PATTERN OF METEOROLOGICAL DROUGHT DISTRIBUTION IN THE SLAHUNG RIVER BASIN, PONOROGO, USING THE THEORY OF RUN METHOD

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ABSTRACT

Drought is a natural event that frequently occurs in Indonesia and significantly impacts various sectors, such as agriculture, plantations, and water resources. This study aims to analyze the level of drought in the Slahung sub-River basin using the Theory of Run method. The data used includes 24 years of rainfall data from three rainfall stations: Ngilo-Ilo, Balong, and Slahung, covering the period from 2000 to 2023. The analysis results show that the longest drought duration at Slahung Station occurred in 2012, lasting 18 months, with the largest cumulative drought recorded in 2010 at -1071 mm. The drought distribution map reveals that 2019 was the driest year, while 2023 was the wettest. This study provides valuable insights into water resource management and drought disaster mitigation planning in the Slahung sub-River basin. Future research is recommended to use longer and higher-quality data, as well as comparisons with other drought analysis methods to improve the accuracy of the analysis.

Keyword: Rainfall, meteorological drought, river basin, Theory of Run

Introduction

Meteorological drought is a natural phenomenon that frequently occurs and has significant impacts on the agricultural sector, especially in Ponorogo Regency. The droughts in this area threaten food security and the well-being of the local population, which heavily depends on rainfall patterns. Therefore, a thorough understanding of the patterns, duration, and intensity of droughts is crucial to formulating effective mitigation strategies. One method used to analyze meteorological drought is the Theory of Run method. This method enables easier and more efficient analysis compared to other methods because it provides a clear picture of the longest drought duration and the largest drought deficit based on monthly rainfall data over a specific period [1-3].

This study aims to evaluate the level of drought in Ponorogo Regency using the Theory of Run method. This method has advantages in drought analysis because it is simpler and more effective in identifying drought events compared to other methods. In addition, this method allows for the calculation of drought duration and the largest drought deficit using the standard deviation of monthly rainfall compared to the normal average rainfall value or the established threshold [4]. In this context, this research uses 20 years of monthly rainfall data to provide a more accurate representation of drought conditions in Ponorogo Regency, which is expected to help formulate better drought mitigation policies.

Previous research conducted by Friyana et al., 2023 used satellite data to analyze the meteorological drought index in the Slahung Sub-River basin, but it also highlighted limitations in the placement of rain gauge stations that were not representative of the entire area. Although satellite data was used to complement the rainfall information from existing rain gauges, this study did not address the limitations or uncertainties that may arise from using satellite rainfall data, which can affect the reliability of drought index calculations and predictions. This study identified gaps in the distribution of rain gauge stations that need to be improved to enhance the accuracy of drought analysis [5].

Other studies, such as those by Arismaya (2016), applied the Theory of Run method to the Upper Bengawan Solo Sub-River basin, but this study did not discuss the underlying causes of drought, such as climate change or other environmental factors that could affect drought occurrence. Additionally, the study did not provide recommendations or practical drought mitigation strategies, leaving gaps in the application of the research results in the field. This highlights the need to fill gaps in understanding the factors influencing drought events and how to mitigate them [6].

The novelty of this study is the use of the Theory of Run method to analyze meteorological drought in Ponorogo Regency using 24 years of monthly rainfall data. This research focuses on calculating the longest drought duration and the largest drought deficit, as well as analyzing the potential impact of drought on the agricultural sector and food security. This study is expected to provide a more accurate representation of meteorological drought, which can help design more efficient mitigation strategies. Moreover, this study will also consider the socio-economic aspects related to drought impacts, which are often overlooked in previous research, to provide more applicable recommendations for natural resource management and drought mitigation policies in Ponorogo Regency [4,7,8].

