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Groundwater Management Strategies to Maintain Food Security and National Security in the Banten Region

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ABSTRACT

This paper evaluates groundwater management strategies for maintaining food security and national security in the Banten region. The study uses monthly rainfall and air temperature data from ten representative locations classified according to Oldeman climate zones during 1981-2010. The Braak method is applied to estimate local air temperature, while the Thornthwaite and Mather water-balance method is used to calculate potential evapotranspiration, soil water content, and available groundwater. The findings show that wet climate zones remain relatively stable, while drier northern zones experience groundwater availability decline for seven to eight months per year. These results highlight the importance of sustainable groundwater management through conservation, artificial recharge, monitoring, irrigation efficiency, groundwater extraction control, and public education. Effective groundwater policy is essential to protect agricultural productivity, community water access, economic stability, and national security resilience.

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INTRODUCTION

Groundwater is a crucial component in maintaining the sustainability of life and food security, and plays a significant role in supporting national security stability. Adequate groundwater availability is essential to meet agricultural irrigation, drinking water and industrial needs (Zhang et al., 2019). However, global climate change and increasing land use intensity are exacerbating the situation by causing changes in rainfall patterns and increasing the frequency of extreme climate events such as El Nino (Jones & Harris, 2020). In Indonesia, particularly in Banten Province, watersheds such as Cilemer and Ciujung show high vulnerability to drought and flood phenomena (Ward et al., 2018). Surplus water in the rainy season often causes flooding due to sloping river flows and high rainfall, while in the dry season, these areas experience a deficit in water availability.

This hydrological cycle, reflected in the water balance, shows an imbalance between water uptake and outflow, resulting in vulnerability in groundwater availability (Haddeland et al., 2014).

Previous research has demonstrated that the availability of groundwater in these regions is significantly impacted by the combination of low evaporation and infiltration rates of rainwater, particularly in low-lying areas with limited groundwater storage capacity (Gerten et al., 2017). A study employing the Thornthwaite and Mather (1957) methodology for quantifying water availability, based on evapotranspiration data and rainfall patterns, indicates that arid zones exhibit a notable reduction in the duration of water availability, reaching as low as 7-9 months annually (Tian et al., 2021). In the Ciujung watershed, for instance, approximately 82.77% of precipitation is lost to evaporation, while only 9.86% infiltrates into groundwater reserves (Mishra & Singh, 2019). This situation underscores the necessity for the implementation of sustainable groundwater management strategies, including comprehensive water balance analysis (Falkenmark et al., 2018). This strategy aims to optimize groundwater management in order to maintain food security, given that groundwater constitutes the primary source for irrigation during the dry season.

The implementation of policies that regulate the wise use of groundwater and land conservation efforts is imperative to prevent a decline in water availability that could impact food productivity and economic stability. With proper management, groundwater availability can be more stable, thereby minimizing the threat of drought and potential conflicts related to water resources. This also supports efforts to strengthen national security through the provision of a stable food supply and year-round water availability (Vörösmarty et al., 2010).

METHODS

The research stages included determining locations based on different Oldeman climate types with each representing one location per climate type. Calculation of average monthly rainfall and average monthly air temperature using the Braak method. Calculation of evapotranspiration potential (ETP) using the Thornthwaite and Mather method. Creation of APWL, KAT, and Ati (%) calculation columns.

Processing Method

Monthly average air temperature data is available at Banten Climatology Station, Soekarno Hatta Meteorological Station, and Serang Maritime Meteorological Station which is used as a reference as a reference station to find air temperature values in other locations that do not yet have air temperature data, so to get the monthly average air temperature at that location, the elevation point of the station is needed to be calculated using the Braak equation method (Every 100 meter increase in temperature will decrease by 0.6 °C) with the following equation.

$$Tx = T0 - [(h / 100) \times 0.6°C]$$

Description:

Tx = Air temperature at the location point (C)

T0 = Reference station air temperature (C)

h = elevation / height at the location point (meter)

Groundwater surplus and deficit values were obtained based on monthly average rainfall and monthly average temperature data using the Thornwaite method calculation. The Thornwaite method ETP estimation only uses monthly average temperature data with the following equation.

Evapotranspiration for temperatures < 26.5°C:

$$ETP = 1.6 \times (10t / I)^a$$

Evapotranspiration for temperatures ≥ 26.5°C:

$$ETP = -0.0433t^2 + 3.2244t - 41.545$$

Description:

ETP = monthly potential evapotranspiration (cm/month)

t = monthly average temperature (°C)

I = accumulated heat index in a year

The accumulated heat index in a year is calculated based on the following equations:

$$I = \Sigma_{i=1}^{12} (t / 5)^{1.214}$$

$$a = 0.000000675I^3 - 0.0000771I^2 + 0.01792I + 0.49239$$

The ETP correction calculation can be calculated using the following equation:

$$TP = 10 \times (H / 30) \times (N / 12) \times ETPbaku$$

H = number of days in a given month

N = possible duration of solar irradiation in one day (hours)

Then, determine the value of field capacity and permanent wilting point. Field capacity is the state of moderately moist soil that shows the most amount of water that can be held by the soil against the force of gravity. Water that can be held by the soil is continuously absorbed by plant roots or evaporates so that the soil gets drier and drier (Siregar et al. 2017). If there is no water given to the soil, then the plant roots find it difficult to reach it and at some point the plant will die which is called the permanent wilting point .

