IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Vulnerability assessment of water resources to climate variability in Noelmina watershed, Timor Island, Indonesia

To cite this article: E Pujiono *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **874** 012007

IOP Conf. Series: Earth and Environmental Science **874** (2021) 012007 doi:10.1088/1755-1315/874/1/012007

Vulnerability assessment of water resources to climate variability in Noelmina watershed, Timor Island, Indonesia

E Pujiono[1*], B D Prasetyo[2], R Setyowati[1] and R Kurniadi[1]

[1]Environment and Forestry Research and Development Institute of Kupang, Jl. Alfons Nisnoni No. 7, Airnona, Kota Raja, Kupang, NTT – Indonesia
[2]Centre for Research and Development of Socio-Economic Policy and Climate Change, Jl. Gunung Batu No 5 Bogor 16610, Indonesia

[*]ekopujiono78@gmail.com (ORCID ID: 0000-0002-5473-6254)

Abstract. The hydrological conditions in Timor Island, Indonesia, are characterized by limited surface water potential. The presence of erratic seasonal changes, which is an indicator of climate variability, exacerbates this situation. Efforts to sustain water resources are often constrained by limited data on climate variability's impact on water resources. The objective of this study is to appraise the vulnerability of water resources to climate variability in Noelmina watershed. Temperature and precipitation data from the last three decades were used to describe climate variability. This study used the vulnerability concept developed by Intergovernmental Panel on Climate Change. It is defined as a combination of exposure and sensitivity minus adaptive capacity. In this concept, groups of criteria-indicators that represent exposure, sensitivity, and adaptive capacity, such as watershed conditions; water demand and community dependence on land; human quality, socio-economic conditions, and water catchment areas, were presented spatially, given weights and values, then overlaid to get indexes and vulnerability maps. Results revealed that annual temperature shows an increasing trend, whereas annual precipitation has been falling during the last three decades. Vulnerability maps showed that the middle region of the watershed has the highest vulnerability level, followed by the upper and downstream watershed regions.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) states that an increase in GHG concentrations in the atmosphere causes global warming. Over the last century (1906-2005), the global temperature on the earth increased by around 0.74°C [1]. According to the World Wide Fund (WWF), the annual temperature in Indonesia has risen by 0.30°C since 1990. In a local scope, an analysis of temperature data in Nusa Tenggara Timur (NTT) Province predicts that the annual temperature will increase by 0.20°C [2]. A rise in temperature causes an increase in evapotranspiration, which directly affects the balance of the hydrological cycle [3–5]. Floods, landslides, high winds, and droughts are examples of climatic disasters caused by disruption of the hydrological cycle due to increased temperatures and changes in precipitation patterns [6].

Because of the semi-arid climate, the hydrological conditions in NTT Province, Indonesia, are generally characterized by limited surface water potential [7]. This situation is exacerbated by erratic seasonal changes and an increase in hydrometeorological disasters, which are indicators of climate variability. On the other hand, NTT's population growth rate of 1,25% from 2010 to 2020 [8] indicates that the water demand will continue to increase. Based on these facts, the National Development Planning Agency (Bappenas) states in its report that the water resources balance in the NTT province is classified at a critical level [6].

One effort to determine the impact of climate variability on water resources is to measure the vulnerability level [9,10]. The level of ease or difficulty to obtain sufficient water in quantity and quality is used to measure the vulnerability of water resources. Unfortunately, there is limited research and information on the level of vulnerability of water resources due to climate change, particularly its variability. Several studies have been conducted to measure the level of vulnerability to climate change. Swandayani investigated community vulnerability to climate change in the Ciliwung watershed using the criteria for exposure to the water use index [4], while Rositasari conducted research on vulnerability to climate change at the coastal zone of Cirebon using remote sensing technology [11]. Effendi used Geographical Information Systems (GIS) to conduct watershed-based research on the vulnerability level of the community to climate change in the Garang watershed, Central Java [12].

Research on climate change vulnerability has been conducted in NTT province on the islands of Sumba and Flores, but not on Timor Island [13,14]. Hence, this study aims to assess the vulnerability level of water resources to climate variability in Timor Island. This study will focus on (1) a description of the phenomenon of climate change/variability based on climatological data (temperature and precipitation); (2) a description of the level of vulnerability of water resources due to climate variability

2. Methods

2.1. Conceptual framework

The theoretical framework underlying this study was the IPCC study, which predicts that climate change/variability indicated by an increase in temperature will have a direct effect on the hydrological cycle and water availability. This change would create another higher-level impact (Figure 1).

