

Environmental carrying capacity based on water provision of Kutai Kartanegara Regency

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ABSTRACT

The environmental carrying capacity is the ability of the environment to support human life and other living beings, while the environmental absorption capacity is the ability to absorb substances, energy, or other components that enter it. This research aims to analyze the carrying capacity and absorption capacity of the environment based on ecosystem services for water provision in Kutai Kartanegara Regency. The ecosystem services method is used to calculate the carrying capacity and absorption capacity of the environment using parameters such as landscapes, vegetation types, and land cover. The analysis results show that most of the area falls into the low-class category, with an extent of 1.787.104,66 ha (70,66%). Tabang District dominates the very low class, while high to very high classes are found in parts of Muara Wis, Muara Kaman, and Kenohan districts.

INTRODUCTION

According to Law No. 6 of 2023 (UU No. 6 Tahun 2023), environmental carrying capacity refers to the ability of the environment to support human life, other living organisms, and the balance between them. Meanwhile, environmental assimilative capacity refers to the ability of the environment to absorb substances, energy, and/or other components introduced into it. The assessment of environmental carrying and assimilative capacities can be conducted through a spatially explicit ecosystem services approach, using ecoregional characteristics, particularly landforms and vegetation types, and land use as the primary basis for parameter development and spatial analysis. This approach serves as an initial step in generating data and information to support the sustainable planning and management of natural resources (Ministry of Environment and Forestry [KLHK], 2021).

Kutai Kartanegara Regency is located in East Kalimantan Province and covers an area of approximately 2,529,224 hectares. Administratively, the regency comprises 18 sub-districts: Anggana, Kembang Janggut, Kenohan, Kota Bangun, Kota Bangun Darat, Loa Janan, Loa Kulu, Marang Kayu, Muara Badak, Muara Jawa, Muara Kaman, Muara Muntai, Muara Wis, Sanga-Sanga, Sebulu, Tabang, Tenggarong, and Tenggarong Seberang. Geographically and functionally, Kutai Kartanegara is characterized by three major regional zones: the upstream, central, and coastal zones (Bappeda Kukar, 2022). These zones exhibit different environmental characteristics, land-use patterns, and levels of development, which may influence the availability and capacity of ecosystem services.

Access to clean water remains an important environmental and development issue in Kutai Kartanegara. Approximately 23–24% of households reportedly do not yet have access to adequate clean-water services, while sanitation conditions remain inadequate in several areas. This situation indicates that the availability, accessibility, and distribution of clean-water services have not yet been evenly achieved throughout the regency (Bappeda Kukar, 2022). Differences in environmental conditions among the upstream, central, and coastal zones may further contribute to spatial variations in the capacity of ecosystems to provide water-related services.

In this context, identifying the Environmental Carrying Capacity and Environmental Capacity (ECC-EC) of Kutai Kartanegara Regency is important for supporting the protection and sustainable management of natural resources and environmental functions. An assessment of ECC-EC can provide spatial information on the extent to which ecosystems are able to support human needs while maintaining ecological functions. Therefore, this study aims to analyze the Environmental Carrying Capacity and Environmental Capacity of water-provisioning ecosystem services across the sub-districts of Kutai Kartanegara Regency. The analysis is expected to identify spatial variations in the performance and capacity of ecosystems to provide water services, thereby providing a scientific basis for water-resource management, spatial planning, and environmental management in the regency.

Despite the importance of water availability for human well-being and regional development, spatial information regarding the capacity of ecosystems to provide water services in Kutai Kartanegara remains limited. Differences in topography, vegetation, land use, and regional characteristics may result in substantial variations in the ability of ecosystems to provide water among sub-districts. Consequently, a spatial assessment of Environmental Carrying Capacity and Environmental Capacity (ECC-EC) is needed to identify areas with relatively high or low capacity to provide water-related ecosystem services. Such information is essential for supporting evidence-based spatial planning, water-resource management, and environmental protection. Therefore, this study aims to assess the carrying capacity and environmental capacity of water-provisioning ecosystem services in each sub-district of Kutai Kartanegara Regency, and to identify their spatial distribution and performance as a basis for sustainable environmental management.

METHODOLOGY

Research Location and Time

This research was conducted from November 2024 to April 2025. The location or area that became the object of the research or data collection is the Kutai Kartanegara Regency, East Kalimantan Province. Data processing was conducted at the Pusat Pengembangan Infrastruktur Informasi Geospasial (PPIIG) located at the di Lembaga Penelitian dan Pengabdian Masyarakat (LP2M) of Mulawarman University, Samarinda. The location that became the object of the research can be seen in Figure 1.

