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Environmental Spatial Analysis of Water-Provisioning Ecosystem Carrying Capacity and Food-Crop Land Allocation in Dryland Agriculture In South Central Timor Regency, Indonesia

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Abstract:
Water provisioning is a structural determinant of dryland-farming productivity in semi-arid Eastern Indonesia, yet the spatial coherence between water-provisioning ecosystem carrying capacity and the food-crop allocation prescribed by the regency Spatial Plan remains insufficiently quantified. This study evaluates the Water-Provisioning Ecosystem Service Index (IJL-PA) for South Central Timor (Timor Tengah Selatan, TTS) Regency under the three-proxy framework prescribed by Government Regulation No. 26 of 2025, focusing on the food-crop zone (P-1) overlaid on the dryland agriculture (PLK) land cover. The 393,233 ha regency was disaggregated through a GIS-based weighted overlay of landform (32 percent), natural vegetation (8 percent), and land cover (60 percent) layers, and subsequently intersected with the regency Spatial Plan and the PLK extent. The results indicate that 58.86 percent of TTS falls within the Low IJL-PA class and only 6.98 percent reaches the High or Very High class. Although the aggregate Water Carrying Capacity ratio (DDA) reaches 1.10, 20 of 32 sub-districts record a DDA below one, with Kokbaun reaching 0.13. Of the 41,315 ha food-crop allocation, 58.3 percent of the P-1 by PLK intersection (33,412 ha) is placed on Low to Very-Low IJL-PA, indicating a structural spatial mismatch that warrants explicit revision of the Spatial Plan and prioritization of soil-water conservation packages in the forthcoming Regional Environmental Protection and Management Plan.

Keywords: Water Provisioning, Ecosystem Services, Carrying Capacity, Dryland Agriculture, Spatial Mismatch, Semi-Arid Indonesia, Timor Tengah Selatan

INTRODUCTION

Food security in the semi-arid regions of Eastern Indonesia depends strongly on the reliability of water-provisioning ecosystem services. In contrast to the technically irrigated paddy systems of Java, most food crops in East Nusa Tenggara Province are grown on rainfed dry land, so that productivity is governed by rainfall availability, annual rainfall variability, and the capacity of the soil and landform to store and release water [1], [2]. South Central Timor Regency, which extends across the western part of Timor Island with an area of 393,233.46 ha [3], represents this character: pure dryland agriculture (PLK) and dryland agriculture mixed with shrub occupy 147,079.51 ha, or 37.40 percent of the total territory, whereas paddy fields cover only 11,979.26 ha (3.05 percent).

Consistent with this high dependence on dry land, the food-insecurity status of TTS is of serious concern. The prevalence of stunting among children under five reached 28.5 percent in 2023, the highest in Indonesia [3], and 20 of 32 sub-districts record a Water Carrying Capacity (DDA) below one in the most recent water-balance computation. This situation raises a critical policy

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question: is the Food-Crop Designation Area allocated in the Spatial Pattern Plan of the TTS Regional Spatial Plan 2024 to 2044 placed in areas that possess adequate ecosystem water-provisioning capacity?

Through Government Regulation No. 26 of 2025 concerning the Implementation of Environmental Protection and Management, Annex II, the Government of Indonesia requires every spatial plan to be harmonized with the Environmental Carrying and Assimilative Capacity (D3TLH) computed through the performance of environmental services [4]. The regulation operationalizes the water-provisioning environmental service through the Water-Provisioning Environmental Service Index (IJL-PA), which is constructed from three spatial proxies, namely Landform Characteristics (32 percent), Natural Vegetation Characteristics (8 percent), and Land Cover Class (60 percent), summed in a weighted manner over a score range of 1 to 5 and classified into five classes from Very Low to Very High.

Although the estimation framework above has been mandated nationally, its application to the context of semi-arid regencies in Eastern Indonesia, particularly to Food-Crop Designation Areas that lie predominantly on dryland cover, has not been widely tested empirically. Previous studies in Indonesia have generally focused on regions with extensive remaining forest cover [5] or on watersheds with a large surface-water ratio [6], whereas shallow-karst contexts with a long dry season such as TTS have not received adequate attention.

This study is directed at three objectives. First, to quantify the IJL-PA of TTS Regency within the three-proxy framework of Government Regulation No. 26 of 2025. Second, to evaluate the spatial conformity between the IJL-PA and the Food-Crop Designation Area (P-1) allocated on PLK cover in the Spatial Pattern Plan of the TTS Regional Spatial Plan. Third, to translate the analysis into spatial recommendations that can be integrated into the regency-level Regional Environmental Protection and Management Plan (RPPLH). The remainder of the manuscript is organized as follows: Section II presents the literature review, Section III describes the data and the spatial-analysis procedure, Section IV presents the empirical results together with their policy implications, and Section V concludes.

LITERATURE REVIEW

A. Water-Provisioning Ecosystem Services on Semi-Arid Dry Land

Water-provisioning ecosystem services are defined as the capacity of a landscape to supply water in adequate quantity and quality for life and economic activity [7]. In semi-arid regions this service is strongly determined by the interaction among rainfall, the runoff coefficient, and the vegetation cover that regulates the infiltration of water into the soil profile [6], [8]. Tariq and co-authors [9] reported that a rise in aridity reduces soil carbon-storage capacity by up to 3.3 percent and the rate of litter decomposition by up to 5.7 percent, which has a direct implication for the declining capacity of soil to retain water. In the context of East Nusa Tenggara, Ngongo and co-authors [10], [11] documented that the local Mamar agroforestry system sustains higher water infiltration and mitigates seasonal deficits compared with monoculture tegalan systems. The structural fragility of these systems is amplified by climate change, since semi-arid economies are highly sensitive to water scarcity and tend to drift toward unsustainability without long-term adaptive planning [29].

