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Mapping Drought Disaster Risk Due to Climate Change in Kulon Progo District, Indonesia

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ABSTRACT

Kulon Progo Regency is one of the regencies that always experiences severe drought. One of the factors that cause drought in Kulon Progo Regency is climate change due to global warming which causes changes in rainfall. The existence of drought certainly causes many problems in life due to the lack of water supply. Therefore, the purpose of this research is to conduct disaster risk mapping to obtain information on how to mitigate drought. The method used is to calculate the drought index using the Thornthwaite Matter method, calculate vulnerability based on BPS data, and calculate regional capacity based on the Regulation of BNBP Number 3 of 2012. After that, the calculation of disaster risk is then mapped. In this study, disaster risk is divided into two, disaster risk per year and dry months. The results of the annual disaster risk found that almost all sub-districts experienced low drought disaster risk, except for the Grimulyo sub-district which experienced moderate drought disaster risk. For the results of disaster risk in dry months, it is found that five sub-districts are classified into the low disaster risk category, namely Temon, Wates, Panjatan, Galur, and Nanggulan sub-districts. In addition, there are five sub-districts that fall into the medium disaster risk category, namely Lendah, Sentolo, Pengasih, Kokap, and Kalibawang. Finally, there are two sub-districts that fall into the high disaster risk category, namely Girimulyo and Samigaluh sub-districts.

Keywords:
Drought; disaster risk; drought index; capacity; vulnerability

1. Introduction

Drought and climate changes are the two natural and hydrological events. Several researchers have conducted research on climate change and drought. Drought, a natural phenomenon caused by low precipitation, exacerbated by climate change [1, 2]. Also, the influence of various rainfall patterns due to climate change has affected the estuarine system [3]. Drought is a state of shortage of water supply in an area for a prolonged period [4]. The impact of climate change on drought severity in Thessaly, Greece is shown by an increase in annual drought severity across all

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hydrological areas and Standardized Precipitation Index (SPI) time scales [5]. Climate change has accelerated the onset of droughts, increasing their intensity and wildfire risk [6]. Also, Climate change has increased drought severity, potentially impacting agriculture in western Canada [7]. A study used the Standardized Precipitation Index (SPI) to identify and monitor droughts in the Sarawak River Basin, and the results showed a decreasing trend in SPI values for three times scales, indicating increased drought events [8].

Drought has significantly impacted agriculture [9], vegetation loss [10] and crops [11]. The impacts of drought vary based on the type, location, socioeconomic conditions, and cultural attitudes towards its causes [12]. Droughts are environmental hazards characterized by prolonged decreases in precipitation across various climatic zones [13]. Increasing greenhouse gas concentrations and temperature influence drought intensity and drought-affected areas [14]. The intensity and impacts varied across regions, emphasizing the need to evaluate drought impacts in a continental country with diverse vegetation, soil, land use, and climate regimes [15].

Indonesia, an archipelagic country on the equator, is grappling with climate change [16]. The country faces significant challenges from climate change, impacting food, water, energy sustainability, and environmental health [17]. Since 1811, Indonesia has experienced drought due to its tropical climate and sensitivity to El-Nino Southern Oscillation [18]. Indonesia faces increasing hydrological drought risk due to climate change hotspots [19]. The drought events are primarily influenced by El Niño, with El Niño increasing drought frequency in various seasons [20]. The widespread impacts include limited irrigation water, reduced crop production, and reduced income. Some regions in Indonesia experience extreme drought in less than four years [21]. Drought is one of the disasters that occurs slowly and lasts for a long time until the arrival of the rainy season and has a very wide impact. Drought disasters can occur due to deviations from normal weather conditions in the area. The intended deviation is the amount of rainfall that is reduced compared to normal conditions which causes the water content in the soil to decrease or worsen until it is absent [22].

Drought is a long-lasting natural disaster, particularly in the Special Region of Yogyakarta [23]. Kulon Progo Regency is one of the areas in the Special Region of Yogyakarta that is quite severely affected by drought. Laksana *et al.,* [24] determined the drought risk in Kulon Progo Regency, focusing on drought level, exposed population, and vulnerable population using fuzzy logic. The results show fluctuating drought risk levels from 2010 to 2019, with southern regions having higher risks.

Hendrayana *et al.,* [25] identified water scarcity areas in Kulon Progo Regency and determined priorities for deep well drilling. The number of water-scarce areas selected for drilling is 104, with 37 being the priority. The population growth rate in Kulon Progo has increased over time, causing the existing green/water catchment areas to decrease due to continuous regional development. The more residential areas that are built, the higher the utilization of groundwater, causing drought [26]. In addition, the occurrence of drought in Kulon Progo is also caused by several other factors such as land closure and clearing for farming, topography, geological conditions, and most importantly rainfall changes due to climate change. In addition, drought can also be caused by human actions due to non-compliance with water use regulations and rampant sand mining.

Based on IRBI data for 2022, Kulon Progo Regency is the second highest-risk area in the Yogyakarta Special Region, with a high-risk class that has a score of 12.36. The ranking of drought disaster risk in Yogyakarta Special Region Province can be seen in Table 1.

The drought that occurs in the Kulon Progo Regency every year is clearly a threat to thousands of residents. Water, which is an important component of human survival, is clearly needed, even though hundreds of hectares of agricultural land have experienced drought, causing huge losses for hundreds of farmers. In addition, residents must be prepared to sacrifice their time to find water. Based on this problems drought mapping is needed to obtain information and analysis related to the drought that occurred in Kulon Progo as an effort to overcome the drought disaster.