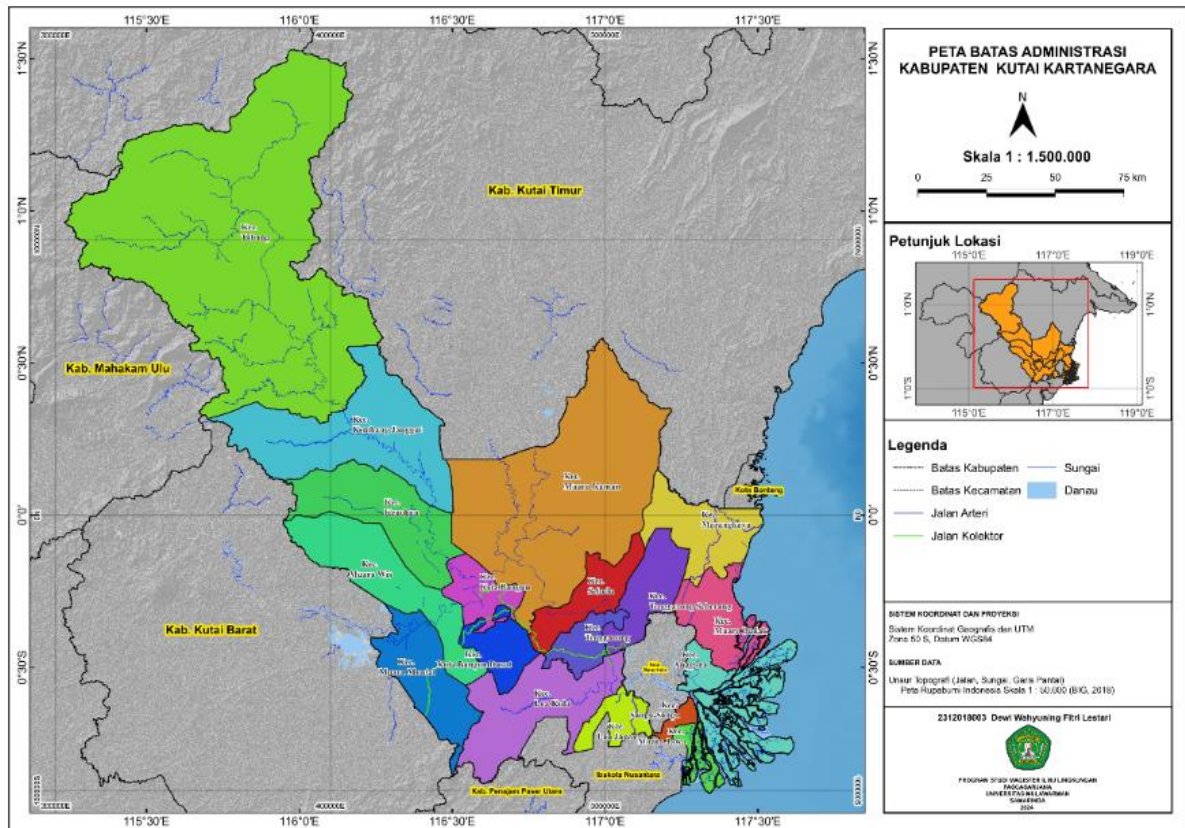


Figure 1. Research location map

Methods of Data Collection and Processing

Data was collected using a literature study approach and secondary data. The secondary data used includes spatial data in shapefiles of the administrative boundaries of Kutai Kartanegara Regency for 2023, landscape for 2021, vegetation types for 2021, and land cover for 2023. Data processing was conducted through spatial analysis using the Quantum Geographic Information System (QGIS) software version 3.34.8, to calculate and illustrate the results based on the stages of data calculation utilized.

Data Processing Stage

1. Preparation of Base Map and Thematic Map

The base map, the administrative area map of the sub-district in Kutai Kartanegara Regency, and the thematic map, which is the eco-region map with land cover, were merged. Furthermore, geometric corrections were made to fix the shapefile that had spatial errors.

2. Merging Attribute Tables with Ecosystem Service Score and Weight Table

This stage involves merging the score and weight tables of ecosystem services based on three parameters: topography, type of natural vegetation, and land cover on the map that has undergone overlay steps. This step uses the Spreadsheet Layer plugin to facilitate the merging of tables from Microsoft Excel format to QGIS software. The merged data consists of scores and weights from the three parameters: topography, type of vegetation, and land cover. The score range used is between 1 and 5, where the number 1 indicates the lowest condition and the number 5 indicates the highest condition for each parameter as determined by experts through the expert judgment method. Based on SK. 146 of 2023, the weight used in

calculating the ecosystem service for water provision is 28% for landscape, 12% for vegetation type, and 60% for land cover. The scores for each parameter are presented in Table 1., Table 2., Table 3.

Table 1. Landscape parameter score

No.	Landscape Type	Score	No.	Landscape Type	Score
1	Lake	5	11	Structural mountains of folded non-carbonate sedimentary rocks	3
2	Alluvial material floodplain	4	12	Structural plutonic mountains made of intrusive igneous rock	2
3	Fluviomarine plain made of alluvium	3	13	Solutional karst hills made of carbonate sedimentary rocks	2
4	Sandy marine plains made of alluvial material	2	14	Structural hills of folded metamorphic rock material	3
5	Organic land made of peat	3	15	Structural hills of folded non-carbonate sedimentary rock	3
6	The karst solutional plains made of carbonate sedimentary rocks	3	16	Structural hills of folded mixture materials of carbonate and non-carbonate sedimentary rocks.	3
7	The structural plain of undulating folds is made of non-carbonate sedimentary rock.	3	17	Structural hills of plutonic material composed of igneous rocks	1
8	The undulating volcanic plain is composed of a mixture of extrusive igneous rock and pyroclastic material.	4	18	Volcanic hills made of pyroclastic material	4
9	Valley of the river with alluvial material	5	19	The volcanic hills of lava domes made of igneous rock material.	2
10	Denudational mountains made up of a mix of extrusive igneous rocks and pyroclastic materials.	3			

