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Study of the Carrying Capacity of the Anai River Basin in West Sumatra Province

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Abstract: This study aims to assess the carrying capacity of the Anai River Basin (Watershed) in West Sumatra Province in response to increasing anthropogenic pressures and environmental changes. The research employed a spatial analysis approach utilizing remote sensing data and geographic information systems (GIS) to evaluate land cover conditions, water quality, and erosion levels. Carrying capacity analysis was conducted by calculating an environmental carrying capacity index, which included hydrological aspects, water quality, and the ecosystem's capacity to provide environmental services. The results indicate that the Anai River Basin is experiencing significant ecological pressure from land use changes, particularly the conversion of forests into agricultural land and settlements. Erosion rates in several sub-watersheds reached moderate to severe categories, with an average value of 15-25 tons/ha/year. River water quality demonstrated a decline in several parameters, especially increased turbidity levels and sediment content during the rainy season. The hydrological carrying capacity of the Anai watershed remains in a moderate category (index 0.65) but has shown a declining trend over the last five years. The findings indicate the necessity for implementing sustainable watershed management strategies. Management recommendations include forest conservation in upstream areas, the application of soil and water conservation techniques on agricultural land, the development of a regular water quality monitoring system, area zoning based on vulnerability levels, rehabilitation of 2,500 hectares of critical land, and the strengthening of watershed management institutions involving the active participation of local communities.

Keywords: Anai River Basin; Carrying capacity; Land use change; Spatial analysis

Introduction

Water bodies (e.g., rivers and lakes), as significant carriers, not only provide various water resources, but also provide suitable environmental carrying capacity to support human survival and development (Meng et al., 2017). Water resources play a vital role in human survival, sustainable socio-economic development, and the ecological environment (Meng et al., 2018). In recent years, the rapid progress of economic and social development, coupled with increasing water consumption, has caused serious problems related to the availability of water resources, environmental capacity and ecological space globally (Zhou, 2025). Indonesia is one of the countries that is prone to disasters due to poor management of natural resources (Riyansyah & Masturi, 2023; Zulfina & Hermon, 2025). Sustainable water resources management in Indonesia is increasingly facing challenges due to climate variability, changes in land use (Auliyani, 2020; Sodikin et al., 2025). A river basin (DAS) is a land area which is a single ecosystem with rivers and tributaries which function to accommodate, store and channel rainwater to lakes or seas (Putra & Saputra, 2024; Hasibuan et al., 2022). DAS has a significant role in Indonesia, namely maintaining the balance of the ecosystem and supporting the lives of the surrounding communities (Firmansyah et al., 2021). The area in the DAS area is widely used for various purposes, including as a residential area, agricultural land and community plantations. The theoretical

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underpinning of this study is grounded in the perspective that a River Basin (Watershed) constitutes an integrated ecosystem, wherein hydrological and ecological processes are inextricably linked. Within this framework, upstream events directly impact downstream conditions. The identified anthropogenic pressures—particularly forest conversion—are best conceptualized through the lens of Land Use and Land Cover Change (LULCC) theory, which elucidates how socio-economic demands propel shifts in land cover. These transformations are not stochastic; it is here that Landscape Ecology theory offers a critical contribution.

Watersheds in Indonesia have experienced quite severe damage, especially in terms of biophysical aspects, water quality and the social conditions of the surrounding community. Several factors causing this damage include changes in land use, poor land use planning, rapid population growth and low public awareness of the importance of environmental conservation in watersheds. Improper management and changes in land use in watersheds can damage their hydrological functions (Ardiansyah et al., 2023). Uncontrolled changes in land use can have a negative impact on environmental balance, including increasing the volume of surface flow that occurs every year (Aditama et al., 2025; Widyaningsih et al., 2021). This function includes the ability of the watershed to absorb, store, and distribute water efficiently, which plays an important role in maintaining the balance of the water system. When the hydrological function is running optimally, the watershed can prevent flooding in the rainy season and reduce the risk of drought in the dry season. If flooding in the watershed increases widely, it causes social losses and economic changes, this condition is categorized as a natural disaster (Ansosry et al., 2019). One of the main causes is damage to the river basin (DAS) ecosystem triggered by deforestation (Mahmud et al., 2024; Siregar et al., 2025). The next factor that causes flooding, one of which is sedimentation (Ghaisani et al., 2024; Supiyati et al., 2024).

