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*Corresponding author(s)
email: herimulyanti@students.undip.ac.id

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Assessing Vulnerability of Agriculture to Drought in East Java, Indonesia: Application of GIS and AHP

Heri Mulyanti[1]*, I. Istadi[2], Rahmat Gernowo [3]

1. *Doctoral Program of Environmental Science, Department of Graduate School, Universitas Diponegoro, Semarang, Central Java 50275, Indonesia*
2. *Laboratory of Plasma-Catalysis (R3.5), Center of Research and Services – Diponegoro University (CORES-DU), Universitas Diponegoro, Semarang, Central Java, Indonesia 50275, Indonesia*
   Department of Chemical Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Central Java 50275, Indonesia
3. *Department of Physics, Faculty of Science and Mathematics, Universitas Diponegoro, Semarang, Central Java 50275, Indonesia*

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Abstract

Drought is known as a 'silent killer' - a slow-moving and unpredictable hazard, with agriculture being the first sector to be affected. In this research, the study used Oldeman Agroclimate data as a physical vulnerability indicator to assess and monitor the vulnerability of agricultural systems to drought in East Java. The study used long-term monthly rainfall observation data to generate climate maps with socio-economic indicators to assess the region's vulnerability to drought. The spatial distribution of vulnerability was mapped using Geographic Information System (GIS) combined with Analytic Hierarchy Process (AHP). The results show there are five categories of vulnerability to drought: very high, high, moderate, low, and very low based on standardized index. Madura Island, particularly Bangkalan, Sampang, and Sumenep considered as most vulnerable region to drought. In addition, most regions in the north plain of East Java, including Tuban, Lamongan, and Gresik categorized as highly vulnerable to drought. Factors affecting vulnerability are mostly related to drier climate which affect acreage and availability of irrigation. The socio-economic factors likewise smallholder farmers and poverty contribute to rising vulnerability level. South part of East Java, particularly Tulungagung and Blitar Regency was least vulnerable because of appropriate climate which induced to acreage of irrigated land. The study emphasizes the utilizing of Oldeman climate pattern as primary indicator in determining vulnerable regions. Smallholder farmers and poverty causing vulnerability in agriculture emerged as priority for further study. The results can provide new insights into drought management for most vulnerable regions by considering local climatic characteristics.

1. Introduction

Drought is often referred to as the 'silent killer' among hazards due to its unpredictable, ever-changing, and dynamic spatial and temporal occurrence. Despite being categorized as a discrete recurrent hazard (Brooks et al., 2005; Wilhite & Glantz, 1985), the risks associated with drought are undeniable. Severe drought has the potential to inflict significant harm on both people and the environment as it can disrupt natural cycles, particularly hydrologic processes (Ault et al., 2016) leading to environmental disturbances and even disaster.

The Intergovernmental Panel for Climate Change (IPCC) has highlighted agriculture as one of the most vulnerable systems impacted by drought (IPCC, 2014), a factor that could further exacerbate global food security concerns in the face of a changing climate (King et al., 2016). The growth of plants is highly dependent on water availability, and as drought conditions persist and temperatures rise, the rate of evapotranspiration may increase, ultimately impeding vegetation growth. These simultaneous effects could result in reduced crop production, and in some cases, crop failure. It's worth noting that in Indonesia, extreme drought occasionally coincides with strong El Niño events (Keil et al., 2009; Rodysill et al., 2013) which cause severe damage to environment and people.

Despite more severe drought hazard in some areas, the impact is mostly determined by vulnerability level of area and community hit by drought. Hence, drought disaster is combination of severe hazard attacked highly vulnerable community. The definition of vulnerability early described by Adger (1995) who views that internal factors of the system stand independently from external hazards. Cutter & Finch (2008) reviewed that vulnerability measure both sensitivity of population to specific natural hazard and ability of the systems to respond, to recover from the hazards. This paradigm of vulnerability concern on identifying most vulnerable members of society for risk reduction (Donatti et al., 2019). In this formulation, impact is the interaction of hazard with the state of vulnerability. Vulnerability must stand dependence on hazard specific, as some typical drought give constrain to different affected sector (Hagenlocher et al., 2019). Vulnerability to climate events has been reported by Intergovernmental Panel on Climate Change (2014) as a separate element from exposure. Thus, the paradigm perceives specific hazard intensity, frequency, and duration as external factors which cause some damage. Similar definition of vulnerability as reported by IPCC (2014) has explained by Kelman et al. (2016), Sharma & Ravindranath (2019), and Estoque et al. (2023). These studies examine that existing vulnerability constitutes as baseline for any risk reduction.

Assessing vulnerable involves considering various indicators, encompassing social, economic, and physical dimensions (Blauhut et al., 2016; Brown et al., 2016; Cruz et al., 2021; Murthy et al., 2015; Rahmi & Dimyati, 2021; Wang et al., 2019). While physical indicators like rainfall are crucial and often act as natural barriers to adaptation, social vulnerability is notably more dynamic. Understanding the climate type can provide a more comprehensive assessment of drought vulnerability, particularly for the agricultural sector. Oldeman (1975) proposed a method in delineate climate-type for agriculture purpose in Indonesia based on water balance. The report specifies that 213 mm rainfall depth for a consecutive 3 months is sufficient for rainfed rice planting. Although the method has been examined (Wahab et al., 2009) and proves suitable for agricultural analysis, it has not been widely applied to assess vulnerability in the agricultural sector. Whether various indicators have been used by earlier study, climate type refers to uncommon indicator for vulnerability assessment. Another research used rainfall and temperature used throughout most physical indicator (Alharbi et al., 2019) as separate indicator. However, Oldeman climate type can be seen as overall climate division which incorporated rainfall, temperature, and water intake for growing rice.

Despite the need to prioritize the vulnerable regions, there is a notable gap in monitoring and assessing the extent of vulnerability across Java Island. This region holds a pivotal role as the heart of rice crop production in Indonesia, particularly East Java. Given the noteworthy correlation between higher production and increased risk, it becomes evident that an in-depth analysis of vulnerability is not only essential but also an imminent necessity. Existing research efforts have explored vulnerability in various regions, such as studies conducted by Keil et al. (2009) focusing on smallholder farmers in Central Java, Trisasongko et al. (2016) conducting research in Central Java, and Arifah et al. (2022) studying vulnerability in South Sulawesi.

The heightened vulnerability of poor communities to drought adds urgency to the situation. East Java is particularly vulnerable due to its susceptibility to the drought-inducing effects of El Nino, as outlined by (Suroso et al., 2021). This concern is further compounded bydrought on both regional and national food security. The fact that 60% of Indonesia's staple food depends on Java rice production, making more concern that drought will affect both regional and national food security. East Java, which produced 9.789 million tons rice with 1.747 million hectares harvested area in 2021 known as largest rice production region in Indonesia. Whilst, East Java has faced climate change, proven by reduced production and harvested area year by year (BPS, 2022). This underscores the compelling need for proactive and sustainable strategies aimed at addressing the evolving challenges posed by climatic fluctuations in East Java.