Source: Pusat Pengembangan Infrastruktur Informasi Geospasial (PPIIG) Universitas Mulawarman

Table 2. Vegetation Type Score Parameter

No.	Vegetation Type	Score	No.	Vegetation Type	Score
1	Vegetation of ultramafic rock forests in lowland areas	2	10	Mangrove swamp vegetation	3
2	Vegetation of the limestone forest on the karst landscape	4	11	Freshwater swamp forest vegetation	5
3	Lake Forest Vegetation	5	12	Vegetation of mangrove riverbank forests	3
4	Dipterocarp lowland forest vegetation	5	13	Mangrove vegetation	2
5	Peat forest vegetation	2	14	Vegetation of brackish water marsh herbs	3
6	Heath forest vegetation	2	15	Freshwater swamp herbaceous vegetation	5
7	Lowland forest vegetation (non-dipterocarp)	5	16	Peat swamp vegetation	2
8	Coastal forest vegetation	4	17	Herbaceous vegetation of brackish water riverbanks	3

No.	Vegetation Type	Score	No.	Vegetation Type	Score
9	Lower mountain forest vegetation	4	18	Herbaceous vegetation of freshwater riverbanks	5

Source: Pusat Pengembangan Infrastruktur Informasi Geospasial (PPIIG) Universitas Mulawarman

Table 3. Land Cover Parameter Score

No.	Land Cover Type	Score	No.	Land Cover Type	Score
1	Airport/Port	1	11	Mining	1
2	Swamp Shrub	2	12	Wetland Agriculture	2
3	Primary Dryland Forest	3	13	Dryland Agriculture	2
4	Secondary Dryland Forest	2	14	Swamp	4
5	Primary Mangrove Forest	1	15	Savanna/Grassland	1
6	Secondary Mangrove Forest	1	16	Shrubland	1
7	Primary Swamp Forest	3	17	Fishpond (Aquaculture)	1
8	Plantation Forest	1	18	Bare Land	1
9	Plantation	1	19	Water Body	5
10	Settlement	1			

Source: Pusat Pengembangan Infrastruktur Informasi Geospasial (PPIIG) Universitas Mulawarman

3. Calculation of the Water Supply Ecosystem Service Index

The calculation formula used in the Ecosystem Service Index refers to Buku Pedoman Penentuan Daya Dukung dan Daya Tampung Lingkungan Hidup Kementerian Lingkungan Hidup dan Kehutanan in 2019 and SK 146 of 2023 concerning the Penetapan Daya Dukung dan Daya Tampung Air Nasional. The formula used in the calculation of DDDTLH is:

$$IJE = (W_{BA} \times S_{BA}) + (W_{TV} \times S_{TV}) + (W_{PL} \times S_{PL}) \quad (1)$$

Where:

IJE : Ecosystem Service Index
 W_{BA} : Landscape Weight
 S_{BA} : Landscape Score
 W_{TV} : Vegetation Type Weight
 S_{TV} : Vegetation Type Score
 W_{PL} : Land Cover Weight
 S_{PL} : Land Cover Score

4. Classification of Ecosystem Service Index Categories

The next stage is to classify the class of water supply ecosystem services according to the results of the calculations. The classification of the types of ecosystem service classes can be seen in Table 4.

Table 4. Classification of ecosystem service classes

No.	Index of Ecosystem Services	Ecosystem Services Class	Coloring on The Map
1	4,21 – 5,00	Very High	
2	3,41 – 4,20	High	
3	2,61 – 3,40	Moderate	
4	1,81 – 2,60	Low	

No.	Index of Ecosystem Services	Ecosystem Services Class	Coloring on The Map
5	1,00 – 1,81	Very Low	

(Source: Kementerian Lingkungan Hidup dan Kehutanan, 2019).

5. Creation of Ecosystem Service Map Layout

The creation of the map layout aims to obtain a visualization or representation of the results of processing the ecosystem service index data for each type of ecosystem service used in the study. At this stage, color arrangements represent each class from very low to very high.

RESULT AND DISCUSSION

The Landscape of Kutai Kartanegara Regency

Landscape is the surface features of the Earth that have interconnected relationships and interdependencies among environmental components (Kementerian Lingkungan Hidup dan Kehutanan, 2019). The types of landforms in Kutai Kartanegara Regency in 2021 include 19 types of landforms. The landform map used is based on the Decree of the Minister of Environment and Forestry No. 1272 of 2021, which can be seen in Figure 2. The area of landscape, along with the percentage of the total area of Kutai Kartanegara Regency, is presented in Table 5.

