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Evaluation of nitrogen and phosphorus in surface reservoirs of the semi-arid region of Brazil using mass balance[1]

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ABSTRACT - Water reservoirs were built in the semi-arid region to mitigate the effects of drought and water scarcity. However, these reservoirs are subject to variables that impact the volume and quality of the stored water, with the contribution of such nutrients as Total Nitrogen (TN) and Total Phosphorus (TP) being one of the main factors in intensifying the eutrophication process. The aim of this study was to quantify the principal inputs and outputs of nutrients (N and P) and calculate the nutrient balance, in order to verify the influence of seasonality on the import and export of these nutrients in surface reservoirs of the semi-arid region of Brazil. Seven campaigns were carried out between 2015 and 2016, with water samples collected at five points in the Pereira de Miranda reservoir and four in the General Sampaio reservoir. The inflow of nutrients was greater when the inflow rate of the water was higher. The balance showed the accumulation of 22.8 tons of TN and 2.8 tons of TP in the Pereira de Miranda reservoir, and 13 tons of TN and 1.5 tons of TP in the General Sampaio. These reservoirs are therefore retaining nutrients, acting as a storage site for nutrients transported by surface runoff in the basin of the Curu River. This increase in storage occurred mainly during the rainy season, when nutrient retention by the reservoirs impaired water quality, resulting in eutrophication, and making it difficult to meet the uses for which the reservoirs were intended.

Key words: Semi-arid regions. Period of extreme drought. Water reservoirs. Nutrient input and output.

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INTRODUCTION

The human population and water resources are both unevenly distributed around the globe. Regions with a high population density are generally not the regions that are rich in water. In the case of Brazil, population distribution is disproportionate to the distribution of water, with some regions significantly impacted by water scarcity and its consequent social and environmental problems (GETIRANA, 2016).

To mitigate the impact caused by the lack of water in some regions, many public policies have been implemented, including the construction of surface reservoirs to store and distribute water to the population (CHAVES *et al*., 2019).

However, water storage in surface reservoirs is subject to physical, chemical and biological variables that often degrade and enhance eutrophication. One of the most common impacts is the excessive growth of algae, which favour the production of toxins that have an adverse effect on human health, and which can also interfere with various other uses of the water (ANDRADE *et al*., 2020).

One of the causes of eutrophication concerns the management of land use and occupation around bodies of water, where eutrophication results from the excessive enrichment of anthropogenic nutrients. One indication of this is the excessive N and P loading that causes the proliferation of harmful algae (DING *et al*., 2018; LOPES *et al*., 2021).

In regions where the rainfall is highly variable, and which are subject to severe drought, as in the semi-arid region of Ceará, the process of eutrophication is even more intensified. Drought acts as a key factor that controls water quality in freshwater ecosystems and that can influence the residence time of the water, reducing the rate of water renewal (LI *et al*., 2017).

In addition to problems of management and monitoring, reservoirs located in the semi-arid region of Ceará often have environmental problems due to water scarcity and the presence of high concentrations of nitrogen and phosphorus in the water. The more eutrophic the water, the more expensive its treatment, and the greater the conflict over its use in the region. Monitoring the water, both quantitatively and qualitatively, guides and supports decision-making and prevents conflict between users (MACHADO; GALVAO; SOUZA FILHO, 2012).

In view of the above, the aim of this study was to quantify the principal inputs and outputs of nutrients (N and P) and calculate the nutrient balance, in order to verify the influence of seasonality on the import and export of these nutrients in surface reservoirs of the semi-arid region of Brazil.

MATERIAL AND METHODS

Characterisation of the area

The study area corresponds to the Pereira de Miranda and General Sampaio reservoirs that dam the Canindé and Curu rivers in the districts of Pentecoste and General Sampaio, respectively, in the semi-arid region of the state of Ceará. They both have a type BSw'h' climate according to the Köppen classification (1918), and are located in the watershed of the Curu River.

The watershed has an annual rainfall of around 700 mm, with a potential annual evapotranspiration of between 1,899 mm and 1,998 mm. The period from August to December has the highest rates of evaporation, and March to May the lowest (COMPANHIA DE GESTÃO DOS RECUROS HÍDRICOS, 2009).

The soils of the watershed of the Pereira de Miranda and General Sampaio reservoirs are predominantly luvisols, podsols and planosols, with argisols also occurring in the district of Pentecoste (FUNDAÇÃO CEARENSE DE METEOROLOGIA, 2018).

The nutrient data under analysis were collected at five georeferenced points in the Pereira de Miranda reservoir and four points in the General Sampaio (Figure 1). These were distributed based on the water input and output sites in the reservoirs, and are shown in Table 1 together with their UTM (Universal Transverse Mercator) coordinates.

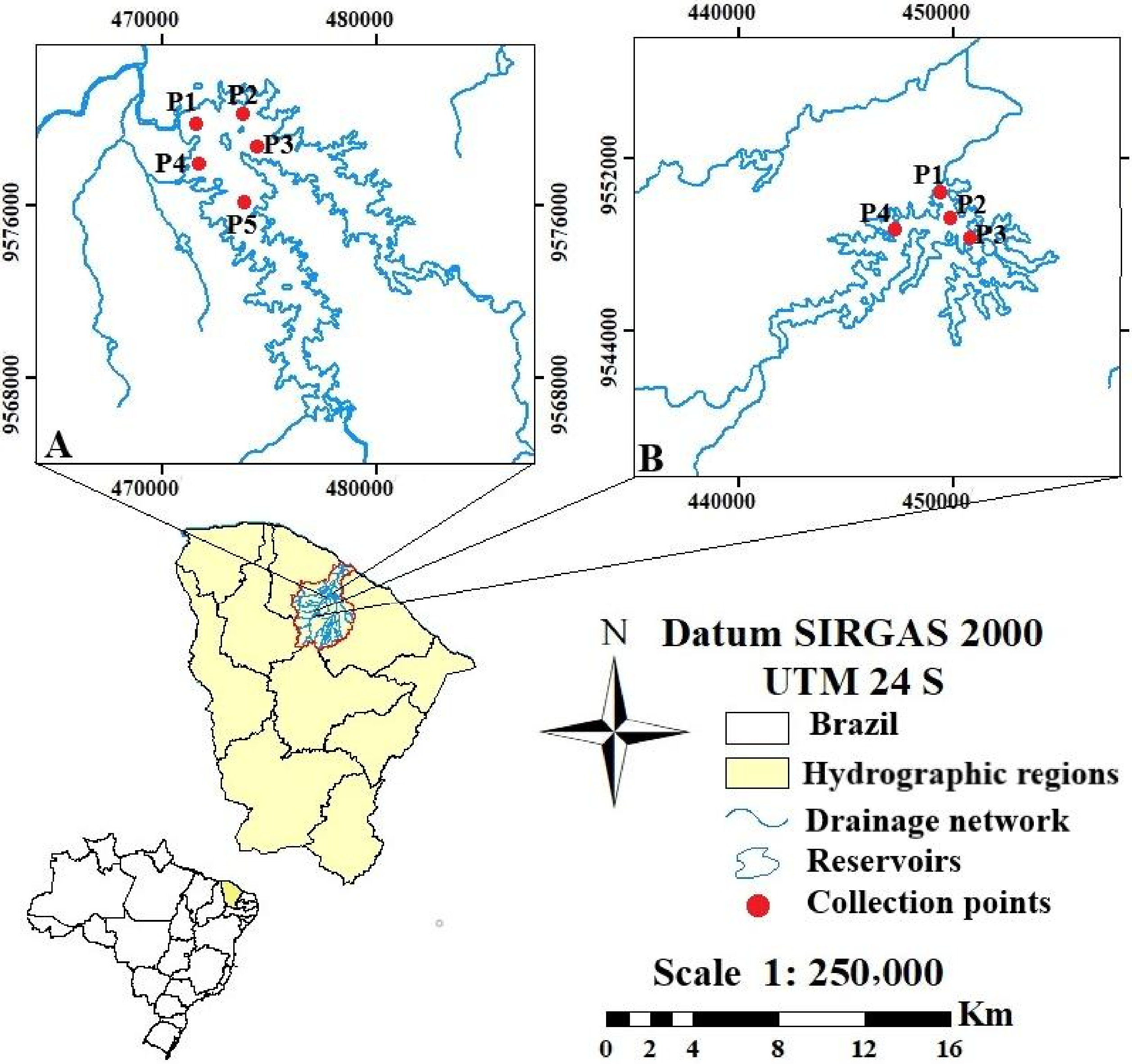
Points P2, P3, P4 and P5 were considered nutrient inputs to the Pereira de Miranda reservoir and correspond to the water input of the Capitão-mor and Canindé rivers, with fish farming in cages located near the beginning of the collection area in P4 (Figure 1). These cages were deactivated at the time of this study due to the low volume of water stored in the reservoir; however, the nutrient loading was still high, a result of the number of years the cages had been active. In the General Sampaio reservoir, point P2, corresponding to the fish farming site, and points P3 and P4, corresponding to the Salvação Stream and the Curu River, respectively, were all sampled. In both reservoirs, the exit point was P1, corresponding to the dam and water outlets.

