Modification Method of Drought Vulnerability at Wonogiri District, Central Java, Indonesia

I.B. Pramono, Endang Savitri

***Abstract:** The water crisis is our problem together. The water crisis is not only caused by the increase in population but also the acceleration of climate change. Wonogiri Regency is one of the prone area of drought-. This study aims to develop method of drought vulnerability assessment in Wonogiri District. The method was modified from Paimin's and Syarif's methods. The drought vulnerability index was derived from the summation function of dry rainfall, actual annual evapotranspiration, geological formation, landform, and surface water source. Each parameter has their own value of important. The results show that the study area has relatively high (63.5%) of drought vulnerability index which is most of them are located in Southern part of district. Meanwhile, the low vulnerability of drought (11.7%) is located in northeast of Wonogiri. Some applicable short term solution such as dropping clean water are suggested in very vulnerable area. In the other hand, medium term solution such as identification of underground water sources, develop deep wells and enforcement of zoning rules in particular area of water catchment area, also long term solution such as land rehabilitation with agroforestry patterns in recharge areas are absolutely needed in Wonogiri Regency, Central Java, Indonesia.*

***Keywords:** Vulnerability, Drought, Wonogiri District*

I. INTRODUCTION

based on Badan Koordinasi Nasional Penanganan Bencana (Indonesian National Board for Disaster Management) drought can be classified into several types such as: meteorological drought, hydrological drought and agricultural drought. Meteorological drought is mainly caused by the lack of rainfall intensity in particular season and place. This type of drought is an early indication of the arrival of drought. Hydrological drought is determined based on the diversity of seasons (Hisdal et al. 2004; Ahadiat et al, 2015). Agricultural drought occurs after meteorological drought when the groundwater does not meet the needs of plants for a certain period and in a wide area. Drought is very complex and has a worst impact on humans (Wilhite, Svoboda, and Hayes 2007; Millanei et al, 2016).

Methods to determine the drought of particular watersheds have been widely developed both in Indonesia and abroad. One of the famous method is Standardized Precipitation Index (SPI). For example in Sicily (Italy), Bonaccorso et al. (2003), in Greece by Livada and Assimakopulos (2007), in Indonesia Utami, Hadiani and Susilowati (2013), and in Ethiopia by Edossa (2010), used SPI to generated the drought vulnerability index in particular area. Additionally, Tsakiris, Pangalou, & Vangelis (2007) in Greece, summarised SPI and potential evapotranspiration parameters or known as Reconnaissance Drought Index (RDI) to modify the drought vulnerability index. Mohammad et al. (2018) compared two indices, namely SPI and Standardized Water-Level Index (SWI) to determine drought in the Yarmouk Basin, Jordan used data from 1993 to 2014. Results showed that the highest drought occurred in 2001, meanwhile by using SWI, the extreme drought occurs almost all years. Furthermore, Zarch et al. (2011) conducted tests on the application of SPI and RDI in Iran. The results showed similar results even though the RDI includes evapotranspiration data to determine the level of drought. Zou, Xia, and She (2017) used Standardized Runoff Index (SRI) to assess the impact of hydrological drought in China and it provided information for drought forecasting and water resources management.

Further, Beguería et al. (2014) modified the Standardized Precipitation and Evapotranspiration Index (SPEI) by including adding details of climatological water balance calculations, accumulated deficits or surpluses at different times. Beguería et al. (2014) found that the modification of the SPEI method by adding the Evapotranspiration (ET0) value was more accurate to predict global drought. Zarch et al. (2011) made SPI modifications by integrating SPI with actual evapotranspiration. Hao and AghaKouchak (2013) developed a drought index called Multivariate Standardized Drought Index (MSDI), which integrates SPI and the Standardized Soil Moisture Index (SSI) for drought determination. Demisse et al. (2018) in Ethiopia used remotely sensed vegetation condition to monitor the pastoral area during drought condition, since pastoral is the most dominant land cover in Ethiopia.

In Indonesia, Darmanto and Cahyadi (2013) concluded that meteorological water balance analysis can be used to plan disaster mitigation based on the time and duration of deficit months. Murtiono (2009) mentioned that watersheds having water deficit needs to be improved especially an effective water resources plan, allocating, and distributing water according to priority establishment e.g. water pond, vegetation with low evapotranspiration, and developing infiltration well.