This condition shows that attention and efforts to maintain the sustainability of watersheds are very important, considering their crucial role in maintaining the balance of the ecosystem and the quality of life of the community. Therefore, a more comprehensive and collaborative approach is needed between the government, the community, and various other stakeholders to address the damage that has occurred and ensure the sustainability of the function of the River Basin Area (DAS) in the future. One of the River Basins (DAS) that requires special attention in Indonesia is the Anai Watershed. The government has made the Anai Watershed a priority in efforts to protect natural resources, including land, water, and vegetation, which play an important role in maintaining the balance of the ecosystem (Naitkakin et al., 2021). The upstream part of the Anai Watershed, as the main buffer zone, has a vital function in protecting the entire watershed area. Disturbances or changes to these elements will have an impact on the entire Anai Watershed ecosystem, therefore, maintaining and preserving the upstream area of the Anai Watershed is very important to prevent damage that can affect the balance of the ecosystem as a whole.

The Batang Anai River originates at the foot of Mount Marapi, Singgalang and Tandikat, then flows from the Anai Valley to the Indian Ocean. This river crosses several areas in Tanah Datar and Padang Pariaman districts, crossing several sub-districts such as X Koto, Padang Panjang Barat, Batang Anai, Lubuk Alung, Ulakan Tapakis, Lembah Anai and Nagari Kataping. Currently, the Anai River Basin (DAS) area is facing great pressure related to the rapidly developing land use in Agam Regency. Land use that is not in accordance with its natural characteristics can worsen the damage. Therefore, it is important to conduct an in-depth study of the Watershed Carrying Capacity to understand land capacity and utilize it optimally according to biogeophysical characteristics. This study aims to create good water management to prevent problems such as flooding and drought. Thus, soil erosion can be controlled, which will support the increase in overall land fertility and productivity.

Method

It is necessary to coordinate the relationship between water resources, ecosystems and socio-economics by considering water holding capacity and water production efficiency and considering them as a relationship (Lu et al., 2021). Carrying capacity evaluation relates to the maximum load on regional, environmental, economic and societal resources (Zhang et al., 2022). This study uses a descriptive quantitative approach involving field surveys and the use of secondary data from various government agencies. Quantitative research is essential to obtain a comprehensive picture of spatial phenomena through data that can be measured and analyzed objectively (Barlian, 2016). For spatial data analysis, Geographic Information System (GIS) is used as a supporting tool in data processing and the preparation of informative maps and produces deeper interpretations and easy-to-understand visualization of results. The research sample was taken purposively from communities spread across several sub-districts that have a direct relationship with the DAS area.

This research instrument includes several secondary data, including: (a) Critical land data based on 20 specific categories (e.g. severity level) in the form of thematic maps from the Ministry of Environment and Forestry, as well as GIS data collection tools for validation in the field. (b) Satellite image data from LAPAN or the Geospatial Information Agency (BIG) and supporting data in the form of GPS and field surveys to verify the conformity of vegetation cover with image data. (c) Erosion analysis models such as USLE (Universal Soil Loss Equation), are used to calculate erosion index based on field data such as land slope, vegetation type, and rainfall intensity. (d) Institutional surveys and annual water discharge recording devices from agencies such as BPDAS or BWS are used to calculate the annual flow coefficient including sediment load. (e) Flood maps from BPBD or BPDAS support information analysis of flood-affected community areas. (f) Data from BPDAS or BWS is used to compare water needs and utilization. (g) Data from BPS or sub-district offices to determine population numbers, density, and distribution in a region. Indicators of welfare levels, such as income, education, and access to health services, and describe the classification of cities based on function, population size, and level of development. (h) Protected area maps from the Ministry of Environment and Forestry or BPDAS are used as the main reference in identifying protected areas and cultivation areas. (i) Supporting instruments in the form of GPS and field survey sheets to record the actual conditions of the area.

