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Natural and anthropic inputs of nutrients in hydrographic basins of reservoirs in the Brazilian semiarid

Aportes naturais e antrópicos de nutrientes em bacias hidrográficas de reservatórios do semiárido brasileiro

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Abstract: Aim: Estimate the input of loads of N and P emitted by natural (atmospheric deposition and soil denudation) and anthropogenic (agriculture, livestock and sewage) factors for the hydrographic basins of two reservoirs in the Brazilian semiarid region (Mendubim and Umari). **Methods:** In the present work, we use georeferenced data provided by official agencies, data presented in academic papers, field samples and laboratory analysis of emission factors in the estimates of nitrogen and phosphorus inputs in reservoir basins of Brazilian semiarid region. **Results:** Soil denudation was identified as the main natural source of N and atmospheric deposition as the main source of P in both basins. Among the anthropogenic sources, the main source of N and P, for the two basins, was livestock. The total loads (natural and anthropogenic) of N (579.01 tonne. year^{-1}) and P (136.35 tonne. year^{-1}) received by the Umari basin was, respectively, 43.90% and 22.10% higher than those received by Mendubim, with a predominance of anthropogenic sources in both nitrogen and phosphorus emission. **Conclusions:** The results showed the importance of monitoring human activities that can enhance nutrient inputs, such as nitrogen and phosphorus, in basins of the Brazilian semiarid region. The quantification of the emission factors analyzed here can be a tool in the development of strategies to mitigate the problems that high concentrations of N and P can bring to the quality and use of water in semiarid reservoirs.

Keywords: soil denudation; eutrophication; anthropogenic sources; natural sources; livestock.

Resumo: Objetivo: Estimar o aporte de cargas de N e P emitidas por fatores naturais (deposição atmosférica e desnudação do solo) e antrópicos (agricultura, pecuária e águas servidas) para as bacias de contribuição de dois reservatórios do semiárido brasileiro (Mendubim e Umari). **Métodos:** No presente trabalho, utilizamos dados georreferenciados disponibilizados por órgãos oficiais, dados apresentados em trabalhos acadêmicos, coletas de campo e análise laboratorial nas estimativas dos aportes de nitrogênio e fósforo para as bacias hidrográficas de dois reservatórios semiárido brasileiro. **Resultados:** O desnudamento do solo foi identificado como a principal fonte natural de N e a deposição atmosférica como a principal fonte de P, em ambas as bacias de contribuição. Dentre as fontes antrópicas, a principal fonte de N e P, para as duas bacias, foi a pecuária. As cargas totais (naturais e antrópicas) de N (579,01 tonne.ano^{-1}) e P (136,35 tonne.ano^{-1}) recebidas pela bacia de contribuição de Umari foram, respectivamente, 43,9% e 22,1% superiores às recebidas por

Mendubim, com predominância de fontes antropogênicas tanto na emissão de nitrogênio quanto de fósforo. **Conclusões:** Os resultados mostraram a importância do monitoramento de atividades antrópicas que possam potencializar aportes de nutrientes, como nitrogênio e fósforo, em bacias do semiárido brasileiro. A quantificação dos fatores de emissão aqui analisados pode ser uma ferramenta no desenvolvimento de estratégias para mitigar os problemas que altas concentrações de N e P podem trazer para a qualidade e uso da água em reservatórios do semiárido.

Palavras-chave: desnudamento do solo; eutrofização; fontes antropogênicas; fontes naturais; pecuária.

1. Introduction

The world demand for water doubled in the 20th century in relation to the population, with the largest consumption coming from agricultural activities (70%), reaching 90% in less developed countries (FAO, 2017). The increase in water consumption, mainly by agriculture, can provide a deficit in several countries until 2050, which can only be minimized by reducing the demands of other sectors and or by avoiding the contamination of surface aquatic environments and groundwater (Grafton et al., 2015). The increase in water demand in several hydrographic basins in the world, especially in densely populated areas, with the economy developing and with reduced annual rainfall, such as basins located in semiarid regions, may have serious problems in the coming decades, especially with the number of people living in these basins increasing from 1.6 billion in 2000 to 3.9 billion in 2050 (OECD, 2012). The drylands cover approximately 47% of the world's surface, comprising 39% of the world's population, and their area may increase by 7% of the Earth's surface by 2100 due to climate change caused by global warming (Koutroulis, 2019).

The arid and semiarid regions of the world are the most susceptible to climate change, due to the variation in rainfall regimes over time and space and also as a result of poverty and underdevelopment (IPCC, 2014). In semiarid regions, which comprise 15% of the Earth's land area (Li et al., 2019), climatic and hydrological conditions, such as prolonged droughts, high evaporation and long residence times, associated with the supply of nutrients from human activities such as agriculture, livestock and urban pollution favor the degradation of water resources (Jeppesen et al., 2015; Santos et al., 2016; Lacerda et al., 2018). In the drylands, interactions between human activities, land surface and climate change, especially those related to global warming, are more intensified than in other regions (Huang et al., 2017a). Drylands of the semiarid region of Northeast Brazil are at risk of having their agricultural activities collapsed, because in the coming decades climate projections show an increase in the area under water stress condition, which can cover 54% of the in 2100, especially if global warming exceeds 4 °C (Marengo et al., 2020).

The Brazilian semiarid region has about 27 million inhabitants, which corresponds to about 12% of the Brazilian population. In this region, which has an area of 1,128.697 Km^2, there is a large amount of water reservoirs, eutrophic or in the process of eutrophication (Malveira et al., 2012; Moura et al., 2016). Activities such as intensive fish farming, irrigated agriculture and livestock can contribute to increasing nutrient concentrations in Brazilian semiarid basins (Rocha Junior et al., 2018; Henry-Silva et al., 2019; Silva et al., 2020; Cacho et al., 2020; Santos et al., 2020). The sources of nutrients for water bodies, mainly nitrogen and phosphorus, are divided into punctual, such as effluents from sewage treatment plants and residential or industrial effluents, and diffuse ones, originating from natural phenomena such as denudations of the soil, or of anthropic activities such as agriculture and livestock, whose discharges in association with the precipitations, reach the surface waters (Huang et al., 2017b).

