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Analysis of Water Balance to Determine Water Requirements for Maize (*Zea mays* L.) Based on Climate Projection Scenarios

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Abstract

Maize is a staple crop widely required by the community for daily activities, yet the high demand is not matched by increased production. The production of maize in Sumenep Regency and Malang Regency has experienced fluctuations from 2017 to 2020. These fluctuations in maize production are due to climate change, which can affect the water requirements of maize plants. Future climate conditions can be predicted using climate projection scenarios, which can be utilized with a water balance. This study aims to analyze the water balance to determine the water requirements of maize based on climate projection scenarios. The research was conducted from April to August 2023 in Sumenep Regency and Malang Regency. The materials used include average rainfall data and average temperature data from 1991-2020 from BMKG, historical data from 1991-2005, projection model data from CNRM-CM5, GFDL-ESM2M, and CSIRO MK 3.6 for 2026-2050, field capacity data, and permanent wilting point data. The research locations were determined using the purposive sampling method. Data analysis was conducted using descriptive statistical analysis and water balance analysis. The water balance analysis in this study used the Thornthwaite and Mather method. The results of this study indicate that the water requirements for maize in Sumenep Regency and Malang Regency will increase during the 2026-2050 period. Sumenep Regency is projected to experience an increase of 1.4-2.2 liters/m²/decade, while Malang Regency is projected to see an increase of 8.9-11.8 liters/m²/decade..

Keywords: Plant water requirements, water balance, climate projection scenarios, maize

INTRODUCTION

Maize is a staple crop widely needed by the community. Each year, the demand for maize increases by 3.77% in line with the growing population (Dewi et al., 2022). This rising demand should be matched by increased production; however, from 2017 to 2020, maize production has experienced fluctuations. This condition has been observed in the major maize-producing regions in East Java, namely Sumenep Regency and Malang Regency. Maize production in Sumenep Regency was 413,053.62 tons in 2017, 406,462.92 tons in 2018, 436,004.49 tons in 2019, and 447,143.13 tons in 2020 (Badan Pusat Statistik, 2023a). In Malang Regency, maize production was 289,192 tons in 2017, 267,472 tons in 2018, 341,847 tons in 2019, and 327,816

tons in 2020 (Badan Pusat Statistik, 2023b). These fluctuations in maize production can be attributed to climate change.

Climate change is characterized by alterations in rainfall patterns and increasing air temperatures. Rising temperatures lead to increased evapotranspiration, causing more water loss from plants. The greater the water loss, the higher the water requirements for the plants. Efforts to predict future water requirements for maize can utilize climate projection scenarios. Climate projections aim to provide an understanding of future climate conditions in response to changes in greenhouse gas emissions (Suryadi et al., 2017). These climate projection scenarios can be used to predict water balance conditions.

Water balance is a detailed account of all water inputs and outputs on a plot of land, determining the amount of water contained and gained over time (Paski et al., 2017). It can also be used to determine plant water requirements. The water balance in this study uses the Thornthwaite and Mather method. This research aims to analyze the water balance to determine the water requirements for maize based on climate projection scenarios.

MATERIALS AND METHOD

This research was conducted from April to August 2023 in Sumenep Regency and Malang Regency. The tools and materials required for this study including a laptop, 30 years of average rainfall and temperature data from BMKG, 15 years of historical climate data, climate projection model data from CNRM-CM5 RCP 45 and RCP 85, GFDL-ESM2M RCP 45 and RCP 85, CSIRO MK 3.6 RCP 45 and RCP 85 for 25 years, and data on field capacity and permanent wilting point.

This study employed a descriptive exploratory approach. The research was carried out by collecting data, analyzing data, and interpreting data. The research locations were determined using a purposive sampling method. Sumenep Regency and Malang Regency were selected because they are major maize production centers in East Java and have diverse climate conditions such as rainfall and temperature. Geographical differences, such as varying altitudes above sea level, can cause differences in weather and microclimates (Istiawan and Katono, 2019).

The study used descriptive statistical analysis and water balance analysis. Data presentation in descriptive statistical analysis can take the form of tables, graphs, and other formats. The water balance analysis in this study used the Thornthwaite and Mather method.

