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Potential rainwater availability and crop water requirement of oil palm crops due to climate change

N D Dharmawati [1,2*], S Suntoro [1], K Komariah[1] and H Hermantoro [2]

1 Doctoral Program of Faculty of Agriculture, Sebelas Maret University Surakarta, Indonesia.
2 Department of Agricultural Engineering, Faculty of Agricultural Technology, Stiper Agricultural Institute, Yogyakarta Indonesia

*E-mail: nuraenidharmawati@student.uns.ac.id

Abstract.

Climate change affects rainfall variability and impacts water availability, rainfall patterns, and the water requirements of oil palm plants. This research aims to analyze rainfall patterns, predict water availability from rainfall with an 80% reliability level, and calculate the water requirements of oil palm plants at various growth stages. The study was conducted using climate data from 2012 to 2023 in Ketapang District, West Kalimantan, Indonesia. The results indicate that the rainfall pattern in the Ketapang region has two peaks, occurring in May and December. Water availability predicted at an 80% probability shows the highest rainfall in December and the lowest in August, with a tendency for rainfall to exceed the 10-year average (2012–2022). The water requirements of immature oil palm plants, aged 2–5 years, range from 996.79 mm/year to 1045.42 mm/year, while the water requirements of mature plants aged 6–9 years range from 1118.35 mm/year to 1130.51 mm/year.

Keywords: climate change, water availability, rainfall patterns, water requirements, evapotranspiration

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1. Introduction

Climate change has significantly altered rainfall patterns over time, affecting both intensity and frequency. Studies indicate increased rainfall values in some parts of Indonesia, accompanied by decrease in the frequency of heavy rains. Climate variability and extreme climate events frequently occur, leading to complex changes in rainfall distribution. For instance, region of Indonesia influenced by monsoon climates show marked differences between wet and dry seasons.

Shifts in rainfall patterns caused by climate change impact irrigation water availability. Areas that previously experienced substantial rainfall now face prolonged droughts, while typically dry region are increasingly prone to flooding. Prolonged rainfall variability and eratic weather pattern disrupt agricultural water management. Insufficient rainfall may lead to crop failure, while excessive rainfall result in floods. The effects of climate change on water resources include: a) an increase in rainfall intensity during the wet season (extreme rainfall); b) more frequent and severe flooding (extreme floods); c) a reduce rainfall and extended dry season leading to drought conditions.

The impacts of climate change on water availability are both direct and indirect. Variables such as rainfall, humidity, and sunshine duration are among the climate factors affected. These changes signifantly influence water availability for crops, particularly oil palm. Altered rainfall patterns, both in intensity and seasonal distribution, create challenges for ensuring sufficient water resources. Analysis of rainfall data from 2013 to 2022 provides insight into trends in rainfall patterns and the estimation of potential rainfall with an 80% reliability level.

Understanding changes in rainfall patterns and climate variability is crucial for effective water management in oil palm plantations. Water availability for oil palm plants in Indonesia is influenced by a tropical climate with two primary seasons: wet and dry [1]. However, climate change introduces uncertainties in water availability due to altered rainfall patterns. Studies highlight are direct correlation between rainfall variability and oil palm productivity, as fresh fruit bunch (FFB) yields decrease significantly during periods of water deficits [2,3].

Water availability is critical for oil palm productivity [4]. Water plays a vital role in supporting growth, development, and overall yield by enabling photosynthesis, nutrient absorption, and fruit bunch formation [3]. Water scarcity, exacerbated by climate change, limits these processes, delaying the opening of spear leaves, disrupting the sex ratio, impairing fruit bunch development [4]. This vulnerability may lead to yield reductions of up to 30% under adverse climatic cconditions [5].

