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Review Article

Drought Disaster Causes and Their Proposed Adaptation Strategies around Karst Areas in Gunungkidul Regency, Indonesia : A Review

Wahyu Endah Christiani Putri[1], Akhmad Zamroni[2]*, Andrea Sumarah Asih[3], Haris Nur Eka Prasetya[4], Saurina Tua Sagala[5], King Joshua Almadrones-Reyes[6]

[1]Department of Mining Engineering, Institut Teknologi Nasional Yogyakarta, Yogyakarta 55281, Indonesia
[2]Department of Geological Engineering, Institut Teknologi Nasional Yogyakarta, Yogyakarta 55281, Indonesia
[3]Department of Civil Engineering, Institut Teknologi Nasional Yogyakarta, Yogyakarta 55281, Indonesia
[4]Department of Mining Engineering, Institut Teknologi Bandung, Bandung 40132, Indonesia
[5]Arnoc Indonesia Energi, Indonesia
[6]Thai Nguyen University of Agriculture and Forestry, Vietnam
*Corresponding author, email : akhmadzamroni@itny.ac.id

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ABSTRACT

Gunungkidul Regency, one of Indonesia's karst regions, frequently experiences droughts. This study aims to investigate the causes of drought disasters and provide adaptation strategies for disasters that may occur near karst areas in Gunungkidul Regency. We used Google Scholar to identify drought causes on the study site. The next stage is making appropriate adaptation strategies using a qualitative and comparative analysis technique. The three main components that cause drought disasters in Gunungkidul Regency include climate characteristics, hydrogeological characteristics, and anthropogenic factors. Some proposed adaptation strategies to address the impacts of drought disasters include planting crops with low water requirements, adopting conservation agriculture and utilizing organic farming, applying structural adaptation strategies, developing agroforestry, giving farmers financial assistance, paying compensation to drought-affected families, distributing knowledge about drought adaptation strategies, reducing family food demand, suggesting seasonal migration, and reducing livestock. Working with multiple stakeholders is essential to putting these adaptation strategies into action.

Keywords: climate; hydrogeological; anthropogenic; agriculture; household

INTRODUCTION

Drought is a severe weather occurrence that is sneaky in nature because it often sneaks up on one. One of the most expensive natural hazards, it can have significant effects when its intensity and duration gradually increase. Additionally, drought has various ecohydrological and socioeconomic implications, such as increased wildfire danger, water scarcity, loss of crops and cattle, higher food costs, migration, and unintended adverse health. Disasters brought on by drought have daily reduced the amount of water in the basin, reduced the size of wetlands, damaged vegetation's ability to perform ecologically, and decreased biodiversity. The intensity and frequency of droughts caused by climate change have increased in recent years. Drought is anticipated to increase in frequency and severity due to population growth's increased demand for water, limited and unreliable water supplies due to climate change's rising temperatures, and

more intense precipitation regimes. Water supplies are crucial for human needs and welfare, and the drought has created problems with water supply to quantify the severity of the drought. Various kinds of drought indices have been developed, such as those that depict drought severity from a meteorological, hydrological, agricultural, and socioeconomic standpoint (Mukherjee et al., 2018; Wang et al., 2022; Nam et al., 2015; & Kim et al., 2015).

Karst regions are landscapes with significant groundwater networks and caves formed on soluble rocks (limestone, gypsum, and marble). Due to high rock solubility and well-developed, fragmented porosity, karst terrains have unique hydrology. Caves, sinking streams, confined depressions, and substantial springs are common geomorphic features in these regions. About 20% of the landscape's dry, ice-free area is covered by karst landscapes, which provide about one-fourth of the world's population with their full or partial water supply. Due to its interconnectedness, which intimately links the surface and subsurface, the karst landscape is thought to be particularly vulnerable. Surface soil is often thin and has less surface water. As fractures are formed, the carbonate rock becomes extremely soluble. Drought and flooding pose the greatest hazards to the Karst region's agricultural development and human life. The unique karst geological environment is a major factor in floods and droughts. In these conditions, underneath the surface, karst growth produced a double-karst hydrogeology system. Precipitation typically penetrates the earth quickly, burying subsurface water and creating a pattern of water and soil separation, which causes surface farmland to experience drought for an extended period. Regular occurrences of drought harm the availability of water resources, which has increased the danger of water-related stresses in the karst areas. Numerous water resources have been forced to quickly infiltrate the deep underground in karst locations, where they are no longer used for agricultural and ecosystem purposes due to high infiltration rates, quick groundwater flow through karst conduits, and small soil water storage capacities (Nerantzaki & Nikolaidis, 2020; Guo et al., 2013; Rui et al., 2012; & Wan et al., 2016).

