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DROUGHT ANALYSIS USING VARIOUS DROUGHT INDICES IN SUB-DISTRICT NGEMPLAK

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Abstract

The study namely Drought Analysis Using Various Drought Indices in District Ngemplak, Boyolali offers a comprehensive examination of drought phenomena in the Ngemplak, Boyolali district through the lens of various drought indices, aiming to understand the impact on agricultural productivity and propose effective water management strategies. Using data from 2009 to 2023, this study used SPI and PDSI. Focusing on the Ngemplak, Boyolali district, this research identifies the most relevant drought indices tailored to the local climatic and geographical contexts, analyzes the correlation between these indices and the productivity of primary crops, and suggests sustainable water management practices to mitigate drought risks. The study underscores the importance of adopting a multifaceted and adaptive water management framework, incorporating sophisticated irrigation technologies, and fostering policy reforms to enhance water use efficiency and resilience against climatic variability. It calls for collaborative efforts involving stakeholders across different sectors to implement these recommendations, ensuring the sustainability of water resources and agricultural productivity in the face of drought challenges.

***Keywords**: Agricultural Productivity, Drought Analysis, Drought Indices, Water Management Strategies*

1. INTRODUCTION

Water is a fundamental resource needed to sustain life, promote economic growth, and maintain environmental integrity. Among the various threats to water security, drought is considered one of the most devastating natural phenomena, leading to severe socio-economic and environmental impacts. (Arra, A.A. & Şişman, E., 2024; Jin, et al., 2024; Avia et al., 2023; Adhyani et al., 2017a; Wilhite, 2000). Climate change, characterized by changes in temperature and rainfall patterns, exacerbates the occurrence and severity of drought events worldwide (Korkmaz, M, & Alban Kuriqi, A., 2024; Morsidi, 2017; Adhyani et al., 2017b; Keyantash & Dracup, 2002). Although there is existing research on drought analysis using various indices, this study focuses specifically on Ngemplak sub-district in Indonesia. Fig 1. Shows the map of Ngemplak sub-district, Boyolali Regency, Indonesia.

Fig. 1. Location of Ngemplak sub-district

There is a dearth of in-depth, localized research that applies these indices to these specific geographic and climatic contexts. Unlike many studies that apply a single drought index to evaluate drought conditions, this study proposes the use of multiple indices. This approach is expected to offer a more comprehensive understanding of drought conditions in the district. In addition to proposing management strategies based on findings, this study also seeks to provide a cost assessment of these strategies. The integration of economic feasibility assessments distinguishes this study. from many previous studies that did not include such an analysis in its scope. While Boyolali district faces drought and flood risks, the study only focuses on understanding and addressing drought conditions. This focus on single extreme climate is a defining characteristic that sets this study apart from studies that cover a broader scope of water-related risks.

The problem of drought, a complex climatic phenomenon, is especially important in areas where agriculture plays an important role, such as in Boyolali district. Despite the serious implications, there is an inadequate understanding of drought patterns in the Boyolali district. While rainfall data are readily available, comprehensive assessments using multiple drought indices to evaluate drought severity, duration, and spatial levels have not been conducted extensively (Nikmatillah et al., 2018).

The existing body of literature includes a large number of global drought indices such as the Standard Rainfall Index (SPI) ((Adnan et al., 2018; Arnone et al., 2020; Cheval, 2015), Palmer Drought Severity Index (PDSI) (Yu et al., 2019), and the Crop Moisture Index (CMI) (Tabari & Hosseinzadeh Talaee, 2013), which offer a standardized approach to drought quantification. However, there seems to be a dearth of research focusing on the application of this index in the unique climatic and geographical context of Boyolali district. This raises the question of whether these indices, when used without localization or calibration, accurately represent the actual drought conditions experienced in the district. The purpose of this study is to identify the most relevant drought indices between SPI and PDSI to be applied in Ngemplak Boyolali District by considering its geographical and climatic characteristics and recommend water management strategies based on drought analysis to reduce the risk of drought in Ngemplak Boyolali.

2. METHODOLOGY

In this study, the data collection method used was secondary data. Data sources come from a variety of sources. Information on rainfall data is obtained through the PUSDATARU Service of Central Java Province. In addition, climatological data was obtained from the PUSDATARU Service of Central Java Province. To make the preparation simpler, research involves several stages. At the initial stage, calculate the consistency of rainfall data, then calculate evapotranspiration and water holding capacity, then calculate SPI and PDSI.

