



ASSESSMENT OF CARRYING CAPACITY AND ENVIRONMENTAL CAPACITY IN EAST JAVA PROVINCE

Ema Umilia¹, Bieby Voijant Tangahu², Ary Mazharuddin Shiddiqi³

^{1,2}Department of Environmental Engineering,

³Department of Informatics Engineering Department,
SEPULUH NOPEMBER INSTITUTE OF TECHNOLOGY

Abstract

Assessing carrying capacity and environmental capacity is essential for sustainable development, especially in regions with rapid population growth and economic expansion. East Java faces increasing pressure on biophysical resources, particularly water, requiring evaluation of the balance between environmental provision and human demand. This study assesses water resources carrying capacity (WRCC) using grid-based spatial analysis and the Simple Additive Weighting method to map water availability and demand. Carrying capacity status is determined by comparing both to identify surplus and deficit conditions. However, only 30.2% of studies include water quality parameters, even though pollutant loading is a key constraint. Research in China dominates, accounting for 95.2%, while tropical regions remain underrepresented. China (95.2%), leaving tropical regions underrepresented. The main gap is the lack of integrated WRCC models that combine machine learning with uncertainty analysis. Results show spatial disparities: some areas remain sustainable, while others exceed critical thresholds. Integrating these findings into governance is crucial to prevent resource depletion.

Keywords: water carrying capacity; water availability; water demand; spatial analysis

² Corresponding author. Email: voijant@its.ac.id

INTRODUCTION

Ecological sustainability depends on the balance between biophysical thresholds and anthropogenic pressures, particularly in jurisdictions with rapid population growth. The theoretical frameworks of carrying capacity and environmental tolerance have emerged as the primary conduits for regional planning; these structures facilitate the rigorous evaluation of whether extant natural resource bases remain congruent with human demands without precipitating irreversible degradation. In Indonesia's regulatory landscape, this approach is formalized through the Environmental Carrying Capacity and Capacity Assessment, which integrates ecological, social, and spatial dimensions into regional planning.

East Java is often cited as a paradigmatic locus for studying hydrological constraints, where the confluence of demographic density and intensified land use exacerbates strain on vital water reservoirs. Disparities in spatial distribution, coupled with rising demands from domestic and industrial sectors, necessitate a rigorous evaluation of environmental thresholds; water scarcity is thus a direct manifestation of these spatial incongruities. Scarcity remains a spatial artifact.

Environmental carrying capacity is defined through the equilibrium established between biophysical water availability and the consumptive pressures exerted by anthropogenic and economic variables. To this end, a grid-based spatial analytical framework is implemented alongside the Simple Additive Weighting protocol, enabling a granular assessment of water carrying capacity. By systematically comparing resource availability with localized demand, this approach facilitates the identification of surpluses and deficits across the regional landscape.

This investigation primarily examines the overall status of environmental capacity in East Java. To address this core objective, the following sub-queries were established:

RQ: *What is the status of carrying capacity and environmental capacity in East Java Province?*

SRQ1: *What is the spatial configuration of water availability?*

SRQ2: *What are the quantitative dimensions of water demand across the population?*

SRQ3: *To what extent does the correlation between water availability and land-use characteristics dictate regional capacity?*

LITERATURE REVIEW

Water Resources Carrying Capacity: Concept and Dimensions

Water resources represent a critical component of environmental carrying capacity, as they directly influence both ecological integrity and human well-being. Water Resource Carrying Capacity (WRCC) is thus interpreted as the

threshold at which a localized jurisdiction can meet demographic and fiscal demands without compromising systemic functionality. This framework is bifurcated into two primary vectors: supply-side biophysical capacity and demand-oriented consumption. Equilibrium remains the objective.

Recent studies published in *Planning Malaysia: Journal of the Malaysian Institute of Planners* emphasize that Water Resources Carrying Capacity (WRCC) is not solely determined by volumetric water availability but is also strongly influenced by environmental quality, spatial characteristics, and risk factors such as hydrometeorological hazards. For instance, Nurul A. Mohd Yassin et al. (2023) highlight that watershed characteristics—including slope, soil, vegetation, and land cover—play a critical role in determining flood potential and hydrological response, thereby affecting the effective carrying capacity of water systems. This indicates that WRCC must incorporate not only supply–demand balance but also landscape vulnerability and hazard exposure.

Furthermore, Bhuiyan et al. (2021) demonstrate that climate-related hazards, particularly flash floods in urban Malaysia, significantly impact socioeconomic systems and water resource stability. This suggests that WRCC should be understood as a dynamic concept influenced by climate variability and extreme events, rather than a static threshold.