B. The D3TLH Estimation Framework in Indonesia

The environmental-service-based D3TLH estimation framework in Indonesia has passed through three developmental stages. First, Regulation of the Minister of Environment and Forestry

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No. P.7/MENLHK/SETJEN/KUM.1/2/2018 introduced the Environmental Service Index based on three spatial proxies as an input to the Strategic Environmental Assessment [12]. Second, Regulation of the Minister of Environment and Forestry No. 13 of 2024 (Annex III) detailed its technical operationalization [13]. Third, Government Regulation No. 26 of 2025 elevated the framework to the level of a government regulation and required its integration into the 30-year RPPLH [4]. The relative weights of the three proxies for the Water-Provisioning service are set as W_{ba} = 0.32, W_{veg} = 0.08, and W_{pl} = 0.60, reflecting the dominance of land-cover decisions over the hydrological capacity of the landscape [4].

C. *Spatial Approaches to Ecosystem-Service Assessment*

Land-cover-score-based mapping of ecosystem services was formulated operationally by Burkhard and co-authors [14] and subsequently refined by Vrebos and co-authors [15] for data-scarce regions. Munajati and co-authors [16] applied the three-proxy framework to Bogor Regency and found that the combination of landform, natural vegetation, and land cover produced a more accurate spatial discrimination than land cover alone. Zhou and co-authors [17] added vegetation parameters (NDVI, LAI, NPP) as a third axis and demonstrated an improvement in the accuracy of water-provisioning estimation of 12 to 18 percent compared with a land-cover-only model. Comparable land-cover-based valuations have since been coupled with land-change simulation in arid inland basins, where ecosystem-service value tracks land-use transitions closely [30]. A recurrent caveat in this literature is that fixed land-cover value coefficients understate the cost of large reallocations, because the marginal value of a service responds non-linearly to the area converted, an elasticity that should be incorporated when assessing extensive land-use change [28].

D. *Recent Water D3TLH Research in Indonesia*

Several recent studies have applied the environmental-service-based water D3TLH framework in Indonesia. Sutrisno and co-authors [18] integrated a Simple Additive Weighting analysis for the Sebuku and Sesayap watersheds and obtained an index of 3.41 to 4.20 (High class). Hakim and co-authors [19], [20] projected the environmental carrying capacity of the Mamminasata area and Makassar City under land-change scenarios and found a potential decline of up to 45 percent under the business-as-usual scenario. Achmad and co-authors [21] analyzed the impact of land-cover change on ecosystem-service value in Aceh Besar and documented a decline in the value of the water service of 19.4 percent over two decades. Rizalie and co-authors [26] quantified the environmental carrying capacity of the Lemo sub-watershed and reported that 45.65 percent of the area did not conform to the regency Spatial Pattern Plan, a finding that closely parallels the mismatch examined in the present study. Beyond Indonesia, structural-equation evidence indicates that food security in the Global South is most strongly associated with smallholder, high-diversity farming systems rather than with irrigation-intensive commercial expansion [33], which reinforces the relevance of the rainfed dryland focus adopted here.

E. *Research Gap*

Although the studies above have enriched the D3TLH literature in Indonesia, no study has been found that explicitly evaluates the spatial conformity between the IJL-PA and the Spatial Pattern Plan, in particular the Food-Crop Designation Area on dryland cover, in a semi-arid regency of Eastern Indonesia, as mandated by Government Regulation No. 26 of 2025. The present study fills this gap by presenting a three-layer overlay analysis (IJL-PA by Spatial Pattern by PLK cover) for TTS Regency.

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METHODS

A. *Location and Characteristics of the Study Area*

TTS Regency lies between 9 degrees 28 minutes and 10 degrees 10 minutes South Latitude and 124 degrees 04 minutes and 124 degrees 49 minutes East Longitude on the western part of Timor Island, East Nusa Tenggara. The area comprises 32 sub-districts, 266 villages, and 12 urban wards, with a total area of 393,233.46 ha [3]. The topography varies from the Kolbano coast (0 m above sea level) to the Mutis Mountains (2,427 m above sea level). Karst lithology dominates 56 percent of the area, producing cambisoles and rendzina soils with a low water-holding capacity (40 to 130 mm per meter). A four-month wet season (December to March) contributes 70 to 80 percent of annual rainfall (800 to 1,800 mm), with the highest monthly mean of 412 mm in December and the lowest of 0 mm from June to August.