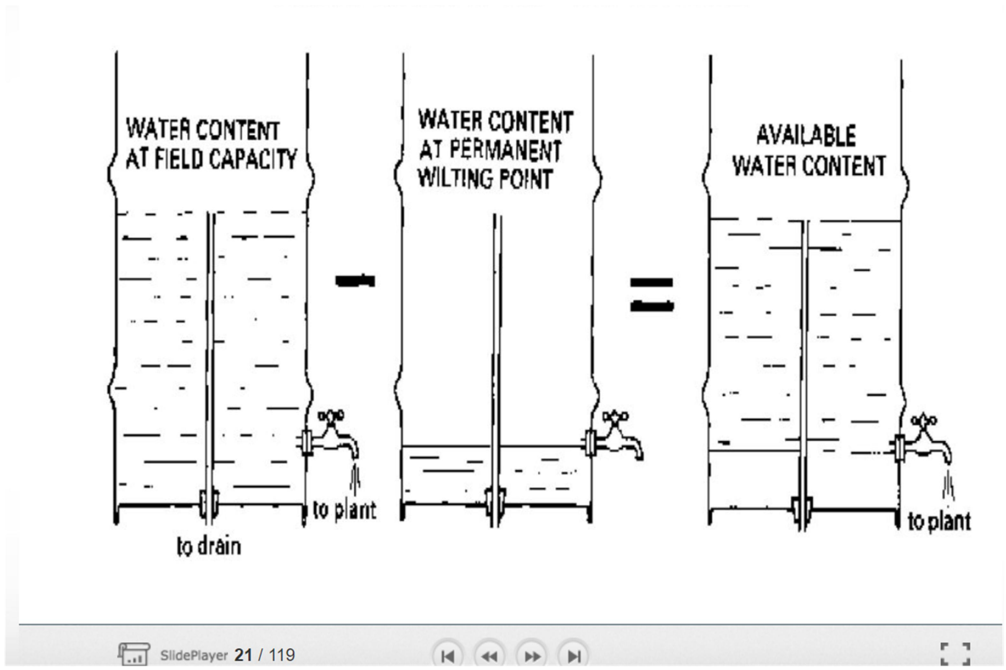
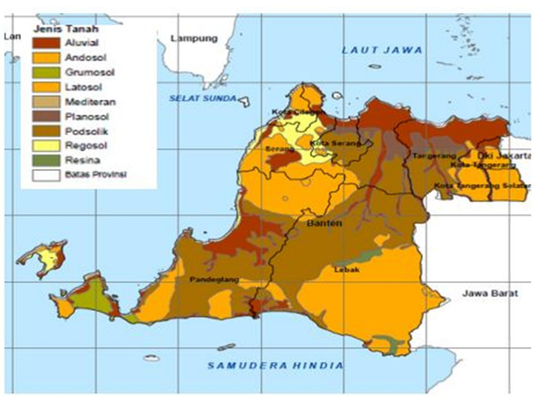


Figure 1. Illustration of Field Capacity and Permanent Wilting Point

Determination of field capacity and permanent wilting point values based on maps and tables shows that the soil types in Banten Province are varied and the most dominant soil types are Podsolik soil located in the Central part, Latosol soil located in almost all parts especially in the south, and Alluvial soil dominating in the north. Banten region (Figure 3) is given an assumed value for KL which is 300 mm and TLP 150 mm. These values are used as a reference for further calculations in determining the value of monthly groundwater availability



Tekstur	Air tersedia (mm/m)	Kedalaman Perakaran (m)	Kemampuan tanah menahan air (mm)
Tanaman Perakaran dangkal (bayam, kacang, wortel			
Pasir halus	100	0.50	50
Geluh pasiran	150	0.50	75
Geluh debuan	200	0.62	152
Geluh lempungan	250	0.40	100
Lempung	300	0.25	75
Tanaman Perakaran Sedang (jagung, tembakau, dll)			
Pasir halus	100	0.75	75
Geluh pasiran	150	1.00	150
Geluh debuan	200	1.00	200
Geluh lempungan	250	0.80	200
Lempung	300	0.50	150
Tanaman Perakaran Dalam (legume, padang rumput, semak belukar)			
Pasir halus	100	1.00	100
Geluh pasiran	150	1.00	150
Geluh debuan	200	1.25	250
Geluh lempungan	250	1.00	250
Lempung	300	0.67	200
Tanaman Perkebunan			
Pasir halus	100	1.00	150
Geluh pasiran	150	1.00	250
Geluh debuan	200	1.25	300
Geluh lempungan	250	1.00	250
Lempung	300	0.67	200
Hutan			
Pasir halus	100	2.50	250
Geluh pasiran	150	2.00	300
Geluh debuan	200	2.00	400
Geluh lempungan	250	1.60	400
Lempung	300	1.17	350

