Drought disaster vulnerability mapping of agricultural sector in Bringin District, Semarang Regency

by Bitta Pigawati

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Drought disaster vulnerability mapping of agricultural sector in Bringin District, Semarang Regency

D R Lestari[1] and B Pigawati[2]

[1]Urban and Regional Planning Department, Diponegoro University, Semarang, Indonesia
[2]Geomatics and Computing Planning Laboratory, Urban and Regional Planning Department, Diponegoro University, Semarang, Indonesia

Email: dwitantri16@pwk.undip.ac.id

Abstract: Agriculture sector is a sector that is directly affected by drought. The phenomenon of drought disaster on agriculture sector has occurred in Semarang regency. One of districts in Semarang which is affected by drought is Bringin district. Bringin district is a productive agricultural area. However, the district experienced the most severe drought in 2015. The question research of this study is, "How is the spatial distribution of drought vulnerability on agriculture sector in Bringin district, Semarang regency?" The purpose of this study is to determine the spatial distribution of drought vulnerability on agriculture sector to village units in Bringin district. This study investigated drought vulnerability based on Intergovernmental Panel on Climate Change (IPCC) by analyzing exposure, sensitivity, and adaptive capacity through mapping process. This study used quantitative approach. There were formulation analysis, scoring analysis, and overlay analysis. Drought vulnerability on agriculture sector in Bringin district was divided into three categories: low, medium, and high.

Keywords: Agriculture, Drought, Semarang, Vulnerability

1. Introduction

The meaning of vulnerability is often equated with the meaning of poverty, when both are two things have different meanings. Vulnerability is potential difficulty which is faced by communities to cope with disasters, while poverty is related to income and consumption levels of society [1]. Policies to reduce vulnerability and to reduce poverty are two different things. Policies to reduce vulnerability focus on community security for disaster, while policies to reduce poverty focus on improving people's incomes.

Drought is a normal and rare phenomenon, but it causes amount of loss. Drought is a natural disaster that happens slowly and lasts long until the rainy season arrives, so it causes broad impact [2]. Drought is closely related to vulnerability on agricultural sector.

Vulnerability on agricultural sector has increased due to fluctuations of environmental conditions, so there is a need for increasing the resilience on agricultural sector [3]. Vulnerability can be formulated into mathematical formulations which comprise exposure, sensitivity, and adaptive capacity[4]. Exposure is the possibility of a disaster in an area [5]. Sensitivity is how a system will be affected when disaster comes [5] Adaptive capacity is how a system can survive from the impact of a disaster [5]. Efforts to manage drought are still ineffective while negative impacts on economic and social conditions continue to increase [6,7]. Effective efforts in response to drought hazard need to be done through enhanced adaptive capacity [8].

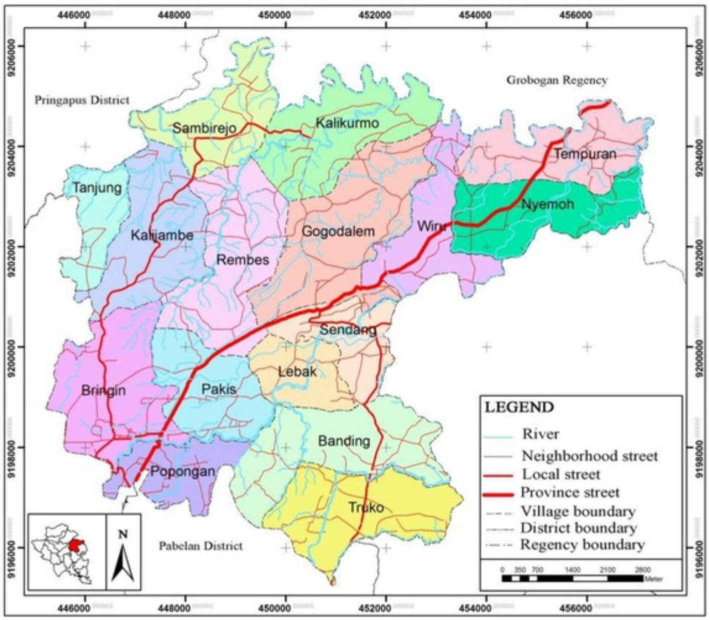

Figure 1. Administrative map of Bringin District.