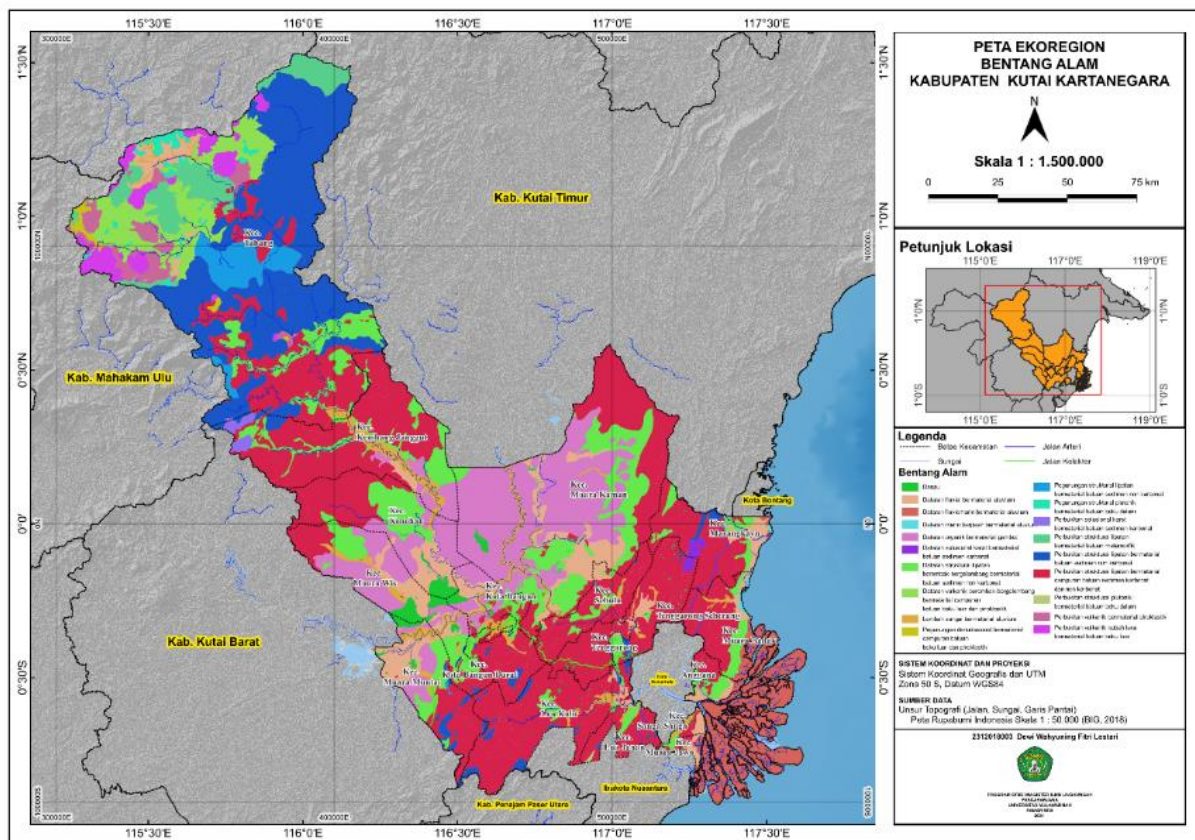


Figure 2. Landscape map of Kutai Kartanegara Regency

Table 5. Types of landscape in kutai Kartanegara Regency

No.	Landscape Type	Area (Ha)	Percentage (%)	No.	Landscape Type	Area (ha)	Percentage (%)
1	Lake	24.885,40	0,98	11	Structural mountains of folded non-carbonate sedimentary rocks	45.570,36	1,80
2	Alluvial material floodplain	156.224,84	6,18	12	Structural plutonic mountains made of intrusive igneous rock	13.825,30	0,55
3	Fluviomarine plain made of alluvium	120.506,57	4,76	13	Solutional karst hills made of carbonate sedimentary rocks	7.274,29	0,29
4	Sandy marine plains made of alluvial material	1.919,49	0,08	14	Structural hills of folded metamorphic rock material	73.281,65	2,90
5	Organic land made of peat	315.375,94	12,47	15	Structural hills of folded non-carbonate sedimentary rock	343.195,75	13,57
6	The karst solutional plains made of carbonate sedimentary rocks	5.202,27	0,21	16	Structural hills of folded mixture materials of carbonate and non-carbonate sedimentary rocks.	882.880,02	34,91
7	The structural plain of undulating folds is made of non-carbonate sedimentary rock.	286.421,26	11,32	17	Structural hills of plutonic material composed of igneous rocks	538,12	0,02
8	The undulating volcanic plain is composed of a mixture of extrusive igneous rock and pyroclastic material.	89.489,98	3,54	18	Volcanic hills made of pyroclastic material	37.378,62	1,48
9	Valley of the river with alluvial material	73.898,70	2,92	19	The volcanic hills of lava domes made of igneous rock material.	44.649,36	1,77
10	Denudational mountains made up of a mix of extrusive igneous rocks and pyroclastic materials.	6.706,42	0,27				

Source: Shapefile Kepmen LHK No.1272 of 2021 and processed using QGIS and Microsoft Excel.

Based on the identification results, the dominant landscape in Kutai Kartanegara Regency consists of structural hills formed from a mix of carbonate and non-carbonate sedimentary rocks with an area of 882.880,02 ha, which covers 34,91%, plutonic structural hills made of igneous rocks, and structural hills of

non-carbonate sedimentary rocks. The type of landscape of plutonic structural hills made of igneous rocks has the smallest area.

Vegetation Types of Kutai Kartanegara Regency

The type of vegetation is a community of plants in a landscape that has not been influenced by human activities (Kementerian Lingkungan Hidup dan Kehutanan, 2019). The types of vegetation in Kutai Kartanegara Regency in 2021 consist of 18 different types of vegetation. The vegetation type map used is derived from the Ministry of Environment and Forestry Decree No. 1272 of 2021 and can be seen in Figure 3. The results of the area of vegetation types along with the percentage of the total area of Kutai Kartanegara Regency are presented in Table 6.