An alternative to estimate the nutrient inputs in a hydrographic basin and in its surface aquatic environments can be through the identification and quantification of the main input pathways, to subsequently calculate the nitrogen and phosphorus emission factors of the natural sources (soil denudation and atmospheric deposition) and anthropic sources (agriculture, livestock and wastewater) (Trepel, 2016; De Paula Filho et al., 2019). The determination of N and P emission factors in regions that do not have details of the concentrations of these substances, as occurs in the Brazilian semiarid region, can be useful in assessing the sensitivity of aquatic systems to these nutrients inputs (De Paula Filho et al., 2015, 2019). In the present work, we used sources of georeferenced data, geoprocessing techniques and emission factors related to natural processes and human activities, to estimate the supply of nitrogen and phosphorus to the basins of two reservoirs in the Brazilian semiarid region.

2. Methods

2.1. Study area

The Umari and Mendubim reservoirs are among the main reservoirs in the state of Rio Grande do Norte. The Umari reservoir is the third largest in the state, with a capacity of 292 million cubic meters of water, while the Mendubim reservoir is the fifth largest reservoir, with a capacity of 77 million cubic meters of water. The basin of the Umari reservoir, inserted in the hydrographic basin of the Apodi-Mossoró river, has a drainage area of 1,546.21 km^2 and its filling began in 2002. The basin of the Mendubim reservoir, inserted in the hydrographic basin of the Piancó-Piranhas-Açu River, occupies an area of 968.13 km^2 and its filling began in 1972 (Figure 1).

These basins have a warm and semiarid climate that, according to Köppen (1936), is classified as BSw'h. The Umari and Mendubim reservoirs region is characterized by a seasonal pattern, with rainfall distributed between January and May, which is the period considered as the regional rainy season, and a dry period between June and December. The average annual rainfall is less than 800 mm. Both basins have predominantly elongated shapes. The drainage networks have low density, slope and flow speed, with permeable substrates and with a relative balance between flow and infiltration (De-Carvalho & Henry-Silva 2020). The annual basin rainfall was defined according to Henry-Silva & Camargo (2022).

2.2. Anthropization

The quantification of anthropized areas was obtained from the shapes of the basins of the reservoirs under study, resulting from the processing of digital elevation models (DEMs) made available by the Instituto Nacional de Pesquisas Espaciais (INPE), through the TOPODATA project (INPE, 2008). In the processing of the DEMs and subsequent elaboration of the shapes of delimitation of the basins, the TauDEM tool of the QGis 2.18 program was used.

To measure the anthropized areas and the remnants of vegetation in the Umari and Mendubim basins, their shapes and one of the QGis vector processing tools were used, these areas being cut from information obtained from the Monitoring Program for Deforestation of Brazilian Biomes by Satellite from the Remote Sensing Center (SCR) of the Instituto Brasileiro do Meio Ambiente e dos

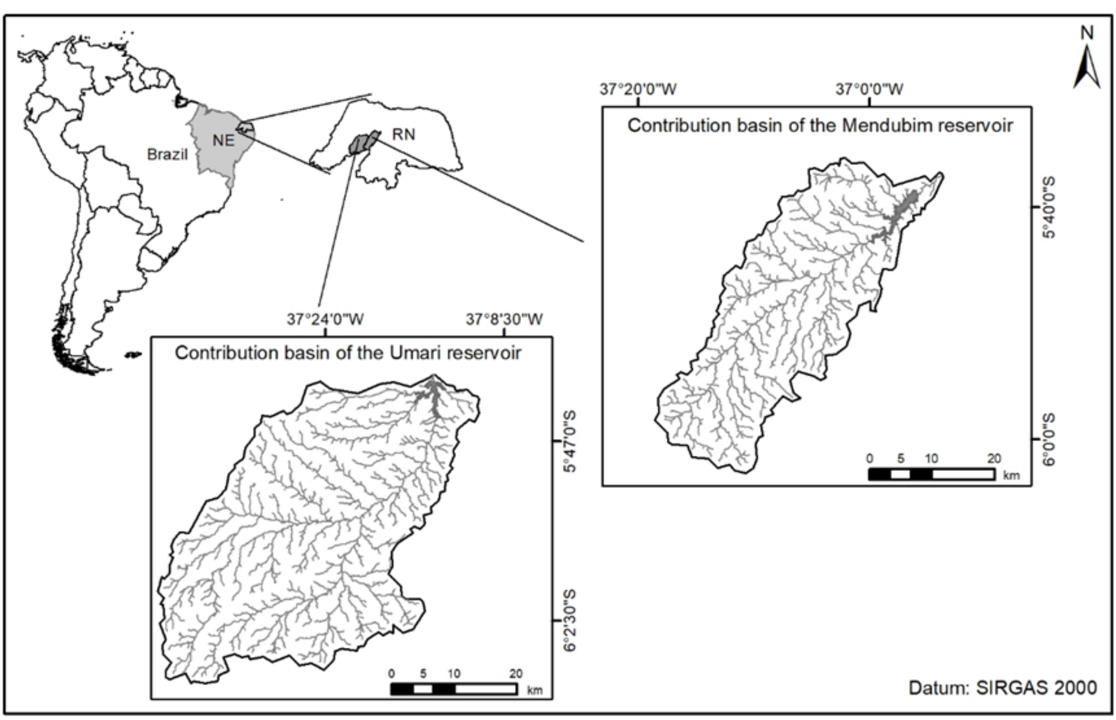

Figure 1. Location and hydrography of the basins of the Umari and Mendubim reservoirs, Northeast Region (NE) of Brazil.

Recursos Naturais Renováveis (IBAMA), updated with images from Google Earth Pro, which were also used to define the urban areas of the basins, extracting from these images the polygons of the municipal seats, in KML format, which was later transformed into form. To measure the rural area, the value of the urban area was subtracted from the anthropized area. Then, we calculated the relative occupancy rate was calculated by the relationship between the anthropized area and the remnant vegetation area.