Bringin district has the largest percentage of drought in Semarang regency. Bringin district is also a district which is dominated by people who work in agricultural sector. Drought in Bringin District causes adverse impacts on agricultural sector and also affects the welfare of farmers. This study can be a consideration to the preparation of regional action plan as drought mitigation in Bringin district. In the end, the establishment of Bringin District as a productive agricultural area can be realized.

2. Methods

2.1. Formulation Analysis

2.1.1. Average Annual Rainfall Calculation

Monthly rainfall data for 5 years was obtained from Meteorology Climatology and Geophysics Agency (BMKG). BMKG receives rainfall data from rain station which has function to identify rainfall. Rainfall on each month for 5 years is summed, then it is divided by the amount of dataas seen in equation (1).

$$\bar{X} = \frac{X_1 + X_2 + \cdots + X_n}{n} \quad (1)$$

Explanation

$\bar{X}$	=	Average
$X_1 + X_2 + \cdots + X_n$	=	Annual rainfall year-1, 2, …, n.
n	=	Amount of data

However, sometimes there is a loss of rain data. The loss of rain data can be calculated by using reciprocal methodas seen in equation (2).

$$.Px = \frac{\frac{PA}{(dxA)^2}+\frac{PB}{(dxB)^2}+\frac{PC}{(dxC)^2}}{\frac{1}{(dxA)^2}+\frac{1}{(dxB)^2}+\frac{1}{(dxC)^2}} \tag{2}$$

Explanation
Px = Average rainfall at rain station X (mm)
dxA = Distance between rain station X with rain station A (km)
dxB = Distance between rain station X with rain station B (km)
dxC = Distance between rain station X with rain station C (km)
PA, PB, PC = Rainfall at rain station A, B, C
[9]

2.1.2. Average Annual Dry Month Calculation

Dry month data were obtained from rainfall data. The selection of dry months was based on the criteria of Mohr. Dry month is a month that has average rainfall below 60 mm [10]. After knowing the number of months that have rainfall below 60 mm, then calculate the average dry months for five years.

2.1.3. Average Annual Actual Evapotranspiration Calculation

Actual evapotranspiration is calculated by using the Turc formula.

$$Ea = \frac{P}{\sqrt{0.9 + \frac{P^2}{L(t)^2}}} \tag{3}$$

Explanation
Ea = Average Annual Actual Evapotranspiration (mm)
P = Average Annual Rainfall (mm)
L(t) = $300 + 25t + 0.05t^3$
t = Average Annual Temperature (^{O}C)
[11]

Based on the formula above, temperature data is needed in order to know the evapotranspiration of water surface. Sometimes, temperature data is not available from the rain station. Therefore, the temperature in each rain station can be calculated by using the Mock formula.

$$dt = (Z_1 - Z_2)\ 0.006\ °C \tag{4}$$

Explanation
dt = The difference between temperature from the measuring station and reference station (°C)
Z_1 = Elevation of the reference station (m)
Z_2 = Elevation of the measuring station (m)

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2.2. Scoring Analysis

Scoring is process of converting answers into numbers [13].

Table 1. Scoring. This table is based on other research. The variables are obtained from other combined studies [14–16] with modification.

