Regional Analysis of Prone Drought Areas under Future Climate Change Scenarios: Case Study Agropolitan of Malang District

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Regional Analysis of Prone Drought Areas under Future Climate Change Scenarios: Case Study Agropolitan of Malang District

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Abstract. Global climate change challenges livelihoods across the globe concerning its potential impacts. Consequently, climate change adaptation (CCA) strategies should be devised to minimize its negative and maximize its positive impacts. In response to the needs for developing CCA strategies, climate risk assessment should be conducted as an approach to identify contributed factors to the climate risks in a region with which the adaptation strategies can be devised. This study focused on modeling prone areas to drought over a specialized area called Agropolitan located in Malang district. The model was developed based on the concept of drought in combination with spatial analysis. The model includes climate component (i.e., rainfall and evapotranspiration) and biophysical component (i.e., land cover/use, green open space, slope/elevation). The regional climate data for the baseline and future condition were processed using the gridded datasets of WorldClim, which also included the outputs of six global climate models, namely: BCC, CCCMA, CSIRO, GISS, MIROC and NCAR, for projecting future climate of the study region. The analysis shows that prone areas to drought in Malang district was projected to be larger under future climate scenarios. The expanded prone areas were Kalipare sub-district and Pagak sub-district, which prone areas were expanded towards to the south. For the sub-districts of Donomulyo, Bantur, Singosari, and Gedangan, the prone areas were expanded towards to the north. The prone areas of drought in Poncokusumo sub-district remained constant. The prone areas showed within the Agropolitan areas of Poncokusumo were in the villages of Ngadas, Gubukklakah, Pajaran, Argosuko, Ngebruk and Jambesari, and were projected to expand under future climate scenarios. This assessment was an essential step for further study focusing on defining proper CCA strategies for the study region.

Keywords: climate change, extreme, drought, agropolitan, malang

1. Introduction

Global climate change has been estimated to affect regional climate of many areas around the globe. The recent report of IPCC published in 2014 estimated that rainfall pattern and magnitude for Asia, including Indonesia, was changing [1]. This new climate regime may pose a challenge particularly on water supply throughout the country given the possibility of lower rainfall over a year. As an approach to address the challenge, climate risk assessment can be conducted to identify contributed factors to the climate risks in a region with which the adaptation strategies can be devised. The strategies were directed to minimize the potential negative impacts and maximize the potential positive impacts of climate change [1].

This research selected the district of Malang, particularly the Agropolitan area, as a case study to observe the impacts of climate change on prone areas to drought in the district. The impacts of drought were diverse and can be broadly classified as economic, environmental and social [8] The Agropolitan area is located in one of sub-districts of Malang, named Kecamatan Poncokusumo. This special area characterized by the complexity of topographical terrain and economic activities in the region (e.g., agriculture, livestock, and tourism). Based on the records of Data and Information on Disasters in Indonesia named Data Indeks Bencana Indonesia (DIBI) in 2011, it was reported that potential climate related hazards that threaten the Malang region were flooding, droughts, landslides, and wind speed. Specifically for drought occurred in 2015, the disaster agency of Malang named *Badan Penanggulangan Bencana Daerah* (BPBD) reported that the drought in 2015 caused the water shortage of about 1.5 million liters. As for floods, in July 2016, there was a flood disaster caused 73 houses were damage. The incidences of climate related hazards are increasing which are in line with increased climate variability induced by climate change causing extreme weather and/or climate extreme events.

The incidents of climate related hazards have been alarming because the extreme events may threat human livelihoods (e.g, water shortage and crop production failure). This situation urges the needs to understand factors contribute to the formation of a climate related hazard, such as drought and flood. This study focuses on the development model of prone areas to drought, which is an essential step for climate risk assessments. The model was constructed based on climate and biophysical factors. The climate component composed of two essential climate variables, i.e. rainfall and air temperature; while, the biophysical component included information on regional characteristics, i.e, land use, slope, and topography. The variables for each component were also chosen considering the availability of data required for each component. The model was expected to provide information on prone areas to drought and the most contributed factors causing drought in that area. Consequently, anticipation strategies can be devised properly by considering factors contributed to drought in a region.

