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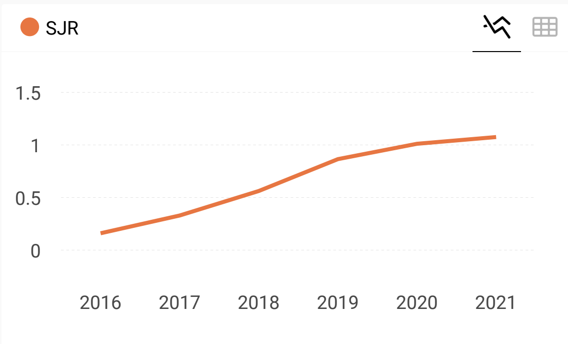

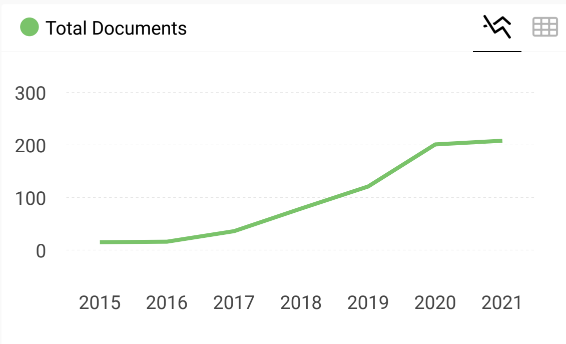

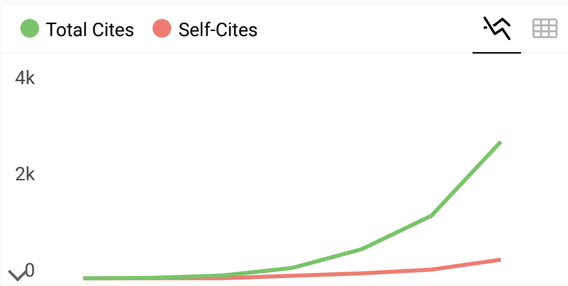

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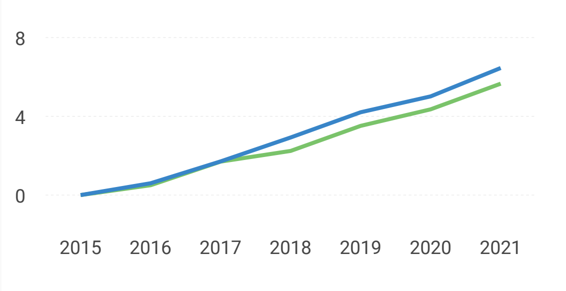

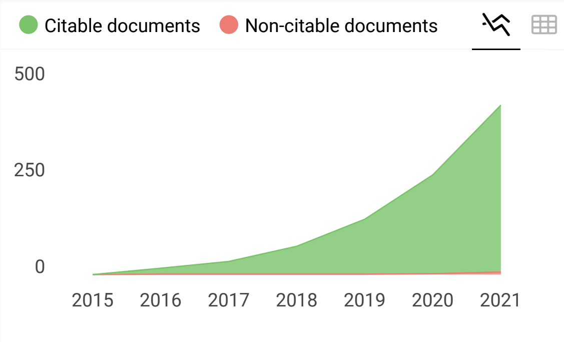

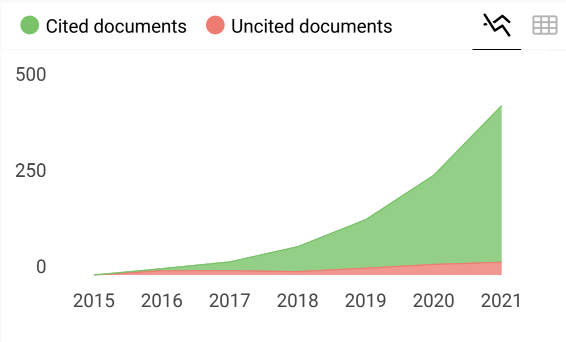

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Research paper

A viable drought vulnerability index for outermost small islands in Indonesia

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ARTICLE INFO

Keywords:
Drought index
GIS approach
Outermost small islands
Water vulnerability status