RESULTS AND DISCUSSION

Rainfall in Sumenep Regency and Malang Regency

The rainfall in Sumenep Regency, according to various models, shows varying results. The average rainfall from BMKG observational data is 37.9 mm/decade, historical data from the CNRM model is 74.4 mm/decade, the GFDL model is 49.3 mm/decade, the CSIRO model is 42.3 mm/decade, projection data from the CNRM RCP 4.5 model is 105.2 mm/decade, the CNRM RCP 8.5 model is 30.2 mm/decade, the GFDL RCP 4.5 model is 56.5 mm/decade, the GFDL RCP 8.5 model is 50.5 mm/decade, the CSIRO RCP 4.5 model is 43.4 mm/decade, and the CSIRO RCP 8.5 model is 41.8 mm/decade (Figure 1). The variability in average rainfall between BMKG observational data, historical data, and projection data is influenced by the use of grid resolution. BMKG observational data is obtained directly using instruments at climate stations, such as observatory rain gauges (OBS), while historical and projection data are grid-resolved data. The RCM (Regional Climate Model) projection data has a grid resolution of 25 km (Nur et al., 2021). The grid resolution in a model can affect the accuracy of specific points (Prasetyo et al., 2021). Another factor is greenhouse gas emissions. Increasing concentrations of greenhouse gas emissions can influence changes in rainfall patterns. According to Ruminta

et al. (2018), Indonesia has experienced climate change characterized by changes in rainfall patterns and a tendency for decreasing annual rainfall and its distributions.

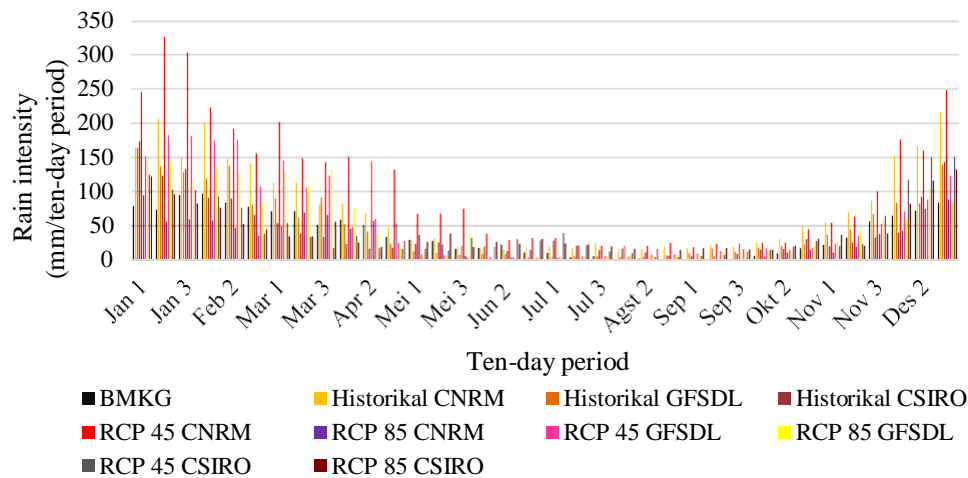


Figure 1. Rainfall in Sumenep Regency

Rainfall variability also occurs in Malang Regency. The average rainfall from BMKG observational data is 52.5 mm/decade, historical data from the CNRM model is 73 mm/decade, the GFDL model is 49.8 mm/decade, the CSIRO model is 114.3 mm/decade, projection data from the CNRM RCP 4.5 model is 76 mm/decade, the CNRM RCP 8.5 model is 77.7 mm/decade, the GFDL RCP 4.5 model is 61.6 mm/decade, the GFDL RCP 8.5 model is 50.6 mm/decade, the CSIRO RCP 4.5 model is 123.1 mm/decade, and the CSIRO RCP 8.5 model is 101.5 mm/decade (Figure 2). The higher rainfall in Malang Regency is influenced by differences in elevation. Sumenep Regency is a lowland area, while Malang Regency is a highland area. According to Lesik et al. (2020), the elevation above sea level is a factor that can influence rainfall, where the higher the elevation from sea level, the higher the rainfall tends to be. Rainfall is an input to meet the water needs of plants, so rainfall needs to be considered. If rainfall conditions are projected for the period 2026-2050, then the CSIRO RCP 8.5 model and the GFDL RCP 8.5 model are models that can depict rainfall conditions close to BMKG rainfall. Excessively high or low rainfall can disrupt the growth process of plants. According to Ekopranoto (2019), water has a significant influence on the growth of maize plants, so if maize plants receive an excessive amount of water, their growth will be inhibited.