In addition, Abdul Malek et al. (2020) underline the importance of integrating GIS-based spatial analysis in assessing water-related risks and carrying capacity. Spatial approaches enable more precise identification of areas with high environmental stress, supporting the argument that WRCC consists of interconnected dimensions: biophysical capacity, socioeconomic demand, environmental quality, and climate risk.

Methodological Approaches: Spatial Analysis and Simple Additive Weighting

Evolutionary shifts in spatial analytics and geographic information systems (GIS) have facilitated a more granular stratification of environmental carrying capacity assessments. By adopting spatial methodologies, researchers can identify regional ecological heterogeneities, enabling precise detection of localized disequilibrium between resource inventories and demand. Within the Environmental Carrying Capacity and Capacity Assessment framework (Daya Dukung dan Daya Tampung Lingkungan Hidup – D3TLH), standardized analytical units are established using grid-based spatial constructs; these structures facilitate rigorous comparisons across divergent geographical domains.

To assess environmental service performance, particularly hydrological availability, the Simple Additive Weighting (SAW) protocol is used. This multicriteria decision-making framework synthesizes disparate environmental variables, including geomorphological traits and natural vegetation patterns, into a single composite index that reflects an ecosystem's capacity to sustain water

supply. Within this methodology, specific weights are assigned to individual parameters and aggregated to formulate an index of service provision; these results are subsequently distributed across the grid-cell architecture. This systemic aggregation rigorously interrogates the multifarious drivers of water availability. Evaluation remains strictly objective.

RESEARCH METHODOLOGY

Study Area and Analytical Framework

This study focuses on East Java Province, Indonesia, a region characterized by diverse land use, high population density, and significant economic activity. The analytical framework adopts a supply–demand approach, where water availability represents environmental supply, and water demand represents anthropogenic pressure. The assessment uses a spatially explicit, grid-based system, enabling identification of spatial variations in carrying capacity across the region. The overall process consists of four main phases: (1) data collection and variable identification, (2) calculation of total water demand, (3) analysis of carrying capacity and environmental limits, and (4) determination of status and final classification.

Data Collection and Variable Identification

The first phase involves identifying key variables representing both water demand and water availability.

Water demand variables include:

1. Population data, used to estimate domestic water demand.
2. Land use/land cover data, particularly agricultural land, used to estimate economic water demand.
3. Water requirement standards, including per capita water demand for a decent living standard and agricultural water requirements based on crop types and cropping intensity.

Water availability variables are derived from environmental characteristics influencing water provisioning services, including:

1. Landscape characteristics (e.g., slope, geomorphology),
2. Natural vegetation cover,
3. Existing land cover conditions.

Water availability is defined as usable water availability, representing the volume of water that can be sustainably utilized within each spatial unit.

Calculation of Water Demand

Total water demand is calculated as the sum of domestic and land-based economic water demand.

Domestic Water Demand (DWD)

Domestic water demand was calculated based on population and the applicable per-capita water requirement standard:

$$DWD_i = P_i \times q$$

where DWD_i is domestic water demand in a grid cell i ($m^3/year$), P_i is the population in grid cell i (persons), and q is the per-capita water requirement ($m^3/person/year$).

Land-Based Economic Water Demand (EWD)

Land-based economic water demand was calculated according to the area of each land-use category and its corresponding water requirement:

$$EWD_i = \sum_{k=1}^m A_{ik} \times q_k$$

where EWD_i is economic water demand in grid cell i ($m^3/year$), A_{ik} is the area of land-use category k within the grid cell i (ha or m^2), and q_k is the water requirement coefficient for land-use category k ($m^3/area/year$).

Total Water Demand (TWD)

Total water demand is calculated as:

$$TWD_i = DWD_i + EWD_i$$

The resulting grid-level values are subsequently aggregated to the regency/city level:

$$TWD_r = \sum_{i=1}^n TWD_i$$

where TWD_r represents total water demand within an administrative unit r .

Estimation of Water Availability

Water availability is assessed using an environmental service index approach that represents ecosystems' capacity to provide water. The analysis applies the Simple

Additive Weighting (SAW) method to integrate multiple environmental parameters.

The water availability index was developed using three groups of environmental criteria: landscape characteristics, vegetation cover, and existing land-cover conditions. Each criterion was transformed into a standardized score to allow comparison among spatial units. We selected the criteria because they represent key environmental characteristics that affect an area's capacity to provide and retain water.