Indicator/ variable	Criteria	Score	Category	Explanation
		Exposure		
Average annual rainfall (mm)	>2000	10	Low	-
	1501-2000	20	Medium low	
	1001-1500	30	Medium	
	500-1000	40	Medium high	
	<500	50	High	
Average annual dry month	0,0-2,0	10	Low	-
	2,01-4,0	20	Medium low	
	4,01-6,0	30	Medium	
	6,01-8,0	40	Medium high	
	>8,00	50	High	
Average annual actual evapotranspiration (mm)	<750	10	Low	Using Turc and Mock formula
	751-1000	20	Medium low	
	1001-1500	30	Medium	
	1501-2000	40	Medium high	
	>2000	50	High	
Geology	Breccia-andesit	10	Low	Geology map
	Clay sand, gravel, napal	20	Medium low	
	Clay, fine tuff, silt	30	Medium	
	Granite, solid	40	Medium high	
	Limestone	50	High	
Land cover	Forest	10	Low	Land cover map
	Agriculture	30	Medium	
	Settlements	50	High	
		Sensitivity		
Rainfed lowland	0-12,5%	10	Low	(rainfed low land area/ total area)*100
	12,6%-25%	20	Medium low	
	25,1%-37,5%	30	Medium	
	37,6%-50%	40	Medium high	
	>50%	50	High	
People working in agriculture	0%-20%	10	Low	(number of population who works in the agricultural sector/ total population who works)*100
	21%-40%	20	Medium low	
	41%-60%	30	Medium	
	61%-80%	40	Medium high	
	81%-100%	50	High	
		Adaptive Capacity		
Head of farmer families who have jobs outside the agricultural sector	0-20%	10	Low	(respondents who have jobs outside the agricultural sector/ total of respondents)*100
	21-40%	20	Medium low	
	41-60%	30	Medium	
	61-80%	40	Medium high	
	81-100%	50	High	
Farmer families who have family members working outside the agricultural sector	0-20%	10	Low	(respondents who have family members working outside the agricultural sector/ total of respondents)*100
	21-40%	20	Medium low	
	41-60%	30	Medium	
	61-80%	40	Medium high	
	81-100%	50	High	
Farmer families who have savings	0-20%	10	Low	(respondents who have savings/ total of respondents)*100
	21-40%	20	Medium low	
	41-60%	30	Medium	
	61-80%	40	Medium high	
	81-100%	50	High	
Farmer families who have livestock	0-20%	10	Low	(respondents who have livestock/ total of respondents)*100
	21-40%	20	Medium low	
	41-60%	30	Medium	
	61-80%	40	Medium high	
	81-100%	50	High	

2.3. Overlay Analysis

Overlay is an essential spatial analysis that combines two thematic layers [17]. Overlay analysis was performed after scoring process that resulted in exposure value (KT), sensitivity value (SN), and adaptive capacity value (KA). The scoring result of the exposure aspect was done in the unit of land. On the other hand, scoring on aspects of sensitivity and adaptive capacity was done in the administrative units of the village. To equate the two, the scoring aspect of the exposure results was made into the administrative units of the village by using the following formula.

$$KT = \left(TS_1 \times \left(\frac{LS_1}{LT}\right)\right) + \left(TS_2 \times \left(\frac{LS_2}{LT}\right)\right) + \cdots + \left(TS_n \times \left(\frac{LS_n}{LT}\right)\right) \quad (5)$$

Explanation

KT	=	Exposure
$TS_1, TS_2, \ldots, TS_n$	=	Score in the unit of land 1, 2, …, n
$LS_1, LS_2, \ldots, LS_n$	=	Area of score 1, 2, …, n (m^2)
LT	=	Total area of the village (m^2)

(Analysis, 2016)

After obtaining the value of exposure, sensitivity, and adaptive capacity, then calculate the value of vulnerability in each village.

$$Vulnerability = (Exposure + Sensitivity) - Adaptive\ Capacity$$

After obtaining the vulnerability value in each village, do the clashing to determine the low, medium, and high vulnerability level so that it has 3 classes.

$$X = \frac{(B - A)}{3} \quad (6)$$

Explanation

X	=	Interval
A	=	Lowest Data
B	=	Highest Data

Table 2. Vulnerability Classification Methods

Class	Formula
Low	A to A + X
Medium	(A + X) +1 to (A + X + 1) + X
High	[(A + X + 1) + X] + 1 to B

3. Discussion

3.1. Analysis of Exposure

The exposure analysis is the overlay of average annual rainfall (CH), average annual dry months (BK), average annual actual evapotranspiration (EA), geology (BP), and land cover (PL). Average annual rainfall, average annual dry months, and average annual actual evapotranspiration were obtained from five rain stations which are getas rain station, grenjeng rain station, tuntang rain station, bawen rain station, and kedungjati rain station. Spatial distribution of average annual rainfall, average annual dry months, and average annual actual evapotranspiration is distributed by Thiessen polygon method. The following section is a description of drought exposure in Bringin District.