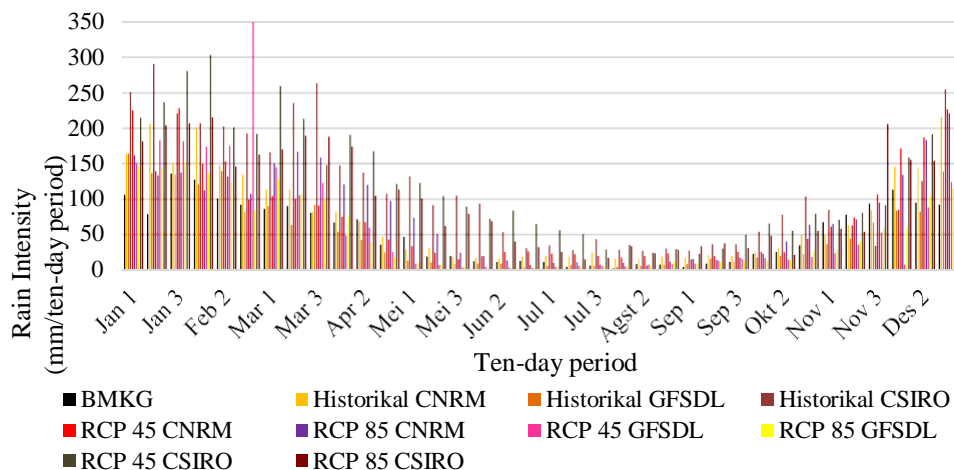


Figure 2. Rainfall in Malang Regency

Temperature in Sumenep Regency and Malang Regency

According to various models, the temperature in Sumenep Regency shows varying results. The average temperature from BMKG observational data is 28.1°C, historical data from the CNRM model is 27°C, the GFDL model is 26.8°C, the CSIRO model is 28°C, projection data from the CNRM RCP 4.5 model is 27.8°C, the CNRM RCP 8.5 model is 28°C, the GFDL RCP 4.5 model is 27.4°C, the GFDL RCP 8.5 model is 27.4°C, the CSIRO RCP 4.5 model is 29.1°C, and the CSIRO RCP 8.5 model is 29.2°C (Figure 3). The temperature during the period 2026-2050 is increasing. The temperature in the RCP 8.5 emission scenario shows a higher increase compared to the RCP 4.5 emission scenario. Each RCP emission scenario depicts emission targets that will occur in 2100, but the RCP 4.5 scenario depicts moderate emission scenarios, while the RCP 8.5 scenario depicts high emission scenarios (Sumarwan et al., 2022). Differences in emissions affect the increase in air temperature. According to Pratama (2019), the increasing concentration of greenhouse gas emissions in the atmosphere leads to a greater amount of heat reflected by the Earth and absorbed by the atmosphere. The higher the amount of greenhouse gas emissions in the atmosphere, the greater the solar heat trapped on the Earth's surface. This condition causes the temperature on the Earth's surface to rise.