2.2.1. Natural emissions (runoff soil and atmospheric deposition)

To quantify areas of occurrence by soil type, vector-based records of the Brazilian Soil Map of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) were used, provided by INPE's Digital Processing Department (INPE, 2009), and then quantified and occurrence area value by soil type. We adopted an average value of soil loss by denudation for regions of the semiarid of 148 tonne. $km^{-2}.year^{-1}$ (Lima Neto et al., 2011; Vasconcelos, 2011) to estimates of the nutrient loads studied here, and the concentration of these nutrients in each type of soil that occurs in the basins under study (Table 1).

Estimates of nitrogen and phosphorus loads, derived from natural emissions, (2) atmospheric deposition, (2) soil runoff and (3) total load (deposition + denudation) were calculated according to the following three Equations 1 to 3.

$$L_{ad} = Abr \times A_{dep} \times S_{rf} \times S \begin{cases} L_{ad}: \text{N or P load atmospheric deposition (tonne)} \\ \text{Abr: annual basin rainfall (mm)} \\ A_{dep}: \text{Atmospheric deposition of N or P} \\ S_{rf}: \text{Solil retention factor}^{**} \\ S: \text{Basin area km}^2 \end{cases} \quad (1)$$

Table 1. Nitrogen and phosphorus concentration per soil type.

Soil type	Nutrients per soil type (mg.kg^{-1})	
	Nitrogen (N)	Phosphorus (P)
Red-Yellow Argisol	600 [b]	5.0 [a]
Chromic Luvisolo	1240 [a]	11.6 [b]
Natric Planosol	940 [a]	18.5[b]
Regolitic Neossol	600 [b]	3.5 [b]
Litolic Neossol	1100 [b]	1.0 [b]
Floss Neossol	930 [a]	10.2 [b]

[a]Rebouças et al. (2014); [b]Jacomine et al. (1971).

$$L_{den} = D_{ra} \times C_{st} \times S \begin{cases} L_{den}: \text{N or P load soil denudation (tonne)} \\ D_{ra}: \text{denudation rate allowed (tonne. km}^{-2} \cdot \text{year}^{-1}) \\ C_{st}: \text{N or P concentration per soil type}^{*} \\ S: \text{occurrence area by soil type} \left(\text{km}^2\right) \end{cases} \quad (2)$$

$$T_{ci} = L_{den} + L_{ad} x R_{rs} \begin{cases} T_{ci}: \text{N or P total charge issued (tonne)} \\ L_{ad}: \text{N or P load atmosferic deposition (tonne)} \\ L_{den}: \text{N or P load soil denudation} \\ R_{rs}: \text{export rate N or P load retained in the soil(\%)}^{***} \end{cases} \quad (3)$$

*Table 1; **Nitrogen: 37%; Phosphorus: 30% (Silva Filho et al., 1998); ***Nitrogen: 35%, Phosphorus: 30%, percentage incorporated into the soil and expected to be carried to the water bodies (Silva Filho et al., 1998).

The atmospheric deposition of N and P depends on the area of the basins, the concentration of these nutrients in the deposition, and the retention performed by the soils. The estimated loads of N and P that are deposited in the hydrographic basins of the semiarid, via atmospheric deposition, are 100 and 8 $mg.m^{-2}$. $year^{-1}$, respectively, and these values were corrected by soil retention rates (63% for N and 70% for P), as a fraction of the atmospheric nutrient load is retained in the soils and only part is drained into surface waters through physical and chemical denudation (Silva Filho et al., 1998). In this way, the fraction of atmospheric deposition retained in the soils was included in the estimates of the loads from the physical and chemical denudation of the basin soils.

2.3. Anthropic emissions (agriculture, livestock farming and sewage)

The main human activities in the region under study that can generate pollutants were identified: livestock, agriculture, and effluent (sewage) release, both urban and rural, to estimate the input of nitrogen and phosphorus in human processes. We consider human and animal populations for the calculation of nutrient loads, per capita water consumption, agricultural areas, and amounts of fertilizers used in the main cultivars by studied basin.

The populations of the rural and urban areas of the basins were estimated, multiplying the values of these areas, resulting from geoprocessing, by the demographic densities (rural and urban) of each municipality, obtained in the demographic census of the Instituto Brasileiro de Geografia e Estatística (IBGE) of 2017. In the case of the urban population, it was considered that of the headquarters of the municipalities, whose areas were entirely within the areas of the basins under study. Rural populations in municipalities that had only part of their area covered by the basins were calculated in proportion to the area covered. The animal population was obtained from data from the Instituto de Defesa e Inspeção Agropecuária do Rio Grande do Norte (IDIARN)

The volume of effluents produced was calculated using the per capita water consumption of rural and urban areas, considering that rural consumption would correspond to 75% of urban water. The values of water consumption per capita were obtained by municipality. The nitrogen and phosphorus contributions were calculated according to Equation 4, which considers the volume of water served as a function of average consumption per capita, the demographic density, the area (rural and urban) of each basin and the average concentration of these nutrients in this type of water.

$$Q_{ef} = \overline{C_{pc}} \times dxSx[\overline{Nt}], \text{ onde } \begin{cases} Q_{ef}: \text{ Nou P load from effluents (tonne)} \\ C_{pc}: \text{per capita water consumption in the basin} \\ d: \text{ urban or rural demographic sensity} \\ [\overline{Nt}]: \text{ concentration of N or P in wastewater}^{**} \end{cases} \quad (4)$$

*Basin of the Umari Reservoir: Urban 88.08 liter. habitant^{-1}.day^{-1}; Rural 66.06 liter.habitant^{-1}.day^{-1}. Basin of the Mendubim Reservoir: Urban 96.23 liter.habitant^{-1}.day^{-1}; Rural 72.18 liter.habitant^{-1}.day^{-1}. **Nitrogen 55 mg.L^{-1}; Phosphorus 15 mg.L^{-1} (Lacerda et al., 2008).

The nutrient input from livestock was calculated according to the volume of manure produced by each type of livestock; considering these wastes play a significant role in the anthropic deposition of nutrients in surface waters, mainly nitrogen. The population of each herd was obtained by geoprocessing with data supplied by the agricultural and livestock census (IBGE, 2017). In this case, the points 'shape' was superimposed, showing the number of heads per type of cattle, with the analysis of the anthropized areas, the cut was made and a new shape was generated from which it was tabulated. The number of heads per type of herd, per anthropized area. To determine the nitrogen and phosphorus load from livestock (Equation 5), in addition to the mass of waste produced, the percentage of these nutrients present in the waste was used (Lacerda et al., 2008), since this percentage varies with the type of cattle (Table 2).

