




RESEARCH ARTICLE

Regionalization of characterization factor in Brazil: freshwater eutrophication category

Regionalização do fator de caracterização no Brasil: categoria de eutrofização da água doce

Regionalización del factor de caracterización en Brasil: categoría de eutrofización de agua dulce

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Abstract

Brazil is privileged to have the most important natural resource in its territory, the water. But currently, the increased concentration of phosphorus (P) affects the water quality. It has two main routes to get into aquatic environment: through the dump of untreated sewage and fertilizers runoff. The P excess may promote eutrophication, a process characterized by microalgae uncontrolled growth, affecting several parameters of freshwater. Due to the great differences at the Brazilian regions, the current Life Cycle Impact Assessment methodologies are not capable to evaluate properly the eutrophication impact in Brazil. The most viable method to obtain a more suitable model is regionalizing it by estimating the characterization factor (CF). Therefore this is the first study that presents a regionalized model to estimate Brazilian CF for freshwater eutrophication. The regionalization was based on the models proposed by Helmes et al. (2012) and Azevedo et al. (2013), which are considered the most complete and suitable models. Due to the lack of data it was possible to calculate the CF for Alto Iguaçu micro watershed and four more subwatersheds: Paraíba do Sul, Parnaíba, Litorânea do Ceará and Litorânea Pernambuco Alagoas. The processes assessment of advection, retention and water use provides valuable information of each region and also results in more realistic Fate Factor (FF), since Brazilian sanitation is completely uneven, and the sewage treatment must be modelled to not overestimated or underestimated the FF. At Alto Iguaçu is the advection rate is the most relevant and its CF is 7.43 103. m³.KgP-1 day. For that reason, the same amount of emitted phosphorus promotes a bigger eutrophication potential at Paraíba do Sul and Parnaíba than other basins. Phosphorus income rates estimate is possible to know the origin of its most significant input. Based on this information, financial resources can be better used. This was the first attempt to develop a Brazilian CF and some improvements need to be done. Firstly, new studies ought to concentrate to promote good quality of data, because the unavailability of data was one of the greatest difficulties of this study. Then the regionalized model should be improved modeling treatment of industrial sewage and, finally, CF needs to be calculated for all subwatershed.

Keywords: Eutrophication. Characterization factor. Freshwater. Brazil. Life Cycle Impact Assessment.

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Resumo

O Brasil tem o privilégio de ter o recurso natural mais importante em seu território, à água. Porém, atualmente o aumento da concentração de fósforo (P) tem afetado a qualidade da água doce. O P entra no meio aquático por duas rotas principais: através do despejo de esgoto não tratado e do escoamento de fertilizantes. O excesso de P pode promover a eutrofização, um processo caracterizado por crescimento descontrolado de microalgas, que afeta vários parâmetros da água doce. Devido às grandes diferenças das regiões brasileiras, as atuais metodologias de Avaliação de Impacto do Ciclo de Vida não são capazes de avaliar adequadamente o impacto da eutrofização no Brasil. O método mais viável para obter um modelo mais adequado é regionalização, estimando o fator de caracterização (CF). Portanto, este é o primeiro estudo que apresenta um modelo regionalizado para estimar o CF de eutrofização de água doce para o Brasil. A regionalização foi baseada nos modelos propostos por Helmes et al. (2012) e Azevedo et al. (2013), considerados os modelos mais completos e adequados. Devido à falta de dados, foi possível calcular a CF para a microbacia do Alto Iguaçu e mais quatro bacias hidrográficas: Paraíba do Sul, Parnaíba, Litorânea do Ceará e Litorânea Pernambuco Alagoas. A avaliação dos processos de advecção, retenção e uso da água forneceram informações valiosas de cada região e também resultaram em um Fator de destino (FF) mais realista, uma vez que o saneamento brasileiro é completamente desigual e o tratamento de esgoto deve ser modelado para não superestimar ou subestimar o FF. No Alto Iguaçu é a taxa de advecção e seu CF é 7,43 10³. m³.KgP-1 dia. Por esse motivo, a mesma quantidade de fósforo emitido promove um maior potencial de eutrofização na Paraíba do Sul e Parnaíba do que em outras bacias. Calculando as taxas de entrada de fósforo nas bacias é possível determinar quais são as fontes de entrada de fósforo mais significativas. Com base nessas informações, os recursos financeiros podem ser melhores utilizados. Esta foi a primeira tentativa de desenvolver CF brasileiro e algumas melhorias precisam ser feitas. Em primeiro lugar, novos estudos devem se concentrar na obtenção de dados de boa qualidade, pois a indisponibilidade de dados foi uma das maiores dificuldades desse estudo. O modelo regionalizado deve ser aprimorado para modelar o tratamento de esgoto industrial e, finalmente, o CF precisa ser calculado para todas as sub-bacias hidrográficas.

Palavras-chave: Eutrofização. Fator de caracterização. Água doce. Brasil. Avaliação de Impacto do Ciclo de Vida.

Resumen

Brasil tiene el privilegio de tener el recurso natural más importante en su territorio, el agua. Sin embargo, actualmente el aumento en la concentración de fósforo ha afectado la calidad del agua dulce. El fósforo ingresa al medio acuático a través de dos rutas principales: a través de la descarga de aguas residuales no tratadas y por la eliminación de fertilizantes. El exceso de fósforo puede promover la eutrofización, un proceso caracterizado por el crecimiento incontrolado de microalgas, que afecta varios parámetros del agua dulce. Debido a las grandes diferencias de las regiones brasileñas, las metodologías actuales de Evaluación del Impacto del Ciclo de Vida no pueden evaluar adecuadamente el impacto de la eutrofización en Brasil. El método más factible para obtener un modelo más adecuado es la regionalización, estimando el factor de caracterización (CF). Por lo tanto, este es el primer estudio que presenta un modelo regionalizado para estimar el CF de la eutrofización de agua dulce para Brasil. La regionalización se basó en los modelos propuestos por Helmes et al. (2012) y Azevedo et al. (2013), considerados los modelos más completos y apropiados. Debido a la falta de datos, fue posible calcular el FC para la microcuenca Alto Iguaçu y otras cuatro cuencas hidrográficas: Paraíba do Sul, Parnaíba, Litorânea do Ceará y Litorânea Pernambuco Alagoas. La evaluación de los procesos de advección, retención y uso de agua proporcionó información valiosa para cada región y también resultó en un Factor de Destino (FF) más realista, ya que el saneamiento brasileño es completamente desigual y el tratamiento de aguas residuales debe ser modelado para no sobreestimar ni subestimar el FF. En Alto Iguaçu es la tasa de advección y su CF es 7.43 10³. m³.KgP-1 día. Por esta razón, la misma cantidad de fósforo emitida promueve un mayor potencial de eutrofización en Paraíba do Sul y Parnaíba que en otras cuencas. Al calcular las tasas de entrada de fósforo en las cuencas, es posible determinar cuáles son la fuente más

importante de entrada de fósforo. Con base en esta información, los recursos financieros pueden ser mejor utilizados. Este fue el primer intento de desarrollar CF brasileño y se deben hacer algunas mejoras. En primer lugar, los nuevos estudios deberían centrarse en obtener datos de buena calidad, ya que la falta de disponibilidad de datos fue una de las mayores dificultades de este estudio. El modelo regionalizado debe mejorarse para modelar el tratamiento de las aguas residuales industriales y, finalmente, el FC debe calcularse para todas las subcuencas.