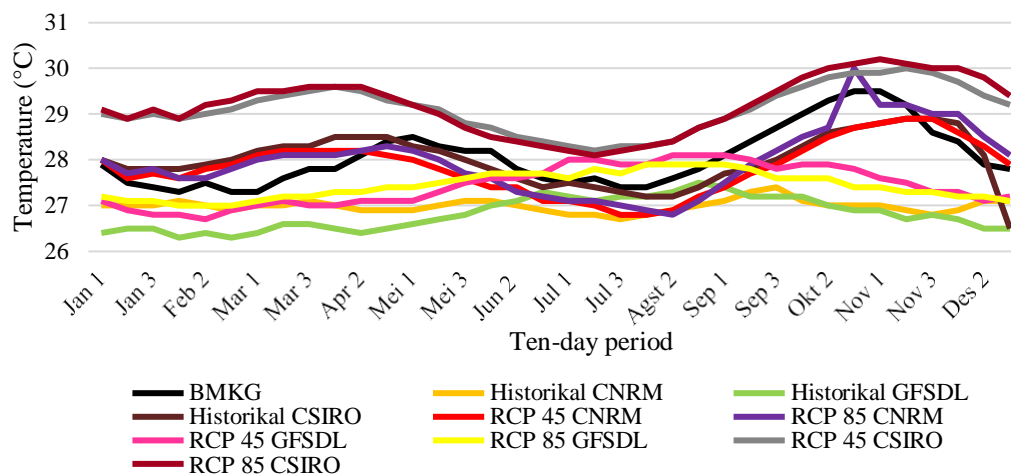


Figure 3. Temperature in Sumenep Regency

Temperature in Malang Regency from all modeling shows varying results. The average temperature from BMKG observational data is 23.5°C, historical data from the CNRM model is 27°C, the GFDL model is 26.8°C, the CSIRO model is 24.4°C, projection data from the CNRM RCP 4.5 model is 21.9°C, the CNRM RCP 8.5 model is 22°C, the GFDL RCP 4.5 model is 27.4°C, the GFDL RCP 8.5 model is 27.7°C, the CSIRO RCP 4.5 model is 25.7°C, and the RCP 8.5 model is 25.8°C (Figure 4). The average temperature in Malang Regency is lower compared to the temperature in Sumenep Regency. Differences in air temperature can be caused by differences in elevation. According to Lesik et al. (2020), varying temperatures in Indonesia are influenced by elevation, where the higher the elevation from sea level, the lower the air temperature. Temperature plays an important role for plants as it relates to their water needs. According to Herlina and Prasetyorini (2020), temperature can affect the plant growth process. An increase in temperature in a location can lead to a decrease in the availability of water for plants and soil to meet their water needs. The temperature during the period 2026-2060 shows that the temperature in the CSIRO RCP 8.5 and GFDL RCP 8.5 models is increasing due to an increase in greenhouse gas emissions, but the temperature is still suitable for maize to grow and develop. Maize can grow and develop at temperatures ranging from 21°C to 30°C, but it is recommended to plant maize under air temperature conditions of 16°C to 35°C (Syukur and Rifianto, 2013).

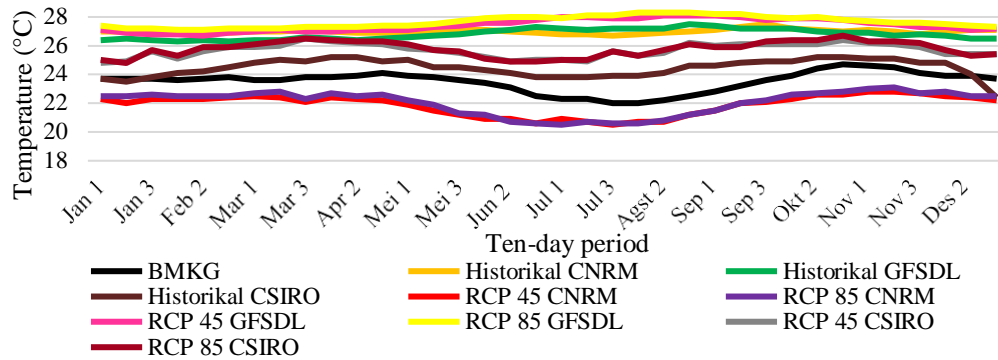
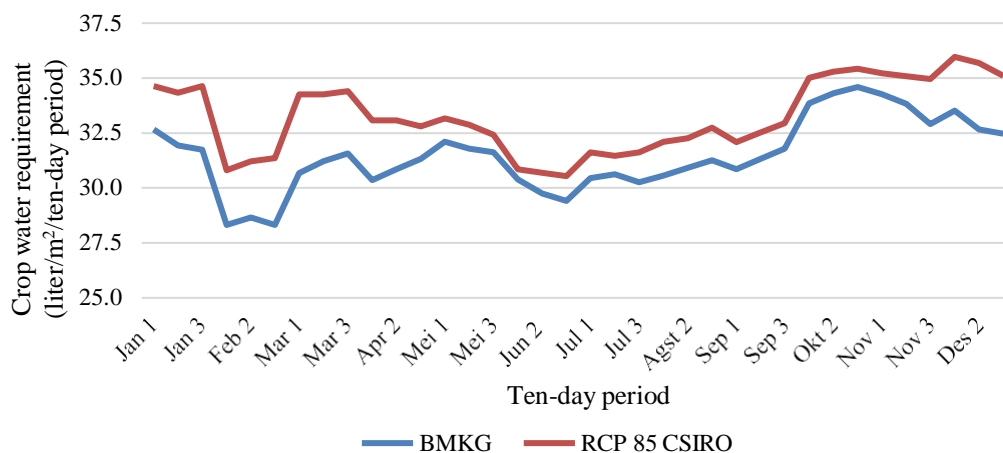