Indonesia have various landforms, geological formations, vegetation covers, and surface water sources, therefore drought prediction is not only precipitation but also need to

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consider those factors. Some of methods have been developed by Paimin et al (2012) and Syarif et al. (2013). The results showed that Moyo watershed, West Nusa Tenggara, has uniform drought vulnerability (Savitri and Pramono 2018; Çanakçı et al, 2018).

Table 1: Method of Drought Prediction

Author	*Notes*
Bonaccorso et al. (2003)	Standardized Precipitation Index (SPI) in Italy
Livada & Assimakopulos (2007)	Standardized Precipitation Index (SPI) in Greece
Edossa (2010)	Standardized Precipitation Index (SPI) in Ethiopia
Utami et al (2013)	Standardized Precipitation Index (SPI) in Indonesia
Tsakiris, Pangalou, & Vangelis (2007)	Reconnaissance Drought Index (RDI) in Greece
Mohammad et al. (2018)	Standardized Precipitation Index combined with Standardized Water Level Index in Jordan
Zarch et al. (2011)	Integrating SPI with actual evapotranspiration in Iran
Begueria et al. (2014)	Standardized Precipitation and Evapotranspration Index (SPEI) adding evapotranspiration
Hao & AghaKouchak (2013)	Integrated SPI and Standardized Soil Moisture Index (SSMI) and called Multivariate Standardized Drought Index (MSDI)
Zou et al (2017)	Standardized Runoff Index in China
Demisse et al (2017)	Predict drought using vegetation condition in Ethiopia
Paimin et al (2012)	Rainfall, geological formation, Water Usage Index, Specific Minimal Discharge
Syarif et al. (2013)	Rainfall, water source, soil texture, water supplying vegetation index

Source: Data Adapted from Author's Surname year of publication

The objective of the research was to modified the method developed by Paimin and Syarif by adding and removing some parameters influencing drought vulnerability. This study try to consider the landform parameters in term of drought vulnerability which was never used before. Moreover, the land use data is available and easily to obtain from the Regional Physical Planning Program for Transmigration (Reppprot) map.

II. RESEARCH METHOD

The drought vulnerability was derived from the modification of Paimin's and Syarif's methods. Paimin's method used rainfall data, evapotranspiration, geology, water usage Index (IPA) and specific minimum discharge. Drought vulnerability analysis based on Paimin's method used the following equation:

Vulnerability = (0.2HT) + (0.175EAT) + (0.125BK) + (0.1GEO) + (0.25IPA) + (0.15DMS) (1)

Where:

HT = Annual Rainfall (mm)
EAT = Actual annual evapotranspiration (mm)
BK = Number of dry months (< 100 mm/month)
GEO = Geological formation
IPA = Water Usage Index
DMS = Specific Minimum Discharge (m^3/sec/km^2)

The Syarif's method also used rain data, but only rainfall during the dry season. The existence of surface water sources obtained by measuring the distance from the river and the depth of groundwater measured from the depth of the household well. Unlike the Paimin's method which used geological formations, the Syarif's method used soil texture to determine susceptibility of drought. The drought hazard index (IBK) used in the Syarif's method is expressed as follows:

IBK = (0.33CH) + (0.27KAT) + (0.20SA) + (0.13T) + (0.06WSVI) (2)

Where:

IBK = Drought Hazard Index
CH = Rainfall
KAT = Depth of ground water
SA = water source
T = soil texture
WSVI = water supplying vegetation index

This study was modification method of Paimin et al. (2012) and Syarif et al. (2013). The parameters used are adjusted from some field observation and analysis. The vulnerability index of this method was expressed in equation below:

Vulnerability = (0.3 CHK) + (0.175 EAT) + (0.20 GEO) + (0.175 BL) + (0.15 SA) (3)

Where:

CHK = Dry rainfall (mm)
EAT = Actual annual evapotranspiration (mm)
GEO = Geological formation
BL = Land Form
SA = Distance from Surface water source (m)

Each parameter has a value then given a category and score. The details can be seen in Table 2 below.