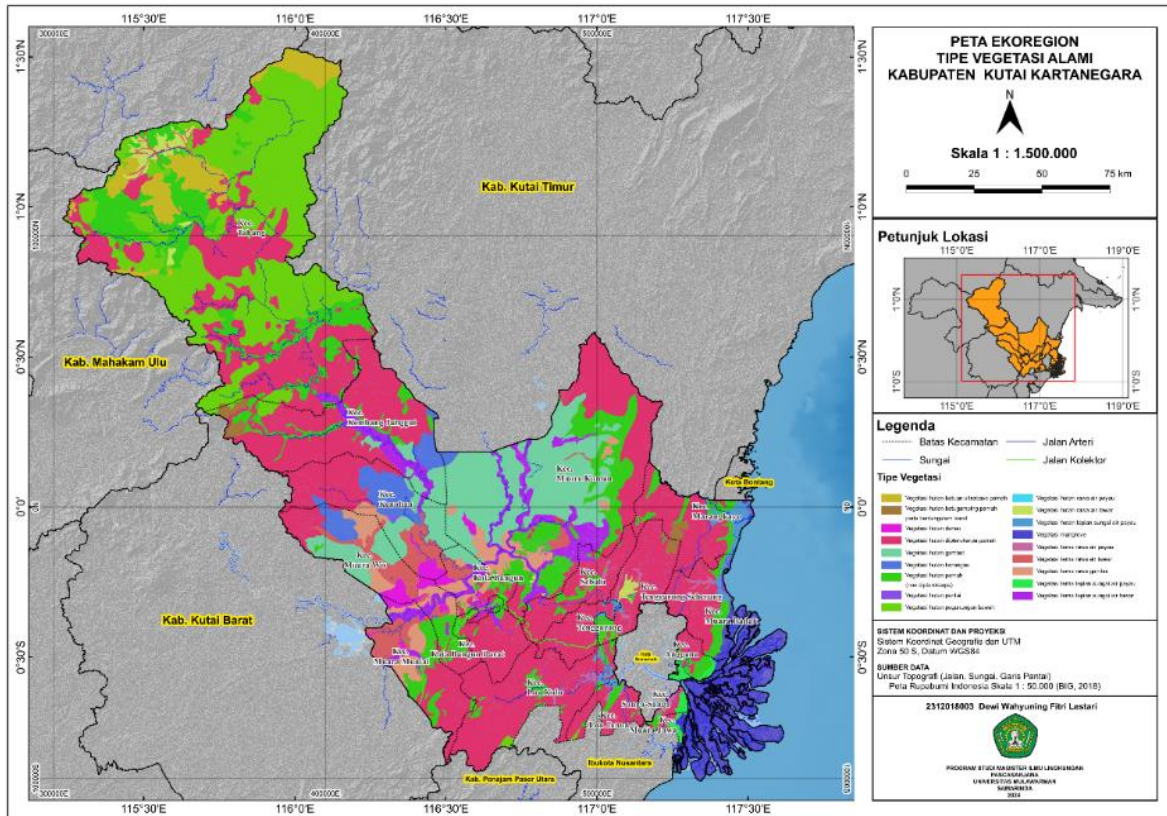


Figure 3. Vegetation type map of Kutai Kartanegara Regency

Table 6. Vegetation Type in The Kutai Kartanegara Regency

No.	Vegetation Type	Area (Ha)	Percentage (%)	No.	Vegetation Type	Area (ha)	Percentage (%)
1	Vegetation of ultramafic rock forests in lowland areas	73.281,65	2,90	10	Mangrove swamp vegetation	75,90	0,00
2	Vegetation of the limestone forest on the karst landscape	12.476,55	0,49	11	Freshwater swamp forest vegetation	19.492,33	0,77
3	Lake Forest Vegetation	24.885,40	0,98	12	Vegetation of mangrove riverbank forests	20.248,06	0,80
4	Dipterocarp lowland forest vegetation	982.402,80	38,84	13	Mangrove vegetation	120.506,57	4,76
5	Peat forest vegetation	245.112,11	9,69	14	Vegetation of brackish water marsh herbs	11.988,94	0,47

6	Heath forest vegetation	53.578,40	2,12	15	Freshwater swamp herbaceous vegetation	72.707,66	2,87
7	Lowland forest vegetation (non-dipterocarp)	328.018,83	12,97	16	Peat swamp vegetation	70.263,83	2,78
8	Coastal forest vegetation	1.919,49	0,08	17	Herbaceous vegetation of brackish water riverbanks	9.535,03	0,38
9	Lower mountain forest vegetation	386.601,73	15,29	18	Herbaceous vegetation of freshwater riverbanks	96.129,05	3,80

Source: Shapefile Kepmen LHK No.1272 of 2021 and processed using QGIS and Microsoft Excel.

The dipterocarp lowland forest vegetation in the lowlands is the dominant type because it covers a total area of 982.402,80 ha, or 38.84% of the total area of Kutai Kartanegara Regency. The coastal forest vegetation type has the smallest area, covering 1.919,49 ha, or 0.08% of the total area of Kutai Kartanegara Regency.