Monitoring

The reservoirs were monitored in four campaigns carried out in April, July, September and December 2015; and three carried out in March, June and September 2016, giving a total of seven campaigns for the collection of data.

Characterisation of the reservoirs was carried out considering the first half of the year as the rainy season and the second half as the dry season. This was done to verify the influence of seasonality on the reservoirs.

Figure 1 - Location of the study area, showing the collection points in the reservoirs



Source: prepared by the author. Legend: A: Pereira de Miranda and B: General Sampaio

Table 1 - Collection points

Pereira de Miranda		General Sampaio	
Collection Point	Coordinates	Collection Point	Coordinates
P01 – Dam	471319 m E 9579671 m N	P1 - Dam	449451 m E 9550660 m N
P2 - Capitão-mor River	473007 m E 9579830 m N	P2 - Fishfarm	449909 m E 9549158 m N
P3 - rio Capitão-mor input	474308 m E 9579211 m N	P3 – Salvação Stream	450709 m E 95488401 m N
P4 – Canindé River	472484 m E 9578369 m N	P4 – Curu River	447334 m E 9548623 m N
P5 - Canindé River input	473672 m E 9576950 m N	-	-

Source: MASSA Research Group

The samples were collected at a depth of 30 cm from the surface of the water, in 1.0-L plastic bottles, previously sterilised and prepared. The samples were then packed in a cool box and sent to the laboratories for immediate processing. The phosphorus was measured using spectrophotometry (ascorbic acid) and the nitrogen by persulfate digestion (AMERICAN PUBLIC HEALTH ASSOCIATION; AMERICAN WATER WORKS ASSOCIATION; WATER ENVIRONMENT FEDERATION, 2005).

The water samples were analysed by the Environmental Chemistry Laboratory (LAQA), at the Department of Analytical and Physical Chemistry of the Federal University of Ceará (UFC).

Water balance and nutrient flux

The method used to calculate the nutrient balance was adapted by Molisani *et al*. (2013) and Vidal and Capelo Neto (2014), who applied it to the semi-arid region of Ceará. The inflow and outflow of water in the reservoirs were determined by means of the continuity equation (Equation 1), where the nutrient balance was established based on the flow rate of the water that enters and leaves the reservoirs.

$$\frac{dS}{dt} = I - Q \quad (1)$$

where: S = Water volume (m^3); t = Time (day); I = Inflow ($m^3\ day^{-1}$); and Q = Outflow ($m^3\ day^{-1}$).

In order to determine the total flow rate of the water at the inlet points to the reservoirs, it was necessary to carry out a water balance for the parameters considered to influence water availability: evaporation, the discharge flow rate, the flow rate released to supply the cities, and the difference in the volume stored in the reservoirs between successive periods. Equation 2 was used to determine the current volume stored in the reservoirs.

$$V_{t+1} = V_t + I - E_t - S_t - R_t \quad (2)$$

where: Vt+1 = Volume at the current time (m^3); Vt = Volume for the previous time (m^3); I = Total inflow to the reservoirs ($m^3\ day^{-1}$); Et = Evaporation ($m^3\ day^{-1}$), using daily data measured on the UFC farm; St = Spill ($m^3\ day^{-1}$); and Rt = Water withdrawal ($m^3\ day^{-1}$), obtained based on the reservoir operating routine of COGERH.

Readjusting the volume equation for the current time gives Equation 3 for the total inflow to the reservoirs.

$$I = \Delta V + E_t + S_t + R_t \quad (3)$$

where: $\triangle$V = Variation in volume ($m^3\ T^{-1}$), determined using the Quota to Volume ratio provided by COGERH; and S_t = Spill ($m^3\ T^{-1}$), obtained by applying the ratio where, if the reservoir quota is lower than the maximum spill quota, the spill is null ($S_t = 0$), otherwise Equation 4 is used.

$$S = C * W * \left(H - H_{spill}\right)^{1,5} \quad (4)$$

where: C = Spill coefficient, equal to 2.1; W = Width of the spillway (m), equal to 200 m for the Pereira de Miranda reservoir and 150 m for the General Sampaio; H = Current quota (m); and Hspill = Spill quota (m), 62 m for the Pereira de Miranda and 124.5 m for the General Sampaio.

After carrying out the water balance of the reservoirs, a mean value was determined for the calculated inflow rate and the outflow rate released at the spillway during the research period. The inflow rate was calculated from the water balance and the outflow rate was obtained using the data provided by the COGERH operating routine. The mean was arithmetic, between the days and the study campaign.

After obtaining the mean inflow and outflow rates of the reservoirs, Equation 5 was used to calculate the inflow and outflow of nutrients.

$$F_{Nutrient} = \frac{[Nutrient] * Q}{1000} \quad (5)$$

where: $F_{Nutrient}$ = Nutrient inflow or outflow for N or P (kg day^{-1}); [Nutrient] = Nutrient concentration, N or P (mg L^{-1}); Q = Inflow or outflow ($m^3\ day^{-1}$); and the denominator 1000 is the conversion factor from mg to kg.

Nutrient balance: input and output

To estimate nutrient input at each point, the mean concentration of each nutrient that entered the reservoirs during each campaign was first calculated using Equation 6.

The input at each point was determined by applying Equation 7, multiplying the concentration of nutrients entering the reservoirs by the volume.

Similarly, nutrient output was calculated applying Equation 8, where the outlet point was the site used by the COGERH operating routine for withdrawals.

$$[X_e] = \frac{\sum_{i=1}^{n} [pn]}{n} \quad (6)$$

$$NI = \frac{[X_e] * V}{10^6} \quad (7)$$

$$NO = \frac{[Pe] * V}{10^6} \quad (8)$$

where: $[X_e]$ Mean concentration at the entrance to each point for each period (mg L^{-1}); $[P_n]$ = Nutrient concentration at each point for each period (mg L^{-1}); n = Number of points - for the Pereira de Miranda reservoir, there are 5 points (4 for input and 1 for output), and for the General Sampaio there are 4 (3 for input and 1 for output); NI = Nutrient input at each point for each period (ton); NO = Nutrient output at the exit point for each period (ton); $[P_e]$ = Nutrient concentration at the exit point for each period (mg L^{-1}); V = Nutrient input volume at each point for each period (m^3); and the denominator 10^6 is the unit conversion factor.

Finally, the sum of the inputs gave the total input in tons, calculated for each point during the study period. Total output was the weight measured at the outlet point of the reservoirs. The nutrient balance between each campaign was given by Equation 9.

$$B = NI - NO \tag{9}$$

where: B = Nutrient balance; NI = Nutrient intake (ton); and NO = Nutrient output (ton).

