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National Water Governance in Indonesia: An Analysis of Hydroclimatology, Coastal Geodynamics, and Regulatory Reform

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Abstract: *Indonesia's clean water crisis is exacerbated by climate change, excessive groundwater extraction, and weak governance, threatening food security, public health, and economic stability. This study aims to holistically analyze national water resource conditions through an interdisciplinary literature synthesis to formulate policy recommendations for sustainable and equitable water governance. Using an integrated literature review combined with qualitative-descriptive case studies, the study synthesizes 22 national and international scientific articles (2014–2026) covering hydroclimatology, coastal geodynamics, environmental economic valuation, water resource regulation, and community-level technological adaptation. Results indicate that climate change reduces surface water availability, degrades groundwater quality, accelerates land subsidence and relative sea-level rise in coastal areas, and causes significant economic losses due to water resource degradation. Implementation of Law Number 17 of 2019 concerning Water Resources still faces institutional obstacles, despite support from technological innovations and community-based adaptation. The study recommends strengthening integrated water governance, restricting groundwater extraction in vulnerable areas, and incentivizing community-based water conservation as strategic measures to realize national water sovereignty.*

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Introduction

Water is an essential natural resource that plays a vital role in human survival, ecosystem balance, and national economic growth (Sari et al., 2024). Globally, the clean water crisis has placed more than 2.3 billion people in the world living in areas with high water stress, where two-thirds of the global population experiences critical water shortages for at least one month a year (Annaifah, 2024). This phenomenon is exacerbated by global climate change triggered by human activities (anthropogenic) through greenhouse gas (GHG) emissions such as carbon dioxide (CO_2) and methane (CH_4) which trigger global warming and massively disrupt the hydrological cycle (Fatimah, 2025; Rejekiningrum, 2014).

In Indonesia, the clean water crisis and declining environmental resilience have reached alarming levels (Sari et al., 2024). In 2025, Indonesia faces the longest extreme dry season in two decades due to intense El Niño modulation, causing a reduction in the flow of key rivers supporting national water security, such as the Bengawan Solo, Citarum, and Musi Rivers, to more than 40% of their normal capacity. This shock directly impacts more than 11 million people in 14 provinces experiencing extreme clean water scarcity, particularly in East Java, Central Java, and East Nusa Tenggara (NTT).

The complexity of these threats not only damages the physical environmental system, but also triggers a chain of socio-economic causalities that harm public health through the transmission of waterborne diseases such as diarrhea and cholera, which in turn exacerbates the triple burden of malnutrition in infants (Kanda & Widiastutie, 2024; UNICEF, 2024). On the other hand, Indonesia's metropolitan and coastal areas are faced with dual geodynamic threats in the form of land subsidence due to excessive groundwater exploitation and relative sea level rise (RSLR) accelerated by global warming (Fauziyah et al., 2026; Iskandar et al., 2025).

National water governance, as stipulated in Law Number 17 of 2019 concerning Water Resources, still faces challenges such as weak implementation, policy inconsistencies across sectors, and minimal public participation and internalization of local wisdom values, such as the Fiqh Bi'ah perspective (Pambudi, 2025; Pininta et al., 2023). Therefore, an integrative scientific study is needed that comprehensively synthesizes various aspects of water governance to provide tactical and solution-oriented policy recommendations.

This study aims to analyze the impact of climate change on the hydrological cycle, surface water availability, groundwater quality, and its relationship to the child nutrition crisis in Indonesia; map and spatially project the impact of land subsidence and sea level rise relative to the potential loss of coastal land in Jakarta and Semarang; estimate the value of economic losses due to clean water degradation using the Replacement Cost method and analyze the influence of environmental variables on property prices using the Hedonic Pricing method; evaluate the national water governance legal framework (Law No. 17 of 2019) and compare the efficiency of various river basin management organizational models in Asia; and formulate technological engineering solutions and adaptation strategies based on local wisdom to overcome water pollution and drought at the site level.

Research Methods

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This study uses an integrated literature review approach combined with a qualitative-descriptive approach based on case studies (Pambudi, 2025); (Annaifah, 2024). This design is designed to synthesize scientific data from 22 selected research journals, in order to produce a comprehensive, cross-disciplinary understanding of the water crisis in Indonesia (Annaifah, 2024). The main data sources in this study are 22 reputable national and international scientific articles (Sinta and Scopus) published between 2014 and 2026. The characteristics of the literature analyzed include empirical hydroclimatology data (UNICEF, 2024); (Rejekiningrum, 2014), geotechnical reports on land subsidence (Chairani et al., 2024; Iskandar et al., 2025), spatial modeling of inundation (Fauziyah et al., 2026), legal regulation analysis (Isnugroho, 2014; Pambudi, 2025; Pininta et al., 2023), experimental studies on water technology engineering (Huda et al., 2021), and sociological-economic studies at the community level (Kanda & Widiastutie, 2024); (Dian & Harini, 2016; Ilmi et al., 2017; Sholihah et al., 2025).