Table 1
Ranking of drought disaster risks in the special region of Yogyakarta [27]

District	Score	Risk class
Bantul	15.60	High
Kulon Progo	12.36	High
Gundung Kidul	11.56	Medium
Yogyakarta City	11.16	Medium

For drought analysis, some methods can be used such as Thornthwaite-Mather, Palmer, and Thomas models [28]. The Thornthwaite-Mather model has been used by many researchers in their studies. Nandini *et al.,* [29] used this method to analyze drought in the Dodokan watershed on Lombok Island, Indonesia. Anna *et al.,* [30] used the method to determine the water balance and fulfillment of domestic water demand in the Upstream and Midstream of Bengawan Solo Watershed, Indonesia. Alley *et al.,* [28] and Toth *et al.,* [31] used the method to analyze drought in their studies. Based on the previous research, this research also uses the Thornthwaite Matter method to determine drought. However, our study attempts to calculate vulnerability and capacity which is then carried out risk calculations in sub-districts located in Kulon Progo Regency, Yogyakarta Special Region.

2. Methodology

2.1 Regional Capacity Using Questionnaire Method

According to Regulation of BNPB No. 03/2012, capacity is the ability of a region or community to take action to reduce disaster risk in a planned, structured, and integrated manner. This research used a questionnaire method to determine the level of capacity in Kulon Progo Regency. The questionnaire method in this research is based on Regulation of BNBP No. 3 of 2012. This questionnaire will be given to relevant agencies containing 88 questions with an answer choice between "YES" or "NO". From the results of the questionnaire, each sub-district will be classified into 3 groups which can be seen in Table 2.

Table 2
Classification of capacity levels [32]

Classification	Value (ranges)	Score
Low capacity	20 – 48	1
Medium capacity	49 – 72	2
High capacity	72 – 88	3

2.2 Regional Vulnerability Using Scoring and Weighting Methods

In this study, the vulnerability level of Kulon Progo Regency was analyzed using the scoring and weighting method. In this research, there are three aspects that are used as a reference in determining the level of vulnerability in Kulon Progo Regency, namely social aspects, economic aspects, and environmental aspects. The classification of each vulnerability aspect in this research is divided into three levels, namely low, medium, and high. The weight of each aspect can be seen in Table 3 (Regulation of BNBP No.2 of 2012).

Table 3
The weighting of vulnerability aspects [33]

Aspects	Weight (%)	Total (%)
Social aspects	40	
Economic aspects	30	100
Environmental aspects	30	

2.3 Drought Index Using the Thornthwaite Matter Method

In calculating the drought index, the water balance is first calculated using the Thornthwaite Matter method. This method prioritizes the importance of rainfall or precipitation (P) and Potential Evapotranspiration (PE) factors as climatological factors. In addition, soil moisture parameters and vegetation types are required. The components of the Thornthwaite Mather method consist of:

i. Potential Evapotranspiration (PE)
ii. Accumulation of Potential Water Loss
iii. Soil Moisture to Field Capacity (STo)
iv. Soil Stiffness (ST)
v. Actual Evapotranspiration (AE)
vi. Surplus (S)
vii. Deficit (D)
viii. Drought Index (Ia)

2.4 Disaster Risk Calculation Method

The occurrence of disasters is due to hazard factors and vulnerability factors caused by a trigger factor, so disasters will cause a disaster risk that may arise from a disaster event. Disaster risk assessment is an approach by provides a comprehensive regional figure of disaster risk by analyzing the level of threat, level of vulnerability, and capacity of an area. To calculate the disaster risk of an area is obtained from Eq. (1).

$$\text{Disaster Risk} = \text{Threat} \times \frac{\text{Vulnerability}}{\text{Capacity}} \quad (1)$$

2.5 Research Stages

Primary data in this study are the results of the questionnaire on the regional capacity level of Kulon Progo Regency while secondary data are obtained from the Central Statistics Agency (BPS) of Kulon Progo Regency. Data obtained from BPS in the form of rainfall and temperature data will be used to assess the drought index. In addition, BPS also obtained population, economic, and environmental data that will be used in analyzing the level of vulnerability. Flow chart of the research is shown in Figure 1.