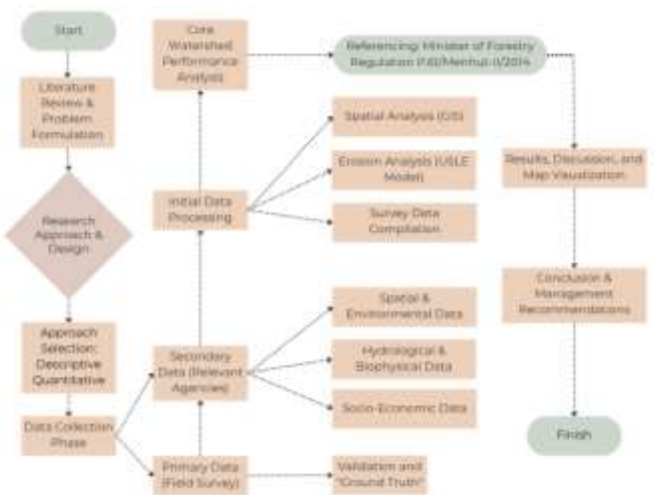

Figure 1. Research flowchart

The data analysis technique of this study is based on Regulation of the Minister of Forestry Number: P.61/Menhut-II/2014 concerning Monitoring and Assessment of River Flow Management by analyzing various aspects, namely land conditions (critical land, vegetation cover and erosion index), water management conditions (flow regime coefficient, annual flow coefficient, sediment load, flooding and water use index), socio-economic conditions (population pressure, level of population welfare, existence and enforcement of regulations), building investment value (city classification, building investment value), space utilization (protected areas, cultivation areas) and watershed carrying capacity conditions. As for the flow diagram, the flow diagram can be seen in Figure 1.

Result and Discussion

Geographically, the Anai Watershed is located at 0023′ North Latitude (LU), 0051′ South Latitude (LS), and 100027′ East Longitude (BT) 100015′ West Longitude (BB). The Anai Watershed has an area of 61,829.61 Ha which runs from north to south. Administratively, the Anai Watershed is located in 6 (six) regencies/cities, namely in Agam Regency, Tanah Datar Regency, Padang Panjang City, Padang Pariaman Regency, Solok Regency, and Padang City. The upstream of the Anai Watershed is in parts of Agam Regency, Tanah Datar and Padang Panjang City. The middle part (midstream) is in parts of Padang Pariaman Regency and Solok Regency. The downstream part is part of Padang Pariaman Regency/City and Padang City, with the boundaries being the North bordering Agam Regency, Tanah Datar Regency and Padang Panjang City. The South bordering Padang City and the West Coast of Sumatra. The east borders Solok Regency. The west borders Padang Pariaman Regency and Pariaman City which is the West Coast of Sumatra.

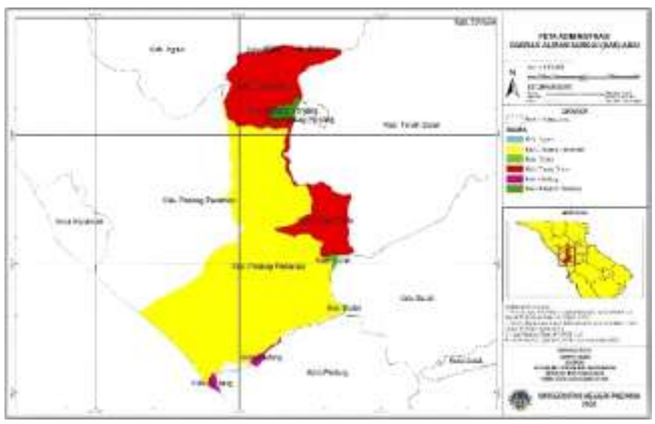

Figure 2. BPDAS Agam Kuantan

Research Results Description of Watershed Carrying Capacity Indicators

Land Conditions

A good river basin is an area where the land quality is stable or does not experience a decline in quality so that it is able to provide a decent life for the residents living in it, both in terms of food, clothing and shelter without having to reduce the quality of the land or environment (Alpiannur et al., 2022; Mubarokah et al., 2020). Land criteria include 3 (three) sub-criteria in determining DAS classification, which include:

percentage of critical land, percentage of vegetation cover, erosion index (IE) (Isnan et al., 2017). Critical land is land that has lost its ecological function, caused by physical and chemical damage to the soil, such as erosion, reduced nutrient content, and damage to soil structure. This land requires rehabilitation efforts to restore its productivity (Sudarmanto, 2015).

