World Journal of Engineering Research and Technology

www.wjert.org

Impact Factor: 7.029 Coden USA: WJERA4

CLIMATE CHANGE IMPACTS ON GROUNDWATER IN THE KARST AREA OF BAUMATA, KUPANG

*[1]Aisyah Ahmad, [2]Noni Banunaek, [3]Andreas Sinuhaji

*[1,2,3]Department of Mining Engineering.

[1,2,3]Nusa Cendana University, Kupang, Indonesia.

Article Received on 03/12/2025 Article Revised on 23/12/2025 Article Published on 01/01/2026

***Corresponding Author**

Aisyah Ahmad

Department of Mining Engineering.

https://doi.org/10.5281/zenodo.18107860

How to cite this Article: *Aisyah Ahmad, Noni Banunaek, Andreas Sinuhaji. (2026). Climate Change Impacts on Groundwater In The Karst Area of Baumata, Kupang. World Journal of Engineering Research and Technology, 12(1), 157–166.

ABSTRACT

This study aims to analyze historical climate trends and project future climate conditions up to the year 2055, while also assessing the impacts on groundwater availability in the karst area of Baumata Village, Kupang Regency. Historical climate data (2004–2024) and projections (2051–2055) were obtained from the Regional Climate Model (RCM) simulations of the CORDEX SEA-22 domain. Variables analyzed included precipitation, minimum temperature, maximum temperature, and average temperature. Field measurements of spring discharge, bore wells, and dug wells were also conducted. Results indicate a sharp projected decline in annual precipitation from 1,877.9 mm to –1,042.6 mm (a decrease of –2,920.5 mm/year or –155.5%), with a downward trend of –74.9 mm/year ($p = 0.096$). Temperature variables showed minor and statistically insignificant changes. The total spring discharge reached 283.61 liters/second, with the largest discharge found at Baumata Spring (200 liters/second). The projected decline in precipitation may lead to reduced recharge of karst aquifers, threatening long-term groundwater sustainability. This study highlights the need for ecosystem-based water resource management in response to climate change in dryland areas.

KEYWORDS: *climate, precipitation, karst, spring discharge, CORDEX.*

I. INTRODUCTION

Climate change is a global concern that directly affects freshwater availability, particularly in tropical drylands such as East Nusa Tenggara, Indonesia (IPCC, 2021). Variations in precipitation and temperature influence hydrological cycles, including groundwater recharge and spring discharge (Taylor et al., 2013). Baumata Village, located in a karst region, is known for its abundant springs that serve as the main water source for local communities. Therefore, understanding both historical and projected climate patterns, as well as their implications for groundwater resources, is essential.

In recent decades, Southeast Asia has experienced increasing variability in rainfall distribution and temperature extremes, influenced by anthropogenic climate change and natural climate oscillations such as the El Niño–Southern Oscillation (ENSO) (Christensen et al., 2013; Wong et al., 2016). These climatic shifts have critical implications for regions with fragile hydrogeological systems, especially those underlain by carbonate rock formations where groundwater storage and flow are highly sensitive to surface water dynamics (Hartmann et al., 2014). In such karst terrains, springs are not only the primary expression of groundwater but also serve as indicators of aquifer responses to climatic variability (Adji et al., 2019).

East Nusa Tenggara, particularly the Kupang region, has been identified as one of the most water-stressed areas in Indonesia (Rahmawati et al., 2020). With distinct dry and wet seasons and limited surface water storage, communities rely heavily on groundwater from springs and wells. However, the sustainability of these sources under future climate scenarios remains uncertain. This is especially critical in rural settlements such as Baumata Village, where spring discharge directly supports domestic needs, agriculture, and livestock. Based on the hydrogeological map by Aquater (1993), the study area is classified as a scarce groundwater zone containing high-productivity, moderate-productivity, and low-productivity aquifers. The hydrogeological map of the study area is presented in Figure 2.1.