We combined the standardized scores for each criterion using the Simple Additive Weighting (SAW) method. The general formulation is:

$$WSI_i = \sum_{j=1}^n w_j r_{ij}$$

where WSI_i is the Water Service Index for grid cell i , w_j is the weight assigned to criterion j , and r_{ij} is the standardized score of criterion j for grid cell i .

The weights and scoring scheme were determined based on the criteria applied in the D3TLH assessment of East Java Province. The weighting procedure ensures that each environmental parameter's contribution is explicitly represented in the resulting index.

Analysis of Carrying Capacity and Environmental Limits

Population Threshold (PT)

The population threshold represents the maximum population that available water resources can support:

$$PT = \frac{WA}{W_s}$$

where:

WA = water availability

W_s = per capita water requirement

Water Utilization Index (WUI)

The Water Utilization Index reflects the ratio between water demand and availability:

$$WUI_i = \frac{TWD_i}{WA_i}$$

where WUI_i is the Water Utilization Index of grid cell i , TWD_i is total water demand, and WA_i is usable water availability.

A WUI value below 1 indicates that water demand remains below the available water supply, whereas a value above 1 indicates that demand exceeds the estimated usable water availability. A value approaching 1 indicates that demand and availability are relatively balanced.

Determination of Status and Classification

The final phase determines carrying capacity and environmental capacity by comparing water availability and water demand.

For the final classification, the water balance is calculated as:

$$WB_i = WA_i - TWD_i$$

where WB_i is the water balance of the grid cell i . Positive values indicate a surplus, while negative values indicate a deficit.

The classification criteria are defined as follows:

1. Surplus: $WA > TWD$ (water availability exceeds demand)
2. Critical: $WA \approx TWD$ (balanced condition)
3. Exceeded (Overshoot): $WA < TWD$ (demand exceeds availability)

We applied the classification consistently to each grid cell and then aggregated it to the administrative level. The classification describes the relationship between estimated water supply and demand. It should therefore be interpreted as a spatial carrying-capacity assessment rather than a direct measurement of physical water scarcity at a specific point in time.

Spatial Analysis and Mapping

All variables and calculations are processed using Geographic Information Systems (GIS). The grid-based spatial approach ensures consistent analysis and allows detailed identification of spatial disparities in water availability, water demand, and carrying capacity status. The final outputs include thematic maps of:

1. Water availability
2. Water demand
3. Water utilization index
4. Carrying capacity status

ANALYSIS AND DISCUSSION

Overview of the Included Studies

Previous studies highlight that environmental carrying capacity depends on the balance between water availability and water demand. Many studies use spatial (GIS-based) approaches and multi-criteria methods, such as the Simple Additive Weighting (SAW), to assess environmental capacity.

In Indonesia, the Environmental Carrying Capacity and Capacity Assessment framework (*Daya Dukung dan Daya Tampung Lingkungan Hidup – D3TLH*) is commonly applied to integrate resource supply and demand in a spatial context. However, most studies still analyze these components separately. Therefore, this study integrates both aspects using a grid-based spatial approach to provide a more comprehensive assessment in East Java Province.

SRQ1: The configuration of water availability is scrutinized through the lens of geographic distribution

Water availability within the East Java administrative domain is quantified using datasets from the Environmental Carrying Capacity and Capacity Assessment (D3TLH) framework; these metrics, disseminated by the Ministry of Environment, establish the baseline for regional resource audits. The province's cumulative annual yield is documented at 32,429,028,339.04 m³. This figure represents the aggregate hydrological endowment distributed across the various regencies and municipalities.

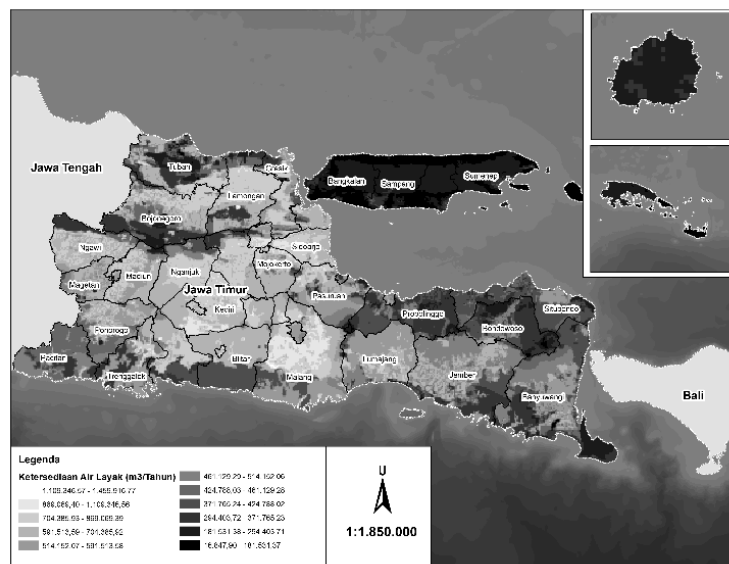


Figure 3: Water Availability Map of East Java Province
 Source: Authors (2026)