Oil palm (*Elaeis guineensis*) native to southwestern Africa, is now widely cultivated in tropical regions. Thriving in lowland areas with annual rainfall between 2,000 and 2,500 mm, oil palm relies on adequate water and favorable soil conditions for optimal growth [6]. Studies have shown that the water footprint of oil palm cultivation, averaging 1,002.1 m3 per ton of FFB, is lower than that of other oi;-producing crops, with most water sourced from precipitation rayhet than groundwater [7].

Each growth phase of oil palm has different water requirements, particulary during the juvenile phase, when the root system is still developing. Proper water management ensures strong root formation and optimal front development.

Water requirement for plants can be defined as the amount of water required to fulfill water loss through evapotranspiration from plants [8]. The daily water requirement for oil palm plants can vary significantly based on environmental conditions, particularly temperature, relative humidity, and solar radiation. Several studies related to the water requirements of oil palm plants have been conducted using various methods. Oil palms typically transpire approximately 6 mm of water daily under optimal conditions; thus, consistent rainfall is crucial for maintaining healthy growth rates. Oil palm requires water in the range of 1,500–1,700 mm of rainfall equivalent per year. The water requirements of oil palm are almost the same as those for sugarcane, which range from 1,000 to 1,500 mm per year [9]. Another study based on climate data from 2002 to 2012 using the Thorthwaite & Mather method [10], found that the average value of plant evapotranspiration (ETc) in oil palm plantations is 100 mm/month, or equivalent to 1,196 mm/year, with a percentage calculation of 52.36% of the annual rainfall opportunity at 75%. Oil palm requires a larger water supply of about 4.10 to 4.65 mm/day. However, the water requirement is actually almost the same as the water requirement of food crops such as rice, corn, and soybean [11].

The calculation of water requirements for oil palm plants in the Central Kalimantan region using the Penman - Mounteith method and climatic data for April - May 2017 [12], revealed that daily water usage ranges between 3.07 to 3.73 mm. Older palms tipycally require more water due to increased root density, with the annual evapotranspiration (ETa) for oil palm is estimated to range 948.7 to 1,323.7 mm, averaging approximately 1,223.8 mm.

Comprehensive research is essential to estimate the water requirements of oil palm plants using long-term average climate data. This study employed the Penman-Monteith method, utilizing on climatic parameters such as maximum and minimum daily temperatures, air humidity, wind speed, and sunshine duration. The data were sourced from the BMKG station in Ketapang District, West Kalimantan, spanning 2013 to 2022. For a deeper analysis of water requirements, the Modified Penman-Monteith method can be applied to calculate potential evapotranspiration (ETo) and effective rainfall, offering a more accurate assesment of plant water needs under diverse climatic conditions [13].

In addition to influencing rainfall patterns and water availability, climate change affects crop water requirements through potential evapotranspiration (ETo) and actual evapotranspiration (ETc). Potential evapotranspiration (ETo) represents the water required by plants under optimal conditions, reflecting environmental factors like climate and vegetation. Understanding ETo and its relationship with rainfall helps evaluate water availability and determine crop water needs.

This study aims to calculate the potential rainwater availability with an 80% probability and assess actual evapotranspiration as an indicator of oil palm water demand. It evaluates the adequacy of rainwater to support oil palm growth by analyzing rainfall and climate data from the BMKG station in Ketapang District, West Kalimantan (2013 – 2022). By applying the Modified Penman – Montheit method, the research provides a comprehensive evaluation of potential water availability and the water requirements of oil palm plants at various growth stages.

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2. Material and Methods

2.1. Analysis of rainfall data
Rainfall data is utilized to calculate the potential availability of water, expressed as rainfall with an 80% reliability level. The data was obtained by downloading daily rainfall records from 2012 to 2022 from the Meteorology, Climatology, and Geophysics Agency (BMKG) station in Ketapang,

West Kalimantan. The daily rainfall data was aggregated to calculate the total rainfall for each month. Subsequently, the monthly totals were averaged to determine the monthly average rainfall over the ten-years periods. This average monthly rainfall data was then sorted from smallest to largest, and the probability of future rainfall events was calculated using the following formula:

$$P = \frac{m}{n + 1} \times 100\ \%$$

where :
P : rain probability
M : rank order number
n : number of data

Furthermore, monthly rainfall data is selected that has an 80% chance of occurrence or called rainfall with a reliability level of 80%.