Palabras clave: Eutrofización. Factor de caracterización. Agua dulce. Brasil. Evaluación del Impacto del Ciclo de Vida.

1. INTRODUCTION

The increase of phosphorus (P) emission compounds in water bodies is responsible for poor water quality. Although P is a nutrient, in excess it may cause eutrophication (Esteves 1998).

The domestic and industrial effluents and agricultural activities are the main sources of anthropogenic phosphorus. A big amount of sewage is released to water bodies without any treatment and part of the fertilizers percolate through the soil reaching aquifers, and another portion is carried out by irrigation and rain water to rivers and lakes (Esteves 1998).

To evaluate freshwater eutrophication's potential impact supports to prevent the environmental impact management, giving information for decision makers (private or public).

The eutrophication potential of products can already be obtained using Life Cycle Impact Assessment (LCIA) methods, however it is important to regionalize the characterization factors (CF), as the same amount of emission does not affect the regions equally due to the fact that, among others, it depends on the phosphorus transport and some water body characteristics (Tundisi, Tundisi, Siagis Galli 2006).

Therefore, the goal of the current study is to calculate the eutrophication freshwater CF for Brazilian subwatersheds with different sanitations and climate conditions.

2. METHOD

Equation (1) shows the generic model to obtain CF.

(1)

$$C_{i,m,r} = FF \cdot EF$$

Where $CF_{i,m,r}$: substance characterization factor, at the compartment m, that is transferred to the receiving environment; FF : Fate factor; and EF : Effect factor

The FF characterizes phosphorus persistence in the environment and the EF shows the connection between the ecological damage and the mass change of phosphorus in the freshwater (Rosenbaum, Margni, Jolliet 2007).

CF depends on FF and EF; therefore, the CF is influenced by the nutrients mass change in the waterbody. In other words, nutrients increment, transport and removal are a significant factor to obtain a representative CF (Civit et al. 2012; Gallego et al. 2010; Helmes et al. 2012; Seppälä et al. 2006).

2.1. Selection of the characterization model

JRC (European Commission, Joint Research Centre, Institute for Environment and Sustainability 2011a; 2011b) and UN Environment recommended indicators for eutrophication. Since the former was published, two methods were developed by Gallego et al. (2010) and by Helmes et al. (2012), the last further studied by Azevedo et al. (2013).

Oliveira and Ugaya (2016) performed an evaluation of the models considering the scope, the geographical coverage, the elementary flows included, definition of covered compartments, position in the environmental mechanism, scientific robustness, the availability of CFs for Brazil, possibility of regionalization and the adaptation feasibility.

As for FF, the model presented by Gallego et al. (2010) and Helmes et al. (2012) obtained the same score, but the former presented a simpler model than the latter, as the wastewater treatment included only phosphorus output about local sewage treatment, and constant EF was adopted.

Helmes et al. (2012) proposed FF calculation estimating three factors: input rate of P by advection ($k_{adv,i}$); output rate of P by retention ($k_{ret,j}$) and output rate of P by water use ($k_{use,j}$).

The FF model proposed by Helmes et al. (2012) indicated phosphorus persistence in the water body. It is calculated on a worldwide scale, at $0.5^\circ \times 0.5$ grid and it also adopts a constant EF.

All in all, according to Ugaya et al. (2019), the model of Azevedo et al. (2013) was considered the most complete, because it fulfilled almost all established criteria, scoring 4.25 (5 is the maximum score). Actually, it used the model developed by Helmes et al. (2012) to calculate FF, however, it included three models to estimate EF for the European context.

To calculate the CF of the Brazilian subwatersheds in the current study, the FF is estimated by Helmes et al. (2012) and EF by Azevedo et al. (2013). These recommendations were similar of UN Environment (2019) for the mid and endpoint freshwater eutrophication.

2.2. FF regionalization

Helmes et al. (2012) proposed the calculation of three processes to estimate the FF, advection, retention and water use. In the appendix I the variables are explained in more detail.

The Brazilian data was available at subwatershed level. Moreover, the sewage treatment was included, which was not modeled in Helmes et al. (2012), due to the massive difference at Brazilian sanitation. This model adaptation is based on the model proposed by Gallego et al. (2010).

Income rate of P by advection from upstream subwatershed ($k_{adv,i}$) is calculated using equation 2. To estimate it some assumptions were made:

- a) Only stream water contributes to the advection process and, in a watershed, secondary rivers flow to the main stem, so the water flowing of the river base level represents the advection from upstream subwatersheds and;
- b) $V_{tot,i}$ was calculated adding the volume of rivers, lakes and reservoirs of upstream subwatershed.

Originally, the model estimated P transference from upstream grid (i) to downstream grid (j) through the water flow using equation 2.

$$k_{adv,i} = \frac{Q_i}{V_{tot,i}} \quad (2)$$

Where:

Q_i : The flow rate of the main stem base level of upstream subwatershed and;

$V_{tot,i}$: was calculated adding the volume of the mean rivers, lakes and reservoirs of subwatershed which is connected with the analyzed subwatershed

Outcome rate of P by retention ($k_{ret,j}$) was estimated using equation 3. The assumptions were:

- a) There was no information of affluent rivers, therefore the river volume at analyzed subwatershed was considered equal to the main river volume;
- b) Removal rate of phosphorus depended of the mean river water flow and;
- c) Phosphorus uptake velocity was $3.80 \cdot 10^{-5}$ at all subwatersheds (Alexander, Smith, Schwarz 2004).

$$k_{ret,j} = \frac{1}{V_{tot,j}} (V_{riv,j} \cdot k_{ret,riv,j} + v_f \cdot (A_{lak,j} + A_{res,j})) \quad (3)$$

Where:

$V_{tot,j}$: Total water volume at analyzed subwatershed

$k_{ret, riv, j}$: Removal rate of phosphorus at main river of downstream subwatershed (ALEXANDER et al., 2004)

$V_{riv, j}$: Total water volume at analyzed subwatershed (ALEXANDER et al., 2004)

v_f : Phosphorus uptake velocity

$A_{lak, j}$: Lake surface area at analyzed subwatershed

$A_{res, j}$: Reservoir surface area at analyzed subwatershed

The outcome rate of P by water use had a positive value and income, negative. Then the rates of P by water used for irrigation (equation 4) and domestic needs (equation 5) were modeled, as the industry sector was not considered in the original model.