2. Related Research

Drought is one of climate extreme events occurred as a result of water deficit, i.e, the amount of evapotranspiration is higher than the amount of rainfall. The development of regional drought models using a variety of techniques has been done in Indonesia. Mujtahiddin et al. [2] assessed drought incidences in the district of Indramayu using the ThornthWaite-Matter that were applied to monthly rainfall data of 13-rainfall stations over a 30-year period (1980-2009). The other study assessed drought occurred in 15 water catchment areas in eastern Java using the threshold level method, which assumed the value of discharge as a drought index to indicate drought incidences [3]. Yusron [4] evaluated drought area based on interpolation of standardized precipitation index (SPI). Another study identified various estimation methods developed for drought analysis, namely: SPI and SPEI applied to monthly climate data [5]. Rosanne *et al* [9] reconstruction of PDSI for Java,Indonesia, that reflects past monsoon drought variability and the influence of ENSO in this region. A considerably skilful simple empirical forecast model for predicting drought over Java Island has been developed using the DMI in combination with Ni no-3.4 [10]. Recent study [6] has developed a method for predicting prone areas to drought based on the concept of net balance between rainfall and evapotranspiration using climate data (i.e., temperature and rainfall) and biophysical data (i.e., topography, slope, and land use).

3. Methods

Malang District has an area of 3347 km^2 with formation of lowlands and highlands. Climatologically, Malang has a monsoonal precipitation type with a peak of rainy seasons from December to February (during the winter Asia) and the dry season from June to August (during the Australian winter). The prone areas to drought for the study region was modeled based on the concept of net balance between rainfall and evapotranspiration, and spatially analyzed using geographical information system. The model of simulated prone áreas was calculated based on regional climate information on rainfall and temperature, and biophysical characteristics of the region. The climate observations were only available from two climate stations, namely: Karangploso and Karangkates. These limited data available from these stations were employed to analyze climate averages such as rainfall pattern over a year and trends as presented in figure 1.

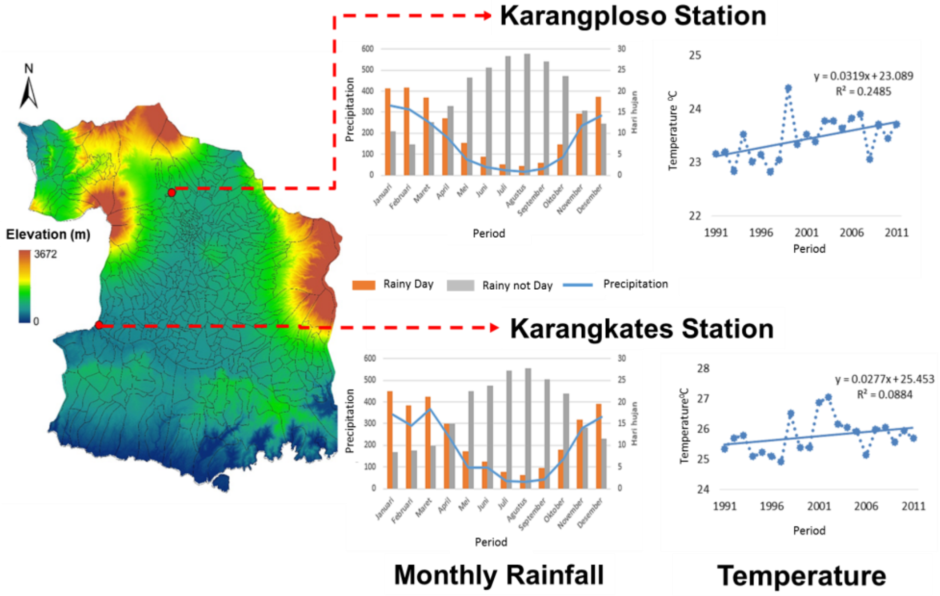

Figure 1. The district of Malang (left), rainfall averages for the period of 1991-2011 at Karangploso station (middle-above) and at Karangkates station (middle-below), and the trend of air temperature for the same period for the two stations (right).

The limited number of climate stations limit the ability to capture regional characteristics of climate over the studied región. This situation offered an opportunity to utilize the outputs of available gridded climate data. This research employed gridded data named WorldClim developed by Hijmans et al. [7] (figure 2). The WorldClim produced the gridded climate data using spatial interpolation techniques at a spatial resolution of 1 km. Climate variables include rainfall and air temperature (i.e., minimum, average, and maximum temperature), and solar radiation for the baseline period (1971-2000) and the future period (2021-2050) under emission scenario of RCP 4.5 projected using six global climate models included in the WorldClim. The included climate models are BCC, CCCMA, CSIRO, GISS, NCAR, and MIROC.