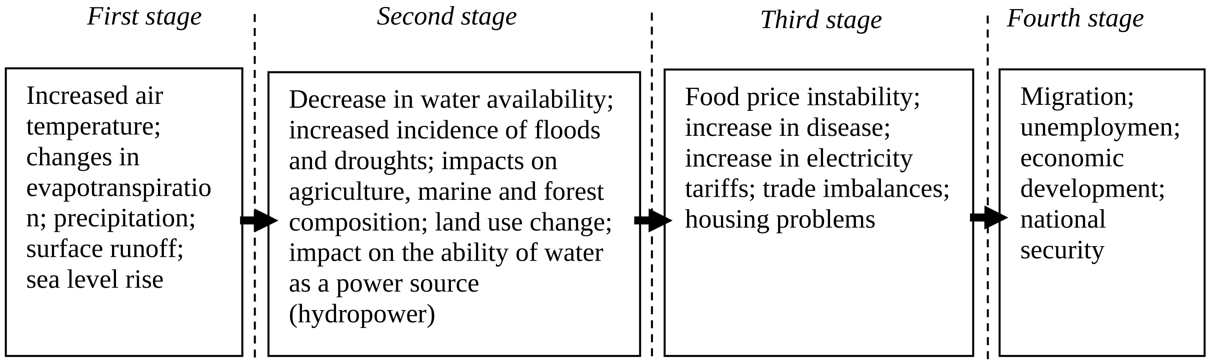

Figure 1. Different stages of climate variability effect on water resources [3].

The vulnerability assessment in this study used the IPCC vulnerability concept because the focus of the study is more on vulnerabilities caused by climate change, specifically climate variability. The IPCC concept is the most widely used concept in vulnerability assessments worldwide, both for scientific publications and reports on institutional activities [3,4,6,11,12,15]. In this concept, vulnerability is defined as a sum of exposure and sensitivity without adaptive capacity (equation 1) [1].

$$Vulnerability = f\,(Exposure + Sensitivity - Adaptive\ Capacity) \quad (1)$$

2.2. Study area

Timor Island, which covers an area of 30 thousand km^2, is located in NTT Province, eastern Indonesia. The coordinates range from 124°5'25" to 124°21'44" E and 9°26'57" to 9°41'28" S (Fig. 2). Timor has a tropical climate, with a dry season (April to October) and a rainy season (November to March). During the rainy season, the average precipitation is recorded at around 1600 millimetres per year [16]. The average temperature is 27°C, usually found in coastal or lowland areas, while for highland and mountain areas, the temperature is relatively cold, reaching around 23°C [16]. The slope class is dominated by moderate slope, with variations of gentle slope and nearly level in coastal areas and steep slopes in hilly/mountainous areas [17]. The highest point is the peak of Mount Mutis, which also serves as a major catchment area and upstream of several watersheds on Timor Island [17]. Timor's land cover is dominated by secondary forest (36%), dry land agriculture (23%), shrubs (15%), savanna (15%) and other remaining land cover includes residential, rice fields, and water bodies [18]. Based on the consideration that the research focuses on the condition of water resources, the Noelmina watershed (Figure 2 – dashed line polygon), one of the first priority watersheds in Timor Island, is used as the unit of analysis.

Administratively, the Noelmina watershed is located in two districts, namely Kupang regency and South Central Timor. The Noelmina watershed encompasses approximately 197 thousand ha and is divided into six sub-watersheds, i.e., Besiam, Boentuka, Bokong, Leke, Maiskolen, and Nefonaik. The flow pattern of the watershed is dendritic, with the main river (Noelmina River) measuring 37.40 km [19].