Table 1. Critical Land Levels Based on Region

No.	Critical Land Criteria	Subdistrict	Critical Land Area (Ha)
1.	Very critical	2 x 11 Kayu Tanam	622.98
		Batang Anai	
		Batipuh Selatan	182.50
		Koto Tangah	17.21
		Lubuk Alung	339.27
		Padang Panjang Barat	338.26
		Sungai Pua	7.16
		X Koto	4,038.03
	Amount 1	-	1594.79
2.	Critical	2 x 11 Kayu Tanam	241.06
		Batang Anai	870.70
		Koto Tangah	103.71
		Lubuk Alung	462.27
		Padang Panjang Barat	31.17
		Sungai Pua	45.49
		X Koto	466.25
	Amount 2	-	2220.65
3.	Somewhat critical	2 x 11 Enam Lingkung	177.00
		2 x 11 Kayu Tanam	11203.92
		Banu Hampu	22.89
		Batang Anai	5186.93
		Batipuh	44.71
		Batipuh Selatan	4287.67
		Junjung Sirih	563.58
		Koto Tangah	197.19
		Lubuk Alung	4648.29
		Malalak	4.72
		Padang Panjang Barat	703.97
		Padang Panjang Timur	0.02
		Patamuan	6.46
		Sungai Pua	64.80
		X Koto	6964.42
	Amount 3	-	34076.58
4.	Critical potential	2 x 11 Enam Lingkung	10.42
		2 x 11 Kayu Tanam	576.10
		Batang Anai	912.86
		Batipuh Selatan	766.43
		Junjung Sirih	0.02
		Koto Tangah	91.28
		Lubuk Alung	532.40
		Padang Panjang Barat	98.06
		Ulakan Tapakis	28.67
		X Koto	181.79
	Amount 4	-	3198.02
5.	Not critical	2 x 11 Enam Lingkung	107.69
		2 x 11 Kayu Tanam	3430.36
		Batang Anai	7557.06
		Batipuh Selatan	84.24
		Koto Tangah	105.70
		Lubuk Alung	5683.22
		Padang Panjang Timur	2.54
		Suntuk Teboh Gadang	90.07
		Sungai Pua	95.74

No.	Critical Land Criteria	Subdistrict	Critical Land Area (Ha)
		Ulakan Tapakis	875.23
		X Koto	2263.31
		Padang Panjang Barat	455.20
	Amount 5	-	20750.36
	Total number (1+2+3+4+5)	-	61.840.40

Land that has the potential to be somewhat critical, critical, and very critical is 61.27%. This figure needs to be watched out for because land with the potential critical and somewhat critical categories can become critical if not managed properly, especially its biophysical conditions that are vulnerable to disturbances (landform and slope) supported by high rainfall. The area of the Anai Watershed is 61,855.66 Ha, the area of critical land with the very critical category is 1,594.79 ha and critical 2,220.66 ha.

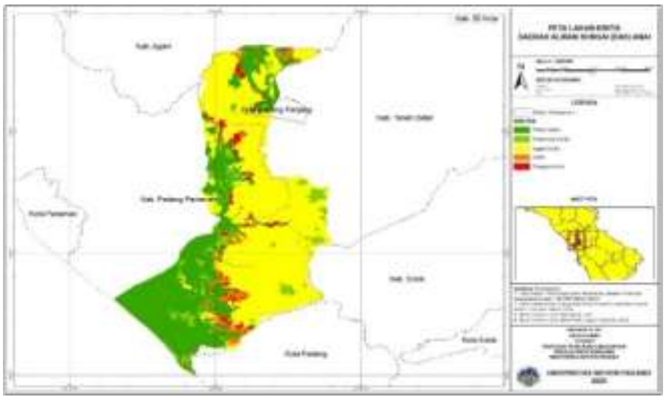

Figure 3. Anai watershed critical land map

Furthermore, to obtain the percentage of vegetation cover, the data used is the area of land that has permanent vegetation. The permanent vegetation analyzed is perennial plants in the form of forests, bushes and gardens. The calculation result of the Percentage of Vegetation Cover (PPV) of the Anai Watershed is 83.1%, so the sub-criteria class of the Percentage of Vegetation Cover of the Anai Watershed is very good (PPV> 80) with a score of 0.5.