The rainfall data of WorldClim showed that the high rainfall ranging from 3300-3600 mm/year were in the plateau territory with elevation of 1700-2500 meters. The regions include the sub-districts of Poncokusumo, Jabung, Karangploso, Dau, Pujon and Ngantang. The value of the lowest rainfall occurred in the coastal area or the south of Malang, which ranged from 1500-1700 mm/year. These regions include the southern part of the sub-district of Donomulyo, the sub-districts of Bantur and Gedangan, and the northern part of the sub-district Kalipare Pagak. The annual temperature averages of Malang ranged from 25-27^{o}C. As the topography rises above 1500 meters, air temperature decreases significantly (figure 2).

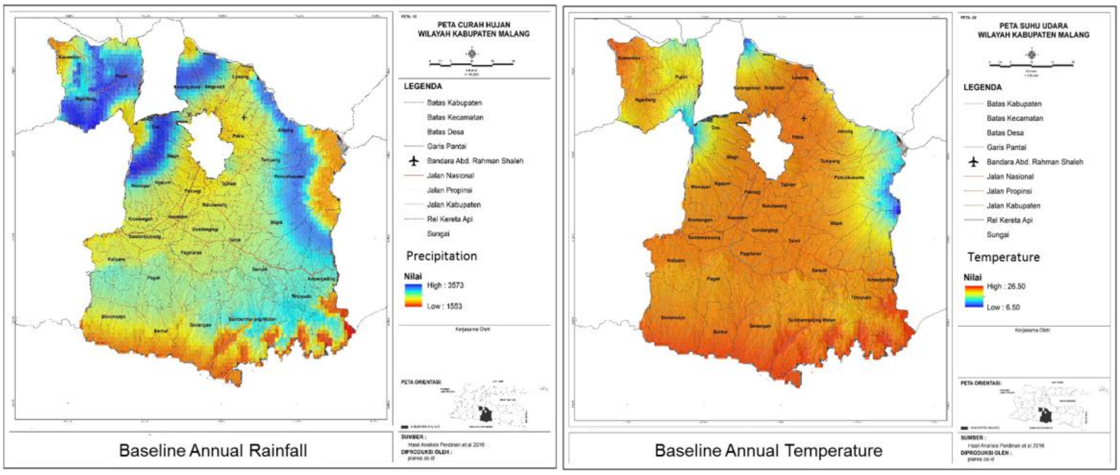

Figure 2. Rainfall (left) and air temperature (right) for the periode of 1971-2000 produced based on the Worldclim gridded data at 1 km resolution. Source of WorldClim: Hijmans et al. [7]

The biophysical components including land cover/use, green open space, and slope/elevation were analyzed. Land cover were analyzed using the outputs of Landsat 8 trained using supervised classification method with the Earth Indonesia map and Google Earth. The Landsat 8 was also employed to produce the green open space map using the Normalized Difference Vegetation Index. Slope was determined utilizing the SRTM data. Threshold values were determined to categorize values for each variable employed in determining the climate and biophysical components as described by Perdinan et al. [6]. The threshold values were parameterized uniquely for the district of Malang on the basis of field surveys and literature review.

4. Results and Discussion

The developed drought model for Malang district produced a map of prone areas to drought in the range of zero to one (0-1), indicating the potential areas to drought was increasing as the index value increased. Categorization was then performed to understand which areas within Malang district and the sub-district of Poncokusumo were prone to drought. The categorizations were 0-0.2 (Very Low), 0.21-0.40 (Low), 0.41-0.60 (Medium), 0.61-0.80 (High) and 0.81-1.00 (Very High). The analysis showed that Malang has the potential Low to Very High prone areas to drought. The prone areas to drought categorized into Very High were in sub-district of Poncokusumo (i.e., the village of Ngadas). The regions categorized into High were sub-districts of Kalipare (i.e., the villages of Kalirejo, Arjosari, Sukosari, and Argowinagun), Pagak (i.e., the villages of Tlogorejo, Gampingan, and Sumberejo), Bantur (i.e., the villages of Karangsari and Rejoyoso), Donomulyo (i.e., the villages of Sumberoto, Banjarejo, and Tulungrejo), Singosari (i.e., the villages of Randuagung, Candirenggo, Dengkol, and Toyomarto), Lawang (i.e., the villages of Lawang, Sumberporong, and Mulyoarjo) and Pakis (i.e., the villages of Buluwetan and Mangliawan). The rest areas were in the category of Medium and Low (figure 3-left). Specifically for the district of Poncokusumo (i.e, the Agropolitan region), the category of Very High was given for the village of Ngadas. The other regions with High category were the villages of Gubukklakah, Pajaran, Argosuko, Ngebruk, and Jambesari. While the rest villages were in the category of Medium to Low (figure 3-right).