Sumber: Thornthwaite dan Mather dalam Darmanto 1980

(a) (b)

Figure 2. Banten Map and Soil Structure Table

Calculation of soil water balance was used to assess several parameters, such as accumulated potential water loss for evaporation (APWL), soil water content (KAT), and available groundwater percentage (ATi%).

a) CH-ETP was calculated to determine the accumulated potential water loss for evaporation (APWL).
b) APWL was assigned a value of 0 when CH-ETP was positive; when CH-ETP was negative, the value was calculated from the preceding APWL value plus CH-ETP.
c) Soil water content (KAT) was assigned a value equal to field capacity (KL) when APWL was 0. If APWL was negative, the following equation was used:

$$KAT = TLP + [1.00041 - (1.07381 / AT)]^{|APWL|}$$

d) The available groundwater percentage (ATi%) was calculated using the following equation:

$$ATi\% = [(KAT - TLP) / (KL - TLP)] \times 100\%$$

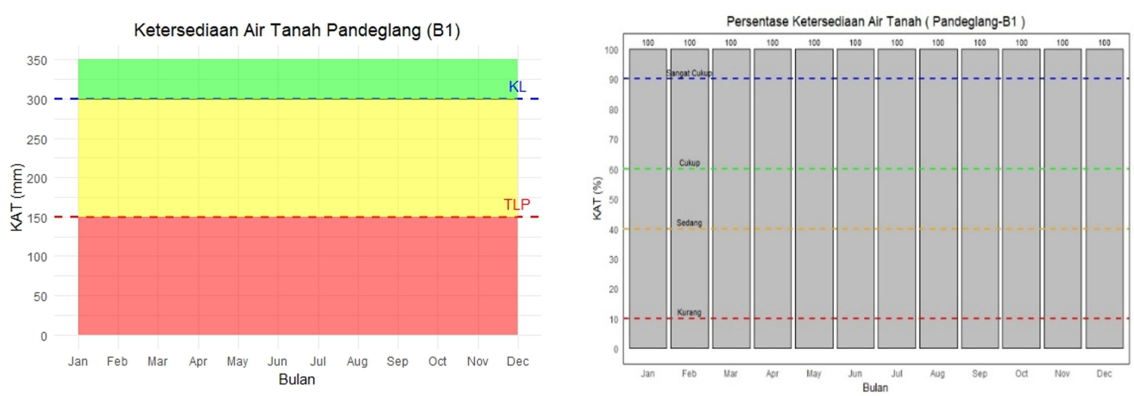
TLP = permanent wilting point (150 mm); AT = KL - TLP

KL = field capacity (300 mm); APWL = absolute value of APWL

KAT = soil moisture content

RESULTS AND DISCUSSION

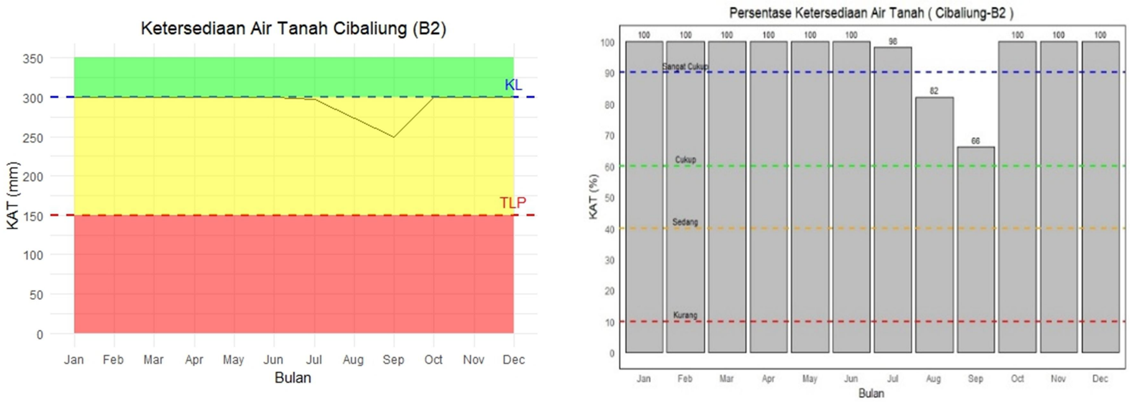
Monthly Groundwater Availability values and monthly percentage of available water in different climate zones in Banten were obtained. The processing results are in the form of graphs and histograms. The graph is the monthly groundwater availability and the histogram is the percentage of available water.