Table 1: Availability of Usable and Contaminated Water in East Java Province

Regency/City	Contaminated Water (m ³ /year)	Usable Water (m ³ /year)
Bangkalan	28.673.830,09	310.180.224,44
Banyuwangi	96.142.539,30	1.906.827.029,53
Blitar	65.205.422,02	1.166.479.920,21
Bojonegoro	87.863.351,46	1.429.900.536,31
Bondowoso	137.952.625,34	677.225.684,30
Gresik	178.196.417,03	822.176.440,06
Jember	494.655.720,81	1.978.622.883,23
Jombang	91.866.113,15	853.842.278,31
Kediri	49.898.685,52	1.370.098.056,67
Batu (City)	5.715.761,23	161.951.039,31
Blitar (City)	1.010.123,13	29.296.601,54
Kediri (City)	2.255.157,92	60.896.841,98
Madiun (City)	2.701.042,82	26.386.215,65
Malang (City)	10.691.452,68	74.840.168,76
Mojokerto (City)	1.702.912,59	17.906.859,29
Pasuruan (City)	2.571.416,93	23.142.752,35
Probolinggo (City)	4.078.604,64	36.707.441,80
Surabaya (City)	43.919.774,97	261.290.614,01
Lamongan	91.154.316,84	1.300.089.835,18
Lumajang	102.408.479,81	1.228.955.012,26
Madiun	34.533.564,25	820.681.003,50
Magetan	120.238.605,83	480.954.423,32
Malang	71.297.229,56	2.780.591.952,90
Mojokerto	72.430.519,68	760.487.139,91
Nganjuk	75.671.964,98	990.580.888,11
Ngawi	97.761.025,01	992.591.696,51
Pacitan	86.155.654,08	775.400.886,73
Pamekasan	21.491.554,88	193.423.993,88
Pasuruan	82.185.290,05	974.452.535,23
Ponorogo	94.423.826,06	938.885.717,19
Probolinggo	309.845.904,29	762.693.485,41
Sampang	22.307.573,52	312.289.299,38
Sidoarjo	70.898.037,04	663.112.078,29
Situbondo	15.018.592,24	856.129.449,56
Sumenep	66.438.597,09	597.947.373,85
Trenggalek	113.305.344,62	805.039.157,05
Tuban	97.631.572,19	1.126.435.280,78
Tulungagung	101.725.845,05	808.491.093,51

Source: Environmental Carrying Capacity and Environmental Capacity of East Java Province (2025)

Of this aggregate, the fraction identified as anthropogenically viable totals 29,377,003,890.32 m³ annually. Conversely, an estimated 3,052,024,448.72 m³ is classified as degraded, indicating water resources that remain unsuitable for direct use without intensive remediation. This bifurcation underscores the critical intersection of volumetric abundance and qualitative integrity. Measuring supply alone is insufficient.

Spatial heterogeneity is particularly pronounced when examining regional sub-sectors. Malang Regency sustains the largest reservoir of viable water at 2,780,591,952.90 m³ per year; this surplus aligns with its robust forest density, mountainous topography, and resulting hydrological stability. In stark contrast, Mojokerto City sits at the lower end of this spectrum, recording a mere 17,906,859.29 m³. This limitation largely stems from constricted administrative boundaries and the prevalence of impervious surfaces common in urbanized centers.

Qualitative degradation follows a distinct spatial logic within the dataset. Jember Regency has the largest volume of polluted water, at 494,655,720.81 m³; this concentration suggests intensified environmental stress, likely from agricultural runoff and land-use conversion. Conversely, the minimal polluted volume identified in Blitar City, totaling 1,010,123.13 m³, signals a localized preservation of hydrological standards.

The overarching spatial configuration of these resources demonstrates a clear divergence between ecological strongholds and urbanized interstices. Systems characterized by upland topography and dense vegetative cover maintain superior hydrological solvency. However, these findings vary, so resource management protocols must be spatially differentiated. Ensuring long-term sustainability requires a strategy sensitive to these regional variances. Precise interventions are required.