2.1 Rainfall Data Consistency Test

Before being implemented, the rainfall data should be checked for its consistency first. The method used in testing the consistency of rain data is the RAPS *(Rescaled Adjusted Partial Sums)* method. The test is carried out by displaying the cumulative deviation from the average value divided by the cumulative root of the average deviation squared against the average value. For more details, the formulas used in the RAPS test are presented as follows:

The equation used is as follows (Pudyastuti & Musthofa, 2020; Sri Harto, 1993):

$$Yi = \frac{\Sigma \text{Station Data}}{n} \quad (1)$$

$$Dy^2 = \frac{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}{n} \quad (2)$$

$$Sk^* = \sum_{i=1}^{k}(Y_i - \overline{Y}) \quad (3)$$

$$Dy = \sqrt{\Sigma\, Dy^2} \quad (4)$$

$$Sk^{**} = \frac{Sk^*}{Dy} \quad (5)$$

where:

n	: Number of data
Yi	: i-th Rainfall Data
$\overline{Y}$	: Average rainfall
Sk*, Sk**, Dy	: Statistical value

a. Statistical Value (Q):

$$Q = \max |Sk^{**}| \quad (6)$$

$0 < k < n$

b. Statistical Value *Range* (R):

R = max Sk** - min Sk** (7)

0 < k < n 0 < k < n

with:

Q and R : Statistical value

n : Amount of rain data

Table 1 shows the values of $Q/\sqrt{n}$ and $R/\sqrt{n}$ for some number of data N.

Table 1. Statistical values $Q/\sqrt{n}$ and $R/\sqrt{n}$ for some N values

N	$\frac{Q}{\sqrt{n}}$			$\frac{R}{\sqrt{n}}$		
	90 %	**95 %**	**99 %**	**90 %**	**95 %**	**99 %**
10	1,05	1,14	1,29	1,21	1,28	1,38
20	1,10	1,22	1,42	1,34	1,43	1,6
50	1,14	1,27	1,52	1,44	1,55	1,78
100	1,17	1,29	1,55	1,50	1,62	1,86
>100	1,22	1,36	1,63	1,62	1,75	2,00

Source (Triatmodjo,2008)

By looking at the statistical values above, it can be found the value of Q/√ n and R/n. The results obtained from the calculation are compared with the value of Q/√n conditions and R/√n conditions from Table 1. If the result is smaller than the value from Table 1, it can be concluded that the data is still within consistent limits.

2.2 Potential Evapotranspiration

Evaporation is the evaporation of water from the surface of soil, water, and other non-vegetation surface forms by physical processes while transpiration is the evaporation of water from leaves and plant branches through leaf pores by physiological processes or in other words, evapotranspiration is the amount of water that evaporates from land and plants in a map due to the heat of the sun (Asdak, 1995). The calculation of potential evapotranspiration is calculated using *Thornthwaite* method, with the equation:

$$ETP_x = 1.62(\frac{10.Tm}{I})^a \quad (8)$$

$$ETP = f \; x \; ETP_x \quad (9)$$

$$a = 675 \times 10^{-9} I^3 - 771 \times 10^{-7} I^2 + 179 \times 10^{-4} I + 492 \times 10^{-3} \quad (10)$$

$$I = \sum_{m=1}^{12} \left(\frac{Tm}{5}\right)^{1,514} \quad (11)$$

where :

ETP_x :Month potential evapotranspiration

ETP : lunar potential evapotranspiration

Tm : Average monthly temperature (°C)

f : Correction coefficient

I : Annual heat index

2.3 Drought Index method *Standardized* Precipitation *Index* (SPI)

The *Standardized Precipitation Index* (SPI) method is a method developed by Mckee *et al* in 1993. The calculation of the SPI value based on the amount of gamma distribution uses a qualification system to define the level of dryness in the SPI analysis, as follows (Mckee et al., 1993) :

a. Wet : >1.00
b. Normal : -0.99 s.d 0.99
c. Moderately dry :-1 s.d 1.49
d. Very dry :-1.5 s.d (-1.99)
e. Extreme Dry :>-2

The steps for working on this SPI method are:

1) Calculate the average value:

$$\bar{x} = \frac{\sum x}{n} \quad (12)$$

with:

$\bar{x}$: Average value of rain occurrence

$\sum x$: Number of rain events

n : Amount of data

2) Calculating Standard Deviation

$$S = \sqrt{\frac{\Sigma(x-\overline{x})}{n}} \quad (13)$$

with:

S : Standard Deviation

3) Calculate shape values

$$\alpha = \frac{1}{4u}\left[1+\sqrt{\frac{4u}{3}}\right] \quad (14)$$

$$U = \ln(\overline{x}) - \frac{\sum \ln(x)}{n} \quad (15)$$

4) Calculating the scale (*scale*)

$$\beta = \frac{\overline{x}}{\alpha} \quad (16)$$

5) Calculating gamma distribution

$$G(x)=\int_0^x g(x)dx=\frac{1}{\beta^{\alpha}\Gamma(a)}\int_0^x t^{a-1} e^{\frac{-x}{\beta}} dx \quad (17)$$