To inform sustainable water resource management in the face of a changing climate, it is necessary to examine both the historical trends and future projections of key climate variables. Regional Climate Models (RCMs), such as those provided through CORDEX-SEA, offer high-resolution climate projections suitable for local-scale impact assessments (CORDEX-SEA, 2023; Wong et al., 2016). When integrated with hydrological observations, these models can help evaluate potential risks to groundwater availability and spring discharge in vulnerable karst regions (Fahon & Andreo, 2018). This study aims to analyze climate trends and project future conditions to assess their potential impact on groundwater discharge in Baumata's karst system. Through the integration of observational data, statistical analysis, and climate modeling, the research provides insights into the future resilience of spring-based water resources in the region.

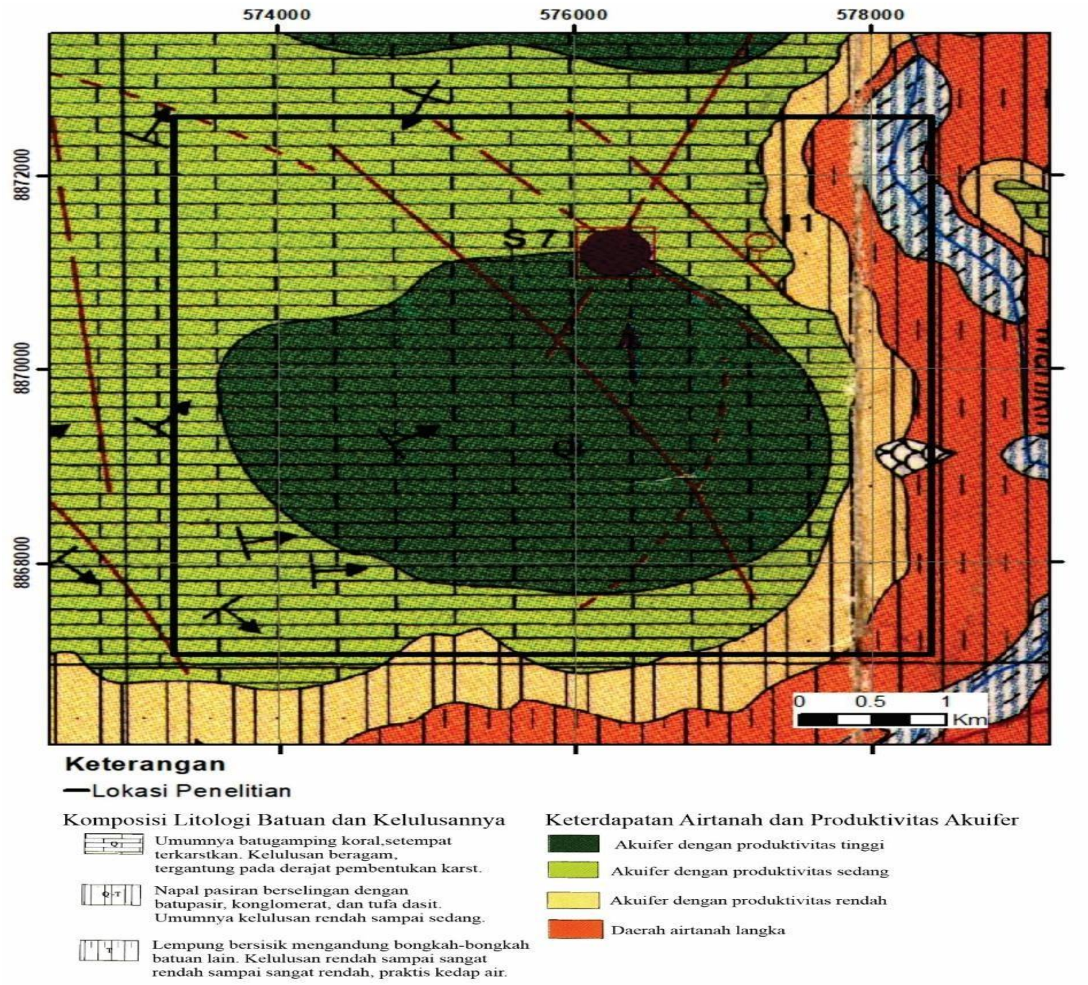

Figure 1. Hydrogeological map by Aquater (1993)

2. METHOD

2.1 Climate Data

Historical (2004–2024) and projected (2051–2055) climate data were obtained from the CORDEX SEA-22 regional climate model database (CORDEX-SEA, 2023). The analyzed variables included precipitation (pr), maximum temperature (tasmax), and minimum temperature (tasmin). Trends were evaluated using linear regression, and statistical significance was assessed via p-values following standard hydro-climatic trend analysis methods (Trenberth et al., 2005).