(4)

$$k_{use\ irrig, j} = f_{WTA, j} \cdot f_{DITW\ irri, j} \cdot k_{adv, j} \cdot (1 - f_{soil, j})$$

(5)

$$k_{use\ dom, j} = f_{WTA, j} \cdot f_{DITW\ dom, j} \cdot k_{adv, j} \cdot (f_{TS} - (1 - f_{NTS}))$$

Where:

$k_{use\ dom, j}$: rate of P by water used for domestic purposes by subwatershed.

$f_{WTA, j}$: Fraction of water returned to the subwatershed after being used by the domestic sector at subwatershed level.

$f_{DITW\ dom, j}$: Share of the total water use that is used for domestic purposes at subwatershed.

$f_{DITW\ irri, j}$: Share of the total water use that is used for irrigation at subwatershed.

$k_{adv, j}$: Outcome rate by advection subwatershed.

$f_{soil, j}$: Fraction of P transferred from the soil to the water body

f_{TS} : Fraction of P removed by sewage treatment (equation 6)

f_{NTS} : Fraction of P transferred to the water body by dumping waste not treated sewage (equation 7)

(6)

$$f_{TS} = t.r$$

(7)

$$f_{NTS} = (1 - t) \cdot d$$

Where:

t: Percentage of treated sewage at analyzed subwatershed

r: Percentage of phosphorus removed at effluent treatment

d: Fraction of P at the not treated sewage

The regionalized equations of income and outcome rates were used to estimate the phosphorus persistence at freshwater (τ_j) and transported phosphorus ($T_{i,j}$). The persistence was obtained by the inverse of the sum of outcomes rates, as in equation 8.

(8)

$$\tau_j = \frac{1}{\text{sum of outcome rates}}$$

The transported phosphorus was calculated according to equation 9.

(9)

$$T_{i,j} = \frac{\text{sum of income rates}}{\text{sum of outcome rates}}$$

FF was obtained multiplying τ_j by $T_{i,j}$ as shown in equation 10.

(10)

$$FF_i = T_{i,j} \cdot \tau_j$$

The regionalized model was tested at Alto Iguaçu micro watershed, because this region has been extensively studied lately, so there is good data availability. Then it was applied at four other subwatersheds: Paraíba do Sul; Litorânea do Ceará; Litorânea Pernambuco e Alagoas and Parnaíba.

Paraíba do Sul is selected because it is located at a populous region, as is Alto Iguaçu, but has a lower rainfall index. Litorânea do Ceará and Litorânea Pernambuco and Alagoas are on the coast and suffer with water shortage. At Parnaíba subwatershed just 21% of sewage is treatment (Agência nacional de Águas [no date]).

2.3. EF regionalization

Azevedo et al. (2013) developed three effect models for European context to estimate the EF based on log—logistic relationships between potentially not occurring fraction¹ (PNOF) of heterotrophic species and total phosphorus concentration (TP), equation 11. As before, some assumptions were made to estimated PNOF.

As there was no information regarding affluent rivers, TP concentration at downstream subwatershed was considered equal to the main stem volume. This estimate decreases the quality of the calculated data.

$$PNOF = \frac{1}{1 + e^{-\frac{(\log C_{j,w} + 0.54)}{0.63}}} \tag{11}$$

Where: $C_{w,j}$ is the average of TP concentration at the main stem

Marginal Effect Factor model (MEF) estimates a small change on the impact of an emission due to a small change in the environmental concentration of TP (equation 12). Table 1 shows how MEF was regionalized.

$$MEF_{w,j} = \frac{\partial PNOF_{w,j}}{\partial C_{w,j}} = PNOF_{w,j} \cdot (1 - PNOF_{w,j}) \cdot \frac{1}{C_{w,j} \cdot \beta_w \cdot \ln(10)} \tag{12}$$

Table 1. MEF regionalization.

Variables	Units	Original model	Assumption	Regionalized model	Regionalized model geographic differentiation
$MEF_{w,j}$:	kg P ⁻¹ ·m ³	MEF model in freshwater at downstream grid	Regionalized at subwatersheds geographic differentiation	Marginal Effect Factor model in freshwater at downstream subwatershed	subwatershed
β_w :	dimensionless	Species sensitivity distributions Slope of the PNOF TP function in steam water	Literature data Azevedo et al. (2013b)	Species sensitivity distributions Slope of the PNOF TP function in steam water	subwatershed

The Linear Effect Factor model (LEF) is used if the pollutant concentration at the ambient is unknown and describes the change from ideal stage (zero concentration of the pollutant) to the

¹ Eutrophication causes the decrease in species richness in other words increase of PNOF of species due to increase of TP concentration.

concentration affecting 50% of the organisms. LEF_w was calculated using equation 13, and the assumptions to regionalize are shown at Table 2.

(13)

$$LEF_w = \frac{0.5}{10^{\alpha_w}}$$

Table 2. LEF regionalization.

Variables	Units	Original model	Assumption	Regionalized model	Regionalized model geographic differentiation
<i>LEF_w</i>	kg P ⁻¹ ·m ³	Linear Effect Factor model in fresh water at downstream grid	Regionalized at subwatersheds geographic differentiation	Linear Effect Factor model in freshwater at downstream subwatershed	subwatershed
<i>α_w</i>	dimensionless	Species sensitivity distributions Slope of the PNOF TP function at lake	Literature data Azevedo et al. (2013b). Coefficient for stream water was used because river volume is more representative than lake volume in a reservoir	Coefficient for stream water	subwatershed

The Average Effect Factor model (AEF) was recently proposed as an alternative to MEF, because it reflects the average distance between the current state and the preferred state of the environment. AEF is calculated using equation 14, which is detailed at the Table 3.

(14)

$$AEF_{w,j} = \frac{PNOF_{w,j}}{C_{w,j}}$$

Table 3. AEF regionalization.

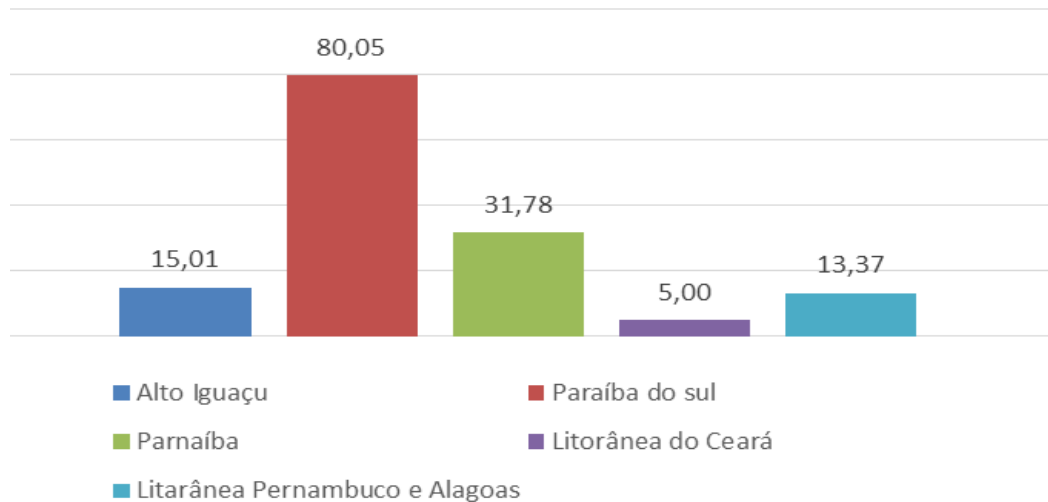
Variables	Units	Original model	Assumption	Regionalized model	Regionalized model geographic differentiation
<i>AEF_{w,j}</i>	kg P ⁻¹ ·m ³	Average Effect Factor model in freshwater at downstream grid	Regionalized at subwatersheds geographic differentiation	Average Effect Factor model in freshwater at downstream subwatershed	subwatershed
<i>PNOF_{w,j}</i>	dimensionless	Potentially not occurring fraction in freshwater downstream the grid	Regionalized at subwatersheds geographic differentiation	Potentially not occurring fraction in freshwater at downstream subwatershed	subwatershed
<i>C_{w,j}</i>	kg P·m ⁻³	TP concentration fraction in freshwater at downstream grid	There is no information only of affluent rivers, so TP concentration at downstream subwatershed is considered equal to the main stem volume	The average of TP concentration at the main stem	River