RESULTS AND DISCUSSION

Nutrient concentrations

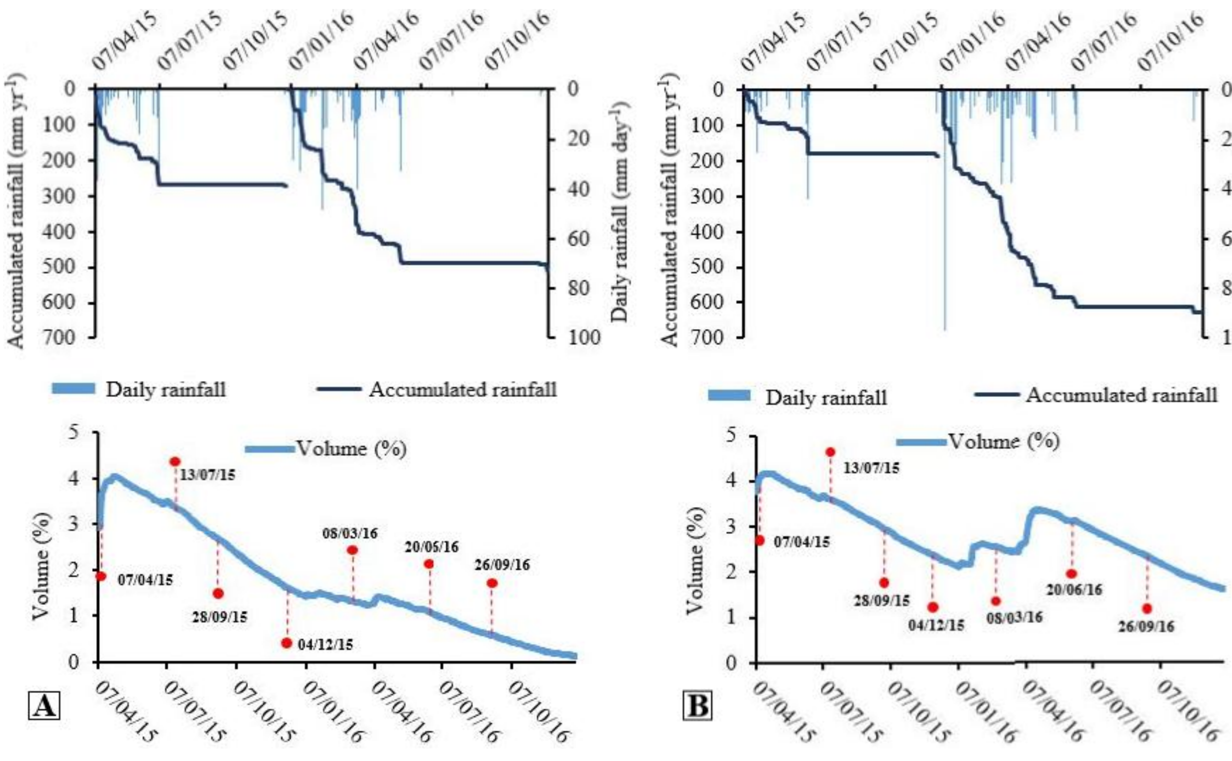
Rainfall, together with the local environmental conditions, is one of the variables that influence the eutrophication process. This is explained by its role in supplying water and the consequent increase in nutrient loadings caused by runoff and the transport of sediments into the reservoirs (BATISTA *et al*., 2014; COPPENS *et al*., 2016). On the other hand, rainfall is also related to the dissolution of these nutrients, causing a reduction in their concentration due to the increase in the volume of water stored in the reservoirs.

During the period under study, the rainfall showed similar behaviour in both reservoirs, occurring mainly during the first half of each year, considered the rainy season in the region, which, during periods when there was also surface runoff, resulted in an increase in the volume of water stored in the reservoirs (Figure 2). However, analysing the beginning and end of the period under study showed a reduction in the volume of stored water. The Pereira de Miranda reservoir started the period with 2.93% of its capacity and ended with 0.49%, while the General Sampaio started the period with 3.37% and ended with 2.25% (Figure 2).

The nutrient concentrations in the Pereira de Miranda reservoir were generally higher than those measured in the General Sampaio, except at the outlet point of the General Sampaio, where the highest concentrations of TP were recorded throughout almost the entire period.

In the Pereira de Miranda reservoir the TN input varied between 2.28 mg L^{-1} and 6.16 mg L^{-1}, with a greater input between March and June 2016. Between March and June, it rains in the region, with a total rainfall of 230.9 mm being recorded during this period (Figure 2). The rainfall that occurred during the period helped to transport the nutrient to the reservoir, in addition to slightly increasing the volume of stored water (Figure 2). The highest concentration of this nutrient at the exit point (6.87 mg L^{-1}) was also seen on the same date, indicating that maximum nutrient input and maximum nutrient output occurred at the same time.

Figure 2 - Rainfall and volume of stored water



Source: COGERH. Legend: A: Pereira de Miranda and B: General Sampaio

TP reached a maximum value (1.02 mg L^{-1}) at the inlet of the Pereira de Miranda reservoir during the dry period, between September and December 2016 (Table 2), confirming the results of Batista *et al*. (2014) in the Orós reservoir in Ceará, where the highest concentrations of phosphorus were obtained during the dry period in the region, and which helped to increase the production of algal biomass in the reservoir.

The period from September to December 2016 is characterised as dry in the region, with either no rainfall or an insignificant amount that causes no surface runoff or water to enter the reservoir. The presence of TP in the Pereira de Miranda reservoir was therefore associated with the presence of fish farming, the low volume of stored water, and the disturbance of sediment at lesser depths caused by wind action (BATISTA *et al*., 2014; MOURA *et al*., 2018). The greatest output concentration was also recorded between September and December 2016, showing that the nutrient both entered and left the reservoir during this period.

TN concentrations at the inlet to the General Sampaio reservoir ranged from 1.66 mg L^{-1} to 2.75 mg L^{-1} (Table 2), with the greatest value between December 2015 and March 2016. As in the Pereira de Miranda reservoir, this period is characterised as the rainy season in the region. There was an accumulated rainfall of 273 mm (Figure 2), one of the highest values for the entire period under study. This resulted in increased concentrations of this nutrient in the reservoir, due to surface runoff of the rainwater, at the same time affording one of the highest outputs of the nutrient.

TP input concentrations in the General Sampaio reservoir were generally lower than those in the Pereira de Miranda (Table 2), except for the period between September and December 2015 and between December 2015 and March 2016, when concentrations at the entry points of the General Sampaio surpassed those of the Pereira de Miranda, especially during the first period, when there was not enough rainfall for surface runoff or to supply the reservoir. This may have been due to nutrient concentrations during the dry period in semi-arid regions tending to remain stable or to increase, even when there is no input from the river, due to the high rates of evaporation (ANDRADE *et al*., 2020).

In general, higher concentrations of TN and TP were found at both the inlet and outlet of the Pereira de Miranda reservoir compared to the General Sampaio (Table 2), except at the outlet of the General Sampaio, where the highest outflow concentrations were identified for TP.

Both reservoirs are located in the same watershed and are subject to the same variations in climate that degrade water quality (BATISTA *et al*., 2014). Nutrients enter reservoirs through local and diffuse sources of pollution. In the case of the local sources, nutrients are received from the fish farms in the reservoirs and the discharge of sewage from nearby residences; the diffuse sources mainly include agriculture and livestock in the watershed of the reservoirs (COMPANHIA DE GESTÃO DOS RESUROS HÍDRICOS, 2011).

The margins of the Pereira de Miranda reservoir have been more impacted by human activity; the reservoir is located in an urban area, receives the direct discharge of sewage from homes that have no sanitation, and there are more animals with direct access to the reservoir compared to the General Sampaio (COMPANHIA DE GESTÃO DOS RECURSOS HÍDRICOS, 2009). The high nutrient loading measured in the Pereira de Miranda reservoir

Table 2 - Total nitrogen (TN) and total phosphorus (TP) concentrations

Collection	Pereira de Miranda				General Sampaio			
	[TN] mg L^{-1}		[TP] mg L^{-1}		[TN] mg L^{-1}		[TP] mg L^{-1}	
	Input	Output	Input	Output	Input	Output	Input	Output
Apr – Jul 2015	2.28	2.61	0.30	0.33	1.85	1.76	0.15	0.10
Jul – Sep 2015	2.59	2.52	0.19	0.11	1.66	1.48	0.16	0.15
Sep – Dec 2015	3.75	3.47	0.19	0.06	1.90	2.05	0.40	0.21
Dec 2015 - Mar 2016	4.65	3.65	0.38	0.24	2.75	2.76	0.38	0.28
Mar – Jun 2016	6.16	6.87	0.35	0.23	2.72	2.90	0.29	0.29
Jun – Sep 2016	4.86	4.52	0.39	0.25	1.81	1.75	0.03	0.31
Sep – Dec 2016	5.69	5.14	1.02	0.70	2.18	2.81	0.37	0.34
Mean	4.28	4.11	0.40	0.27	2.12	2.22	0.25	0.24

Source: research data

compared to the General Sampaio was linked to these different characteristics, which when combined in the reservoirs increased nutrient enrichment and productivity in these aquatic ecosystems, favouring the presence of phytoplankton and the emergence of cyanobacteria (ROCHA *et al*., 2019).