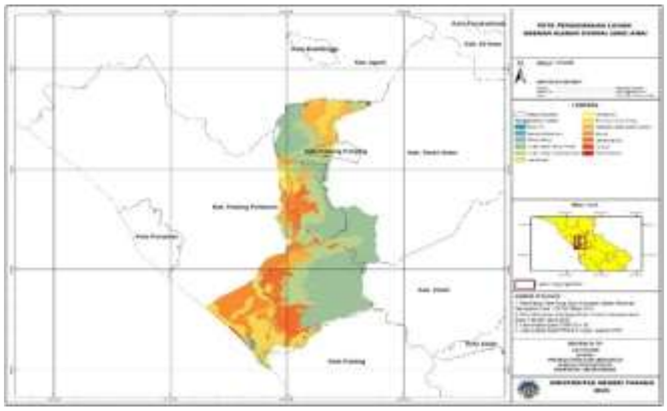

Figure 4. Anai watershed land cover map

The next indicator of land condition is the erosion index. The calculation of the erosion index is a comparison between current erosion or actual erosion with tolerated erosion. The actual erosion value of the Anai Watershed is 162.00 tons/ha/year.

Table 2. Actual Erosion that Occurred in the Anai Watershed

Value R	Value K	Value CP	Value LS	Actual erosion (ton/ha/thn)	Area of distribution (Ha)	(%)	Categori
3.500	0.28	0.13	0.10	24.5	14,823.27	57.14	Low
3.500	0.28	0.13	0.50	78.4	3,331.42	4.59	Medium
3.500	0.28	0.13	1.00	156.9	4,989.10	0.36	High
3.500	0.28	0.13	1.50	235.3	12,923.25	18.25	Very High
3.500	0.28	0.13	2.00	313.8	25,789.27		
					9,969		Lake/ Water body
Average amount				162.0	61,855.66	100.00	

This study is based on previous empirical findings that consistently show a negative correlation between land-use changes and hydrological health of watersheds. Studies in various watersheds in Indonesia, such as those conducted by (Budi Lesmana et al., 2024), have quantitatively proven that the conversion of forest land in upstream areas to intensive agricultural land significantly increases the rate of surface erosion and sediment load in water bodies, which is in line with our initial findings in the Anai watershed (15-25 tons/ha/year). Furthermore, this impact is not only limited to erosion. Research by Fadhil et al. (2021) confirms that land cover degradation changes the hydrological response of watersheds. They found that degraded watersheds tended to have higher surface flow coefficients (runoff), which not only contributed to increased flooding frequency in the rainy season but also (paradoxically) decreased water availability or baseflow in the dry season. Our findings regarding the "downward trend in hydrological carrying capacity" in the Anai watershed reinforce the urgency of this phenomenon.

Water System Conditions

Reservoir management strategies that can solve the problems of drought and water supply in the future completely. The study of water management aims to assess the impact of management on the continuity, volume, and quality of water flow in the River Basin Area (DAS) (Khalis et al., 2025). Some of the elements analyzed include flow regime coefficient, annual flow coefficient, sediment load, flood potential, and water utilization index (Fitriani Nur et al., 2021). If the condition of the water system is not properly looked after, it will result in flooding, assuming that rainwater falls on flat areas, with the assumption that the water does not evaporate, does not seep in, and does not flow (Sari & Hermon, 2025; Tristanti et al., 2024; Virgota et al., 2024). The calculation result of the flow regime coefficient is a comparison between the maximum discharge and the minimum discharge. The Anai Watershed discharge data was obtained from the Silaing Atas rainfall observation station (SPAS) data of the Anai River Basin (DAS). Based on the calculation results of daily discharge from the Anai Dam post data, the largest discharge occurred in May 2024, which was 131.2 m3, while the lowest discharge occurred in September 2024, which was 9.3 m3. Based on rainfall data from several rainfall stations in the Anai Watershed (table 24), it was obtained that the annual rainfall (P annual) was 2,894 mm. So it can be seen that the total water use index is 0.47 mm, with a low class ($0.25 < IPA \leq 0.75$) with a score of 0.75.

Socio-Economic Conditions

The study of watershed carrying capacity takes into account the maintenance of the ecological function of the river and the protection of healthy economic and social development (Bing et al., 2021). Socio-economic factors play a crucial role in the analysis of the carrying capacity of the Watershed (DAS) because human activities directly affect the condition and sustainability of the DAS ecosystem. In this socio-economic condition factor, there are 3 indicators, namely population pressure, the level of population welfare and the existence and enforcement of regulations. Population pressure. The more people who have a livelihood as farmers compared to the availability of agricultural land, the higher the population pressure on land will be. After analyzing the land cover map data of the Anai DAS, it was obtained that agricultural land in the Anai DAS was 20,106.34 ha consisting of 7381.35 ha of dry land agriculture, 5291.34 ha of mixed dry land agriculture and 7433.66 ha of rice fields. While the number of heads of families who have a livelihood as farmers is 57,460 heads of families, population pressure is 1.01 with a moderate class with a score of 0.75.

