Drought Analysis Using Standardized Precipitation Index (SPI) Based on Representative Concentration Pathways (RCPs) in Bantul and Gunung Kidul Regencies, DI Yogyakarta

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Abstract. One of the natural disasters that is increasing in frequency due to the phenomenon of climate change and very detrimental to agriculture is drought. Future drought events need to be known so that adaptation and mitigation can be carried to avoid large losses. The purpose of this study is to determine the amount of future precipitation in the next 25 years (2025–2049) and to determine the drought category of the SPI based on climate change scenarios RCP2.6, RCP4.5, and RCP 8.5. The initial stage of the study was carried out by calculating future precipitation with a 5-year period during 2024–2049 based on the RCP2.6, RCP4.5, and RCP 8.5 scenarios. This calculation is done using SDSM software version 4.2. The next step is to calculate the 3-month SPI from future precipitation data for each scenario. The results show that the worst 3-month SPI drought index shows extreme dry conditions in the RCP2.6 scenario during the 2040–2044 period, in the RCP4.5 scenario during the 2035–2039, and in the RCP8.5 scenario during the 2030–2034 period.

Keywords: drought · Standardized Precipitation Index (SPI) · Representative Concentration Pathways (RCP) · precipitation

1 Introduction

Weather and climate are one of the factors that greatly affect the production of the agricultural sector in various regions. Weather conditions in an area can experience extreme conditions where weather and climate variables have values that are more than or less than certain thresholds from normal conditions. Extreme weather or climate can cause disasters such as heat waves, cold waves, heavy rains, droughts, floods, and severe storms [1]. Extreme weather phenomena can occur naturally within a few decades of time. However, with climate change, the frequency of extreme weather such as drought is increasing in several regions of the world.

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Drought is a natural disaster that has a huge impact on agriculture. Drought occurs when water reserves both on the surface and in the ground are reduced. This water shortage occurs because precipitation is decreasing from the normal amount. This causes plants to be unable to meet their water needs to grow properly. If this condition occurs over a long period of time, it can result in a decrease in production and lead to crop failure. In Indonesia, drought disasters rank third as the most frequent disasters with 1,529 events out of a total of 9,375 occurrences of all disasters in Indonesia [2]. Drought in the world is predicted to continue to increase during the 21st century [3].

Various drought indices have been developed to determine drought in the world, such as SPI, Palmer drought severity index, and Exploration Drought Index (RDI). Among these indices, SPI is more widely used because the calculation of this index only uses precipitation as a meteorological variable and can be easily used for calculations at different time intervals [4]. In addition, the SPI index can consider meteorological and agricultural drought both in the short-term and long-term [5]. Many studies using the SPI index to analyze historical drought have been carried out [6, 7] so that future drought predictions are necessary.

The Intergovernmental Panel on Climate Change (IPCC) has published several Global Climate models (GCM) that can be used to predict global climate. GCM has several greenhouse gas concentration scenarios, namely Representative Concentration Pathways (RCP) in the future. This scenario describes the radiative forcing received by the earth that was produced up to the 21st century [8]. The Canadian Center for Climate Modeling and Analysis (CCCma) developed the CanESM2 GCM which can be used as a climate change model suitable for the Indonesian region [9]. Thus, the purpose of this study is to determine the amount of precipitation for the next 25 years (2025–2049) and determine the drought category of the SPI index based on the climate change scenario RCP2.6, RCP4.5, and RCP 8.5.

2 Methods

2.1 Study Area and Data Collection

The daily precipitation data for 32 years (1988–2019) from 7 rain stations in Bantul and Gunung Kidul regencies was used in this study (Fig. 1). Bantul was chosen because it is classified as an area that is prone to natural disasters [10], while Gunung Kidul was chosen because it is known as an area that is barren and prone to drought due to low rain intensity during the dry season [11].

Moreover, we use NCEP/NCAR data and a grid for the CanESM2 GCM model which is downloaded via https://climate-scenarios.canada.ca/?page=pred-canesm2 as a predictor. This grid has a resolution of 2.8° × 2.8° which is adjusted is adjusted to the research location. Meanwhile, the CanESM grid numbers selected are 40X and 30Y.