The main objective of this study is to evaluate the level of drought in Ponorogo Regency using the Theory of Run method, based on 24 years of monthly rainfall data. This study aims to calculate the longest drought duration and the largest drought deficit, as well as provide a better understanding of drought occurrences in the region. By integrating more accurate data, this research is expected to make a significant contribution to designing more sustainable water and agricultural resource management strategies in Ponorogo Regency, as well as providing recommendations for more effective drought mitigation [3, 9, 10].

Methodology

Study Area Location

The study was conducted in the Slahung Sub-Sub River basin, covering an area of 240.60 km², which is in the Kali Madiun Sub-River basin, part of the Bengawan Solo River basin. It is administratively situated in Ponorogo Regency, East Java Province, which has a total area of 1,371.78 km², divided into 21 districts and consisting of 305 villages/sub-villages. The Sub-Sub River basin spans 7 districts, namely Jenangan, Jambon, Balong, Badengan, Sambit, and Sawoo. Geographically, the study area is located between 117°7' and 111°52' East Longitude and 7°49' and 8°20' South Latitude.

The Slahung Sub-River basin has six existing rainfall stations: Ngilo-ilo Station, Slahung Station, Balong Station, Sungkur Station, Wilangan Station, and Ngrayun Station [5].

The map of the boundaries of the Slahung Sub-River basin is as follows:

a. To the West, it borders Pacitan Regency and Wonogiri Regency
b. To the East, it borders Tulungagung Regency and Trenggalek Regency.
c. To the North, it borders Magetan Regency, Madiun Regency, and Nganjuk Regency.
d. To the South, it borders Pacitan Regency.

Data Collection Techniques

This study uses secondary data from the Bengawan Solo River Basin Management Agency (BBWS) to analyze rainfall patterns at Ngilo-Ilo, Balong, and Slahung stations over 24 years (2000-2023) https://hidrologi.bbws-bsolo.net/curahhujan/31. This data is crucial for understanding the environmental conditions in the Slahung River basin. The Theory of Run method is applied to identify periods of low rainfall, helping to predict drought potential and design effective mitigation strategies. By calculating drought duration and deficits, this approach provides valuable insights into drought severity, aiding in better water resource and environmental management.

Theory of Run

The Theory of Run method is used to calculate the longest drought duration and the largest deficit at rainfall stations.

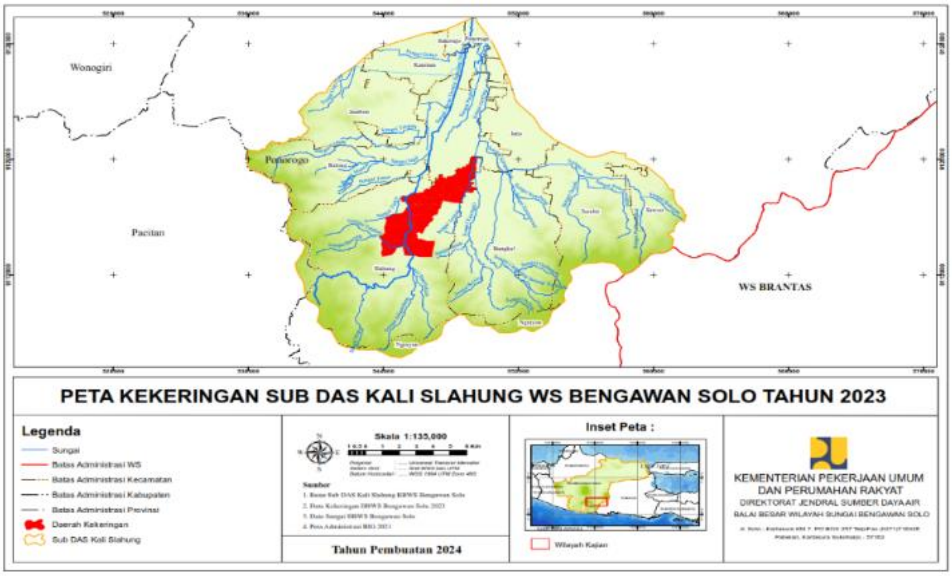


Figure 1. Location map Slahung River basin

This method compares water deficits and total water deficits by identifying two main categories: positive Run (surplus) and negative Run (deficit). Drought duration is calculated based on the number of constant deficits and the duration of continuous deficits in months [12].