Here we show, incorporating climate type for specific vulnerability (Hagenlocher et al., 2019) could lead to better results. The Oldeman Climate Type was created for agriculture region which depend on rainfall for cultivation. This study using combination of Analytic Hierarchy Process (Saaty, 1987) and Geographic Information Systems (GIS) to assess drought vulnerability to agriculture system. Whilst GIS gives better performance on spatial pattern heterogeneity, AHP performs well on decision making process. AHP tests the consistency of decision-making process through repeated steps to compare importance of variables. Combination of GIS and AHP offers improved results for spatial and temporal analysis. GIS and AHP have been conducted to assess drought vulnerability of a river basin (Alharbi et al., 2022) using remote sensing data. Kundu et al. (2021) found that among socio-economic indicators, agricultural household determine the vulnerability of community to drought. Here, vulnerability assessment become appropriate precedent for risk reduction (Wilhite, 2015). By using these tools, the most vulnerable area could be determined then mitigated for future water management during drought. The vulnerability index helps in determining which areas require efforts during the emergency response period. Vulnerability identification contributes to preparedness, emergency response, mitigation efforts, and recovery from a drought disaster.

2. Data and Methods

2.1. Description of Location

East Java, located in the Southern Hemisphere within the Maritime Continent of Indonesia, boasts a monsoonal climate that significantly shapes its geographical characteristics. The island's topographic distribution and coastal positioning play a pivotal role in defining its terrestrial, aquatic, and atmospheric features. The northern plain of East Java, formed by the deposition of alluvial material from the downstream areas of the Brantas and Solo catchment areas, exhibits relatively flat terrain. In the central region, a range of active volcanoes takes shape as the Indian Ocean Plate dips beneath the Sumatran-Java Continental Plate. Notably, the southern coast of East Java is renowned for its rugged and mountainous terrain, characterized by a narrow coastal zone adjacent to steep cliffs (as illustrated in Figure 1). This pronounced heterogeneity in topographic conditions serves as a primary determinant for the diverse land-use patterns observed throughout East Java.

Agricultural activities dominate the northern part of the region, benefiting from the gentle slopes in proximity to river channels. A smaller area in the southern part, greater access to water resources contributes to the agricultural sector. The dynamic relationship between the southern and northern parts of East Java is largely driven by the stark topographical differences between these regions. While the southern coast experiences ample rainfall, the northern coast has lower precipitation levels. This topographical variance establishes a mutual exchange of resources with the southern coast supplying abundant rainfall to the northern coast.

Figure 1 shows that East Java is delineated into three distinct spatial regions. The largest and most prominent is the eastern part of Java Island, which serves as the primary region. Located to the north of this primary East Java is the second-largest region, Madura Island. The smallest in terms of land area encompasses a collection of small islands scattered across the Java Sea. Within East Java's boundaries, there are a total of 29 regencies, with 25 of them located on the primary Java Island and the remaining 4 forming part of Madura Island. In the northern expanse of East Java, where the terrain is predominantly lowland, rice cultivation prevails. Regencies, such as Tuban, Bojonegoro, Lamongan, Gresik, Ngawi, Jombang, Mojokerto, Nganjuk, and Sidoarjo, are notable for their significant contributions to rice production. Conversely, in the southern region of East Java, the central areas of Tulungagung, Blitar, and Jember are pivotal to the rice production landscape. These areas collectively form the core of rice cultivation in the southern part of East Java.

2.2. Data Observation and Methods

In this study, we consider eight vulnerability indicators that are categorized into sensitivity and adaptability. Sensitivity denotes a condition in which an object is more prone to being adversely affected compared to other objects. Notably, beginning in 2014, the IPCC revised its approach by excluding the exposure aspect from vulnerability assessment (IPCC, 2014). The removal of exposure consideration was prompted by the exposure can vary depending on the intensity (Hall & Leng, 2019). It is essential to emphasize that exposure to drought differs significantly from hydrometeorological events like floods and flash floods. Flood events typically impact specific areas near river tunnels, whereas the areas affected by drought events are characterized by a sparse, dynamic, and variable nature that hinges on spatial and temporal fluctuations in rainfall. In our assessment, sensitivity aspects encompass both biophysical and socioeconomic conditions.

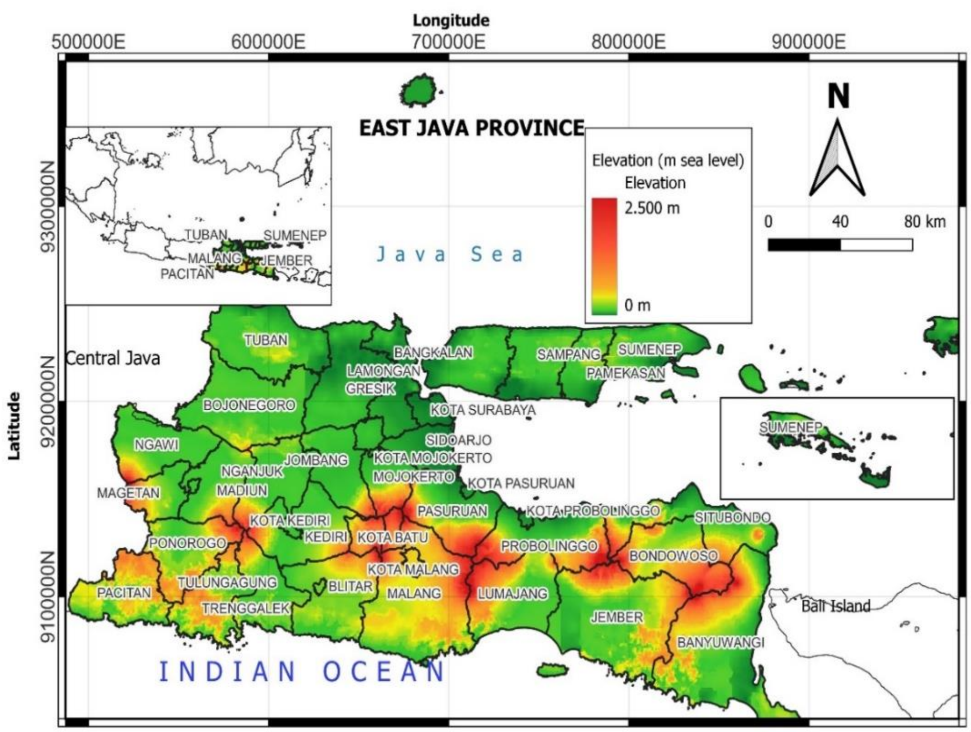

Figure 1. Topographic map of East Java Province.
The region consists of large main area and small islands on Java Sea

2.2.1. Rainfall Dataset and Methods

Precipitation data forms a fundamental component of our assessment as a physical vulnerability indicator. To operationalize this, we transformed the datasets into the Oldeman Agroclimate Type, as pioneered by Oldeman and Frere (Oldeman & Frère, 1982). Notably, Oldeman's extensive study in 1975 categorically mapped East Java as one of the driest regions in comparison to central and western Java (Oldeman, 1975). Within the boundaries of East Java, the northern coastal experienced longer periods of dry season accompanied by a shorter wet month. The rainfall data necessary for generating Oldeman's Agroclimate map was taken from the Department of Water Resources Public Affairs in East Java Province and spanned the years from 1981 to 2020. To ensure robust and representative analysis, we strategically selected a total of sixty stations for the study based on topographic features. These stations were meticulously distributed, both horizontally and vertically, across the region, encompassing various altitudes, ranging from low to high.