Land Cover of Kutai Kartanegara Regency

Land cover is a line that illustrates the boundary of the area covered on the Earth's surface, which consists of natural and artificial landscapes. In 2023, there were 19 types of land cover in Kutai Kartanegara Regency, resulting from the land cover mapping process at a scale of 1:50,000. The land cover map can be seen in Figure 4, and the results of the land cover area along with the percentage area of the total area of Kutai Kartanegara Regency are presented in Table 7.

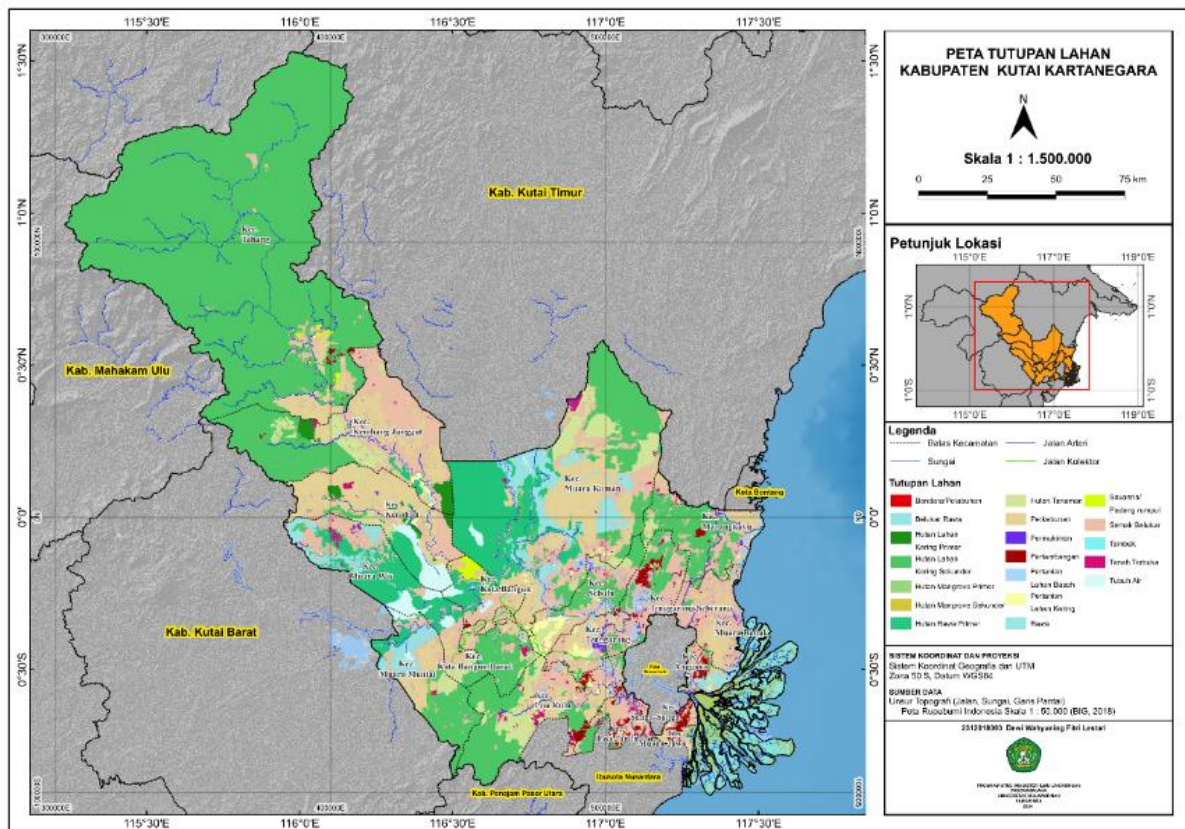


Figure 4. Land cover map of Kutai Kartanegara Regency

Table 7. Types of land cover in the Kutai Kartanegara Regency

No.	Land Cover Type	Area (ha)	Percentage (%)	No.	Land Cover Type	Area (ha)	Percentage (%)
1	Airport/Port	85,50	0,00	11	Mining	23.195,16	0,92
2	Swamp Shrub	71.489,35	2,83	12	Wetland Agriculture	15.111,35	0,60
3	Primary Dryland Forest	17.561,49	0,69	13	Dryland Agriculture	24.998,30	0,99
4	Secondary Dryland Forest	1.144.150,5	45,24	14	Swamp	24.863,56	0,98
5	Primary Mangrove Forest	50.527,62	2,00	15	Savanna/Grassland	8.320,24	0,33
6	Secondary Mangrove Forest	9.860,76	0,39	16	Shrubland	374.002,6	14,79
7	Primary Swamp Forest	185.811,74	7,35	17	Fishpond (Aquaculture)	55.942,51	2,21
8	Plantation Forest	101.732,01	4,02	18	Bare Land	19.453,15	0,77
9	Plantation	335.717,20	13,27	19	Water Body	51.858,35	2,05
10	Settlement	14.542,85	0,57				

Source: Shapefile Land Cover PPIIG UNMUL of 2023 and processed using QGIS and Microsoft Excel.

Based on the identification results, the dominant land cover in Kutai Kartanegara Regency is secondary dry land forest with an area of 1.144.150,5 ha, which covers 45,24%, shrubs, plantations, and primary swamp forest. Meanwhile, the type of land cover for airports/ports is the type of land cover that has the smallest area in Kutai Kartanegara Regency, with a total area of 85,50 hectares.