The basic equation of the Theory of Run method is:

$$Y(m) < X(t, m),\ \text{so } D(t, m) = X(t,m) - Y(m) \tag{1}$$

Total drought:

$$Dn = \sum_{m=1}^{i} D(t,m)A(t,m) \tag{2}$$

Drought duration:

$$Ln = \sum_{m=1}^{i} A(t,m) \tag{3}$$

Where:

Y(m) = rainfall of month m.

X(t, m) = monthly rainfall data series for month m, year t.

m = the m-th month; t = the t-th year.

Dn = total drought from month m to month m+I (mm).

Ln = drought duration from month m to month m+I (months).

A(t, m) = an indicator value of 0 if Y(m) ≥ X(t, m).

A(t, m) = an indicator value of 1 if Y(m) < X(t, m).

A(t, m) = deficit or surplus indicator.

Result and Discussion

Hydrological Analysis

Hydrological analysis for drought using the Theory of Run method involves comparing observed rainfall data with the long-term average to identify periods of water deficit. The method calculates drought severity by measuring the difference between actual rainfall and expected rainfall, then quantifies the duration and intensity of the deficit. This analysis helps predict future droughts, guiding effective water resource management and drought mitigation strategies.

Data Consistency Test

The data consistency test in hydrological analysis aims to ensure the reliability and validity of the rainfall data used in the study by comparing data from various sources or stations and applying statistical methods to verify its adherence to required quality standards.

From the three double curve graphs obtained after performing the consistency test on the three-Monthly Rainfall Stations (Ngilo-Ilo, Slahung, and Balong), the consistency analysis results showed very good correlation values. Based on Figures 2(a) Ngilo-Ilo Rainfall Station achieved an R^2 value of 0.9842, Figure 2(b), Slahung Rainfall Station reached an R^2 value of 0.9985, and Figure 2(c), Balong Rainfall Station obtained an R^2 value of 0.9918. The results of this consistency test indicate that the data used is very reliable, as the correlation values are close to the maximum value of 1, which signifies a very strong relationship between the data.