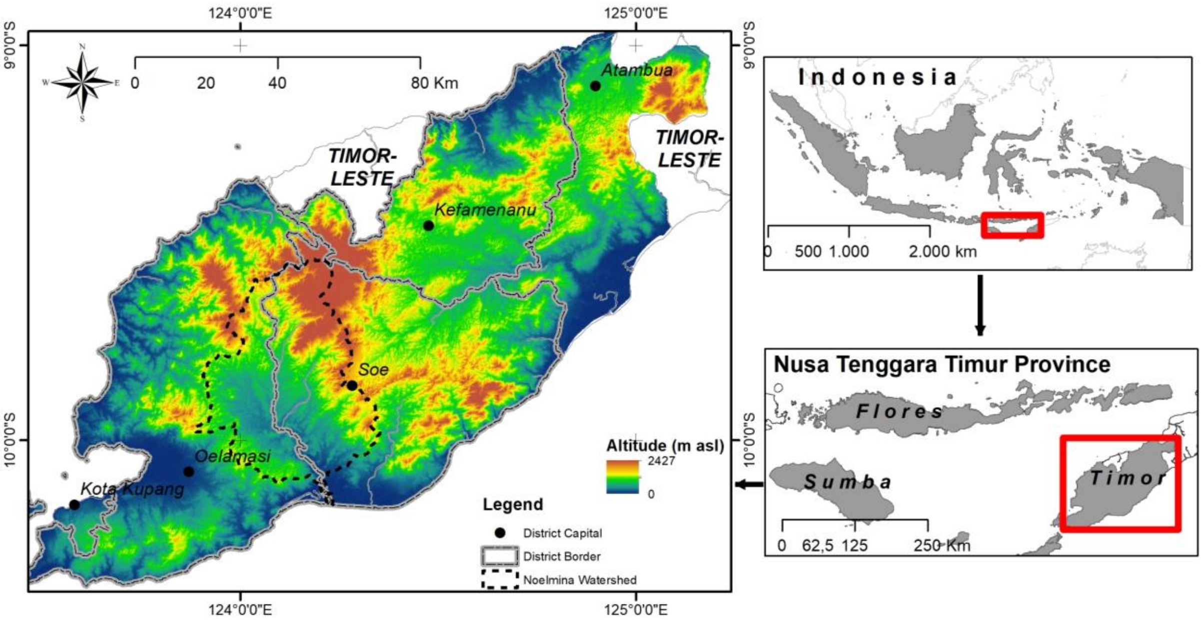

Figure 2. Study area – Timor Island, NTT province, Indonesia, depicted on Digital Elevation Model (DEM) Imagery, dashed line polygon indicated the location of the Noelmina watershed.

2.3. Research design

This study uses the watershed as the unit of analysis. The following are the reasons for using the watershed as the unit of analysis: (a) The watershed approach is more holistic and can be applied to evaluate the connection between biophysical and socio-economic factors faster and easier, (b) the watershed has clear natural boundaries in the field, (c) the watershed has very strong bio-geophysics linkages between upstream and downstream so it can describe the behaviour of water due to changes in landscape characteristics, (d) the existence of an outlet where water will accumulate, allowing water flow to be traced [13]. The area of the watershed analysis unit is divided into three regions, namely upstream, middle, and downstream, which are distinguished by slope level, area function, and drainage density [20]. A sample of village-based research was selected in each region to collect data on the socio-economic aspects of the community and climate variability.

2.4. Research procedures

2.4.1. Observation of temperature and precipitation trends. Changes in temperature and precipitation patterns and trends were used as indicators to assess the occurrence of climate variability in the study area. The data collected was time-series numerical data of temperature and precipitation data for approximately the last 30 years. The data were collected from various sources; air temperature data were obtained from Meteorological, Climatological and Geophysical Agency (BMKG) NTT, and precipitation data were obtained from the office of District Agriculture Service and several weather or precipitation observation stations closest to the study location. Trends in air temperature changes and average precipitation were analysed by regression analysis with reference to time series data.

2.4.2. Measurement of the level of water resources vulnerability to climate vulnerability. The level of vulnerability was measured using a spatial-based approach, in which the criteria and indicators of climate variability were arranged spatially with the help of a GIS to obtain a vulnerability map. The stages of preparing a vulnerability map are as follows:

- Determination of criteria and indicators.
- The exposure criteria and indicators were obtained from several references [6,12,13]. Table 1 shows the criteria and indicators used in the spatial approach. The final result at this stage was a set of criteria and indicators that were all converted into maps. In this study, maps were converted into raster data.
- Weighting and scoring. Weighting and scoring on the criteria and indicators were performed based on literature studies/previous studies [6,12,13]. Weights and scores were assigned according to the level of significance of these criteria and indicators to the water resources vulnerability
- Mapping vulnerability. The vulnerability index was calculated by reducing the exposure and sensitivity index with the adaptability index [6,12,13].