3.1.1. Average Annual Rainfall

Villages that have low category of exposure are Kalikurmo, Gogodalem, Wiru, Nyemoh, and Tempuran. Those village has average annual rainfall >2000 mm. On the other hand, Bringin district is dominated by medium low category of exposure which has average annual rainfall 1501 mm to 2000 mm.

3.1.2. Average Annual Dry Months

Village that has medium low category exposure with average annual dry month 2,1-4,0 months are Kalikurmo, Gogodalem, Wiru, Nyemoh, and Tempuran. Bringin district is dominated by medium category exposure which has average annual dry months 4,1-6,0 months.

3.1.3. Average Annual Actual Evapotranspiration

Bringin District has two categories of average annual actual evapotranspiration which are medium (1001 mm to 1500 mm) and high (1501 mm to 2000 mm).

3.1.4. Geology

There are two types of constituent rocks in Bringin district which are volcanic rock and kerek formations. Kerek formation consists of clay and sandstone (score 20). Volcanic rock consists of volcanic breccia, lava breccia, lava (igneous rock), and tuff (rock containing volcanic dust). Kerek formation has score 20 and volcanic rock has score 10.

3.1.5. Land Cover

Bringin District is dominated by agricultural land cover (score 20) with percentage of 48.73%. Forest cover (score 10) has a percentage of 35.42% and settlements (score 30) has a percentage of 15.85%.

Table 3. Exposure Score

Village	Score					Total
	Rainfall	Dry month	Actual evapotranspiration	Geology	Land cover	
Bringin	20	30	30	12	22	114
Popongan	20	30	30	11	21	112
Pakis	20	30	30	13	28	121
Lebak	20	30	30	16	27	123
Banding	20	30	30	14	29	123
Truko	20	30	30	10	32	122
Nyemoh	13	23	37	17	25	115
Tempuran	10	20	40	20	26	116
Wiru	19	29	31	15	29	123
Sendang	20	30	30	14	31	125
Gogodalem	20	30	30	16	21	117
Rembes	20	30	30	18	25	123
Kalikurmo	19	29	31	20	25	124
Sambirejo	20	30	30	20	28	128
Kalijambe	20	30	30	19	26	125
Tanjung	20	30	30	18	25	123

Exposure score of each village is divided into three classes in ArcMap. The classification of this study is done manually, not based on certain standards. So, the result of this study is only valid for Bringin district, not valid for other area. The classification result can be seen in figure 2.