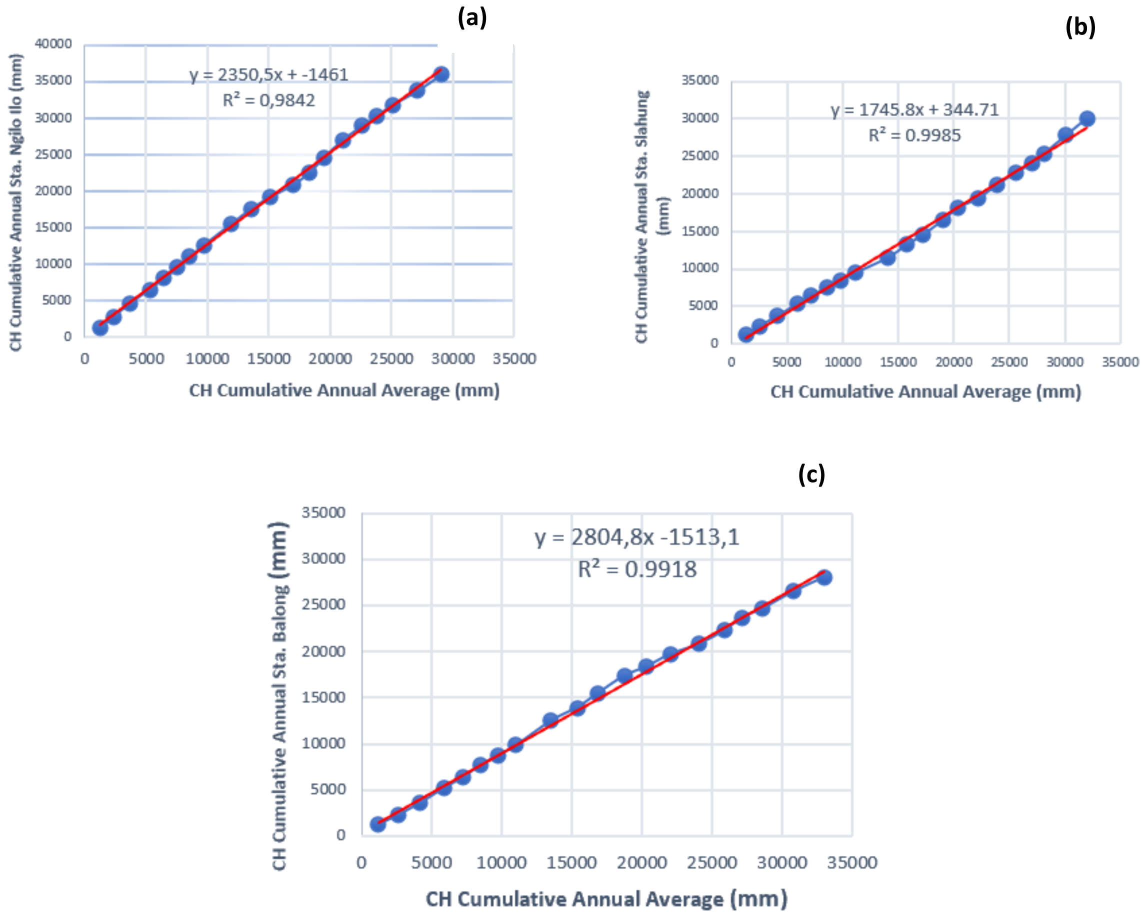


Figure. 2 Analysis of Double Curves for Ngilo-Ilo Station (a), Slahung Station (b), and Balong Station (c)

Drought Analysis Using the Theory of Run Rainfall Data

In this section, the rainfall data collected from the rainfall stations is analyzed to assess the occurrence and severity of droughts using the Theory of Run method. The data used includes monthly rainfall records from various stations.

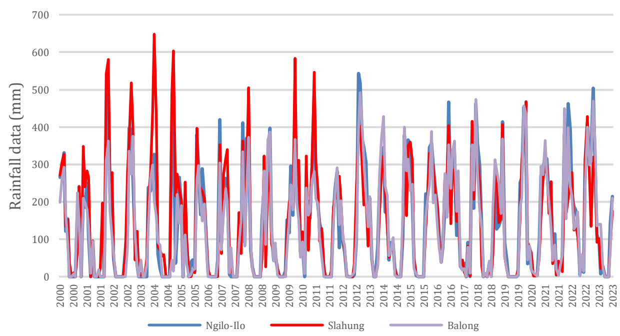


Figure 3. Rainfall data at Ngilo-Ilo Station, Slahung Station and Balong Station [11].

Figure 3, the rainfall data used in this study was obtained from three rainfall stations managed by the Bengawan Solo River Basin Management Agency (BBWS), namely Ngilo-Ilo Station, Balong Station, and Slahung Station, with an observation period of 24 years (2000-2023). Each station represents a different area within the River basin, where Ngilo-Ilo Station represents the upper reaches with higher rainfall, Balong Station in the middle represents the transition zone between the upper and lower reaches, and Slahung Station represents the lower reaches with lower rainfall.

