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Assessing Eutrophication Severity in the Apodi-Mossoró River Basin Using the Trophic State Index: A Statistical Analysis from 2018 to 2026

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Abstract: ***This study investigates the trophic state of the Apodi-Mossoró river basin from 2018 to 2026 using the Trophic State Index (IET) to assess water quality in terms of nutrient enrichment and its effects on phytoplankton proliferation. Descriptive statistics—including mean, mode, median, standard deviation, and variance—were calculated, accompanied by box-plot visualization and hypothesis testing. The results reveal that the basin exhibited a severe degree of eutrophication during the study period, indicating substantial pollutant loading that directly impairs water quality. These findings underscore the urgent need for targeted pollution control and basin management strategies to mitigate eutrophication and restore ecological balance.***

Keywords: Trophic State Index, Eutrophication, water quality, Apodi-Mossoró basin, Phytoplankton, Pollution load.

1. INTRODUCTION

Water, in liquid and solid forms, covers more than two-thirds of our planet and, in gaseous form, is a component of the Earth's atmosphere. Without water, life as we know it would not be possible (Santana, 2023).

The availability of clean water is potentially one of the most important problems the global community will have to face in the coming years, as a large part of water is still used irrationally and unsustainably, and consequently, it is found that water is not available and of sufficient quality to meet all human needs (Bernardi et al., 2013).

A hydrographic basin is a natural catchment area for rainwater precipitation that converges flows to a single point. This exit point is called the exultório (Finkler, 2022).

The hydrographic basin is composed of a set of sloping surfaces and a drainage network, formed by watercourses that converge until resulting in a single channel at its exutório, defined as the lowest elevation in a drainage system. Therefore, because it has well-defined characteristics, it is a unit that allows characterizing and combating environmental impacts (Ferreira et al., 2022). It can be considered the basic unit of study in ecological and economic contexts, becoming a priority for the planning and management of water resources, as it provides various products and services that sustain the human population (Lopes et al., 2020).

The water use activities of users in a hydrographic basin are competitive and intensify as per capita water availability decreases, and managing this competition means creating a set of rules for water allocation, which is ultimately the essence of the water resources management system. To create this set of rules, management instruments that institutionalize them and the creation of a local decision-making body are necessary (Porto; Porto, 2008).

The Apodi-Mossoró River hydrographic basin covers an area of 14,278km^2, corresponding to 26.8% of the estimated area of the State. Located in the region where the Caatinga biome predominates, it is entirely within the State of Rio Grande do Norte, from its source in the Serra de Luiz Gomes to its mouth between the municipalities of Areia Branca and Grossos, traveling approximately 210km along this route (Rocha, 2009).

Despite its socioeconomic importance, the Apodi-Mossoró River hydrographic basin has been suffering constant impacts from the leaching of fertilizers and pesticides from various agricultural activities developed around the river; the transport of allochthonous material, in addition to constant discharges of domestic and industrial sewage released throughout the basin (Oliveira et al., 2009).

The eutrophication process can be defined as the increase in the fertility of aquatic environments caused by the excessive input of nutrients, mainly total phosphorus and nitrogen, into water bodies (Batista et al, 2014), and can lead to changes in taste, odor, turbidity, water color, and a reduction in dissolved oxygen, resulting in the excessive growth of aquatic plants, the death of fish and other aquatic species, as well as the impairment of minimum conditions for recreation in the water body (Smith; Schindler, 2009).

Indicators and indices are designed to simplify information about complex phenomena in order to improve communication, and can be applied to a wide range of situations, including public information and scientific research (Ramos, 1997). The Trophic State Index - TSI aims to classify water bodies into different trophic levels, that is, it evaluates water quality in terms of nutrient enrichment and its effect related to the excessive growth of algae and cyanobacteria. (Cetesb, 2017).

The article concerns the use of official Trophic State Index - TSI measurement data from the Blue Water Program, obtained between 2008 and 2016, to conduct a temporal analysis of the behavior of the Apodi-Mossoró River Hydrographic Basin regarding water body eutrophication.

2. METHODOLOGY

The development of the article followed the following sequence: TSI data were organized into a table; calculations of mean, mode, median, standard deviation, and variance were performed; box plots were produced; t-tests were conducted for each analyzed year; and finally, the information presented in the graphs and statistical data was interpreted.