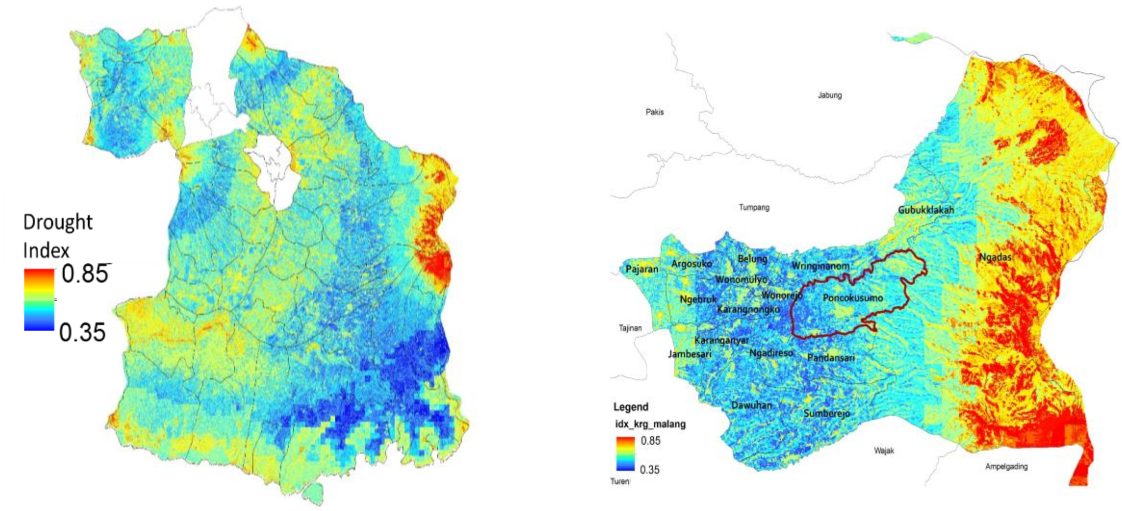

Figure 3. Potential prone areas to drought in the district of Malang (left) and the sub-district of Poncokusumo, i.e., the Agropolitan region (right).

The future climate was projected using the outputs of six (6) available global climate models (GCMs) within the WorldClim database, i.e., BCC, CCCMA, CSIRO, GISS, NCAR, and MIROC, under emission scenario of RCP4.5. The projected climatic condition was performed on rainfall and air temperature for the period of 2021-2050. Annually, the amount of rainfall may change in the range of -15 to 27%. The projected outputs of CCCMA, GISS, NCAR, BCC show a projected decrease in the rainfall amount ranging from -15 to -0.3% for the district of Malang. The CCCMA, BCC and NCAR indicated that the amount of rainfall was projected to decline for areas within the sub-districts of Dampit, Tirtoyudo, Ampelgading, and Sumbermanjing Wetan. The GISS model shows a decline of projected rainfall for areas within the sub-districts of Kalipare, Pagak, Sumberpucung, Kromengan, and Kepanjen. The CSIRO wss projected decreasing rainfall for areas within the sub-district of Poncokusumo and Singosari. As for GFDL, the rainfall amount was projected to increase for the district of Malang, especially for areas in the coastal and mountainous region (figure 4).