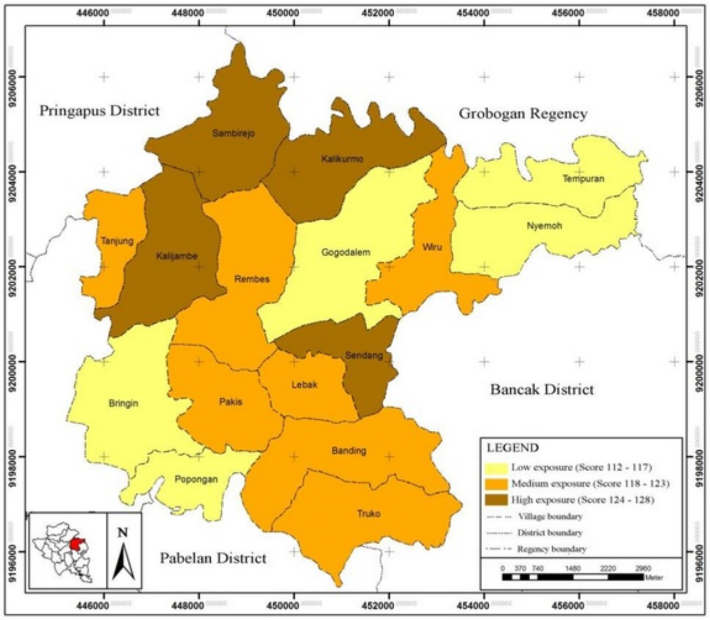

Figure 2. Exposure Map

The high exposure (score 124-128) is distributed in 4 villages, they are Sendang, Kalijambe, Sambirejo, and Kalikurmo. The high exposure in these four villages was caused by the constituent rocks which is dominated by kerek formations and land cover which is dominated by rice fields. Medium exposure (score 118-123) is distributed in 7 villages: Truko, Banding, Pakis, Lebak, Rembes, Tanjung, and Wiru. Medium exposure in these seven villages is caused by constituent rocks which are dominated by volcanic rocks. Low exposure (score 112-117) is distributed in 5 villages: Bringin, Popongan, Gogodalem, Nyemoh, and Tempuran. The low exposure in these five villages were caused by the volcanic rocks, the larger cover of forest land compared to other villages, and lower score of average annual rainfall and average annual dry month compared to other villages.

The village that has the highest exposure score is Sambirejo. The total score of exposure in Sambirejo is 128. Sambirejo is one of the villages that has the highest score in land cover aspect. Sambirejo is dominated by agricultural land. The percentage of agricultural land to the total land area in Sambirejo is 54%. That percentage is one of the highest percentage on agricultural land in Bringin district. The domination of agricultural land became one of the most influential factors to the exposure score of Sambirejo. Another factor that influences the high total score of Sambirejo exposure is the type of constituent rock. The whole area of Sambirejo has a type of kerek formation. This type of constituent rock has a higher exposure score than the type of volcanic rock. Kerek formation is good enough in absorbing and storing water, but not as good as volcanic rock. This causes the total score of exposure in Sambirejo is high.

Village with the lowest exposure score is Bringin with score 114. Bringin is dominated by volcanic rocks that have low category in exposure. The geology aspect score in Bringin is 12. This score is the second lowest score after Popongan. Bringin is dominated by forest (56%) that resulting score of 22 in land cover aspect. This score is the second lowest score after Popongan and Gogodalem.

3.2. Analysis of Sensitivity

Sensitivity analysis is the result of overlaying the rainfed lowland and population in the agricultural sector. Each condition in those variables has a score. Each village has total sensitivity score as listed in table.

Table 4. Sensitivity Score

Village	Score		Total
	Rainfed lowland	People working on agriculture	
Bringin	10	10	20
Popongan	10	20	30
Pakis	10	20	30
Lebak	10	30	40
Banding	30	40	70
Truko	20	50	70
Nyemoh	20	40	60
Tempuran	10	30	40
Wiru	10	40	50
Sendang	10	40	50
Gogodalem	10	40	50
Rembes	10	30	40
Kalikurmo	10	40	50
Sambirejo	10	40	50
Kalijambe	10	40	50
Tanjung	10	30	40

The sensitivity score of each village is calculated in ArcMap to know the spatial distribution. The distribution of low, medium, and high class is done manually, not based on certain standard, so the result of classification on this research is only valid for Bringin district, not valid for other study area.