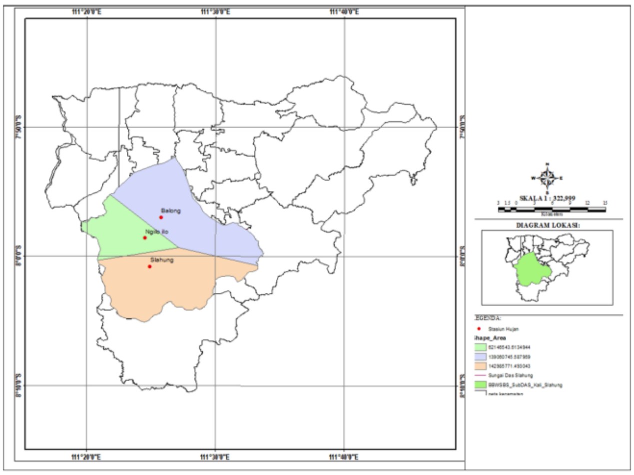


Figure 4. Thiessen Polygon for Slahung Sub-River basin

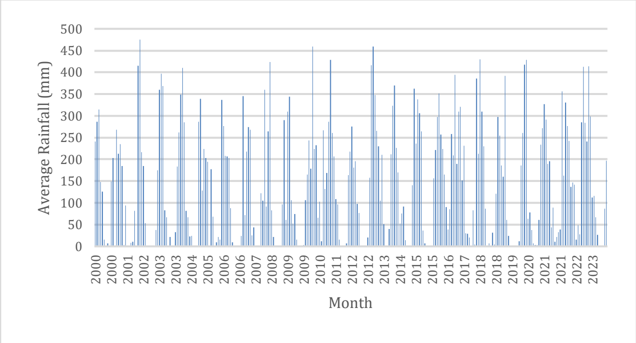
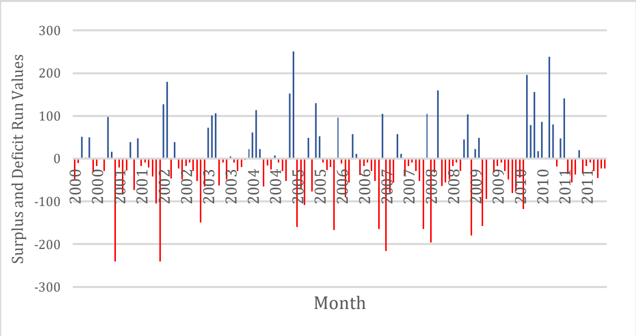
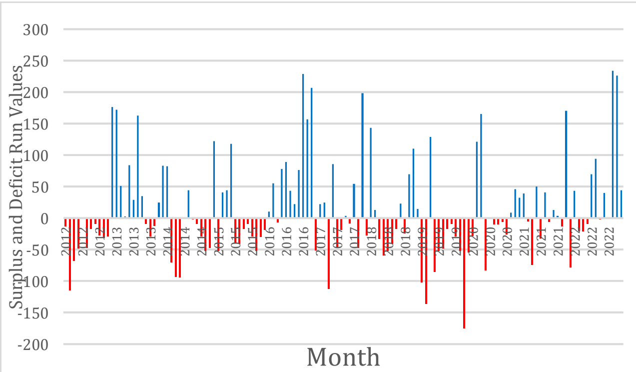


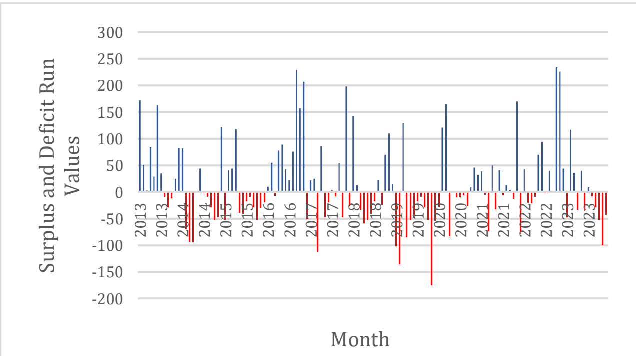
Figure 5. Monthly Rainfall of Slahung River Basin



(a) 2000-2011



(b) 2012-2022



(c) 2013-2023

Figure 6. Surplus and Deficit Run Values in the Slahung Sub-River basin

Before conducting the drought trend analysis, the average rainfall in the Slahung Sub-River basin was calculated using the Thiessen polygon method.