2.2. Climate Data Analysis

The climate data parameters used to calculate potential evapotranspiration (Eto) include: minimum temperature (Tn), maximum temperature (Tx), average humidity (RH_avg), sunshine duration (ss), maxsimum wind speed (ff_x). The climate data analyzed covers 10-years periods, from 2013 to 2022. Potential Evaportranspiration (ETo) is calculated using the Modified Penman Monteith Method.

$$Eto = \frac{0,48 * \Delta\ (Rn-G) + g\ [Cn/\ (T+278)]\ M2\ (es-ea)}{\Delta + g\ (1+Cd)}$$

where:
ETo = reference evapotranspiration (mm day^{-1});
Rn = net radiation at the crop surface (MJ m^{-2} day^{-1});
G = soil heat flux density (MJ m^{-2} day^{-1});
T = mean daily air temperature at 2 m height (_C);
u2 = wind speed at 2 m height (m s^{-1});
es = saturation vapor pressure (kPa);
ea = actual vapor pressure (kPa);
es – ea = saturation vapor pressure deficit (kPa);
D = slope vapor pressure curve (kPa $\_C^{-1}$);
g = psychrometric constant (kPa $\_C^{-1}$);
Cn = numerator constant for reference type and calculation time step, aerodynamic resistance where the constant was 900 for daily, and 37 for hourly daytime and night-time;
Cd = denominator constant for reference type and calculation time step. Bulk surface resistance and aerodynamic resistance where the constant was 0.34 for daily, 0.24 for hourly daytime, and 0.96 for hourly night-time.

The water requirement of oil palm plants is approached by calculating the actual evapotranspiration value, with the formula:

$$ETc = Eto \times Kc$$

Where: ETc = actual evapotranspiration (mm/day)
ETo = Potential evapotranspiration (mm/day)
Kc = Plant coefficient

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Table 1 shows the age of the plant and the value of the crop coefficient (Kc) of oil palm.

Table 1. Table 1. Plant age and coefficient value of oil palm

Age (year)	Leaf Area Index	Crop Coefficient (Kc)
< 2	1.8	0.82
2 – 2.9	3.1	0.83
3 – 4,9	4.0	0.86
5 – 6.9	4.9	0.92
7 – 8.9	5.1	0.93
>= 9	6.4	0.93

3. Results and Discussion

3.1. Analysis of Potential Water Availability from Rainfall

Water availability is a critical factor influenced by various environmental and climatic conditions. Estimation of potential water availability based on rainfall data is used to determine the adequacy of water availability for oil palm plants. Monthly rainfall data obtained from downloading data from BMKG Ketapang Regency West Kalimantan for ten years from 2012 - 2022 is presented in Table 2.

Table 2. Rainfall Data for A Period Of 2013-2022

	Monthly Rate Rainfall (mm/day)											
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2013	6.25	10.33	3.89	13.07	18.39	6.24	12.78	1.93	5.05	0.00	7.37	12.51
2014	3.34	2.76	4.91	6.14	8.28	7.44	1.25	4.49	0.00	5.62	12.20	16.04
2015	20.54	33.13	18.60	12.06	24.90	4.30	10.83	1.20	0.00	8.16	19.34	25.54
2016	16.34	16.58	8.65	15.51	14.72	11.46	16.71	1.33	9.87	12.77	14.15	10.04
2017	15.78	10.13	5.04	16.77	8.57	7.26	7.85	6.38	3.40	4.83	13.32	13.60
2018	11.27	6.87	16.94	9.29	19.83	8.00	0.84	0.74	2.84	15.13	9.69	19.94
2019	10.58	19.51	7.31	20.98	4.82	13.13	2.28	0.67	0.66	6.15	10.02	15.83
2020	18.71	15.43	20.56	13.52	16.15	14.68	14.72	4.42	8.41	12.10	24.69	8.54
2021	21.40	2.33	9.73	9.13	9.09	12.11	8.26	12.94	24.87	13.98	24.99	27.12
2022	10.95	14.96	9.46	9.46	10.39	12.46	8.50	20.95	15.58	15.58	13.57	15.53