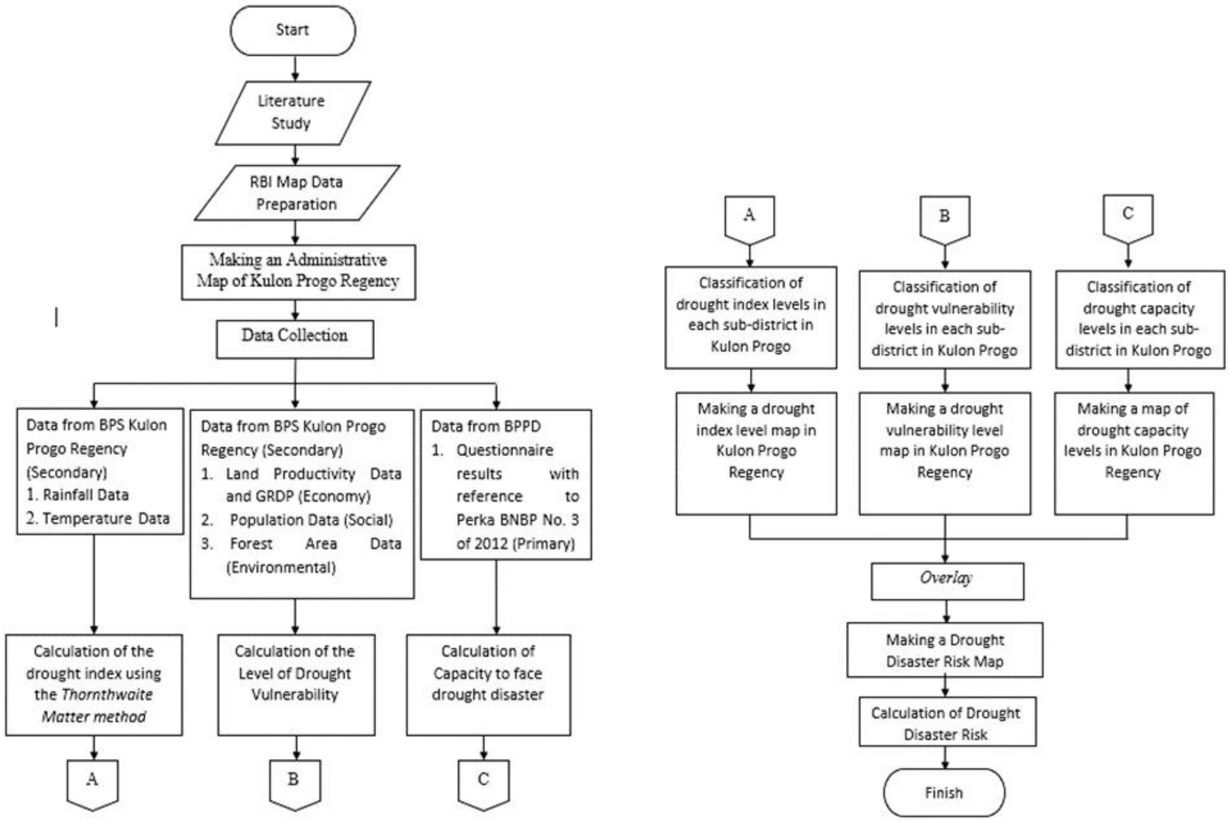


Fig. 1. Flowchart of this research

3. Results

3.1 Regional Capacity Using Questionnaire Method

Based on the results of the questionnaire to each sub-district office to determine the level of regional capacity, the results of the questionnaire and its classification are shown in Table 4 and Figure 2.

Table 4
Questionnaire results and classification

District	Yes	No	Category	Score
Temon	58	30	Medium capacity	2
Wates	64	24	Medium capacity	2
Panjatan	74	14	High capacity	3
Galur	76	12	High capacity	3
Lendah	67	21	Medium capacity	2
Sentolo	60	28	Medium capacity	2
Pengasih	55	33	Medium capacity	2
Kokap	53	35	Medium capacity	2
Girimulyo	48	40	Low capacity	1
Nanggulan	52	36	Medium capacity	2
Kalibawang	46	42	Low capacity	1
Samigaluh	43	45	Low capacity	1

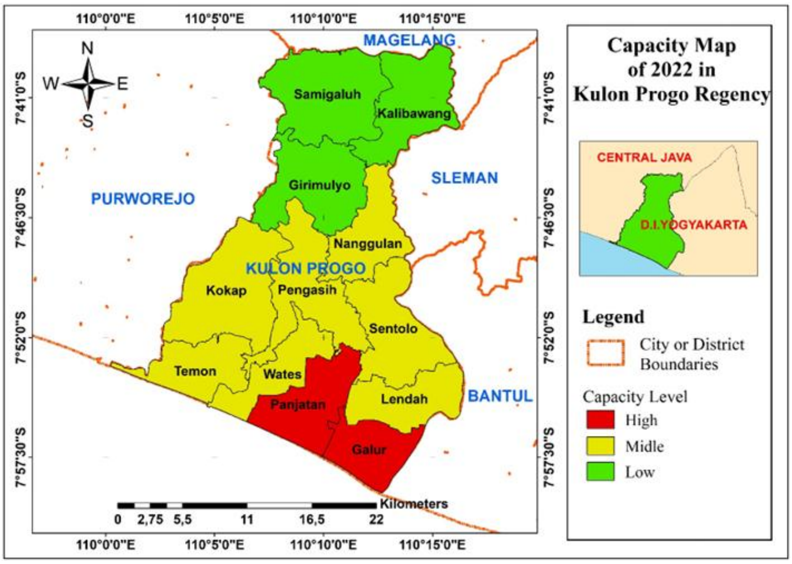


Fig. 2. Map showing the location of regional capacity

3.2 Regional Vulnerability Using Scoring and Weighting Methods

Parameters on social aspects in the study are divided into two, namely population density and vulnerable groups, which have a weight of 60% and 40% respectively. The results of vulnerability in social aspects can be seen in Table 5.

Table 5
Vulnerability scores on social aspects

District	Population density value	Vulnerable group value	Social aspect vulnerability score	Weight (%)	Final social vulnerability Score
Temon	1.2	0.9	2.1	40	0.84
Wates	1.8	0.9	2.7		1.08
Panjatan	1.2	1.2	2.4		0.96
Galur	1.8	0.9	2.7		1.08
Lendah	1.8	1.2	3.0		1.20
Sentolo	1.2	1.2	2.4		0.96
Pengasih	1.2	1.2	2.4		0.96
Kokap	0.6	1.2	1.8		0.72
Girimulyo	0.6	1.2	1.8		0.72
Nanggulan	1.2	1.2	2.4		0.96
Kalibawang	1.2	1,2	2.4		0.96
Samigaluh	0.6	1.1	1.7		0.68

Parameters in the economic aspect of the study are divided into two, namely productive land area and GRDP, which have a weight of 60% and 40% respectively. The results of vulnerability in social aspects can be seen in Table 6. The environmental aspect in this study consists of one parameter, namely forest area. The results of vulnerability in environmental aspects can be seen in Table 7.