Average monthly data, $P_{i,mean}$ calculated from year spans to determine the length of dry months and wet months as shown in Equation 1.

$$\boldsymbol{P_{i,mean}} = \frac{\sum_{i=1}^{n} P_i}{n} \quad \text{..........} \; (Eq.\ 1)$$

where, P_i denotes for rainfall month *i* of specific year *n*. Each station resulting a set row of monthly means rainfall from n years span.

The first step in our methodology involved the interpolation of rainfall data for each month to predict rainfall patterns beyond the meteorological stations. We employed the Inverse Distance Weighting (IDW) method, a geospatial technique that predicts values at unsampled locations based on the assumption that closer locations exhibit greater similarity. Using this method, we generated a comprehensive dataset comprising twelve months of rainfall data, calculated according to Equation 1. Once this dataset was completed, we employed an overlay method to compute the average monthly rainfall. Notably, our approach utilized a grid-based framework rather than contour areas to access the necessary data.

The second component of our methodology centered on identifying the duration of consecutive wet and dry months within each grid. In our analysis, wet months were characterized by monthly rainfall exceeding 200 mm, a threshold established as the minimum requirement for sustaining essential plant functions, including water intake, water holding capacity, and evapotranspiration. Conversely, months receiving less than 100 mm of precipitation were classified as dry. Rainfall amount more than 200 mm for consecutive 3 months is the minimum requirement for growing rice. The spatial analysis for this study was conducted using Quantum Geographic Information Systems (QGIS) 3.4.2 Tisler.

Both consecutive dry months and wet months classified as shown in Table 1. Based on the consecutive dry season and wet season, length of growing seasons can be determined. Type A1 to E1 has longer growing season, although type E has least accumulated water. Oldeman & Frere (1982) suggested that wet period more than 5 months sufficient for 2 growing period of rice. As for rainfed system, plantation can be done all year round for area with 10-12 consecutive wet months (A1).

2.2.2 Sensitivity and Adaptive Capability Indicator Dataset: Socio-Economic

Vulnerability tends to be intrinsic characteristics before any hazard disturb the systems (Collins, 2018). Socio-economic indicator can be perceived as human state condition of the specific region. The study using five primary socio-economic indicators to assess sensitivity of systems to drought hazards: proportion of rainfed field, smallholding farmers, agriculture household, and agriculture sector contribution for regional product.

Table 1. Oldeman's Agroclimate Classification

Consecutive wet months	Consecutive dry months	Type	Length of growing season
10-12	<2	A1	11-12
10		A2	9-10
7-9	<2	B1	11-12
	2-3	B2	9-10
5-6	<2	C1	11-12
	2-3	C2	9-10
	4-6	C3	6-8
3-4	0-2	D1	11-12
	2-3	D2	9-10
	4-6	D3	6-8
	>7	D4	0-5
0-2	0-1	E1	11-12
	2-3	E2	9-10
	4-6	E3	6-8
	>7	E4	0-5

Source: Oldeman, 1982

Among farmers, smallholder farmers whose cultivate less than 0.5 hectares of land were most vulnerable to extreme climate event (Harvey et al., 2014; Jamshidi et al., 2019). The limited expanse of arable land accentuates the vulnerability of agricultural households to drought, compounding their susceptibility to other challenges, including the adverse impacts of climate change, the burden of disease, and the volatility of market prices. Within this context, the number of smallholders assumes a critical role as a barometer for the overall success of agricultural development within a given region.

Smallholder farmers often struggle with poverty, rendering them less resilient to cope with extreme climate events, particularly droughts. The Poverty Severity Index (PSI) is an indicator that measures the severity of poverty by assessing the ability of impoverished individuals to meet their basic needs, including food, shelter, education, and healthcare, based on their expenditures. The farming community, in this context, emerges as a vulnerable group when confronted with drought (Zarafshani et al., 2016). Moreover, larger farming families whose livelihoods are heavily dependent on agriculture face an increasing level of vulnerability in the region. The significance of the agricultural sector in the Gross Domestic Regional Product (GDRP) further magnifies vulnerability, as a higher dependency on agriculture correlates with an increased risk of drought. Consequently, regions where most of the population relies on agriculture are more susceptible to these climatic challenges. In contrast, regions where agriculture does not constitute the primary economic sector tend to experience greater economic stability.

Adaptive capacity works as counteract of risk. Whist vulnerability tends to raise risk, adaptive capacity provides resilience to the incoming threats. Vulnerability similar as weakness and capacity classify as strength inside systems. Food and Agricultural Organization (FAO) stated that the organization goal's is to develop the capacity of drought-prone areas, to increase community resilience, enhance responses to drought and planning to recovery from extreme drought. This study assesses the overall resilience of the system to drought by analyzing the availability of irrigation and the extent of irrigated land. Irrigation plays a critical role in ensuring water availability for crop cultivation during periods of insufficient precipitation. Studies have consistently shown that the availability of irrigation is a fundamental factor influencing a community's ability to adapt to drought (Mwadzingeni et al., 2022). It is generally expected that larger areas of irrigated land can contribute to reducing vulnerability to drought.

Socio-economic data were obtained from the Statistics Center Agency (BPS) of East Java Province for the years 2016 to 2020. The statistics for each year were averaged to determine representative figures. All indicators, including rainfed areas, smallholding farmers, poverty indices, contribution to GDRB (Gross Domestic Regional Product), and irrigated land, were normalized for each region to establish the proportion of specific data. The data for small farmers was calculated by comparing the total number of small farmers to the total number of farmers in each region. The proportion of each parameter was identified by averaging the data and dividing it by the total population of the region.

2.3. Unweighting and Weighting Scoring

Scores based on data categories belong to quantitative method. This method is widely used in the study using multi variables. Scoring is used to give weight to the indicators in the study as shown in Table 2. Irrigated land and irrigation availability are negatively associated with vulnerability. To reflect this relationship, a reverse score was applied to each criterion. The total score was then calculated through unweighting and standardized to identify areas with extreme vulnerability. Regions with a standardized value greater than +2 Standard Deviation (SD) were considered highly vulnerable, while areas with values less than -2 SD were deemed less vulnerable. If the standardized value fell between -1 SD and +1 SD, the region was categorized as having moderate vulnerability. The distribution of vulnerability was assessed based on spatial patterns, and QGIS 3.14 Tisler was utilized to compute and map the spatial distribution using the unweighted vulnerability method.