(a) (b)

Figure 3. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone B1 (Pandeglang)

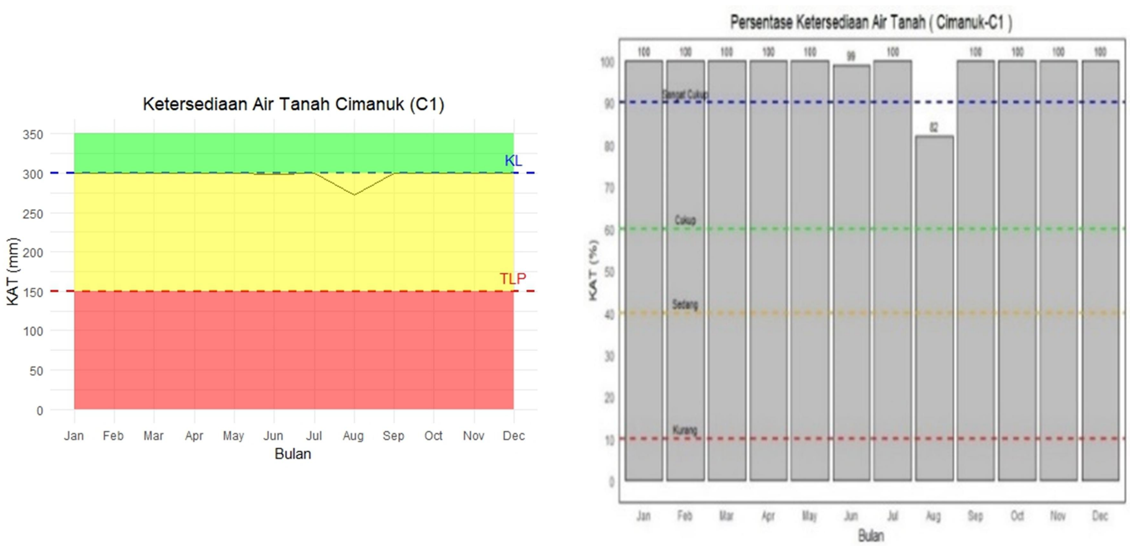
Groundwater availability in climate type B1 (Pandeglang) from January to December based on Figure 3 has not decreased. The percentage of available water in climate type B1 (Pandeglang) from January to December is always very sufficient (100%). This is because rainfall in the wet or humid period can provide sufficient groundwater availability in the dry month period.



(a) (b)

Figure 4. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone B2 (Cibaliung)

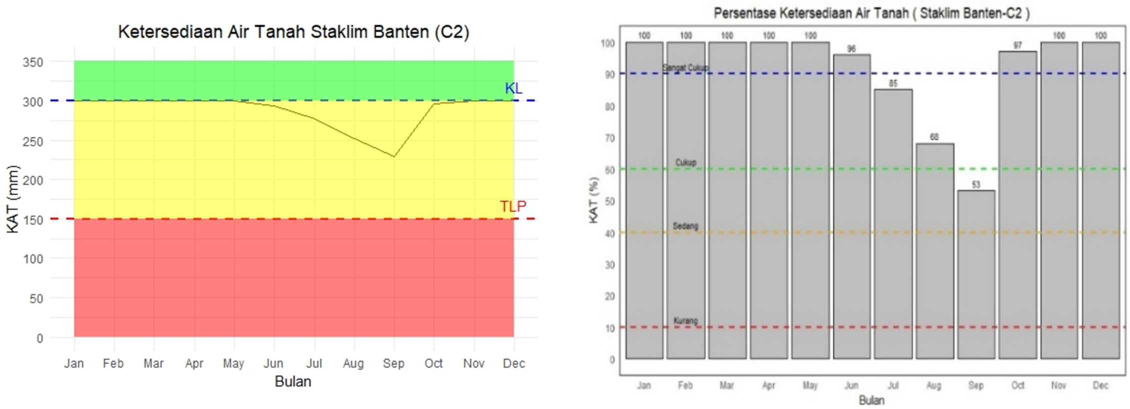
The availability of groundwater B2 (Cibaliung) based on Figure 4 experienced a decrease in KAT from July-September (3 months). This was due to a decrease in rainfall during that month. The percentage of Available Water B2 (Cibaliung) decreased to 98% in July in the very sufficient category and 82% (August) and 66% (September) in the sufficient category.



(a) (b)

Figure 5. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone C1 (Cimanuk)

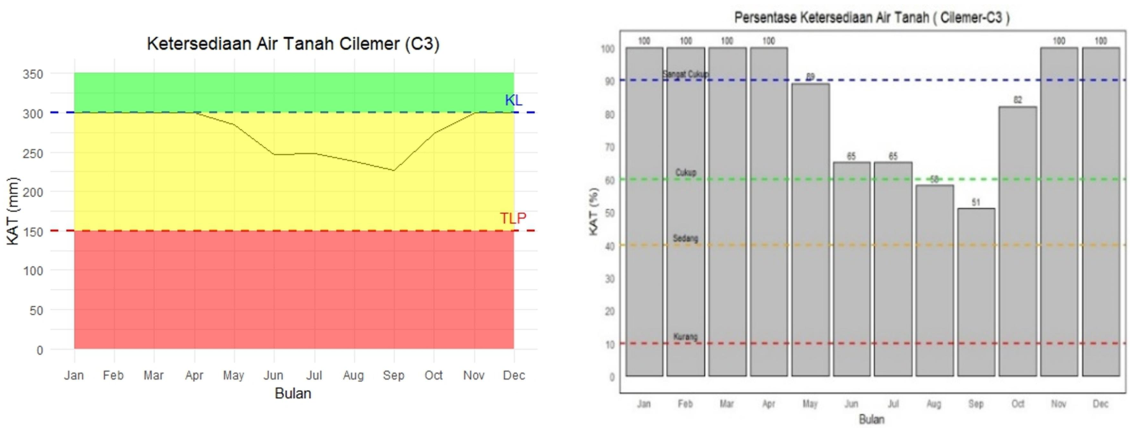
The availability of groundwater C1 (Cimanuk) decreased in June-August (2 months). The percentage of Available Water C1 (Cimanuk) decreased to 99% in June in the very sufficient category and 82% in the sufficient category (August).