Based on the rainfall data in Table 2, the average rainfall for 10-year period from 2012 to 2023 was calculated and arranged in ascending order, from the smallest to the largest rainfall values. The probability of occurrence for each data point was then determined, and rainfall with an 80% probability was selected as the measure of potential water availability in the Ketapang District and surrounding areas.

The 80% reliable rainfall (R80) is a metric commonly used in water management planning to estimate the amount of rainfall that can be expected with 80% reliability, meaning there is a 20% probability that rainfall will fall below the specified value. R80 is particulary valuable in agriculture, where it helps ensure sufficient water availability for crops [14].

In oil palm plantation water management, understanding reliable rainfall is crucial for estimating water availability, identifying periods of drought and water surplus and efficiently managing water resources. This knowledge enables effective water conservation during surplus periods and supports sustainable water use. Accurate rainfall prediction is vital for improving agricultural productivity, managing water resources, mitigating flash floods, adapting to climate change, and enhancing public safety through disaster preparedness and management startegies [15-17].

Rainfall prediction with 80% probability are particularly useful for the anticipating extreme rainfall events, which has significant implications for water resources management. In this study, prediction for extreme rainfall with high probability indicated that such events are most likely occur in February, with a propability value of 0.940 [18].

From Table 3, a comparison of average rainfall and 80% probability rainfall reveals clear monthly rainfall variability. The average rainfall at 80% probability shows a higher rate of 15.07 mm/day. When compared to the 10- year rainfall data from 2012 to 2023, predictions of potential future water availability suggest water condition, as the average monthly rainfall is higher. This is in aligns with the findings of Rosita Rahim et al. [19], who note that regional weather studies indicate a significant upward trend in rainfall across the Indonesian region, including West Kalimantan. In Ketapang Regency, annual rainfall during the 2011-2020 period consistently exceeded 2,000 mm/year, which is higher than the historical average.

Table 3. Average Rainfall Table with 80% Probability of Rainfall

Month	Average	80% probability
Jan	13.51	18.71
Feb	13.20	16.58
Mar	10.19	16.94
Apr	12.59	15.51
May	13.51	18.39
Jun	9.71	12.46
Jul	8.40	12.78
Ags	5.51	6.38
Sept	7.07	9.87
Oct	10.27	13.98
Nov	14.93	19.34
Dec	16.47	19.94

Based on rainfall prediction with 80% probability, December has the highest rainfall value at 19.94 mm/day, making it the wettest months. The dry period occurs in August, with rainfall 6.38 mm/day. This aligns with data from BMKG, which indicates that in 2023, November had the highest average rainfall in Ketapang at 326 mm, while August recorded the lowest average rainfall at 88 mm. Figure 1 illustrates the averagee rainfall pattern alongside 80% probability rainfall.