6) Calculate the transform gamma distribution

$$t = \sqrt{\ln\left[\frac{1}{Hx^2}\right]} \text{ where } Hx < 0.5 \quad (18)$$

$$t = \sqrt{\ln\left[\frac{1}{(1-Hx^2)}\right]} \text{ where } Hx < 1.0 \quad (19)$$

with $Hx = q+(1-q)G(x)$ (20)

q = m/n where m is the number of 0 mm rain events in the rain data series series

7) Calculating the SPI value

$$Z = SPI = -\left[t-\frac{c0+c1t+c2t^2}{1+d1+d2t^2+d3t^3}\right] \quad (21)$$

where Hx < 0.5

$$Z = SPI = +\left[t-\frac{c0+c1+c2t^2}{1+d1+d2t^2+d3t^3}\right] \quad (22)$$

where Hx < 1.0

With the value of the coefficient from Mc. Kee as follows:

Co = 2,515517 d1 =1,432788

C1 =0,802853 d2 =0,189269

C2 =0,010328 d3 =0,001308

2.4 Drought Index method *Palmer Drought Severity Index* (PDSI)

A method that is still often used in drought analysis is the *Palmer Drought Severity Index* method, which is often referred to as the Palmer method, uses soil moisture as a parameter for the drought index (Sarmila, 2016). The input data in this method are rainfall, groundwater capacity (WHC) and potential evapotranspiration using the Thornthwaite method. In the Palmer method analysis, the drought index classification is divided into 11 classes with an index of zero as a normal state. Table 2 shows the PDSI classification.

Table 2. PDSI Classification

No	Drought Index	Clasification
1	≥4,00	Extreme wet
2	3,00 - 3,99	Very wet
3	2,00 - 2,99	A bit wet
4	1,00 - 1,99	A little wet
5	0,50 - 0,99	The beginning of the wet
6	0,49 - (-0,49)	Approaching normalcy
7	(-1,00) - (-1,99)	Slightly dry
8	(-0,50) - (-0,99)	The beginning of the dry
9	(-2,00) - (-2,99)	A bit dry
10	(-3,00) - (-3,99)	Very dry
11	≥(-4,00)	Extreme dry

The steps for working on the *Palmer* method are:

a. Calculates average rainfall (P).
b. Calculates potential evapotranspiration (ET).
c. Calculate water holding *capacity*.
   Calculates the difference between *P* and *ET*.
   - (P-ET)>0, there is a surplus of rainfall (wet month period).
   - (P-ET)<0, there is a rainfall deficit (dry month period).
d. Calculates the cumulative amount of APWL (*Accumulated Potential Water Loss*) rainfall deficit.

By summing the numbers (P-ET) for months that have more potential evapotranspiration than negative precipitation (P-ET).

$$APWL = -\sum_{1}^{n}(P-ET)neg \quad (23)$$

$$APWL_i = APWL_{i-1}+(P-ET)_{neg} \quad (24)$$

When *P>ET*, this data series is disconnected APWL = 0

e. Calculating soil flexibility
- In wet months (P>ET), ST=STo (WHC) values
- In dry months (P<ET), in this month the ST of each month is calculated by the formula:

$$ST=ST_O \times e^{-(\frac{APWL}{STo})} \quad (25)$$

with:

ST :Soil moisture content in the root area (mm)

STo :Soil moisture content in field conditions (mm) *STo* What is meant in this formula is the value *WHC*

e :Number *Navier* (e = 2,718)

APWL :Cumulative amount of rainfall deficit (mm)

f. Calculating changes in soil moisture content (ΔST)

Changes in soil moisture content (ΔST) every month are obtained by reducing soil moisture (ΔST) in the month concerned with (ST) in the previous month ($\Delta ST=ST_i-ST_{i-1}$), then negative values cause the soil to become dry. (26)

g. Calculating actual evapotranspiration (EA)

In wet months (P>ET), values EA=ET
In the dry months (P<ET), the value of EA= P-ΔST (27)

h. Calculating the moisture deficit

D = ET-EA (28)

with:

D : Deficit (mm/month)
ET : Evapotranspiration Potential (mm/month)
EA : Actual Evapotranspiration (mm/month)

i. Calculating surplus (Excess moisture)

S'= (P-ET)- ΔST (29)

with :

S' : Surplus (mm/bulan)
P : Rainfall (mm/bulan)
ET : Evapotranspiration Potential (mm/bulan)
ΔST : Changes in soil laxity (mm)

j. Counting runoff (Ro)

Shows the amount of water flowing on the surface of the ground. (30)

k. Calculating potential soil overfill (PR)

PR=WHC-ST (31)

l. Calculating soil moisture recharge (R')