(a) (b)

Figure 6. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone C2 (Staklim Banten)

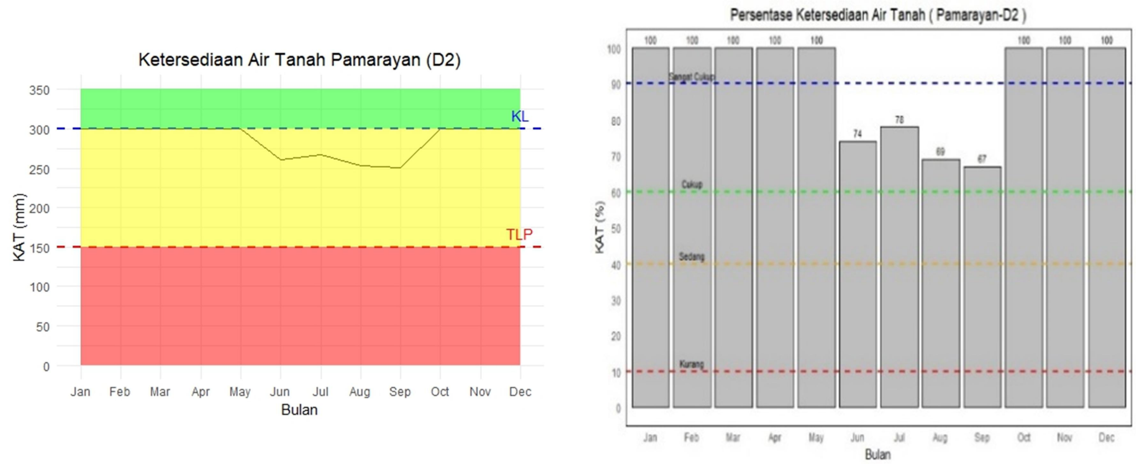
The availability of groundwater C2 (Banten) decreased in June-October (5 months) based on Figure 6. The percentage of Available Water C2 (Staklim Banten) decreased to 99% in June in the very sufficient category and successively in the sufficient category 85%, 68%, 53% in July, August and September, then returned to 97% in October very sufficient.



(a) (b)

Figure 7. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone C3 (Cilemer)

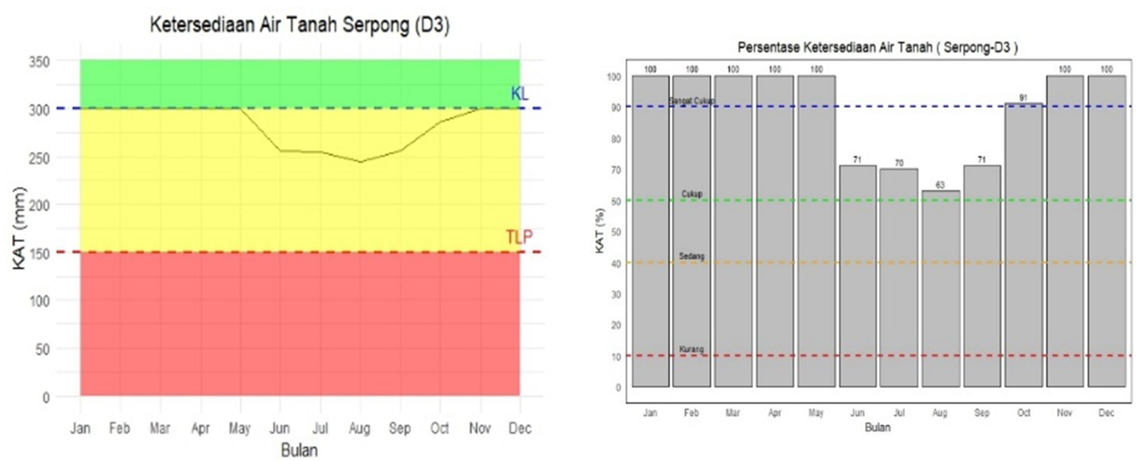
The availability of groundwater C3 (Cilemer) decreased from May to October (6 months) based on Figure 7. The percentage of Available Water C3 (Cilemer) decreased to sufficient 89% (June), 65% (July), 65% (August), then medium category 58% (August), 51% (September), then returned to sufficient 82% in October.