3. RESULTS

3.1 FF results

The figure 1 presents FF results, figure 2 income rates and the figure 3 the outcome rates.

Figure 1. Subwatershed's FF (days).



Helmes et al. (2012) estimated the FF of Alto Iguaçu between 30-300 days while this study obtained a much smaller value of 15.01 days. The dominant input process was $k_{adv,i}$ therefore the water from Ribeira River contributed substantially to the eutrophication at Alto Iguaçu. This region had a good sanitation that was reflected at $k_{use,dom,j}$, which was very low. The $k_{use,irrig,j}$ was relevant, in spite of the fact that this basin is in an urban area, which imply a lower amount of water used for irrigation when compared to the amount used to domestic supply.

The advection was also the most important variable. $k_{ret,j}$ was significant, because water flow from Iguaçu River to Alto Iguaçu was low (around 86 m³/s) and this increased the P retention time increasing its assimilation and precipitation. Therefore, investing at sewage treatment at Ribeira do Iguapé subwatershed seems to be the most efficient way to improve the eutrophication condition at Alto Iguaçu.

The results of FF for Paraíba do Sul using the original model was also between 30-300 days, and using the regionalized data and the model adaptation, it was 80.05 days.

The original FF results of Paraíba, Litorânea do Ceará and Litorânea Pernambuco and Alagoas ranged from 3 to 10 days, whereas using the regionalized model the FF were respectively 31.78, 5.0, 13.37 days, none of them within the previous range.

Paraíba do Sul is located at the border of São Paulo, Rio de Janeiro and Minas Gerais States, with almost 2 million inhabitants (HÍDRICO, 2016). It is located at tropical altitude zone, the average temperature is 17 °C to 22 °C (Agência nacional de Águas [no date]).

The high temperature contributes to accelerate the eutrophication (Tundisi, Tundisi, Siagis Galli 2006).

Paraíba River is the main river and it is connected to Bacia Grande and Bacia Doce watersheds.

Although Paraíba do Sul has 37% of its sewage treated and Parnaíba only 21%, in the former, the situation is worse than the latter, because it is located at a populous region, so the $k_{use,dom,j}$ and $k_{use,irrig,j}$ are extremely high. Besides, Paraíba's River water flow is high, approximately 1120 m³/s, consequently, $k_{ret,j}$ is under most and $k_{adv,j}$ is the highest of all watersheds studied. The $k_{adv,i}$ from Bacia Grande and Bacia Doce ($1.13 \cdot 10^{-3}$ and $4.51 \cdot 10^{-3}$ days⁻¹ respectively) is quite relevant, therefore, to improve the eutrophication at Paraíba do Sul it is not enough to expand the sewage treatment, it is also necessary to invest at the wastewater treatment of Bacia Grande and Bacia Doce. Industrial activity is very intense in this region, but the regionalized model does not model it, therefore the FF should be even worse than the estimated.

Parnaíba, Litorânea Pernambuco Alagoas and Litorânea do Ceará are located at northeast of Brazil and in a megathermal rainy zone, which has an average temperature of 16 C to 32 ° C. They are not connected with any subwatersheds. Litorânea do Ceará is divided in five regions: Acaraú, Coreau, Curú, Litoral and Metropolitana.

For those three watersheds, $k_{adv,i}$ is zero because the spring rivers are located inside the basin, therefore there is no income rate from upstream watershed. At Parnaíba, Litorânea Pernambuco Alagoas, the dominant input rate was $k_{use,irrig,j}$ and at Litorânea do Ceará it was $k_{use,dom,j}$. At the coast, very low results of $k_{use,dom,j}$ can be explained due to the fact that a large amount of sewage is dumped at the sea and the current regionalized model is for freshwater eutrophication. Nevertheless, this information is relevant for marine eutrophication.

These three basins are located at a region with optimal temperature conditions for microalgae development so $k_{ret,j}$ is the dominant output process. As Litorânea Pernambuco Alagoas and Litorânea do Ceará suffer with water shortage, this resulted in low rates of $k_{adv,j}$.

Figure 2. Subwatershed's input rates (day⁻¹).