Strategies against immediate consequences (coping measures) and long-term effects that make up adaptation can reduce the harmful effects of droughts. The extent to which the system can deal with anticipated natural disasters and climate change impacts, while also reducing vulnerability is defined by adaptation strategies. In addition to reducing vulnerability, adaptation strategies also promote the long-term sustainability of rural households. In the context of anticipated future drought episodes, adaptation techniques are crucial to minimize damage and take advantage of both existing and new opportunities (Sam et al., 2020; Zamroni & Faustino-Eslava, 2023). Plans for shifting a region toward an adaptable and robust system for future climatic changes are known as adaptation strategies. They are integrated into larger planning and apply to the regional climate change impacts (Nam et al., 2015). There are many different adaptation tactics, such as changing how people perceive risk, making industrial companies more adaptable, and evolving social systems to place more emphasis on climate fluctuation than consistency. Many adaptations are "no regrets" acts because they may be justified without emphasizing the impending effects of climate change (Joyce et al., 2013). They will contain guidelines and actions to lessen the vulnerability of the nation. Depending on the situation, the plan may be more constrained, concentrating on just one or two sectors or regions. At the national level, it might be all-inclusive, addressing adaptation in various industries, geographical areas, and populations at risk (Biesbroek et al., 2010). There is much anxiety about how communities will react to climate-related catastrophes, especially as they grow more regular and severe. Future management and policy efforts can benefit from knowing what adaptation measures are employed to mitigate, minimize, or offset the impacts of climate change on households (Shinbrot et al., 2019).

In karst regions, agricultural practices such as deforestation, fertilizer and pesticide application, alterations in grazing intensity, and farm waste storage can impact the soil and water. Of particular concern is water quality, which includes suspended sediment, nitrate, pesticides, and microbial pathogens (Rodríguez et al., 2018). High-intensity agricultural practices under intense population pressure have worsened rocky desertification, resulting in widespread soil erosion and vegetation degradation. This has made rocky desertification a major barrier to social and economic development in karst areas (Gu et al., 2022; Nolos et al., 2023). A significant

ecological problem in karst mountain regions is the rocky desertification that results from soil erosion. The local population's lack of understanding of the importance of protecting the soil has resulted in significant human disturbance, which has hastened soil loss and, ultimately, caused rocky desertification to spread over a large area of rural land (Zhao & Hou, 2019). In addition, climate change-related severe droughts have posed a serious threat to many local livelihoods. A lack of knowledge about how households perceive droughts and local adaptation initiatives hinders effective adaptation tactics and policies (Sam et al., 2020). Two steps that make households adapt to drought risk are learning about the lack of previous drought experiences and creating local adaptation strategies to lower the likelihood of drought (Binternagel et al., 2010). People's ability to recognize drought and its intensification will be the foundation for collaborative efforts to improve adaptation techniques. Additionally, it aids decision-makers in deciding on adaptation strategies and initiatives to raise public consciousness and understand climate variability. To inspire ideas and activities to address the consequences, the effects of the drought on people and society must be identified and expressed (Ogundeji & Okolie, 2022).

One of the limestone karst zones that make up the southern part of Daerah Istimewa Yogyakarta Province in Indonesia is in Gunungkidul Regency, based on morphological characteristics. The local population heavily depends on karst groundwater, particularly during dry seasons. Additionally, it suggests that karst could serve as a catchment area during rainy seasons. However, the subterranean flow system in this environment is hard to access. As a result, drought is a recurring risk in karst environments (Widyastuti et al., 2019).

One of Indonesia's karst regions, Gunung Sewu in Gunungkidul Regency, is subject to repeated droughts (Figure 1). Gunung Sewu is highly vulnerable to climatic parameter variations, particularly rainfall. Rainfall significantly impacts water resources, agriculture, and livestock farming, the two primary economic sectors in Gunung Sewu. Along with lakes and epikarst springs, many of its residents still rely on rainfall as their main source of clean water throughout the rainy season. Rainfall has an enormous impact on how much water is available. The absence of rain, even for a few months, can cause most of these lakes and epikarst springs to dry up and lose water (Cahyadi et al., 2021a). The majority of the limestones in the Gunung Sewu karst area are from the Wonosari Formation, which typically exhibits karstification and occasionally calcification. The earliest and youngest lithologic units are found in the basement of the Wonosari Formation. These include the Semilir Formation's tuffaceous sandstones, the Nglanggran Formation's volcanic rock, which includes breccias and lava, the Sambipitu Formation's marl, and the Oyo Formation's sandy-tuff limestones. The middle to late Miocene is when the Gunungsewu limestone was deposited (Kusumayudha et al., 2021). The Gunung Sewu Karst is bound to the northeast by Massive Panggung, an ancient volcanic peak. All of the lithology in this formation is composed of rocks of a volcanic origin, including sandstone, agglomerates, tuff, and volcanic breccias. Because of this impermeable rock formation, there is little groundwater storage. The high overland flow during the rainy season is what supplies some allogeneic rivers that enter the Gunung Sewu Karst (Adji et al., 2017). There are few studies on drought disaster adaptation tactics in karst regions, particularly in Gunungkidul Regency. Therefore, the study aims to identify the factors contributing to drought disasters and propose adaptation strategies for drought disasters around karst areas in Gunungkidul Regency. Adaptation measures are crucial because they may lessen financial and material losses, help people in drought-prone areas, and build coping mechanisms.