Land overfilling occurs if the ST in the previous month is smaller than the ST in the month concerned, the addition of the ST value becomes to fill soil moisture.

$$R'=ST-ST_{J-1} \quad (32)$$

with:

R' : Soil inert filling
ST : The inert content of the soil in the month
ST_{J-1} : The inert content of the soil in the previous month's item

m. Calculate potential soil loss (PL)

PL=ET-ΔST (33)

n. Calculating soil loss (L)

$$L=ST_{J-1}-ST \quad (34)$$

o. Determination of the coefficient

The coefficient in question is to determine the value of CAFEC *(Climatically Appropriate for Existing Condition)*. Value of the data coefficients is determined by the formula:

1. Coefficient of evapotranspiration

$$\alpha = \frac{\overline{AE}}{\overline{ET}} \quad (35)$$

2. Coefficient moisture filling into the soil

$$\beta = \frac{\overline{R'}}{\overline{PR}} \quad (36)$$

3. Runoff coefficient

$$\gamma = \frac{\overline{Ro}}{\overline{S'}} \quad (37)$$

4. Coefficient of loss of soil moisture

$$\delta = \frac{\overline{L}}{\overline{PL}} \quad (38)$$

5. Approaches to climate weighting

$$K = \frac{(\overline{ET}+\overline{R})}{(\overline{P}+\overline{L})} \quad (39)$$

p. Determination of Value CAFEC *(Climatically Appropriate for Existing Condition).*

1) Determining the CAFEC evapotranspiration value

$$\widehat{ET} = \ddot{\alpha}*ET \quad (40)$$

2) Determining the soil moisture into the CAFEC

$$\widehat{R} = \beta*PR \quad (41)$$

3) Determining runoff values CAFEC

$$\widehat{Ro} = \gamma*Ro \quad (42)$$

4) Determining soil moisture loss CAFEC

$$\hat{L} = \delta*PL \quad (43)$$

5) Determining precipitation loss CAFEC

$$\hat{P} = \widehat{ET}+\hat{R}+\widehat{Ro}-\hat{L} \quad (44)$$

q. Determination of periods of lack or excess of rain *(d)*

$$d = P - \hat{P}` \quad (45)$$

r. Determination of absolute value ($\overline{D}$)

$\overline{D}$ = average value d

s. The second approach to factor value *K (k')*

$$K' = 1.5 \log 10 \left(\left(\frac{PE+R+Ro}{P+L} + 2{,}80\right) : \frac{25{,}4}{\overline{D}} \right) + 0{,}5 \quad (46)$$

$$DK' = \overline{D}*k' \quad (47)$$

t. Climate character as a weighting factor (*K)*

$$K = \frac{\overline{D}*K'}{\sum_1^{12} \overline{D}*K'} K' \quad (48)$$

u. Lenggal deviation index (anomaly) *(Z)*

$$Z = d*K \quad (49)$$

v. Drought index *Palmer*

$$X = \left(\frac{Z}{3}\right)_{j-1} + \Delta X \quad (50)$$

$$\Delta X = \left(\frac{Z}{3}\right)_j - 0.103 \left(\frac{Z}{3}\right)_{j-1} \quad (51)$$

3. RESULT AND DISCUSSION

3.1. Rainfall Data Consistency Test

The method used in testing the consistency of rain data is the RAPS *(Rescaled Adjusted Partial Sums)* method. The test is carried out by displaying the cumulative deviation from the average value divided by the cumulative root of the average deviation squared against the average value.

In this study, the rain data consistency test used was the RAPS (*Rescaled Adjusted Partial Sums*) method.

An example of the calculation of the rainfall data contingency test for the Ngemplak sub-district is as follows:

1. The year's rainfall 2009 (Yi) is calculated using equation **(1)**, so:
   (Yi) = 1939 mm
2. The number of the data:
   (n) = 15 year
3. The average overall rain rating ($\bar{Y}$):
   ($\bar{Y}$) = 2118,85 mm
4. The tatistical Value Sk* is calculated using equation **(3)**, so:
   Sk*= (1939 - 2118,85) + 0
   Sk*= -179,85 mm
5. The statistical Value Dy^2 is calculated using equation **(2)**, so:
   $Dy^2 = \frac{(1939-2118,85)^2}{15}$
   Dy^2 = 1540,34 mm^2
6. The Dy value is calculated using equation **(4)**, so:
   Dy = $\sqrt{1540,34}$
   Dy = 427,08 mm
7. The Statistical Value Sk** is calculated using equation **(5)**, so:
   $Sk^{**} = \frac{-179,85}{427,08}$
   Sk** = -0,42
8. The Absolute Price $|Sk^{**}|$ is calculated using equation **(6)**, so:
   $|Sk^{**}|$= 0,42

The result of further calculation can be seen in the Table 3.