This region is climatically characterized as being in a semi-arid area, with an average annual temperature of $28,5°C$ and concentrated rainfall, mainly from March to April (Bezerra et al., 2013), and is located between the Araripe Plateau (800 to 1000m) and the Borborema Plateau (670 to 1100m) (Rocha et al., 2009). With an area of 14,276 km^2, equivalent to 26.8% of the estimated area of the state, it represents the largest hydrographic basin native to Rio Grande do Norte. There are 618 registered reservoirs, totaling a water volume of 469,714,600m^3, which corresponds to 27.4% and 10.7% of the total number of reservoirs and accumulated volumes in Rio Grande do Norte, respectively (Oliveira et al., 2009). The studied hydrographic basin is illustrated in Figure 1.

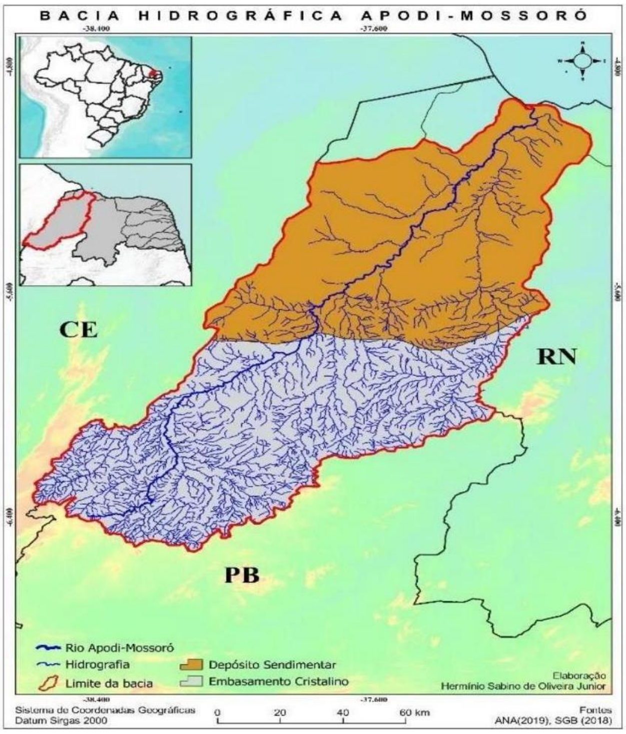

Figure 1: Location of the Apodi-Mossoro River basin

2.2 Study Period and Data Collection

The Blue Water Program produced multiple reports between 2008 and 2016, with the exception of 2013, for all basins in the state of Rio Grande do Norte. In the preparation of these reports, attributes were obtained that generated 10 indicators, which serve to determine the quality of water bodies in the state. For this research, data from the Trophic State Index - TSI of the Apodi-Mossoró River Hydrographic Basin available in these reports were analyzed. The collection points are indicated in Figure 2.

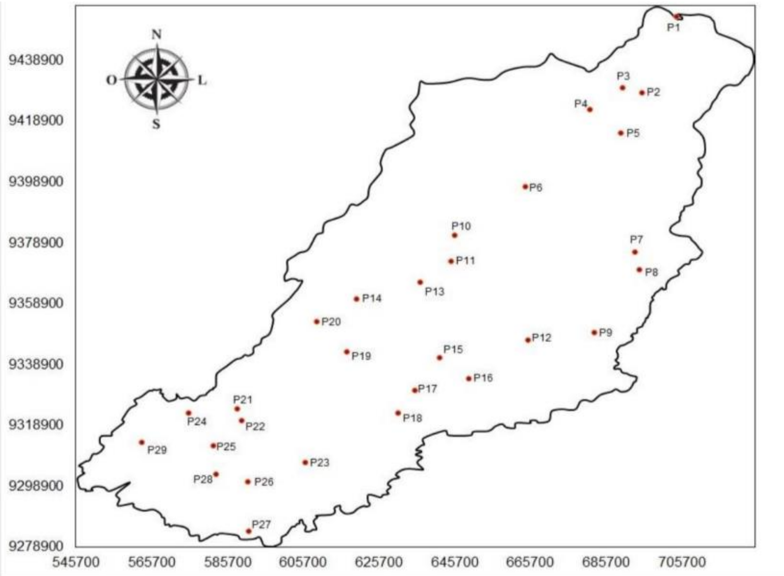

Figure 2: Spatial distribution of PAA collection points for the Apodí-Mossoró Basin