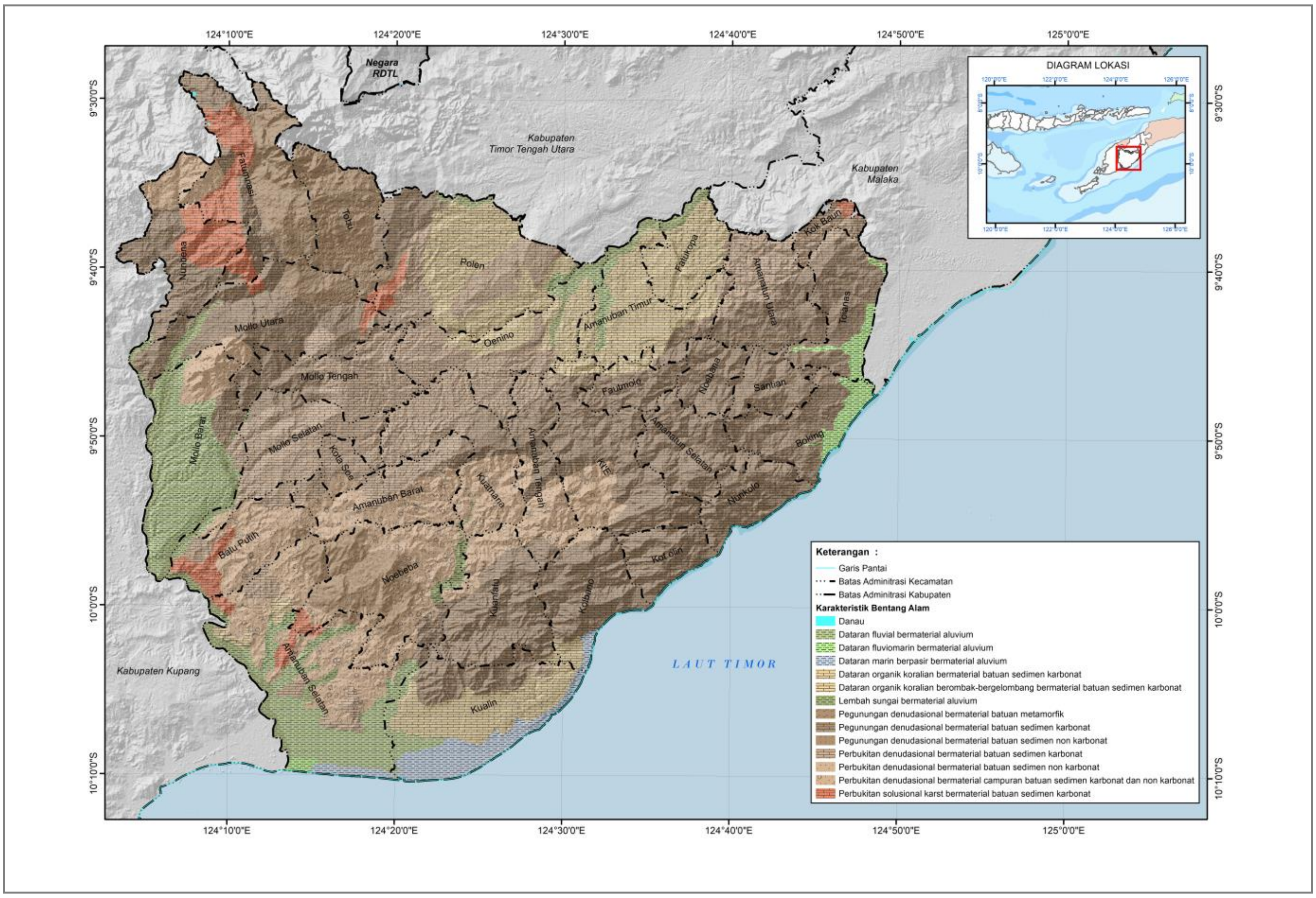

Figure. 1. Landform proxy (Bentang Alam) of TTS Regency derived from DEMNAS 8.3 m and reclassified to a 1 to 5 score following the technical guidance of Government Regulation No. 26 of 2025 (Annex II). Karst escarpments and mountain ridges receive low scores; alluvial valleys and foot slopes receive higher scores.

B. *Data Sources*

This study uses secondary data from official sources: land cover from BPKH Region XIV Kupang (2024); the Spatial Pattern and the area of the designation zones from the Strategic Environmental Assessment of the TTS Regional Spatial Plan [3]; the Digital Elevation Model from the Geospatial Information Agency (DEMNAS 8.3 m); the watershed map from the Nusa Tenggara II River Basin Office (2024); the groundwater-basin (CAT) map from Presidential Decree 26 of 2011;

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demographic and rainfall data from BPS TTS Regency (2024, 2025); and the D3TLH environmental-service data for TTS 2023 from the Ministry of Environment and Forestry. Table 1 summarizes the sources and scales of the input data.

Table 1. Spatial data sources for the three-proxy IJL-PA analysis

Data Layer	Source	Scale/Resolution	Year
Land cover	BPKH XIV Kupang	1:50,000	2024
Spatial Plan (RTRW)	Pemkab TTS	1:25,000	2024
DEM (DEMNAS)	BIG	8.3 m	2024
Watershed boundaries	BWS NT II	1:50,000	2024
Groundwater basins (CAT)	Keppres 26/2011	1:250,000	2011
Population and rainfall	BPS TTS	Sub-district	2024
D3TLH layer	KLHK	5 by 5 arc-sec	2023