Table 2: Parameters, Magnitudes, Values and Scores used in Drought Vulnerability at Wonogiri District

No	*Parameters*	*Magnitude*	*Value*	*Score*
1.	*Rainfall in dry months (mm)*	> 60	Very low	1
		45 - 60	Low	2
		30 - 45	Medium	3
		15 - 30	High	4
		< 15	Very high	5
2.	*Actual Evapotranspiration yearly*	< 750	Very low	1
		751-1000	Low	2
		1001-1500	Medium	3
		1501-2000	High	4
		> 2000	Very high	5

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No	*Parameters*	*Magnitude*	*Value*	*Score*
3.	*Geological formation*	Volcano	Very low	1
		Mix volcano & mountain folds	Low	2
		Mountain folds	Medium	3
		Sediment	High	4
		Limestone	Very high	5
4.	*Land form*	Swamps	Very low	1
		Alluvial valley	Low	2
		Plain	Medium	3
		Alluvial fan & terrace	High	4
		Mountains & Hills	Very high	5
5.	*Distance from surface water sources (m)*	0 – 100	Very low	1
		100 – 200	Low	2
		200 – 300	Medium	3
		300 – 400	High	4
		>400	Very high	5

Source: Data Modified from Paimin et al (2012) and Syarif (2013)

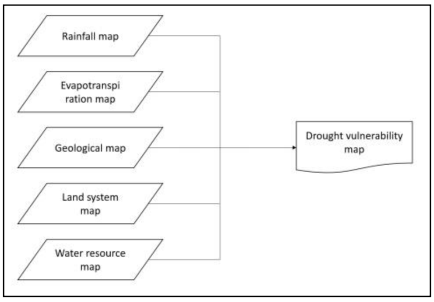

Figure 1: Flowchart of the Research
Source: Pramono & Savitri 2018

The rainfall data used was the daily rainfall data which was calculated into dry month rain value. Evapotranspiration data was calculated based on land cover. Geological formations were obtained from land forms and RePProt maps, while surface water sources are obtained from river network maps.

III. RESULT AND DISCUSSION

The drought vulnerability index was derived based on the overlay analysis in GIS platform. Detail map of drought vulnerability index can be seen in Figure 2 below.

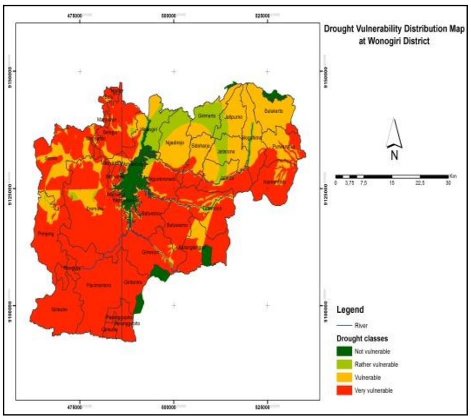

Figure 2: Drought Vulnerability at Wonogiri District
Source: Pramono & Savitri 2018

It can be seen in Figure 2 that the very vulnerable area of drought is located in the southern part of Wonogiri District. In spite of less rainfall, southern part area consists of hilly areas with limestone formation. Therefore, the areas have very vulnerable drought. In other hand, at northeast areas of the district have lower vulnerable drought due to higher rainfall and volcanic formation. The complete list of drought vulnerability of each sub district can be seen in Table 3.

Table 3: Drought Vulnerability (in percentage) at Each Sub District in Wonogiri

Sub District	Non vulnerable	Rather vulnerable	Vulnerable	Very vulnerable
Baturetno	0,08	0,07	0,19	2,79
Batuwarno	0,00	0,00	0,17	2,39
Bulukerto	0,00	0,01	3,28	0,24
Eromoko	0,13	0,30	1,75	9,88
Girimarto	0,00	1,60	1,08	0,00
Girisubo	0,01	0,01	0,02	5,36
Giritontro	0,00	0,00	0,00	2,15
Giriwoyo	0,01	0,04	0,26	4,61
Jatipurno	0,00	0,58	1,89	0,00
Jatiroto	0,00	0,38	1,31	1,81
Jatisrono	0,01	0,80	1,59	0,02
Karangtengah	0,00	0,00	0,81	2,85
Kismantoro	0,00	0,00	0,46	3,09
Manyaran	0,00	0,01	0,26	0,75
Ngadirojo	0,00	1,24	2,46	0,33
Nguntoronadi	0,16	0,22	0,47	2,10
Nguter	0,00	0,00	0,00	0,19
Pacimantoro	0,01	0,00	0,01	8,49
Paranggupito	0,00	0,00	0,00	1,81
Purwantoro	0,00	0,00	1,63	1,30
Selogiri	0,00	0,05	0,60	3,50
Semin	0,00	0,03	2,30	4,68
Sidoharjo	0,00	0,02	1,56	0,91
Slogohimo	0,07	0,23	2,22	0,72
Tirtomoyo	0,01	0,22	0,77	3,62
Wonogiri	0,36	1,68	1,20	0,50
Wuryantoro	0,11	0,05	0,35	0,75
Grand total	0,99	7,55	26,64	64,82