Data synthesis was carried out through several stages of structured analysis including physical and geodynamic quantitative model analysis, economic valuation quantitative model analysis, regulatory and governance qualitative analysis, and descriptive analysis of technological engineering. The physical and geodynamic quantitative model analysis included the calculation of alluvial clay soil compression consolidation in Central Jakarta using the Terzaghi equation, as well as the spatial projection of permanent inundation of Relative Sea Level Rise (RSLR) in Jakarta and Semarang based on high-resolution Digital Elevation Model (DEM) (8.25 m) and Sentinel-2 Imagery (Fauziyah et al., 2026; Iskandar et al., 2025). The economic valuation quantitative model analysis included the calculation of domestic-agricultural water needs of BSN in Tuban (Dian & Harini, 2016), estimation of real Replacement Cost expenditure (Ilmi et al., 2017), and multiple linear regression analysis of Hedonic Pricing land prices (Ilmi et al., 2017). Qualitative analysis of regulations and governance includes a content analysis of legal products (Law No. 17 of 2019) (Pininta et al., 2023) and a comparative study of institutional models of River Basin Organizations (RBOs) in Asia (Isnugroho, 2014). Descriptive analysis of technological engineering includes a synthesis of the effectiveness of anaerobic-aerobic biofilter systems and rainwater harvesting (RWH) techniques (Huda et al., 2021; Sholihah et al., 2025).

Results and Discussion

Hydroclimatological Synthesis and Causal Relationship with Child Nutrition in Indonesia

Global hydroclimatological anomalies in the form of monsoon shifts and extreme El Niño events have significantly contributed to the decline in the main river discharge of Indonesia's major rivers (Rejekiningrum, 2014). Projections of per capita surface water availability until 2045 show a sharp downward trend that places Java and Bali below the critical water scarcity threshold (below 1,000 m³/capita/year) (Pambudi, 2025; Rejekiningrum, 2014).

Table 1. Projection of Surface Water Availability in Indonesia (m³/capita/year)

Island Region	Year 2000	2010	2020	2030 (Projection)	Year 2045 (Projection)
Sumatra	12,371.06	10,653.77	9,195.15	7,950.12	6,392.18
Java	836.55	724.74	630.26	546.52	445.82

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Bali	2,411.12	2,149.88	1,920.31	1,713.35	1,443.74
Kalimantan	61,838.35	53,542.24	46,412.35	40,305.76	32,741.38
Sulawesi	13,659.40	11,865.03	10,316.67	8,956.95	7,293.24
Maluku	40,182.60	35,398.52	31,194.01	27,451.80	22,550.18
Papua	236,139.95	206,023.46	179,889.10	157,197.03	128,568.84

This degradation of clean water availability indirectly triggers a child nutrition crisis through four theoretical causal pathways (Fatimah, 2025; UNICEF, 2024): the agricultural and food systems pathway, the economic vulnerability pathway, the environmental health pathway, and the childcare pathway. Based on the combined parameters of InaRISK disaster risk, the food security index (IKP), and the prevalence of malnutrition in the Indonesian context, East Nusa Tenggara (NTT) is categorized as very high, while Maluku, North Maluku, and West Papua are categorized as high (UNICEF, 2024).

Regulatory Evaluation,*Integrated Water Resources Management*(IWRM), and*River Basin Organizations*(RBOs) in Asia

Law No. 17 of 2019 concerning Water Resources restores water management to the principle of state sovereignty and rejects water privatization that harms the people (Pininta et al., 2023). However, the implementation of IWRM in Indonesia still faces bureaucratic obstacles, overlapping regulations, and weak inter-institutional coordination (Pambudi, 2025; Fulazzaky, 2014; Pininta et al., 2023).

A comparative analysis shows that the institutional models of River Basin Organizations (RBOs) in Japan, South Korea, the Philippines, Malaysia, and Indonesia differ in terms of autonomy, financing, and management. Non-profit corporate models such as K-Water and Perum Jasa Tirta are considered more adaptable in implementing IWRM principles because they have the financial flexibility to fund upstream conservation programs through cross-subsidization of downstream commercial revenues (Isnugroho, 2014).

Coastal Geodynamics, Land Subsidence, and Spatial Inundation Projections

Uncontrolled groundwater extraction in Central Jakarta causes a decrease in pore water pressure which increases the effective vertical stress based on Terzaghi's Law and results in compaction of alluvial soft clay (Iskandar et al., 2025).

Table 2. Results of Calculation of Groundwater Subsidence and Consolidation Rate in Central Jakarta

Island Region	Year 2000	2010	2020	2030 (Projection)	Year 2045 (Projection)
Sumatra	12,371.06	10,653.77	9,195.15	7,950.12	6,392.18
Java	836.55	724.74	630.26	546.52	445.82
Bali	2,411.12	2,149.88	1,920.31	1,713.35	1,443.74
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Papua	236,139.95	206,023.46	179,889.10	157,197.03	128,568.84

Spatial modeling results show that by 2100 under the RCP 8.5 scenario, the Jakarta coast is projected to lose up to 75.86 km² of land due to permanent seawater inundation, while Semarang City is projected to lose 45.89 km² of its coastal land (Fauziyah et al., 2026).