SRQ2: The Volumetric Quantification of Consumption Requirements

Quantifying hydraulic requirements in East Java Province requires synthesizing domestic consumption metrics with land-contingent economic pressures. While domestic demand remains tethered to demographic distribution, economic requirements are extrapolated from land-use typologies and their respective spatial footprints. This estimation is facilitated through a grid-based analytical framework; consequently, data aggregation occurs at the resolution of individual spatial units. Two distinct investigative phases were used: the first focused on domestic consumption, and the second on land-centric economic activities.

The aforementioned grid-cell methodology identified an aggregate volume of 3,687,020,139.60 m³/year as the domestic threshold. These results reflect differences in urban density. Surabaya City shows a maximum requirement of 256,809,123.60 m³/year, directly reflecting its concentrated

population. Conversely, Mojokerto City recorded a domestic nadir of 12,142,498.80 m³/year. This variance aligns with the latter's smaller population.

Substantially greater volumes are attributed to land-centric economic processes; the total was calculated at 43,749,237,022.12 m³/year. Expansive agrarian footprints largely drive this magnitude. Jember Regency, characterized by intensive production systems, registers the peak at 2,758,618,476.60 m³/year. Conversely, the 5,502,928.07 m³/year observed in Trenggalek Regency reflects a truncated land-use intensity.

Consolidation of these vectors yields a province-wide requirement of 47,436,257,161.72 m³/year. Jember Regency sits at the top of this demand hierarchy at 2,988,142,302.60 m³/year. In contrast, Mojokerto City represents the total minimum at 30,220,771.07 m³/year.

Ultimately, the data reveals that hydraulic appropriation in East Java is fundamentally driven by land-based economic production. Agriculture constitutes the primary pressure. These findings underscore a critical spatial stratification: integrating population dynamics and land-use characteristics is mandatory for viable resource governance. Planning must reflect these interstices.

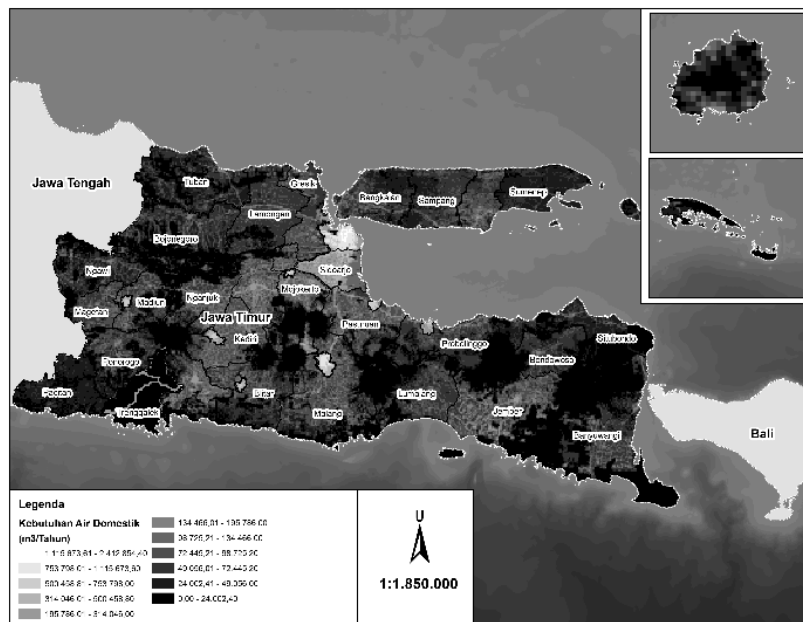


Figure 2: Map of Domestic Water Demand in East Java Province
Source: Authors (2026)

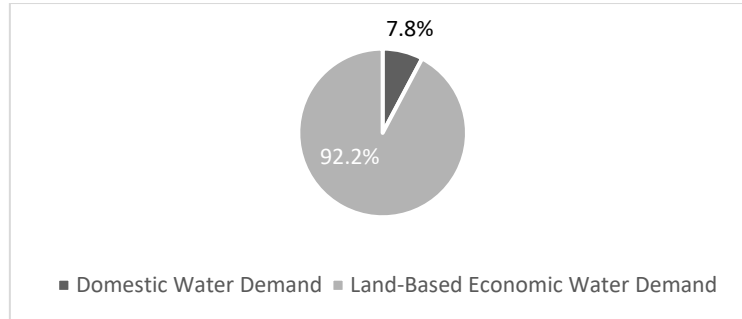


Figure 3: Total Water Demand in East Java Province
 Source: Authors (2026)