Source: Primary Data, 2018

The very vulnerable and vulnerable area to drought in Wonogiri reach an area of 65% and 27%, respectivley of the total area of Wonogiri District, while those that are not vulnerable and rather vulnerable are 7% and 1% respectively.

IV. RESULTS AND DISCUSSION

Based on modification methods of Paimin and Syarif, they gave satisfied result in Wonogiri District. Areas of hilly form and limestone formations have high drought vulnerability. When only rainfall parameter used in the method such as SPI (Standard Precipitation Index) developed by Bonaccorso et al. (2003), Livada and

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Assimakopulos (2007), and Edossa (2010), the areas have hilly and limestone may be has the same drought index with others areas having same rainfall. The SPI may develop in the relatively plain area with homogenous geological formation.

The Paimin's method is also not applicable in the area due to difficulties collecting data of minimum specific discharge since the most of the area has not hydrological station availability. The Syarif method is also not applicable in the area since difficulties collecting depth of ground water level. Additionally, they use river or spring to daily water needs in spite of using household well. Actually land form also presents the ground water level; in hilly areas has deeper ground water level than in the plain or alluvial areas. In general, geological formation is also presents the soil texture, in volcanic formation has rougher texture than limestone formation.

Standardized Precipitation and Evapotranspiration Index (SPEI) developed by Beguería et al. (2014) is more suitable to predict global drought than the local or regional drought. Using SPI, Utami et al. (2013) found that Wonogiri during 2014-2015 was very dry

Hao and AghaKouchak (2013) developed a drought index called Multivariate Standardized Drought Index (MSDI), which integrates SPI and the Standardized Soil Moisture Index (SSI) for drought determination. The results obtained in the application of MSDI are more realistic to predict drought. The methods above are more suitable in developed countries due to the data availability, but in developing countries such as Indonesia, the most suitable method to predict drought should considered the data availability. Therefore, the modification of Paimin's and Syarif's method is better in this case.

After having drought vulnerability in Wonogiri district, the Government should have priority area that will solve the drought problem. The most priority is located in the southern part with case of drought problem in Wonogiri. There are some solutions, dropping clean water for short term solution, while identification of underground water sources, developing deep wells and artificial aquifer, regulating cropping patterns, counselling public awareness about the importance of maintaining conservation areas (water catchment areas), enforcement of zoning rules in particular in the water catchment area are suitable for medium term solution, and for long term solution the land rehabilitation with agroforestry patterns in recharge areas are absolutely needed.

V. RESULTS VALIDATION

The field rechecking is used to compare whether the result of analysis and reality in the field are consistent. Figure 3 and Table 4 shows the location of the observation points.