Table 2. Amount of waste produced and the percentage of Nitrogen (N) and Phosphorus (P) by type of herd (Lacerda et al., 2008).

Livestock type	Waste (kg.head^{-1}.day^{-1})	N%	P%
Cattle	10	0.6	0.35
Horses	10	0.6	0.35
Pigs	2.5	0.5	0.30
Sheep	1	0.5	0.50
Goats	1	0.5	0.50

$$Q_{pec} = NxD_c x[C] \times T_{rt}, \text{ onde } \begin{cases} Q_{pec}: \text{N or P load emitted livestock farming (tonne)} \\ N_h: \text{ number head} \\ D_c: \text{ amount of waste per head}^{*} \\ [C]: \text{ concentration of N or P per animal type}^{*} \\ T_{rt}: \text{ retention rate in soil}^{**} \end{cases} \quad (5)$$

*Table 2; **Nitrogen 20-35% and Phosphorus 35-60% (Bouwman et al., 1997), in the two basins was used the percentual average.

Loads of nitrogen and phosphorus contributed by agriculture in the basins under study were calculated according to the type of crop, the amount of fertilizer used in each type of crop, its percentage of loss to the soil and cultivated area (Equation 6). We obtained from the literature (Table 3) the values needed to calculate the percentage of loss of nutrients understudy, by type of cultivar. The cultivation areas, by type of crop, come from the agricultural and livestock census (IBGE, 2017).

$$Q_{agr} = S_{ct} \times F_{pc} \times T_{rt}, \text{ onde } \begin{cases} Q_{agr}: \text{N or P load from agriculture (tonne)} \\ S_{ct}: \text{ cutivated area}^{*} \\ F_{pc}: \text{ amount of fertilizer used for cultivating}^{**} \\ T_{rt}: \text{ retention rate in soil}^{**} \end{cases} \quad (6)$$

*IBGE (2017); **Table 3.

Table 3. Amounts of Nitrogen (N) and Phosphorus (P) applied by type of crop and estimated percentage of soil loss.

Cultivars	N (Kg.ha^{-1})	P (Kg.ha^{-1})	Loss N (%)	Loss P (%)	References
Bean	10	60	20.5	1.05	Lacerda et al. (2008)
Forage	200	50	50	30	Cóser & Pereira. (2001)
Broad bean	135	30	50	30	Alves et al. (2008)
Manioc	20	37.5	25	20	Lacerda et al. (2008)
Watermelon	100	120	33	12	Mendes et al. (2010)
Melon	80	275	63	43	Zebalos et al. (2017)
Corn grain	40	55	29	13	Lacerda et al. (2008)
Grain sorghum	39.4	17.7	35	40	Coelho et al. (2002)

2.4. Nutrients in reservoir water

Water samples (one liter/samples) were collected from the Umari and Mendubim reservoirs between 2017 (9/2017; 12/2017) and 2018 (02/2018; 05/2018; 06/2018; 08/2018) to determine the concentrations of total phosphorus (μg.L^{-1}) and total nitrogen (mg.L^{-1}) (AOAC, 2005) and analyze the relationship between the concentrations of N and P present in the reservoir water and the loads of these nutrients. Initially, samples were made at 18 and 12 points in the Umari and Mendubim reservoirs, respectively. With the increase in the water depth of the reservoirs caused by the increase in rainfall, the number of samples points increased to 21 and 20, respectively, in the Umari and Mendubim reservoirs (Figure 2).

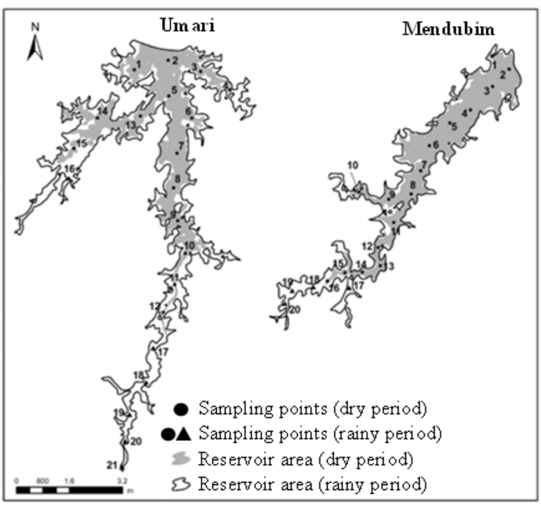

Figure 2. Water sampling points in Umari and Mendubim reservoirs in the dry and rainy periods.

3. Results and Discussion

3.1. Anthropization

The basin of the Umari reservoir had an anthropized area 2.5 times greater than that of Mendubim. Considering the relative occupation index, the basins presented similar occupation rates. The Umari and Mendubim basins, respectively, had anthropization averages of 30% and 20% and relative occupancy rates of 0.66 and 0.46. However, some municipalities in both basins had more than 50% of their areas anthropized, mainly by agriculture and livestock (Figure 3).

The cities with the lowest degree of anthropization were Caraúbas and Campo Grande. The municipality of Paraú has about 93.5% of its area in the Umari basin and only 6.5% in the Mendubim basin, and in Mendubim this municipality did not present nutrient loads from anthropogenic emissions, but only from natural emissions (Table 4).

Analyzing the spatialization of anthropization in the basins of the studied reservoirs, it is observed that anthropic activities tend to advance in a discontinuous caatinga area. What was also observed in an inventory carried out from 1984 to 1996, in the semiarid basin of the state of Pernambuco (Maldonado et al., 2002). Deforestation has contributed to the degradation of arid soils worldwide (Pinheiro Junior et al., 2019) and in the case of the areas under study, the greatest degradation occurred in discontinuous caatinga areas, probably due to the easy access to these partially open areas, which can stimulate the implementation of agricultural activities.