After analyzing the data using the Thiessen polygon method, the influence of each station on the study area was determined. The results show that the influence of Ngilo-Ilo Station accounts for 18.0% (0.180), the influence of Slahung Station is 41.6% (0.416), and the influence of Balong Station is 40.4% (0.404). These percentages reflect the relative contribution of each station's rainfall data to the overall rainfall distribution in the Slahung Sub-River basin, with Slahung Station having the largest influence, followed by Balong Station and Ngilo-Ilo Station.

Surplus and Deficit Run Values

The surplus and deficit values are obtained by subtracting the rainfall for each month of each year from the average of all data for that month. Using equation 2-1, the surplus and deficit run values are calculated. Below is an example of how the surplus and deficit values are calculated for the Slahung Sub-River basin.

Drought Duration

The calculation of drought duration is carried out using equation 2-3. The calculation refers to Figure 6. If the values in Figure 6 are positive, the value is assigned zero (0), and if the values are negative, the value is assigned one (1).

Total Drought

The calculation of the total drought that occurs is done using equation 2-2 and refers to Table 1. This process is similar to calculating the drought duration. If the drought duration is consecutive and exceeds one, then the subsequent month represents its cumulative value, and the same applies to the total drought. The total deficit will be accumulated based on whether the value is surplus or deficit. If the value in Table 1 is positive, it is assigned a value of zero (0); if the result is negative, it is assigned the corresponding negative value (-).

Drought Severity Classification

The purpose of the drought severity classification is to determine the level of drought occurring at each rainfall station. The classification is divided into 3 types as shown in Table 1.

From Table 2, the maximum drought duration and maximum drought total for each year are obtained. For drought classification, it is also necessary to calculate the normal rainfall amount. Normal rainfall is the average rainfall value for a given month across all observation stations, as shown in Table 2.

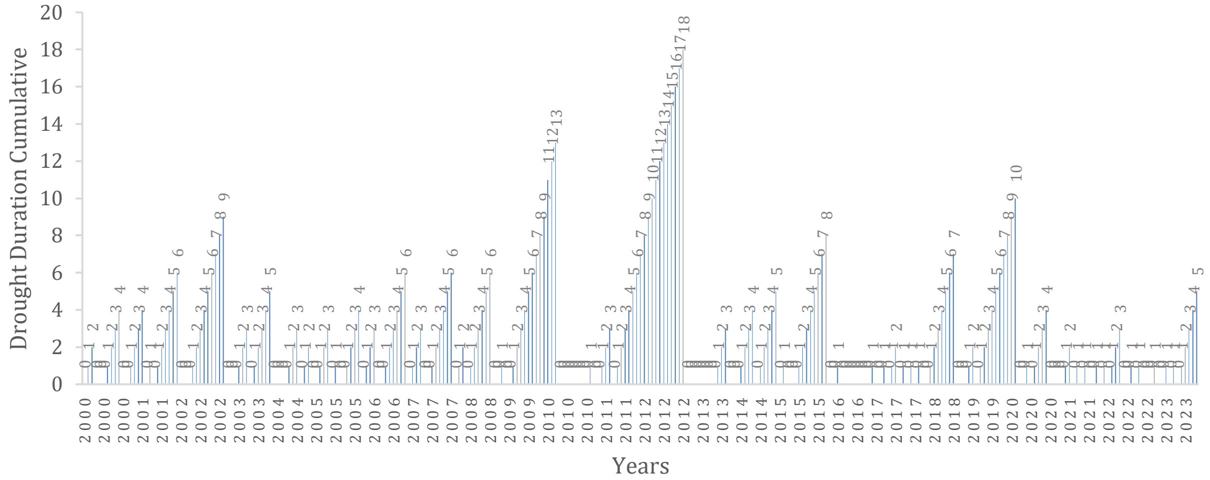


Figure 7. Cumulative Drought Duration of Monthly Rainfall in the Slahung Sub-River basin