2.2 Precipitation Prediction Analysis

We calculated precipitation prediction using the CanESM2 model which has three RCP scenarios, namely RCP2.6, RCP4.5, and RCP8.5. These scenarios are characterized by

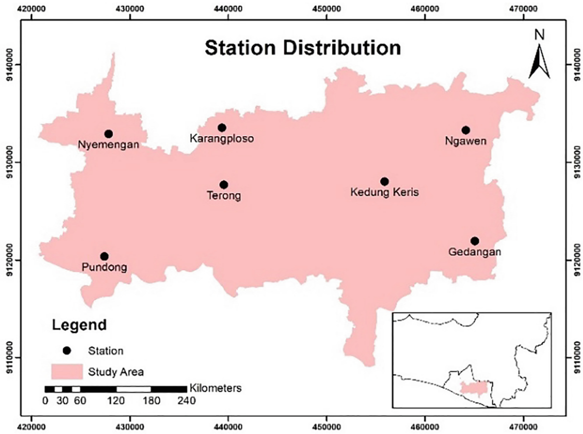

Fig. 1. Station Distribution Map

the radiative forcing (W/m^2) that was produced by the end of the 21st century. RCP2.6 is a peak scenario with a radiative forcing (RF) around 3 W/m^2 before 2100 and then decreases. RCP4.5 is a medium-line scenario with an RF around 4.5 W/m^2 and will stabilize after 2100. RCP8.5 is a scenario with RF around 8.5 W/m^2 in 2100 and will continue to increase for some time [8].

2.2.1 Stages of Analysis

Future precipitation is predicted by a downscaling method using SDSM software version 4.2. There are five stages of future precipitation analysis based on the RCP scenario, which can be seen bellow [12]:

1. Quality Control. This stage is carried out to check the daily precipitation data so that it is known the amount of data used and the amount of missing data.
2. Screening Variables. This stage is carried out to determine the relationship between predictor (NCEP data) and predict and (precipitation data). There are 26 NCEP re-analysis predictors (Table 1) that can be selected as super predictors. The super predictor selection is done by choosing the predictor that has the largest positive correlation value and the smallest p-value.
3. Calibration. Calibration is performed to generate regression parameters from the selected predictor. The transformation process used is a conditional process because the precipitation data has a non-linear distribution [12].
4. Weather Generator. This stage is the generation of weather data based on observation data on atmospheric predictor variables with the same time as the calibration process, namely 1988–2019. The results of data generation at this stage (observation and prediction data) were evaluated statistically with Root Mean Square Error (RMSE) and coefficient of determination (R2).
5. Scenario Generator. This stage is the stage of generating precipitation prediction data based on scenarios RCP2.6, RCP4.5, and 8.5. Predicted precipitation in 5 years for 25 years (2025–2029; 2030–2034; 2035–2039; 2040–2044; 2045–2049).

Table 1. Reanalysis NCEP Predictors Variables

No.	Predictors	Description	No.	Predictors	Description
1	ncepmslpgl	Mean sea level pressure	14	ncepp5zhgl	500 hPa Divergence
2	ncepp1_fgl	1000 hPa Wind Speed	15	ncepp8_fgl	850 hPa Wind Speed
3	ncepp1_ugl	1000 hPa Zonal velocity	16	ncepp8_ugl	850 hPa Zonal velocity
4	ncepp1_vgl	1000 hPa Meridional velocity	17	ncepp8_vgl	850 hPa Meridional velocity
5	ncepp1_zgl	1000 hPa Vorticity	18	ncepp8_zgl	850 hPa Vorticity
6	ncepp1thgl	1000 hPa Wind direction	19	ncepp850gl	850 hPa Geopotential height
7	ncepp1zhgl	1000 hPa Divergence	20	ncepp8thgl	850 hPa Wind direction
8	ncepp5_fgl	500 hPa Wind Speed	21	ncepp8zhgl	850 hPa Divergence
9	ncepp5_ugl	500 hPa Zonal velocity	22	nceppr cpgl	Precipitation
10	ncepp5_vgl	500 hPa Meridional velocity	23	nceps500gl	500 hPa Specific humidity
11	ncepp5_zgl	500 hPa Vorticity	24	nceps850gl	850 hPa Specific humidity
12	ncepp500gl	500 hPa Geopotential height	25	ncepshumgl	1000 hPa Specific humidity
13	ncepp5thgl	500 hPa Wind direction	26	nceptempgl	Screen (2m) air temperture

2.3 Standardized Precipitation Index (SPI) Analysis

The Standardized Precipitation Index was used to calculate the magnitude of the deviation of precipitation from normal in a timeline. In this study, the SPI value was calculated over 3 months. The SPI value is calculated based on the number of gamma distributions defined as a frequency function as in Eq. (1).