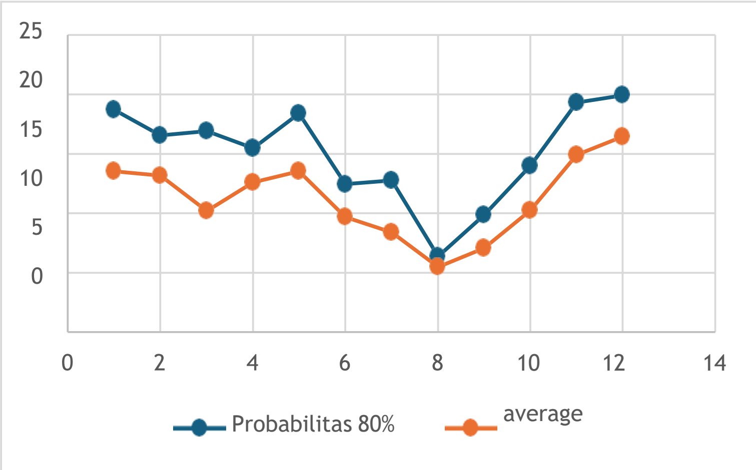

Figure 1. Average Rainfall Graph with 80% Probability

Figure 1 shows that the highest rainfall with 80% probability occurs in Decemberat 19.94 mm/day, followed by a secondary peak in May at 18.31 mm/day. The lowest rainfall occurs in August with a value of 6.38 mm/day. The Fast Fourier Transform analysis by [20] reveals that the rainfall pattern in Ketapang as well as in Samarinda, Sendawar, Tarakan, Tanjung Selor, Malinau, Pangkalan Bun, Ketapang and Sintang follows an equatorial pattern.

As depicted in Figure 1, the Ketapang area exhibits a bimodial rainfall distribution, characterized by two peak rainy season in December and May. Locations near the equator typically experience high rainfall with two distinct rainy periods annually, a phenomenon referred to as a bimodal rainfall pattern [14].

3.2. Potential Evapotranspiration and Water Requirements of Oil Palm Plants

Potential evapotranspiration (ETP is the potential amount of water lost through evaporation and transpiration, under optimal conditions, assuming no water shortages and a soil surface fully covered by plans [21]. It is calculated based on climate data and represents the rate of evaporations that occurs when water and soil moisture are consistently available [22]. The climate parameters used to calculate potential evapotranspiration include minimum and maximum temperatures, relative humidity, wind speed, solar radiation and sunshine duration.

Table 4 presents average climate data for the 2013–2022 periods and the corresponding potential evapotranspiration (Eto)calculations. The data include daily temperature, rainfall, relative humidity, and wind speed. Analysis of the table reveals that the average daily temperature ranges from 23.5°C to 32.1°C throughout the year, indicating a consistently warm conditions. The average relative humidity is 81 %, and the potential evapotranspiration is calculated at 3.3 mm/day.

The potential evapotranspiration value represents the expected rate of water loss in Ketapang District are of West Kalimantan, calculated using these climate parameters. The value of

3.4 mm/day indicates the potenial for evapotranspiration under the given climate conditions, highlighting the water requirements of the region.

Table 4. average climate data from 2013 – 2022 and the results of potential evapotranspiration

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m^2/day	ETo mm/day
January	23.5	32.3	84	2	4	14.8	3.12
February	23.7	32.1	84	2	4	15.4	3.25
March	23.9	32.4	84	2	4.2	16	3.41
April	24.1	32.3	82	2	4.8	16.6	3.5
May	24.4	32.4	84	2	5.3	16.6	3.49
June	23.9	32.2	82	2	5	15.7	3.25
July	23.4	32.6	82	2	5.5	16.6	3.44
August	22.3	31.4	77	2	5.2	16.8	3.38
September	23	32.2	78	2	4.2	15.8	3.31
October	21.6	30	72	2	4.2	15.7	3.07
November	23.8	32.7	83	2	4.4	15.4	3.21
December	23.9	32.3	83	2	4.4	15.1	3.17
Average	23.5	32.1	81	2	4.6	15.9	3.3

The highest potential evapotranspiration occurred in May at 3.49 mm/day, coinciding with the longest sunshine duration during the year. ETo exhibited seasonal variations, peaking during the drier months. Relative humidity remained consistently high throughout the year, ranging from 72% to 84%, creating relatively humid environmental conditions. Average wind speeds varied slightly but generally stayed within an acceptable range for optimal plant growth.