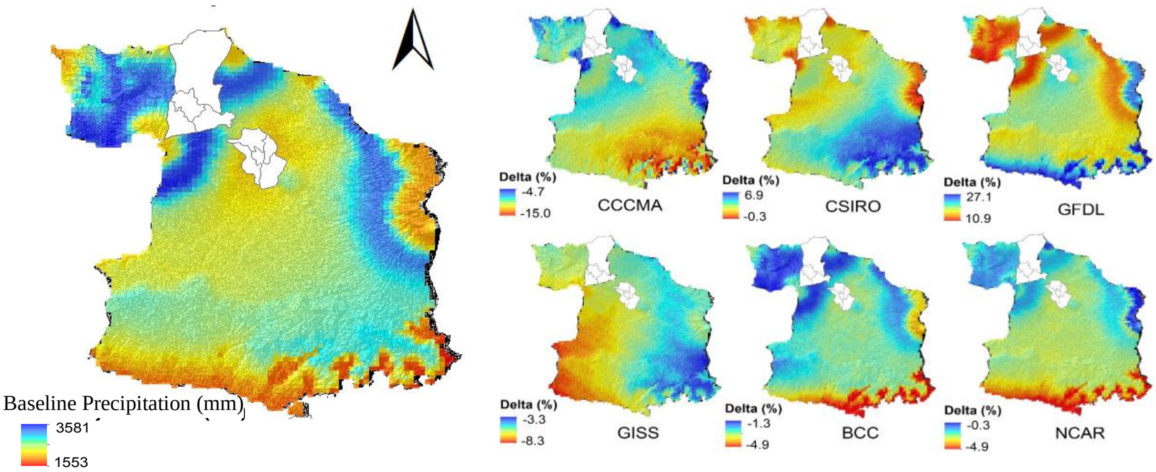

Figure 4. Projected of rainfall resulted from six global climate models simulated under RCP 4.5 archieved in WorldClim and extracted for the Malang district for the period of 2021-2050.

As rainfall data, the projection of air temperature was performed using the same models and period archived in WorldClim. The results show that changes in air temperature ranged from 0.5 to 1.4◦C. The CCCMA model exhibited the highest increase, whereas, the BCC model displayed the smallest increase. The projections of increasing temperature for the CCCMA, GFDL and GISS were distributed evenly throughout the district of Malang. The CSIRO and BCC display the highest increased temperature were in the territory of North Malang; while, the NCAR showed the highest increase for the southern areas of the study region (figure 5).

Employing the projections of rainfall and temperature, the prone areas to drought in Malang were simulated. The results suggested that there were potential extended drought areas. For example, the prone areas within the sub-district of Kalipare and Pagak showed the widespread moved towards the south. For the sub-districts of Donomulyo, Bantur, and Gedangan, the prone areas to drought may expand towards the north. For the sub-district of Singosari, the simulated drought index was increasing, but the index range will be narrowed as with those for the areas of the sub-district Poncokusumo. Specifically for the Agropolitan- Poncokusumo, the potential prone areas to drought include areas categorized into the Medium (M) to Very High (ST). Generally, the villages of Ngadas, Gubukklakah, Pajaran, Argosuko, Ngebruk and Jambesari were prone to drought for the baseline and future period, indicating future climate may expand prone areas to drought (figure 6).

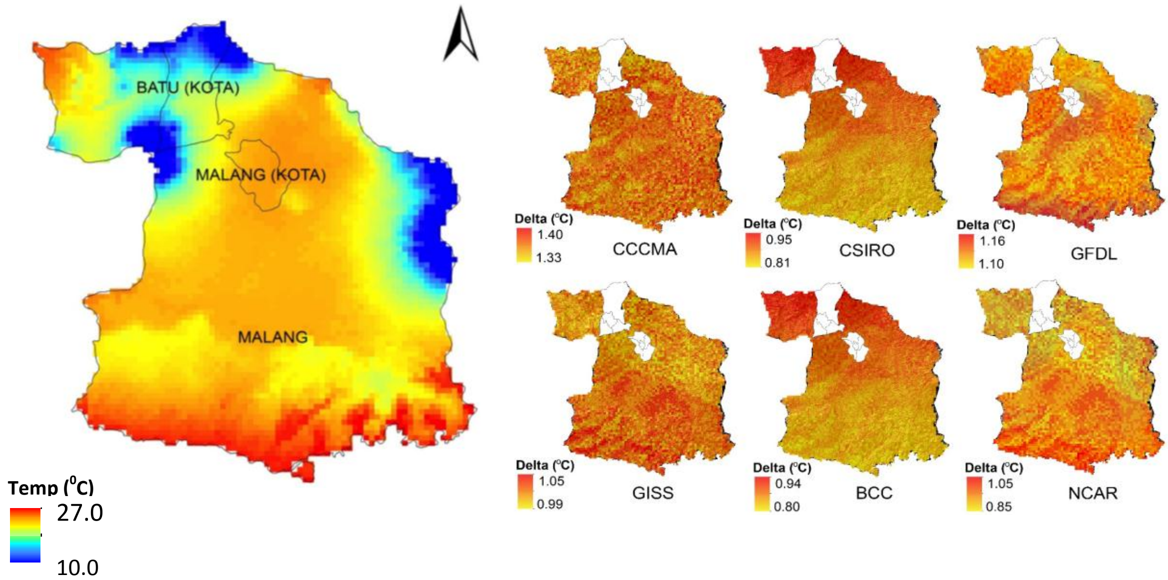

Figure 5. Projected of air temperature resulted from six global climate models simulated under RCP 4.5 archieved in WorldClim and extracted for the Malang district for the period of 2021-2050.