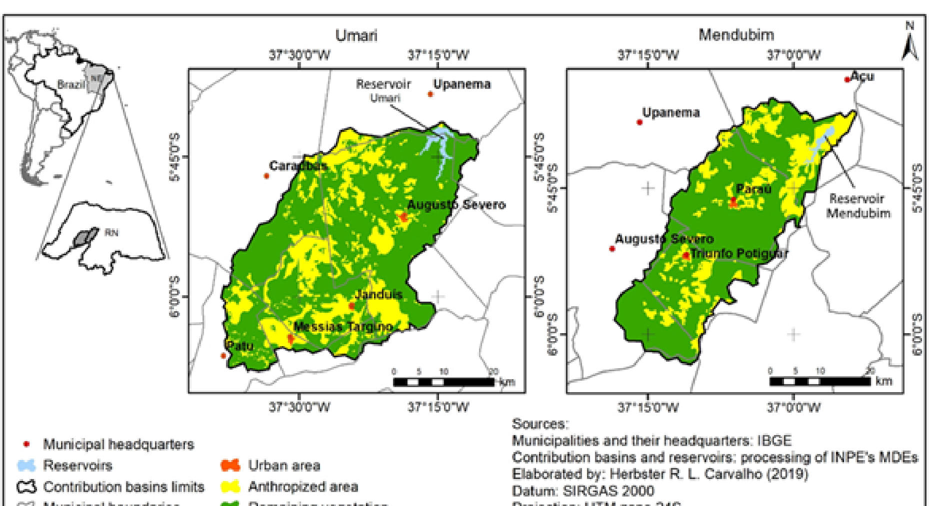

Figure 3. Urban, anthropized areas, and vegetation remaining from the basins of the Brazilian semiarid reservoirs.

Table 4. Percentage of anthropization by municipal areas (km²) covered by the basins of the Brazilian semiarid reservoirs.

Basins	Counties	Area in the basin (km²)	Anthropized area	Urban area	Rural area	Anthropization	Relative occupancy index
Umari	Campo Grande	749.1	193.2	1.30	191.9	26%	0.35
	Caraúbas	215.3	26.6	0	26.6	12%	0.14
	Janduís	301.3	134.8	0.75	134.1	45%	0.81
	Messias Targino	78.6	42.4	0.92	41.4	54%	1.17
	Paraú	24.6	0.0	0.0	00.0	0.0	0.0
	Patu	129.5	35.2	0.0	35.2	27%	0.37
	Upanema	44.1	23.1	0.0	23.1	53%	1.11
	Total	1,546.2	455.6	2.97	452.6	31%*	0.56*
Mendubim	Açu	234.5	94.2	0.0	94.2	40%	0.67
	Campo Grande	142.2	8.1	0.0	8.1	6%	0.06
	Paraú	375.3	45.9	1.33	44.6	12%	0.14
	Triunfo Potiguar	209.6	42.4	0.80	41.6	20%	0.25
	Upanema	6.3	3.4	0	3.4	54%	1.18
	Total	968.13	194.08	2.13	191.9	26.4%*	0.46*

*Mean.

3.2. Natural emissions (runoff soil and atmospheric deposition)

The basin of the Umari reservoir showed higher loads of nitrogen (172.3 tonne.year^{-1}) and phosphorus (1.79 tonne.year^{-1}), resulting from the chemical and physical denudation of the soil when compared with the Mendubim (87.1 tonne. year^{1} of N and 0.54 tonne.year^{-1}of P). Loads of N and P were, respectively, 2.0 and 3.2 times higher in the Umari basin compared to the Mendubim basin. The denudation of soils by erosion is the result of the physical and chemical weathering of the rock and the removal and export of dissolving nutrients to the water bodies of the hydrographic basins. The interactions between erosion, climate, and lithostructure are the most important factors in the quantification of nutrient emission loads from denudation (Ritter et al., 2006). The intensity and seasonality of rainfall in a hydrographic basin are also important in determining the loss of nutrients in areas occupied by agriculture, which may be without vegetation cover during certain periods of the year, depending on the type of crop and management method (Summerfield & Hulton, 1994; von Blanckenburg et al., 2004; Fernandes et al., 2020). Studies carried out in the Brazilian semiarid have concluded that the average value of soil lost by denudation varies from 128 to 148 tonne^{-1} km^{-2} year^{-1} (Lima Neto et al., 2011).

Even though the area of the Umari basin is 37% larger than that of Mendubim, this fact alone does not explain the differences observed. It is also necessary to take into account the predominant soil types and their nutrient concentrations in each of the basins. The Chromium Luvissol, for example, which predominates in the Umari basin, has levels of N and P 1.1 and 11.6 times higher, respectively, than those found in the Neossol Litolic, which predominates in the Mendubim basin. The fraction of atmospheric deposition retained in each soil is included in the load estimates that originated in physical and chemical denudation.

The basin of the Umari reservoir had a nitrogen load of 69.74 tonne. yr^{-1} and phosphorus of 7.49 tonne.year^{-1}, depending on the atmospheric deposition. These values are equivalent to 2.2 and 2.7 times more atmospheric depositions of N and P, respectively, for the Umari basin than that observed for the Mendubim basin. This difference is due to the differences between the basin areas and also the higher average rainfall in the Umari basin (628.85 mm ±112.82) in relation to the Mendubim basin (513.15 mm ± 97.36). Atmospheric deposition is mainly related to the basin area, rainfall, the concentration of substances in total deposition, particle size and surface where the substances will be deposited (Tamatamah et al., 2005; Eimers et al., 2018). In this context, continental and coastal aquatic ecosystems are subject not only to the input of N and P of effluents from diffuse and punctual origins, but also to deposition from the atmosphere (Weiss et al., 2018; Zhang et al., 2020). When the atmospheric supply of nutrients exceeds the biological demand of terrestrial ecosystems, they reduce the capacity to retain N and P, increasing the supply of these nutrients to ground and surface waters such as rivers, lakes and reservoirs (Chantara & Chunsuk, 2008; Zhou et al., 2020).