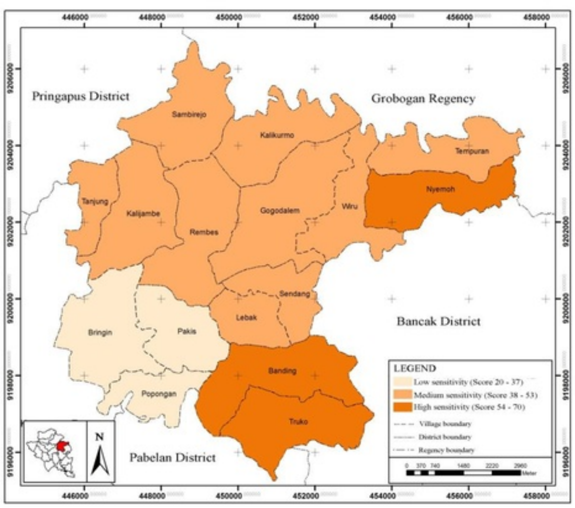

Figure 3. Sensitivity Map

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High sensitivity (score 54-70) is distributed in 3 villages which are Truko, Banding, and Nyemoh. High sensitivity in those three villages caused by rainfed lowland and the number of people who work in agriculture sector which is higher than other villages. Medium sensitivity (score 38-53) is distributed in 10 villages: Sendang, Lebak, Rembes, Kalijambe, Tanjung, Sambirejo, Kalikurmo, Gogodalem, Wiru, and Tempuran. Medium sensitivity in those ten villages caused by the area of rainfed lowland which is not as extensive compared to other villages. Low sensitivity (score 20-37) is distributed in 3 villages which are Bringin, Popongan, and Pakis. The low sensitivity in these three villages is caused by the number of people working in the agricultural sector is lower than other villages.

The villages with the highest score on the sensitivity aspect were Banding and Truko with a total sensitivity score of 70. Banding has the highest score on the rainfed lowland, while Truko has the highest score on the population working in the agricultural sector. Meanwhile, Bringin has the lowest score of sensitivity with a total score of 20. Bringin has the lowest score of rainfed lowland and population working in the agricultural sector.

3.3. Analysis of Adaptive Capacity

Adaptive capacity analysis consists of analysis of head of farmer families who have jobs outside the agricultural sector, farmer families who have family members working outside the agricultural sector, farmer families who have savings, and farmer families who have livestock. Those four variables analyzed in this aspect of adaptive capacity are modifications of the prosperous family phasing indicator. This modification was done, so that the research results really describe the actual conditions in Bringin district. Each village has a total adaptive capacity score as listed in table 5.

Table 5. Score of Adaptive Capacity

Village	Score				Total
	Head of farmer families who have jobs outside the agricultural sector	Farmer families who have family members working outside the agricultural sector	Farmer families who have savings	Farmer families who have livestock	
Bringin	10	20	20	20	70
Popongan	20	20	20	10	70
Pakis	20	20	10	20	70
Lebak	20	10	10	10	50
Banding	20	20	10	20	70
Truko	20	10	10	10	50
Nyemoh	20	20	10	20	70
Tempuran	10	10	10	20	50
Wiru	10	20	10	10	50
Sendang	10	20	10	10	50
Gogodalem	20	20	10	10	60
Rembes	10	20	10	10	50
Kalikurmo	10	10	10	20	50
Sambirejo	10	20	10	10	50
Kalijambe	20	20	10	10	60
Tanjung	10	10	10	20	50

The total score of each village was divided into three classes which are low adaptive capacity, medium adaptive capacity, and high adaptive capacity. Low, medium, and high classification on adaptive capacity is done manually and not based on certain standards, so the results of classification in this study only valid to the study area. The classification is done by using ArcMap. The result of adaptive capacity classification can be seen in figure 4.