2.2 Discharge Measurements

Field measurements were conducted at 21 spring locations and multiple bore wells and dug wells across several villages. Discharge was measured using volumetric techniques and flow meters, and coordinates were recorded with GPS. Such approaches are widely used in karst hydrogeology to estimate aquifer output and spring response (Hartmann et al., 2014; Adji et al., 2019).

2.3 Data Analysis

Absolute and relative changes were calculated by comparing historical and projected periods. Linear trends were analyzed to determine slope and significance. Discharge data were evaluated descriptively to understand groundwater availability across the study area, consistent with hydrological assessment frameworks in tropical karst regions (Fahon & Andreo, 2018).

2.4 RESULT AND DISCUSSION

2.5 Climate Trends And Projection Method

To determine the future direction of climate change, projections were generated using a linear regression method based on historical trends. The projection period extends to the year 2055, with particular focus on the five-year interval 2051–2055 as the comparative baseline against historical conditions. The projected changes in precipitation and temperature are illustrated in Figures 2 to 4.

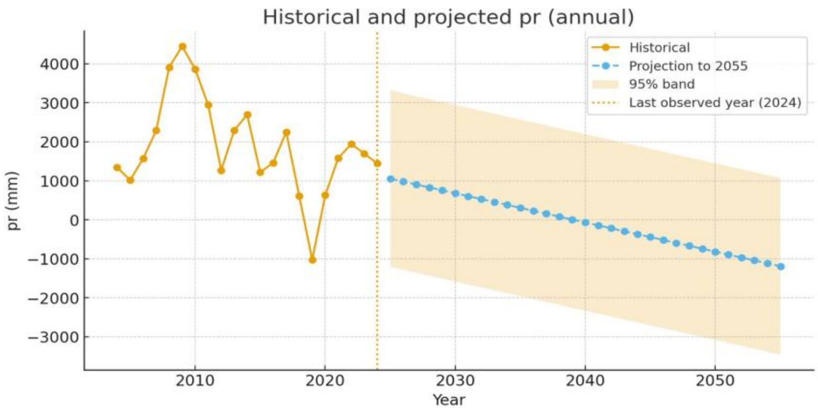

Figure2. Projected Precipitation (2025–2055).

The mean annual precipitation for the historical period (2004–2024) was 1,877.9 mm/year, whereas projections for 2051–2055 indicate a substantial decline to approximately –1,042.6 mm/year. This represents an absolute decrease of –2,920.5 mm/year or –155.5% relative to the historical average. Linear trend analysis shows a slope of –74.9 mm/year with a p-value of 0.096, indicating that although the downward trend is not statistically significant ($p > 0.05$), it demonstrates a strong negative direction. These results suggest a long-term reduction in precipitation, which may adversely affect water availability and increase the risk of drought in the future.

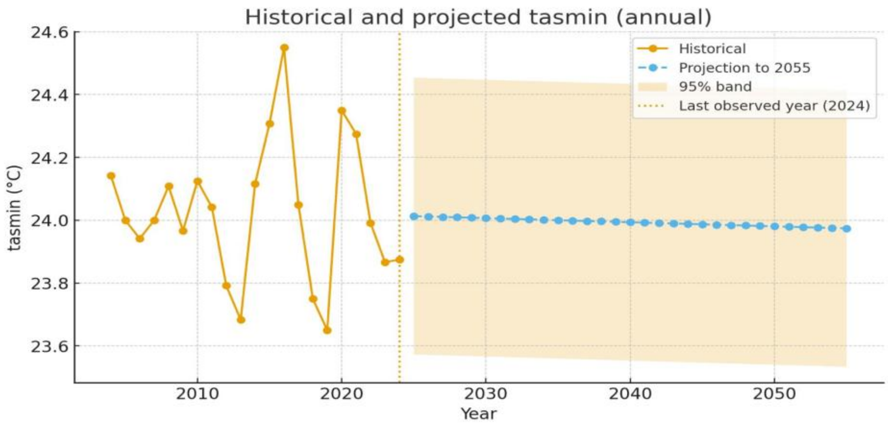

Figure 3. Projected Minimum Temperature (2025–2055).