2.3 Descriptive Statistics

2.3.1 Determination of mean, median, mode, standard deviation, and variance

As described by Loesch (2015), these statistical calculations are performed through the following calculations:

a) mean

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{1}$$

where:

x is the mean, n is the number of items in the sample, and xi is the individual value of each item in the sample.

b) median

For n (number of items in the sample) odd:

$$Me = \frac{x_{(n+1)}}{2} \tag{2}$$

For n (number of items in the sample) even:

$$Me = \frac{x_{(n/2)}+x_{(1+n)/2}}{2} \tag{3}$$

where:

Me is the median,
n is the number of items in the sample

c) mode

The Mode (Mo) is the value(s) that occur with the highest frequency, that is, the value that repeats the most; therefore, it is a measure of central tendency.

d) standard deviation

$$s = \sqrt{\frac{1}{n=1} \sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (4)$$

where:

s is the standard deviation
x is the mean
n is the number of items in the sample; and
xi is the individual value of each item in the sample.

e) variance

2.3.2 Trophic level

To determine the trophic level values of the basin, IGARN (Water Management Institute of Rio Grande do Norte) and UERN (State University of Rio Grande do Norte) adapted to our reality the calculations developed by the Environmental Company of the State of São Paulo - CETESB (2007), being categorized as shown in table 1:

Table 1: Water category according to the trophic level (IET)

Weighting	Trophic State Category
TSI≤ 47	Ultraoligotrophic
$47 < IET \leq 52$	Oligotrophic
$52 < IET \leq 59$	Mesotrophic
$59 < IET \leq 63$	Eutrophic
$63 < IET \leq 67$	Supereutrophic
TSI > 67	Hypereutrophic

2.3.3 Box Plot and Hypothesis Test

The box plot was produced using a spreadsheet program, which also performs the descriptive statistics calculations, as described in the previous section. The necessary information is summarized in Table 2:

Table 2: Trophic state values by year per measurement point

Trophic State Index - TSI								
Measurement point	2008	2009	2010	2011	2022	2014	2015	2016
APM01	67,5	68	55	60	66	67,5	65	51,5
APM02	62,4	68,5	60	63,5	64,5	65,5	67	62
APM03	72,1	66,3	64	64,5	57,5			
APM04	76,7	67,1	61	64	69,5	71,5	70	69
APM05	72,1	73,9	62	66,5	71,5	71	72,5	
APM06	68,6	84,5	31	67	72	58	69	
APM07	80,4	67,7	65	66,5	69	72,5	71,5	
APM08	66,2							
APM09	69,9	68,4	60	63,5	66	62,5	70,5	
APM10	63,2	66,1	60	65,5	66	68,5	70	66
APM11	66,2	69,6	51	68,5	71,5	70	71	
APM12	70,5	62,1	70	71,5	72	61,5	70	
APM13	66,9	69,3	64	58,5	57	64	65,5	70
APM14	70,4	80,1	39	54	61,5	62,5	63,5	71
APM15	69,6	77,8	36	52	64	55,5	53	
APM16	72,5	63,3	44	61	58,5	55		
APM17	67,6	63,4	70	52	59,5	53	51	54
APM18	59,6	69,3	37	53	54	71	29,5	58
APM19	65,2	61,5	38	60,5	67	56	30,5	44,5
APM20	60,1	62,2	48	61,5	63	68	36	80
APM21		57,8	55	63	85,5	78	46	63
APM22	48,1	66,7	47	60,5	59,5	64,5	23,5	66
APM23	50,4			54,5	52	50	61	72
APM24	62,2	65,1	37	54	52	49,5	48,5	53
APM25	54	69,8	37	48,5	39		25	40

APM26	52,7	70,1	37	60	55,5	63		
APM27		71,1	55	67,5	70	61,5	68	
APM28		70,1	63	59	65,5			
APM29		81,4	60					74

3. RESULTS AND DISCUSSIONS

Investigations into the TSI showed that, during the PPA monitoring period, the study watershed presented a high trophic level, as indicated by the statistical calculations shown in Table 3, the box plot shown in Figure 3, and the hypothesis tests summarized in Table 4.

The analysis was performed using a cutoff value of 59 as the limit for a high trophic level, as values above this can be categorized as Eutrophic, Supereutrophic, or Hypereutrophic, as shown in the PAA categorization (Table 4).