Table 2. Score of vulnerability parameter

Indicator	Effect to Vulnerability	Criterion			
		Score			
Oldeman's Agroclimate Type	Positive (+)	A1, A2, B1, B2	C1, C2, C3	D2, D3, D4	E3, E4
		1	2	3	4
Rainfed Proportion	Positive (+)	0 – 0.25	0.25 – 0.50	0.50 – 0.75	> 0.75
		1	2	3	4
Small Farmer	Positive (+)	0 – 0.25	0.25 – 0.50	0.50 – 0.75	> 0.75
		1	2	3	4
Agricultural Household	Positive (+)	0 – 0.25	0.25 – 0.50	0.50 – 0.75	> 0.75
		1	2	3	4
Poverty Index	Positive (+)	0 – 0.25	0.25 – 0.50	0.50 – 0.75	> 0.75
		1	2	3	4
Agricultural Contribution	Positive (+)	0 – 0.25	0.25 – 0.50	0.50 – 0.75	> 0.75
		1	2	3	4
Irrigation Availability	Negative (-)	Technical Irrigation	Semi-Technical	Rainfed	
		3	2	1	
Irrigated Land	Negative (-)	0 – 0.25	0.25 – 0.50	0.50 – 0.75	> 0.75
		4	3	2	1

AHP Vulnerability Analysis

Scoring without weighting means that each variable gives the same priority in determining the results. The analytical hierarchy process (AHP) was developed for multi criteria decision making (Saaty, 1987). The method enables the assignment of weights to the selected indicators, and these weights are determined through a pair-wise comparison to establish their relative importance. Indicators that hold greater significance receive a higher weight percentage. The AHP involves organizing the indicators and systematically comparing them with each other to determine their respective priorities. The indicators are compared on a priority scale, starting with 1, which means they are equally important, to a scale of 9, which means the parameter is extremely important. A diagonal matrix of 8 x 8 compares the value of each unit in pairs. The remaining values of each row reflect the relative importance of variables. The ranking of each indicator was ascertained through the relative weight matrix in the pair-wise comparisons and the normalized principal eigenvector. The principal eigenvector, obtained through these calculations, is known as the priority vector. The priority vector offers more comprehensive information and is more pertinent for decision-making than a mere ranking. AHP was performed using AHP Excel Template version 07.07.2022 (Goepel, 2013). The AHP final score were calculated from 3 respondents: owner of farmland, expert on socio-economic agricultural, and the researcher.

The consistency of AHP checked by using principal eigen value. Saaty (1987) formulated Consistency Ratio (CR) as comparison Consistency Index (CI) and Random Consistency Index (RI). CR was calculated using Equation 2.

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \quad \text{or} \quad \boldsymbol{CR} = \frac{\boldsymbol{\lambda_{max} - n}}{\boldsymbol{(n-1)RI}} \quad \ldots\ldots\ldots\ (Eq.\ 2)$$

Here, λ_{max} = maximum eigen value, and n is the size of comparison matrix, and RI is value of random consistency index. The study used 8 parameter which means RI valued for 1.41. If CR falls under 10%, the decision making is acceptable. Acceptable eigen value roles as coefficient factor of AHP score. AHP vulnerability score was calculated using Equation 3.

$$AHP_n = OT_n.f_{OT} + RF_n.f_{RF} + SF_n.f_{SF} + AH_n.f_{AH} + PI_n.f_{PI} + AC_n.f_{AC} + IA_n.f_{IA} + IP_n.f_{IP} \qquad (Eq.\ 3)$$

Similar as Equation 2, OT_n is Oldeman's climate type of n_{th} polygon; RF_n for rainfed proportion; SF_n for smallholding farmers AH_n agricultural household; PI_n poverty index; AC_n contribution of agriculture to domestic regional product; IA_n irrigation availability; and IP_n proportion of irrigated land. f_{OT} is the weighting factor derived from AHP for each indicator. Since weighting factors are percentage, value of AHP incomparable with UWS. Total scores from AHP are standardized to identify distribution tendency. The rank for AHP same as UWS method where more than +2 SD classified as most vulnerable areas. The structured method to assess the vulnerability of agriculture to drought in Figure 2.

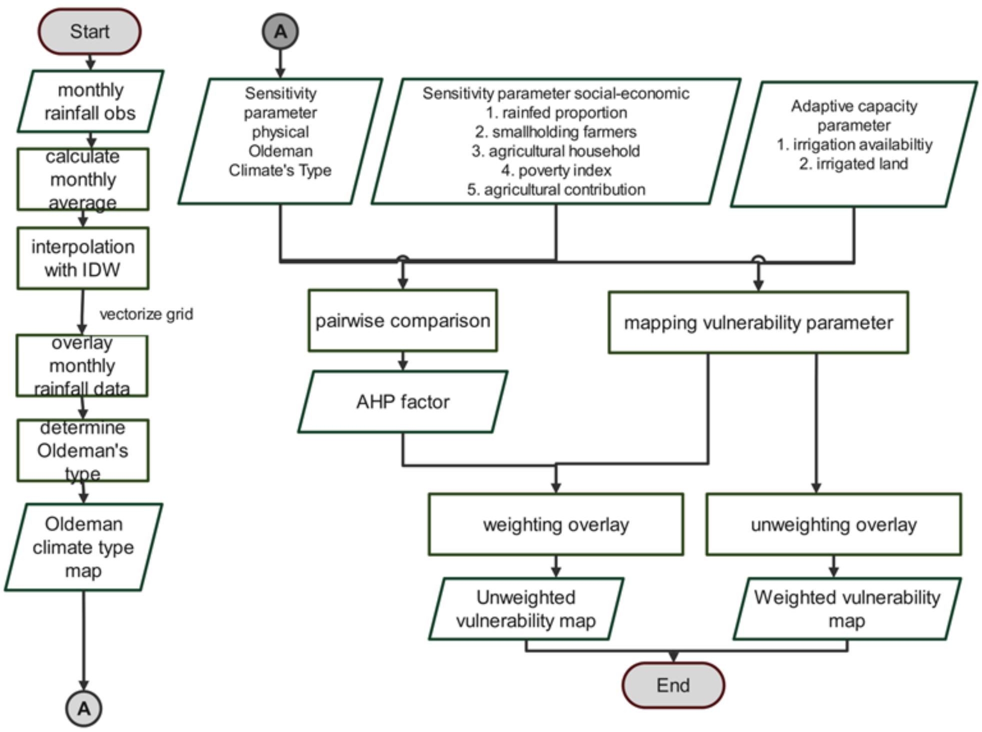

Figure 2. Flowchart for Assessing Vulnerability

3. Result and Discussion

3.1. Sensitivity Parameter: Oldeman's Agroclimate Classification

Climatic conditions, especially precipitation, play a pivotal role in assessing the vulnerability of agricultural systems. Unsuitable climate conditions can lead to water resources depletion. In the case of the agricultural sector which heavily relies on water, may suffer. Furthermore, climate-related issues can result in environmental degradation, including the overexploitation of deep groundwater resources. Sustainable agriculture depends primarily on water availability and management. The distribution of agricultural land affected by drought is closely linked to rainfall and the area under cultivation (Boer & Subbiah, 2005).