(a) (b)

Figure 8. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone D2 (Pamarayan)

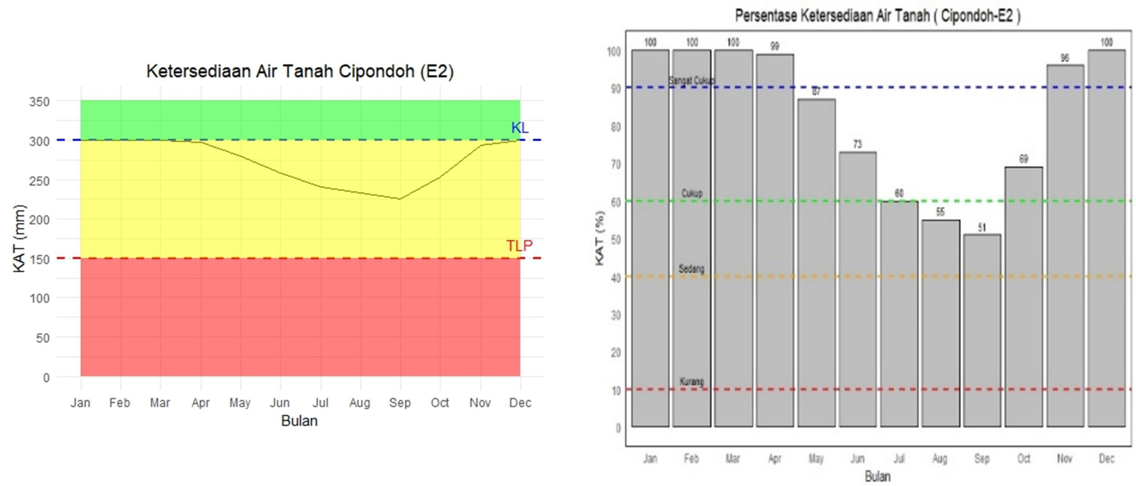
Groundwater Availability D2 (Pamarayan) decreased in June-September (4 months) based on Figure 9. The percentage of Available Water D2 (Pamarayan) decreased to 74% (June), 78% (July), 69% (August) and 67% (September).



(a) (b)

Figure 9. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone D3 (Serpong)

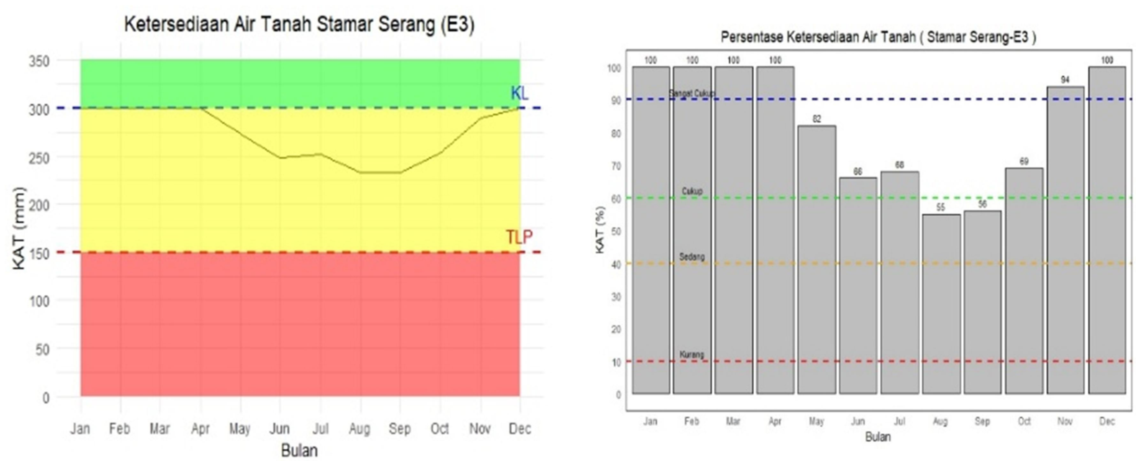
Based on Figure 9 Groundwater Availability D3 (Serpong) decreased in June-October (5 months). The percentage of Available Water D3 (Serpong) decreased to 71% (June), 70% (July), 63% (August), 71% (September), then returned to 91% in October.



(a) (b)

Figure 10. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone E2 (Cipondoh)

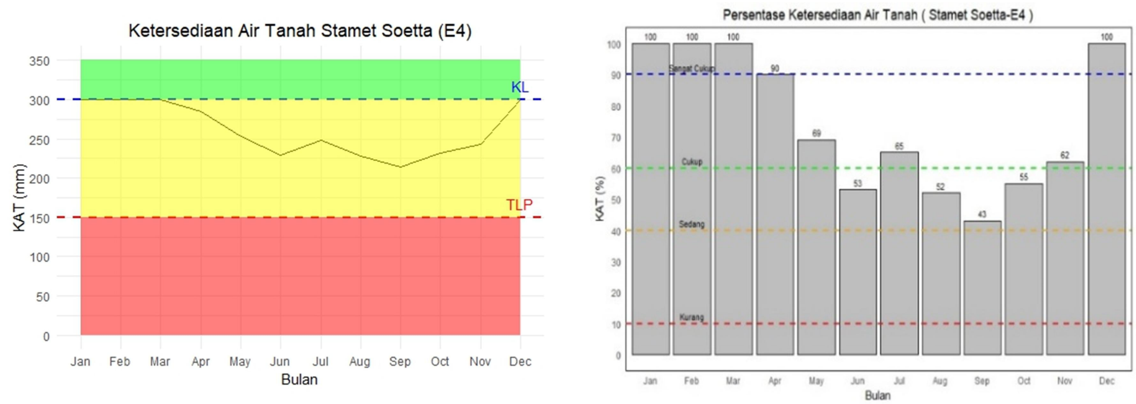
Based on Figure 10 Groundwater Availability E2 (Cipondoh) decreased from May to November (7 months). The percentage of Available Water E4 (Stamet Soetta) decreased to Adequate 87% (May), 73% (June), 60% (July), then decreased to Moderate 55% (August), 51% (September), then returned to Adequate 69% (October) and Very Adequate 96% (November).