The analysis of prone areas to drought (figure 6) indicates that the district of Malang, particularly the sub-district of Agropolitan-Poncokusumo, should consider the prone areas when designing the development plan. Further exploration through field visits to the prone areas was also suggested to identify the exact factors contributed to drought in the prone areas, so proper anticipation strategies can be devised. The strategy should also be mainstreamed into development plan in order to support the achievement of the development targets.

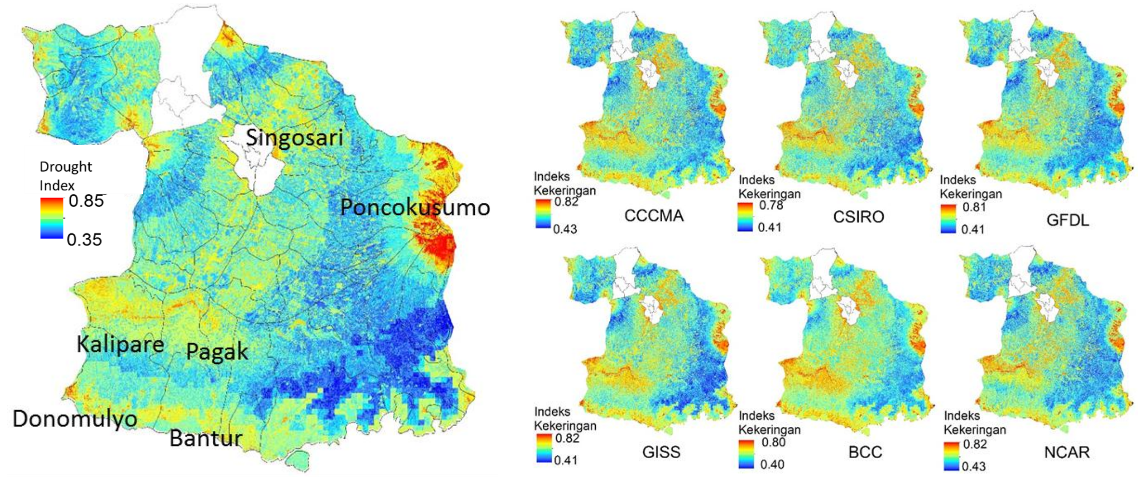

Figure 6. Analysis of prone areas to drought in the district of Malang for the baseline period of 1971-2000 and the future period of 2021-2050.

5. Conclusion

Modeling of prone areas to climate-related hazards such as drought essentially required climate information, e.g., rainfall and air temperature, as inputs. The modeling approach were developed by considering the drought concept in combination with geographic information system. The model simulateed the interactions between climate (i.e., rainfall and evapotranspiration) and biophysical factors (e.g., land use/cover, topography). Climate data for the baseline and future condition were obtained from gridded datasets available worldwide called WorldClim, and the future climate were projected based on the outputs of six global climate models, namely: BCC, CCCMA, CSIRO, GISS, MIROC and NCAR, archieved in WorldClim.

The analysis showed that prone areas to drought in Malang district were projected to be expanded under future climate scenarios. The expanded prone areas were for the sub-districts of Kalipare and Pagak, in which the prone areas were expanded towards the south. For the sub-districts of Donomulyo, Bantur, Singosari, and Gedangan, the prone areas were expanded towards the north. The prone areas to drought in Poncokusumo sub-district were not change. The employment of various global climate models exhibited diffferent expanded prone areas. This difference was commonly evaluated to show uncertain future climate condition, which may affect the hazard analysis. For example: CCCMA, GISS and NCAR show the largest increase, while the lowest is showed by CSIRO. Furthermore, specifically for the Agropolitan-Poncokusumo, the villages of Ngadas, Gubukklakah, Pajaran, Argosuko, Ngebruk and Jambesari were considered prone to drought for the baseline and future period, indicating future climate may expand prone areas to drought. The results provide an early warning information on which areas should be prioritized in addressing the potential impacts of drought which may pose adverse impacts on livelihoods in the district of Malang and specifically the Agropolitan areas of Poncokusumo. This urges proper anticipation strategies should be devised and mainstreamed into the development plan.

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