Table 6
Vulnerability scores on economic aspects

District	Land productivity value	GRDP value	Economic vulnerability score	Weight (%)	Final economic vulnerability Score
Temon	1.8	1.2	3.0	30	0.9
Wates	1.8	1.2	3.0		0.9
Panjatan	1.8	1.2	3.0		0.9
Galur	1.8	1.2	3.0		0.9
Lendah	1.8	1.2	3.0		0.9
Sentolo	1.8	1.2	3.0		0.9
Pengasih	1.8	1.2	3.0		0.9
Kokap	1.8	1.2	3.0		0.9
Girimulyo	1.8	1.2	3.0		0.9
Nanggulan	1.8	1.2	3.0		0.9
Kalibawang	1.8	1.2	3.0		0.9
Samigaluh	1.8	1.2	3.0		0.9

Table 7
Vulnerability scores on environmental aspects

District	Area (Ha)	Tiers	Environmental vulnerability score	Weight (%)	Vulnerability score for economic aspects of the environment
Temon	50	Medium	2.0	30	0.6
Wates	5	Low	1.0		0.3
Panjatan	651	High	3.0		0.9
Galur	50	Medium	2.0		0.6
Lendah	50	Medium	2.0		0.6
Sentolo	740	High	3.0		0.9
Pengasih	822.3	High	3.0		0.9
Kokap	2751.19	High	3.0		0.9
Girimulyo	1210	High	3.0		0.9
Nanggulan	25	Medium	2.0		0.6
Kalibawang	492	High	3.0		0.9
Samigaluh	350	High	3.0		0.9

Based on the results of the calculation of social, economic, and environmental aspects, the level of vulnerability will be calcified based on Table 8. The results of the vulnerability level can be seen in Table 9 and Figure 3.

Table 8
Vulnerability scores on environmental aspects

Hazard Category	Value	Score
Low	1 - < 1.67	1
Medium	1.67 - < 2.34	2
High	2.34 – 3	3

Table 9
Vulnerability score for each sub-district

District	Vulnerability value of aspects			Value vulnerability	Category	Score
	Social	Economy	Environment			
Temon	0.84	0.9	0.6	2.34	High	3
Wates	1.08	0.9	0.3	2.28	Medium	2
Panjatan	0.96	0.9	0.9	2.76	High	3
Galur	1.08	0.9	0.6	2.58	High	3
Lendah	1.20	0.9	0.6	2.70	High	3
Sentolo	0.96	0.9	0.9	2.76	High	3
Pengasih	0.96	0.9	0.9	2.76	High	3
Kokap	0.72	0.9	0.9	2.52	High	3
Girimulyo	0.72	0.9	0.9	2.52	High	3
Nanggulan	0.96	0.9	0.6	2.46	High	3
Kalibawang	0.96	0.9	0.9	2.76	High	3
Samigaluh	0.68	0.9	0.9	2.48	High	3

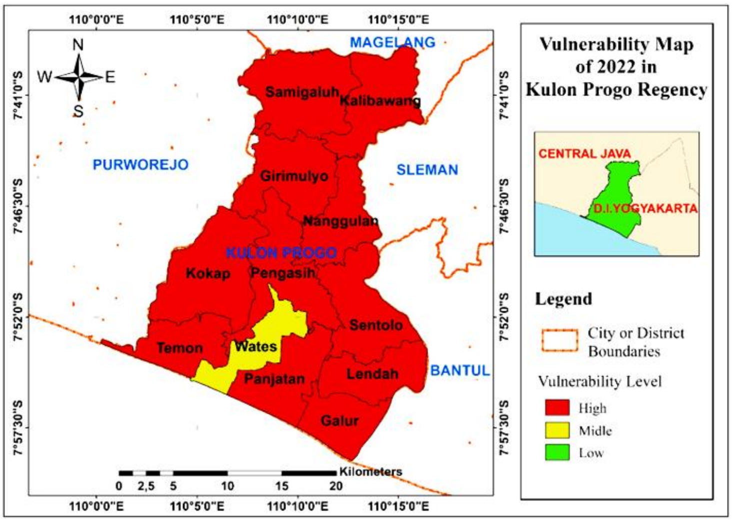


Fig. 3. Map showing the location of regional vulnerability

3.3 Drought Index Using the Thornthwaite Matter Method

The drought index in this study is divided into two assessments, namely the drought index per year and the category of drought index in dry months (April - September). The data required are rainfall and temperature data obtained through BPS. For the category of the Drought Index level, it is shown in Table 10. For the recapitulation of the Drought index, it can be seen in Figure 4. The category of drought level per year can be seen in Table 11 and Figure 5(a). The category of drought index in dry months can be seen in Table 12 and Figure 5(b).

Table 10
Interval values for the drought Index

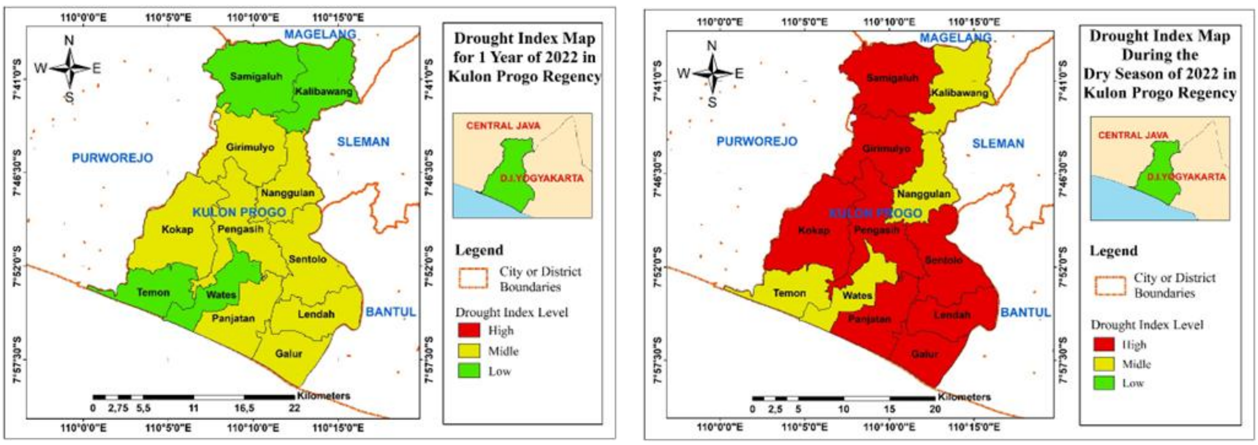
Drought Index (%)	Drought Level	Score
< 16.67	Low	1
16.67 – 33.33	Medium	2
> 33.33	High	3