(a) (b)

Figure 11. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone E3 (Stamar Serang)

Based on Figure 11 Groundwater Availability E4 (Stamet Soetta) decreased in May-November (7 months). The percentage of Available Water E3 (Stamar Serang) decreased to 82% (May), 66% (June), 68% (July), then decreased to 55% (August), 56% (September), then returned to 69% (October) and 94% (November).



(a) (b)

Figure 12. Graph (a) KAT and (b) Percentage of Available Water in Climate Zone E4 (Stamet Soetta)

Based on Figure 12 Groundwater Availability E4 (Stamet Soetta) decreased from May to November (7 months). The percentage of Available Water E4 (Stamet Soetta) decreased to 82% (May), 66% (June), 68% (July), then decreased to 55% (August), 56% (September), then returned to 69% (October) and 94% (November).

The research study points conducted at 10 points in Banten Province, such as Pandeglang (B1), Cibaliung (B2), Cimanuk (C1), Staklim Banten (C2), Cilemer (C3), Pamarayan (D2), Serpong (D3), Cipondoh (E2), Stamar Serang (E3), and Stamet Soetta (E4) obtained the value that based on the land water balance, the soil water content (KAT) is always above the permanent wilting point (TLP). The following table recapitulates the calculation of the value of groundwater availability and the percentage of available water on a monthly scale.

No	Bulan	B1		B2		C1		C2		C3		D2		D3		E2		E3		E4	
		Pandeglang		Cibaliung		Cimanuk		Sta Banten		Cilemer		Pamarayan		Serpong		Cipondoh		Sta Serang		Sta Soetta	
		KAT	ATi	KAT	ATi	KAT	ATi	KAT	ATi	KAT	ATi	KAT	ATi	KAT	ATi	KAT	ATi	KAT	ATi	KAT	ATi
1	Jan	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100
2	Feb	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100
3	Mar	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100
4	Apr	300	100	300	100	300	100	300	100	300	100	300	100	300	100	298	99	300	100	285	90
5	May	300	100	300	100	300	100	300	100	284	89	300	100	300	100	280	87	273	82	254	69
6	Jun	300	100	300	100	299	99	294	96	247	65	261	74	256	71	259	73	248	66	229	53
7	Jul	300	100	298	98	300	100	277	85	248	65	267	78	255	70	240	60	253	68	248	65
8	Aug	300	100	273	82	272	82	252	68	238	58	254	69	245	63	233	55	233	55	228	52
9	Sep	300	100	249	66	300	100	230	53	227	51	250	67	256	71	226	51	234	56	214	43
10	Oct	300	100	300	100	300	100	296	97	274	82	300	100	286	91	253	69	253	69	232	55
11	Nov	300	100	300	100	300	100	300	100	300	100	300	100	300	100	294	96	290	94	243	62
12	Dec	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100	300	100

Table 1. Recapitulation of Groundwater Availability (KAT) and Available Water (ATi) Value Results

It is notable that several periods exhibit KAT values that do not reach field capacity (KL). These include the Stamet Soetta from April to November, the Stamar Serang from May to November, the Cipondoh from April to November, the Serpong from June to October, the Pamarayan from June to September, and the Cilemer from May to October. Furthermore, the Staklim Banten, Cimanuk, Cibaliung, and Pandeglang areas demonstrated consistent field capacity throughout the observation period. However, when the 60% KAT limit was employed as a threshold, all of these regions exhibited the potential to reach the moderate KAT limit and beyond. It is noteworthy that the Pandeglang area exhibited consistently high KAT values, reaching 100% in all periods of climatological balance measurement. This indicates a potential for surplus throughout the period, which could potentially lead to runoff and subsurface runoff.