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha T(\alpha)} \int_0^x t^{\alpha-1} e^{-x/\beta} dx \tag{1}$$

Beta and alpha values are estimated for each rain station using Eqs. (2) and (3):

$$\alpha = \frac{\overline{x}^2}{s^2} \tag{2}$$

$$\beta = \frac{\overline{x}}{s^2}, \text{ for x} > 0 \tag{3}$$

The gamma function is not defined for x = 0, so for precipitation that the value equal to 0 using the Eq. (4):

$$4\ H\ (x) = q + (1 - q) \cdot G(x) \tag{4}$$

where q is the number of rain data divided by the number of data (n). The SPI value is the change from the Gamma distribution of precipitation to a normal distribution using Eqs. 5 and 6.

$$Z = SPUI = -\left(t - \frac{c_0 + c_1 t + c_2 t}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \text{ for } 0 < \text{H (x)} \leq 0.5 \tag{5}$$

$$Z = SPUI = +\left(t - \frac{c_0 + c_1 t + c_2 t}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \text{ for } 0.5 < \text{H(x)} \leq 1.0 \tag{6}$$

where:

$$t = \sqrt{ln\left(\frac{1}{(H(x))^2}\right)} \text{ for } 0 < \text{H(x)} \leq 0.5 \tag{7}$$

$$t = \sqrt{ln\left(\frac{1}{(1 - H(x))^2}\right)} \text{ for } 0.5 < \text{H (x)} \leq 1.0 \tag{8}$$

where:

$$c_0 = 2.515517 \quad d_1 = 1.432788$$

$$c_1 = 0.802853 \quad d_2 = 0.189269$$

$$c_2 = 0.010328 \quad d_3 = 0.001038$$

The results of the calculation of the SPI value are then classified into several categories to determine the level of drought in an area (Table 2) [14].

Table 2. SPI value classification

SPI Values Range	Condition
>2.0	Extremely wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

Source: WMO 2012 Standardized Precipitation Index User Guide. Online: www.wamis.org/agm/pubs/SPI/WMO_1090_EN.pdf

3 Result and Discussion

3.1 Selected Predictors

The 26 NCEP predictors can be selected to develop the model. The selected predictor has a relationship with precipitation data where the correlation coefficient (r) is more than 0 and the significance level is 95% ($p < 0.05$) [15]. The predictors selected for the 7 rain stations are presented in Table 3. A description of each predictor can be seen in Table 1.

3.2 Model Calibration and Validation

Model calibration and validation were carried out for the period 1988–2019. The validation process is carried out by comparing the observed precipitation data with the historical model. The purpose of the validation process itself is to determine the level of accuracy of a model to describe the actual conditions. The results of the model validation are the RMSE, R^2, and correlation coefficient values which are presented in Table 4.

The RMSE value is considered good if it is closer to 0. Meanwhile, the R-square is said to be good if it is closer to 1. The lowest RMSE value with the highest R-square is

Table 3. Selected NCEP Predictors

Station	Selected Predictors
Nyemengan	ncepp8_ugl, ncepp8thgl
Karangploso	ncepmslpgl, nceps850gl
Ngawen	ncepp5_ugl, ncepp8thgl
Terong	ncepp1_ugl, ncepp8_ugl
Kedungkeris	ncepp1_ugl, ncepp1thgl, ncepp8_ugl
Pundong	ncepp1thgl
Gedangan	ncepp1thgl, ncepp8_ugl

Table 4. Model Validation

Station	RMSE	R^2
Gedangan	1.2154	0.9151
Karangploso	0.6080	0.9984
Kedungkeris	0.8600	0.9624
Ngawen	0.7767	0.9805
Nyemengan	1.5742	0.9578
Pundong	1.0624	0.9597
Terong	1.9315	0.9297

found at Karangploso station. While the highest RMSE value performs by the Gedangan station, and the lowest R-square is shown by Terong station. However, the RMSE and R-square values in all stations indicate that the model used is good enough to describe the actual conditions.

3.3 Future Precipitation

The future annual precipitation under scenarios RCP2.6, RCP4.5, and RCP8.5 has varying results (Table 5). In almost all stations and all climate change scenarios, the annual precipitation has higher value compared to the observed precipitation. The largest increase in precipitation from observation data (1988–2019) occurred in the period 2025–2029 with an RCP8.5 scenario at Ngawen station, which was 30.07% compared to the observed precipitation. During the period 2025–2049 precipitation has increased successively by 11.68% for RCP2.6, 11.79% for RCP4.5 and 9.93% for RCP8.5 compared to observed precipitation.