Table 1. Criteria and indicators in assessing the vulnerability of water resources to climate variability

Variable	Criteria	Indicator	Category	Score
Exposure	The Changes on watershed condition	Precipitation	<1,500 mm	Low (1)
			1,500-2,500 mm	Moderate (3)
			>2,500 mm	High (5)
		Land cover	Forest	Low (1)
			Crops	Slightly Low (2)
			Agriculture	Moderate (3)
			Savanna	Slightly High (4)
			Settlement	High (5)
		Degraded land	Non-degraded	Low (1)
			Potentially degraded	Slightly Low (2)
			Light degraded	Moderate (3)
			Degraded	Slightly High (4)
			Very degraded	High (5)
Sensitivity	Water demand	Population density	<Watershed pop.density	Low (1)
			=Watershed pop.density	Moderate (3)
			>Watershed pop.density	High (5)

Variable	Criteria	Indicator	Category	Score
		Water accessibility	0-20%	Low (1)
			21-40%	Slightly Low (2)
			41-60%	Moderate (3)
			61-80%	Slightly High (4)
			81-100%	High (5)
	Land dependency	Agricultural dependency	0-12,5%	Low (1)
			12,6-25%	Slightly Low (2)
			25,1-37,5%	Moderate (3)
			37,6-50%	Slightly High (4)
			>50%	High (5)
Adaptive capacity	Quality of human resources	Education	<50%	Low (1)
			50-75%	Moderate (3)
			>75%	High (5)
		Conservation preferences	0-20%	Low (1)
			21-40%	Slightly Low (2)
			41-60%	Moderate (3)
			61-80%	Slightly High (4)
			81-100%	High (5)
	Socio-economic	Community welfare level	0-60%	Low (1)
			61-70%	Slightly Low (2)
			71-80%	Moderate (3)
			81-90%	Slightly High (4)
			91-100%	High (5)
		Conflicts	0-20%	Low (1)
			21-40%	Slightly Low (2)
			41-60%	Moderate (3)
			61-80%	Slightly High (4)
			81-100%	High (5)
	Health facility	Health facility	None	Low (1)
			Exist	Moderate (3)
			Complete	High (5)
	Water catchment area	Water catchment area	0-20%	Low (1)
			21-30%	Slightly Low (2)
			31-40%	Moderate (3)
			41-50%	Slightly High (4)
			>50%	High (5)

3. Results and discussion

3.1. Trend of temperature and precipitation

Observation of the temperature trend in the Noelmina watershed was hampered by the absence of a meteorological station that measures the temperature inside of Noelmina watershed. In addition, isotherms data or maps were also difficult to obtain. As anticipation, observations of temperature at the Kupang meteorological station were used as a proxy for the temperature in the Noelmina watershed. The reason underlying this anticipation is the similarity of the landscape's condition. The results show that the average annual temperature is fluctuating, but a trend analysis shows an increasing trend, with an increase of approximately 0.6°C between 1980 and 2020 (Figure 3). Results of this study are in line with previous studies, which showed that there was climate variability in the form of an annual increase in temperature in the Aesesa watershed, Flores, and Kambaniru watershed, Sumba [13,14].