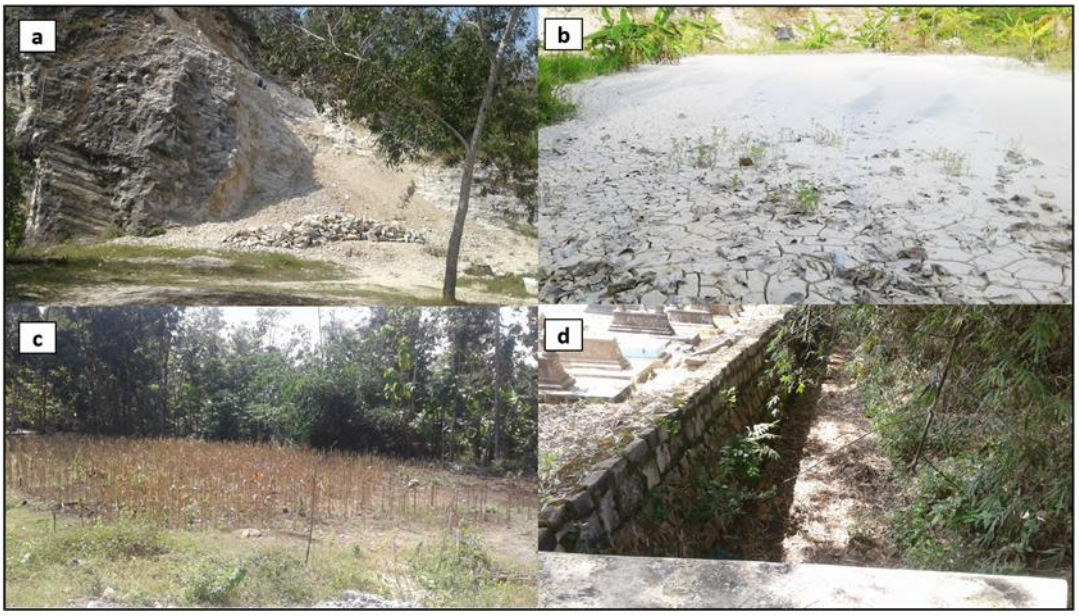

Figure 1. Drought in Gunungkidul Regency; (a) limestone mining activities dominated in Gunungkidul Regency; (b) soil cracking due to drought; (c) corn plants wither due to drought; and (d) dry waterways.

METHODS

The study site is in Gunungkidul Regency, Daerah Istimewa Yogyakarta Province, Indonesia (Figure 2). The physical characteristics of the karst in Gunungkidul Regency in the south of the area are distinctive, signifying and linking to water shortages and poverty as the region's cachet (Retnowati et al., 2014). Due to the lack of surface rivers in karst regions and the allegedly lower quality of their water when they do exist, karst springs are the primary water source for the people of Gunungkidul Regency (Riyanto et al., 2020).

The flowchart of the study method is shown in Figure 3. We used Google Scholar to analyze the literature on drought disasters in Gunungkidul Regency to determine the causes of the drought and its impacts on the local communities. To limit this assessment of the reasons for the drought to the last 20 years (2002–2022), we solely limited our search to those years. Using keywords was a method employed in this inquiry. A semantically rich ontology reduces the need for lengthy text retrieval descriptions and improves retrieval accuracy, while the interface is straightforward to use and offers a reasonable degree of retrieval precision. Applications such as summarization, text mining, text clustering, and text and web page retrieval can all benefit from keyword extraction. Eliminating the key terms simplifies the process of choosing which document to read to comprehend the connections between texts (Poulimenou et al., 2014). The primary keywords serve as an article's title and describe its content. It could make it simpler for others, including academics, to locate relevant publications (Mohaghegh et al., 2018). The words "drought," "Gunungkidul," and "karst" were used throughout this section. Using these terms, the authors attempted a comprehensive data search that considered all aspects of the investigation. To eliminate entries that were not required, publication titles and abstracts were looked at. Read abstracts to get a general understanding of previous research before selecting references. It is necessary to read the complete document to comprehend it more fully (Suprapto et al, 2017). Table 1 displays the findings from the literature review in this section. The Digital Elevation Model (DEM), a data source for topographic characteristics, was also employed to model the karst area and the causes of dryness at the study location. The details of the morphological description of a given area and the computation of topographic derivatives can be impacted by the raster resolution. However, it is not always true that the highest resolution yields the best outcomes, contrary to popular belief. In some circumstances, the properties of the mapped terrain features

determine the best solution. To figure out how much water is in the ground, the resolution of the topographic derivatives may be needed in quite different landscapes, like the karst landscape, which has rough terrain with deep depressions and steep hills (Luo et al., 2019).