The total nutrient loads from natural sources were higher in the Umari basin (266.49 tonne.year^{-1}of N and 11.53 tonne.year^{-1}of P) when compared to the loads in the Mendubim basin (128.72 tonne.year^{-1} of N and 4.10 tonne.year^{-1}of P). That is, considering soil denudation, atmospheric deposition and percentages of nutrient incorporation into the soil, the total loads of N and P from natural sources were, respectively, 2.2 and 2.7 times higher in the Umari basin. However, we observed a similar contribution between runoff soil and atmospheric deposition when comparing the percentage of incorporation by type of emission in each basin (Figure 4).

3.3. Anthropic emissions (agriculture, livestock farming and sewage)

The livestock raised in the areas of the basins of the Umari and Mendubim reservoirs, presented a similar percentage, highlighting sheep, cattle, and goat farming as the main activities practiced in the areas covered by both basins (Figure 5). Sheep and goat farming together accounted for 60.6% of livestock activities in the Umari basin and 64.6% in the Mendubim basin. These results corroborate that sheep and goats are the main livestock activities in Northeast Brazil (Guilherme et al., 2017). A similar situation occurs in Central Chile, where sheep farming accounts for 80 to 86% of small livestock units (Toro-Mujica et al., 2015). It can be seen that the Umari basin had higher nutrient loads from livestock (187.56 tonne.year^{-1}of N and 86.76 tonne.year^{-1}of P) compared to the Mendubim basin (140.04 tonne.year^{-1}of N and 65.63 tonne.year^{-1}of P). Among the anthropic factors responsible for the supply of nutrients to surface waters, livestock is one of the most important sources of nutrients (Leip et al., 2015). Nutrients from animal excreta accumulate in the soil and can be carried by surface waters to water bodies (Uwizeye et al., 2020).

Among the livestock activities, the one that most contributed to N and P emissions was cattle farming (Figure 6). Despite the percentage of sheep dominating livestock in both basins, the largest contribution of cattle in the emissions of these nutrients is due to the higher concentrations of nitrogen and phosphorus present in the feces of these

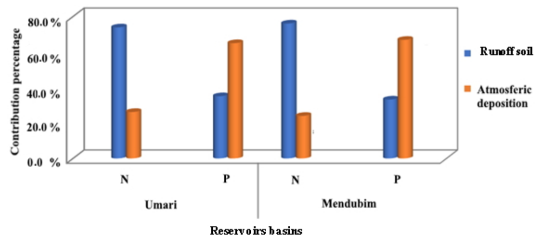

Figure 4. Percentage of the contribution of natural factors in emissions of nitrogen (N) and phosphorus (P) loads in the Umari and Mendubim basins.

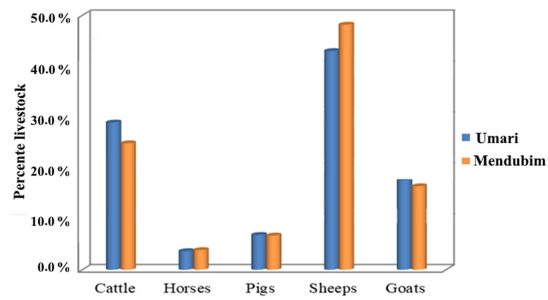

Figure 5. Composition percentage per livestock type in the Brazilian semiarid reservoir's basins.

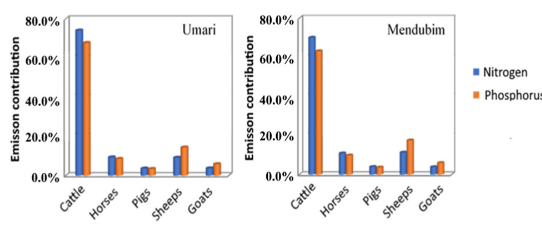

Figure 6. Contribution percentage of nitrogen and phosphorus emission by livestock type in the Brazilian semiarid reservoir's basins.

animals, as well as the amount of waste produced per head. Cattle produce about 10 kg.head^{-1}.day^{-1} of manure with 0.6% N and 0.35% of P, while sheep and goats produce 1 kg.head^{-1}.day^{-1} of manure with 0.5% N and 0.5% P (Lacerda et al., 2008). The indirect influence of livestock on the physical and chemical characteristics of aquatic environments, depending on the density of organisms and potential natural vegetation (Tanaka et al., 2016; Mello et al., 2020). According to Strassburg et al. (2014), cattle breeding in Brazil occurs on natural pastures with low productivity and low animal density, which minimizes the impacts on water quality in aquatic environments, but which can negatively influence some ecosystem services such as biodiversity and carbon storage.

The Umari basin received 1.9 times more nitrogen loads from agriculture (91.45 tonne. year^{-1}) than the Mendubim basin (45.85 tonne. year^{-1}). However, phosphorus loads were similar in both basins, Umari 31.79 tonne.year^{-1}and Mendubim 32.41 tonne.year^{-1}. These differences can be explained by the cultivated areas in each basin and their main cultivars. The Umari basin has a cultivated area 2.7 times larger than that of Mendubim, which contributes to a greater load of N. In the Umari basin, beans (44.6%) and corn (21.9%) stood out as the main cultivars, and in the Mendubim basin, the main cultivars were beans (31.2%) and forage (23.6%) (Table 5). Nitrogen and phosphorus in agriculture come mainly from fertilizers and have as main emission factor the loss to the soil, subsequently, part of these nutrients can be leached into surface waters (Kelly et al., 2018; Xu et al., 2020). Fertilizers are important for agriculture, improving the development of vegetables and increasing the harvest, however, they can cause problems of artificial eutrophication of inland and coastal waters (Sharpley, 2016; Huang et al., 2017b).

In the Umari basin, forages were the main sources of nitrogen (72.90 tonne. year^{-1}) and phosphorus (10.9 tonne. year^{-1}). In the Mendubim basin, the main sources of this nutrient were also forage (29.88 tonne. year^{-1}), while melon cultivation was the main source of phosphorus (21.94 tonne. year^{-1}). Melon requires 5.5 times more P than that required by forages, in addition to being 1.4 times more lost to the soil than with the cultivation of forages (Zebalos et al., 2017). This higher requirement of P for the cultivation of melon was the main responsible for the high values of loads of this nutrient towards the Mendubim basin. In this context, the municipality of Açu contained in the basin of the Mendubim reservoir was the one that most contributed to loads of P (25 tonne. year^{-1}), as it has extensive areas cultivated with melon. These crops, with an emphasis on beans and corn, are the most practiced in the Brazilian Northeast semiarid and are also the ones that cause impacts on native vegetation and on the habitat of endemic species (Cunha et al., 2019). Non-assimilated phosphorus remains immobilized in the soil, forming poorly soluble compounds, and a fraction of this immobilized phosphorus can be resolved and reach the continental water bodies by leaching (Smil, 2004). With respect to nitrogen, there is a greater dispersion of nitrogen compounds in the environmental compartments due to their chemical properties (such as solubility and volatility) (Galloway et al., 2003, 2008).