The East Java Province is predominantly characterized by climate type D3, which is prevalent along the northern coastal area (Figure 2). Additionally, climate type C3 is observed in the central to southern regions. Climate type D is characterized by wet months spans from 3 to 4 months followed by consecutive dry months of 4-6 months. In climate type D3, wet months are distributed throughout each quarter of the year, while dry months are interspersed with wet months in a short span of about 2-3 months. In contrast, type C3 exhibits a zone with wet months for approximately half of the year, while dry months persist for 4 to 6 months. When considering these variations, it becomes apparent that climate type C3 offers a longer growing season compared to climate type D3. Changes can be seen in the southern type, where the division of dry months and wet months are contrast. On the other hand, the regions identified as climate type D3 faces challenges in establishing a consistent climate pattern, as wet months typically occur during the transition from dry to rainy periods and vice versa.

Due to the low rainfall, it is only possible to plant rice once solely on rain dependencies or twice a year on irrigation. However, in certain areas inside watersheds, agriculture can be supported by surface runoff, as in the northern coastal areas of Java Island: Bojonegoro, Lamongan, Tuban, Gresik. In the southern part of East Java province, rainfall is more frequent with high intensity resulting on shorter dry months. Figure 2 can be compared with Oldeman's (1975) climatological results, which indicate that most of the area has transitioned to a drier climate. Southern region has more A, B1, B2, B2, and C2 zone based on Oldeman early documentation (Oldeman, 1975). Recent years, type D3 dominates northern region and C3 dominates southern part. The study confirmed that after 1990, East Java come to drier with type C1 to D4 (Wahab et al., 2009). The increase in the length of dry month followed by a shorter wet month occurred elsewhere, as revealed by (Fu et al., 2013) in Amazonia. Amazonia as tropical rainforest, experienced delaying of dry-season end has prolonged fire season. Locations that experience longer dry seasons exacerbate to drought (Ye, 2018). Siswanto & Supari (2015) revealed that Java Island experience decreasing trend during dry season since 1980. The research supported Aldrian & Djamil (2008) that lowlands in East Java has increasing trend of dry periods, while rainfall tend to decrease. By using the method, it is giving bigger pattern how vulnerable of region to drought based on physical characteristics.

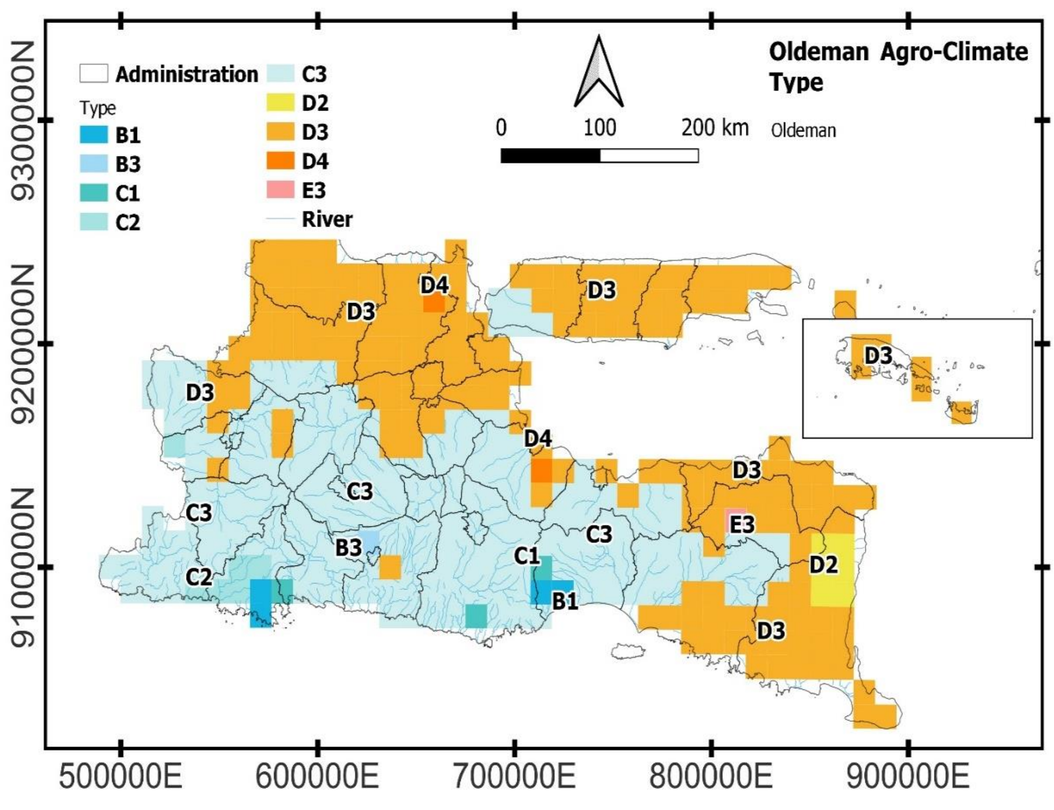

Figure 3. Oldeman's Agroclimate Map of East Java. Northern coast generally has less wet month typically D class. Southern Coast has more wet months. Type B1, B3, C1, C2 has less common compared to type D

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3.2. Socio-Economic Vulnerability: Sensitivity and Adaptive Capability

Figure 4a. shows that rainfed land concentrated in the north. The northern area has rainfed more than 50% of total cultivated. Larger rainfed means more vulnerable to climatological changing Rainfed areas are highly dependent on the incoming precipitation. Climate disturbances obviously affecting agricultural production (Ward & Makhija, 2018). These findings underscore the relationship between climate types (Figure 3) and the extent of rainfed agricultural land. In agroclimatic zone C, there is a noticeable lower rainfed agricultural acreage compared to agroclimatic zone D. specifically, in the regencies of Gresik and Pamekasan, the proportion of rainfed area proportion is highest among all the regencies in East Java. Rainfall dependence of rainfed cropping systems is correlated with agroclimatic zones. Regions with higher average annual rainfall exhibit greater opportunities for cultivation. Conversely, rainfed areas that receive precipitation solely during the rainy season encounter more challenges when it comes to adapting during climate anomaly.

The agricultural sector depends on the land ownership (Thao et al., 2019). According to the Indonesian Statistics Agency (BPS), smallholders are farmers that cultivate less than 0.5 hectares. Limited cultivate land increases the vulnerability of smallholders to drought (Keil et al., 2009; Harvey et al., 2014; Jamshidi et al., 2019). Narrow land is identical to lower production because low capitalization and low technology (Morton, 2007). The yield of a cropping season on this land is probably only enough to survive for few months. If there is a failure during the growing season, smallholder could not afford to buy food (Keil et al., 2009; Lybbert & Carter, 2013). Donatti et al. (2019) stated that vulnerability among smallholder farmers can be reduced through answer 3 questions about where and who communities have most vulnerable, what causes of vulnerability, and what the most effective and efficient strategy to adapt with climate change. The conclusions states that most vulnerable farmers need to be prioritizing. There are six regions that have a small number of smallholder farming households as found in Figure 4b. Most smallholders concentrated in the northern East Java, including Tuban, Lamongan, Gresik, and Bojonegoro regency, and the other two are in southern East Java, namely Pacitan and Malang regencies. It can be described that most of northern encounter with drier climate and large proportion of smallholder farmers.