ABSTRACT

The rate and duration of precipitation in many outermost small islands within the Indonesian region have been projected to decrease during the dry season due to prolonged droughts. Thus, drought mitigation plans for these islands must be adaptive and continually improved. As a result of recent advances, drought periods can be monitored and relevant information communicated using water requirement assessment embedded within a geographical information system (GIS)-based model. Although improved tools and models have been used to analyse data concerning water conditions, only a few studies have focused on drought in the outermost small islands in Indonesia. The main purpose of this study was to inform regulatory agencies on the drought status of these small islands. Thus, the viable drought vulnerability index (DVI) was developed to contribute to the construction of a support system to make relevant decisions about the drought status of the islands. Specific parameters were selected to develop and analyse DVI, involving three considerations: meteorological, physical, and socio-economic aspects. This study focused on the analysis of data from water resources availability (rainfall, surface water, and groundwater), population, and interpretations from GIS to establish the rainfall index (RI), water use index (WUI), water supplying vegetation index (WSVI), and critical-land rate index (CRI) to develop a viable DVI. The results provide a clear understanding for all stakeholders concerning the drought problem and use a viable index and vulnerable map as valuable tools for water management in the study area. The results also confirm that a GIS approach is effective in identifying and measuring the vulnerability index in the outermost small island area, aiding in the implementation of better adaptive drought management practices for sustainable development.

1. Introduction

Indonesia is an archipelago consisting of approximately 17,000 islands, out of which about 13,000 are small islands. Previous studies have shown that the outermost small islands are experiencing water resource vulnerability, with lack of water resources and poor water conditions being common phenomena (Kirono et al., 2016; Suroso et al., 2009; Suryawan et al., 2019). As a result of climate change, which affects both surface water and groundwater (Nistor et al., 2020; Rahardjo et al., 2014), water resource availability in Indonesia has been projected to decrease during the dry season. This could lead to prolonged droughts, resulting in water scarcity (Rahardjo et al., 2007; Tallar and Suen, 2015; Temam et al., 2019; Y. Zhang et al., 2019). On the island of Java, the water resource availability is predicted to drop to 476 m^3 per person/yr by 2040, far below the current annual level of 1169 m^3 per person/yr, with the ideal level being 1600 m^3 per person/yr (Geothermal Power Generation Project: Climate Change Assessment, 2020). The

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https://doi.org/10.1016/j.gsd.2021.100698
Received 28 February 2021; Received in revised form 29 October 2021; Accepted 29 October 2021
2352-801/© 2021

Ministry of Public Works and Housing of Indonesia reported that almost 10% of Indonesia is expected to experience a water crisis by 2045 (Lowy Institute, 2019).

Recent advances have enabled the monitoring and communication of drought information using a water requirement assessment or an index embedded within a GIS-based model (Kawo and Karuppannan, 2018; Nistor et al., 2019, 2020; Rahardjo et al., 2019; Singh, 2019; Taloor et al., 2020; Valencia Gómez et al., 2020; Yang et al., 2017; H. Zhang et al., 2019). Such an index has been considered an effective and simple indicator for describing or analysing water-related problems (Nayak et al., 2020; Tallar and Suen, 2016). Several previous studies have adapted the water resources vulnerability index to assess the present condition (Tallar and Suen, 2015; Wang et al., 2020; Williams et al., 2019). In addition, several studies of drought situations in large islands of Indonesia with well-documented data for interpretation and analysis have been presented (Amalo et al., 2019; Mursidi and Sari, 2017). However, few studies have focused on drought status in the outermost small islands in Indonesia.

A viable instrument is required to assess drought vulnerability in these outermost small islands. Such vulnerability strongly depends on the sectoral focus as well as on the geographical context of the assessment. Previous drought assessment methods, such as iSECA DVI (de Azevedo Reis et al., 2020), the standardised DVI (Karavitis et al., 2014), the standardised precipitation index (McKee, 1993), and the Palmer Drought Index (PDI) (Yang et al., 2017), require considerable existing data, such as abundant dense distribution of rain gauges (Dabanlı et al., 2017; Karavitis et al., 2014; McKee et al., 1993; Yang et al., 2017) or hydrographic regions (de Azevedo Reis et al., 2020). These methods have a complex methodology based on numerous parameters. It is difficult for stakeholders from the outermost small islands to measure and assess the drought status with very limited available rain gauge stations and data.

We have developed a simplified drought vulnerability index (DVI) to inform regulatory agencies about the drought status of these outermost small islands and support adaptive management for drought mitigation. To enable the easy comprehension of the drought status at different times and places, the DVI reduces the vast quantity of selected parameter information into its simplest form and some information may be lost during the simplification process. As a trade-off, the connotation of the drought level can be imparted to the untrained stakeholders as well as the water resource managers and decision-makers of the outermost small islands. The proposed viable DVI can be implemented without extensive fieldwork or substantial financial costs while including the specific parameters that involve the three major issues (meteorological, physical, and socio-economic aspects) of drought.