The Umari basin received inputs of nitrogen (33.5 tonne. year^{-1}) and phosphorus (6.3 tonne. year^{-1}) from the effluents, larger than those received by the Mendubim basin (12.5 tonne. year^{-1}of N and 3.9 tonne. year^{-1}of P) (Table 6). Wastewater is an important source of pollutants, such as nitrogen and phosphorus. These effluents are responsible for the high anthropic loads of these nutrients in surface waters (Chen et al., 2019).

The inputs of N and P in the Umari basin were, respectively, 2.7 and 1.6 times higher than the inputs of these nutrients in the Mendubim basin. Both basins received inputs of nitrogen and phosphorus from urban effluents larger than those from rural areas, a common situation to occur when comparing the inputs of these nutrients by wastewater between these two types of media (Khatri & Tyagi, 2015).

The total nitrogen load emitted by anthropogenic factors was greater in the basin of the Umari reservoir (312.80 tonne.year^{-1}) was 1.5 times that emitted in that of the Mendubim reservoir (200.92 tonne.year^{-1}); however, for phosphorus,

Table 5. Estimates of Nitrogen (N) and Phosphorus (P) loads emitted by agriculture in the Brazilian semiarid reservoir's basins.

Cultivars	Umari			Mendubim		
	Area (km^2)	N (tonne.year^{-1})	P (tonne.year^{-1})	Area (km^2)	N (tonne. year^{-1})	P (tonne. year^{-1})
Broad bean	-	-	-	37.68	2.54	0.34
Bean	1,512.82	3.10	9.53	395.32	0.81	2.49
Forage	729.04	72.90	10.9	298.76	29.88	4.48
Manioc	112.01	0.56	0.84	-	-	-
Watermelon	70.89	2.34	1.02	53.67	1.77	0.77
Melon	23.16	1.17	2.74	185.55	9.35	21.94
Corn grain	741.98	8.61	5.31	255.41	2.96	1.82
Grain Sorghum	201.08	2.77	1.42	78.31	1.08	0.55
Total	3,390.97	91.45	31.79	1,267.02	45.85	32.07

this difference was smaller, with the emission in Umari (124.82 tonne.year^{-1}) corresponding to 1.2 times that in Mendubim (101.96 tonne.year^{-1}). Agriculture and livestock stood out as the main anthropic activities emitting N and P for the studied basins. In the Umari basin, livestock contributed 60% and 69% of N and P emissions, respectively, while in the Mendubim basin, activity contributed 69% and 64% of all anthropogenic emissions of N and P, respectively (Figure 7).

3.4. Total loads of nitrogen and phosphorus (natural and anthropic)

The Umari basin received total (natural and anthropic) input of N (579 tonne.year^{-1}) and P (136.4 tonne.year^{-1}) greater than the Mendubim basin (329.7 tonne.year^{-1}of N and 106.0 tonne.year^{-1}of P) (Table 7).

Anthropic loads accounted for most of a total load of these nutrients in both basins (53% N and 92% P in the Umari basin; 61% N and 96% P in the Mendubim basin), with livestock being responsible most of these nutrient loads of anthropic origin. In the Umari basin, soil denudation was responsible for the largest N inputs (46%), since almost 70% of the area in this basin is composed of soils with higher concentrations of nutrients when compared to the concentrations existing in the soils predominant in the Mendubim basin (Figures 8 and 9). Also, the Umari basin has 30% of its anthropized area, against 20% of the anthropized area of the Mendubim basin.

Making a comparison with other research carried out in Brazil, it is possible to observe that the loads of nutrients of anthropic origin are predominant concerning the loads of natural origin,

Table 6. Nitrogen (N) and phosphorus (P) loads emitted by urban and rural effluents in the Brazilian semiarid reservoir's basins.

Basins	Urban load (tonne.year^{-1})		Rural load (tonne.year^{-1})		Total load (tonne.year^{-1})	
	N	P	N	P	N	P
Umari	23.8	4.3	9.7	1.9	33.5	6.3
Mendubim	9.0	2.5	3.5	1.4	12.5	3.9

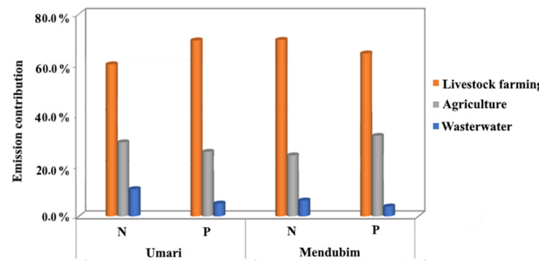

Figure 7. Percentage of nitrogen (N) and phosphorus (P) emissions per anthropic activities in the Brazilian semiarid reservoir's basins.

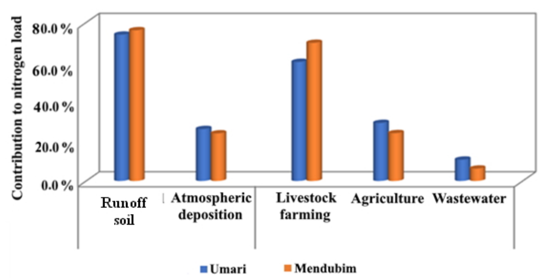

Figure 8. Estimates of total loads of Nitrogen (N) emitted by natural and anthropic factors in the basins of Brazilian semiarid reservoirs.

