki, Pulau Yamdena. *Jurnal Budidaya Pertanian*, 16(2), 173–179.
<https://doi.org/10.30598/jbdp.2020.16.2.173>
- Wahyuni, I., Adipraja, P. F. E., & Mahmudy, W. F. (2018). Determining Growing Season of Potatoes Based on Rainfall Prediction Result Using System Dynamics. *Indonesian Journal of Electrical Engineering and Informatics*, 6(2), 210–216.
<https://doi.org/10.11591/ijeei.v6i2.315>
- Wei, T. C., & McGuinness, J. L. (1973). *Reciprocal Distance Squared, a Computer Technique for Estimating Area Precipitation* (Technical Report ARS-NC-8). U.S. Agricultural Research Service, North Central Region.
- Yulianti, V., Impron, & Pramudia, A. (2023). The Optimum Planting Time and Cropping Pattern of Potatoes and Other Horticultural Commodities Based on Water Balance in Solok, Indonesia. *Agromet*, 37(1), 1–11.
<https://doi.org/10.29244/j.agromet.37.1.1-11>



Copyright (c) 2026 by the authors. This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).