Sub District	January	February	March	April	May	June	July	August	September	October	November	December	Ia per year	Ia dry month
Temon	0	0	0	0	0	1.660	19.877	48.843	56.288	0.0	0.0	0.0	9.287	21.111
Wates	0	0	0	0	0.008	16.707	47.990	65.467	59.521	0.0	0.0	0.0	13.26	31.616
Panjatan	0	0	0	0	0	18.191	52.013	64.713	68.736	33.685	0.0	0.0	17.43	33.942
Galur	0	0	0	0.528	6.8960	34.035	63.755	74.022	71.913	53.988	0.0	0.0	22.323	41.858
Lendah	0	0	0	0	8.1953	41.065	66.362	67.720	79.961	25.129	0.0	0.0	20.395	43.884
Sentolo	0	0	0	0	0	22.248	53.891	75.096	81.803	55.181	27.593	0.0	24.412	38.840
Pengasih	0	0	0	0.349	0	18.581	52.270	67.442	79.318	44.991	21.934	0.0	21.853	36.327
Kokap	0	0	0	0	0	15.559	50.175	70.253	70.842	48.087	0.0	0.0	19.095	34.471
Girimulyo	0	0	0	0	0	16.665	50.971	65.482	70.515	49.666	22.096	0.0	21.254	33.939
Nanggulan	0	0	0	0	0	4.564	38.371	60.412	70.028	45.880	27.106	0.0	19.588	28.896
Kalibawang	0	0	0	0	0	0.171	26.645	45.381	47.266	7.939	0.0	0.0	9.385	19.911
Samigaluh	0	0	0	0	0	15.197	48.710	67.239	72.290	5.788	0.0	0.0	14.903	33.906

Fig. 4. Recapitulation of the drought index

Table 11
Drought index level per year for each sub-district

District	Drought Index Level per Year (%)	Category	Score
Temon	9.287	Low	1
Wates	13.260	Low	1
Panjatan	17.430	Medium	2
Galur	22.323	Medium	2
Lendah	20.395	Medium	2
Sentolo	24.412	Medium	2
Pengasih	21.853	Medium	2
Kokap	19.095	Medium	2
Girimulyo	21.254	Medium	2
Nanggulan	19.588	Medium	2
Kalibawang	9.385	Low	1
Samigaluh	14.903	Low	1



(a) (b)

Fig. 5. Result showing the map of drought index (a) In the year (b) In the dry months

Table 12
Drought index level of dry months for each sub-district

District	Drought index level per dry months (%)	Category	Score
Temon	21.111	Medium	2
Wates	31.616	Medium	2
Panjatan	33.942	High	3
Galur	41.858	High	3
Lendah	43.884	High	3
Sentolo	38.840	High	3
Pengasih	36.327	High	3
Kokap	34.471	High	3
Girimulyo	33.939	High	3
Nanggulan	28.896	Medium	2
Kalibawang	19.911	Medium	2
Samigaluh	33.906	High	3

3.4 Disaster Risk Calculation

After determining the level of capacity, the level of drought index, and the level of vulnerability of each sub-district, the next map will be made using the ArcGIS 10.2 software application. Later the maps will be used as analysis material to create a disaster risk map using the overlay method. The overlay results will then be analyzed to calculate the risk of drought. The results of drought disaster risk in the study are divided into two, namely the risk of drought disaster per year and the risk of drought disaster in dry months. The interval value of disaster risk is shown in Table 13. The results of the drought disaster risk category per year can be seen in Table 14 and drought disaster risk in dry months can be seen in Table 15.

Table 13
Drought risk interval values

Risk Category	Value	Score
Low	0.33 - < 3.2	1
Medium	3.2 - < 6.1	2
High	6.1 – 9	3

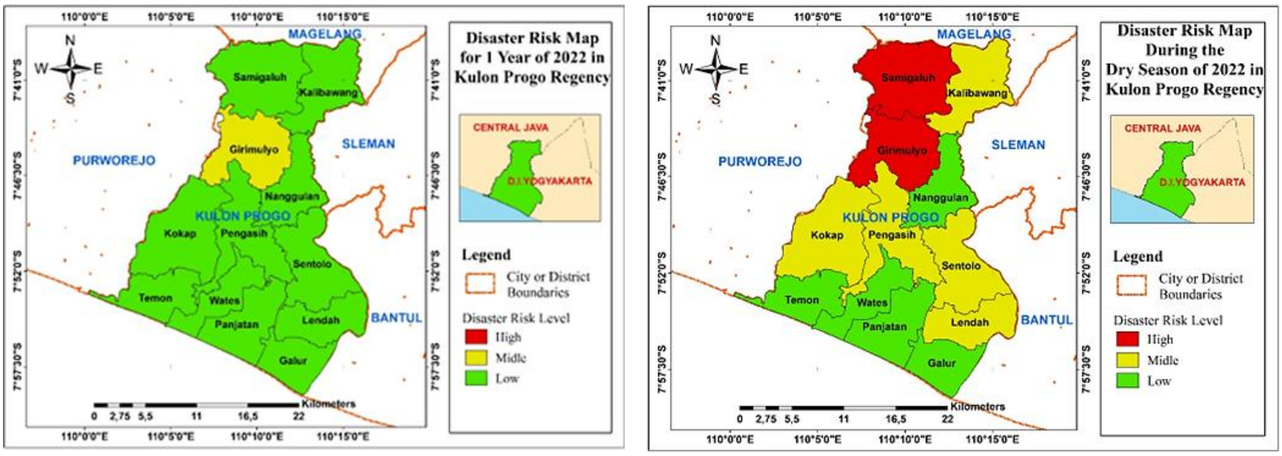
Table 14
Results of drought risk analysis per year for each sub-district