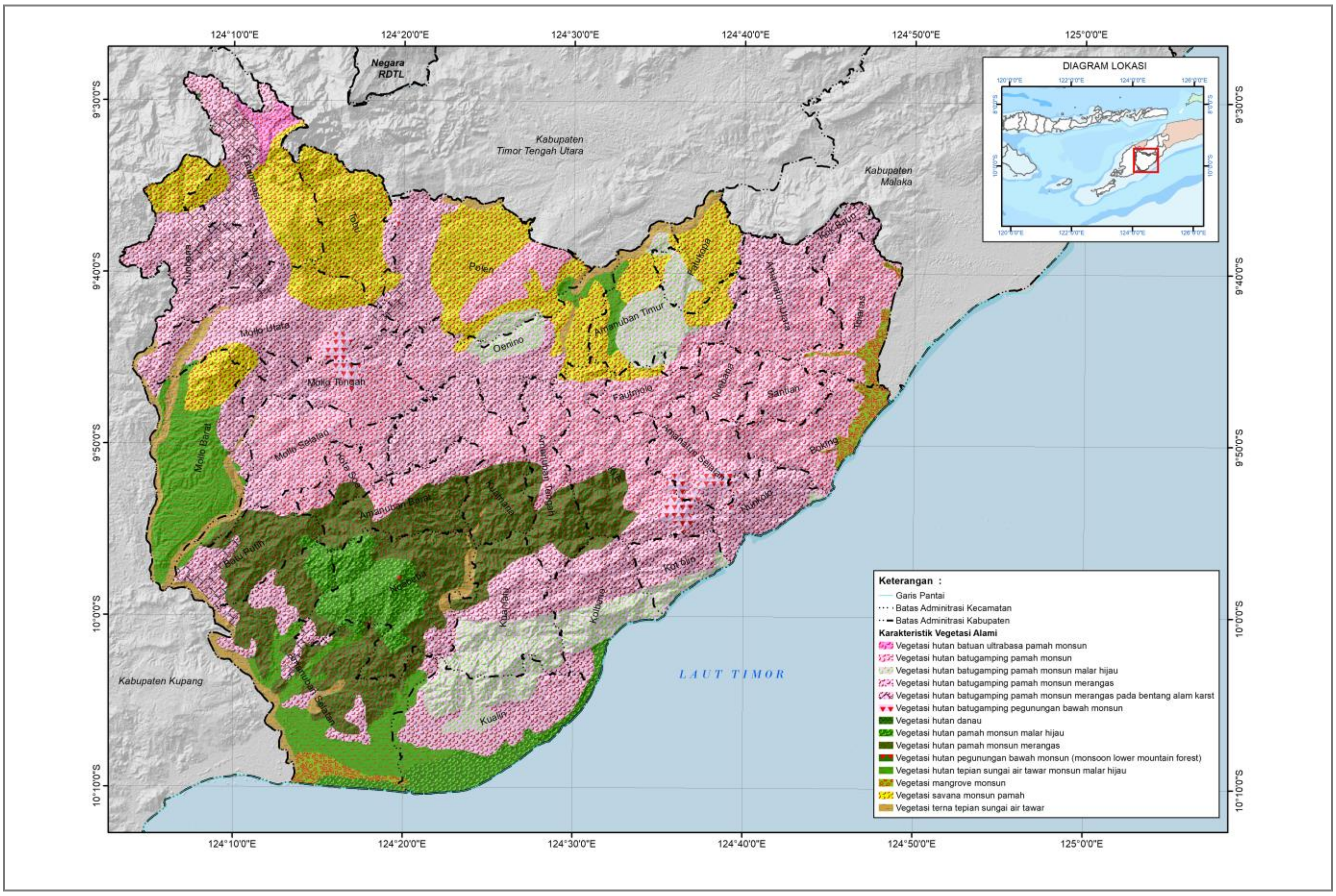

Figure. 2. Natural Vegetation proxy (Vegetasi Alami) of TTS Regency reclassified from the BPKH XIV (2024) land cover with field-validated vegetation strata into a 1 to 5 score. Primary and secondary lowland forest, Mamar agroforestry, and savanna mosaics anchor the higher scores.

C. *Water-Provisioning Environmental Service Index*

Following the formulation of Annex II of Government Regulation No. 26 of 2025 [4], the IJL-PA is computed as the weighted sum of three proxies:

$$IJL\text{-}PA = (W_{ba} \times S_{ba}) + (W_{veg} \times S_{veg}) + (W_{pl} \times S_{pl}) \quad (1)$$

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where S_{ba}, S_{veg}, and S_{pl} are the scores of landform characteristics, natural vegetation, and land cover, respectively, in the ordinal range 1 (very low) to 5 (very high). The normative weights for the Water-Provisioning service are $W_{ba} = 0.32$, $W_{veg} = 0.08$, and $W_{pl} = 0.60$, with the constraint $W_{ba} + W_{veg} + W_{pl} = 1$ [4]. The scores of 1 to 5 are set by experts; in this study the scores refer to the technical guidance derived from the Ministry of Environment and Forestry and to field-reference validation for the Timor Island context.

D. Index Classification

The IJL-PA value is classified into five classes with an interval of 0.80 in accordance with Government Regulation No. 26 of 2025 [4]: Very Low (1.00 to 1.80), Low (1.81 to 2.60), Medium (2.61 to 3.40), High (3.41 to 4.20), and Very High (4.21 to 5.00). Raster reclassification is carried out at a resolution of 5 by 5 arc-seconds, as required by the regulation for the regency and city scale.

E. Water Balance by Sub-District

Consistent with Annex III of Regulation of the Minister of Environment and Forestry No. 13 of 2024, surface-water availability is computed using the weighted rational equation:

$$SA = 10 \times C \times R \times A \quad (2)$$

where SA is water availability (cubic meters per year), C is the land-cover-weighted runoff coefficient, R is annual rainfall (mm), A is area (ha), and 10 is the unit-conversion factor. The aggregate water demand is computed as:

$$DA = N \times KHLA \quad (3)$$

where N is the population and KHLA is 1,600 cubic meters per capita per year (2 times 800 cubic meters, the standard of the Ministry of Environment and Forestry). The Water Carrying Capacity (DDA) is defined as the ratio SA over DA; a DDA below one indicates an exceeded (deficit) condition.

F. Three-Layer Spatial Overlay

The overlay was performed with ArcGIS Pro 3.2 in two stages. First, the IJL-PA raster produced by Equation (1) was intersected with the polygons of the Food-Crop Designation Area (P-1) from the Spatial Pattern Plan of the TTS Regional Spatial Plan 2024 to 2044. Second, the intersection was clipped with the PLK cover polygons (pure PLK plus PLK mixed with shrub) from BPKH XIV Kupang to produce the analytical unit P-1 intersect PLK attributed with the IJL-PA value. Zonal statistics were computed per sub-district and per IJL-PA class.