2. Study area and methods

2.1. Description of study area

The study area is located in the Savu Rai Jua Regency, East Nusa Tenggara Province (NTT), Indonesia, which includes two of the outermost small islands in Indonesia (Fig. 1). Geographically, the Regency is located between 10°25′ 7″–10°49′ 46″ S and 121°16′ 11″–122°0′ 30″ E and has an area of approximately 459 km². The maximum altitude is ~350 m above sea level (asl) on Savu Island

Fig. 1. Location of study area and rain gauge.

and ~177 m asl on Rai Jua Island. Major soil types in the Savu Rai Jua Regency include grumosols, lithosols, alluvial and Mediterranean soils, which overlie carbonate bedrock (marl and limestone), calcareous sandstones, and melange facies (Harris et al., 1998; Roosmawati and Harris, 2009; Susilawati, 2012; Intan, 2016). The dominant land cover is agricultural and typical trees include palmyra, pine, gewang (*Corypha utan lamk.*) and mangrove.

The study area is classified as semi-arid, marked by a long dry season (approximately 8 months, from April to November) and maximum annual rainfall of ~100–400 mm/year (based on data from 2000 to 2015). There is a single rain gauge on Savu Island at 10°29′38″ S and 121°50′43″ E (Fig. 1). The monthly rainfall data for the study area are listed in Table 1 for 2016 and shown in Fig. 2 for 2005–2016. January exhibited the highest rainfall intensity, with June and August exhibiting the lowest (Fig. 2). The average monthly temperature ranged between 25 and 34 °C.

Based on data from the Central Bureau of Statistics (BPS), in 2016, there were 88,826 people in 58 villages in Savu Rai Jua Regency, with an average population density of approximately 193 people/km^2. The highest population in 2016 was in the Sabu Barat sub-district, which accounted for 36% of the total population of Savu Rai Jua Regency, while the highest population density (298 inhabitants/km^2) was in the Hawu Mehara sub-district. The demographic data on population and density according to sub-districts in Savu Rai Jua Regency are shown in Table 2.

Table 1
Monthly rainfall data in Savu Rai Jua Regency in 2016.

Month	Rainfall (mm)	Duration (rainfall days)
January	329	12
February	149	14
March	169	16
April	21	3
May	44	5
June	–	–
July	23	4
August	–	–
September	41	1
October	46	1
November	40	10
December	174	19