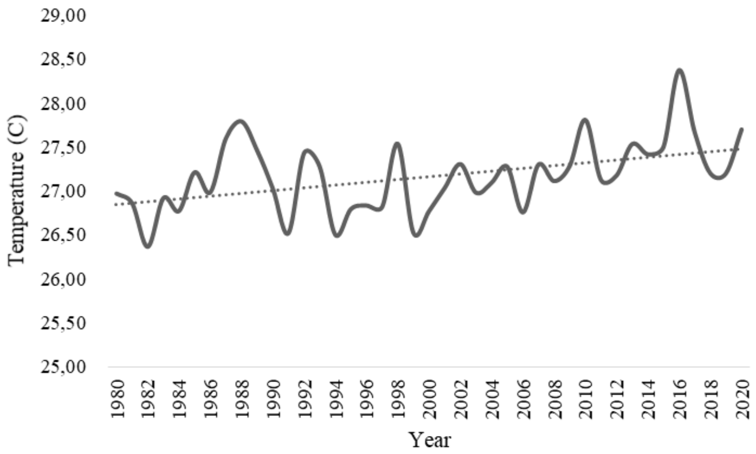

Figure 3. The trend of annual temperature in Noelmina watershed

Analysis of the average annual precipitation in Lelogama weather station, the upstream area of Noelmina watershed, from 1973 to 2010 shows a decreasing trend, whereas in Soe weather station, representation of the middle area of Noelmina watershed, and Panite weather station, representation of the downstream area of Noelmina watershed, show an increasing trend (Figure 4). This result is consistent with the results of previous studies, which found a trend of decreasing annual precipitation in the Kambaniru watershed, Sumba Island [14]. On the other hand, this result contradicts a similar study conducted in the Aesesa Watershed, Flores Island, which found an increase in annual precipitation, which was primarily observed in the upstream area of the watershed [13]. This difference may be due to the characteristics of the islands of Timor and Sumba, which are identical in terms of dry areas and land cover dominated by savanna with a limited proportion of forest area, while Flores Island is relatively wet with a relatively larger proportion of forest cover compared to Timor and Sumba Island [18].

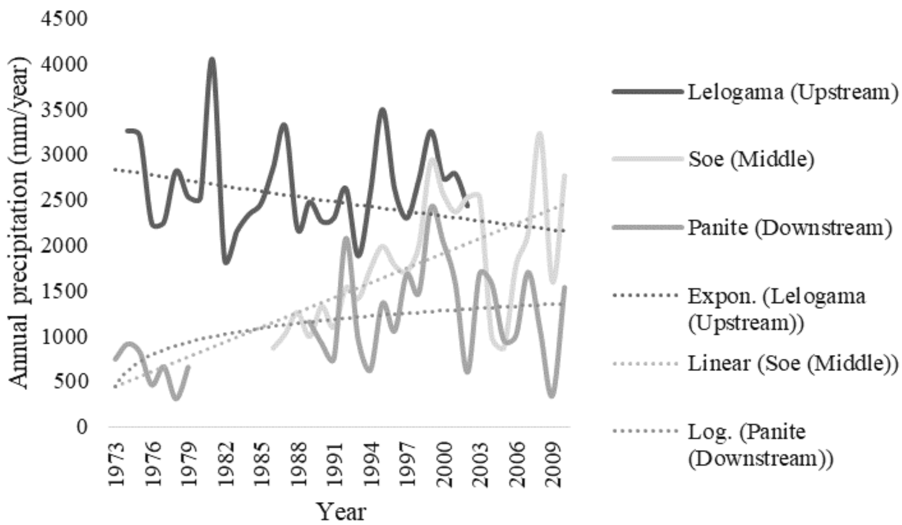

Figure 4. The trend of annual precipitation/precipitation in Noelmina watershed

IOP Conf. Series: Earth and Environmental Science **874** (2021) 012007 doi:10.1088/1755-1315/874/1/012007

3.2. The level of water resources vulnerability to climate variability map

The map of water resources exposure to climate variability is caused by overlapping rainfall and land cover maps, as well as maps of degraded land levels in the Noelmina watershed area. The results show that the middle region is more vulnerable to climate variability than the upstream and downstream regions (Figure 5a). Because of the savanna-dominated land cover in the middle region, and a large number of degraded lands, this region has the highest exposure index.

The sensitivity of water resources to climate variability is influenced by the level of water demand, which is spatially represented by the level of population density and access to clean water and community dependence on the land, or the proportion of people who rely on agriculture. In terms of population density, the upstream region, Soe - the district capital area, has a higher population density than the middle and downstream regions; however, in terms of the population dependent on agriculture, the number of people dependent on agriculture in the middle and downstream regions is relatively larger than those in the upstream region. The accumulation of these variables shows that the sensitivity index in all regions is relatively the same, which is classified as sensitive level (Figure 5b)

The following criteria and indicators are used to assess adaptive capacity in the water resources sector: quality of human resources (education index, conservation behavior), social status (level of community welfare, conflict, and government support), health facilities, and water catchment areas. The middle region has the highest adaptive capacity index, followed by downstream and upstream regions (Figure 5c). People in the upstream region, which is located around the capital district, have a higher level of education and community welfare than those in the middle and downstream regions, resulting in the upstream region having the highest adaptive capacity index, followed by the middle and downstream regions. The adaptation patterns are dominated by reactive adaptation types (e.g. protection of water ground sources, increased water supply and rainwater harvesting), while anticipatory adaptation types (e.g. water catchment conservation, use of drought-resistant seeds and disaster early warning systems) are still rare.