District	Capacity level	Vulnerability level	Drought index	Risk value	Category	Score
Temon	2	3	1	1.5	Low	1
Wates	2	2	1	1	Low	1
Panjatan	3	3	2	2	Low	1
Galur	3	3	2	2	Low	1
Lendah	2	3	2	3	Low	1
Sentolo	2	3	2	3	Low	1
Pengasih	2	3	2	3	Low	1
Kokap	2	3	2	3	Low	1
Girimulyo	1	3	2	6	Medium	2
Nanggulan	2	3	2	3	Low	1
Kalibawang	1	3	1	3	Low	1
Samigaluh	1	3	1	3	Low	1

Table 15
Results of drought risk analysis in the dry month for each sub-district

District	Capacity level	Vulnerability level	Drought index	Risk value	Category	Score
Temon	2	3	2	3	Low	1
Wates	2	2	2	2	Low	1
Panjatan	3	3	3	3	Low	1
Galur	3	3	3	3	Low	1
Lendah	2	3	3	4.5	Medium	2
Sentolo	2	3	3	4.5	Medium	2
Pengasih	2	3	3	4.5	Medium	2
Kokap	2	3	3	4.5	Medium	2
Girimulyo	1	3	3	9	High	3
Nanggulan	2	3	2	3	Low	1
Kalibawang	1	3	2	6	Medium	2
Samigaluh	1	3	3	9	High	3

After obtaining the results of drought disaster risk in each sub-district, then finishing the overlay map that has been made to be a disaster risk map per year and a drought disaster risk map in dry months. The results of the drought disaster risk map per year can be seen in Figure 6(a), and the drought disaster risk map for dry months can be seen in Figure 6(b).



(a) (b)

Fig. 6. Result showing the map of drought risk (a) In the year (b) In the dry months

3.5 Discussion

The data shown in Table 4 and Figure 2 shows that there are 2 sub-districts in the high category, 7 sub-districts in the medium category, and 3 sub-districts in the low category for their capacity to face drought disasters. Based on these results, it is necessary to increase the capacity of each sub-district to face disasters, especially for those in the low and medium categories. Table 9 and Figure 3 show the community's vulnerability to drought disasters. Based on this data, this shows that almost all sub-districts have a vulnerability to drought in the high category. There are only 2 sub-districts in the medium category. This shows that social, economic, and environmental community activities cannot be separated from the presence of water. The data shown in Table 11 and Figure 5, shows that in calculating the drought index in a year, 4 sub-districts are in the low category and 8 sub-districts are in the medium category. However, if the drought index is calculated only in the dry months, as shown in Table 12 and Figure 5, this shows that there are 8 sub-districts in the high category and 4 sub-districts in the medium category. These results illustrate that the amount of high-intensity rain is only collected during the rainy season. Meanwhile, in the dry season, there is almost no rain at all.

Based on the results of the calculation for the level of disaster risk obtained through the analysis of the level of capacity, vulnerability, and vulnerability index, two conclusions are obtained, namely regarding sub-districts that have a level of risk of drought per year and sub-districts that have a level of risk of drought in dry months, as shown in Figure 6. The level of drought disaster risk per year found that there is only one sub-district that is classified into the category of moderate disaster risk, namely the Girimulyo sub-district. The other eleven sub-districts fall into the low disaster risk category. The level of drought disaster risk in dry months found that five sub-districts are classified into the low disaster risk category, namely Temon, Wates, Panjatan, Galur, and Nanggulan sub-districts. In addition, five sub-districts fall into the medium disaster risk category, namely Lendah, Sentolo, Pengasih, Kokap, and Kalibawang. And two sub-districts that fall into the high disaster risk category, namely Girimulyo and Samigaluh.

4. Conclusions

Based on the results of the calculation for the level of drought disaster risk per year, only one sub-district is classified into the category of moderate disaster, and the other sub-districts are in the low disaster risk category. However, when the calculation for the level of drought disaster risk in dry months, there are five, five, and two sub-districts that are classified into low, medium, and high disaster risk categories, respectively. The results of this study can be used by the Kulon Progo regional government to make policies for handling drought disasters in Kulon Progo Regency. Apart from that, the results of this study can also be used as a reference by other regional governments in determining the risk of drought disasters in an area.