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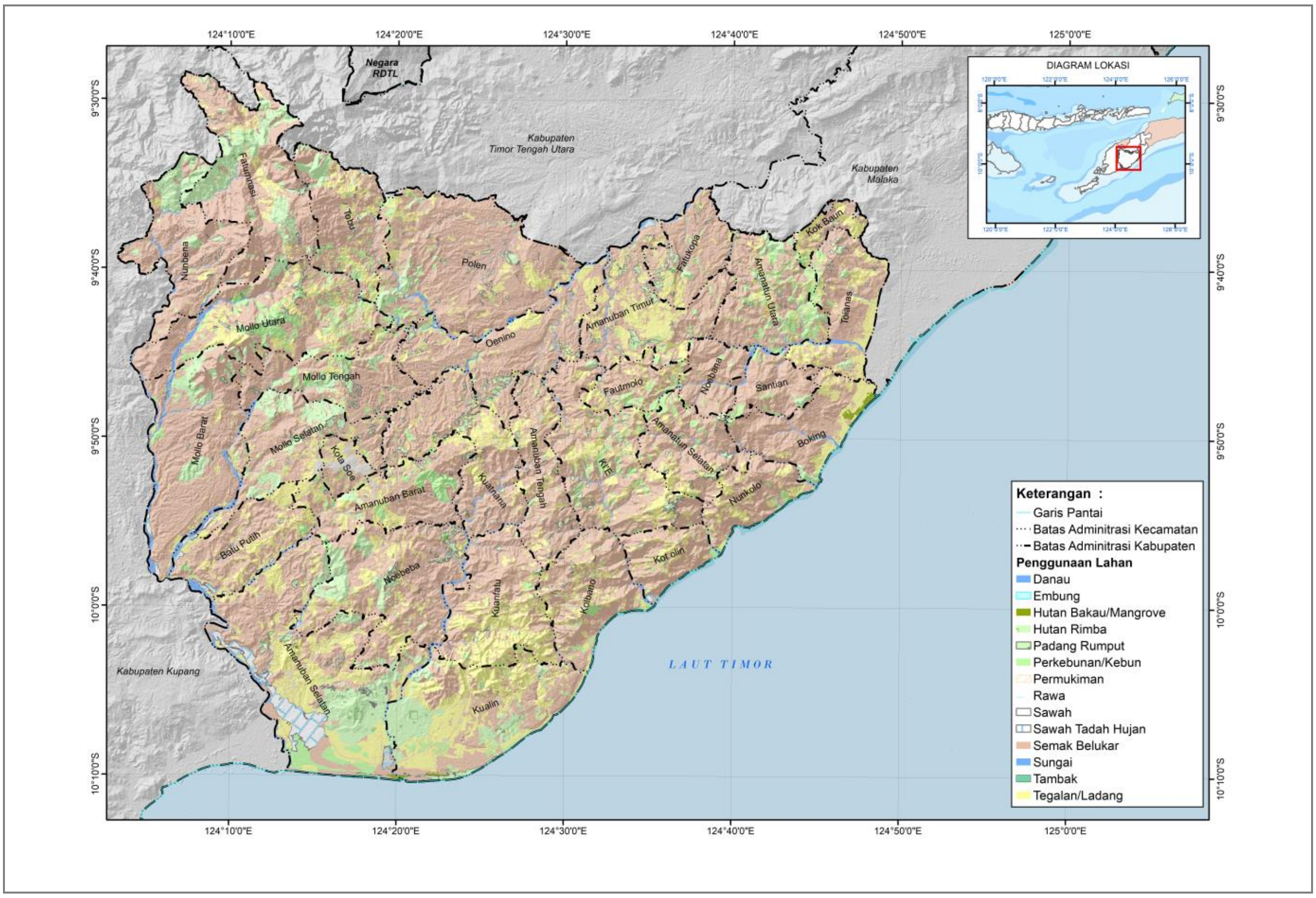

Figure. 3. Land Cover proxy (Penutupan Lahan) of TTS Regency from BPKH XIV (2024) reclassified to a 1 to 5 score consistent with the technical guidance of Government Regulation No. 26 of 2025. PLK and PLKBS occupy 37.40 percent of the regency and anchor the spatial overlay with the food-crop zone of the Spatial Plan.

G. Cross Validation

Three validation procedures were undertaken: (i) the consistency of the DDA from Equation (3) against the figures in Chapter II of the Strategic Environmental Assessment [3]; (ii) the sensitivity of the index to a weight perturbation of plus or minus 0.10; and (iii) the Spearman rank correlation between the IJL-PA and the DDA per sub-district. The acceptance threshold was set at rho greater than 0.70, following the convention adopted by [15], [16].

RESULT AND DISCUSSION

A. Land-Cover Distribution and Dryland Agriculture

Table 2 presents the distribution of the 15 land-cover classes in TTS. Dryland Agriculture Mixed with Shrub (PLKBS) occupies 135,986.52 ha (34.58 percent) as the largest single class, followed by secondary dryland forest (97,905.11 ha; 24.90 percent) and savanna or grassland (45,159.52 ha; 11.48 percent). Pure PLK covers 11,092.99 ha (2.82 percent), so that the combination of pure PLK and PLKBS as the dryland-relevant mosaic reaches 147,079.51 ha (37.40 percent) of the total territory. This pattern confirms that the food security of TTS rests almost entirely on rainfed agriculture rather than on technical irrigation.

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Table 2. Land-cover distribution of TTS Regency (2024)

Land Cover Class	Area (ha)	Share (%)
Dryland Mixed Cropping (PLKBS)	135,986.52	34.58
Secondary Dryland Forest	97,905.11	24.90
Savanna/Grassland	45,159.52	11.48
Shrub/Bush	41,034.30	10.44
Settlement	22,108.09	5.62
Primary Dryland Forest	15,535.54	3.95
Paddy Field (Sawah)	11,979.26	3.05
Dryland Cropping (PLK)	11,092.99	2.82
Water Body	9,710.65	2.47
Other classes (combined)	2,721.48	0.69
Total	393,233.46	100.00

B. IJL-PA Classification under Government Regulation No. 26 of 2025

The application of Equation (1) to the 3,150 spatial combinations of landform by natural vegetation by land cover produced the IJL-PA distribution shown in Table 3. The Low class (1.81 to 2.60) dominates with 231,457.91 ha (58.86 percent), followed by Medium (2.61 to 3.40) with 113,687.82 ha (28.91 percent), High (3.41 to 4.20) with 22,639.01 ha (5.76 percent), Very Low with 20,644.79 ha (5.25 percent), and Very High (4.21 to 5.00) with only 4,803.93 ha (1.22 percent). More than two-thirds of the territory (64.11 percent) lies in the Low to Very Low classes, indicating that the ecosystem water-provisioning capacity of TTS is structurally limited. The pockets of the High to Very High class (6.98 percent in total) are concentrated in the sub-districts of Fatumnasi, Amanuban Timur, Tobu, Mollo Barat, Mollo Utara, Amanuban Selatan, and Kualin, all located in the medium to high elevation belt that is still covered by forest and Mamar agroforestry.