The higher TN concentration in the Pereira de Miranda reservoir afforded greater potential for eutrophication via algal and cyanobacterial blooms since phytoplankton growth was favoured by the high availability of the nitrogen (COTOVICZ JÚNIOR *et al*., 2013). The presence of these algae was associated with the response of the water to excess nutrients, and in turn, the eutrophication of the reservoir (SCHINDLER *et al*., 2016).

The greater TP concentrations seen in water reservoirs is mainly a result of agricultural and livestock activities carried out upstream of the watershed (JORDAN *et al*., 2012; VON SPERLIN, 1996); this was the case of the Pereira de Miranda reservoir. The presence of TP in a reservoir is understood as a measure of eutrophication potential, since the nutrient acts as the main causative agent of the process (PAULINO; OLIVEIRA; AVELINO, 2013).

The Pereira de Miranda and General Sampaio reservoirs are unclassified. According to Article 42 of CONAMA Resolution 357 of 2005 (BRASIL, 2005), unclassified reservoirs should be considered as Class II. As such, the limits established by the above resolution for TN and TP concentrations in reservoirs were exceeded during most of the study period.

The limit of TP concentrations for the characteristics of the Pereira de Miranda and General Sampaio reservoirs is 0.03 mg L^{-1}. Concentrations greater than 0.03 mg L^{-1} were recorded throughout the period, except for June to September 2016, when the General Sampaio reservoir had a measured concentration of 0.03 mg L^{-1}. This suggests that for most of the period there was a higher intake than established in the resolution, and that generally the input of this nutrient to the reservoirs was greater than the output (ANDRADE *et al*., 2020).

CONAMA Resolution 357 of 2005 (BRASIL, 2005) does not address limits for total TN concentrations in fresh waters of Class II lentic environments, only fractions. The limit for TN is only applicable when this happens to be the limiting nutrient for the body of water, in which case the limit for the reference outflow rate for the period is 1.27 mg L^{-1}.

High concentrations of nitrogen and phosphorus, as in the case of the reservoirs under study, may become limiting nutrients for water quality and eutrophication (ROCHA *et al*., 2019) since they are consumed by phytoplankton at an average N:P ratio of 10:1 (GREEN; FINLAY, 2010; VIDAL; CAPELO NETO, 2014). When the N:P ratio in the reservoirs was high, greater than 10, it was assumed that the limitation on the reservoir was due to phosphorus; however, when the opposite occurred, an N:P ratio lower than 10, the limitation was assumed to be due to nitrogen.

The predominantly limiting nutrient to the growth of algae and microorganisms in the Pereira de Miranda reservoir was TP (Table 3), with the highest N:P ratio seen from September to December 2015, suggesting that for the Pereira de Miranda reservoir, water pollution was mainly due to the release of domestic sewage upstream (WIEGAND; PIEDRA; ARAÚJO, 2016).

In the General Sampaio reservoir, the predominantly limiting nutrient was TN, with the lowest N:P ratio identified for the same period, September to December 2015, showing that water pollution occurred mainly due to arable areas in the watershed of the reservoir where fertilisers are used, to

Table 3 - Limiting nutrient for each period

Collection	Pereira de Miranda		General Sampaio	
	N:P	Nutrient	N:P	Nutrient
Apr – Jul 2015	7.8	Nitrogen	14.58	Phosphorus
Jul – Sep 2015	16.6	Phosphorus	10.22	Phosphorus
Sep – Dec 2015	27.9	Phosphorus	6.49	Nitrogen
Dec 2015 - Mar 2016	13.4	Phosphorus	8.35	Nitrogen
Mar – Jun 2016	22.5	Phosphorus	9.65	Nitrogen
Jun – Sep 2016	14.7	Phosphorus	10.57	Phosphorus
Sep – Dec 2016	6.3	Nitrogen	7.09	Nitrogen

Source: prepared by the author

livestock, fish farming, and domestic sewage containing nutrients that were transported by surface runoff into the reservoir (PEREIRA *et al*, 2021).

Nutrient inflows and outflows

The inflow and outflow of water in the Pereira de Miranda and General Sampaio reservoirs were evaluated using hydrological data. The inflow rates were calculated using the water balance and the outflow rates from the COGERH operating routine (Table 4).

According to the evaluated water flows, there was no inflow during two periods of the Pereira de Miranda reservoir and four of the General Sampaio. This was due to the intermittent character of the rivers in the region (Table 4), the dry period during the years of this research, the absence of rainfall, and the lack of any increase in the volume of stored water (Figure 2), as no water was transferred to the reservoirs during these periods.

The inflow rate varied greatly between the beginning and end of the overall period, significantly impacting the quantity and quality of the stored water. The periods when the inflow rate was zero shows that there was no water input, but rather a loss, due to the high evaporation recorded during the period and consequent reduction in the volume of stored water.

Evaporation was responsible for a large loss of water in the reservoirs, which evaporated far greater volumes than those released during the COGERH operating routine. This impacted the results, helping to aggravate the eutrophication process in the reservoirs due to the reduction in the volume of stored water and the increase in nutrient concentrations (ANDRADE *et al*., 2020).

During periods of water flow, the inflow rate was higher than the outflow rate for both the Pereira de Miranda and General Sampaio reservoirs (Table 4), except from September to December 2016, a period that saw the lowest recharge of the Pereira de Miranda reservoir due to low rainfall (3.4 mm). During this period, the water in the reservoir was not recharged (Figure 2); there were, however, losses due to the high evaporation and amount of water released at the outlet to the reservoir. This means that there was an increase in nutrient concentrations, as the evaporation process continued.

From April to July 2015, the inflow rate of the water to the Pereira de Miranda reservoir was at maximum (Table 2); this was associated with an increase in the volume of water stored during the period, which was due to the larger volume of rainwater (267 mm). In the General Sampaio reservoir, the greatest inflow rate was between March and June 2016. For the same period, the maximum rainfall (319 mm) occurred, with one of the largest volumes of water stored during the period (Figure 2).

Throughout the period, even with the loss of water due to the reduction in the stored volume (Figure 2), water was released in the COGERH operating routine (Table 4). However, the input of water to the reservoirs was greater than the output, meaning that the water balance was positive.

The inflow of nutrients to the Pereira de Miranda and General Sampaio reservoirs followed the same trend as the inflow rate of the water, showing peaks in the nutrient flow at the same time as peaks in the flow rate of the water (Figure 3). The Pereira de Miranda reservoir had higher TN and TP input loadings than the General Sampaio, in addition to a greater inflow rate for the water which was stored in the reservoir.