A vulnerability map of water resources to climate variability is produced by combining three variables: water resource exposure, water resource sensitivity, and water resource adaptive capacity (Figure 5d). The index of water resources vulnerability to climate variability in the middle watershed is relatively higher than in the upstream and downstream regions (Figure 5d; Table 2). The results of this study reveal that the level of water resources vulnerability to climate variability in the Noelmina watershed is dominated by a slightly high vulnerable level. This level is found in each watershed region, accounting for nearly half of the total area of each watershed region (Table 2). In detail, the proportions of the level of the low, moderate, slightly high, and high vulnerability of water resources to climate variability are 1%, 33%, 47%, and 19% of the total watershed area, respectively (Table 2).

Table 2. The level of water resources vulnerability to climate variability by region in Noelmina watershed

Vulnerability level	Region			Total vulnerable area (hectares)
	Downstream	Middle	Upstream	
Slightly low vulnerable	309	17	-	326
Moderate vulnerable	13.844	32.381	18.392	64.617
Slightly high vulnerable	10.429	52.889	28.109	91.427
High vulnerable	1.459	23.785	12.526	37.770
Total region (hectares)	26.041	109.073	59.027	194.140

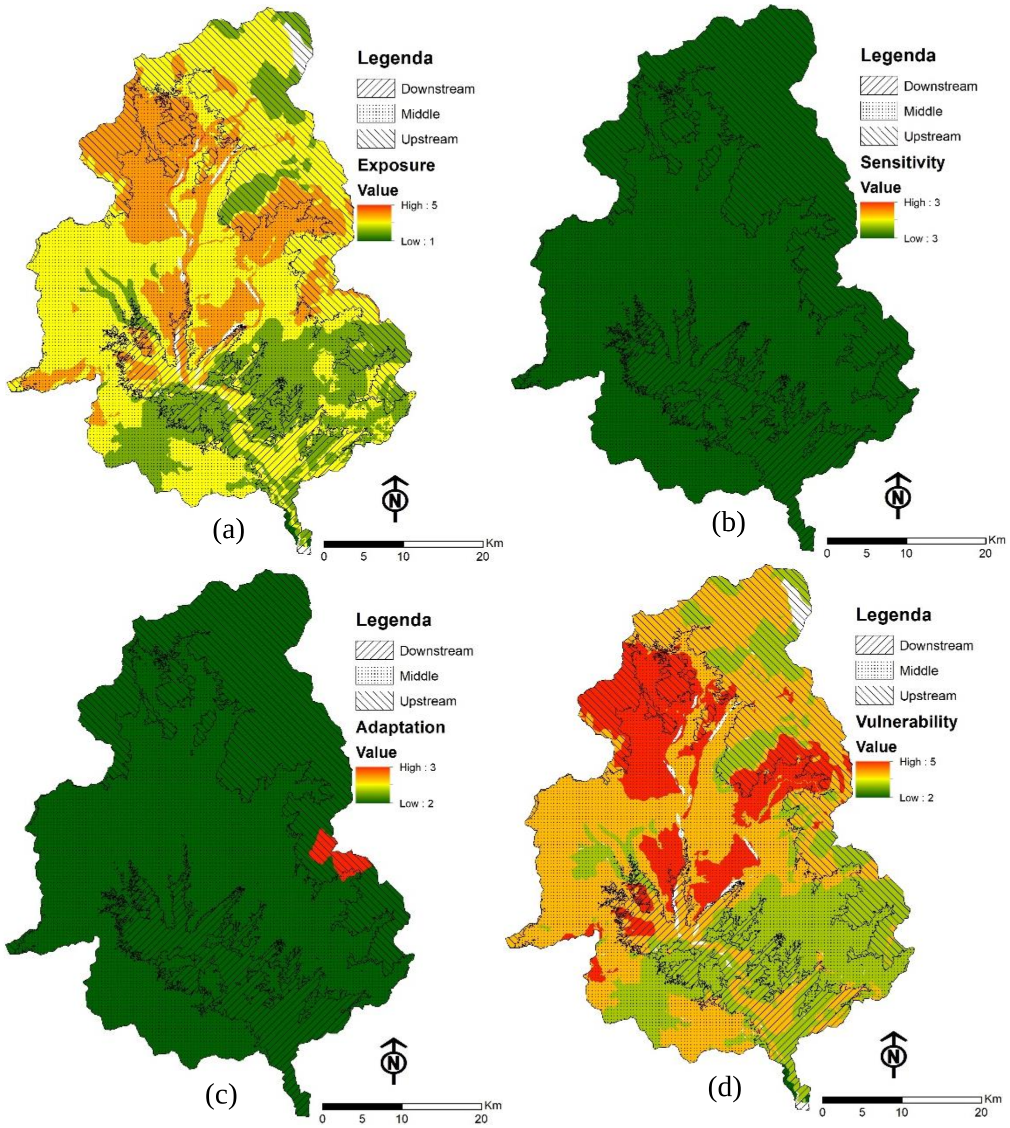

Figure 5. Maps of water resources exposure (a), water resources sensitivity (b), water resources adaptive capacity (c), and water resources vulnerability to climate variability (d)

3.3. The advantages and weaknesses of water resources vulnerability to climate variability map

The assessment of water resources vulnerability to climate variability can be used as a basis data to develop a vulnerability management strategy in the Noelmina watershed. The proposed alternative strategies include (1) reforestation in the upstream watershed region, particularly around the Mutis-Timau protective forest, which is threatened by illegal logging, community encroachment, and wild grazing; (2) land use management in the middle region, which has a relatively high population density and is threatened by agricultural land expansion and land conversions into the settlement; (3) disaster protection in all watershed regions, especially in areas with a high level of vulnerability. These strategies can be used as an alternative to proposed activities/programs by