Table 3: Descriptive statistics values for TSI from the period 2018 to 2026

	Trophic State Index							
Statistical variables	2008	2009	2010	2011	2022	2014	2015	2016
MEANS	65,404	68,933	52,321	60,786	63,357	64,080	55,840	62,125
MODE	72,100	69,300	60,000	60,000	66,000	71,000	70,000	66,000
MEDIAN	66,900	68,400	55,000	61,250	64,750	64,000	64,250	64,500
STANDARD DEVIATION	7,762	6,113	11,656	5,662	8,580	8,079	16,278	10,771
VARIANCE	60,248	37,373	135,861	32,061	73,622	65,274	264,976	116,016

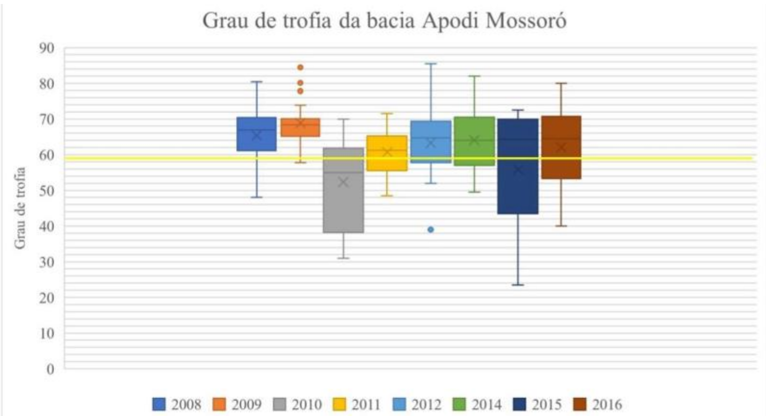

Figure 3: Trophic state graph of the Apodi Mossoró basin for the period from 2018 to 2026

Table 4: Summary of t-test hypotheses for each year of the period from 2018 to 2026

ANO	t-Test of Hypotheses			
	tCALC	t_{TAB}	$t_{CALC} > t_{TAB}$	Situation H_0
2008	4,12	1,711	yes	Rejected
2009	8,44	1,706	yes	Rejected
2010	3,03	1,703	yes	Rejected
2011	1,66	1,703	no	Accepted
2022	2,68	1,703	yes	Rejected
2014	3,14	1,711	yes	Rejected
2015	0,95	1,714	no	Accepted
2016	1,16	1,753	no	Accepted

Based on the information highlighted by the descriptive statistics in the mean, mode, and median items, it is observed that the behavior of the watershed over time generally fluctuates between Eutrophic and Hypereutrophic in most of its values, except for the years 2010 and 2015, which are categorized as Mesotrophic.

This fact is also repeated in the box plot analysis, where the yellow line divides the value of 59, from which it is inferred that most values are concentrated above this line, also with the exception of the years 2010 and 2015, where the concentration of these values is spread over a larger interval, with most of this interval lying below the yellow line.

Corroborating the previous facts, the hypothesis analysis also indicates that within the studied period, the basin exhibits Eutrophic or higher behavior, as most of the tested hypotheses (for each studied year) show that the values are concentrated in values greater than 59, except for the years 2011, 2015, and 2016. Figure 4 shows the behavior of the IET for the basin during the studied period.

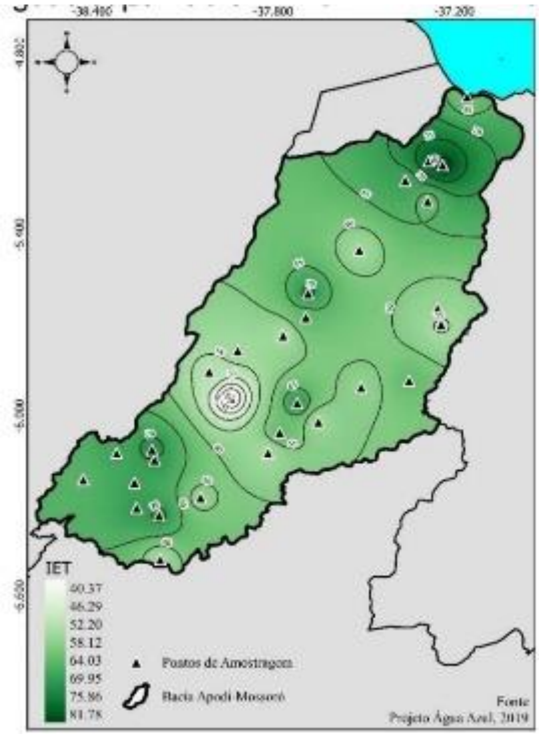

Figure 4: Behavior of the IET for the Apodí-Mossoró River basin from 2018 to 2026.