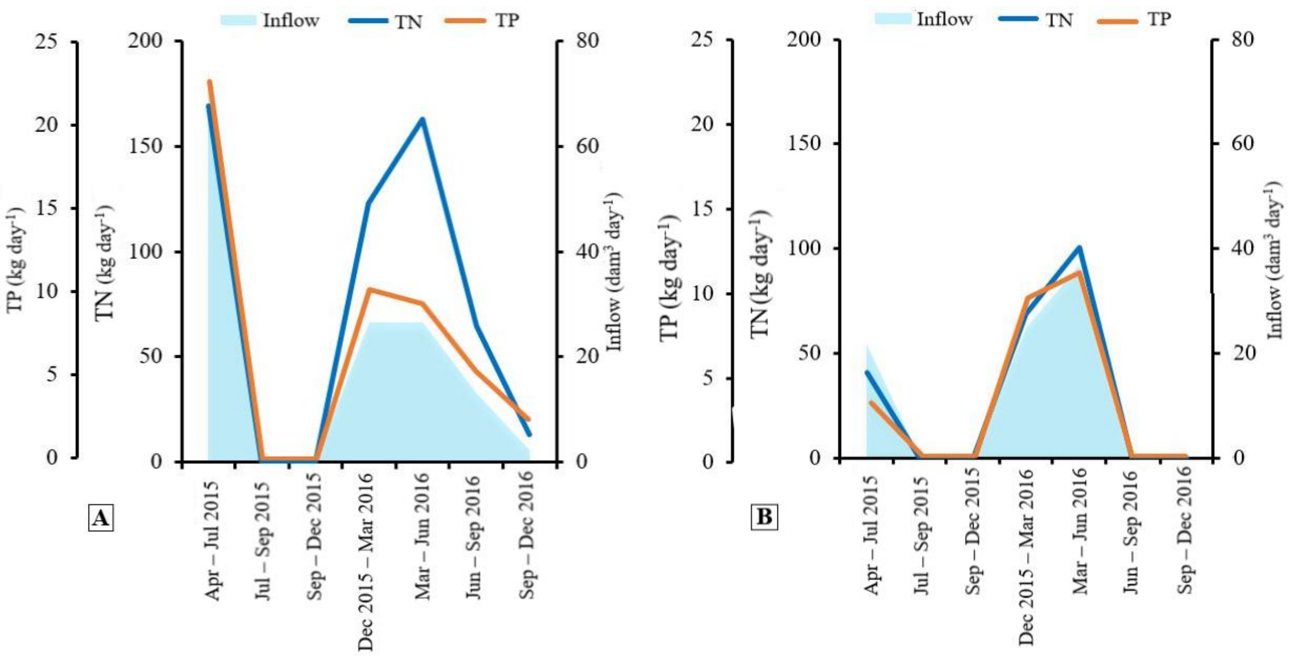
The daily TN flow in the Pereira de Miranda reservoir (Figure 3) increased significantly between April and July 2015, with a peak in the daily inflow rate of the water accompanied by a daily TN inflow of almost 169 kg. TP also varied, with the highest concentration of 22.2 kg occurring during periods of increased water inflow (Figure 3).

Table 4 - Water inflow and outflow rates

Period	Number of days in each period	Pereira de Miranda			General Sampaio		
		Total inflow ($m^3period^{-1}$)	Daily inflow (m^3d^{-1})	Daily outflow (m^3d^{-1})	Total inflow ($m^3period^{-1}$)	Daily inflow (m^3d^{-1})	Daily outflow (m^3d^{-1})
Apr – Jul 2015	97	7,200.015	74.227	11.232	2,123.452	21.891	5.616
Jul – Sep 2015	77	0	0	11.232	0	0	5.616
Sep – Dec 2015	67	0	0	11.232	0	0	5.616
Dec 2015 – Mar 2016	95	2,518.124	26.507	11.232	2,368.159	24.928	5.616
Mar – Jun 2016	104	2,751.063	26.453	11.232	3,835.725	36.882	5.616
Jun – Sep 2016	98	1,304.848	13.315	11.232	0	0	5.616
Sep – Dec 2016	92	212.691	2.312	11.232	0	0	5.616

Source: research data

Figure 3 - Total nitrogen (TN) and total phosphorus (TP) inflow



Source: prepared by the author. Legend: A: Pereira de Miranda and B: General Sampaio.

TN and TP loadings in the General Sampaio reservoir followed the same trend as in the Pereira de Miranda reservoir (Figure 3), with the higher loadings (100.5 kg TN day^{-1} and 10.9 kg TP day^{-1}) corresponding to the periods of greater water inflow, highlighting the periods from December 2015 to March 2016 and from March to June 2016 in which TP flows were higher for the General Sampaio reservoir compared to the Pereira de Miranda. This was associated with the greatest inflow of water into the General Sampaio reservoir in any one period (Table 4), the greatest recorded rainfall, and an increase in the volume of stored water (Figure 2).

The outflow of TN and TP did not follow the same trend as the outflow rate of the reservoirs; their behaviour was seen to vary as the inflow rate varied. The periods with the greater outflow of nutrients were the same as those with nutrient inflow to the reservoirs (Figure 4), with minimum values for outflow recorded during periods with no inflow, suggesting that the retained nutrients come mainly from the use and occupation of the watershed of each reservoir (DUARTE *et al*., 2021; PEREIRA *et al*., 2021).

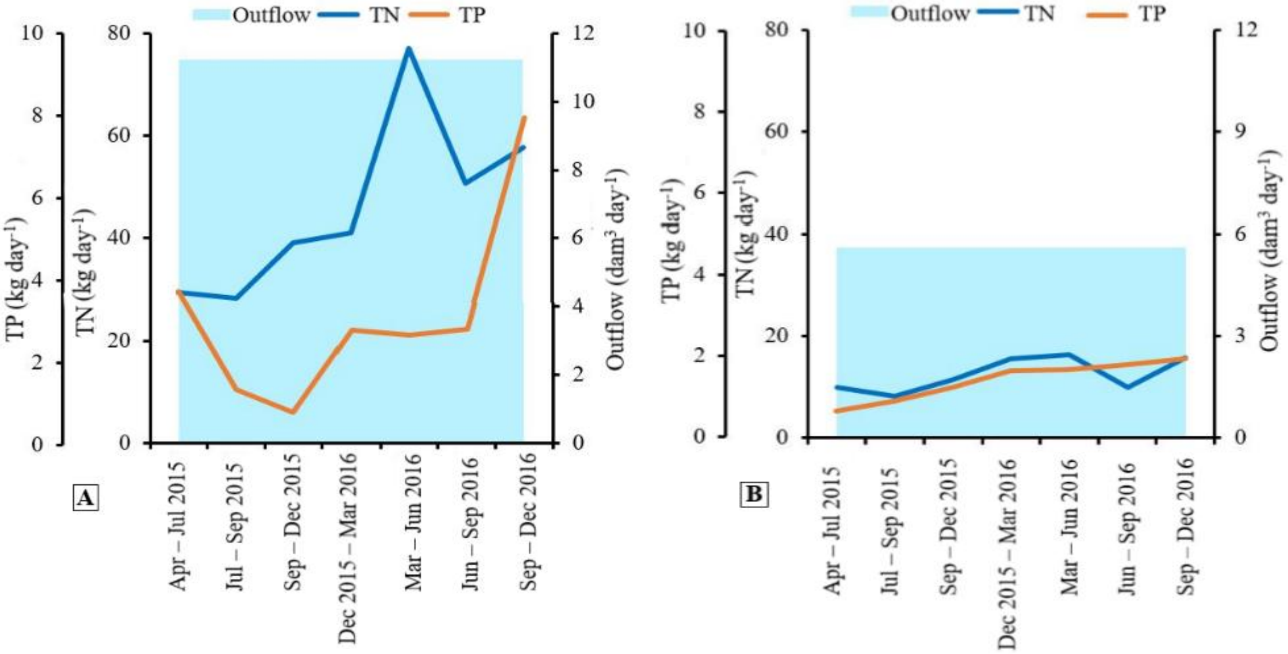
The highest nutrient concentrations being associated with the highest flow rates of the water show that the nutrients originate mainly from agricultural activity, since it is usual in agriculture to add more fertiliser than the cultivated area can absorb (LOPES *et al*., 2014; VON SPERLING, 1996), and from livestock farming that is very common in the region; these nutrients are not absorbed by the soil and drain from the surface into the reservoirs during periods of rainfall.

Such behaviour shows that the sources of these nutrients are diffuse and associated with agriculture and livestock activities in the watershed of each reservoir. The region is characterised by shallow soils, which together with the removal of natural vegetation for agriculture, favours greater surface runoff and less water retention during the infiltration process; this water flows into the reservoirs during periods of rainfall (ANDRADE; MEIRELES; PALÁCIO, 2010) carrying all the unabsorbed nutrients.

When assessing the flow and balance of nutrients in the reservoirs, it was seen that their presence was highly variable, depending on the use and occupation of the watersheds that supply the reservoirs. There was a progressive increase in TN and TP accumulation throughout the period and an increase in the flow rate of the water stored in the reservoirs (Figures 5 and 6) with only a few small variations, and smaller outflows than inflows, meaning that nutrient enrichment predominated during the period.