stakeholders/institutions related to water resources management and anticipating the impacts of climate variability. Moreover, water resources vulnerability assessment can also be used as (1) a tool for understanding the causes of water resources vulnerability; (2) baseline data set for prioritizing adaptation activities; (3) risk measurement tools; and (4) tools for empowering and mobilizing vulnerable community groups [17,21].

One of the weaknesses of this water resources vulnerability map is its data sources, where the majority of spatial data is obtained from secondary data. A review of several scientific publications on vulnerability maps revealed that only about 9% of these publications used primary data [22]. It was also stated that the advantage of water resources vulnerability to climate variability map is its ability to display spatial information related to water resources vulnerability to climate variability. Despite all these advantages and disadvantages, a vulnerability map remains a cost-effective tool for relevant agencies for spatial planning or the preparation of adaptation plans to climate variability [23]. For future studies on the water resources vulnerability to climate variability, it is necessary to incorporate other approaches, such as the concept from United Nations Environment Programme (UNEP), with its main elements, for example, water stress, water development pressure, ecological health, and management capacity [24] and the DPSIR framework, which consists of the relationship of Driver, Pressure, State, Impact, and Response of water resources system [25].

4. Conclusion

A combination of climatological data analysis, IPCC vulnerability concept, and spatial approach were used in this study to assess the vulnerability of water resources to climate variability. Our findings highlighted that, based on climatological data from the last several decades, there had been a phenomenon of climate variability in the Noelmina watershed, with an increasing trend in temperature and a tendency to decrease precipitation. Regarding water resources vulnerability, we determined that most of the Noelmina watershed areas are vulnerable to climate variability, which is dominated by a slightly high vulnerability level. These results are important for the Noelmina watershed authority in prioritizing actions for sustainable water resources management and anticipating the effects of climate variability.