Figure 4. Temperature in Malang Regency

Maize Water Requirement

Plant water requirement is the amount of water needed by plants to replace water lost due to evaporation. Evaporation can occur from the earth's surface, known as evaporation, while evaporation can also originate from plant leaves, known as transpiration (Nadjamuddin et al., 2014). Plant water requirements can vary due to climatic factors and plant types. The water requirement for maize plants in Sumenep Regency based on BMKG observational data ranges from 28.3 to 34.6 liters/m²/decade, while during the period 2026-2050, the water requirement for maize plants in the CSIRO 85 model increases by 30.5-36 liters/m²/decade (Figure 5). The water requirement for maize plants in Malang Regency based on BMKG observational data is 16.2-23.6 liters/m²/decade (Figure 6). During the period 2026-2050, the water requirement for maize plants in Malang Regency in the GFDL RCP 85 model also increases by 28-32.5 liters/m²/decade. The increase in maize water requirement during the period 2026-2050 is influenced by the increase in air temperature. The temperature in the CSIRO RCP 85 model increases by 1.1°C, while the temperature in the GFDL RCP 85 model increases by 2.2°C.

The increasing air temperature causes evapotranspiration to increase, resulting in greater water loss due to the evaporation process. According to Afifah and Prijono (2022), plant water requirement shows an increase with increasing air temperature. The increasing air temperature leads to faster water evaporation, thus reducing water availability. To compensate for the water lost due to evaporation, plants require more water. The water requirement for maize plants needs to be considered to prevent water deficiency or excess water. Water deficiency in maize plants leads to disrupted plant growth, a decrease in photosynthesis rate, and a decrease in maize plant productivity (Sirait et al., 2020). Excess water in maize plants causes soil pores to be filled, pushing out air and reducing gas diffusion, then toxic compounds accumulate, which can affect a decrease in photosynthesis (Ekopranoto, 2019).



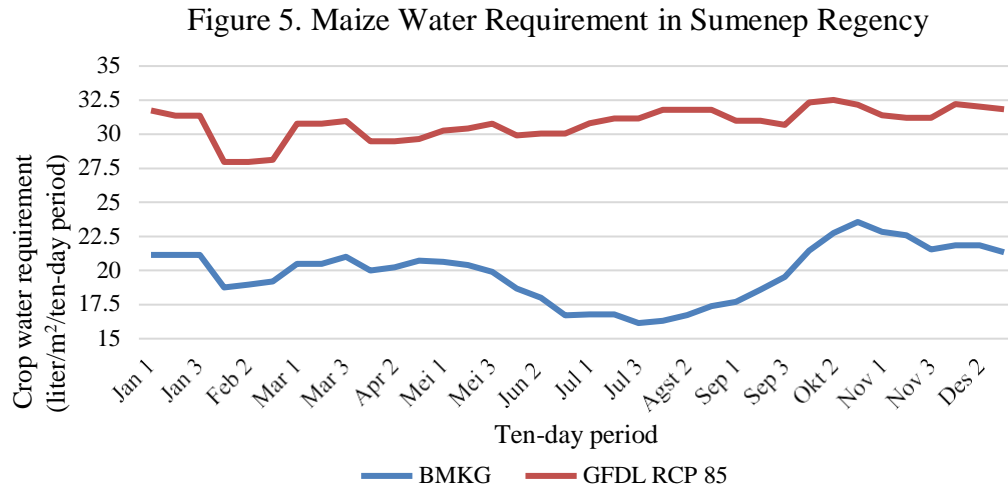


Figure 6. Maize Water Requirement in Malang Regency

Maize Water Balance

The results indicate that the water requirement for maize plants based on BMKG observational data can be fulfilled during surplus periods, which occur from December II to April I, while deficit periods occur from April II to December I (Figure 7). The water requirement for maize plants based on climate projection data in the CSIRO RCP 85 model can be fulfilled during surplus periods, which occur from December I to February I, while deficit periods occur from February II to November III (Figure 8). The water requirement for maize plants based on BMKG observational data can be fulfilled during surplus periods, which occur from November I to May I, while deficit periods occur from May II to October III (Figure 9). The water requirement for maize plants based on climate projection data in the GFDL RCP 85 model can be fulfilled during surplus periods, which occur from November III to April I, while deficit periods occur from April II to November II (Figure 10).