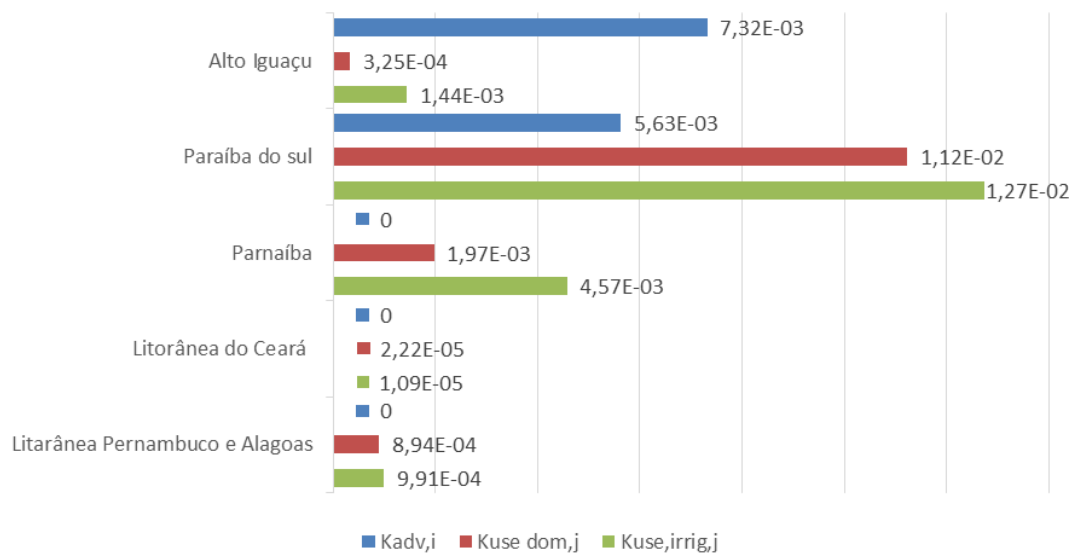
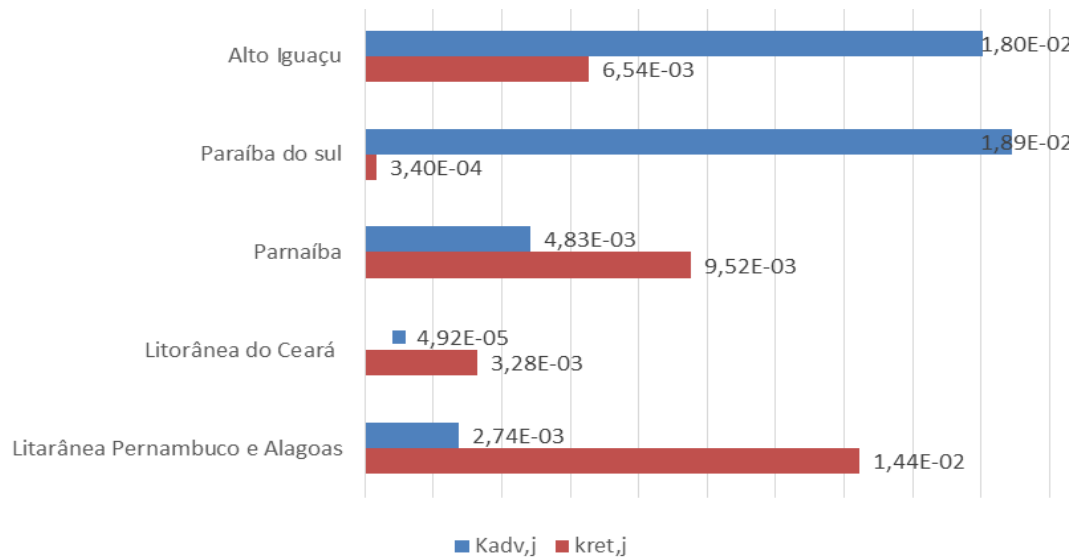


Figure 3. Subwatershed's output rates (day⁻¹).



3.2. EF results

At Alto Iguaçu micro watershed TP concentration data of affluent rivers is not available, so the average of the four values collected at Iguaçu River was used. The coefficients α and β were used for water stream, because the rivers' water volume is much bigger than in lakes and reservoirs. The Table 4 presents the data for Alto Iguaçu micro watershed, and Table 5 the result of Average, Marginal and Linear effect factor.

Table 4. Alto Iguaçu data to calculated EF.

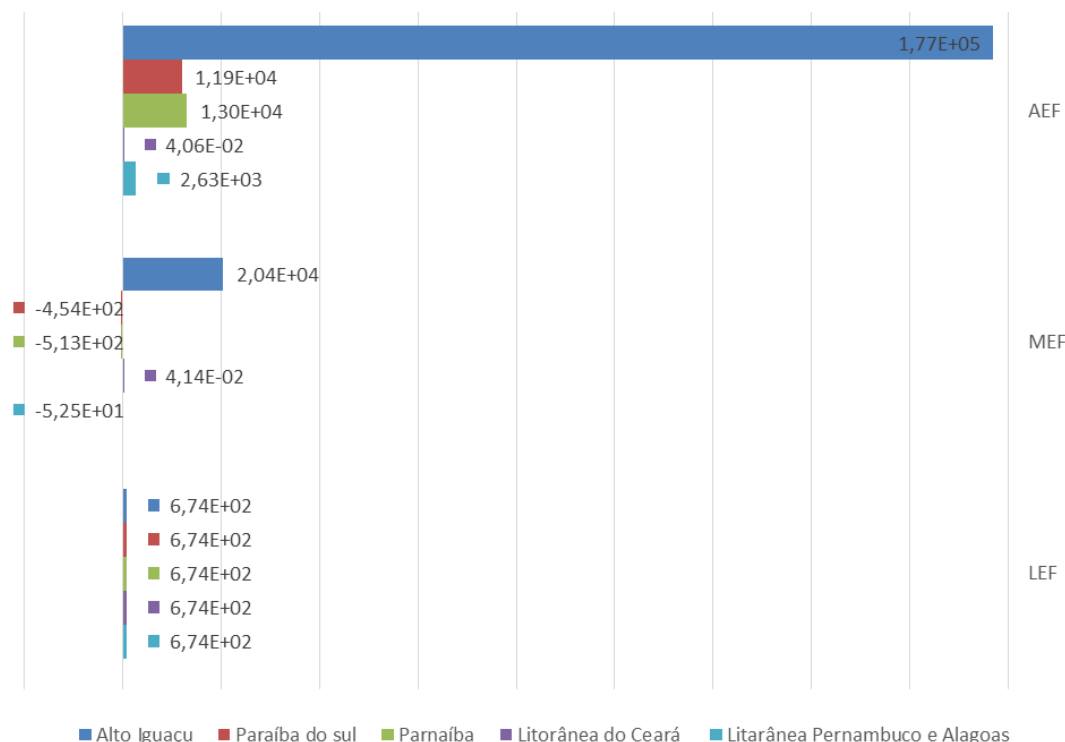
Variables	$PNOF_{AI}$:	C_{AI} :	α	β
Meaning	Potentially not occurring fraction	TP concentration at Alto Iguaçu subwatershed	Species sensitivity distributions Slope of the PNOF TP function at lake	Species sensitivity distributions Slope of the PNOF TP function in steam water
Units	Dimensionless	kg .m ³	Dimensionless	Dimensionless
Value	0,99	2 10 ⁻³	-3,13	0,426
Source	Calculated using the equation $PNOF_{AI} = \frac{1}{1 + \exp\left(\frac{-(\log C_{AI} + 0.54)}{0.63}\right)}$	(Kramer 2012)	(Azevedo et al. 2013)	(Azevedo et al. 2013)
Qualitative analysis				
Year/Period	-	2012	2013	2013
Especial differentiation	-	River	0.5°x0.5°	0.5°x0.5°
Representativeness	-	Medium	Low	Low
Method	-	Average	Average	Average
Available region	-	Alto Iguaçu	Europe	Europe

Table 5. EF results.

Variables	AEF_{AI} :	MEF_{AI} :	LEF_{AI} :
Meaning	Average effect factor	Marginal effect factor	Linear effect factor
Units	m ³ . kg P ¹⁻	m ³ . kg P ¹⁻	m ³ . kg P ¹⁻
Value	495.25	4.79	674.48
Source	Calculated using the equation $AEF_{AI} = \frac{PNOF_{AI}}{C_{AI}}$	Calculated using the equation $MEF_{AI} = PNOF_{AI} \cdot \left(1 - PNOF_{AI}\right) \cdot \frac{1}{C_{AI} \cdot \beta \cdot \ln(10)}$	Calculated using the equation $LEF_{AI} = \frac{0.5}{10^\alpha}$

The figure 4 shows the results of EF obtained using the three models. LEF was used to estimated the effect if the concentration of P is unknown. As LEF does not depend of TP concentration, and since there is not Brazilian data to estimate the water stream coefficient, the same α_w from literature was used for all subwatersheds. As a result, LEF causes the same value for subwatershed, making it impossible to evaluate the effect using it.