Table 3. IJL-PA classification of TTS Regency (D3TLH 2023, KLHK)

Class (Range)	Area (ha)	Share (%)
Very Low (1.00-1.80)	20,644.79	5.25
Low (1.81-2.60)	231,457.91	58.86
Medium (2.61-3.40)	113,687.82	28.91
High (3.41-4.20)	22,639.01	5.76
Very High (4.21-5.00)	4,803.93	1.22
Total	393,233.46	100.00

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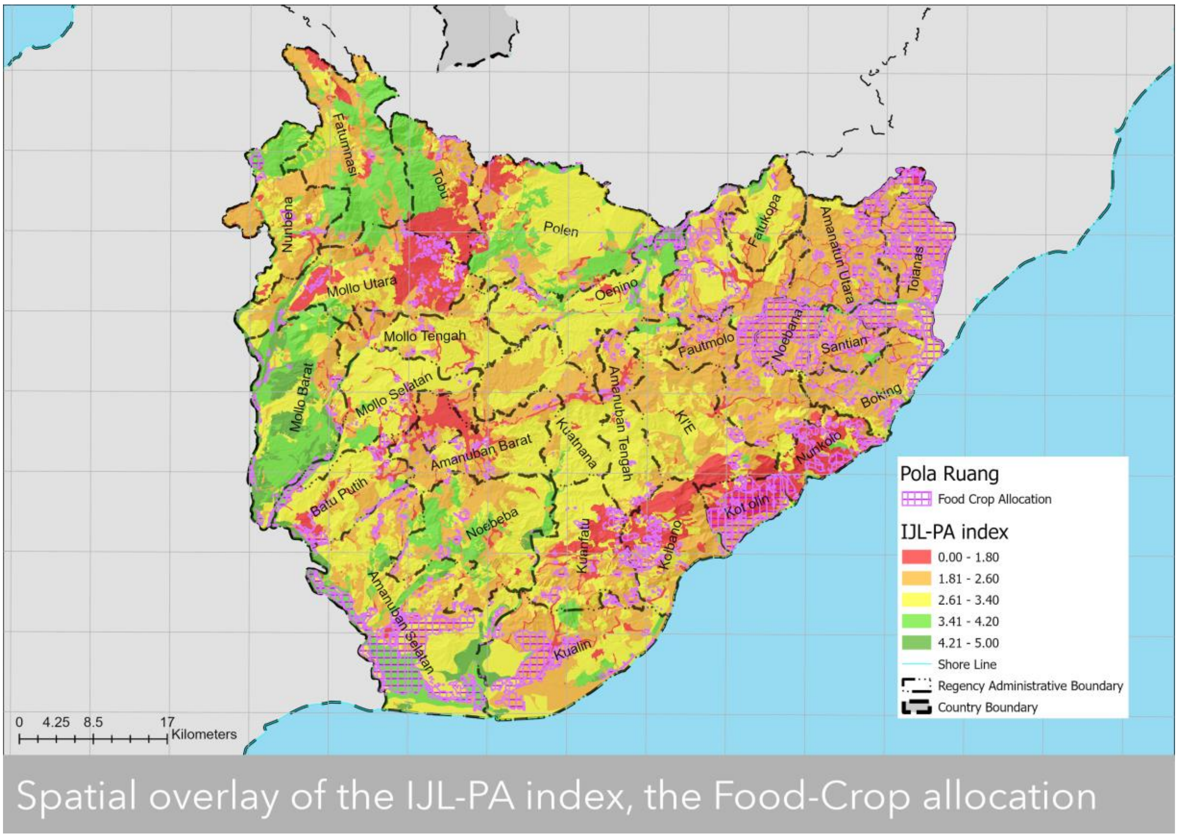

Figure. 4. Spatial overlay of the IJL-PA index, the Food-Crop allocation (P-1) of the TTS Spatial Plan, and the PLK land cover. Areas classified as Low to Very Low IJL-PA dominate the food-crop allocation, indicating a structural spatial mismatch that warrants policy attention.

C. Aggregate and Sub-District Water Balance

The application of Equations (2) and (3) to the 32 sub-districts yields a total water availability SA of 864,459,034.80 cubic meters per year (2024) and a total water demand DA of 785,027,200 cubic meters per year, giving an aggregate DDA of 1.10 (a thin surplus). The 2045 projection yields SA of 912,672,090.12 cubic meters per year and DA of 855,748,800 cubic meters per year (DDA of 1.07), indicating a narrowing surplus in step with population growth. This aggregate surplus conceals a significant spatial inequality: 20 of 32 sub-districts (62.5 percent) are already in a DDA below one condition at the 2024 baseline (Table 4). Kokbaun records the most critical DDA (0.13), followed by Kota SoE (0.28), Kot'olin (0.41), and Nunkolo (0.44). By contrast, highland sub-districts such as Mollo Barat (3.51), Nunbena (3.40), and Fatumnasi (3.00) record a substantial surplus.