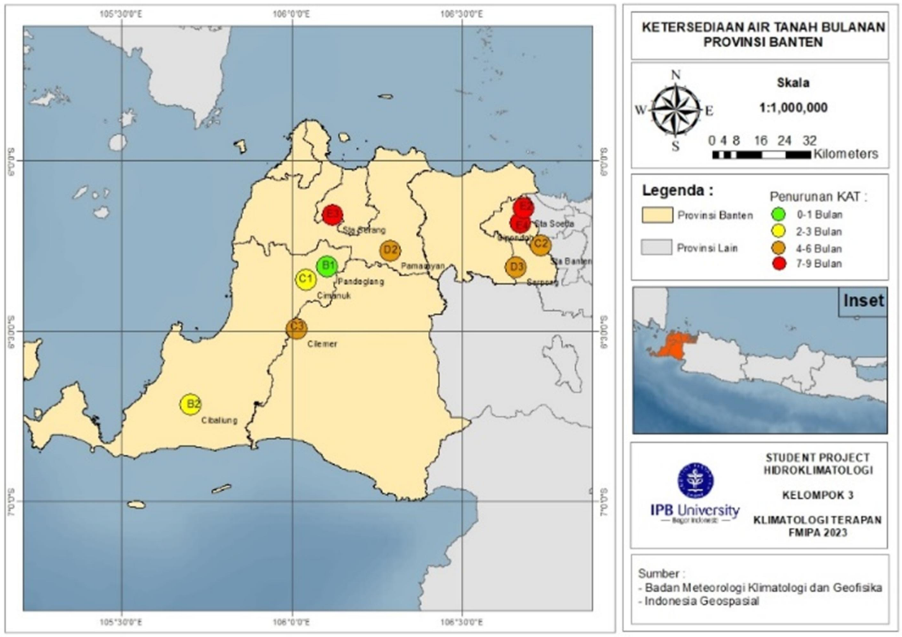


Figure 13. Spatial Distribution Map of Groundwater Availability in Banten Province Based on Oldeman Climate Type

The distribution of groundwater availability based on Figure 13 shows that for the northern part of Banten in climate zones E2, E3 and E4 the decrease in KAT is between 7-8 months, which is in the vulnerable category of groundwater availability. For the central part, it can be seen in the category of decreasing KAT between 4-6 months in the type of climate zones C2, C3, D2 and D3. Then in the B2 and C1 climate zone areas the KAT decrease category is 2-3 months, only the B1 climate zone area is categorized as not vulnerable because the KAT decrease is only 0-1 month.

Overall, the results indicate that groundwater vulnerability in Banten is spatially differentiated. The northern part of Banten requires more intensive groundwater governance because the duration of KAT decline is longer than in the central and southern areas. This pattern has direct implications for food security because agricultural productivity depends on water availability during the dry season. It also has implications for national security because water scarcity can trigger economic instability, social tension, and potential conflict over access to water resources.

CONCLUSION

In light of the research findings indicating disparities in groundwater accessibility (KAT) across different climate zones in the Banten region, it is imperative to adapt effective groundwater management strategies to ensure food security and national security. The following section outlines a series of groundwater management strategies that can be implemented in the Banten region, tailored to the specific characteristics of each climate zone.

For climate zones B and C, where groundwater availability is relatively high, the main priorities are groundwater conservation and water-use efficiency. Water-saving irrigation systems, such as drip irrigation or micro-irrigation, should be promoted to reduce excessive groundwater withdrawal. Rainwater harvesting should also be strengthened to support natural recharge and maintain long-term groundwater reserves.

For climate zone D, which experiences declining water availability during the dry season, aquifer recovery through artificial recharge is required. Rainwater and surface water can be directed into recharge wells or infiltration ponds during the rainy season. Groundwater extraction limits during the dry season are also needed to maintain groundwater levels and prevent critical shortages.

For climate zone E, where groundwater availability decreases for several dry months, a more intensive strategy is necessary. Satellite-based monitoring and real-time groundwater observation can support early warning and decision-making. Crop diversification with low-water-demand plants should also be promoted to reduce dependence on groundwater during dry periods.

Across all zones, local governments need to strengthen groundwater regulation, public education, and community-based water management. Quotas or taxes on groundwater extraction, village ponds, water catchment areas, and agricultural water conservation campaigns can help balance agricultural needs, community water access, and environmental sustainability. These strategies are essential for maintaining food security and supporting national security resilience in the Banten region.

REFERENCES

Falkenmark, M., et al. (2018). Water resilience for human prosperity. Ambio, 47(Suppl 1), S1-S9.

Gerten, D., et al. (2017). Reconciling contrasting views on water management in the Anthropocene. Nature Geoscience, 10(6), 410-412.

Haddeland, I., et al. (2014). Global water resources affected by human interventions and climate change. Proceedings of the National Academy of Sciences, 111(9), 3251-3256.

Jones, B., & Harris, R. (2020). Climate extremes and groundwater management. Environmental Research Letters, 15(9), 093004.

Mishra, A. K., & Singh, V. P. (2019). Drought modeling: A review. Journal of Hydrology, 574, 467-493.

Tian, D., et al. (2021). Assessing the vulnerability of groundwater resources to climate change. Journal of Hydrology, 598, 126434.

Vörösmarty, C. J., et al. (2010). Global threats to human water security and river biodiversity. Nature, 467(7315), 555-561.

Ward, P. J., et al. (2018). Global flood risk under climate change. Nature Climate Change, 8(4), 331-336.

Zhang, X., et al. (2019). Groundwater resources and sustainable management in arid regions. Water Resources Research, 55(6), 4787-4810.