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Water Pollution, Consumption Patterns, and Anthropogenic Behavior of Society

Surface water pollution in Indonesia is in critical condition, with the national Water Quality Index (IKA) of 53.88 in 2022 (Farhan et al., 2023). Sources of pollution include industrial waste, agricultural runoff, domestic waste, and the habit of dumping detergent, used cooking oil, and plastic waste into water bodies, triggering eutrophication and microplastic pollution (Farhan et al., 2023; Rismawati & Sya'aban, 2023).

Environmental Economic Valuation

Water balance analysis in Semanding District, Tuban Regency shows that the total annual clean water availability reaches 25,865,917,491 m³/year, while the total combined water demand is 2,085,033 m³/year. This comparison confirms that the potential water availability has a very large surplus, but villages such as Bektiharjo, Jadi, and Boto continue to experience extreme drought every dry season due to the imbalance in distribution infrastructure and the topographic conditions of the highlands (Dian & Harini, 2016). Through the Willingness to Pay (WTP) approach, the affected community expressed a willingness to pay Rp17,318 per household per month to fund improvements to the clean water distribution system (Dian & Harini, 2016).

In Bedono Village, Demak, coastal abrasion has caused land shrinkage, degraded shallow well water quality, and increased clean water supply costs. Based on the Replacement Cost method, the total economic loss due to the loss of clean water benefits reached Rp1,304,647,938.46 per year, or an average of Rp1,351,010.56 per household per year (Ilmi et al., 2017).

Table 3. Estimated Cost of Replacing Clean Water Due to Abrasion in Bedono Village in 2015

Expenditure Sector	Real Financing Components	Annual Monetary Value (Rp)
Consumer Sector	Cost of installing new pipe connections	413,300,000.00
	Cost of purchasing communal deep well water	268,019,714.29
	Cost of purchasing 19 liters of bottled refillable drinking water	86,054,285.71
Management Sector	Deep well drilling costs & electricity bills (12 units)	537,273,938.46
Total Loss	**Estimated Total Replacement Cost of Water Feasibility**	**1,304,647,938.46**

Hedonic pricing analysis results indicate that road accessibility has a positive effect on land prices, while the frequency of tidal flooding has a significant negative effect. The cost of providing clean water does not significantly affect land prices (Ilmi et al., 2017).

Hydrological Technology Engineering and Community Drought Adaptation

Various technological innovations and local adaptations have demonstrated their effectiveness in supporting clean water provision and water resource conservation. In the agricultural sector, the application of the Alternate Wetting and Drying (AWD) method can save irrigation water by 20% to 70% without reducing crop productivity, while also reducing methane (CH_4) emissions from rice paddies (Annaifah, 2024; Fatimah, 2025).

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In the wastewater treatment sector, anaerobic-aerobic submerged biofilter technology in a water recirculation system (RAS) in Burai Village has been proven to produce clean, odor-free water, rich in dissolved oxygen, with minimal ammonia concentrations, and safe for reuse to support local freshwater fish farming (Huda et al., 2021). In Karang Tengah Hamlet, Gotakan Village, adaptation was carried out through the construction of a watertight membrane-lined reservoir, tiered rorak holes, and reforestation of protective vegetation to address the highly porous characteristics of regosol soil (Sholihah et al., 2025).

Water resource conservation efforts are also being carried out at the Uwe Gusu Spring in Palu City, through upstream vegetation protection, the construction of a discharge measuring station, and the integration of local wisdom into water catchment area management (Hamsiah & Nuradji, 2025). Meanwhile, the community of Ciwantani Village, West Bandung Regency, has developed various adaptation strategies to the El Niño drought by providing communal water tanks, constructing deep wells, and implementing simple water purification techniques at the household level (Kanda & Widiastutie, 2024).

Conclusion

Based on the results of an integrative analysis of 22 interdisciplinary scientific studies, climate change has significantly degraded the national hydrological cycle, reduced the availability of surface water, and worsened the quality of groundwater, which has an impact on increasing environmental health vulnerability and child nutrition crisis in Indonesia.

Excessive groundwater exploitation accelerates land subsidence and increases the rate of relative sea level rise, so that coastal areas of Jakarta and Semarang are projected to experience land loss due to permanent inundation in the future. Environmental economic valuation instruments indicate that water resource degradation causes significant economic losses, while the implementation of Law Number 17 of 2019 concerning Water Resources still faces various obstacles in implementing the principles of Integrated Water Resources Management (IWRM).

Various environmentally friendly technological innovations and community-based adaptation strategies, such as anaerobic-aerobic biofilters, Alternate Wetting and Drying (AWD), rainwater harvesting, water catchment conservation, and community-based water resource management, show great potential in supporting clean water provision and sustainable water resource management.

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