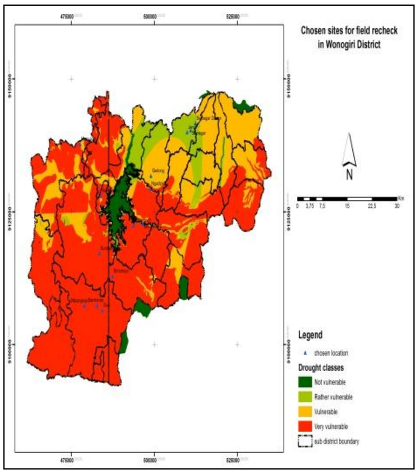

Figure 3: Locations of Observation Points at Wonogiri District

Source: Pramono & Savitri 2018

Table 4: List of Observation Points in Sub Districts at Wonogiri

Location	Coordinates	Classification according to the map
1. Manyaran	S07°48'06.7" E110°47'51.0"	Very vulnerable
2. Wuryantoro	S07°56'24.9" E110°51'08.4"	Very vulnerable
3. Sumberharjo	S07°59'26.4" E110°49'50.3"	Very vulnerable
4. Watangrejo	S08°05'00.0" E110°47'52.0"	Very vulnerable
5. Sambiroto	S08°04'34.5" E110°50'31.5"	Very vulnerable
6. Suci1	S08°04'36.5" E110°50'41.5"	Very vulnerable
7. Suci2	S08°05'37.7" E110°52'26.1"	Very vulnerable
8. Sirnoboyo	S08°01'49.3" E110°53'29.8"	Very vulnerable
9. Baturetno1	S07°56'23.0" E110°56'05.9"	Very vulnerable
10. Baturetno2	S07°56'30.4" E110°58'00.9"	Very vulnerable
11. Ngadipiro	S07°52'28.3" E110°59'07.2"	Vulnerable
12. Gedong	S07°51'21.6" E110°59'05.1"	Vulnerable
13. Jendi	S07°46'41.5" E111°05'12.8"	Rather vulnerable
14. Semagar	S07°46'37.7" E111°05'22.9"	Rather vulnerable
15. Semagar Duwur	S07°45'57.1" E111°06'07.1"	Rather vulnerable

Source: Pramono and Savitri 2019

From 15 chosen points, 10 points are classified as very vulnerable, 2 (two) points are vulnerable and 3 (three) points are rather vulnerable. Five point areas (Watangrejo, Sambiroto, Suci1, Suci2 and Sirnoboyo) are the southernmost areas, which at that time the community have already buy water from the residents living in the northern areas. Most of the southern part of Wonogiri have already prepared water storages in their houses.


a. Manyaran b. Wuryantoro


c. Baturetno d. Sirnoboyo

Figure 4: Examples of Very Vulnerable Areas at Wonogiri District

Source: Pramono & Savitri 2019

Figure 4 shows the condition of the areas very vulnerable to drought. Most of the rice field are left bare due to the scarcity of water. The farmers will start to plant in the rainy season. The general yearly planting pattern is paddy – paddy/maize – bare.


a. Ngadipiro b. Gedong

Figure 5: Examples of Vulnerable Areas at Wonogiri District

Source: Pramono & Savitri 2019

Figure 5 shows areas that vulnerable to drought. Different to the previous locations, in Ngadipiro and Gedong some shrubs still survive while the rice field is bare. The community can still use water for their daily needs and no need for them to move out due to the water scarcity. On the contrary, Semagar and Semagar Duwur Sub districts which are located in the northern part of Wonogiri, are still wet and paddy field are still exist (Figure 6). Those areas are located in the higher altitude, wetter climate and better rock formation.


a. Semagar b. Semagar Duwur

Figure 6: Examples of Rather Vulnerable Areas at Wonogiri District

Source: Pramono & Savitri 2019

The condition in the field shows that the analysis using modification of Paimin and Syarif can classify the conditions in the field correctly.

VI. CONCLUSION

Wonogiri district have 64.8% area very vulnerable to drought. Most of the very vulnerable droughts were located in the southern part of the district. The non vulnerable and rather vulnerable areas are8.5% and they are located in northeast part of Wonogiri. The southern parts of Wonogiri consists of undulating or hilly with limestone formation. In other hand, northeast Wonogiri consists of terrace with volcanic formation. In fact, the southern areas are always drier than the northeast areas. Therefore, parameters land forms and geology formations are suitable to predict drought vulnerability in Wonogiri. Parameters used in the method are easy to obtain and available for public. The only data source of surface water is difficult to get, meanwhile we used river as the sources of surface water. It will be better if data of springs are available and incorporated in the analysis.

The Government of Wonogiri district should have priority area for solving the drought problem. The most priority is located in the southern part with hilly topography and limestone formation. The solution will be identification of underground water sources, developing deep wells and artificial aquifer, regulating cropping patterns, counselling public awareness about the importance of maintaining conservation areas (water catchment areas), enforcement of zoning rules in particular in the water catchment area is for medium solution, and land rehabilitation with agroforestry patterns in recharge areas.

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