Water Provision Ecosystem Services

The assessment of support capacity and carrying capacity based on ecosystem services for clean water provision implies that the higher the class of ecosystem services for clean water in an area, the better the capability of that area to support the availability of clean water. Conversely, the lower the class of ecosystem services for clean water in an area, the worse the capability of that area to support the availability of clean water (Santoso et al., 2020). The ecosystem services for water provision are calculated using the simple additive weight method by summing the products of weights and scores from each parameter. A map of the support capacity and carrying capacity of water ecosystem services is obtained based on the overlay results between administrative maps and landforms, vegetation types, and land cover, which have undergone scoring and weighting processes. As shown in Figure 5, a map of Environmental Carrying Capacity based on ecosystem services for water supply in Kutai Kartanegara Regency is presented:

The calculation of ecosystem services for water supply in Kutai Kartanegara Regency is divided into five classes: very low, low, medium, high, and very high. In more detail, the distribution of the area of water supply ecosystem services in Kutai Kartanegara Regency based on Sub-districts can be seen in Table 8.

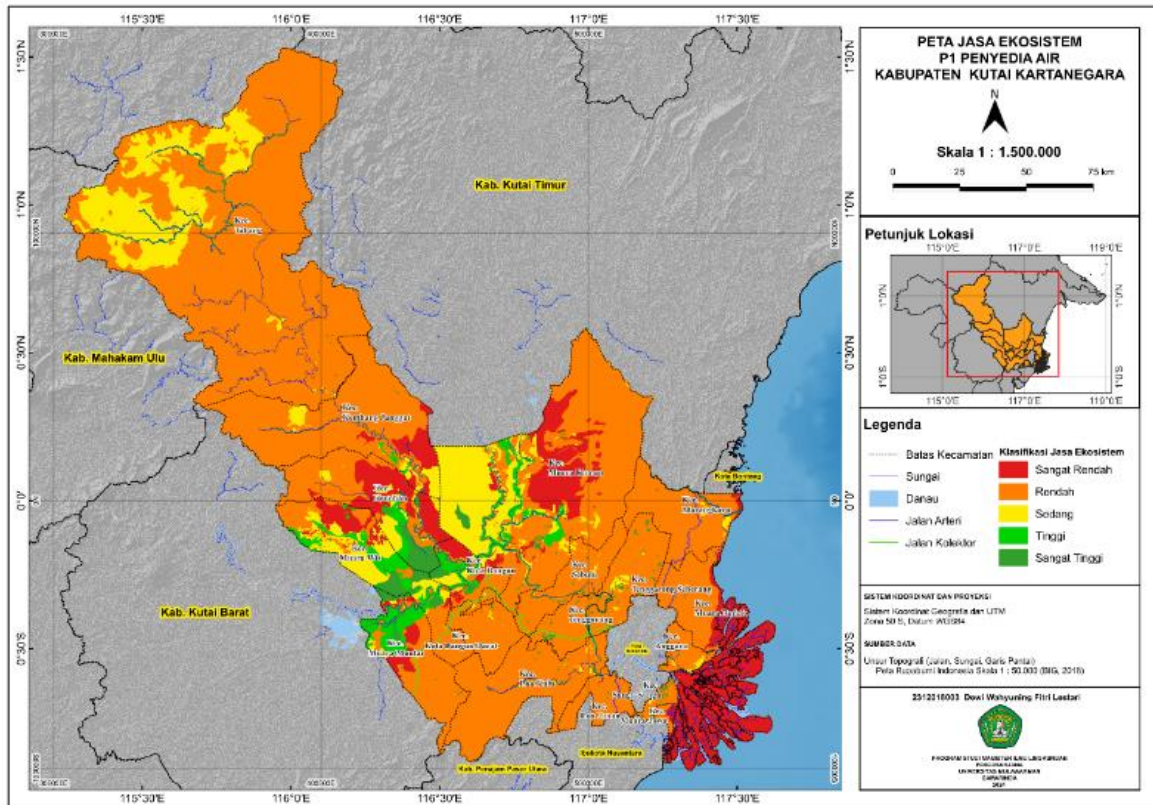


Figure 5. Map water supply ecosystem services in Kutai Kartanegara Regency

Based on the results of the calculation, water supply ecosystem services can be classified with most of the areas in Kutai Kartanegara Regency falling into the low class, with a total area of 1.787.104,66 ha, or covering 70,66% of the total area of Kutai Kartanegara Regency. The sub-district that has a dominant low class is Tabang. Areas in the low class have a combination of parameters with low scores in Tabang sub-district, where the land cover that dominates the low class includes secondary dryland forest shrubs, plantations, bushes, savanna/grasslands, and mining, with scores ranging from 1 to 2. Furthermore, regarding the landscape parameters, this area is largely situated in structural hills made of non-carbonate sedimentary rock, structural hills consisting of a mix of carbonate and non-carbonate sedimentary rock, and structural hills made of metamorphic rock, while the types of vegetation present include low montane forest vegetation, dipterocarp lowland forest vegetation, and ultramafic lowland rock vegetation with scores ranging from 2 to 4.