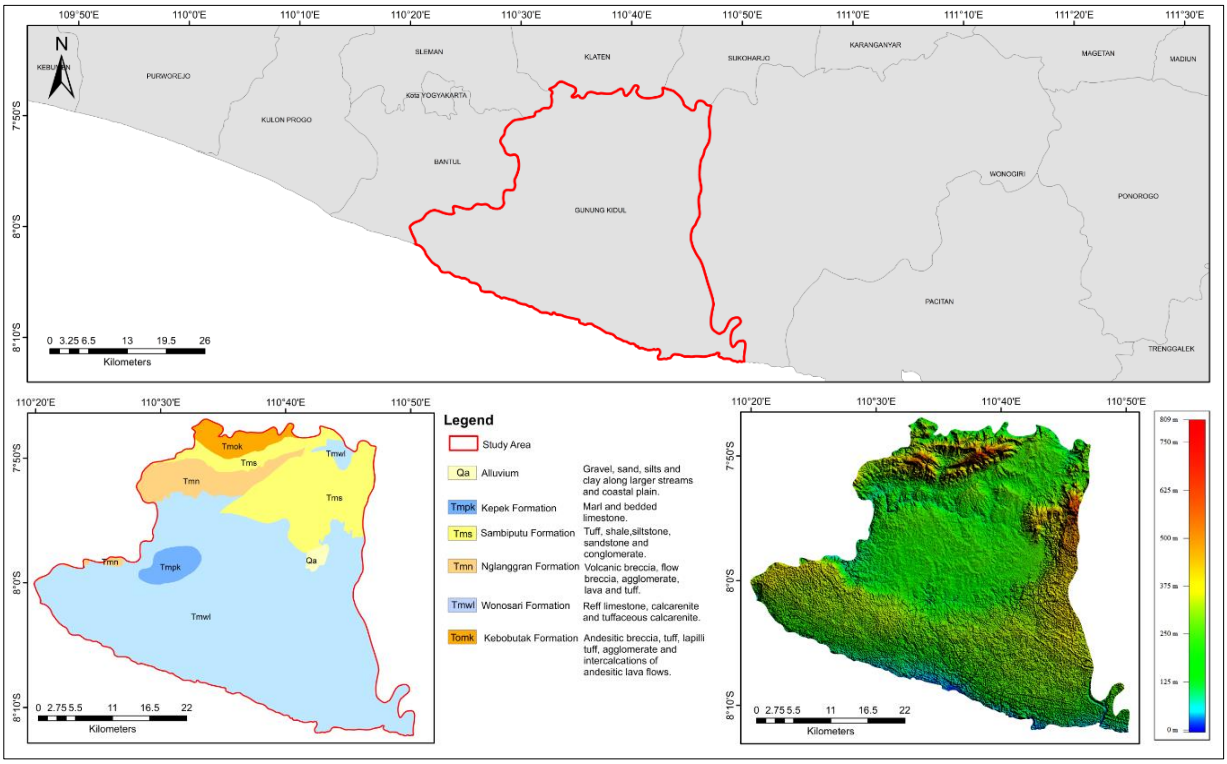

Figure 2. The study site, (a) Gunungkidul administration map, (b) Geological map (redrawn after Rahardjo et al., 1995), and (c) Shuttle Radar Topography Mission.

After finding the causes of the drought in Gunungkidul Regency, the next step is to formulate appropriate adaptation strategies to be proposed at the study site. The goals of this study were accomplished using a qualitative and comparative analysis technique (Sembiring et al, 2015). As a result, specific case studies would be chosen based on pertinent knowledge about drought disasters in Gunungkidul Regency. After that, the transfer of the adaptation strategies is formulated based on the following questions:

1. What adaptation strategies should be implemented?
2. Who are the stakeholders who play a role in implementing the adaptation strategies?
3. What are the roles of each stakeholder in implementing adaptation strategies?