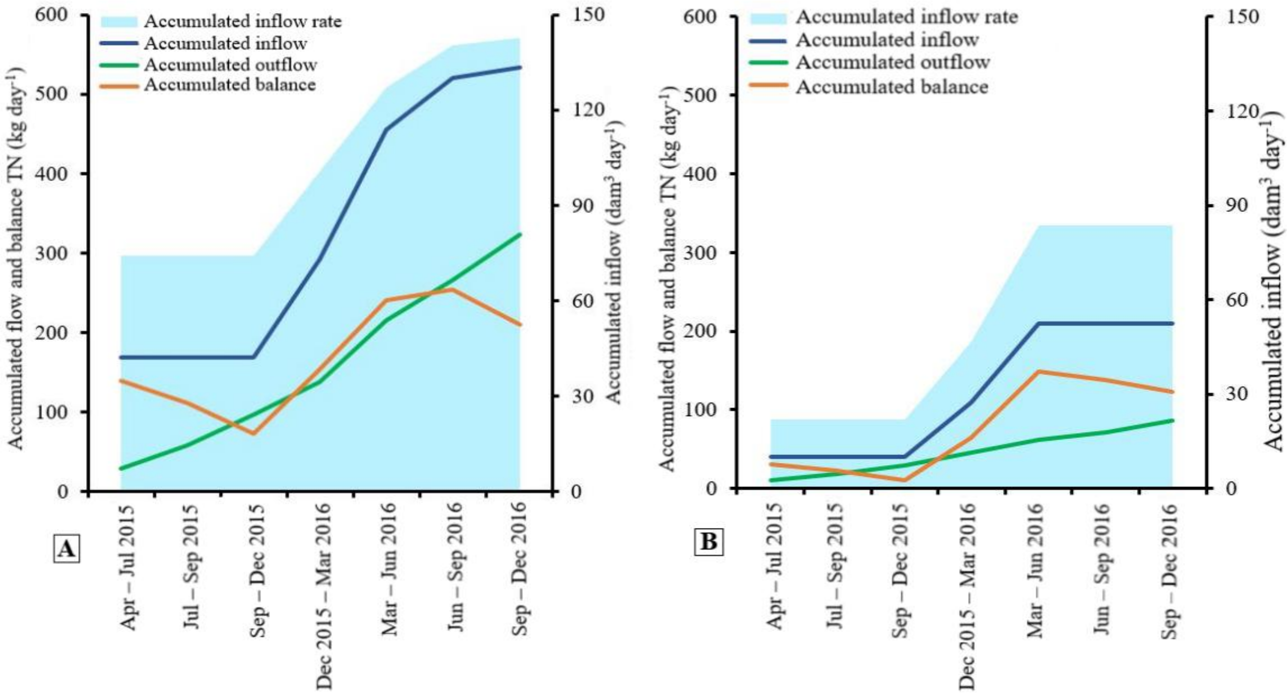
Nutrient accumulation in the reservoirs increased as the volume of accumulated water increased, a greater trend towards this behaviour being seen in the General Sampaio reservoir. This suggests that accumulation of these nutrients in the reservoir mainly originated from sources such as agriculture and livestock farming, which are the basis of the economy in the area (COMPANHIA DE GESTÃO DOS RESURSOS HÍDRICOS, 2011), and that the nutrients were then carried by surface runoff into the reservoir (ANDRADE *et al*., 2020).

Figure 4 - Total nitrogen (TN) and total phosphorus (TP) outflow



Source: prepared by the author. Legend: A: Pereira de Miranda and B: General Sampaio

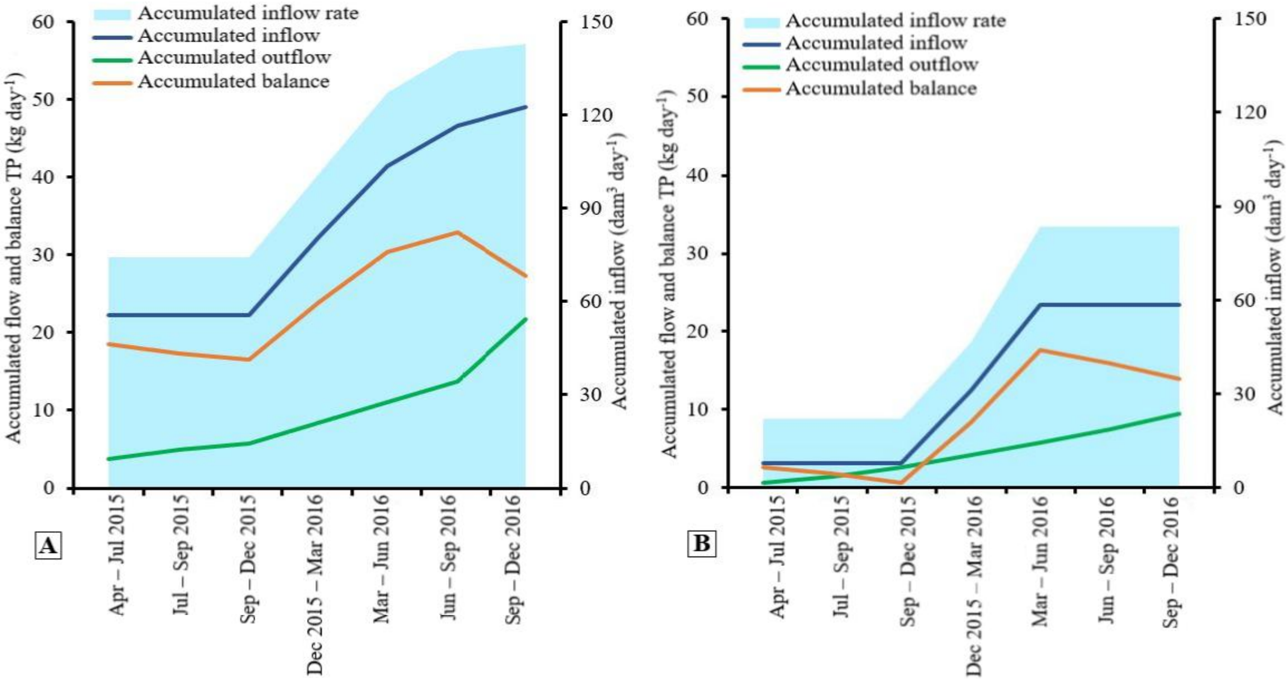
Figure 5 - Flows and balance for total nitrogen (TN)



Source: prepared by the author. Legend: A: Pereira de Miranda and B: General Sampaio

Nutrient accumulation in the Pereira de Miranda reservoir was also influenced by variations in the volume of water that entered the reservoir, albeit not as markedly as in the General Sampaio. It is believed that the greatest contributions to the Pereira de Miranda reservoir were due to local sources, such as the deactivated fish farming, urban sewage, and animals along its banks (DUARTE *et al*., 2021).

Figure 6 - Flows and balance for total phosphorus (TP)



Source: prepared by the author. Legend: A: Pereira de Miranda and B: General Sampaio

In the Pereira de Miranda and General Sampaio reservoirs, the accumulated inflow of TN and TP for the period was greater than the outflow, thereby causing a positive accumulated balance throughout the period, meaning that more nutrients were imported than exported (Figures 5 and 6).

In general, it was found that the greatest inflows and increases in nutrient accumulation occurred mainly during the first half of the year, a period considered in this study to be the rainy season. This explains the availability of nutrients in the reservoirs, favouring their eutrophication (LOPES et al., 2014; VON SPERLING, 1996).

Nutrient balance: input and output

The TN and TP loadings that entered and left the Pereira de Miranda and General Sampaio reservoirs, as well as the rates at which they entered and left the reservoirs, showed very similar behaviour over the periods under analysis (Figures 7 and 8).

The highest inputs were seen to occur during the rainy season, with the highest input registered in the Pereira de Miranda reservoir from April to July 2015, around 13.56 tons of TN and 1.8 tons of TP, and in the General Sampaio reservoir from March to June 2016, with around 8.76 tons of TN and 0.96 tons of TP. These periods saw the greatest discharge of water from the reservoirs and, consequently, the highest input of nutrients (VIDAL; CAPELO NETO, 2014).