After calculating the potential evapotranspiration, the water needs of oil palm plants at different growth stages were estimated by multiplying Eto by the crop coefficient (Kc) Young plants under 2 years old, the Kc value is 0.82; for plants aged 2 - 2.9 years, it is 0.83; and for plants aged 3 - 3.9 years, the Kc value is 0.86. The calculated water requirements for young immature plants (TBM) are presented in Table 5.

Table 5, it is shown that the water requirement of young oil palm plants vary with age. Plants less than 2 years old require 996.79 mm/year, those aged of 2 – 2.9 years require 1008.95 mm/year, and plants aged of 3 – 3.9 years require 1,045.42 mm/year. When compared to the to the water availability from rainfall with an of 80% probability, the rainfall sufficient to meet the water needs of oil palm plants throughout the year; resulting in a water surplus of 2,877.78 mm/year. Additionally, the annual actual evapotranspiration (ETa) for oil palm plants in the Central Kalimantan region is estimated range between 948.7 and 1,323.7 mm, with an average of approximately 1,223.8 mm [9]. The data in Table 5 also highlight differences actual Evapotranspiration (ETa) for oil palm plants before during their non-productive period (TBM). Plants less than 2 years old have an actual evapotranspiration of 996.79 mm/year, increasing to

1008.95 mm/year for plants aged 2 to 2.9 years, and 1045.42 mm/year for plants aged 3-4.9 years. This trend indicates that younger oil palm plants exhibit lower actual evapotranspiration values compared to older ones.

Table 5. The Actual Evapotranspiration for Young Oil Palm Plants (TBM)

Month	Eto	Kc	Eta >2 year	Kc	Eta 2-2.9 year	Kc	Eta 3 – 3.9 year	Rain	Surplus
Jan	100.5	0.82	82.41	0.83	83.42	0.86	86.43	410.7	324.27
Feb	105	0.82	86.10	0.83	87.15	0.86	90.30	397.5	307.20
Maret	94.2	0.82	77.24	0.83	78.19	0.86	81.01	253.1	172.09
April	101.7	0.82	83.39	0.83	84.41	0.86	87.46	366	278.54
Mei	100.5	0.82	82.41	0.83	83.42	0.86	86.43	403.8	317.37
June	98.4	0.82	80.69	0.83	81.67	0.86	84.62	291.7	207.08
July	103.8	0.82	85.12	0.83	86.15	0.86	89.27	284.1	194.83
Augst	111.3	0.82	91.27	0.83	92.38	0.86	95.72	159.6	63.88
Sept	114	0.82	93.48	0.83	94.62	0.86	98.04	167.8	69.76
Oct	94.2	0.82	77.24	0.83	78.19	0.86	81.01	338.7	257.69
Nov	95.7	0.82	78.47	0.83	79.43	0.86	82.30	359.6	277.30
Dec	96.3	0.82	78.97	0.83	79.93	0.86	82.82	490.6	407.78
Total Amount			996.79		1,008.96		1,045.41	3923.2	2,877.78

Table 6 provides the calculated water requirement for mature, productive oil palm plants aged of 5 - 6.9 years, 8 - 9 years, and those over 9 years. Based on the potential evapotranspiration value, the actual evapotranspiration (Eta) for oil palm plants has been calculated. The results are presented in Table 6. The actual evapotranspiration values indicate the water requirement for oil palm plants at various ages 1,118.35 mm/year, for plants aged 5-6.9 years, 1,130.51 mm/year for plants aged of 7 - 8.9 years and 1130.51 mm/yea for plants older than 9 years. Figure 2 illustrates the water balance graph showing the relationship between water availability (at an 80% probability) and the actual evapotranspiration of oil palm plants. For plants older than 9 years, the graph reveals a water surplus throughout the year, amounting to 2,792.69 mm/year.