The comparison of future precipitation that is smaller than the observed precipitation occurs in all scenarios. In RCP2.6 the future precipitation is -4.10% less than the observed precipitation at Kedungkeris station in the period 2040–2044. In RCP4.5 and RCP8.5, the observed precipitation was smaller than the predicted precipitation, mostly occurring at Gedangan, Kedungkeris, and Pundong stations with different time periods. The difference in the results of the analysis of future precipitation at each station and each period occurs because each station experiences the impact of climate change on a local scale that is different from one another. In addition, several local factors such as altitude, the direction of the slope, orographic conditions, and morphology of the area also greatly affect the formation of rain [16].

Figure 2 present the monthly precipitation prediction based on the RCP scenario for each station. The highest average precipitation projection occurs in January and December, whereas the lowest average precipitation occurs in August and September. Moreover, the observed precipitation value is lower than the projected rain in January, March, April, May, October, and December. Meanwhile, the projection rain in other months is less than the observed rain.

3.4 Standardized Precipitation Index (SPI) Based on Climate Projection

SPI drought index analysis was carried out for a 3-month deficit period. This period was chosen because the 3-month SPI reflects short-term humidity conditions and provides forecasts of seasonal precipitation. This condition is very suitable for agricultural activities where the planting season is usually every 3 months [16]. Table 6 shows the worst drought index value based on the RCP scenario. The result of the RCP2.6 scenario informs that there will be various levels of drought taking place in almost all future periods. The worst drought will occur during the 2040–2044 period when one station experienced extreme drought, 3 stations experienced moderate drought, and 3 stations experienced severe drought. In other future periods, extreme drought will not occur in all rain stations so there will be stations that do not experience drought, some stations experience moderate drought, and the rest experience severe drought.

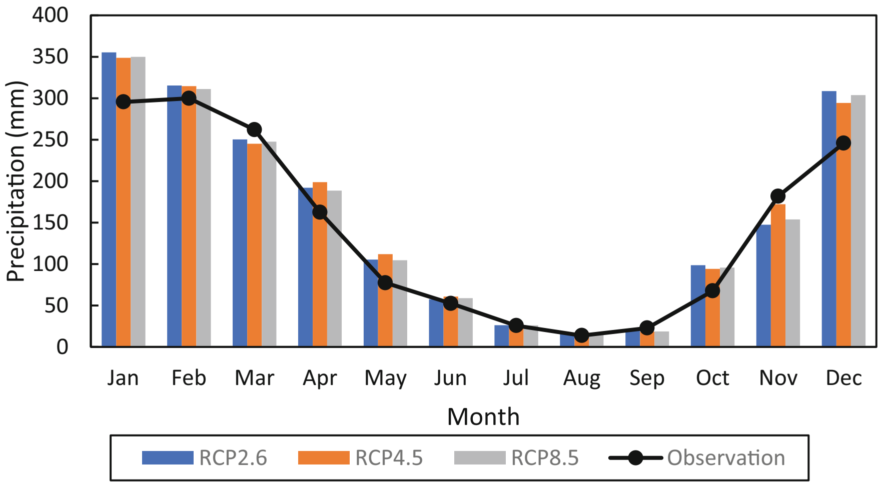

Fig. 2. Comparison between observation data (1988–2019) and projected precipitation (2025–2049)

Table 5. Average annual precipitation prediction based on RCP2.6, RCP4.5, and RCP8.5 (mm)

Year Period	Data	Station						
		Gedangan	Karangploso	Kedungkeris	Ngawen	Nyemengan	Pundong	Terong
1988–2019	Observation	1767	1749	1862	1389	1847	1755	1580
2025–2029	RCP 2.6	1824	1847	1936	1558	2162	1810	1948
	RCP 4.5	1984	2028	1942	1719	2272	1787	1915
	RCP 8.5	1914	1924	1923	1806	2327	1726	1898
2030–2034	RCP 2.6	1927	1962	1967	1723	2195	1807	1974
	RCP 4.5	1859	1972	1974	1556	2174	1800	2030
	RCP 8.5	1838	1871	1799	1622	2018	1776	1947
2035–2039	RCP 2.6	1821	2040	1868	1680	2099	1807	1955
	RCP 4.5	1848	2001	1830	1593	2068	1835	1905
	RCP 8.5	1743	1926	1837	1568	1955	1789	1977
2040–2044	RCP 2.6	1825	2012	1785	1556	2098	1804	1904
	RCP 4.5	1811	1878	1873	1753	1993	1776	2020
	RCP 8.5	1863	2070	1822	1647	2154	1858	1805
2045–2049	RCP 2.6	1906	2013	1977	1719	2159	1805	1985
	RCP 4.5	1911	1997	1852	1744	2198	1726	1866
	RCP 8.5	1719	2029	1871	1597	2144	1773	1852