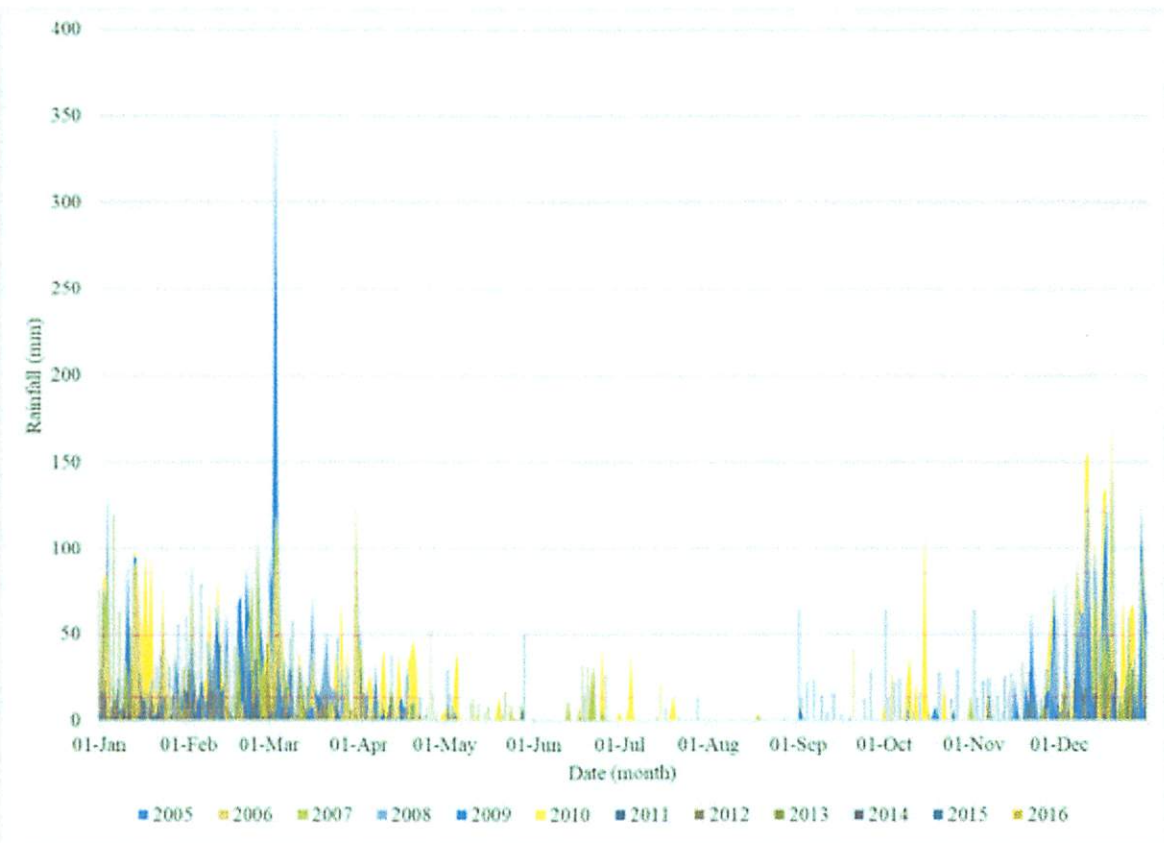

Fig. 2. Daily rainfall data (2005–2016) at Tardamu rain gauge, Savu Rai Jua.

Table 2
Demographic data in Savu Rai Jua Regency.

District	Population (persons)	Area (km^2)	Density (per km^2)
Raijua	9316	39	238
Sabu Barat	32,138	185	174
Hawu Mehara	18,741	63	298
Sabu Timur	8939	60	148
Sabu Liae	10,788	58	187
Sabu Tengah	8904	79	113

2.2. Methodology

This study used a GIS and interpretations from digital images (Fig. 3). Specific parameters were selected to develop the system and to analyse the DVI involving three major issues (meteorological, physical, and socio-economic aspects). Population data (Table 2) and water resource availability were used to calculate the water use index (WUI). The common approach is to calculate drought vulnerability levels based on the length of the dry month (Al Adaileh et al., 2019; Oke, 2018). According to previous studies, a particular area is expected to be excessively dry if the number of dry months is up to 8 months/yr (Amalo et al., 2019; Oke, 2018; Temam et al., 2019). Therefore, rainfall index (RI) analysis was conducted within the development of DVI considering the length of the dry season within the study area. The Schmidt-Ferguson methodology was modified to indicate that rainfall lower than 60 mm/month indicated a dry month. Based on previous studies (Istyarini et al., 2018), this was considered as a well-known and appropriate method to analyse the rainfall distribution in Indonesia considering the lack of non-continuous data, which becomes a problem when conducting analysis and collecting information about climate classification.

The water supplying vegetation index (WSVI) was analysed by interpreting Landsat 8 imagery sourced from the United States Geological Survey. Bands 4 and 5 were used to analyse the normalised difference vegetation index (NDVI), while band 10 was used to analyse land surface temperature (LST). Lower values of NDVI and LST indicate a higher value of WSVI (Syarif et al., 2013). The results of the transformation of WSVI on the image produced a variety of values; therefore, the results were simplified by clustering the designed data to determine the best arrangement of values into different classes. The water requirement assessment also involved the calculation of the critical-land rate index (CRI), based on data from the BPS, to measure land capacity as an important variable in developing DVI. These four parameters (WUI, RI, WSVI, and CRI) were scaled and weighted according to the order of their abilities and conditions of the study area so that the analyses produced a viable result for DVI. In this study, the weighting method of the DVI variables used a ranking system (Tallar and Suen, 2016). The analytical hierarchy process (AHP) method was also used to validate the weight values of variables by interviewing and filling questionnaires to collect opinions from an expert panel of academicians, practitioners, and government agencies. The AHP method was processed using Expert Choice 11.0. The result of the AHP verified the assignment of weight values to the variables. The DVI weight values are shown in Table 3.