Figure 4c shows that households which depended on agriculture are more common in the western part of East Java province and Madura Island. Only in urban areas is the proportion of farmers less than 25%. This proportion illustrates the sensitivity of a property to drought. The higher the proportion of farming families, the higher the degree of dependency. Failure in agricultural activities can have far-reaching consequences, from the agricultural household itself even the community. Research Lybbert & Carter (2013) shows that the proportion of agricultural household will increase the degree of dependence. The higher the dependency, the more people are affected by failure due to drought. This suggests that urban areas are less vulnerable to drought, as measured by the proportion of farm families. Urban residents are more engaged in other economic activities such as trade and private employment. The low proportion of farming families is also found in Sidoarjo Regency, which is geographically adjacent to Surabaya City. The characteristic of Sidoarjo regency is similar to Surabaya City with various economic activities in the non-agricultural sector.

Poverty can be seen as a major barrier to vulnerability alleviation. The poverty severity index provides an overview of the distribution of expenditures among the poor in an area. A high index indicates that spending is unequally distributed among the poor. Figure 4d shows that poverty is evenly distributed in the East Java region. Bangkalan regency has the highest poverty index, followed by Probolinggo and Sumenep. Vulnerability is closely related to socioeconomic conditions in a society (Cutter & Finch, 2008; Wilhelmi & Wilhite, 2002). Therefore, vulnerability may change over time followed by the dynamic of society. Drought affected lives, infrastructure and livelihoods. Higher vulnerability found among populations who are having difficulty making a living after a drought caused by poverty. Poverty limiting community to gain capitalize during crop failure causing deeper poverty level. Droughts threaten livelihoods and make it difficult to maintain economic conditions. As Lybbert & Carter (2013), impact of drought mostly on food prices they cannot afford. Moreover, Figure 4e shows that the agricultural sector less important sector contributing to regional income in East Java province.

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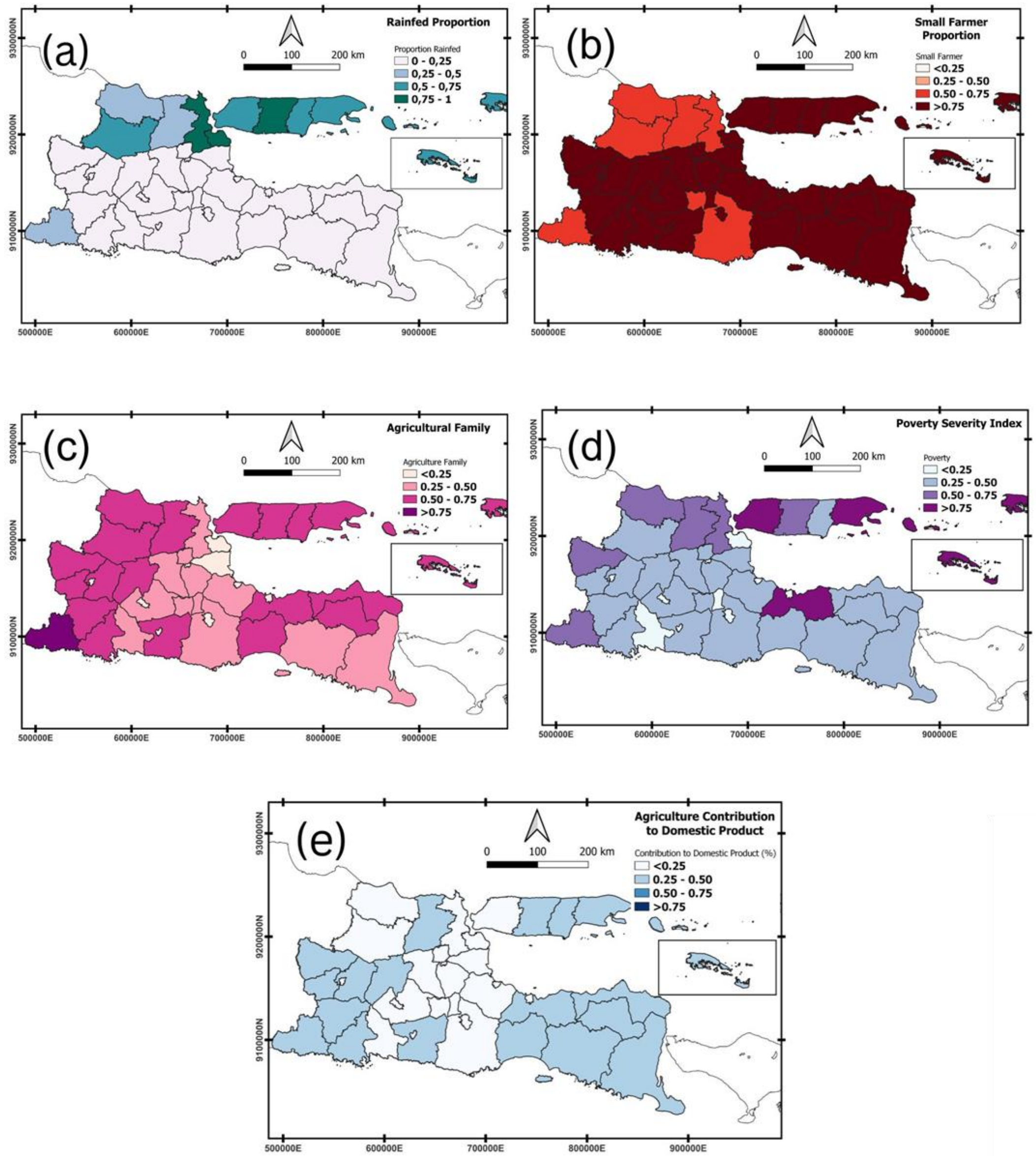

Figure 4. Sensitivity of each region to drought. Darker color corresponding with higher proportion from vulnerability indicator; (a) Rainfed area proportion of each regency/ city in East Java. (b) Proportion of smallholder farmers for each regency (c) Agriculture household refer to household rely on farming; (d) Poverty Severity Index (e) Contribution of agriculture to regional product.

The agricultural sector contributes less than 50% of the total regional income. This fact reflects the transformation of jobs and sectors in the agricultural areas of Java Island. Java Island is the largest island in Indonesia that is best suited for agricultural activities.

Rice cultivation considering water-intensive agricultural activity, heavily depends on water availability. The primary source of this crucial resource is rainfall, either directly as rainwater or through irrigation systems supplied by rivers or canals. Technical irrigation dominates the water supply for agriculture in East Java, especially in the southern region. This was made possible by the climatic conditions favoring a more extended rainy season in this area. The northern part of this area does not receive as much rain as the southern part. Figure 5a show that the cropland in the northern region is dominated by rainfed agriculture. The presence of technical irrigation systems creates an opportunity for more frequent agricultural activities, especially in the drier rainfed areas, which face limiting water. Figure 5b shows the distribution of irrigated areas divided into north and south. The southern part of this region has the largest irrigated area, covering more than 75% of the total. Regions with the lower irrigated area are Gresik and Sampang. The Southern part has an abundance of water resources from its topographic feature and coastal side which affect to water availability for irrigation. The Northern part struggles with water resources since less precipitation affect irrigation availability. Proportion of irrigated land distributed evenly in the southern part, but uneven in the north. Less irrigated land was found in the northern part.