Tabel 1. Cumulative Drought of Monthly Rainfall in the Slahung Sub-River basin

Years	Month Rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Ags	Sep	Oct	Nov	Dec
2000	-47	-57	0	0	0	-32	-49	-50	-79	0	0	-240
2001	-260	-343	-371	0	-73	0	-17	-26	-46	-88	-193	-434
2002	0	0	-46	0	-23	-70	-87	-96	-125	-176	-325	-391
2003	0	0	0	-63	-72	-119	0	-9	-37	-57	-60	0
2004	0	0	0	-65	-80	-106	0	-9	-37	-89	0	0
2005	-160	-232	-340	0	-76	0	0	-9	-35	-54	-220	0
2006	-11	-99	-155	0	0	-38	-55	-63	-92	-144	-307	0
2007	-216	-295	-351	0	0	-38	-55	-63	-92	-144	-307	0
2008	-196	-228	0	-64	-118	-166	-183	-191	-220	0	0	-179
2009	0	0	-157	-251	-253	-286	-302	-311	-340	-389	-469	-544
2010	-588	-707	0	0	0	0	0	0	0	0	-18	0
2011	0	-36	-91	-129	0	-32	-49	-58	-86	-132	-155	-178
2012	-190	-305	-373	-421	0	-47	-64	-73	-100	-131	-160	0
2013	0	0	0	0	0	0	0	-9	-37	-49	0	0
2014	0	-70	-163	-257	-258	0	-2	-11	-40	-91	-139	0
2015	-52	0	0	0	-39	-80	-97	-106	-134	-186	-217	-235
2016	0	0	-7	0	0	0	0	0	0	0	0	-51
2017	0	0	-112	0	-47	-65	0	-8	0	-47	0	-27
2018	0	0	-33	-93	-145	-186	-202	0	-24	0	0	0
2019	-102	-238	0	-85	-138	-185	-202	-211	-239	-291	-466	-521
2020	-548	0	0	-83	0	-10	-20	-26	-51	0	0	0
2021	0	-5	-79	0	-32	0	-6	0	0	-13	0	-78
2022	0	-20	-41	-50	0	0	-2	0	-1	0	0	0
2023	-47	0	0	-33	0	-35	0	-8	-36	-88	-188	-231

Discussion of Drought Analysis Results Using the Theory of Run Method

Drought in the Slahung Sub-Watershed shows significant variation every year, with some years experiencing severe droughts, such as those recorded in 2001, 2005, and 2006. Based on the data, these years fall into the Extremely Very Dry (ASK) category, with very low rainfall during the dry months, reaching only 19%-22% of normal rainfall. In other years, such as 2002, 2009, and 2010, drought conditions were classified as Very Dry (SK), with rainfall during the dry months still higher, but still well below normal levels. In contrast, other years such as 2003, 2016, and 2022 were recorded as Wet (B), with rainfall approaching or even exceeding normal levels during the dry months.

To address the recurring drought conditions, mitigation measures need to be implemented comprehensively. The construction of reservoirs or water retention ponds in areas prone to extreme drought is essential as a backup water supply during the dry season.

Table 2. Classification of Maximum Cumulative Drought Severity in the Slahung River Basin