The quantitative distribution in the data indicates that water requirements from terrestrial economic activities make up a clear majority in East Java Province; this segment accounts for an estimated 92.2% of the total volume. This disproportionate consumption stems from the extensive allocation of regional topography to agrarian and silvicultural activities, where maintaining irrigation networks requires persistent, high-magnitude hydro-logistic dependence. Domestic requirements remain marginal. This 7.8% allocation is a byproduct of fragmented demographic distribution; moreover, residential consumption patterns inherently lack the volume and intensity characteristic of industrial-scale cultivation. Thus, the hydro-spatial architecture of East Java Province is governed by land-centric economic pressures; consequently, optimizing agrarian water management is the underlying prerequisite for long-term ecological viability.

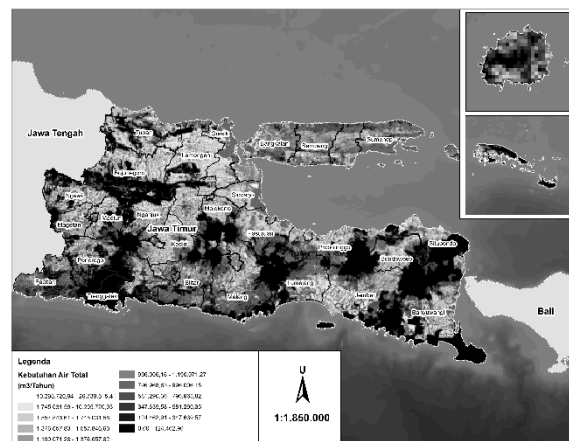


Figure 4: Total Water Demand Map of East Java Province
 Source: Authors (2026)

SRQ3: The correlation between localized water availability and varied land-use classifications

The Water Utilization Capacity Index (Indeks Kemampuan Pemanfaatan—IKP) indicates the balance between total water demand—including domestic needs and land-based economic activities—and the availability of usable water resources. This index shows the extent to which a region can supply adequate water to support its population and economic activities without stressing or depleting water resources.

In East Java Province, the Water Utilization Capacity Index is classified as very low, with a value of 1.61. This result indicates that the province has a very limited capacity to provide sufficient, usable water to meet domestic and economic demands without leading to water scarcity.

Comparing total water availability with total water demand reveals the carrying capacity and environmental capacity of water resources. This study assesses the gap between water availability and total water demand, allowing identification of water balance conditions at both provincial and regency/city levels.

The analysis shows that East Java Province's water resources carrying capacity and environmental capacity were exceeded in 2025. Total water availability is estimated at 32,429,028,339.04 m³/year, which is significantly lower than total water demand of 47,436,257,161.72 m³/year. This results in a deficit (gap) of -18,059,253,271.40 m³/year, indicating that water resources are insufficient to meet existing needs. This condition reflects an overall water deficit, where available resources can no longer adequately support both domestic consumption and land-based economic activities.

From a population threshold perspective, East Java Province can support the water needs of only about 38,641,727 people, while the current population has reached 42,089,271. This indicates a shortfall of 3,447,544 people, further emphasizing that existing water resources are under significant pressure and cannot sustainably meet current population demands.

Overall, these findings confirm that East Java Province is experiencing a critical imbalance between water availability and demand, highlighting the urgent need for more sustainable water resource management and policy interventions.