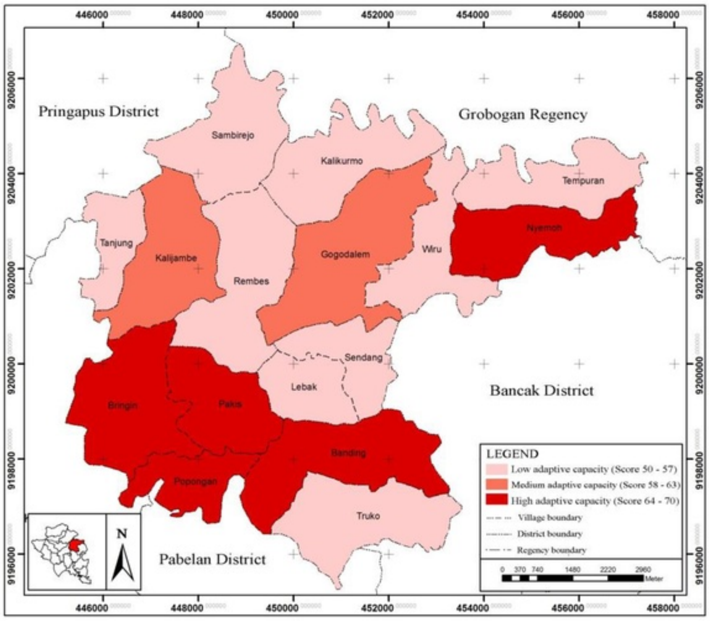

Figure 4. Adaptive Capacity Map

The villages with the highest adaptive capacity score (score 70) were five villages which are Bringin, Popongan, Pakis, Banding, and Nyemoh. The high adaptive capacity of these five villages was causes by the dominance of score 20 (low category) on the adaptive capacity variables. Villages that have medium category on adaptive capacity scores are two villages: Kalijambe and Gogodalem with a total adaptive capacity score of 60. Medium adaptive capacity in those village caused by score of 20 on job variable outside the agricultural sector and family members outside the agricultural sector, and score of 10 on the variable farmer families who have savings and farmer families who have livestock. The other nine villages: Truko, Sendang, Lebak, Rembes, Tanjung, Sambirejo, Kalikurmo, Wiru, and Tempuran have the lowest adaptive capacity score compared to the other seven villages. Those nine villages have total score of 50 on the adaptive capacity aspect. Adaptive capacity on those nine villages is low because of dominance of score of 10 (low) on adaptive capacity variables.

Although there are three classes of adaptive capacity, adaptive capacity for drought in Bringin district is in poor condition. This is evident from the scores on each variable in adaptive capacity that are in the low and medium low categories.

3.4. Analysis of Vulnerability

Analysis of vulnerability is the process of overlaying three maps which are exposure maps, sensitivity maps, and adaptive capacity maps. Each village has different scores as listed in table 6. The total score of each village is divided into three classes: high, medium, and low. The process of division is done manually, not based on certain standards, so the result of this study is only valid to the study area. The results of classification can be seen in figure 5.

Table 6. Vulnerability Score

Village	Exposure	Sensitivity	Adaptive capacity	Vulnerability
Bringin	114	20	70	64
Popongan	112	30	70	72
Pakis	121	30	70	81
Lebak	123	40	50	113
Banding	123	70	70	123
Truko	122	70	50	142
Nyemoh	115	60	70	105
Tempuran	116	40	50	106
Wiru	123	50	50	123
Sendang	125	50	50	125
Gogodalem	117	50	60	107
Rembes	123	40	50	113
Kalikurmo	124	50	50	124
Sambirejo	128	50	50	128
Kalijambe	125	50	60	115
Tanjung	123	40	50	113