Table 3. RAPS Test of Ngemplak District

No	Year	Rainfall	$Yi-Y_{average}$	Sk*	Dy^2	Sk**	I Sk** I
1	2009	1939,00	-179,85	-179,85	1540,34	-0,42	0,42
2	2010	2852,00	733,15	553,29	25595,43	1,30	1,30
3	2011	2045,00	-73,85	479,44	259,73	1,12	1,12
4	2012	1973,00	-145,85	333,59	1013,01	0,78	0,78
5	2013	2441,00	322,15	655,73	4941,83	1,54	1,54
6	2014	1724,00	-394,85	260,88	7424,25	0,61	0,61
7	2015	1171,00	-947,85	-686,97	42782,19	-1,61	1,61
8	2016	2236,30	117,45	-569,53	656,84	-1,33	1,33
9	2017	2899,00	780,15	210,62	28982,32	0,49	0,49
10	2018	1579,00	-539,85	-329,23	13878,17	-0,77	0,77
11	2019	1778,00	-340,85	-670,09	5532,43	-1,57	1,57
12	2020	1938,50	-180,35	-850,44	1548,92	-1,99	1,99
13	2021	2825,00	706,15	-144,29	23744,91	-0,34	0,34
14	2022	2693,00	574,15	429,85	15697,35	1,01	1,01
15	2023	1689,00	-429,85	0,00	8798,76	0,00	0,00
Amount		31782,80			182396,49		
Average		2118,85					

From the calculation results for the RAPS *(Rescaled Adjusted Partial Sums)* test, and compared to the value on Table 1 with confidence interval 90%, the rainfall data meets the requirements $R/\sqrt{n} < R/\sqrt{n}Q/\sqrt{n} < Q/\sqrt{n}$.

3.2. Evapotranspiration Potential

Calculate monthly potential evapotranspiration from monthly air temperature data for the period 2009-2023. An example of the calculation is as follows

1. Coordinates of Ngemplak District, Boyolali Regency
   = 07° 07' 36'' LS and 110° 22' 50'' BT
   = 7,1267 LS and 110,3806 BT
2. Time and latitude adjustment factors
   Here is an example of a calculation in 2009
3. The Monthly Heat Index is calculated using equation **(11)**, so:
   (I) = $\left(\frac{28,4}{5}\right)^{1,514}$
   = 13,870
4. I (Year Heat Index) = 175,592
5. The (a) is calculated using equation **(10)**, so:
   $a = 675 \times 10^{-9} \times 13{,}870^3 - 771 \times 10^{-7} \times 13{,}870^2 + 179\ 10^{-4} \times 13{,}870 + 492 \times 10^{-3}$
   $a_{monthly}$ = 0,727
   a_{year} = 4,912
6. The ETPx is calculated using equation **(8)**, so:
   ETPx =1,62 $\left(\frac{10x28,4}{175,592}\right)^{4,912}$
   ETPx = 171,900 mm
7. The ETP is calculated using equation **(9)**
   ETP = 171,900 x 1,069
   = 183,676 mm

From the calculation of Potential Evapotranspiration in Ngemplak District during 2009-2023, an average Potential Evapotranspiration value of 228.28 mm was obtained.

3.3. Method *Standardized Precipitation Index* (SPI)

Drought occurs when the SPI is continuously negative and reaches drought intensity with an SPI value of -1 or less, while drought will end when the SPI value becomes positive.

Example of calculation in January 2009-2023:

1. Calculating the average using equation **(12)**, so:
   $\bar{x} = \frac{5959}{15} = 397{,}067$ mm

2. Calculating Standard Deviation using equation **(13)**, so:

$$Sd = \sqrt{\frac{((568-241,10)^2+(436-241,10)^2+...+}{15-1}} \sqrt{\frac{(3,00-241,10)^2}{15-1}}$$

$= 119,087$ mm

3. Calculating shape values alpha using equation **(14)**, so:

$$\alpha = \frac{397,067^2}{119,087^2} = 11,117$$

4. Calculating the scale beta using equation **(16)**, so:

$$\beta = \frac{397,067}{11,117} = 35,716$$

5. Calculating gamma distribution using equation **(17)**, so:

Example of January 2009 calculation:

$$G(x) = \frac{1}{35,716^{11,11} \times \Gamma(11,11)} \times 568^{(11,11-1)} e^{-(\frac{568}{35,716})}$$

$= 0,914$ mm

6. Calculating probability H(x) using equation **(20)**, so:

Example of January 2009 calculation

H(x) = q+(1-q) . G(x)