Table 2: Water Carrying Capacity Status of East Java Province

Regency/City	Population (inhabitants)	Water Availability (m ³ /year)	Total Water Demand (m ³ /year)	Status
Bangkalan	1.112.956	338.854.054,53	1.567.247.960,91	Exceeded
Banyuwangi	1.764.540	2.002.969.568,83	2.646.627.309,00	Exceeded
Blitar	1.273.451	1.231.685.342,22	1.600.823.916,47	Exceeded
Bojonegoro	1.330.516	1.517.763.887,77	2.250.826.148,23	Exceeded
Bondowoso	796.300	815.178.309,64	1.323.451.510,36	Exceeded
Gresik	1.377.287	1.000.372.857,10	1.731.212.386,92	Exceeded
Jember	2.620.135	2.473.278.604,03	2.988.142.302,60	Exceeded
Jombang	1.373.793	945.708.391,46	1.364.002.279,52	Exceeded
Kediri	1.702.262	1.419.996.742,19	2.016.306.918,23	Exceeded
Batu (City)	225.120	167.666.800,54	128.698.560,17	Not Exceeded
Blitar (City)	156.330	30.306.724,68	39.951.880,41	Exceeded
Kediri (City)	301.202	63.151.999,90	93.065.620,94	Exceeded
Madiun (City)	203.552	29.087.258,47	45.891.485,36	Exceeded
Malang (City)	879.873	85.531.621,44	157.080.902,21	Exceeded
Mojokerto (City)	138.613	19.609.771,88	30.220.771,07	Exceeded
Pasuruan (City)	222.334	25.714.169,28	57.144.232,52	Exceeded
Probolinggo (City)	252.085	40.786.046,45	85.996.074,15	Exceeded
Surabaya (City)	2.931.611	305.210.388,98	507.821.825,40	Exceeded
Lamongan	1.386.390	1.391.244.152,03	2.561.344.969,38	Exceeded
Lumajang	1.152.264	1.331.363.492,06	1.566.675.363,96	Exceeded
Madiun	760.948	855.214.567,75	932.973.014,58	Exceeded
Magetan	689.209	601.193.029,16	982.273.885,13	Exceeded
Malang	2.755.438	2.851.889.182,46	2.894.359.051,04	Exceeded
Mojokerto	1.162.696	832.917.659,59	1.107.912.537,33	Exceeded
Nganjuk	1.138.604	1.066.252.853,10	1.300.039.722,89	Exceeded
Ngawi	887.172	1.090.352.721,52	1.440.412.207,03	Exceeded
Pacitan	589.034	861.556.540,81	1.159.216.139,68	Exceeded
Pamekasan	893.327	214.915.548,76	975.817.269,06	Exceeded
Pasuruan	1.669.400	1.056.637.825,28	1.762.470.994,79	Exceeded
Ponorogo	966.111	1.033.309.543,25	1.231.173.636,78	Exceeded
Probolinggo	1.193.272	1.072.539.389,71	1.608.883.652,67	Exceeded

Sampang	1.027.538	334.596.872,89	1.509.622.876,52	Exceeded
Sidoarjo	2.193.692	734.010.115,32	1.343.964.195,05	Exceeded
Situbondo	704.243	871.148.041,80	1.165.816.143,76	Exceeded
Sumenep	1.159.397	664.385.970,95	1.970.710.893,85	Exceeded
Trenggalek	747.614	918.344.501,67	70.993.914,47	Not Exceeded
Tuban	1.231.374	1.224.066.852,97	2.289.020.761,74	Exceeded
Tulungagung	1.119.588	910.216.938,57	928.063.847,49	Exceeded
Jawa Timur	42.089.271	32.429.028.339,04	47.436.257.161,72	Exceeded

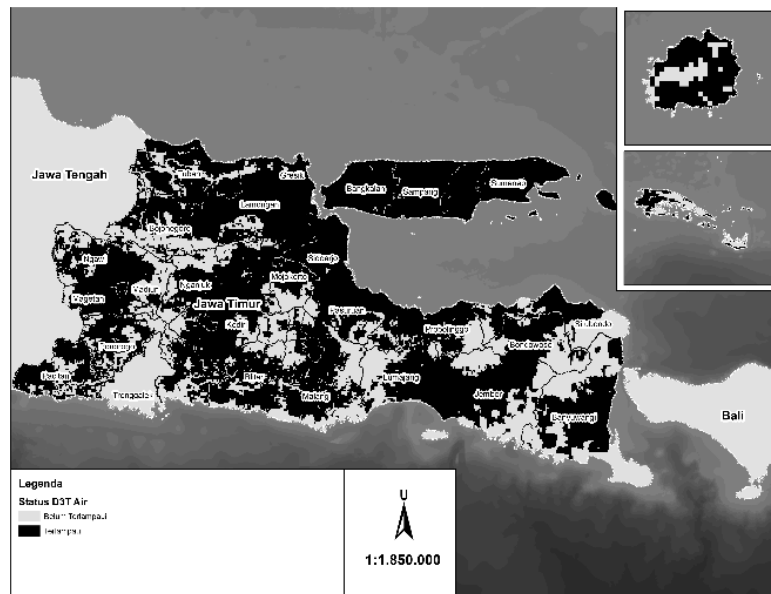


Figure 5: Water Carrying Capacity Status of East Java Province
Source: Authors (2026)

Interpret the results with several sources of uncertainty in mind. First, water availability is represented through an environmental service index and therefore reflects a spatial estimation rather than direct continuous measurements of streamflow, groundwater storage, or actual water withdrawals. Second, domestic water demand depends on population estimates and per-capita water-requirement standards. In contrast, land-based economic water demand depends on land-use classification and the corresponding water-requirement coefficients.