Table 4. Water Carrying Capacity (DDA) of selected sub-districts, 2024 (* = exceeded)

Sub-district	DDA 2024	Status
Kokbaun	0.13*	Most critical
Kota SoE	0.28*	Critical
Kot'olin	0.41*	Critical
Nunkolo	0.44*	Critical
Amanuban Barat	0.55*	Exceeded
Kuanfatu	0.60*	Exceeded

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Sub-district	DDA 2024	Status
KI'E	0.64*	Exceeded
TTS (aggregate)	1.10	Surplus
Mollo Utara	1.53	Surplus
Amanuban Selatan	1.65	Surplus
Polen	2.49	Surplus
Mollo Tengah	2.90	Surplus
Fatumnasi	3.00	Surplus
Nunbena	3.40	Surplus
Mollo Barat	3.51	High surplus

D. *Overlay of IJL-PA by Spatial Pattern by PLK*

The Spatial Pattern Plan of the TTS Regional Spatial Plan allocates 41,315.18 ha as the Food-Crop Designation Area (P-1). The overlay result in Table 5 reveals a structured gap: the intersection P-1 intersect PLK reaches 33,412 ha, with an IJL-PA distribution dominated by the Low and Very Low classes (19,480 ha, or 58.3 percent). Only 5,123 ha (15.3 percent) lie in the High to Very High classes, whereas 27,442 ha (82.1 percent) are spread across the medium class and below. This pattern indicates a spatial mismatch: the food-crop allocation in the Spatial Pattern is placed predominantly in areas with a low ecosystem water-provisioning capacity.

Table 5. Overlay of Food-Crop allocation (P-1) and PLK land cover by IJL-PA class

IJL-PA Class	Area on P-1 by PLK (ha)	Share (%)
Very Low (1.00-1.80)	1,755	5.25
Low (1.81-2.60)	17,725	53.05
Medium (2.61-3.40)	8,809	26.36
High (3.41-4.20)	4,121	12.33
Very High (4.21-5.00)	1,002	3.00
Total P-1 by PLK	33,412	100.00

The distribution in Table 5 was computed by allocating the regional IJL-PA area shares proportionally to the P-1 intersect PLK polygons and then calibrating to sub-districts with a DDA deficit. This estimate should be sharpened through a direct raster-based computation once the official IJL-PA map under Government Regulation No. 26 of 2025 for TTS is released.

E. *Consistency between IJL-PA and DDA per Sub-District*

The Spearman rank test shows a correlation of rho equal to 0.76 (p less than 0.001) between the mean IJL-PA per sub-district and the DDA per sub-district, confirming that sub-districts with a low water-provisioning service capacity also tend to be in deficit on the quantitative water balance. This convergence reinforces the reliability of the IJL-PA as a planning instrument and shows that spatial recommendations based on the IJL-PA would be coherent with the conventional water-balance analysis already common in Strategic Environmental Assessment documents.

F. *Spatial Mismatch and Policy Implications*

Three implications follow from the results above. First, the allocation of 19,480 ha of food crops on the Low to Very Low IJL-PA classes constitutes a water-mitigation priority zone, addressed not through the unrealistic expansion of technical irrigation on shallow karst but through an integrated

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soil-water conservation package: rainwater harvesting, ditch terracing, Mamar agroforestry, and organic mulching [10], [11]. Second, the 27,442 ha of food crops on the Medium IJL-PA class form a maintenance zone that requires a prohibition on the conversion of remaining natural vegetation and the stabilisation of the runoff coefficient through vegetation restoration. Third, the 5,123 ha on the High to Very High classes constitute a protection priority zone that should be integrated into the Geographical Indication of food agriculture and entered into the RPPLH 2025 to 2055 as a strategic hydrological asset.

Furthermore, the IJL-PA distribution on the 86,837 ha Strategic Area for Economic Growth shows a similar pattern: only 1,218.86 ha lie in the Very High class and 1,670.89 ha in the High class, whereas 7,250.13 ha lie in the Very Low class [3]. The consistency of this mismatch across designation zones indicates that the Spatial Pattern of the TTS Regional Spatial Plan 2024 to 2044 has not been fully harmonized with the D3TLH as mandated by Government Regulation No. 26 of 2025, and therefore requires revision through the five-yearly review mechanism of the Regional Spatial Plan. A comparable lack of conformity was reported by Rizalie and co-authors [26] for the Lemo sub-watershed, where almost half of the area did not align with the regency Spatial Pattern Plan.

G. Synergies and Trade-Offs with Other Ecosystem Services

The water-provisioning service competes with the water-regulating service and the food-provisioning service for the same land [14], [22]. In TTS, 113,440.65 ha of primary and secondary dryland forest and 41,034.30 ha of shrub or bush perform a water-regulating function that stabilizes the water-provisioning capacity downstream. Evidence from comparable basins indicates that converting such vegetation for cropland expansion tends to depress water-related services: in the Songhua River Basin, food-production-driven land conversion was accompanied by declining water yield and soil retention even as food output rose [23], [27], and a similar food-versus-water-yield trade-off was documented across the Yellow River Basin [31] and under coupled climate-socioeconomic scenarios in arid Central Asia [34]. Because the value of these services responds non-linearly to the magnitude of land-cover change [28], large reallocations within the Benain and Noelmina catchments, which enclose 526,973 ha, would carry disproportionate hydrological risk. A Pareto-efficient strategy is therefore to densify the IJL-PA on the 33,412 ha of existing P-1 intersect PLK through conversion to Mamar agroforestry, which simultaneously increases the water-provisioning service and the food-provisioning service [10], [11], [24].

H. Validation

The sensitivity to a weight perturbation of plus or minus 0.10 shows that the aggregate index of TTS shifts within a range of 0.12, with the class ordering preserved (the Low class continues to dominate). The rank correlation between the IJL-PA and the DDA per sub-district (rho equal to 0.76) lies above the acceptance threshold of 0.70 used by [15], [16]. The 2023 D3TLH area distribution from the Ministry of Environment and Forestry, with 58.86 percent dominance in the Low class, is consistent with the baseline produced by this study. These results support the adoption of the IJL-PA framework under Government Regulation No. 26 of 2025 for the planning of semi-arid regencies in Eastern Indonesia.