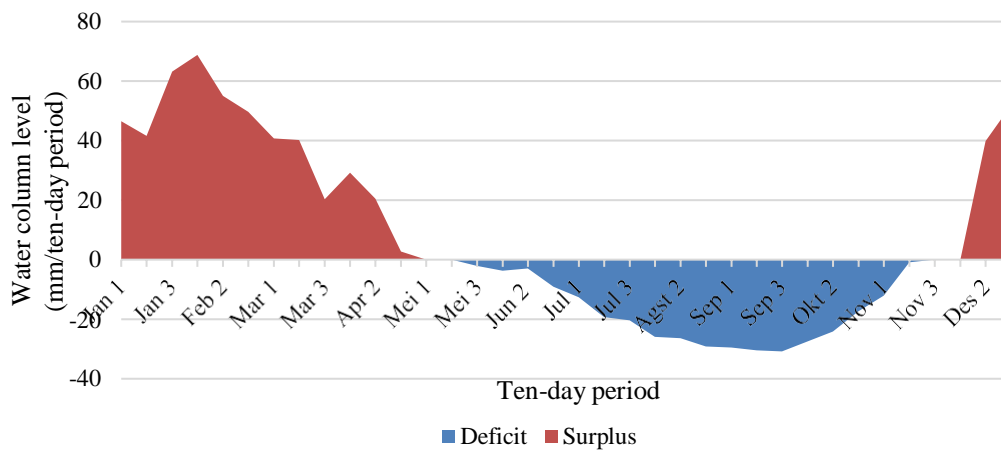


Figure 7. Water Balance BMKG Observational Data in Sumenep Regency

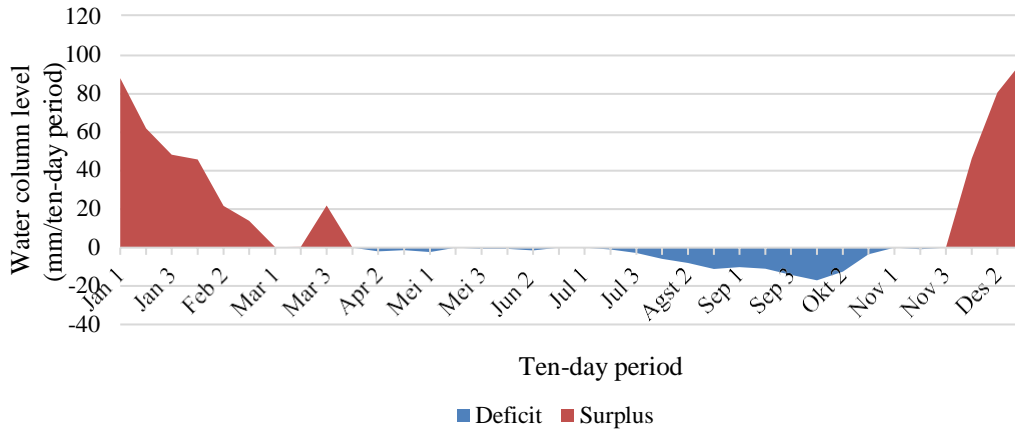


Figure 8. Water Balance CSIRO Model Projection Data RCP 85 in Sumenep Regency

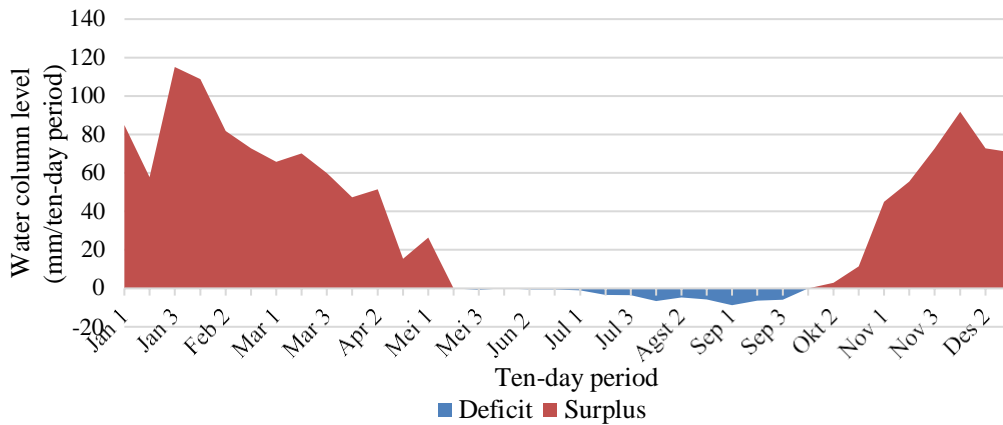


Figure 9. Water Balance BMKG Observational Data in Malang Regency

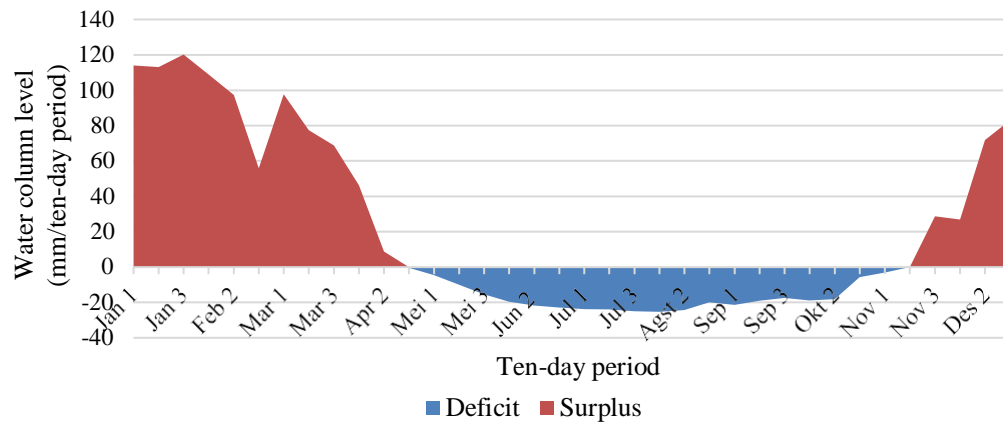


Figure 10. Water Balance GFDL Model Projection Data RCP 85 in Malang Regency

Water balance is the input and output of water at a specific location over a certain period with the aim of determining whether the amount of water is in a surplus or deficit condition (Perwitasari and Bafdal, 2016). The surplus or deficit condition of water in the water balance is related to rainfall and evapotranspiration. Rainfall is an input component in the water balance, while evapotranspiration is an output component in the water balance. According to Simanjutak et al. (2016), Evapotranspiration and rainfall will provide information about the estimated amount of water that can be used to determine deficit and surplus periods. If rainfall exceeds evapotranspiration, a surplus will occur, so that water availability is sufficient to meet the needs

of the plants. If rainfall is less than evapotranspiration, a deficit will occur, so that water availability is not sufficient to meet the needs of the plants. Water balance has various models that can be used such as Thornthwaite-Mather, Blaney-Criddle method, Hargreaves method, and radiation method. The Thornthwaite-Mather method is a simple method because it requires minimal climate data such as rainfall and temperature, while other methods require more comprehensive climate data such as humidity, wind speed, solar radiation, and duration of sunlight (Wirawan et al., 2013).

CONCLUSION

The conclusion of this study is that the water requirement for maize plants in Sumenep Regency and Malang Regency has increased. The water requirement for maize plants in Sumenep Regency based on BMKG data ranges from 28.3-34.6 liters/m²/decade and increases in the CSIRO RCP 85 model projection data to 30.5-36 liters/m²/decade. The water requirement for maize plants in Malang Regency based on BMKG data is 16.2-23.6 liters/m²/decade and increases in the GFDL RCP 85 model projection data to 28-32.5 liters/m²/decade. The increase in maize water requirement is influenced by rainfall and temperature.