Third, the spatial aggregation process may influence the magnitude and distribution of estimated availability and demand. Differences in the spatial resolution of input datasets may introduce uncertainty when variables are

standardized into a common grid. Fourth, the SAW method requires assigning criteria weights and scores, which may affect the resulting spatial index. Consequently, the carrying-capacity classification should be interpreted as an assessment based on the selected datasets, assumptions, and methodological framework for the 2025 assessment period.

Future research should incorporate temporal variability in rainfall and hydrological flows, observed water quality, actual water abstraction, climate-change scenarios, and uncertainty or sensitivity analysis to evaluate the robustness of the carrying-capacity classification.

CONCLUSION

This study assessed total service quality and environmental challenges in East Java Province's hydrological resources using a high-resolution, grid-based spatial analysis approach. Spatial heterogeneity in water resource availability was observed: high densities in ecological preserves, while a dramatic decline occurred in highly urbanized areas. The supply-demand balance is largely determined by land-based economic productivity, with the agricultural sector being the main water consumer.

By systematically comparing resource availability to volumetric demand, the province-wide hydrological deficit is uncovered. Exceeding ecological thresholds indicates a clear excess of carrying capacity. Similar discrepancies appear in the underperforming utilization indices, as the current resource base fails to sustain the present demographic density.

This signals an urgent need for better management of water resources, carrying capacity, and land use planning to make the environment more sustainable.

ACKNOWLEDMENT

This research is funded by the Indonesian Endowment Fund for Education (LPDP) on behalf of the Indonesian Ministry of Higher Education, Science and Technology and managed under the EQUITY Program (Contract No 4299/B3/DT.03.08/2025 & No 3757/PKS/ITS/2025)

REFERENCES

- Abdul Malek, N., Zayid, S., Ahmad, Z., Ya'acob, S., & Abu Bakar, N. (2020). Data understanding for flash flood prediction in urban areas. *Journal of Environmental Treatment Techniques*, 8(2), 770–778.
- Badan Pusat Statistik (BPS). (2025). *East Java Province in figures 2025*. Jakarta: BPS-Statistics Indonesia.
- Bhuiyan, T. R., Er, A. C., Muhamad, N., & Pereira, J. J. (2021). The socioeconomic impact of climate-related hazards: Flash flood impact assessment in Kuala Lumpur, Malaysia. *Natural Hazards*, 109, 1509–1538.

- Falkenmark, M., Lundqvist, J., & Widstrand, C. (1989). Macro-scale water scarcity requires micro-scale approaches. *Natural Resources Forum*, 13(4), 258–267. <https://doi.org/10.1111/j.1477-8947.1989.tb00348.x>
- Food and Agriculture Organization. (2012). *Coping with water scarcity: An action framework for agriculture and food security*. Rome: FAO.
- Hoekstra, A. Y., & Mekonnen, M. M. (2012). The water footprint of humanity. *Proceedings of the National Academy of Sciences*, 109(9), 3232–3237. <https://doi.org/10.1073/pnas.1109936109>
- Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, 20(7), 703–726. <https://doi.org/10.1080/13658810600661508>
- Ministry of Environment and Forestry of the Republic of Indonesia. (2023). *Environmental carrying capacity and environmental capacity assessment (D3TLH) report*. Jakarta: KLHK.
- Ministry of Environment and Forestry of the Republic of Indonesia. (2025). *National environmental carrying capacity and capacity report (D3TLH Nasional)*. Jakarta: KLHK.
- Nurul A. Mohd Yassin, N. A., Adnan, N. A., & Md Sadek, E. S. S. (2023). Analysis of flash flood potential index (FFPI) and scenario assessment in Shah Alam using GIS approach. *Planning Malaysia*, 20(2).
- Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83–98. <https://doi.org/10.1504/IJSSCI.2008.017590>
- Triantaphyllou, E. (2000). *Multi-criteria decision making methods: A comparative study*. Dordrecht: Springer.
- Turner, R. K., Daily, G. C., & Ehrlich, P. R. (2003). Valuing ecosystem services: Toward better environmental decision-making. *Ecological Economics*, 45(3), 293–301. [https://doi.org/10.1016/S0921-8009\(03\)00064-6](https://doi.org/10.1016/S0921-8009(03)00064-6)
- United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. New York: United Nations.
- World Bank. (2020). *Indonesia: Water security and resilience*. Washington, DC: World Bank.

Received: 15th May 2026. Accepted: 6th June 2026