Level of Population Welfare. The level of community/farmer income in the DAS is one of the benchmarks of welfare and a reflection of family income obtained from agricultural business results and non-agricultural business results as well as the results of gifts from other parties to farmer families (KK/year) in each Nagari in the Anai DAS. Based on BPS data in 2023 and the coverage area of the Anai DAS (covering part of Padang City, Padang Pariaman Regency, and Tanah Datar Regency), it is known that the average income of the population per month is IDR 1,924,000 with an estimated population in the entire Anai DAS area of 648,757 people. Thus, the level of population welfare with a very poor class score of 1.5.

Existence and Enforcement of Regulations The existence and enforcement of regulations are carried out to determine whether or not there are community norms, both formal and informal, related to soil and water conservation and the level of implementation of the intended norms in community life. The existence of these norms and their widespread implementation in community life are expected to have a positive impact on increasing the carrying capacity of the DAS. From the results of data collection on the existence or absence of regulations issued by related agencies related to soil and water conservation, there are no regulations related to soil and water conservation issued by the regional government or the village government. Thus, the sub-criteria for the existence and enforcement of regulations are included in the poor class with a score of 1.25.

Building Investment Value

The Building Investment Value Factor is an important component in the analysis of watershed carrying capacity that is often ignored, even though it has a significant impact on ecosystem sustainability and spatial planning (Alsa et al., 2023). There are 2 indicators of building investment value in the analysis of watershed carrying capacity, namely city classification and water building investment value. The city classification study was conducted to determine the existence and status/category of cities in a watershed. The existence of city status is based on areas that have non-agricultural main activities with the arrangement of regional functions as urban settlements, concentration and distribution of government services, social services, and economic activities. The area included in the city classification in the Anai watershed area is Koto Tangah District with a population of 203,475 people. From the results of this data, the Anai watershed area is included in the category of medium cities (> 100,000 to 500,000 people), with a medium class score of 1.

A study of the investment value of water structures was carried out to determine the value of water structures (in rupiah) in the watershed. The water structures in question are reservoirs, dams, dams and irrigation canals. Based on data on water structures in the Anai watershed, there is a water structure in the form of the Anai Dam with an investment value of Rp. 231,530,604,437,-, included in the very high class with a score of 1.5.

Utilization of Regional Space

The spatial utilization factor is a fundamental element in the analysis of watershed carrying capacity because it determines the spatial distribution of human activities and their impacts on hydrological, ecological, and socio-economic functions DAS (Lilis Anggraeni et al., 2021). There are 2 indicators of regional space utilization, namely Protected Areas and Cultivation Areas. Areas included in protected areas are protected forests and conservation forests. Conservation forests include nature reserves, wildlife sanctuaries, hunting parks, Tahura, nature tourism parks and national parks. Based on the analysis of the land function direction map, it is known that the total area of the Anai Watershed protected area is 34,281.89 ha while the area of the protected area with vegetation is 51,954.54 ha. So that the Anai Watershed protected area is included in the good class with a score of 0.75. The slope class of 0-25% is the most suitable slope class for plant cultivation so that it will be suitable in the cultivation area. The higher the percentage of land unit area with a slope of 0-25% in the cultivation area, the better the watershed condition. Conversely, the lower the percentage of land unit area with a slope of 0-25% in the cultivation area, or in other words, the higher the percentage of land unit area with a slope of >25% in the cultivation area, the better the watershed condition. Based on the analysis of the DAS land function direction map, it is known that the total area of the Anai DAS cultivation area is 31,077.95 ha while the area of cultivation area with a slope of 0-25% is 18,154.69 ha. So that the Anai DAS cultivation area is included in the very low class with a score of 0.75.

Table 3. Area of Cultivation Area with a Slope of 0-25%

Land function direction	Slope (ha) 0-8%	8-15%	25-40%	Total area (ha)
Seasonal plant cultivation area and residential area	14,823.27	3331.42	-	18,154.69
Perennial plant cultivation area	-	-	12,923.25	31,077.95

Carrying Capacity Condition DAS

The study of the carrying capacity of the watershed was carried out in an integrated manner against 5 (five) criteria that have been carried out, including: land conditions, water management conditions, socio-economic conditions, water building investment conditions and regional space utilization conditions. The results of the addition of the values of each criterion obtained the Anai watershed carrying capacity condition value of 99.00. Land conditions with a value of 35.00, water management conditions with a value of 18.50, socio-economic conditions with a value of 21.75, water building investment conditions with a value of 16.25 and regional space utilization conditions with a value of 7.50. Thus, the classification of the Anai watershed carrying capacity condition is included in the moderate category (90<DDD≤110).