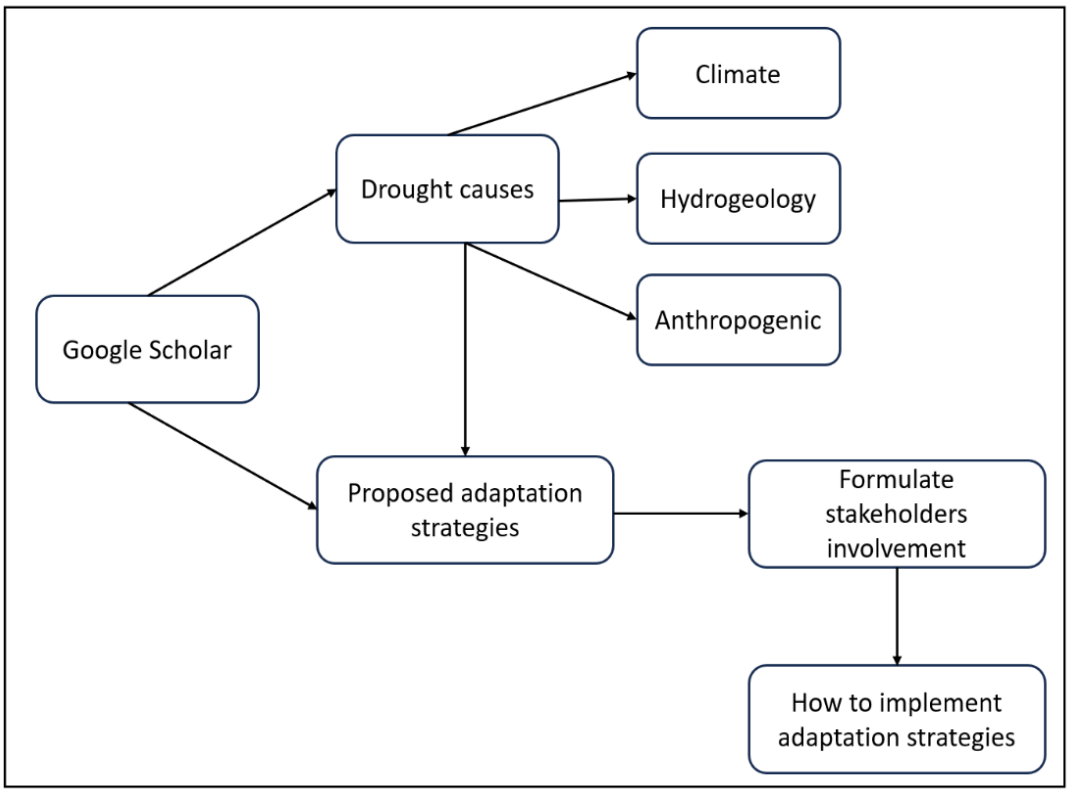

Figure 3. The flowchart of the study method

RESULTS AND DISCUSSION

The causes of the drought disasters around karst areas in Gunungkidul Regency

Mo et al. (2014) divided the three main components that cause drought disasters, namely climate characteristics, hydrogeological characteristics, and anthropogenic factors. Based on the literature review, below are the causes of the drought disaster in Gunungkidul Regency based on those three components.

Climate characteristics

With a tropical environment, Indonesia is highly vulnerable to the El Niño-Southern Oscillation (ENSO), a cause of the drought. Positive Indian Ocean Dipole (IOD), a regional climate event in the Indian Ocean, and El Nino impact the drought in Indonesia. Long after the drought has ended, its effects are extensive and complex (Mursidi & Sari, 2017). Because the dry season would start earlier and the next rainy season would arrive later than usual, the climate anomaly brought on by the El Nino phenomenon may make droughts more likely to occur. As far as drought is concerned, El Nino is a phenomenon that reduces rainfall from its usual level, making it one of the main causes of drought in Indonesia. One of the regions referred to as arid and vulnerable to drought due to the low intensity of precipitation during the dry season is Gunungkidul Regency (Putra & Nurjani, 2021). Gunungkidul Regency only experiences rain during the rainy season (October to March) (Subandi et al., 2019). Despite having 103 rainy days on average per year and a noticeable 6-month dry season when rainfall is less than 100 mm per month (Sudomo et al., 2021), with a maximum temperature of up to 32.4 °C and a minimum temperature of 23.3 °C, the average daily temperature is 27.7 °C. About 80–84% of the relative humidity is present (Ulfa & Samidjo, 2021). The annual variation in precipitation was between 1.175 and 2.489 mm/year (2010–2020). Up until June 2020, Gunungkidul Regency continued to get light rain. Gunungkidul Regency often experiences little rainfall; however, in 2020, there was only one rainy day in July

(Maharani et al, 2022). In addition, climate change had an impact on Gunungkidul Regency. This is evident from several variables, including the rise in temperature over the past ten years, the intensity of the uneven average precipitation, and the rising sea levels that erode coastal regions (Misbahuddin, 2021).