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References
[1] Yilmaz, Abdullah G., Arwa Najah, Aysha Hussein, Athra Khamis, Naseraldin Kayemah, and Serter Atabay. "Climate change effects on drought in Sharjah, UAE." *International Association of Computer Science and Information Technology Press (IACSIT)* 11, no. 3 (2020): 116-122. https://doi.org/10.18178/ijesd.2020.11.3.1236
[2] Kasiman, Erwan Hafizi. "Flood Mitigation for Sungai Pinji, Ulu Kinta, Perak Using HEC-HMS and HEC-RAS Model." *Frontiers in Water and Environment* 2, no. 1 (2024): 10-27.
[3] Ali, Siti Nurhayati Mohd, Nuryazmeen Farhan Haron, Zulkiflee Ibrahim, Mazlin Jumain, Md Ridzuan Makhtar, Wan Nor Afiqa Wan Mustafah Kamal, and Azanni Nur Izzati Jamaludin. "Salinity-Various Flow Characteristics Investigation in an Identical Meandering Channel." *CFD Letters* 16, no. 3 (2024): 28-36. https://doi.org/10.37934/cfdl.16.3.2836
[4] Adi, Henny Pratiwi, Slamet Imam Wahyudi, Rahmatia Sarah Wahyudi, and Floris Boogard. "Identification, mapping and solutions for drought management in Kaliori District, Rembang Regency, Indonesia." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 45, no. 2 (2025): 111-117. https://doi.org/10.37934/araset.45.2.111117
[5] Loukas, A., L. Vasiliades, and J. Tzabiras. "Climate change effects on drought severity." *Advances in Geosciences* 17 (2008): 23-29. https://doi.org/10.5194/adgeo-17-23-2008
[6] Mukherjee, Sourav, Ashok Mishra, and Kevin E. Trenberth. "Climate change and drought: A perspective on drought indices." *Current climate change reports* 4 (2018): 145-163. https://doi.org/10.1007/s40641-018-0098-x

[7] Zare, Mohammad, Shahid Azam, David Sauchyn, and Soumik Basu. "Assessment of meteorological and agricultural drought indices under climate change scenarios in the South Saskatchewan River Basin, Canada." *Sustainability* 15, no. 7 (2023): 5907. https://doi.org/10.3390/su15075907

[8] Bong, Charles Hin Joo, and J. Richard. "Drought and climate change assessment using standardized precipitation index (SPI) for Sarawak River Basin." *Journal of Water and Climate Change* 11, no. 4 (2020): 956-965. https://doi.org/10.2166/wcc.2019.036

[9] Ogunrinde, Akinwale T., Mike A. Enaboifo, Yahaya Olotu, Quoc Bao Pham, and Alao B. Tayo. "Characterization of drought using four drought indices under climate change in the Sahel region of Nigeria: 1981–2015." *Theoretical and Applied Climatology* 143 (2021): 843-860. https://doi.org/10.1007/s00704-020-03453-4

[10] Seidenfaden, Ida Karlsson, Karsten Høgh Jensen, and Torben Obel Sonnenborg. "Climate change impacts and uncertainty on spatiotemporal variations of drought indices for an irrigated catchment." *Journal of Hydrology* 601 (2021): 126814. https://doi.org/10.1016/j.jhydrol.2021.126814

[11] Hou, Wei, Pengcheng Yan, Guolin Feng, and Dongdong Zuo. "A 3D copula method for the impact and risk assessment of drought disaster and an example application." *Frontiers in Physics* 9 (2021): 656253. https://doi.org/10.3389/fphy.2021.656253

[12] Viliamu, Iese, Anthony S. Kiem, Mariner Azarel, Malsale Philip, Tofaeono Tile, Kirono Dewi GC, Vanessa Round, Craig Heady, Robson Tigona, Filipe Veisa, Kisolel Posanau, Faapisa Aiono, Alick Haruhiru, Arieta Daphne, Vaiola Vainikolo, and Nikotemo Iona. "Historical and future drought impacts in the Pacific islands and atolls." *Climatic Change* 166, no. 1-2 (2021). https://doi.org/10.1007/s10584-021-03112-1

[13] Orimoloye, Israel R., Johanes A. Belle, Yewande M. Orimoloye, Adeyemi O. Olusola, and Olusola O. Ololade. "Drought: A common environmental disaster." *Atmosphere* 13, no. 1 (2022): 111. https://doi.org/10.3390/atmos13010111

[14] Halik, Gusfan, Victorius Setiaji Putra, and Retno Utami Agung Wiyono. "Assessment of climate change impact on drought disaster in Sampean Baru watershed, East Java, Indonesia based on IPCC-AR5." *Natural Hazards* 112, no. 2 (2022): 1705-1726. https://doi.org/10.1007/s11069-022-05245-7

[15] Cunha, Ana Paula MA, Marcelo Zeri, Karinne Deusdará Leal, Lidiane Costa, Luz Adriana Cuartas, José Antônio Marengo, Javier Tomasella, Rita Marcia Vieira, Alexandre Augusto Barbosa , Christopher Cunningham , João Victor Cal Garcia, Elisangela Broedel, Regina Alvalá, and Germano Ribeiro-Neto. "Extreme drought events over Brazil from 2011 to 2019." *Atmosphere* 10, no. 11 (2019): 642. https://doi.org/10.3390/atmos10110642

[16] Ikhwali, M. Faisi, Maulana Ibrahim Rau, Chalermchai Pawattana, and Husnawati Yahya. "Evaluation of flood and drought events using AR5 climate change scenarios in Indonesia." In *Journal of the Civil Engineering Forum*, pp. 37-46. 2023. https://doi.org/10.22146/jcef.4721

[17] Basuki, Tyas Mutiara, Hunggul Yudono Setio Hadi Nugroho, Yonky Indrajaya, Irfan Budi Pramono, Nunung Puji Nugroho, Agung Budi Supangat, Dewi Retna Indrawati, Endang Savitri, Nining Wahyuningrum, Purwanto, Sigit Andy Cahyono, Pamungkas Buana Putra, Rahardyan Nugroho Adi, Agung Wahyu Nugroho, Diah Auliyani, Agus Wuryanta, Heru Dwi Riyanto, Beny Harjadi, Casimerus Yudilastyantoro, Luthfi Haninidityasari, Firda Maftukhakh Hilmya Nada, and Daniel Pandapotan Simarmata. "Improvement of integrated watershed management in Indonesia for mitigation and adaptation to climate change: A review." *Sustainability* 14, no. 16 (2022): 9997. https://doi.org/10.3390/su14169997