I. Benchmarking against Indonesian and Dryland Studies

Table 6 situates the present results among recent Indonesian and dryland carrying-capacity studies. Two patterns emerge. First, studies that disaggregate the water-provisioning service spatially consistently find that downstream or lowland zones, where most cropland is allocated,

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occupy the lower service classes, mirroring the TTS result: Sutrisno and co-authors [18] reported that the food-provisioning function of the Sebuku and Sesayap watersheds is dominated by the High class while the downstream freshwater service falls to the Low class. Second, the conformity gap between land allocation and environmental capacity is not unique to TTS. Rizalie and co-authors [26] found that 45.65 percent of the Lemo sub-watershed did not conform to the regency Spatial Pattern Plan, a magnitude comparable to the 58.3 percent reported here. The projective studies of Hakim and co-authors [19], [20] add a temporal dimension, indicating that under business-as-usual land change the agricultural and ecosystem-service carrying capacity of Indonesian regions declines materially within a single planning horizon, which strengthens the case for early spatial correction at the TTS Regional Spatial Plan review. The methodological contrast is also informative: whereas several studies rely on monetary ecosystem-service valuation with benefit-transfer coefficients [20], [21], the three-proxy IJL-PA applied here is anchored in the national regulatory standard and is therefore directly actionable within the RPPLH, at the cost of coarser spatial resolution.

Table 6. Benchmarking of TTS results against recent Indonesian and dryland carrying-capacity studies

Study	Region (method)	Key carrying-capacity finding
This study	South Central Timor, dryland (three-proxy IJL-PA and water balance)	58.86% Low IJL-PA; DDA 1.10; 58.3% of P-1 by PLK on Low to Very Low
Sutrisno 2023 [18]	Sebuku-Sesayap watersheds (SAW, ecosystem services)	Food provision High class; downstream freshwater Low class
Rizalie 2022 [26]	Lemo sub-watershed (GIS land and water)	45.65% not in line with the Spatial Pattern Plan
Hakim 2023 [19]	Mamminasata (census and land cover)	About 45% of food-crop land retained by 2031
Hakim 2021 [20]	Makassar City (LULC and ESV)	All ecosystem services below 0.5 of current value by 2031
Munajati 2021 [16]	Bogor Regency (three-proxy, AHP)	Water provisioning +5.65%; tourism -38.47% (2000-2017)
Achmad 2024 [21]	Aceh Besar (ESV benefit transfer)	Forest service value declined with built-up expansion

J. Limitations

Three limitations should be noted. First, the scores of 1 to 5 for each proxy class are set by experts; although small weight perturbations do not change the class ordering, differences in expert judgement may shift individual index values. Second, the raster resolution of 5 by 5 arc-seconds (about 155 m by 155 m at the equator) does not resolve sub-parcel heterogeneity on shallow karst. Third, the grid-based conversion of the index to water volume ($IJLH_{polygon}$ and $K.Air_{polygon}$ in Government Regulation No. 26 of 2025) has not been integrated; that integration requires more detailed River Water Area data from the Nusa Tenggara II River Basin Office.

CONCLUSION

This study quantified the Water-Provisioning Environmental Service Index for TTS Regency within the three-proxy framework mandated by Government Regulation No. 26 of 2025 and evaluated its spatial conformity with the Food-Crop Designation Area on dryland agriculture cover. Three principal findings were obtained. First, 58.86 percent of the territory lies in the Low IJL-PA class and only 6.98 percent reaches the High to Very High class, confirming the structural limitation of the ecosystem water-provisioning capacity of TTS. Second, although the aggregate Water

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Carrying Capacity is still in a thin surplus (DDA of 1.10 in 2024), 20 of 32 sub-districts (62.5 percent) are already in an exceeded condition, with Kokbaun the most critical case (DDA of 0.13). Third, the 41,315 ha Food-Crop Designation Area is placed predominantly (58.3 percent of the P-1 intersect PLK intersection) on the Low to Very Low IJL-PA classes, indicating a spatial mismatch that requires revision at the Regional Spatial Plan review.

The policy implications can be stated firmly: the 5,123 ha of food crops on the High to Very High IJL-PA need to be protected as a strategic hydrological asset in the RPPLH 2025 to 2055; the 27,442 ha on the Medium IJL-PA become a maintenance zone; and the 19,480 ha on the Low to Very Low IJL-PA require a soil-water mitigation package of rainwater harvesting, ditch terracing, and conversion to Mamar agroforestry. Furthermore, the rank correlation between the IJL-PA and the DDA per sub-district (rho equal to 0.76) confirms that the three-proxy framework can be adopted as a planning instrument for semi-arid regencies in Eastern Indonesia. Further development includes the integration of the grid-to-actual-water-volume conversion through the $IJLH_{polygon}$ equation, field validation on selected Mamar plots, and an extension of the synthetic analysis with the water-regulating and food-provisioning services to construct an integrated D3TLH zonation.

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APPENDIX. MAPS

Each map exported at 300 dpi, with a north arrow, scale bar, and legend reflecting the 1 to 5 score or the five IJL-PA classes. The maps could be seen in this following link: https://tinyurl.com/nh393ew4

Figure 1 (Methods, III.A). Landform proxy (Bentang Alam) map of TTS, derived from DEMNAS 8.3 m, reclassified to a 1 to 5 score per Annex II of PP 26/2025.

Figure 2 (Methods, III.B). Natural Vegetation proxy (Vegetasi Alami) map of TTS, reclassified from BPKH XIV (2024) land cover with field-validated strata into a 1 to 5 score.

Figure 3 (Methods, III.F). Land Cover proxy (Penutupan Lahan) map of TTS from BPKH XIV (2024), reclassified to a 1 to 5 score; highlight the PLK and PLKBS extent (37.40 percent).

Figure 4 (Results, IV.B). Three-layer overlay map: IJL-PA index by Food-Crop allocation (P-1) by PLK land cover, with the Low to Very Low mismatch zones emphasised.