Hydrogeological characteristics

The karstic, rocky, and steep Gunungkidul Regency has few water sources. Dryland areas and forests predominate in Gunungkidul's agriculture, with numerous farms producing crops of dryland rice and other dryland crops, such as cassava and sweet potatoes (Utami et al., 2015). The Gunungsewu karst area's hydrological circumstances are similar to those in other karst regions. A network of underground rivers refilled by diffuse infiltration, allogenic rivers, and autogenic percolation makes up the primary water flow system. In Gunungsewu, the growth of voids as a result of the dissolution process distinguishes karstic aquifers from one another. However, depending on geological features and lithological variances, local variations can still be identified (Haryono et al., 2022; Prasetya et al., 2021). The Panggang Subsystem is one of the hydrogeological blocks with severe water resource problems, particularly a lack of clean water. The lack of a powerful underground system and the hydrogeological conditions of the region, which are characterized by sparsely spaced small-discharge springs around the limestone formation's periphery, contribute to the area's water shortage. Consequently, the central area of the Panggang Subsystem has limited water supplies (Riyanto et al., 2019). The underground river and scant spring water are to blame for the drought. Before the 1990s, the doline pond, one of the surface waterways frequently found in karst environments, provided up to 90% of the community's water needs. Unfortunately, deforestation, sedimentation, and leaks contribute to the Gunungsewu Karst's many doline ponds drying up (Haryono et al., 2022; Khansa et al., 2020). Subsurface water flows are created due to karst growth, resulting in less developed and less imposing surface karst hydrology. This is because the karst region has cavities that make it simpler for surface water to seep underground (Zakaria et al., 2021). The westernmost karst region of Gunungsewu is home to Mbangsri Cave, which is part of the Panggang Subsystem. The subsystem's northern, western, and southern portions are interspersed with several springs that typically have minor discharges. Groundwater moves in three directions: north, west, and south. A slight discharge naturally occurs during the dry season from springs that flow to the north, as in the case of Mbangsri Cave. Water resources at Mbangsri Cave have fairly limited potential. A thin epikarst layer, a fissure south of the cave that prevents groundwater entry from nearby locations, and a small catchment area all contribute to a modest diffuse flow. There is only a static pool of water in this cave; there is no subsurface river flow (Cahyadi et al, 2021b). In addition, there is a limited amount of water available due to the high investment and operating expenses associated with accessing karst water, which is often found at considerable depths (>100 m). In addition, many doline ponds become dry following the rainy season. In Gunungkidul Regency, just 30% of the original doline ponds are still operational and able to supply water all year. Rapid sedimentation and infiltration rates cause the water storage capacity of doline ponds to diminish (Wacano et al., 2021).

Anthropogenic factors

Anthropogenic influences impact the quality and quantity of water supplies (Asih et al., 2022; Zamroni et al., 2022). Artificial greenhouse gas emissions affect natural climatic variability, changing the frequency and severity of dry spells or lengthening and worsening droughts. In this context, we concentrate on the causes of drought at the local scale, where anthropogenic forces and behavioral changes, such as shifting land use and cover and rising water demand (for agriculture, homes, mining, etc.), can better explain the phenomenon of drought (AghaKouchak et al., 2022). The shrinking forest area and increasing number of towns in Gunungkidul Regency indicate a change in land use (Sunkar, 2008). Given that water is a scarce natural resource, communities in karst regions frequently establish houses and carry out activities close to water sources. As a result, the karst region's numerous communal activities center on water sources

such as surface rivers, springs, lakes, or dolines (Reynaldi & Damayanti, 2020). Moreover, mining causes most of the harm in karst regions and takes a long time to treat for conservation. Watercourses may shift or relocate, limestone's ability to store water may be reduced due to mining in karst regions, and water supplies may become less abundant (Widowaty et al., 2021). Traditional limestone mining has become a side business for many farmers in several parts of Gunungkidul Regency. The farmers who participate in this activity benefit from it. First, it gives miners' families sufficient financial income during the lean season. Second, it enables land mining owners to remove limestone from their property before reclamation to expand their farms (Haryanti, 2021). Agricultural activities need water to optimize production (Corkal & Adkins, 2008). Sometimes, farmers use surface water or groundwater for irrigation. This can lead to drought if they overexploit the water. In Gunungkidul Regency, dry land—both calcareous and rain-fed land—is used for agriculture most frequently. The calcareous region is mountainous, primarily made up of latosol or clay soil, and has a minimum soil depth of about 50 cm on average. The calcareous land's mountainous topography offers little room for agricultural activities and makes it highly susceptible to the risk of soil erosion (Istiyanti et al., 2018).

A summary of the causes of drought disasters in Gunungkidul Regency is presented in Table 1, and it is reconstructed by using DEM in Figure 4.

Table 1. A summary of the causes of drought disasters in Gunungkidul Regency.

Components causing drought disasters	**Description**
Climate characteristics	The climate anomaly El-Nino Southern Oscillation (ENSO)
	An increase in temperature in the last ten years
	Low average annual precipitation
Hydrogeological characteristics	More underground rivers than surface water
	Small-discharge springs
	Many doline ponds are drying up
	A narrow catchment area
	A fault blocking groundwater infiltration from other areas
	Rapid sedimentation and infiltration rate around doline ponds
Anthropogenic factors	The decreasing amount of forest and the increasing number of total settlements
	Increased mining activities
	Increased agricultural activities