Table 8. Result of water supply ecosystem services in Kutai Kartanegara Regency

No	Sub-district	Water Provisioning Ecosystem Service											
		Very Low		Low		Medium		High		Very High		Total	
		Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
1	Anggana	84,501.92	3.34	19,030.43	0.75	1,670.16	0.07	71.59	0.00	148.14	0.01	105,422.23	4.74
2	Kembang Janggut	18,743.09	0.74	182,521.04	7.22	13,440.63	0.53	2,533.98	0.10	1,891.79	0.07	219,130.53	9.86
3	Kenohan	42,532.08	1.68	55,221.75	2.18	14,330.07	0.57	7,433.65	0.29	12,111.99	0.48	131,629.53	5.92
4	Kota Bangun	8,425.75	0.33	19,583.02	0.77	6,064.55	0.24	6,521.05	0.26	3,479.42	0.14	44,073.78	1.98
5	Kota Bangun Darat	34.22	0.00	44,999.86	1.78	862.26	0.03	2.61	0.00	126.00	0.00	46,024.95	2.07
6	Loa Janan	7.11	0.00	32,353.34	1.28	107.71	0.00	0.00	0.00	478.80	0.02	32,946.96	1.48
7	Loa Kulu	0.00	0.00	133,463.22	5.28	1,530.17	0.06	0.00	0.00	1,553.50	0.06	136,546.89	6.14
8	Marangkayu	1,403.14	0.06	82,406.43	3.26	2,433.55	0.10	17.95	0.00	223.50	0.01	86,484.58	3.89
9	Muara Badak	17,767.30	0.70	55,794.26	2.21	3.59	0.00	180.45	0.01	87.77	0.00	73,833.37	3.32
10	Muara Jawa	16,289.38	0.64	4,148.04	0.16	0.00	0.00	0.00	0.00	46.80	0.00	20,484.22	0.92
11	Muara Kaman	67,371.18	2.66	229,234.58	9.06	103,927.27	4.11	17,454.28	0.69	5,883.27	0.23	423,870.57	19.07
12	Muara Muntai	10,316.16	0.41	56,179.16	2.22	2,804.00	0.11	20,031.70	0.79	5,377.91	0.21	94,708.94	4.26
13	Muara Wis	17,047.25	0.67	46,938.02	1.86	32,899.26	1.30	23,866.13	0.94	10,525.03	0.42	131,275.70	5.90
14	Sanga-Sanga	53.59	0.00	9,312.03	0.37	203.54	0.01	0.00	0.00	466.39	0.02	10,035.55	0.45
15	Sebulu	0.00	0.00	56,506.51	2.23	1,784.50	0.07	0.00	0.00	1,728.33	0.07	60,019.35	2.70
16	Tabang	5.60	0.00	663,963.35	26.25	145,504.10	5.75	244.74	0.01	1,442.98	0.06	811,160.78	36.49
17	Tenggarong	0.00	0.00	34,313.51	1.36	40.37	0.00	0.00	0.00	1,494.46	0.06	35,848.35	1.61
18	Tenggarong Seberang	0.00	0.00	61,136.09	2.42	2,826.86	0.11	26.76	0.00	1,738.36	0.07	65,728.07	2.96
Total		284,497.77	11.25	1,787,104.66	70.66	330,432.61	13.06	78,384.88	3.10	48,804.43	1.93	2,529,224.00	100

The predominantly very low class subdistrict is Anggana subdistrict, which has an area of 85,501.92 ha. The subdistrict with a predominant medium class is Tabang subdistrict with an area of 145,504.10 ha. The subdistrict with a predominantly high class is Muara Wis subdistrict, with an area of 23,866.13 ha. The very high class in the Kutai Kartanegara district has a total area of 48,804.43 Ha, or covers 1.93%, which is distributed across 18 subdistricts in Kutai Kartanegara district, with this class being dominated by Kenohan, Muara Wis, and Muara Kaman subdistricts.

CONCLUSION

This study evaluated the environmental carrying capacity and environmental capacity (ECC-EC) based on water-provisioning ecosystem services across the 18 sub-districts of Kutai Kartanegara Regency. By integrating parameters for landscape forms, vegetation types, and land cover using spatial analysis in QGIS, the assessment provides a clear overview of the spatial distribution of water supply capabilities across the region. The findings indicate that the majority of Kutai Kartanegara Regency falls into the low-capacity category for water provisioning, covering approximately 1,787,104.66 hectares or 70.66% of the total area, with Tabang Sub-district representing the largest portion of this class.

Spatial variations across sub-districts highlight distinct ecological characteristics and capabilities within the regency's upstream, central, and coastal zones. While low and very low categories dominate vast areas, such as Anggana Sub-district, which contains the largest extent of the very low class at 85,501.92

hectares—areas with high to very high water-provisioning capacities are concentrated in specific sub-districts, including Muara Wis, Muara Kaman, and Kenohan. These higher-capacity zones benefit from key ecological features such as lakes, river valleys, primary swamp forests, and freshwater swamp vegetation, which naturally enhance water retention and supply.

Overall, these findings offer a crucial scientific foundation to address existing challenges in clean water accessibility and regional sanitation across Kutai Kartanegara. The spatial mapping of water-provisioning ecosystem services serves as a vital tool for policymakers to guide evidence-based spatial planning, targeted natural resource management, and environmental protection strategies. Prioritizing the conservation of high-capacity zones while implementing sustainable land-use practices in low-capacity areas will be essential to ensure long-term water security and ecological balance for the regency.

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