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REFERENCES

1. Afifah, A. N. dan S. Prijono. 2022. Simulation of Climate Change Impact on Cocoa's Soil Ability to Store Available Water and Production Potential in Malang Regency. *Jurnal Tanah Dan Sumberdaya Lahan*, 9(2), 385–394. doi: 10.21776/ub.jtsl.2022.009.2.19. (in Indonesia)
2. Badan Pusat Statistik. 2023a. Sumenep Regency in Figures 2023. Badan Pusat Statistik Kabupaten Sumenep. Sumenep
3. Badan Pusat Statistik. 2023b. Malang Regency in Figures 2023. Badan Pusat Statistik Kabupaten Malang. Malang
4. Dewi, A. S., D. H. Setiawan dan R. Novitaningrum. 2022. Potential and Development of Hybrid Corn In Indonesia. *Jurnal Science Innovation and Technology*, 3(1), 1-6. (in Indonesia)
5. Ekopranoto, M. A. H. 2019. Influence of water stagnation on corn production in the group of "Tani Makmur" Village Kaliwungu, District Kudus. *Prosiding Konser Karya Ilmiah Nasional 2019*. Salatiga, 96-102. (in Indonesia)
6. Herlina, N. dan A. Prasetyorini. 2020. Climate Effect on Growing Season and Corn Productivity (*Zea mays* L.) In Malang District. *Jurnal Ilmu Pertanian Indonesia*, 25(1), 118-128. (in Indonesia)
7. Istiawan, N. D. dan D. Katono. 2019. Effect of Altitude on clove oil (*Syzygium aromaticum* (L.) Merr. & Perry.) quality in Subdistrict Samigaluh, Kulon Progo, *Jurnal Vegetalika*, 8(1), 27-41. (in Indonesia)
8. Lesik, E. M., H. L. Sianturi, A. S. Geru dan Bernadus. 2020. Analysis of Rain Pattern and Distribution based on Altitude in Flores Island. *Jurnal Fisika*. 5(2): 118-128. (in Indonesia)
9. Nadjmuddin, D. F., W. Soetopo dan M. Sholichin. 2014. Irrigation Scheduling in Paguyaman Kanan Region, District Boalemo Province Gorontalo. *Jurnal Teknik Pengairan*, 5(2), 158-165. (in Indonesia)
10. Nur, I. A., R. Hidayat, A. L. Latifah dan Misnawati. 2021. Effect of bias correction and ensemble method on rainfall data from four output regional climate model (RCM) CORDEX-SEA over Sumatera. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan*, 11(1), 49-56. (in Indonesia)
11. Paski, J. A. I., G. I. S. L. Faski, M. F. Handoyo dan D. A. S. Pertiwi. 2017. Analysis of Land Water Balance for Rice and Corn Crops in Bengkulu City. *Jurnal Ilmu Lingkungan*, 15(2), 83-89. (in Indonesia)

12. Perwitasari, S. D. N. dan N. Bafdal. 2016. Water Balance Based Irrigation Scheduling in Surface Runoff Water Harvesting Systems for Dry Land Agriculture. *Jurnal Keteknikan Pertanian*, 4(2), 219-226. (in Indonesia)
13. Prasetyo, S., U. Hidayat, Y. D. Haryanto dan N. F. Riama. 2021. Variations and Trends in Surface Air Temperature in Java Island on 1990-2019. *Jurnal Geografi*. 18(1): 60-68. (in Indonesia)
14. Pratama, R. 2019. Efek Rumah Kaca Terhadap Bumi. *Jurnal Buletin Utama Teknik*, 14(2), 120-126. (in Indonesia)
15. Ruminta., Handoko dan T. Nurmala. 2018. Indication Of Climate Change And Its Impact On Rice Production In Indonesia. *Jurnal Agro*, 5(1), 49-60. (in Indonesia)
16. Simanjutak, B. H., Y. H. Agus dan S. Yulianto. 2016. Study of Groundwater Availability to Determine Groundwater Surplus-Deficit and Cropping Patterns. *Prosiding Konser Karya Ilmiah*, 113-124. (in Indonesia)
17. Sirait, S., L. Aprilia dan Fachruddin. 2020. Analysis of Water Balance and Crop Water Requirements of Corn (*Zea mays* L.) Based on Growth Phases in Tarakan City. *Jurnal Rona Teknik Pertanian*, 13(1), 1-12. (in Indonesia)
18. Suryadi, Y., D. N. Sugianto dan Hadiyanto. 2017. Identification of Temperature and Rainfall Change and its Projections in Semarang City. *Proceeding Biology Education Conference*, 14(1), 241-246. (in Indonesia)
19. Sumarwan, R., E. Riawan, Y. S. M. Simanjutak dan D. E. Irawan. 2022. Study of Climate Change in Coastal Jakarta Based on Rainfall and Temperature Data. *Buletin Oseanografi Marina*, 11(1), 99-110. (in Indonesia)
20. Syukur, M. dan A. Rifianto. 2013. *Jagung Manis*. Penebar Swadaya. Jakarta. (in Indonesia)
21. Wirawan, J., M. Idkham dan S. Chairini. 2013. Analysis of Evapotranspiration using Thornthwaite, Blaney Criddle, Hargreaves, and Radiation Methods. *Jurnal Teknik Pertanian*, 6(2), 451-457. (in Indonesia)