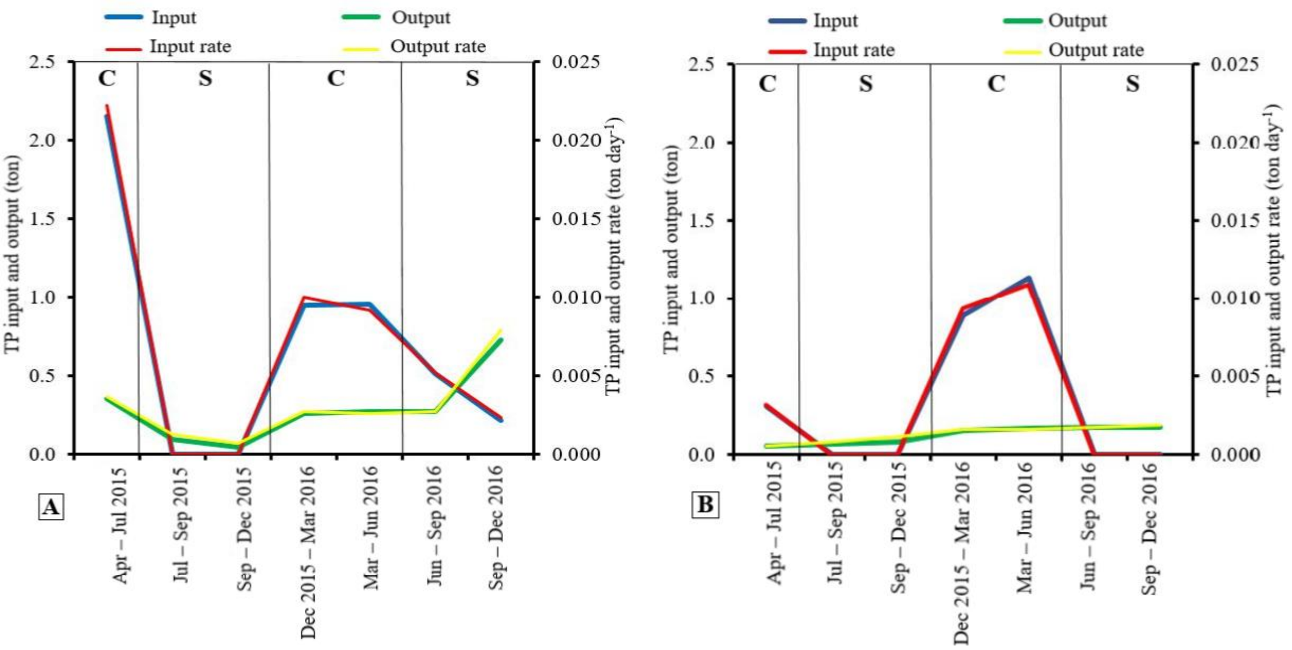
This suggests that agriculture and livestock farming are carried out in the tributaries upstream of the reservoirs, which greatly contributes to the enrichment of nutrients carried by the rainfall and surface water that drains into the reservoirs (ANDRADE *et al*., 2020; ESTEVES; MEIRELLES, 2011).

Nutrient input to the Pereira de Miranda reservoir was generally higher than the output, with the input subject to a greater variation due to the greater control and uniformity of the outflow released in the COGERH operating routine. However, for most of the period, the General Sampaio reservoir output more nutrients than it stored; only during certain periods, due to the more intense rainfall, did nutrient input exceed output.

Freitas, Righetto and Attayde (2011) found the same dynamics as seen here, where the highest nutrient values were recorded for the period during which the reservoir received water, as in the study by Vidal and Capelo Neto (2014) and Andrade *et al*. (2020), meaning that during some periods, eutrophication of the reservoirs is greatly influenced by seasonality and the lack of rain in the region.

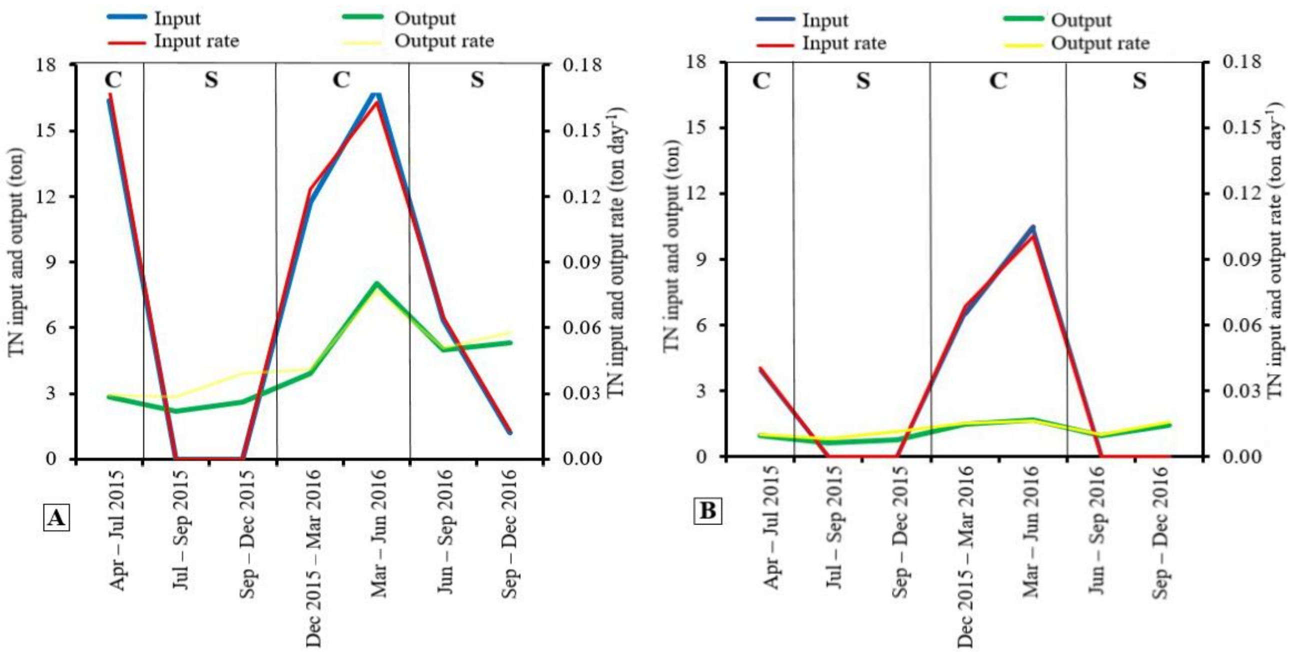
The TN and TP balance is shown in Figures 9 and 10. It can be seen that throughout the period more nutrients were stored than released, the highest concentrations being stored in the Pereira de Miranda reservoir.

Figure 7 - Input and output of total nitrogen (TN)



Source: prepared by the author. Legend: A: Pereira de Miranda, B: General Sampaio, C: Rainy season and S: Dry season

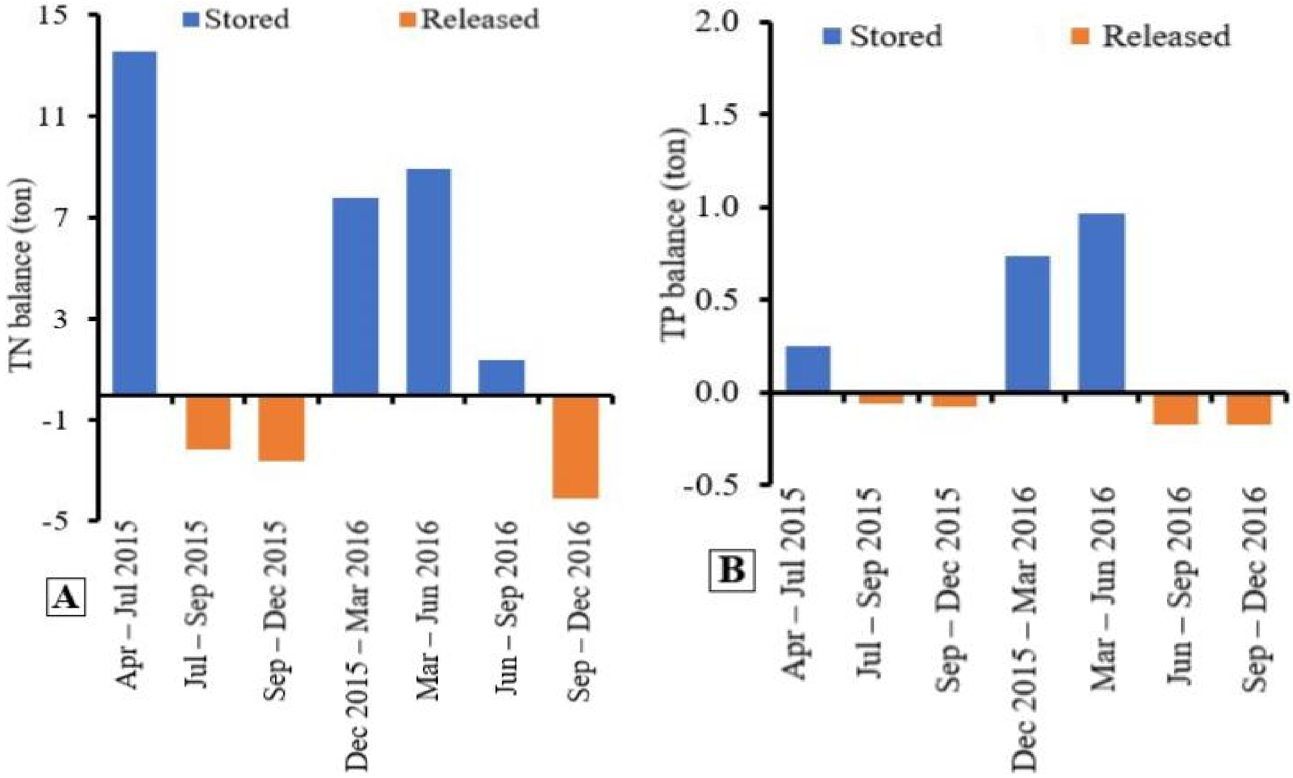
Figure 8 - Input and output of total phosphorus (TP)