3.3. Unweighted and Weighted Vulnerability: Comparison

Utilizing weighted calculations represents an enhancement to the results obtained from the unweighted analysis. The study highlights that despite assuming each variable has same implication to vulnerability, assigning weights allows us to identify the key factors of vulnerability. Based on unweighted calculation, Figure 6a, the southern part of Java Island is categorized as very low, low, and moderate vulnerability. Regions with very low or low vulnerability are clusters in urban areas, such as Blitar city, Kediri city, Malang city, Pasuruan city, Probolinggo city, Madiun city, Malang, Tulungagung, Kediri, Sidoarjo. Kediri, and Sidoarjo. These regions have low vulnerability to agriculture, indicating that agricultural activities cannot be significantly disrupted and are supported both physically and socioeconomically. This is due to a lower poverty index, and few agricultural households and smallholder farmers. Under these conditions, vulnerability is considered very low or low. Moderate vulnerability experienced by most of regions in East Java: Banyuwangi, Blitar, Bojonegoro, Bondowoso, Gresik, Jombang, Jember, Madiun, Magetan, Lumajang, Mojokerto, Nganjuk, Ngawi, Pacitan, Pasuruan, Ponorogo, Situbondo, and Trenggalek.

Vulnerability without considering the weight, assumes that each variable has an equal role. However, some variables have a higher degree and have more influence. AHP considering the magnitude of the weight to obtain possible decisions. Based on Table 3, climate and irrigation network have determined vulnerability of agricultural systems to drought. As know, climate is something that is not easy to change. During dry months, irrigation availability substitutes water deficit from precipitation. Shorter rainy season means lower rainfall which generated limited water storage. The obstacle certainly complicates agricultural activities. Thus, irrigation is actually a general description of the climate in a region. Figure 5a and Figure 5b revealed that most of the irrigated areas are concentrated in on appropriate rainfall regime. Rainfed is concentrated in the northern region with a drier climate type. Among socio-economic parameters, smallholder farmers and poverty index contribute the highest percentage of eigenvector. However, agricultural contribution gives little weight to the vulnerability.

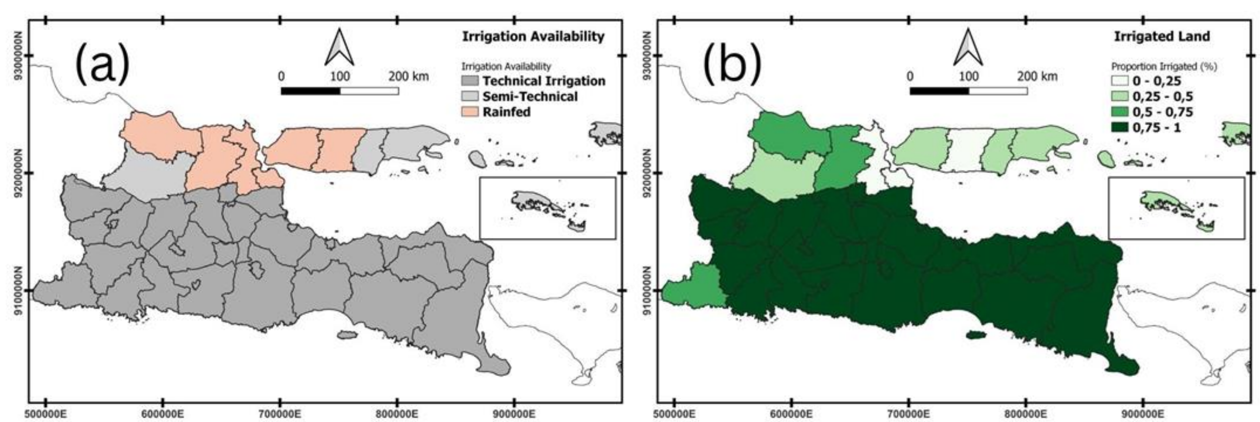

Figure 5. (a) Irrigation availability in the East Java Province; (b) Proportion of irrigated land

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Table 3. Pair wise comparison matrix of selected parameters for drought vulnerability

Parameter	**Oldeman**	**Rainfed**	**Small Farmer**	**Agriculture Household**	**Poverty Index**	**Agricultura l Contributio**	**Irrigation Availability**	**Irrigated Land**	**Normalized principal eigenvector (%)**
Oldeman	1	1 7/9	1	2	1 1/4	2 1/2	3/4	1 1/3	16.19
Rainfed	5/9	1	5/9	1	3/5	2	1/2	1	9.86
Smallholding Farmer	1	1 7/9	1	1	1 1/3	1 8/9	1	1	14.82
Agriculture Household	½	1	1	1	3/5	1 3/7	½	1	9.73
Poverty Index	4/5	1 2/3	¾	1 2/3	1	2	7/8	1 3/7	14.22
Agricultural Contribution	2/5	½	½	2/3	½	1	½	½	6.66
Irrigation Availability	1 1/3	1 8/9	1	2 1/7	1 1/7	2	1	1 1/3	17.06
Irrigated Land	3/4	1	1	1	2/3	2	3/4	1	11.46
Maximum eigenvalue 8.092			**CI 0.03**		**CR 0.09**				

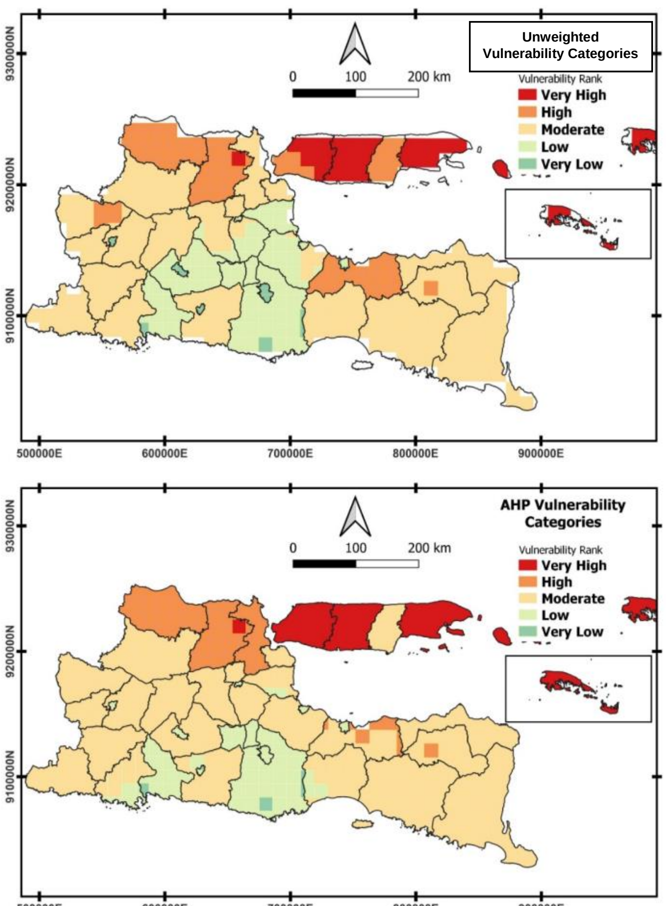

Figure 6 Drought vulnerability for agricultural systems based on unweighted scoring method. (b) AHP based vulnerability

Table 4. The Most Vulnerable Area to Drought in East Java. Total area does not represent harvested area.