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Table 6. Actual Evapotranspiration of Productive Oil Palm Plants (TM)

Month	ETo	Kc	Eta 5-6.9 year	Kc	Eta 8-9 year	Kc	Eta > 9 year		Surplus
Jan	10.,5	0.92	92.46	0.93	93.47	0.93	93.47	410.7	317.24
Feb	105	0.92	96.60	0.93	97.65	0.93	97.65	397.5	299.85
March	94.2	0.92	86.66	0.93	87.61	0.93	87.61	253.1	165.49
April	101.7	0.92	93.56	0.93	94.58	0.93	94.58	366	271.42
May	100.5	0.92	92.46	0.93	93.47	0.93	93.47	403.8	310.34
June	98.4	0.92	90.53	0.93	91.51	0.93	91.51	291.7	200.19
July	103.8	0.92	95.50	0.93	96.53	0.93	96.53	284.1	187.57
Augs	111.3	0.92	102.40	0.93	103.51	0.93	103.51	159.6	56.09
Sept	114	0.92	104.88	0.93	106.02	0.93	106.02	167.8	61.78
Oct	94.2	0.92	86.66	0.93	87.61	0.93	87.61	338.7	251.09
Nov	95.7	0.92	88.04	0.93	89.00	0.93	89.00	359.6	270.60
Dec	96.3	0.92	88.60	0.93	89.56	0.93	89.56	490.6	401.04
Amount			1118.35		1130.51		1130.51	3923.2	

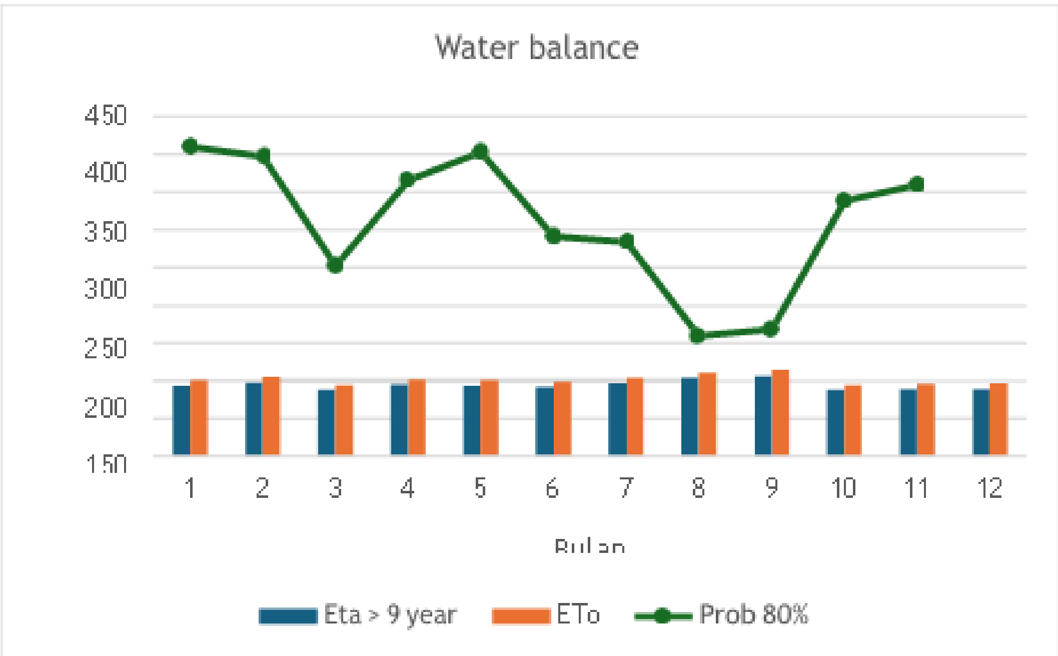

Figure 2. The water balance graph

4. Conclusion

Climate change has introduced significant uncertainty in rainfall patterns, affecting variability based on regional and geographical conditions. The Ketapang region exhibits an equatorial rainfall pattern with a bimodal distribution, characterized by two peaks rainy seasons in December and May. The potential water availability, calculated at an 80% rainfall probability, shows a higher average compared to the 2012-2022 historical rainfall data, with an 80% average rainfall value of 15.07 mm/day. The highest rainfall occurs in December (19.94 mm/day), while the driest period is in August, with rainfall at 6.38 mm/day.