Table 4. Results of the Calculation of the Weight and Carrying Capacity Value of the Anai DAS

Criteria/ sub criteria	Weight %	%	Score	Value
A. Land conditions	40			35.00
1. Percentage of critical land		20	0.75	15.00
2. Percentage of vegetation cover		10	0.50	5.00
3. Erosion index		10	1.50	15.00
B. Water system conditions	20			18.50
1. Flow regime coefficient (kra)		5	0.50	2.50
2. Annual flow coefficient (kat)		5	1.00	5.00
3. Sediment load		4	1.25	5.00
4. Flood		2	1.50	3.00
5. Water use indeks		4	0.75	3.00
C. Socio-economic conditions	20			21.75
1. Population pressure		10	0.75	7.50
2. Level of population welfare		7	1.50	10.50
3. Existence and enforcement of regulations		3	1.25	3.75
D. Building investment	10			16.25
1. City classification		5	1.00	5.00

Criteria/ sub criteria	Weight %	Weight %	Score	Value
2. Classification of water building values		5	1.50	11.25
E. Utilization of regional space	10			7.50
1. Protected areas		5	0.75	3.75
2. Cultivation areas		5	0.75	3.75
				99.00

Discussion

Changes in land use and land utilization that are not based on conservation aspects, especially in the upstream areas of river basins (DAS), can increase the rate of erosion and critical land and have an impact on water management DAS (Naitkakin et al., 2023; Rahman dkk et al., 2021). Based on the data presented above through several indicators of land conditions, water coefficient conditions, socio-economic conditions, water building investment conditions, and regional space utilization conditions. Critical land is land that has experienced degradation and has decreased its function and potential. According to Arsyad (2010), critical land is defined as land with vegetation cover of less than 25%, a topographic slope of 15% or more, and is characterized by erosion symptoms such as erosion of furrows and ditches. Critical land that occurs in the Anai Watershed area is caused by several factors, both natural and due to human activities. Deforestation and Land Conversion such as Deforestation in the upstream part of the Anai Watershed reduce the capacity of the soil to absorb water, thereby increasing erosion and sedimentation. Human activities, climate change, and seismic events have caused an increasing trend in flood-scale sediment loads (Barlian et al., 2024; Wang et al., 2025). Changes in land use into settlements, intensive agriculture, and plantations without proper soil conservation accelerate land degradation. Land use that is not in accordance with the land capability class and in agricultural cultivation practices without considering the principles of soil and water conservation, which ultimately causes physical, chemical and biological damage to the soil and has an impact on the damage to hydrological functions, decreased agricultural production, settlements, and the socio-economics of the community.

The Anai River Basin Area (DAS) generally has four main types of soil, namely Andosol, Gley Humus (Latosol), Regosol, and Kambisol. Andosol soil is formed from the weathering of volcanic materials such as tuff and volcanic ash, and develops in areas with annual rainfall between 2,500 and 2,700 mm. According to Sukarman et al. (2014), Andosol soil has loose physical characteristics, crumb structure, and high organic matter content. The actual erosion rate in the Anai River Basin Area (DAS) is currently quite high, namely 162 tons/ha/year. The highest erosion rate was recorded on land with steep slopes (>40%) and land cover in the form of open land or bushes, reaching >600 tons/ha/year, which is included in the very heavy category, namely in the upstream area of the Anai Watershed, especially around the hilly areas that have experienced land degradation. On the other hand, the lowest erosion rate was found on land with good vegetation cover such as forests or plantations with low slopes (<8%), which is around 5-10 tons/ha/year, which is classified as light to moderate, namely in the downstream area of the Anai Watershed which is relatively flat and still has fairly good land cover. This difference shows the importance of the role of vegetation cover and land conservation in suppressing the erosion rate in the watershed area. In general, the actual erosion rate in the Anai Watershed which is relatively high is greatly influenced by factors such as climate factors, soil factors, vegetation factors, topography and human factors (Tian et al., 2024).