Eutrophication occurs due to the enrichment of nutrients, mainly nitrogen and phosphorus, in water bodies. These nutrients come from the pollutant load discharged into the basin's watercourses and produce profound quantitative and qualitative modifications in aquatic communities and, in the physical conditions of the environment, lead to the occurrence of cyanobacteria and an increase in the incidence of algae and microalgae blooms, many of which produce cytotoxins (Esteves, 2011; Barbosa et al, 2006). The growth of these algae alters the entire chemical system of the water, directly affecting oxygen levels, which has implications for the survival of other organisms such as fish, and carbon dioxide levels, which has a direct impact on pH (Smaha; Gobbi, 2023). Figure 5 shows an urban stretch of the Apodí-Mossoró River basin, located in the city of Mossoró-RN, containing macrophyte-type algae.

The seasonality of rainfall and the high temperatures observed in the semi-arid climate may be contributing to the increase in the trophic degree of water bodies, leading to a higher evaporation rate, which can potentially result in a decrease in the purification capacity of the watershed. The study period was mostly characterized by rainfall indices below average, except for the years 2008, 2009, and 2011, as shown in Table 5; therefore, this fact may have contributed to this high trophic degree. Additionally, due to the climate, high temperatures are recorded.

Table 5: Rainfall behavior in the Apodi-Mossoró River Hydrographic Basin from 2018 to 2026

Year	Rainfall Behavior
2008	Within the Average
2009	Above the Average
2010	Below the Average
2011	Above the Average
2022	Below the Average
2013	Below the Average
2014	Below the Average
2015	Below the Average
2016	Below the Average

A similar occurrence happened in an assessment of the TSI of the Orós Reservoir, in the state of Ceará, conducted by Batista et al (2014), which supports this study, as it shows, through Table 6, that during the rainy season the reservoir volume exhibits lower eutrophication.

Table 6: Mean TSI values for Orós Reservoir water

Points	IET - Rainy	Category	IET - Drought	Category
P1	53,1	Mesotrophic	54,3	Eutrophic
P2	58,4	Eutrophic	55,5	Eutrophic
P3	56,1	Eutrophic	53,7	Mesotrophic
P4	51,5	Mesotrophic	59,2	Eutrophic
P5	53,8	Mesotrophic	60,6	Eutrophic
P6	52,9	Mesotrophic	55,3	Eutrophic
P7	53,3	Mesotrophic	56,9	Eutrophic

The eutrophication factor has become a widely recognized problem of water quality deterioration (Ribeiro et al, 2005); in fact, in the case of the Apodi-Mossoró River basin, the pollutant discharge points along its course are notorious, which justifies the results of the analyses performed.

In conjunction with the high trophic index is the emergence of cyanobacteria. Studies by Oliveira et al (2020) state that, at the Pau dos Ferros Reservoir, Lucrécia Reservoir, and Rodeador Reservoir sites, the cyanobacteria density was almost entirely above the standards that establish the maximum permitted limits, according to Ministry of Health Ordinance 2914/2011 and CONAMA Resolution 357/2005, which set a limit of 20,000 cells/L or 2mm^3/L for class 1 freshwater.

A similar fact occurs in reservoirs in the state bordering Rio Grande do Norte, Paraíba, as evidenced by Vasconcelos et al (2011), who emphasize: the occurrence of cyanobacterial blooms in Paraíba's reservoirs has been recorded frequently with successive increases over time, particularly between the years 2006 to 2009. Among the 20 largest water supply reservoirs in the state, 3% presented cyanobacterial blooms in 2006. In 2007, the percentage became 20%, in 2008 45%, and 62% in 2009. These data are related to the increase in eutrophication associated with growing anthropogenic impacts in the river basins.

The pollutant load reaching the basin caused, within the study period, a severe degree of eutrophication in the water body, a fact that directly interferes with water quality. Statistical tools were decisive in determining the basin's behavior regarding the trophic degree during the study period.

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