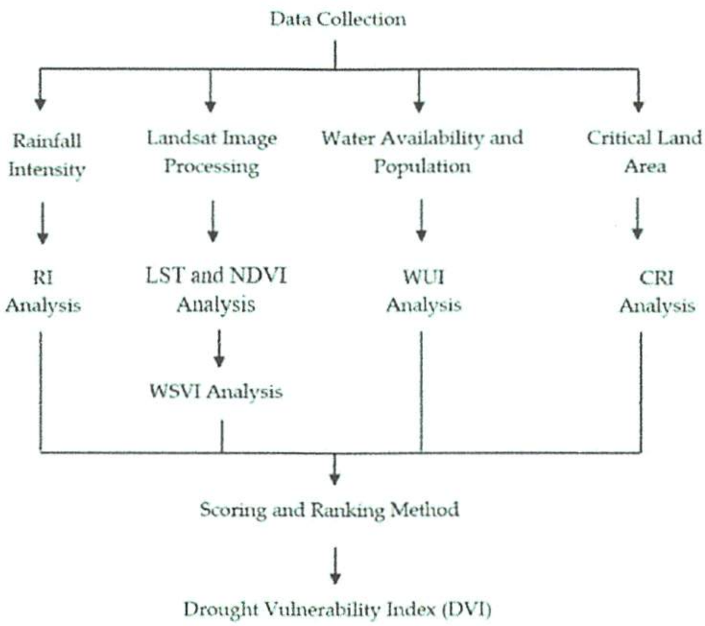

Fig. 3. Methodology of the study.

Table 3
Weight values of DVI.

Ranking	Variable	Weight
1	WUI	0.4
2	WSVI	0.3
3	CRI	0.2
4	RI	0.1

Table 4
Results of RI classification.

Dry Month	Rainfall Intensity (mm/month)	Class	Scoring	Classification
April	20.5	>15-30	4	High Vulnerable
May	44.2	>30-45	3	Vulnerable
June	0	<15	5	Very High Vulnerable
July	22.6	>15-30	4	High Vulnerable
August	0	<15	5	Very High Vulnerable
September	41.0	>30-45	3	Vulnerable
October	45.6	>45-60	2	Very Low Vulnerable
November	40.0	>30-45	3	Low Vulnerable
Average	26.7	>15-30	4	High Vulnerable

Table 5
Water resources availability in study area.

District	Surface Water Resources			Groundwater	Water Availability
	Stream (Mm^3/yr)	Pond (Mm^3/yr)	Spring (Mm^3/yr)	(Mm^3/yr)	(Mm^3/yr)
Rai Jua	–	6.574	0.112	2.775	9.461
Sabu Barat	2.316	31.17	0.778	7.323	41.59
Hawu Mehara	3.551	10.57	0.176	3.247	17.55
Sabu Timur	6.290	6.264	1.114	2.727	16.40
Sabu Liae	1.756	9.700	0.300	0.724	12.48
Sabu Tengah	1.185	13.24	1.245	3.393	19.06

Table 6
Results and classification of WUI.

District	Water Resources Availability (Mm^3/yr)	Water Use Index	Range	Classification
Rai Jua	9.461	1015	<1700	High Vulnerable
Sabu Barat	41.59	1294	<1700	Vulnerable
Hawu Mehara	17.55	936	<1700	Vulnerable
Sabu Timur	16.40	1834	1700–3400	High Vulnerable
Sabu Liae	12.48	1157	<1700	High Vulnerable
Sabu Tengah	19.06	2140	1700–3400	High Vulnerable

3. Results and discussion

Dry-season rainfall in 2016 averaged 27 mm/month, which led to an overall classification of the study area as high vulnerable based on RI (Table 4). Based on the lack of rainfall recorded in June and August, those months are classified as very high vulnerable, while April and July were classified as high vulnerable. May, September, and November are classified as vulnerable, while October is low vulnerable. For calculating WUI, data on various types of water resources and population in the study area were obtained (Table 5). Based on the results of WUI analysis, Sabu Tengah and Sabu Timur Districts are classified as vulnerable, while the rest are very vulnerable (Table 6). The results of WSVI analysis classify Sabu Tengah, Sabu Liae, and Rai Jua districts as very vulnerable, while Sabu Barat, Sabu Timur, and Hawu Mehara Districts are classified as vulnerable (Table 7). Finally, the results of the CRI analysis indicate that Sabu Timur, Sabu Liae, and Hawu Mehara Districts are classified as very vulnerable; Sabu Barat and Sabu Tengah districts are classified as vulnerable; and Rai Jua District is classified as fairly vulnerable to drought (Table 8). Consequently, the DVI classifies most of the districts in the study area as vulnerable, with only one (Sabu Liae) being highly vulnerable (Table 9 and Fig. 4). These findings necessitate the development of an adaptive management strategy for drought mitigation in the outermost small islands (Fig. 5).