[18] Mursidi, Andi. "Management of disaster drought in Indonesia." *Jurnal Terapan Manajemen dan Bisnis* 3, no. 2 (2017): 165. https://doi.org/10.26737/jtmb.v3i2.273

[19] Primadita, B. D., and R. D. Ahmad. "Projecting and managing hydrological drought in Indonesia." In *IOP Conference Series: Earth and Environmental Science*, 724, no. 1, p. 012087. IOP Publishing, 2021. https://doi.org/10.1088/1755-1315/724/1/012087

[20] Sabuna, Flegor Hermes, Rini Hidayati, I. Putu Santikayasa, and Muh Taufik. "Drought events in western part of Timor Island Indonesia." *Agromet* 36, no. 1 (2022): 11-20. https://doi.org/10.29244/j.agromet.36.1.11-20

[21] Kuswanto, Heri, Anggi Wahyu Puspa, Imam Safawi Ahmad, and Fausania Hibatullah. "Drought analysis in East Nusa Tenggara (Indonesia) using regional frequency analysis." *The Scientific World Journal* 2021, no. 1 (2021): 6626102. https://doi.org/10.1155/2021/6626102

[22] Mujtahiddin, Muhamad Iid. "Analisis spasial indeks kekeringan Kabupaten Indramayu." *Jurnal Meteorologi dan Geofisika* 15, no. 2 (2014). https://doi.org/10.31172/jmg.v15i2.179

[23] Ayuningtyas, Fajar, and Sri Yulianto Joko Prasetyo. "Pemanfaatan teknologi machine learning untuk klasifikasi wilayah risiko kekeringan di daerah istimewa Yogyakarta menggunakan citra landsat 8 operational land imager (OLI)." *Jurnal Transformatika* 18, no. 1 (2020): 13-24. http://dx.doi.org/10.26623/transformatika.v18i1.2140

[24] Jayadri, Bertolomeus Laksana, and Agus Maman Abadi. "Fuzzy logic application for drought risk determination in Kulon Progo Regency, daerah istimewa Yogyakarta Province, Indonesia." *EKSAKTA: Journal of Sciences and Data Analysis* (2021): 62-75. https://doi.org/10.20885/EKSAKTA.vol2.iss1.art9

[25] Hendrayana, Heru, M. Widyastuti, Indra Agus Riyanto, Azmin Nuha, and Briyan Aprimanto. "Neraca Airtanah Cekungan Airtanah (CAT) Menoreh dan Wates Kabupaten Kulon Progo." *Geo Media: Majalah Ilmiah dan Informasi Kegeografian* 18, no. 2 (2020): 77-96. http://dx.doi.org/10.21831/gm.v18i2.33636

[26] Mustikarini, Dyah Dhani, Karlina Karlina, and Joko Sujono. "Analisis hubungan urban heat island terhadap indeks kekeringan meteorologis di daerah istimewa Yogyakarta." *Jurnal Riset Rekayasa Sipil* 5, no. 2 (2022): 108-114. https://doi.org/10.20961/jrrs.v5i2.55415

[27] W. Adi, Asfirmanto, Osmar Shalih , Fathia Z. Shabrina, Ahmad Rizqi, Anggara S. Putra, Rafa Karimah, Franta Eveline, Afif Alfian, Syauqi, Rizky Tri Septian, Yudhi Widiastomo, Yusuf Bagaskoro, Afifa Nomita Dewi, Irena Rahmawati, Seniarwan, Hannura Ayu Suryaningrum, Dian Ika Purnamasiwi, and Trevi Jayanti Puspasari. “IRBI Indonesia disaster risk index 2022. 1st ed” *National Board for Disaster Management (BNPB)* 1, 2023.

[28] Alley, William M. "On the treatment of evapotranspiration, soil moisture accounting, and aquifer recharge in monthly water balance models." *Water Resources Research* 20, no. 8 (1984): 1137-1149. https://doi.org/10.1029/WR020i008p01137

[29] Nandini, Ryke, and Ambar Kusumandari. "Land Use Improvement as the Drought Mitigation to Manage Climate Change in the Dodokan Watershed, Lombok, Indonesia." *Land* 11, no. 7 (2022): 1060. https://doi.org/10.3390/land11071060

[30] Anna, Alif Noor, Kuswaji Dwi Priyono, Suharjo Suharjo, and Yuli Priyana. "Using water balance to analyze water availability for communities (a case study in some areas of Bengawan Solo Watershed)." In *Forum Geografi*, vol. 30, no. 2, pp. 166-175. 2016. https://doi.org/10.23917/forgeo.v30i2.2550

[31] Tóth, Ariel, Gábor Soós, Szabina Simon, and Brigitta Simon-Gáspár. "Examination of the evapotranspiration dynamics of maize in Thornthwaite-Mather type compensation evapotranspirometer." *Acta Agraria Kaposvariensis* 26, no. 1 (2022): 55-69. https://doi.org/10.31914/aak.2851

[32] National Board for Disaster Management (BNPB). “BNPB Regulation No. 3 of 2012 Guidelines for Regional Capacity Assessment in Disaster Management.” 3. Jakarta, Indonesian, 2012.

[33] National Board for Disaster Management (BNPB). “BNPB Regulation No. 2 of 2012 Concerning General Guidelines for Disaster Risk Assessment.” 2. Jakarta, Indonesian, 2012.