References

[1] McCarthy J J, Canziani O F, Leary N A and Dokken D J 2001 Climate change 2001: Impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change (Geneva: UNEP/WMO)
[2] Faqih A 2011 Kajian ilmiah perubahan iklim dan hubungannya dengan kajian iklim ekstrim di Indonesia *Perubahan Iklim dan Launching IPCC Indonesia* (IPB International Convention Center, Bogor)
[3] Gain A K, Giupponi C and Renaud F G 2012 Climate change adaptation and vulnerability assessment of water resources systems in developing countries: A generalized framework and a feasibility study in Bangladesh *Water* **4** 345–66
[4] Swandayani T H 2010 *Pemetaan kerentanan masyarakat terhadap perubahan iklim dan adaptasi berbasis ekosistem hutan (Studi kasus: DAS Ciliwung)* (Bogor: IPB (Bogor Agricultural University))
[5] The Energy and Resources Institute 2009 *Climate change and water vulnerability: strategies and practices for emerging water management and governance challenges-executive summary* (Copenhagen, Denmark)
[6] Bappenas 2010 *Indonesia climate change sectoral roadmap ICCSR: Sektor sumber daya air* (Jakarta: Badan Perencanaan Pembangunan Nasional)
[7] Bappeda 2009 *Rencana Pembangunan Jangka Menengah Daerah Provinsi NTT Tahun 2009-2013* (Kupang: Badan Perencanaan Pembangunan Daerah NTT)
[8] BPS 2020 *Nusa Tenggara Timur dalam Angka* (Kupang: Badan Pusat Statistik NTT)
[9] Anandhi A and Kannan N 2018 Vulnerability assessment of water resources – Translating a theoretical concept to an operational framework using systems thinking approach in a changing climate: Case study in Ogallala Aquifer *J. Hydrol.* **557** 460–74
[10] Soumaila K I, Niandou S S, Naimi M, Mohamed C and Scimmel K 2019 Analysis of water resources vulnerability assessment tools *J. Agric. Sci. Technol.* **9** 69–86

[11] Rositasari R, Setiawan W B, Supriadi I H, Hasanuddin and Prayuda B 2011 Kajian dan prediksi kerentanan pesisir terhadap perubahan iklim: Studi kasus di Pesisir Cirebon (Coastal vulnerability prediction to climate change: Study case in Cirebon coastal land) *J. Ilmu dan Teknol. Kelaut. Trop.* **3** 64

[12] Muchtar Efendi 2012 *Kajian tingkat kerentanan masyarakat terhadap perubahan iklim dan strategi adaptasi berbasis daerah aliran sungai (Studi kasus: Sub DAS Garang Hulu)* (Semarang: Universitas Diponegoro)

[13] Pujiono E and Setyowati R 2015 Penilaian tingkat kerentanan sumber daya air terhadap variabilitas iklim di DAS Aesesa, Pulau Flores, Nusa Tenggara Timur - Neliti *J. Penelit. Sos. dan Ekon. Kehutan.* **12** 177–95

[14] Pujiono E 2015 Kajian spasial tingkat kerentanan sumber daya air akibat perubahan iklim di DAS Kambaniru *Prosiding Seminar Regional Pembangunan Kehutanan Berkelanjutan dalam Prespektif Tata Ruang* (Kupang: Balai Litbang Kehutanan Kupang)

[15] Hamouda M A, Nour El-Din M M, Fawzia ·, Moursy I, Hamouda M A, Moursy F I and Nour El-Din M M 2009 Vulnerability assessment of water resources systems in the Eastern Nile Basin *Water Resour Manag.* **23** 2697–725

[16] BMKG 2019 Data online-Pusat database-BMKG

[17] Pujiono E, Sadono R, Hartono and Imron M A 2019 Assessment of causes and future deforestation in the mountainous tropical forest of Timor Island, Indonesia *J. Mt. Sci.* **16** 2215–31

[18] BPKH Wilayah XIV Kupang 2016 Peta penutupan lahan Provinsi NTT

[19] Kumalajati E 2017 Menentukan arahan fungsi lahan daerah aliran sungai Noelmina dengan aplikasi Sistem Informasi Geografis (SIG) *ForestSains* **14** 85–90

[20] Asdak C 2018 *Hidrologi dan pengelolaan daerah aliran sungai* (Yogyakarta: Gadjah Mada University Press)

[21] Malone E L and Engle N L 2011 Evaluating regional vulnerability to climate change: purposes and methods *Wiley Interdiscip. Rev. Clim. Chang.* **2** 462–74

[22] Preston B L, Yuen E J and Westaway R M 2011 Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks *Sustain. Sci. 2011 62* **6** 177–202

[23] Harter T and Walker F G 2001 *Assessing vulnerability of ground water* (University of Carolina & Caroline Department of Health Science)

[24] Al-Kalbani M S, Price M F, Abahussain A, Ahmed M and O'Higgins T 2014 Vulnerability assessment of environmental and climate change impacts on water resources in Al Jabal Al Akhdar, Sultanate of Oman *Water* **6** 3118–35

[25] Bär R, Rouholahnedjad E, Rahman K, Abbaspour K C and Lehmann A 2015 Climate change and agricultural water resources: A vulnerability assessment of the Black Sea catchment *Environ. Sci. Policy* **46** 57–69