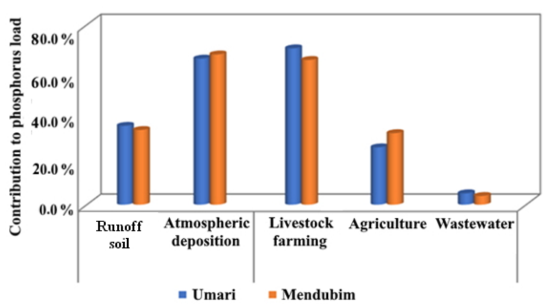

Figure 9. Estimates of total loads of Phosphorus (P) emitted by natural and anthropic factors in the basins of Brazilian semiarid reservoirs.

Table 7. Estimates of total N and P loads emitted by natural and anthropic factors in the Umari and basins.

Emission factors (tonne.year^{-1})		Basins			
		Umari		Mendubim	
		N	P	N	P
Natural	Runoff soil	196.8	4.0	97.9	1.4
	Atmospheric deposition	69.7	7.5	30.8	2.7
	Total	266.5	11.5	128.7	4.1
Anthropic	Wastewater	33.5	6.3	12.5	3.9
	Livestock farming	187.6	86.8	140.0	65.6
	Agriculture	91.5	31.8	48.4	32.4
	Total	312.5	124.8	202.9	101.9
Total load		579.0	136.4	329.7	106.0

as seen in the basins of the Umari and Mendubim reservoir (Table 8).

The largest source of N in the Umari basin came from livestock. This activity alone was responsible for 42% of the total N load in this basin, mainly due to the creation of cattle. Brannan et al. (2000) saw reductions in nutrient loads from cattle ranching in a hydrographic basin in the USA, only increasing good management practices, such as appropriate waste disposal sites and fences along with watercourses for preventing animals from accessing. With relatively simple measures, the authors found reductions in the supply of nutrients to the aquatic environments, about 78% of particulate phosphorus and 39% of soluble phosphorus, in addition to a 35% reduction in nitrogen loads.

Other measures can still be implemented in the basins of the Brazilian semiarid region to reduce the supply of nutrients and organic matter by livestock, such as the treatment of waste, which can be used as organic fertilizer or biogas, to preserve natural vegetation along rivers, springs and around natural or artificial ponds, lakes and reservoirs, studying three reservoirs in the Brazilian semiarid, found that urbanization, agriculture and deforestation increase the nutrient load in the reservoirs, contributing to a greater occurrence of the eutrophication process of these aquatic environments. According to the authors, the vulnerability of the reservoirs was associated with the release of loads from urban sewage and the creation of oxen on the banks of aquatic environments. We can conclude that the basins studied in the present work have rural characteristics, where agriculture and, mainly, livestock exert an important influence on N and P emissions.

3.5. N and P in the water of the reservoirs and the emission factors

The comparison of the N and P values of the reservoir water with the total emission loads showed that, although the basin area of the Mendubim reservoir is 37% smaller than that of Umari, the estimated phosphorus loads were only 22% smaller. Another aspect that may have influenced the 23% higher values of total phosphorus in the Mendubim water is the age of the reservoir. The Mendubim reservoir had its filling started in 1972, while Umari is a recent reservoir, with filling started in 2002 (Table 9).

Table 8. Loads of Nitrogen (N) and Phosphorus (P) emissions (tonne.year^{-1}) from anthropic and natural sources in basins in northeastern Brazil

Basins	Anthropic		Natural		Anthropic and Natural	
	N	P	N	P	N	P
Rio das Contas (BA)[1]	1,726	1,554	516	19	2,242	1,573
Timonha (CE)[2]	322	102	43	36	365	138
Acaraú (CE)[2]	1,305	1,046	217	177	1,522	1,223
Coreaú (CE)[2]	896	490	275	206	1,171	696
Aracatiaçú (CE)[2]	274	180	116	97	390	276
Aracatimirim (CE)[2]	309	236	56	40	365	276
Curu (CE)[2]	833	302	50	27	883	329
Mundaú (CE)[2]	1,362	969	176	122	1,538	1,091
Pirangi (CE)[2]	556	529	110	27	666	556
Icapui (CE)[2]	171	171	31	8	201	179
Guamaré (RN)[2]	217	251	41	7	258	257
Ceará Mirim (RN)[2]	89	53	20	3	109	56
Guaraíras (RN)[2]	1,387	735	35	12	1,422	747
Curimataú (RN)[2]	996	327	40	15	1,036	342
Rio Salgado (CE)[3]	13,641	2,933	2,979	278	16,620	3,211
Umari (RN)[4]	313	125	275	11	588	136
Mendubim (RN)[4]	203	102	129	4	330	106

[1]Paula et al. (2010); [2]Lacerda et al. (2008); [3]De Paula Filho et al. (2019); [4]This study.

Table 9. Means and standard deviations (+) of Nitrogen (N) and Phosphorus (P) concentrations in the water of the Umari and Mendubim reservoirs and total emission of N and P by natural and anthropic factors in the reservoir's basins.

Reservoirs/ Basins	P and N concentrations in the water of the reservoirs		Total P and N contributions natural and anthropic factors in the reservoir's basins	
	Total P (µg.L^{-1})	Total N (µg.L^{-1})	P (tonne.year^{-1})	N (tonne.year^{-1})
Umari	43 (±27)	321 (±107)	136 (±35)	588 (±75)
Mendubim	56 (±23)	214 (±51)	106 (±28)	223 (±34)

4. Conclusions

The applied methodology and the emission factors analyzed in the present study can be an important tool to quantify the main contributions of nutrient loads of natural and anthropic origin in Brazilian semiarid basins. This information can be useful to predict which reservoirs are most susceptible to the eutrophication process. Other factors must also be taken into account in this projection, such as the age of the reservoir, residence time, variation in the volumes of these reservoirs, and their specific hydrological and biological conditions. All of this information can help public managers to make the best decisions regarding the management and use of water resources in reservoirs in the semiarid. In the two basins studied, as in others in the Northeast region of Brazil, there is a consensus that emissions of anthropic nature (livestock, agriculture, and wastewater) are the main sources of nitrogen and phosphorus for surface waters, contributing decisively to the process of eutrophication of reservoirs in these basins. However, natural sources, such as atmospheric deposition and soil denudation, cannot be disregarded, even though they have smaller participation, when compared with anthropic sources.

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