Further improvements for drought mitigation action plans in the study area should provide data networks, early warning systems and preparedness, drought forecasting, drought monitoring tools, drought impact assessment methodology, and reactive/proactive response systems. To date, drought mitigation and preparedness programs have been largely reactive and not proactive; moreover, both local and central governments have devoted little effort towards mitigation and preparedness for drought problems, particularly

Table 7
Classification of WVSI.

District	WVSI	Range	Classification
Rai Jua	3.3	>2.6–3.4	Vulnerable
Sabu Barat	2.8	>2.6–3.4	Vulnerable
Hawu Mehara	2.5	>1.8–2.6	Low Vulnerable
Sabu Timur	2.8	>2.6–3.4	Vulnerable
Sabu Liae	2.9	>2.6–3.4	Vulnerable
Sabu Tengah	2.9	>2.6–3.4	Vulnerable

Table 8
Classification of CRI.

District	CRI	Range	Classification
Rai Jua	52	41–60	Low Vulnerable
Sabu Barat	72	61–80	Vulnerable
Hawu Mehara	91	>80	High Vulnerable
Sabu Timur	87	>80	High Vulnerable
Sabu Liae	81	>80	High Vulnerable
Sabu Tengah	74	61–80	Vulnerable

Table 9
Classification of DVI.

District	DVI	Range	Classification
Rai Jua	3.9	>3.4–4.2	Vulnerable
Sabu Barat	4.1	>3.4–4.2	Vulnerable
Hawu Mehara	4.0	>3.4–4.2	Vulnerable
Sabu Timur	3.9	>3.4–4.2	Vulnerable
Sabu Liae	4.3	>4.2–5.0	High Vulnerable
Sabu Tengah	3.7	>3.4–4.2	Vulnerable

on the outermost small islands. Mitigation approaches to predict drought problems have several important issues, such as the lack of appropriate early warning systems to predict climate change, insufficient databases for assessing minimum water requirements, lack of political will and coordination at various levels of government concerning drought problems, and appropriate mitigation programs aimed at reducing vulnerability to drought problems in the outermost small islands. Within the context of drought, it is essential to provide basic water requirements to all people prior to allocations for other water use. Generally, a basic water requirement assessment is the first step to describe the overall water use and can often be provided through adaptive management for drought mitigation.

4. Conclusions

Indonesia is experiencing increased vulnerability to extended periods of reduced rainfall during the dry season. The resultant increase in drought-induced disasters has led to considerable interest in drought mitigation and preparedness. Food insecurity and the absence of drought warning systems are the main issues affecting drought vulnerability in the outermost small islands. Therefore, it is increasingly recognised that stakeholders at various levels of government require the development of adaptive management for drought mitigation in these islands. This study has shown that all four selected parameters (WUI, WSVI, CRI, and RI) are important for developing a viable DVI for the outermost small islands. Many previous studies have used rainfall intensity and/or water use parameters to develop and standardise the DVI (Amalo et al., 2019; Dabanlı et al., 2017; de Azevedo Reis et al., 2020). However, few studies have assessed water supplying vegetation combined with critical-land rate parameters.

The study results classified all districts in the study area as vulnerable or, in one instance, high vulnerable. Vulnerability to drought is dynamic and influenced by many variables, including meteorological, physical, and socio-economic aspects. To determine drought vulnerability, the most important consideration is to select and weigh the variables that are commonly subjective and may vary between areas. Our findings confirmed that using a GIS approach, in conjunction with remote sensing, to identify and measure the DVI is instrumental in developing better adaptive drought management practices. Several methods of water requirement assessment can be added, such as principal component analysis and fuzzy evaluation method. Future research using this assessment could not only produce a visualisation of drought but potentially pave the way for further analysis of this product to estimate the possible damaging effects of droughts.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Fig. 4. DVI map in study area.

Fig. 5. Proposed adaptive management for drought mitigation in outermost small islands.

Acknowledgements

The authors acknowledge the support provided for this research by the Maranatha Christian University, Indonesia, in collaboration with the Hydraulics and Ocean Engineering Department, National Cheng Kung University, Taiwan R.O.C.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gsd.2021.100698.

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