The historical mean minimum temperature was 24.03°C, while the projection for 2051–2055 shows a slight decrease to 23.98°C. The absolute change is only –0.05°C (–0.21%). Trend analysis yields a slope of –0.001°C/year with a p-value of 0.876, indicating no statistically significant trend. Minimum temperatures in Baumata have remained relatively stable over the past 20 years and are expected to remain stable through mid-century. This suggests that nighttime warming is not yet a dominant signal in the region, unlike global trends where minimum temperatures generally increase.

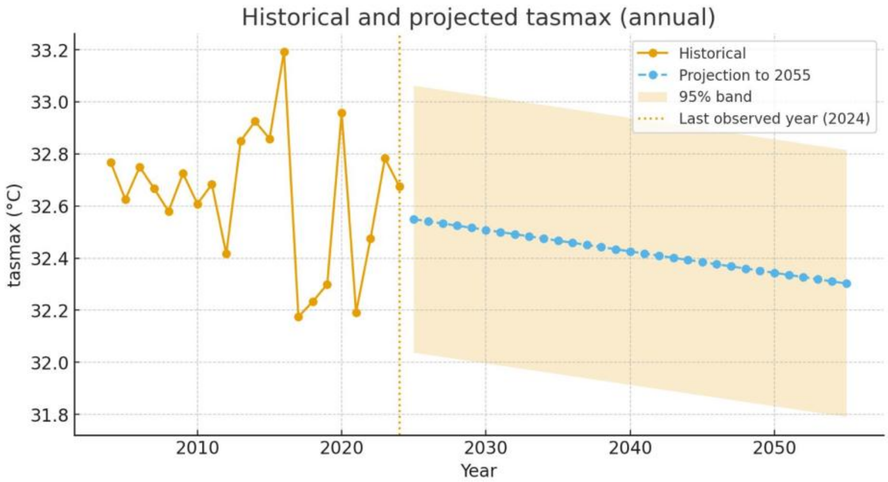

Figure 4. Projected Maximum Temperature (2025–2055).

For maximum temperature, the historical mean (2004–2024) is 32.64°C, while projections for 2051–2055 show a slight decline to 32.32°C. This corresponds to an absolute change of –0.32°C (–0.98%). The linear trend slope is –0.008°C/year with a p-value of 0.405, also statistically insignificant. Overall, maximum temperatures in Baumata appear stable or slightly decreasing, potentially due to interannual variability and moderating influences such as vegetation cover or seasonal winds that limit extreme daytime heating.

2.6 Trens Analysis and Significance Testing

Trend analysis for the historical period (2004–2024) was performed using simple linear regression. The results for each variable are as follows:

- Precipitation: slope −74.9 mm/year; p-value = 0.096. Although the trend is negative, it is not statistically significant (p > 0.05).
- Minimum temperature: slope −0.001°C/year; p-value = 0.876.
- Maximum temperature: slope −0.008°C/year; p-value = 0.405.
- Mean temperature: slope −0.005°C/year; p-value = 0.542.

The p-values (all > 0.05) indicate that no statistically significant trends were detected for temperature in Baumata during the past two decades.