Regency	Area with Very High Vulnerability (ha)		Area with High Vulnerability (ha)	
	Unweighted Scoring	AHP	Unweighted Scoring	AHP
Bangkalan	75 884.9	120 968.2	-	-
Sampang	107 568.3	107 568.3	-	-
Pamekasan	-	-	71 223.9	0
Sumenep	138 808.7	138 808.7	-	-
Tuban	-	-	176 326.7	176 326.7
Lamongan	11 875.8	11 875.8	150 846.8	150 846.8
Gresik	-	-	77.6	104 858.8
Probolinggo	-	-	168 257.3	43 879.8
Bondowoso	-	-	11 929.8	11 929.8

Note: total area does not reflect harvested area

Figure 6 clarifies the difference between high and low vulnerable zones. High vulnerability constantly experienced by the north plain region due to the influence of climate types which have implications for the availability of irrigation, irrigated land area, to rainfed land area. Bangkalan, Sampang, Sumenep categorized as very highly vulnerable to drought by using AHP. We did not find much difference between unweighted and AHP based vulnerability in the north region, except for Pamekasan and Gresik. Pamekasan has lower vulnerability by using AHP because poverty index and irrigation give more weight to overall scores as shown in Table 3 (note that Table 3 does not describe the total harvested area). Similar result suggest that poverty and irrigation strongly correlated with vulnerability in agriculture sector (Hagenlocher et al., 2019; Keil et al., 2009; Thao et al., 2019). The data displays the total area with particular vulnerability level. This condition reveals that the north coastal and plain area of East Java is more physically, socially, and economically vulnerable to drought. Differences can be seen for the south zone, where AHP based provides a higher degree of vulnerability than unweighted one. By using AHP, there are small areas which are categorized as very low vulnerability.

Weighted calculation gives more reliable results because each parameter contributes dissimilar impact, both relative dynamic or relative static. Based on the AHP factor, more static condition has higher multiply effect, just as climate type and irrigation availability. Similar research found that social vulnerability affected most of region to drought risk (Kundu et al., 2021). In addition, a more comprehensive approach reveals that drought vulnerability is mostly relevant to climate type. Arid and semiarid region has more vulnerable because limiting rainfall affect overall condition, particularly irrigated land and irrigation availability (Alharbi et al., 2022).

Longer dry months require infrastructure to support irrigated areas. The construction of reservoirs and dams allows irrigation during the dry season. However, when the rains fail and the temperature is high, dam's capacity is unable to drain the irrigated area. Lowland regions such as Bojonegoro regency, Tuban regency, Lamongan regency, and Gresik regency face this obstacle. Agricultural land is large; however, the agro-climatic zone is considered inappropriate for maximizing production. Irrigation is provided by the Bengawan Solo River and reservoirs such as the Pacal Reservoir. Rice cultivation in East Java is often concentrated around the Bengawan Solo River and the Brantas River. However, due to the scarcity of irrigation sources and limited rainfall, many farmers start to digging deep water wells to sustain their rice fields. This practice poses a significant risk to the long-term stability of groundwater. Continuous and extensive groundwater drilling can potentially disrupt the balance of groundwater resources (Aeschbach-Hertig & Gleeson, 2012). The vulnerability to water scarcity is more pronounced in the plain-downstream regions, as they heavily rely on water supply originating from the mountainous areas during dry season. This overreliance on groundwater resources underscores the need for sustainable water management practices for future agricultural activity.

Agriculture is highly dependent on water availability. The interaction between the agricultural sector ant the regional climate patterns directly influences the irrigation networks. Regions experienced longer wet months are less vulnerable to drought, primarily because the benefit from larger irrigated areas sustained by abundant rainfall. The Northern part of the region typically has irrigated land smaller than the rainfed, reflecting the constraints of water resources. While rainfall and irrigation are the primary factors for rice cultivation in Java, the regions confronted by additional challenges. These include agricultural soil degradation, a decline in water quantity, and uneven water distribution. Therefore, the presence and effectiveness of irrigation systems play a pivotal role in mitigating vulnerability to drought in East Java. It is worth noting that the vulnerability is further exacerbated by intrinsic factors within the farming community, particularly when smallholder farmers dominate unirrigated land. Their limited capacity can intensify vulnerability, increasing the challenges faced by the agricultural households.

The scope of this study constrained by the scale employed, given the extensive area under consideration. To enhance practical implementation, we suggest refining the focus to the individual regencies within high-vulnerability regions to drought. Expanding the indicators would yield a more comprehensive assessment, even though the indicators in this study were originally selected carefully for their relevance to agricultural activities. This work will be helpful in water management in agricultural activity, particularly highly vulnerable region in East Java: Madura Island, Tuban, Lamongan, Gresik. There is a need for conducting research on poverty and smallholders in these regions. Moreover, a novel mapping approach using climate type may be applied in similar humid region to assess spatial drought vulnerability.

4. Conclusion

The north East Java regions are more vulnerable to drought than the south regions because of irrigation and climate type. The highest level of drought vulnerability is found in Bangkalan, Sampang and Sumenep Regencies. The overall result suggests that agroclimate type has similar characteristics with irrigation availability and irrigated land. Agroclimate type can be considered for further research on drought vulnerability among rainfed regions. Irrigation availability determines vulnerability level to drought, followed by Oldeman Agro-climate type, poverty severity index, and smallholder farmers. The East Java region generally has short wet months (type D). The dominance of climate type D3 in the north and C3 in the south reflects the difference on the distribution of seasonal rainfall. This makes East Java one of the priority areas for drought management in Indonesia. The areas of East Java Province that have the lowest level of vulnerability are Tulungagung, Kediri, Blitar, Malang and Batu Regencies, which are in the Agro-climate Zone B and C. these five regions have a higher level of population welfare, marked by a low poverty index accompanied with less of rainfed This work will be helpful in water management in agricultural activity, particularly highly vulnerable region in East Java: Madura Island, Tuban, Lamongan, Gresik. Moreover, a novel mapping approach using climate type may be applied in similar humid regions to assess spatial drought vulnerability. The research provides a broad picture of vulnerability levels among regions. Therefore, further research needs to encompass the most vulnerable area for water management during drought for sustainable agriculture. Focused and detailed study among smallholder farmers and agricultural households need to be considered.

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