Figure 4. results of EF obtained using the three models.



MEF measures small changes on TP concentration at water bodies, so it is not adequate for regions with low rate of effluent treatment presenting negative results for Paraíba do Sul, Parnaíba and Litorânea Pernambuco Alagoas.

For this reason, the AEF allows a better evaluation of the Brazilian subwatersheds than LEF and MEF. According to AEF model, the same amount of dropped P affects more species richness at Alto Iguaçu, Parnaíba and Paraíba do Sul, hence preventive measures should be a priority at these regions.

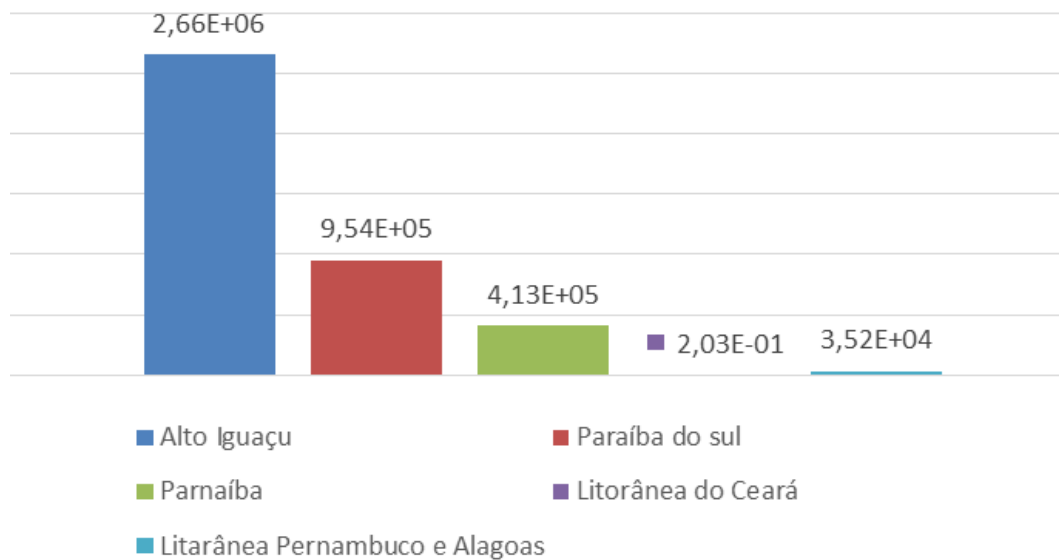
3.3. Characterization Factor results

The results of the Alto Iguaçu CF using three different EF models are shown at Table 6.

Table 6. CF results.

Variables	ACF_{AI}	MCF_{AI}	LCF_{AI}
Meaning	CF calculated using AEF model	CF calculated using MEF model	CF calculated using LEF model
Units	day	day	day
Value	$6.18 \cdot 10^3$	$5.97 \cdot 10^1$	$8.41 \cdot 10^3$
Source	$CF = FF \cdot EF$	$CF = FF \cdot EF$	$CF = FF \cdot EF$

The calculation of the other basins is detailed at the Appendix I and CF calculated using AEF model of all subwatersheds are shown in figure 5.

Figure 5. CF results – ACV ($\text{day}\cdot\text{m}^3\cdot\text{kgP}^{-1}$).

Alto Iguaçu and Paraíba do Sul presented the highest CF of all subwatersheds, consequently the same amount of emitted phosphorus results in values of eutrophication potential higher at these regions than in others.

Because of this high eutrophication potential there is concentration of hypereutrophy water bodies at these watersheds.

4 CONCLUSIONS

The proposed goal was achieved through the LCIA method of freshwater eutrophication that was regionalized promoting the first CF to estimate the eutrophication impact at Brazilian subwatersheds.

This is the first study that presents a regionalized model to estimate Brazilian CF for freshwater eutrophication. The regionalization was based on the models proposed by Helmes et al. (2012) and Azevedo et al. (2013), which are considered the most complete and suitable models.

Due to the lack of data it was possible to calculate the CF for Alto Iguaçu micro watershed and four subwatersheds: Paraíba do Sul, Parnaíba, Litorânea do Ceará and Litorânea Pernambuco Alagoas. Among these watersheds, Alto Iguaçu has the highest CF.

The processes assessment of advection, retention and water use provides valuable information of each region and also results in more realistic FF, since Brazilian sanitation is completely uneven, and the sewage treatment must be modelled to not overestimated or sub estimated the FF.

It is not feasible to apply the original models in Brazil, because there is no data of geographical differentiation in $0.5^\circ \times 0.5^\circ$ grids. Therefore, regionalizing the CF is the most reasonable way

to promote higher quality information, which can be used to make strategic decisions in order to avoid eutrophication impact.

Finding the necessary data was the crucial part of the work because the lack of available data in Brazil only considers the main rivers with low quality and low representativeness. To improve the CF quality, is very important having data of affluent rivers, such as lakes and reservoirs.

Understanding the subwatershed, it becomes possible to direct financial resources to prioritize preventives actions, such as sanitation and environmental education programs at regions as Paraíba do Sul.

This was the first attempt to develop a Brazilian CF and some improvements need to be done. Firstly, new studies ought to concentrate to promote good quality of data, then the regionalized model should improve modeling treatment of industrial sewage and, finally, CF needs to be calculated for all subwatershed.