= 0,0 + (1 – 0,00) x 0,914

= 0,914

7. Calculates the gamma transform distribution using equation **(18)** and **(19)**, so:

Example calculation with $0 < H(x) \leq 0.5$ in January 2011:

t = 1,538

Example calculation with $0.5 < H(x) \leq 1.0$ in January 2009:

t = 2,216

8. Calculating *the* SPI value using equation **(21)** and **(22)**, so:

Example calculation with $0 < H(x) \leq 0.5$ in January 2011:

Z = - 0,506

Example calculation with $0.5 < H(x) \leq 1.0$ in January 2009:

Z = 1,367

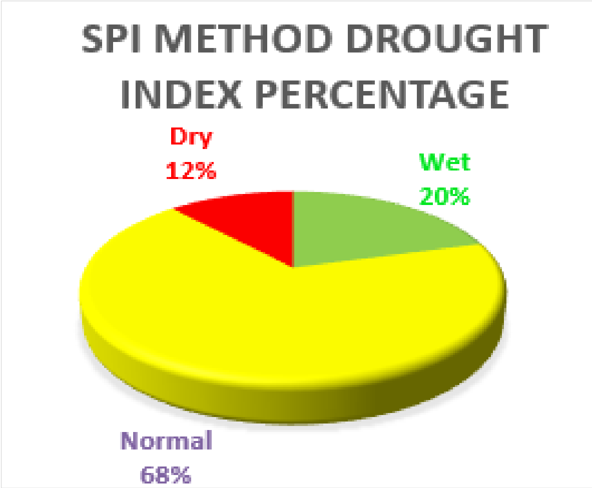

Fig. 2. Percentage of SPI Index in Ngemplak District for 2009-2023

From Fig. 2, it can be seen that in Ngemplak District during the 15-year period, it was dominant in normal conditions with a percentage of 68%, wet conditions of 20%, and dry conditions of 12%.

3.4. Method *Palmer Drought Severity Index* (PDSI)

a. Calculating Monthly Rainfall (P)

The rainfall in January 2009 was 568 mm.

b. Calculating Evapotranspiration Potential

Potential Evapotranspiration in January 2009 was 183.676 mm.

c. Calculating Water Storage Capacity (*Water Holding Capacity*)

Based on sources from the Boyolali Central Statistics Agency, it was found that the soil texture of Ngemplak sub-district is predominantly dusty clay and clayey clay, so Ngemplak sub-district is included in the type of shallow-rooted plant area with estimated water values, rooting zones and soil moisture values. Then, each area is divided by the total area multiplied by the value of the depth of the root zone contained in the table estimating the available water capacity multiplied by the available water based on the soil texture, then added up then the *WHC* or *sto value* in Ngemplak sub-district, for more details can be seen in Table 4.

Table 4. Calculation of WHC value

Texture	Area (Km^2)	Root Zone (m)	Available Water (mm/m)	Soil Moisture (mm)
Dusty Clay	23,28	0,62	200	74,960
Loamy Clay	15,23	0,4	250	39,548
Amount	38,51			114,508

d. Calculating the difference P and *ET*

P-ET = 568-183,676

= 384,324 mm

(P-ET) > 0, there is a surplus of rainfall (wet month period)

(P-ET) < 0, there is a rainfall deficit (dry month period)

From the calculation of P-ET, January 2009 is a wet month period (UN)

e. Calculates the cumulative amount of APWL rainfall deficit (*Accumulated Potential Water Loss*).
If *P > ET,* this data series is disconnected APWL = 0

f. Calculating soil flexibility
- In the wet months (*P>ET*), value *ST*=STo (WHC)
- In dry months (*P<ET),* in this month the ST of each month is calculated by the formula using equation **(25)**, so:

$$ST = 114{,}508 \times e^{-\left(\frac{0}{114{,}508}\right)}$$
$$= 114{,}508$$

g. Calculating changes in soil moisture content *(ΔST)* using equation **(26)**, so:
ΔST = 114 - 137,231

= -22,873 mm

h. Calculating actual evapotranspiration (EA) using equation **(27)**, so:
EA = 568 - (-22,723)
= 590,723 mm

i. Calculating the deficit using equation **(28)**, so:
D = 183,676 – 590,723
= -407,047 mm/month

j. Calculating *surplus* (Advantages of Softness) using equation **(29)**, so:
S' = 384,324 – (-22,873)
= -407,197 mm/moon

k. Counting runoff *(Ro)*
Shows the amount of water flowing on the surface of the ground. Calculate it 50% multiplied by the surplus value using equation **(30)**, so:
Ro = 0,5 x (-407,197) = 203,599 mm/month

l. Calculating potential soil overfill (PR) using equation **(31)**, so:
PR = 114,508 – 114,508 = 0 mm

m. Calculating soil moisture recharge (R')
Land overfilling occurs if the ST in the previous month is smaller than the ST in the month, the addition of the ST value becomes a soil overfill capacity using equation **(32)**, so:

R' = (-22,723) – (-2,417) = -20,306 mm

n. Calculate potential soil loss *(PL)* using equation **(33)**, so:

PL = 183,676 – (-22,723) = 206,399 mm

o. Calculating soil loss (*L)* using equation **(34)**, so:
L = 137,231 – 114,508 = 22,723 mm

p. Determination of the coefficient
The coefficient in question is to determine the value of CAFEC *(Climatically Appropriate for Existing Condition).* The values of the coefficients above are determined by the formula:
- Coefficient of evapotranspiration using equation **(35)**, so:
$\alpha = \frac{153{,}256}{211{,}215} = 0.726$
- Coefficient of soil moisture using equation **(36)**, so:
$\beta = \frac{-6{,}779}{71{,}874} = 0{,}094$
- Runoff coefficient using equatin **(37)**, so:
$\gamma = \frac{-20{,}379}{-40{,}754} = 0{,}5$
- Coefficient of loss of soil moisture using equation **(38)**, so:
$\delta = \frac{8{,}874}{220{,}089} = 0{,}040$
- Approaches to climate weighting using equation **(39)**, so:

$$K = \frac{(211{,}215)+(-6{,}779)}{(161{,}583+8{,}874)} = 1{,}199$$

q. Determination of CAFEC value *(Climatically Appropriate for Existing Condition)*

- Determining the value of evapotranspiration CAFEC using equation **(40)**, so:
  $\widehat{ET} = 0{,}726 * 183{,}676 = 133{,}275$ mm
- Determining the soil moisture into the CAFEC using equation **(41)**, so:
  $\widehat{R} = 0{,}094 * 0 = 0$ mm
- Determining runoff values CAFEC using equation **(42)**, so:
  $\widehat{Ro} = 0{,}5 * 203{,}524 = 101{,}762$ mm
- Determining soil moisture loss CAFEC using equation **(43)**, so:
  $\widehat{L} = 0{,}040 * 206{,}399 = 8{,}322$ mm
- Determining precipitation loss CAFEC using equation **(44)**, so:
  $\widehat{P} = 133{,}275 + 0 + 101{,}762 - 8{,}322$
  $= 226{,}714$ mm

r. Determination of periods of lack or excess of rain (*d*) using equation **(45)**, so:
$d = 568 - 226{,}714 = 341{,}286$

s. Determination of absolute value ($\overline{D}$) using equation **(46)**, so:
$\overline{D} = 20{,}611$ mm

t. The second approach to factor value *K (k')* using equation **(47)**, so:

$$K' = 1.5 \log 10 \left(\left(\frac{211{,}215+(-6{,}779)+(-20{,}379)}{140{,}972+8{,}874} + 2{,}80\right) : \frac{25{,}4}{20{,}611}\right) + 0{,}5$$
$$= 0{,}502$$
$$DK' = 20{,}611 * 0{,}502 = 10{,}341$$

u. Climate character as a weighting factor (*K)* using equation **(48)**, so:

$$K = \frac{10{,}341}{10{,}341 \text{x} 12} \text{ x } 0{,}502 = 0{,}042$$

v. Lenggal deviation index (anomaly) *(Z)* using equation **(49)**, so:
$Z = 341{,}286 \text{ x } 0{,}042 = 14{,}270$

w. Drought index *Palmer* using equation **(50)** and **(51)**, so:
Calculation example:

$$\Delta X = \left(\frac{14{,}267}{3}\right) - 0.103\left(\frac{0}{3}\right) = 4{,}756$$

$X = 0 + 4{,}757 = 4{,}756$ (Extreme Wet)

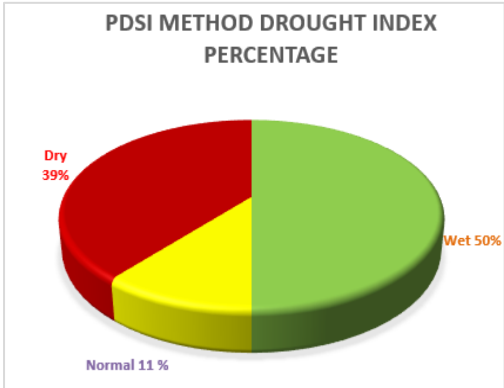

Fig. 3. Percentage of PDSI Index at Station WD. Cengklik 2009-2023

From Fig. 3., it can be seen that in Ngemplak District during the 15-year period, the dominant wet condition was 50%, dry 39%, and normal with a percentage of 11%.

Fig. 4 shows the maps representing the drought indices for the Boyolali district, captured in a Geographic Information System (QGIS), for the months of January and Desember across the years 2009 and 2023. These visual representations are likely to depict the spatial distribution and severity of drought conditions within the district during these months.