Drought events based on the RCP4.5 precipitation scenario begin to occur more frequently in the period 2035–2039 to 2045–2049 compared to the previous 2 periods. The worst average SPI index is expected to occur in the 2035–2039 period. In that

Table 6. The worst 3-month SPI value

RCP 2.6					
Station	**Time Periode**				
	2025–2029	**2030–2034**	**2035–2039**	**2040–2044**	**2045–2049**
Gedangan	-1.42[a]	-0.53	-1.96[b]	-1.31[a]	-0.95
Karangploso	-1.85[b]	-1.37[a]	-1.14[a]	-1.13[a]	-1.39[a]
KedungKeris	-1.67[b]	-1.90[b]	-1.16[a]	-1.78[b]	-1.37[a]
Ngawen	-1.97[b]	-1.81[b]	-0.81	-1.81[b]	-1.62[b]
Nyemengan	-0.96	-1.16[a]	-1.89[b]	-2.37[c]	-1.4[a]
Pundong	-1.58[b]	-1.74[b]	-1.15[a]	-1.87[b]	-1.81[b]
Terong	-1.24[a]	-1.58[b]	-1.59[b]	-1.47[a]	-0.87
Average	-1.53	-1.44	-1.39	-1.68	-1.34
RCP 4.5					
Station	**Time Periode**				
	2025–2029	**2030–2034**	**2035–2039**	**2040–2044**	**2045–2049**
Gedangan	-0.93	-1.06[a]	-2.21[c]	-1.94[b]	-1.68[b]
Karangploso	-1.31[a]	-0.97	-2.71[c]	-1.71[b]	-1.43[a]
KedungKeris	-1.61[b]	-0.64	-1.67[b]	-1.63[b]	-1.56[b]
Ngawen	-0.76	-1.65[b]	-1.73[b]	-0.6	-0.21
Nyemengan	-0.13	-0.82	-1.50[b]	-1.91[b]	-1.05[a]
Pundong	-1.25[a]	-0.74	-1.52[b]	-1.23[a]	-2.35[c]
Terong	-1.11[a]	0.38	-1.82[b]	-1.72[b]	-1.78[b]
Average	-1.01	-0.79	-1.88	-1.53	-1.44
RCP 8.5					
Station	**Time Periode**				
	2025–2029	**2030–2034**	**2035–2039**	**2040–2044**	**2045–2049**
Gedangan	-1.61[b]	-2.01[c]	-1.58[b]	-1.4[a]	-1.91[b]
Karangploso	-1.94[b]	-2.46[c]	-1.12[a]	-0.81	-0.87
KedungKeris	-1.52[b]	-1.59[b]	-1.46[a]	-1.48[a]	-1.26[a]
Ngawen	0.38	-1.34[a]	-1.3[a]	-1.26[a]	-1.86[b]
Nyemengan	-1.62[b]	-1.70[b]	-1.56[b]	-1.7[b]	-1.45[a]
Pundong	-1.79[b]	-1.60[b]	-1.79[b]	-1.39[a]	-1.37[a]
Terong	-1.23[a]	-0.42	-0.8	-1.87[b]	-1.86[b]
Average	-1.33	-1.59	-1.37	-1.42	-1.51

Note: a: moderately dry; b: severely dry; c: extremely dry period there will be extreme drought at 2 stations (Gedangan and Karangploso) and 5 other stations will experience severe drought. Extreme drought also occurred during the period 2045–2049 at Pundong station. The worst average SPI index based on the RCP8.5 scenario occurred during 2030–2034. In this period, 2 stations experienced extreme drought, 3 stations experienced severe drought, and 1 station experienced moderate drought. Extreme drought can occur due to the influence of the El Nino factor which is quite strong. However, not all extreme events are followed by El Nino events [17].