As centers of ecosystems and human societies, watersheds are complex social-ecological systems (SES) that rely on natural flow regimes and hydrological variability to adapt to change and absorb disturbances (Garza-Díaz & Sandoval-Solis, 2022). The environment has been severely damaged, and the contradictions in the human settlement development system are still unclear. Therefore, it is very important to clarify their relationships in order to coordinate their interactions (Liao et al., 2023). Then the type of dominant economic activity in the watershed greatly influences the pattern of resource utilization (Siwabessy et al., 2024). Communities that rely on intensive agriculture tend to use fertilizers and pesticides that can pollute river water. Manufacturing and mining industries produce waste that has the potential to reduce water quality. In contrast, service-based economies or ecotourism generally put less pressure on the environment. Calculations of socio-economic conditions in the Anai Watershed area are based on three main components, namely: (1) population pressure, (2) level of community welfare, and (3) existence and enforcement of regulations related to natural resource management. From the analysis results, a socio-economic index value of 21.75 was obtained. This value indicates that socio-economic conditions in the Anai Watershed are quite high in terms of pressure on the environment, but still low in terms of management capacity and sustainability.

Next, investment in water structures is a criterion that includes two sub-criteria that affect the carrying capacity of the watershed, the sub-criteria are city classification and the investment value of water structures. City classification is an assessment of the presence or absence of a city in the watershed area. The larger the city in the watershed, the greater the potential to damage the carrying capacity of the watershed so that the watershed requires high carrying capacity. Based on the administrative map of West Sumatra Province, the Anai Watershed is located in the administrative areas of Tanah Datar Regency and Padang Pariaman Regency. However, the Anai Watershed is mostly located in the Padang Pariaman Regency area. Based on the highest population, namely Batang Anai District with 56,755 people, the Anai Watershed is included in the category of small cities. In addition to city classification, this criterion includes investment in water structures. The classification of water structures is a sub-criterion that shows how much investment is spent to build water structures such as irrigation, reservoirs, dams and so on. In the Anai Watershed, the investment funds spent are relatively high with an investment value of Rp. 67,533,010,000, thus with these funds the classification of water structures is included in the very high class.

Finally, the last criterion that influences the determination of watershed carrying capacity is the utilization of regional space. This criterion describes two functions of the area, namely protected areas and cultivated areas. According to Barlian (2016), unbalanced use of space between protected and cultivated areas can reduce environmental carrying capacity, especially in the context of watersheds that are sensitive to changes in land cover. Therefore, spatial planning based on ecological carrying capacity is very important to maintain a balance between environmental conservation and development needs. In accordance with the land function direction map, the Anai watershed has a total protected area of 34,281.89 ha consisting of 13,283.76 ha of protected forest and 20,998.13 ha of conservation area. The area that has vegetation covering 51,954.54 ha is thus included in the very good class.

Conclusion

Based on the research results that have been described previously, the following conclusions were obtained: The results of the calculation of the Anai watershed land conditions include: the percentage of critical land with a score of 0.75 so that the value is 15, the percentage of vegetation cover with a score of 0.50 so that the value is 5.00, and the erosion index score of 1.50 so that the erosion index value of the Anai watershed is 15.00. The water system conditions of the Anai watershed include: the flow regime coefficient (KRA) with a score of 0.50 so that the value is 2.50, the annual flow coefficient (KAT) with a score of 1.00 with a value of 5.00, sediment load score of 1.25 so that the value is 5.00, Flood with a score of 1.50 so that the value is 3.00 and the water use index (IPA) score of 0.75 so that the value is 3.00. The socio-economic conditions of the Anai Watershed are: population pressure (TP) with a score of 0.75 and its value is 7.50, the level of population welfare with a score of 1.50 with a value of 10.50 and the existence and enforcement score of 1.25 with a value of 3.75. Investment in Anai Watershed buildings includes: city classification with a score of 1.00 so that its value is 5.00 and classification of water building values with a score of 1.50 with a value of 11.25. Utilization of the Anai Watershed area space is: protected areas located in the Anai Watershed with a score of 0.75 so that its value is 3.75 and cultivation areas with a score of 0.75 with a value of 3.75. From the calculation of the criteria and indicators of the carrying capacity of the Anai Watershed which include land conditions, water management, social, economic, building investment and utilization of regional space, a total value of 96.50 is obtained. So based on the classification of the carrying capacity of the watershed, the Anai Watershed is in the medium category.

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