Years	Slahung River basin					
	Type of Maximum Cumulative Drought (mm)	Maximum Drought Duration (mm)	Total Normal Rainfall	Total Rainfall in Dry Months	Rainfall Percentage	Classification
2000	-240	4	102	23	22%	Extremely Very Dry
2001	-434	6	533	100	19%	Extremely Very Dry
2002	-391	9	803	451	56%	Very Dry
2003	-119	5	516	478	93%	Wet
2004	-106	3	140	107	76%	Dry
2005	-340	4	276	57	21%	Extremely Very Dry
2006	-307	6	341	33	10%	Extremely Very Dry
2007	-351	6	341	33	10%	Extremely Very Dry
2008	-228	6	324	104	32%	Extremely Very Dry
2009	-544	10	1066	521	49%	Extremely Very Dry
2010	-707	13	1650	943	57%	Very Dry
2011	-178	7	581	403	69%	Very Dry
2012	-421	18	1990	1410	71%	Dry
2013	-49	3	89	40	45%	Extremely Very Dry
2014	-258	5	293	154	53%	Very Dry
2015	-235	8	657	422	64%	Very Dry
2016	-51	1	263	256	98%	Wet
2017	-112	2	124	59	47%	Extremely Very Dry
2018	-202	7	587	383	65%	Very Dry
2019	-521	9	803	23	3%	Extremely Very Dry
2020	-548	10	1090	283	26%	Very Dry
2021	-79	2	559	480	86%	Wet
2022	-50	3	705	655	93%	Wet
2023	-231	5	516	285	55%	Very Dry

Note: (Syahrial, 2017)
Wet = >85%
Dry = >70-85%
Very Dry = >50-70%
Extremely Very Dry = <50%

Additionally, the implementation of efficient irrigation systems, such as drip irrigation, can help optimize water use, especially in the agricultural sector, which is most affected. Diversifying water sources, by utilizing shallow groundwater or harvesting rainwater, is also an alternative that can strengthen water resilience for communities.

Drip irrigation is one of the most effective drought mitigation strategies, particularly in the agricultural sector, which is most vulnerable to water crises. By delivering water directly to the plant roots slowly and precisely, this method reduces the risk of crop failure due to water scarcity. Compared to conventional irrigation systems, drip irrigation can save up to 50% of water while maintaining stable soil moisture even during low rainfall periods. This efficiency is crucial in facing prolonged dry seasons caused by climate change, as it enables farmers to continue production with limited water resources.

In the context of optimizing water use for drought mitigation, drip irrigation enables smart and adaptive water management. The system can be controlled through timers or soil moisture sensors to ensure that watering occurs only when necessary, avoiding waste and preserving water reserves. Through this approach, drip irrigation not only supports food security but also strengthens water resilience at the community level. The adoption of this technology plays a vital role in long-term adaptation to drought and the degradation of water resources [13].

It is also important to educate the community about wise water management practices. Outreach on water conservation and the selection of drought-resistant crops can help farmers and communities in drought-affected areas. Furthermore, reforestation or ecosystem rehabilitation will improve the soil's ability to absorb water, which can reduce the long-term impacts of drought. By regularly monitoring rainfall and implementing early warning systems, we can ensure that mitigation measures are taken in a timely and effective manner, ensuring the sustainability of water resources and the well-being of the community.

Conclusion

Based on the drought analysis results using the Theory of Run method, the longest drought duration at the Slahung Rainfall Station occurred in 2012, lasting for 17 months, from June 2011 to October 2012, while the shortest duration was recorded in February 2016, lasting only 1 month. The longest drought was also recorded at the Ngilo-Ilo Rainfall Station in 2010, with a duration of 12 months, from March 2009 to February 2010. At the Balong Rainfall Station, the longest drought occurred in 2011, lasting 12 months. The largest cumulative drought at the Slahung Rainfall Station occurred in 2010, with a total of -1071 mm, followed by the shortest cumulative drought in 2004, which was -94 mm. The drought distribution map shows that 2019 was the driest year, while 2023 was the wettest year.

For future research, it is recommended to use longer and higher quality rainfall data, as more complete data will help to identify drought trends more accurately. Additionally, it is important to ensure that the rainfall data used does not have many gaps or data loss, which can affect the analysis results. A comparison of the Theory of Run method with other drought analysis methods should also be conducted to see if there are differences in results, so that the most suitable method for measuring drought in the region can be chosen. Lastly, when creating drought maps, the interpolation method used should be evaluated to ensure that the maps produced are highly accurate and effectively represent the distribution of drought.

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