4 Conclusion

In this study, rainfall is projected every 5 years during 2025–2049 (25 years) based on scenarios RCP2.6, RCP4.5, and RCP8.5. The predicted annual rainfall based on all RCP scenarios is greater than the observed rainfall in almost all stations and period. The worst 3-month SPI drought index shows extreme drought conditions in the RCP2.6 scenario in the 2040–2044 period, in the RCP4.5 scenario in the 2035–2039 period, and in the RCP8.5 scenario in the 2030–2034 period. The results of this study do not predict drought in the coming period in more detail. Thus, further research is needed that can predict future droughts with more detailed periods.

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References

1. National Academies of Science, Engineering, and Medicine 2016 Attribution of Extreme Weather Events in the Context of Climate Change *The National Academies Press* Washington DC
2. Badan Nasional Penanggulangan Bencana Indonesia 2019 Data Informasi Bencana Indonesia (DIBI)
3. Dai A 2011 Drought under global warming: A review *Wiley Interdisciplinary Reviews: Climate Change*, **2** 45–65.
4. Rolbiecki R, Yücel A, Kocięcka J, Atilgan A, Marković M, Liberacki D. Analysis of SPI as a Drought Indicator during the Maize Growing Period in the Çukurova Region (Turkey) 2022 *Sustainability* **14** 3697. https://doi.org/10.3390/su14063697
5. Wang, C.; Linderholm, H.W.; Song, Y.; Wang, F.; Liu, Y.; Tian, J.; Xu, J.; Song, Y.; Ren, G. 2020 Impacts of Drought on Maize and Soybean Production in Northeast China During the Past Five Decades. *Int. J. Environ. Res. Public Health* **17** 2459.
6. Dewita M, Harisuseno D, and Suhartanto E 2001 Analisis Kekeringan Meteorologi dengan Metode Standardized Rainfall Index (SPI) dan China Z Index (CZI) Di Sub DAS Kadalpang, Kabupaten Pasuruan *JTRESDA* **2** 1–13.
7. Dubey S K, Ranjan R K, Misra A K, Wanjari N, and Vishwakarma S 2022 Variability of rainfall extremes and drought intensity over the Sikkim State, India, during 1950–2018 *Theor. Appl. Climatol.* **148** 1–14.
8. Jubb I, Canadell P, and Dix M 2013 Representative Concentration Pathways. *Australian Government, Department of the Environment.*

9. Daksiya, V., Mandapaka, P., & Lo, E. Y. M. 2017 A Comparative Frequency Analysis of Maximum Daily Rainfall for a SE Asian Region under Current and Future Climate Conditions *Advances in Meteorology*.
10. Sukmawati, A M, Utomo, P. 2021 Drought hazard assesment in urban areas: A case of Bantul Regency, Special Region of Yogyakarta IOP Conf. Series: Earth and Environmental Science 738 012068
11. Putra Q I & Nurjani E 2021 Study of meteorological drought and its impact on rainfed paddy productivity in Gunung Kidul Regency E3S Web of Conferences 325, 01017
12. Wilby R L and Dawson C W 2007 SDSM 4.2—A decision support tool for th e assessment of regional climate change impacts, User Manual Dep. Geogr. Lancaster Univ. UK.
13. Romadhoni A Z, Wulandari D A, and Suharyanto 2021 Dampak Perubahan Iklim Terhadap Indeks Erosivitas Hujan *J. Rekayasa Sipil dan Lingkungan* **4** 107–120.
14. Jovana B. 2012 *Standardized Rainfall Index User* (Geneva:Guide World Meteorol. Organ., no. WMO-No. 1090).
15. Nugraha D K, Nugroho B D A 2021 Dampak Perubahan Curah Hujan Terhadap Tingkat Kerentanan Erosi Tanah di Sub DAS Merawu, Jawa Tengah *Jurnal Teknik Pertanian Lampung* **10** 356–366.
16. Dibyosaputro S., Cahyadi, A., Nugraha, H., & Suprayogi, S. 2016 Estimasi Dampak
17. Perubahan Iklim Terhadap Kerawanan Banjir Lahar Di Magelang, Jawa Tengah.
18. *Seminar Nasional Geografi UMS 2016*
19. Nurrohmah H and Nurjani E Kajian Kekeringan Meteorologis Menggunakan Standardized Rainfall Index (Spi) Di Provinsi Jawa Tengah 2017 *Geomedia Maj. Ilm. dan Inf. Kegeografian* **15** 1–15.