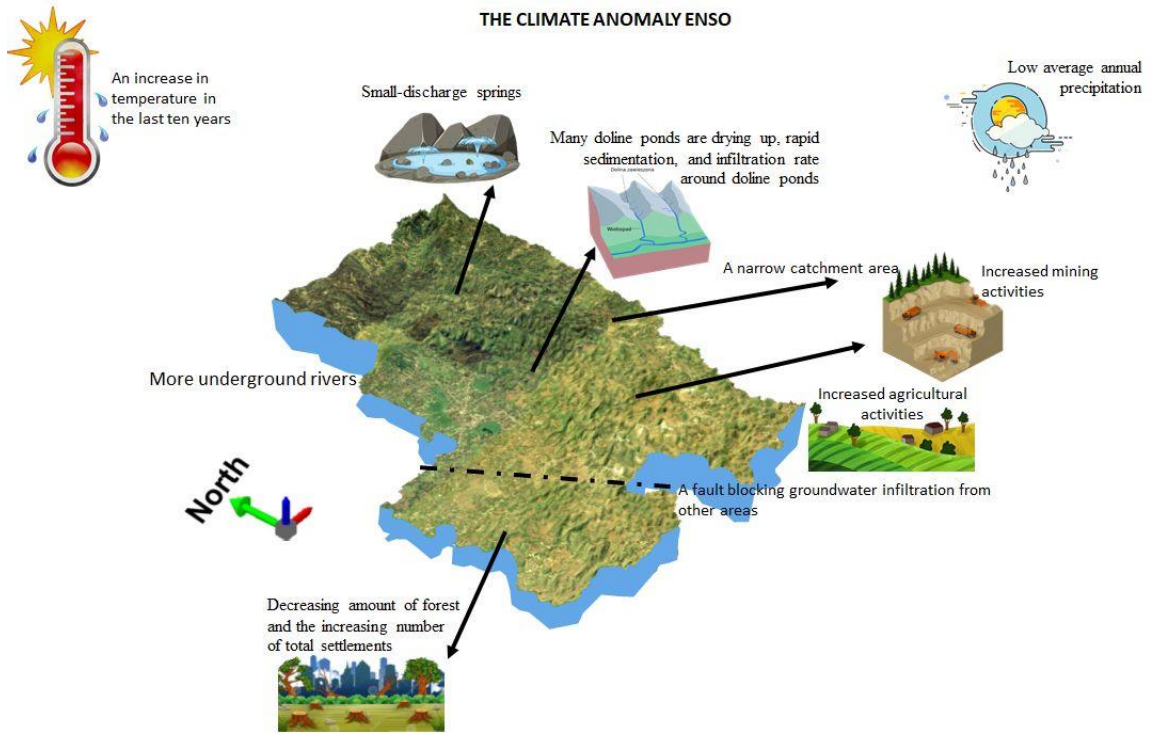

Figure 4. Reconstruction of the drought disasters in Gunungkidul Regency.

Adaptation strategies toward drought disasters around karst areas in Gunungkidul Regency

Drought disasters harm communities in Gunungkidul. Gunungkidul has a population density of 496 people per km^2 throughout its villages. Agriculture, tourism, agroforestry, and mining are the primary sources of income for the locals. The karst region's agricultural carrying capacity is 3.14 times greater than its agricultural productivity for food. People relocate to different cities, islands, or nations due to poor farm output and challenging water supplies (Haryono et al., 2022). One effect of climate and weather disruptions on agriculture is the expansion of crop-failure land, which is widely believed to be the result of unpredictable meteorological conditions. Due to the early dry season, Gunungkidul Regency saw a significant expansion of crop failure land over the previous three years (Putra & Nurjani, 2021). The changing patterns of rain and dry spells brought on by global climate change have left the people of Gunungkidul Regency with harsh conditions. These include crop failure, ponds, and artificial lakes drying up at an alarming rate due to high evaporation, forcing people to purchase water for domestic use, farming, and livestock (Rahmawati & Lestari, 2018). In the 78 villages and 14 districts that make up Gunungkidul Regency, at least 135 thousand people did not have access to potable water during the dry season of 2019. Gunungkidul households reported difficulties finding enough water for daily necessities and agricultural land. With 2,000 clean water tanks holding five to six thousand liters of water apiece, the total expenditure for clean water aid was IDR 530 million. It was anticipated that the tanks would empty before the rainy season (Wicaksono, 2020). Gunungkidul's topographical features make it challenging and occasionally impossible to build wells, leaving 67% of homes without a permanent water source. In addition, Gunungkidul households must travel an additional 1.25 kilometers to reach the water source. Furthermore, Gunungkidul households must either buy water from private water providers during the dry season or save rainwater during the rainy season for their domestic daily needs. Additionally, the hamlet of Gunungkidul reported other disputes over access to water in the agricultural region (Utami et al., 2015).

According to the explanation above, drought disasters generally cause losses in agriculture and household scale. Many farmers suffer crop failure, and communities suffer from

water shortages for household needs. Following are some proposed adaptation strategies to address the impacts of drought disasters in agriculture:

1. Farmers can transition from crops with high water requirements, like rice, to crops with low water requirements, like maize. As part of adaptation efforts, future agricultural research should focus on developing drought-resistant cultivars, even if farmers decide to cultivate rice. A similar adaptation method involves encouraging crops less susceptible to erratic rainfall, like turmeric, ginger, and peanuts, as income crops. Similarly, farmers can use other crucial adaptation strategies such as changing crop varieties and timing, promoting mixed cropping and organic farming, replacing failed crops, increasing the use of farmyard manure, creating fallow fields, promoting conservation agriculture, as well as crop-livestock integration, and using biopesticides (Adhikari, 2018).
2. Adopting conservation agriculture and utilizing organic manures should be encouraged to improve the soil's ability to hold moisture. Using organic manure on farms can improve the physical characteristics of soil, such as porosity, bulk density, soil moisture, water retention properties, temperature, and water transmission properties, as well as soil processes like runoff, infiltration, evaporation, and soil loss, for better crop growth and yield. Improved agricultural methods for essential crops should also be employed, taking into account the many weather-sensitive crop stages and farm operations, to lower cultivation costs and boost yield or net returns (Udmale et al., 2014).
3. The implementation of rainwater collection, conservation ponds, irrigation channels, early warning systems for drought occurrences, and low-cost soil conservation technologies can all be recommended as structural adaptation techniques to mitigate the effects of drought on farming systems (Adhikari, 2018).
4. Agroforestry is a systematic approach to land-use planning that seeks to strike a balance between the growth of forests and food crops. Agroforestry practices increase the quantity of organic matter in the soil, improving agricultural output and reducing the strain on forests. They can be enhanced to meet the new conditions that are anticipated under drier conditions and a larger population density (Akinnagbe & Irohibe, 2014).
5. Giving farmers financial assistance to make agricultural adaptations or discover alternate sources of income (Adhikari, 2018). By diversifying their agricultural and non-agricultural enterprises, farmers can increase their drought resilience and flexibility. A larger and more secure income for farmers may be obtained by working more outside the farm than by only continuing to engage in agricultural output. Due to their variety of options and improved capacity to make up for drought-related losses, farmers may be more resilient and adaptable to drought (Lei et al., 2016).

Cooperation among several stakeholders is a valuable step in catastrophe mitigation efforts (Zamroni et al., 2020). Working with multiple stakeholders is essential to putting these adaptation techniques into action. These call for multidisciplinary partnerships involving the Department of Agriculture and Food in Gunungkidul Regency, the government (policymakers), local organizations, academic institutions or researchers, and farmer's groups. For farmers to have more alternatives for coping methods in the future, policymakers should work to improve and execute those coping mechanisms that farmers believe are necessary. The Department of Agriculture and Food should consider educating smallholder farmers and offering them resources to expand their understanding of alternative coping mechanisms. Farmers with more education and experience have a higher chance of surviving droughts. Therefore, a government program is implemented to aid farmers, help them with drought preparation, and support them with decision-making processes during drought seasons (Muthelo et al., 2019; Rachmawati & Zamroni, 2020). Additionally, the district government oversees formulating policies for farming protection. Government-appointed field facilitators should educate farmers on climate change and the farming calendar and conduct pest control field monitoring (Rahmawati & Lestari, 2018).

To effectively respond to drought disasters, decision-makers must incorporate adaptation techniques into their plans (Banales-Seguel et al., 2018). It is essential to comprehend the current

adaptation measures and the variables influencing the adaptation techniques used by the stakeholders to create policies that promote successful adaptation strategies. Government spending should go toward initiatives that increase water efficiency, such as building dams and irrigation systems. To combat climate change, it is crucial to enhance agricultural extension networks, particularly for small-scale farmers with limited resources. In addition, the state of the economy calls for incentives to help farmers develop drought-coping mechanisms (Arimi, 2014). Therefore, by employing information and communication technologies, the government, stakeholders, and donor organizations must provide innovations for increasing capacity in the agricultural extension system and climate change education. Local agricultural extension organizations and the Department of Agriculture and Food should collaborate more closely to regularly assess farmers' needs, problems, and opportunities to introduce adaptation strategies against severe drought and crop-specific coping, supported by an essential policy instrument for drought-prone areas (Ashraf et al., 2014). The existing adaptations that farming households utilize on their farms should be considered when planning and implementing national and local adaptation initiatives. Researchers should work with policymakers to provide smallholder farmers with research findings and a cognitive resource for drought adaptation techniques (Ojo & Baiyegunhi, 2020).

CONCLUSION

The three main components that cause drought disasters in Gunungkidul Regency include climate characteristics (ENSO, increasing temperature, and low annual precipitation), hydrogeological characteristics (more underground rivers, small discharge springs, drying up doline ponds, narrow catchment area, a fault blocking groundwater infiltration, and rapid sedimentation and infiltration rate around doline ponds), and anthropogenic factors (decreasing amount of forest, increasing number of total settlements, and increased mining and agricultural activities). Some proposed adaptation strategies to address the impacts of drought disasters include planting crops with low water requirements, adopting conservation agriculture and utilizing organic farming, applying structural adaptation strategies, developing agroforestry, giving farmers financial assistance, paying compensation to drought-affected families, distributing knowledge about drought adaptation techniques, reducing family food demand, suggesting seasonal migration, and reducing livestock. Collaborating with various stakeholders to put these adaptation strategies into practice is crucial. These ask for multidisciplinary collaborations involving the Department of Agriculture and Food in Gunungkidul Regency, the government (policymakers), local organizations, university institutions or researchers, and farmer's associations.

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DECLARATIONS

Conflict of Interest

We declare no conflict of interest, financial or otherwise.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

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