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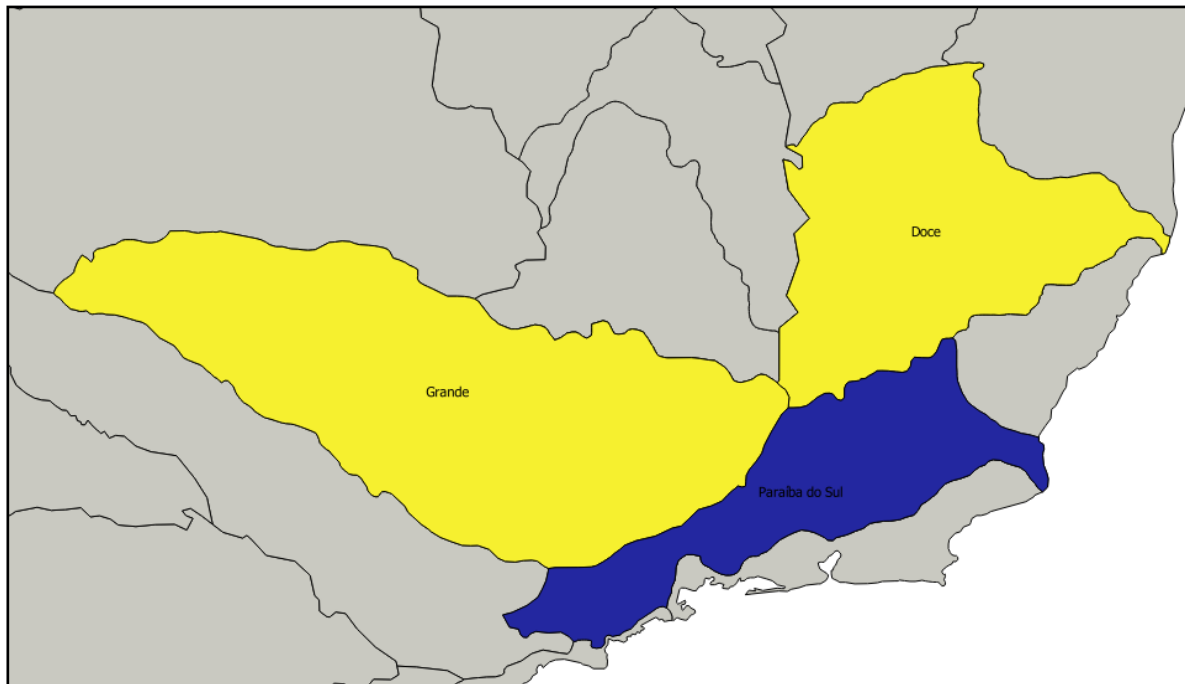
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APPENDIX I

- **Paraíba do Sul subwatershed**

Paraíba do Sul is located on the border of São Paulo, Rio de Janeiro and Minas Gerais, where around 1,966,728 inhabitants live (HÍDRICO, 2016). It is located at a tropical altitude zone, and the average temperature is from 17°C to 22°C (MMA/ANA). Paraíba River is the main stem and it is connected to Bacia Grande and Bacia Doce watersheds.



- **FF calculation**

Applying the Subwatershed model FF takes 35.89 days. The process calculations are detailed below.

- Calculation of $k_{adv,i}$

The income rate by advection was estimated for Preto (Bacia Doce watershed) and Pomba River (Bacia Grande watershed) and the total advection rate is $5.63 \cdot 10^{-3} \text{ days}^{-1}$, which is the sum of the rate of both rivers.

The main stem water flow rate was collected just before it disembogues in the Paraíba do Sul watershed. The water volume at Paraíba do Sul was estimated by the same process as Alto Iguaçu's water volume.

Variables	$k_{adv,Grande}$	Q_{Grande}	$V_{tot,Grande}$	A_{Grande}	P_{Grande}
Meaning	Income rates by advection of Bacia Grande subwatershed	Preto river flow rate at the spring of Bacia Grande watershed	Total water volume of Bacia Grande subwatershed	Water surface area of Bacia Grande subwatershed	Average depth of Preto river
Units	day ⁻¹	m ³ /day	m ³	m ²	m
Value	1.13 10 ⁻³	7.89 10 ⁶	6.96 10 ⁹	4.64 10 ⁹	1.5
Source	Calculated by the equation 2 $k_{adv,i} = \frac{Q_i}{V_{tot,i}}$	(ATLAS DAS AGUAS, 2016)	Calculated by the equation below $V_{tot,i} = A_{tot,i} \cdot P_{tot,i}$	(DISPONIBILIDADE HIDRICA, 2016)	(CPRJ, 2016)
Qualitative analysis					
Year/Period	-	From 1950 to 2009	-	2016	2006
Especial differentiation	-	River	-	River, lake and reservoir	River
Representativeness	-	Low (only the mean river water flow is considered)	-	Medium (Reservoir isn't considered)	Medium (Average depth is considered)
Method	-	Average	-	Sum	Average
Available region	-	Paraíba subwatershed	-	Brazil	Bacia Grande subwatershed

Variables	$k_{adv,Doce}$	Q_{Doce}	$V_{tot,Doce}$	A_{Doce}	P_{Doce}	$k_{adv,TOT}$
Meaning	Income rates by advection of Bacia Doce subwatershed	Pomba river flow rate at the spring of Parnaíba do Sul watershed	Total water volume of Bacia Grande subwatershed	Water surface area of Bacia Doce subwatershed	Average depth of Pomba river	Total income rates by advection
Units	day ⁻¹	m ³ /day	m ³	m ²	m	day ⁻¹
Value	4.5 10 ⁻³	3.58 10 ⁶	7.95 10 ⁸	5.3 10 ⁸	1.5	5.63 10 ⁻³
Source	Calculated by the equation 2	(ATLAS DAS AGUAS, 2016)	Calculated by the equation below $V_{tot,i} = A_{tot,i} \cdot P_{tot,i}$	(DISPONIBILIDADE HIDRICA, 2016)	(CPRJ, 2006)	$k_{adv,TOT} = k_{adv,BG} + k_{adv,BD}$
Qualitative analysis						
Year/Period	-	From 1950 to 2009	-	2016	2006	-
Especial differentiation	-	River	-	River, lake and reservoir	River	-
Representativeness	-	Low (only the mean river water flow is considered)	-	Medium (Reservoir isn't considered)	Medium (Average depth is considered)	-
Method	-	Average	-	Sum		-
Available region	-	Brazil	-	Brazil	Ribeira subwatershed	-

○ Calculation of $k_{ret,j}$
 $k_{ret,j}$ is $3.4 \cdot 10^{-4} \text{days}^{-1}$. Water volume data of Paraíba do Sul is available. P removal rate at rivers is 0.012 day^{-1} because Paraíba do Sul flow rate is higher than $14.55 \text{ m}^3/\text{s}$ (ALEXANDER et al., 2004).

Variables	$k_{ret,PR}$	$V_{tot,PR}$	$k_{ret,riv,PR}$	$V_{riv,PR}$
Meaning	Outcome rates by retention of Paraíba do Sul subwatershed	Total water volume of Paraíba do Sul subwatershed	Removal rate of phosphorus Paraíba do Sul River	Paraíba do Sul River volume
Units	day^{-1}	km^3	day^{-1}	km^3
Value	$3.4 \cdot 10^{-4}$	5.12	0.012	$1.44 \cdot 10^{-1}$
Source	Calculated by the equation 3 $k_{ret,j} = \frac{1}{V_{tot,j}} (V_{riv,j} \cdot k_{ret,riv,j} + v_f \cdot (A_{lak,j} + A_{res,j}))$	(BOLETIM, 2016)	(ALEXANDER et al., 2004)	Calculated by the equation below $V_{tot,i} = A_{tot,i} \cdot P_{tot,i}$
Qualitative analysis				
Year/Period	-	2016	2004	-
Especial differentiation	-	River, lake and reservoir	River	-
Representativeness	-	High (Estimated by GIS)	Low (The same rate for all regions)	-
Method	-	Sum	Average	-
Available region	-	Paraíba do Sul watershed	Global	-