2.7 Trens Analysis and Significance Testing

a. Precipitation (pr)

The mean annual precipitation for 2004–2024 was 1,877.9 mm/year. However, climate projections for 2051–2055 indicate a drastic decline to –1,042.6 mm/year, representing an absolute reduction of –2,920.5 mm/year or –155.5% relative to historical values. Linear trend analysis indicates a slope of –74.9 mm/year (p = 0.096). Although not statistically significant, the sharp downward trend suggests a potential reduction in surface and groundwater availability in the future. In regions such as Baumata, where water availability depends heavily on seasonal rainfall and shallow aquifers, this change could significantly affect domestic and agricultural water supply.

b. Minimum Temperature (tasmin)

The historical mean minimum temperature was 24.03°C, projected to decrease slightly to 23.98°C during 2051–2055. The change is very small (–0.05°C or –0.21%). The trend slope is –0.001°C/year (p = 0.876), indicating no significant trend. Nighttime temperatures in Baumata have been stable over the past two decades and are expected to remain so through 2055.

c. Maximum Temperature (tasmax)

The mean historical maximum temperature was 32.64°C, and projections for 2051–2055 show a small decrease to 32.32°C. This represents an absolute change of –0.32°C (–0.98%). The linear trend slope is –0.008°C/year ($p = 0.405$), also not statistically significant. Maximum temperatures remain relatively stable, likely influenced by annual variability and local climatic modulation.

d. Mean Temperature (tasmean)

Mean annual temperature declined slightly from 28.33°C (historical) to 28.15°C (projected), an absolute change of –0.19°C (–0.66%). The trend slope is –0.005°C/year ($p = 0.542$), again not significant. These small fluctuations may reflect natural interannual variability rather than long-term warming.

2.8 Groundwater Discharge

Total discharge from the 21 identified springs amounted to 283.61 L/s, with the highest value recorded at Baumata Spring (200 L/s). The smallest discharge (0.01 L/s) was observed in Oeletsala Village. Bore wells provided a total of 12.25 L/s, with individual discharges ranging from 0.16 to 1.66 L/s. Dug wells yielded an average of 0.4 L/s, indicating limited availability in shallow aquifers.

These findings suggest that the karst aquifer system has high storage and release capacity, typical of mature tropical karst systems with well-developed conduits. However, the projected reduction in rainfall may compromise recharge processes, particularly during extended dry seasons when spring flow depends heavily on stored subsurface water.

2.9 Implications for Water Security

The link between decreasing precipitation and spring discharge indicates that karst regions like Baumata are vulnerable to climate variability. Large springs such as Baumata Spring are currently reliable but could face stress if recharge zones degrade or excessive extraction occurs. Alternative water sources, including bore wells, require sustainable management to avoid aquifer depletion, a challenge well-documented in tropical karst basins experiencing drying trends.

3. CONCLUSION

This study reveals a significant downward trend in annual precipitation, both historically and in future projections. Although temperature trends are minor and statistically insignificant, the declining rainfall poses a substantial risk to groundwater recharge in the karst region of Baumata. Current spring discharge levels remain high, but future water security may be jeopardized if climate trends persist. Integrated water resource management and catchment protection are essential to ensure long-term sustainability.

REFERENCES

1. Adji, T. N., Haryono, E., Fatchurohman, H., & Oktama, R. (2019). Karst hydrogeology and sustainable water resource management in tropical regions. Environmental Earth Sciences, 78(12): 1–14. https://doi.org/10.1007/s12665-019-8312-2
2. Arheimer, B., Donnelly, C., & Lindström, G. (2017). Regulation of snow-fed rivers affects flow regimes more than climate change. Nature Communications, 8: 62–75. https://doi.org/10.1038/s41467-017-00092-8
3. Bergström, S., & Fowler, H. (2020). Impacts of climate change on groundwater recharge: A global synthesis. Hydrology and Earth System Sciences, 24(11): 4899–4916. https://doi.org/10.5194/hess-24-4899-2020
4. Christensen, J. H., et al. (2013). Climate phenomena and their relevance for future regional climate change. In IPCC AR5 WG1 (1217–1308).
5. CORDEX-SEA. (2023). Southeast Asia Regional Climate Downscaling Data. Coordinated Regional Downscaling Experiment. https://cordex.org
6. Fahon, A., & Andreo, B. (2018). Groundwater response in karst systems under climate variability. Journal of Hydrology, 567: 790-802. https://doi.org/10.1016/j.jhydrol.2018.01.045
7. Hartmann, A., Goldscheider, N., Wagener, T., Lange, J., & Weiler, M. (2014). Karst water resources in a changing world: Review of hydrological modeling approaches. Reviews of Geophysics, 52(3): 218–242. https://doi.org/10.1002/2013RG000443
8. IPCC. (2021). Climate Change 2021: The Physical Science Basis. Cambridge University Press.
9. Koutroulis, A. G., Papadimitriou, L., Grillakis, M. G., & Tsanis, I. K. (2016). Freshwater vulnerability under high-end climate change. Science of The Total Environment, 573: 829–844. https://doi.org/10.1016/j.scitotenv.2016.08.020