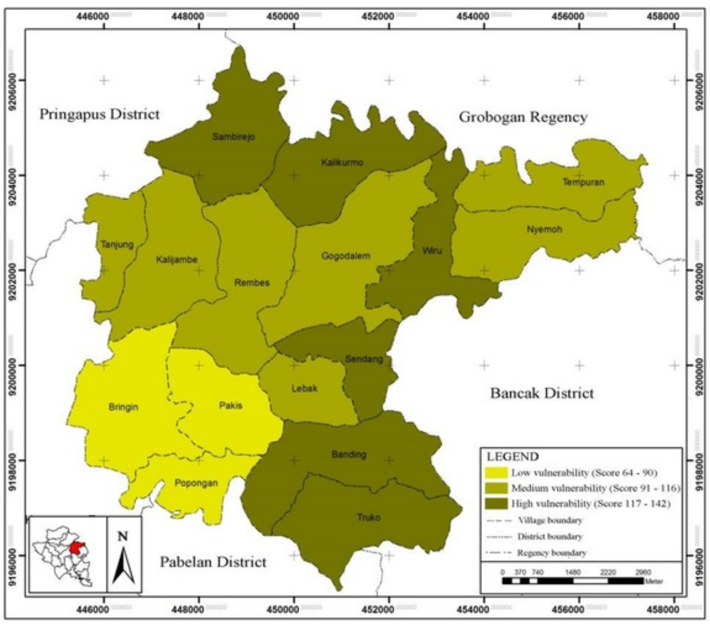

Figure 5. Vulnerability Map

High vulnerability (score 117-142) is distributed in 6 villages: Truko, Banding, Sendang, Wiru, Kalikurmo, and Sambirejo. High vulnerability in those six villages caused by high exposure and sensitivity scores and low adaptive capacity scores compared to other villages. The medium vulnerability (score 91-116) is distributed in 7 villages: Lebak, Tanjung, Kalijambe, Rembes, Gogodalem, Nyemoh, and Tempuran. Medium vulnerability in those seven villages caused by low exposure and sensitivity scores compared to other villages. Low vulnerability (score 64-90) distributed in 3 villages which are Bringin, Popongan, and Pakis. Low vulnerability in those three villages caused by low exposure and sensitivity scores and high adaptive capacity scores compared to other villages.

The village with the highest score is Truko. Truko has vulnerability score of 142. Truko has the highest sensitivity score of 70. In exposure aspect, Truko has medium exposure category with a score of exposure of 122. In adaptive capacity aspect, Truko has low category (Score 50). The village that has the lowest score of vulnerability is Bringin. Bringin has vulnerability score of 64. In sensitivity aspect, Bringin has the lowest sensitivity score in Bringin District. Bringin is also one of the villages with low category of exposure in Bringin District, with score of 114. In adaptive capacity aspect, Bringin has adaptive capacity score of 70. This score belongs to the category of high adaptive capacity in Bringin District.

Policymakers can refer to this vulnerability map within five years and review it in every 2 year. This is based on the Head of BNPB Regulation Number 4 of 2008 on Guidelines for the Preparation of Disaster Management Plan. The research must use data within the last five years (2011-2015). In addition, El-Nino phenomena is occurring within 3-7 years that also affects the planning period based on the results of this study.

4. Conclusion

The high exposure (score 124-128) is distributed in 4 villages, they are Sendang, Kalijambe, Sambirejo, and Kalikurmo. The high exposure in those four villages was caused by the type of constituent rock which is dominated by kerek formation and land cover that was dominated by rice fields (agriculture). The ability to pass water (save water) of kerek formation is lower than volcanic rock. That condition caused Kalijambe, Sambirejo, and Kalikurmo have high category of exposure aspect. Agriculture area has higher C factor (coefficient of running water) compared to forest, so that Sendang has high exposure category.

High sensitivity (score 54-70) is distributed in 3 villages which are Truko, Banding, and Nyemoh. Those three villages have high sensitivity because the percentage of rainfed lowland area and the population that works in the agricultural sector. Those variables have the highest score compared to other villages. Rice fields with rainfed irrigation have the highest risk of drought disaster and people working in agriculture are the most affected people from drought. These conditions cause Truko, Banding, and Nyemoh, which has a percentage of rainfed lowland area and the highest agricultural worker population in Bringin District, belongs to the high sensitivity category.

Low adaptive capacity (score 50-57) is distributed in 9 villages: Truko, Lebak, Sendang, Rembes, Tanjung, Sambirejo, Kalikurmo, Wiru, and Tempuran. Low adaptive capacity is caused by the dominance of score 10 (low category) in each variable. Scores on each variable in adapative capacity are in low and medium low categories. adaptive capacity for drought in Bringin district is in poor condition.

High vulnerability (score 117-142) distributed in 6 villages which are Truko, Banding, Sendang, Wiru, Kalikurmo, and Sambirejo. Those six villages have high vulnerability because of high exposure and sensitivity. In addition, low adaptive capacity also leads to high vulnerability in those six villages. High exposure is caused by the type of constituent rock dominated by the kerek formation and the type of land cover that is dominated by rice fields (agriculture). High sensitivity is caused by the percentage of rainfed lowland area and the population working in the agricultural sector. Low adaptive capacity is caused by the dominance of score 10 on each variable of adaptive capacity. This condition caused Truko, Banding, Sendang, Wiru, Kalikurmo, and Sambirejo have high vulnerability.

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Planning Agency of Semarang Regency, and Geology Agency of Ministry of Energy, Resources, and Mineral who gave data for this research..

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