Climate change also influences evaporation and transpiration rates in oil palm plants, which are critical factor in determining their water requirements. The water requirements of immature, non productive oil plam plants (TBM) vary based on age: plants under 2 years require 996.79 mm/year, those aged 2-2.9 year require 1,008.95 mm/year, and those aged 3-4.9 years require 1,118.35 mm/year and 1,130.51 mm/year. Despite these variations, the available water potential, with an 80% propability, is sufficient to meet the water requirements of oil palm plants at all growth stages

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References

[1] Veranica N 2014 *Anterior Jurnal* **13** (2) pp 16 –172
[2] Ardiyanto A, Murtilaksono K, Wahjunie, D E, & Sutandi A 2021 *Jurnal Penelitian Kelapa sawit* 29 **1** ,pp 11-20
[3] Burhani D. 2021 *The Jakarta Post Jakarta* Mon, March 22, 2021
[4] Gunawan S, Budiastuti M T S, Sutrisno J, Wirianata H. 2020 *IJASEIT* **10** 1 pp 356-361
[5] Junaedi Y M, Darmawan, B Baba. 2021 *J Agroplantae* **10** 2 pp 114–23
[6] Harahap FS, Purba J, Rauf A. 2021 *Agrikultura* **32** pp 37-42
[7] Safitri L, Hermantoro H, Purboseno S, Kautsar V, Saptomo S, Kurniawan A. 2018 *Water* **11** pp 2-26
[8] Pasaribu H, Mulyadi A, Tarumun S. 2012 *Jurnal Ilmu Lingkungan* **6** pp 953-960
[9] Harahap I Y, Darmosarkoro W. 1999 *Jurnal Penelitian Kelapa Sawit* **7 2** pp 87-104
[10] Thornthwaite CW. 1948 *JSTOR* **38** 1 pp 55–94. Available from: https://www.jstor.org/stable/210739
[11] Murtilaksono K, Siregar H H, Darmosarkoro W, Hidayat Y. 2013 *Prosiding Konggres HITI IX Yogyakarta* pp 162-171
[12] Nugroho B D A, Utami S N H, Purwanto B H. 2019 *Agritech* **39** 2 pp 108–8
[13] Ludji R K, Yamin M, Dewi N M N B S. 2023 *Sosial Sains dan Teknologi* **3** 1 pp 54-64
[14] Rakhim R, Pattipeilohy W J. 2022 *Buletin Meteorologi, Klimatologi, dan Geofisika* **3** 5 pp 35-43
[15] Mungale N, Shinde J. 2024 *International Jornal of Intelligent Systems and Applications in Engineering* **12** 125 pp 380-393
[16] Munir AQ, Ismanto H. 2023. *Jurnal Ilmu Pengetahuan dan Teknolgoi Komputer* **9** 1 pp 30-39
[17] Bedane H R, Beketie KT, FantahunE E, Feyisa GL, Anose F A. 2022, *Environmental Sytems Research* **11** 1 pp 1-19
[18] Mondiana Y Q, Zairina A, Sari R K. (2022) *Journal of Forest Science* **4** 2 pp 96-101
[19] Hidayah, Ridlotul R, Sri N, Elis K. 2020 *Scientific Repository IPB University*
[20] Tukidin 2010 *Jurnal Geografi* **7** 2 pp 136-145
[21] Nuryanto DE, Rizal J. 2013 *Jurnal Meteorologi dan Geofisika* **14** 2 pp 75-85
[22] Wilnaldo A, Putra Y S, Adriat R. 2020 *Prisma Fisika* **8** 3 pp 165-171