Source: prepared by the author. Legend: A: Pereira de Miranda, B: General Sampaio, C: Rainy season and S: Dry season

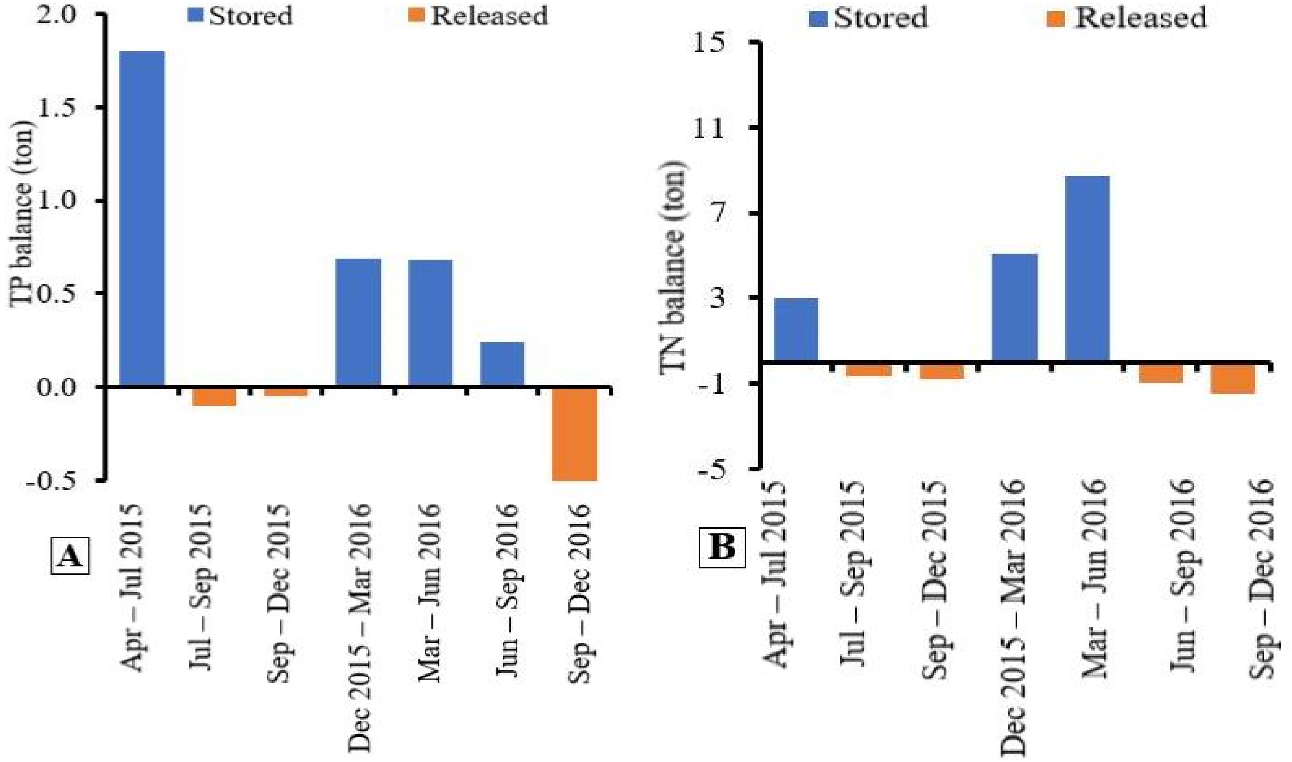
The greatest storage was calculated for the period from April to July 2015 in the Pereira de Miranda reservoir and from March to June 2016 for the General Sampaio. This is explained by the higher rainfall indices recorded for each reservoir during these periods, and shows that the nutrient balance was dependent on the rainfall, and that the import of nutrients was greater than the export.

Figure 9 - Total nitrogen (TN) balance



Source: prepared by the author. Legend: A: Pereira de Miranda, B: General Sampaio

Figure 10 - Total phosphorus (TP) balance



Source: prepared by the author. Legend: A: Pereira de Miranda, B: General Sampaio

Table 5 - Input and output of total nitrogen (TN) and total phosphorus (TP)

Period	Pereira de Miranda		General Sampaio	
	TN (tons)	TP (tons)	TN (tons)	TP (tons)
Apr – Jul 2015	13.56	1.80	2.98	0.25
Jul – Sep 2015	-2.18	-0.10	-0.64	-0.06
Sep – Dec 2015	-2.61	-0.05	-0.77	-0.08
Dec 2015 – Mar 2016	7.81	0.69	5.05	0.74
Mar – Jun 2016	8.92	0.68	8.76	0.96
Jun – Sep 2016	1.36	0.24	-0.96	-0.17
Sep – Dec 2016	-4.10	-0.51	-1.45	-0.17
Total	22.8	2.8	13.0	1.5

Source: prepared by the author

Table 5 shows the loading in tons of TN and TP that were retained and exported by the Pereira de Miranda and General Sampaio reservoirs between 2015 and 2016. Positive values mean that the reservoirs acted to retain nutrients, while negative values mean that they acted to export nutrients.

The Pereira de Miranda reservoir acted to export TN and TP during three periods only, albeit with low output loadings, which were not equal to the amount stored. Whereas the General Sampaio reservoir exported nutrients during four periods, again not equal to the amount stored.

Throughout the period under analysis, the Pereira de Miranda and General Sampaio reservoirs mainly acted as nutrient sinks in the basin of the Curu river. The Pereira de Miranda reservoir stored a greater amount of nutrients, with a total of 22.8 tons of TN and 2.8 tons of TP. The General Sampaio reservoir accumulated less of these nutrients, with a TN loading of 13.0 tons and a TP loading of 1.5 tons.

It was found that in addition to the water flow having increased the presence of these nutrients in the reservoirs, other factors, such as the residence time of the water, rainfall and evaporation, as well as other environmental and climate factors contributed to the presence and distribution of these nutrients in the reservoirs. For Wiegand, Piedra and Araújo (2016), the phenomenon that best explains the high retention of phosphorus and nitrogen in reservoirs of the semi-arid region is the residence time of the water, which directly affects the residence time of the nutrients, as the water is not renewed.

Management-planning, and corrective and preventative action are essential so that in the future, water quality in the reservoirs under study is not impaired to the point of culminating in a need to modify the technology used in the treatment stations, or in the processes becoming too expensive or unfeasible (ANDRADE *et al*., 2020; VIDAL; CAPELO NETO, 2014).

CONCLUSIONS

1. The input and output of nutrients in semi-arid reservoirs is influenced by seasonal variations in climate;
2. In semi-arid regions, the inflow of nutrients into reservoirs occurs mainly during the rainy season and whenever there is rainfall;
3. Nutrients tend to increase input and accumulation in reservoirs over time, and come from the following sources: agriculture, livestock, sewage and fish farming;
4. Reservoirs in semi-arid regions act as nutrient sinks, which reflects in a reduction in the quality of the stored water and an increase in eutrophication.

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