10. Rahmawati, N., Wardenaar, E., & Mardiansjah, F. (2020). Hydrogeological characteristics of karst aquifers in East Nusa Tenggara, Indonesia. Geosciences, 10(9): 345–360. https://doi.org/10.3390/geosciences10090345
11. Taylor, R. G., Scanlon, B., Döll, P., Rodell, M., van Beek, R., Wada, Y., … Treidel, H. (2013). Groundwater and climate change. Nature Climate Change, 3(4): 322–329. https://doi.org/10.1038/nclimate1744
12. Trenberth, K. E., Fasullo, J., & Smith, L. (2005). Trends and variability in precipitation and the hydrological cycle. Journal of Hydrometeorology, 6(3): 506–523. https://doi.org/10.1175/JHM424.1
13. Wong, C. R., Aldrian, E., & Tangang, F. (2016). Future climate projections over Southeast Asia from CORDEX-SEA. Climate Research, 69(1): 63–77. https://doi.org/10.3354/cr01387
14. management in all/more electric vehicles with multiple energy storage units," IEEE International Electric Machines and Drives Conference, 2003. IEMDC'03., 1-4 June 2003; 1: 222- 228.
15. L. C. Rosario, Patrick C. K. Luk, ―Applying Management Methodology to Electric Vehicles with Multiple Energy Storage Systems,‖ International Conference on Machine Learning and Cybernetics, 19-22 Aug, 2007; 7: 4223-4230.
16. F.R. Salmasi, ―Control strategies for hybrid electric vehicles: Evolution, classification, comparison, and future trends,‖ IEEE Trans. Veh. Technol., Sep. 2007; 56(5): 2393–2404.
17. Haifang Yu, Shumei Cui and Tiecheng Wang, ―Simulation and Performance Analysis on an Energy Storage System for Hybrid Electric Vehicle Using Ultracapacitor‖ in IEEE Vehicle Power and Propulsion Conference, Harbin, China, September, 2008; 3-5.
18. V. A. Shah, Jivanadhar A. Joshi, Ranjan Maheshwari and Ranjit Roy, ―Review of ultracapacitor Technology and its Applications,‖ 15th National Power Systems Conference, Mumbai, 2008.
19. Osamu Fuji, ―The Development and Application of Hybrid Vehicles,‖19th Electrical Vehicle Symposium, Busan, Korea, October 2002.
20. R. A. Dougal, Shengyi Liu and Ralph E. White, ‗Power and Life Extension of Battery Ultracapacitor Hybrids,‖ IEEE Transactions on Components and Packaging Technologies, March 2002; 25(1):
21. Xiaolai He, Parten M, Maxwell T, ―Energy Management Strategies for a Hybrid Electric Vehicle,‖ IEEE Conference on Vehicle Power and Propulsion, 7-9 Sept., 2005; 536-540.

22. N. Jalil, N. A. Kheir, and M. Salman, ―A Rule-Based Energy Management Strategy for a Series Hybrid Vehicle," Proceedings of the American Control Conference, 1997; 689-693.
23. Yi. L. Murphy, ―Inteligent Vehicle Power Management – An Overview,‖ Comput. Intel. In Automotive Applications, Springer 2008; SCI 132: 223-251.
24. Prokhorov, D.V., ―Approximating Optimal Controls with Recurrent Neural Networks for Automotive Systems.‖ Proceedings of the 2006 IEEE International Symposium on Intelligent Control Munich, Germany, October 2006; 4-6.
25. Schouten, N.J., Salman, M.A., Kheir, N.A., ―Fuzzy logic control for parallel hybrid vehicles‖. IEEE Trans. Contr. Syst. Technol., 2002; 10(3): 460–468.