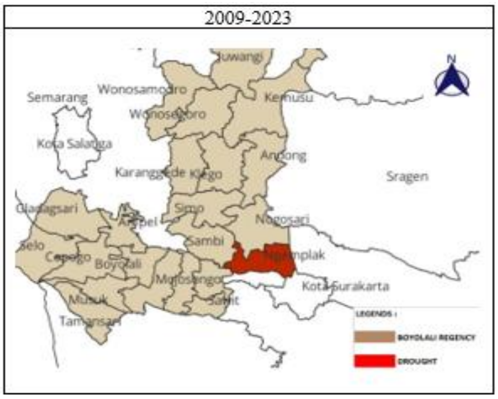

Fig. 4. Application Qgis Boyolali Map Drought Indices July

From Fig. 4 above for the PDSI method where the above conditions are included in the Dry category where the index at Ngemplak district is (-2.393).

3.5. DISCUSSION

3.5.1 Application Indices in the Ngemplak, Boyolali District Based on its Geographical and Climatic Context

The utilization of the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI) within Ngemplak, Boyolali District, underscores a strategic approach to grappling with the unique geographical and climatic challenges of the district. Characterized by its diverse topography and the dichotomy between wet and dry seasons, Ngemplak's reliance on these indices is a testament to their value in enhancing drought management and agricultural planning. The PDSI, with its comprehensive assessment of moisture conditions, including temperature and soil moisture considerations, is pivotal for long-term water resource management. It aids in understanding prolonged drought impacts, crucial for sustainable environmental stewardship. Conversely, the SPI's simplicity and focus on precipitation make it indispensable for immediate agricultural decision-making, offering a clear picture of short-term drought conditions. Together, these indices provide a holistic view of Ngemplak's climatic variability, guiding the implementation of adaptive strategies that resonate with the district environmental and socio-economic realities.

This dual-index approach enables a nuanced understanding of drought dynamics, fostering resilience and ensuring the sustainable development of the Boyolali district amidst climatic uncertainties.

The final validation of this discussion is for the SPI and PDSI methods. The SPI method is simpler but less accurate, while PDSI requires a lot of data but is detailed.

3.5.2 Water Management Strategies

The comprehensive study on Ngemplak, Boyolali district's hydrological patterns stresses the critical need for multifaceted water management strategies to address the alternating periods of drought and excessive wet conditions. Insights from the Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) underscore the district's vulnerability to climatic extremes, advocating for the implementation of rainwater harvesting to bolster water reserves during droughts and the adoption of water-saving irrigation techniques to enhance agricultural water efficiency (Sarang et al., 2023). Moreover, the study suggests expanding water conservation efforts through community engagement and policy incentives to promote sustainable water usage. Enhanced forecasting and the diversification of water sources are also recommended to improve water security against climate-induced variability. This holistic approach, combining technological, behavioral, and policy-driven measures, aims to foster a resilient and sustainable water management system in Ngemplak, Boyolali, capable of navigating the challenges posed by its dynamic climatic conditions (Chidiac et al., 2023).

4. CONCLUSION

1. From the SPI results, it can be seen that in Ngemplak District, during the 15-year period, it was predominantly normal with a percentage of 68%, wet conditions 20%, and dry conditions 12%, and the results of PDSI also show that in Ngemplak District, during the 15-year period, it was predominantly dry with a percentage of 50%, wet 39%, and normal with a percentage of 11%. Thus, the Palmer Drought Severity Index (PDSI) is very effective for Ngemplak Regency, Boyolali because of its ability to measure long-term humidity conditions, which reflect the variability of the district's climate between the rainy season and the dry season. Its suitability for Ngemplak, with its diverse geography and seasonal climate change, is evidenced by its application from 2009 to 2023, highlighting its role in improving water management and agricultural planning.
2. An integrated water management strategy, informed by PDSI insights, is vital for addressing Ngemplak, Boyolali's drought challenges. This strategy should include water conservation, efficient agricultural water use, and policy development aimed at drought resilience.

A collaborative effort among all stakeholders is essential to establish a comprehensive water management system that ensures the district sustainability and resilience against climatic extremes.

5. RECOMMENDATION

The recommendations from this study focus on addressing the challenges posed by drought conditions in Ngemplak, Boyolali, This strategy emphasizes the importance of integrating sophisticated irrigation technologies, such as drip and sprinkler systems, to minimize water wastage and enhance water use efficiency in agricultural practices. It also underscores the necessity for governmental and regulatory bodies to incentivize the adoption of efficient irrigation technologies through policies that may include subsidies, technical support, and educational programs. Additionally, the study suggests broadening water management initiatives to include soil conservation techniques and the diversification of water sources to enhance water security and mitigate the impacts of climate-induced variability.

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