Variables	$A_{riv,I}$	$P_{riv,I}$	v_f	$A_{lak,Al}$
Meaning	Water surface area of Paraíba do Sul River	Average depth of Paraíba do Sul River	Phosphorus uptake velocity at Paraíba do Sul subwatershed	Lake and Reservoir surface area at Paraíba do Sul subwatershed
Units	km^2	km	$\text{km} \cdot \text{day}^{-1}$	km^2
Value	$9.58 \cdot 10^{-2}$	$1.5 \cdot 10^{-3}$	$3.80 \cdot 10^{-5}$	$4,29 \cdot 10^{-1}$
Source	(DISPONIBILIDADE HIDRICA, 2016)	(CRPJ, 2006)	(ALEXANDER et al., 2004)	(DISPONIBILIDADE HIDRICA, 2016)
Qualitative analysis				
Year/Period	2016	2006	2004	2016
Especial differentiation	River	River	River	Lake
Representativeness	High (Estimated by GIS)	Medium (Average depth is considered)	Low (The same rate for all regions)	High (Estimated by GIS)
Method	Sum	Average	Average	Sum
Available region	Brazil	Iguaçu River	Global	Brazil

- Calculation of $k_{use,j}$
It is $-1,44 \cdot 10^{-2} \text{day}^{-1}$ and it is calculated by the equation 7. The same assumptions used at Alto Iguaçu about domestic effluent and particulate phosphorus are applied to Paraíba do Sul. The outcome rate by advection is estimated at the last station at the basin in São João da Barra city.

Variables	$k_{use\ dom,j}$	$f_{WTA,AI}$	$f_{DITW\ dom,j}$	$k_{adv,j}$	f_{TS}
Meaning	Income rate of P by water used for domestic purpose at Paraíba do Sul subwatershed	Fraction of water returned to downstream grid after being used for domestic sector at subwatershed.	Share of the total water use that is used for domestic purposes at Paraíba do Sul subwatershed	Outcome rate by advection of Paraíba do Sul subwatershed	Fraction of P removed by sewage treatment.
Units	day ⁻¹	Dimensionless	Dimensionless	m ³ /day	Dimensionless
Value	$-1,13 \cdot 10^{-2}$	0.8	0.55	$1.89 \cdot 10^{-2}$	0.26
Source	Calculated by the equation 9 $k_{use\ dom,j} = f_{WTA,J} \cdot f_{DITW\ dom,j} - (1 - f_{NTS})$	(SPERLING M., VON, 1996)	(ABASTECIMEN TO URBANO, 2016)	Calculated by the equation 5 $k_{adv,j} = \frac{Q_j}{V_{tot,j}}$	It is calculated by the equation 10 $f_{TS} = t \cdot r$
Qualitative analysis					
Year/Period	-	1996	2016	-	-
Especial differentiation	-	River	subwatershed	-	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	-
Method	-	Average	Sum	-	-
Available region	-	Global	Alto Iguaçu subwatershed	-	-

Variables	t	r	f_{NTS}	d	$C_{P\ river}$	$C_{P\ TS}$
Meaning	Percentage of treated sewage at Paraíba do Sul subwatershed	Percentage of phosphorus removed at effluent treatment	Fraction of P transferred to the water body by dumping non-treated sewage	Fraction of P at non-treated sewage	P concentration at Paraíba river	P concentration at treated sewage
Units	Dimensionless	Dimensionless	Dimensionless	Dimensionless	mg/L	mg/L
Value	0.37	0.71	-0.62	-0.98	0.087	14
Source	(TRATA BRASIL, 2016)	(CONAMA, 2011)	It is calculated by the equation 11 $f_{NTS} = (1 - t) \cdot d$	Calculated by the equation below. $d = \frac{(C_{P\ river} - C_P)}{C_{P\ TS}}$	(PGRH, 2016)	(CONAMA, 2011)
Qualitative analysis						
Year/Period	2016	2011	-	-	2016	2011
Especial differentiation	Paraíba do Sul subwatershed	Brazil	-	-	Paraíba river	Brazil
Representativeness	Medium (Percentage estimate of treated sewage)	Low (The same rate for all regions)	-	-	Low (Average of 3 samples)	Low (The same rate for all regions)
Method	Average	Average	-	-	Average	Average
Available region	Paraíba do Sul subwatershed	Brazil	-	-	Paraíba river	Brazil

Variables	$k_{use\ irrig,j}$	$f_{WTA,j}$	$f_{DITW\ irrig,j}$	$f_{soil,j}$	R	$k_{TOT,j}$
Meaning	Outcome rate of P by water used for domestic purpose at Paraíba do Sul subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for irrigation at Paraíba do Sul subwatershed	Fraction of total phosphorus emissions transferred at Paraíba do Sul subwatershed	Runoff rate at Paraíba do Sul subwatershed	Income rate of P by water used at Paraíba do Sul subwatershed
Units	day ⁻¹	Dimensionless	Dimensionless	Dimensionless	mm.year ⁻¹	day ⁻¹
Value	-1.27 10 ⁻²	0.8	0.23	4.62	596.38	2.40 10 ⁻²
Source	$k_{use\ irrig,j} = f_{WTA,j} \cdot f_{DIP} - f_{soil,j}$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $f_{DIP} = \frac{0.29}{\left(1 + \left(\frac{R}{0.85}\right)^{-2}\right)}$ $f_{DIP} = 0.01 \cdot R^{0.95}$	(ATALAS,2016)	Calculated by the equation below. $k_{TOT,j} = k_{use\ dom,j} - k_{use\ irrig,j} $
Qualitative analysis						
Year/Period	-	1996	2016	-	1950-2000	-
Especial differentiation	-	River	subwatershed	-	0.5°x0.5°	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	High	-
Method	-	Average	Sum	-	Average	-
Available region	-	Global	Alto Iguaçu subwatershed	-	Global	-

• EF calculation

TP concentration is measured between Santa Branca and the Paraíba River base level. The coefficients α and β are used to analyze stream water, because the rivers watershed volume is more representative than the lake and reservoir volumes.

Variables	$PNOF_{AI}$:	C_{AI} :	α	β
Meaning	Potentially non-occurring fraction	TP concentration at Paraíba do Sul subwatershed	Species sensitivity distributions Slope of the PNOF TP function at lake	Species sensitivity distributions Slope of the PNOF TP function in steam water
Units	Dimensionless	kg .m ⁻³	Dimensionless	Dimensionless
Value	0.96	8.73 10 ⁻⁵	-3,13	0,426
Source	Calculated using the equation $PNOF_{AI} = \frac{1}{1 + \exp\left(\frac{-(\log C_{AI} + 0.54)}{0.63}\right)}$	(PGRH, 2016)	(AZEVEDO at al., 2013b)	(AZEVEDO at al., 2013b)
Qualitative analysis				
Year/Period	-	2016	2013	2013
Especial differentiation	-	River	0.5°x0.5°	0.5°x0.5°
Representativeness	-	Medium	Low	Low
Method	-	Average	Average	Average
Available region	-	Alto Iguaçu	Europe	Europe

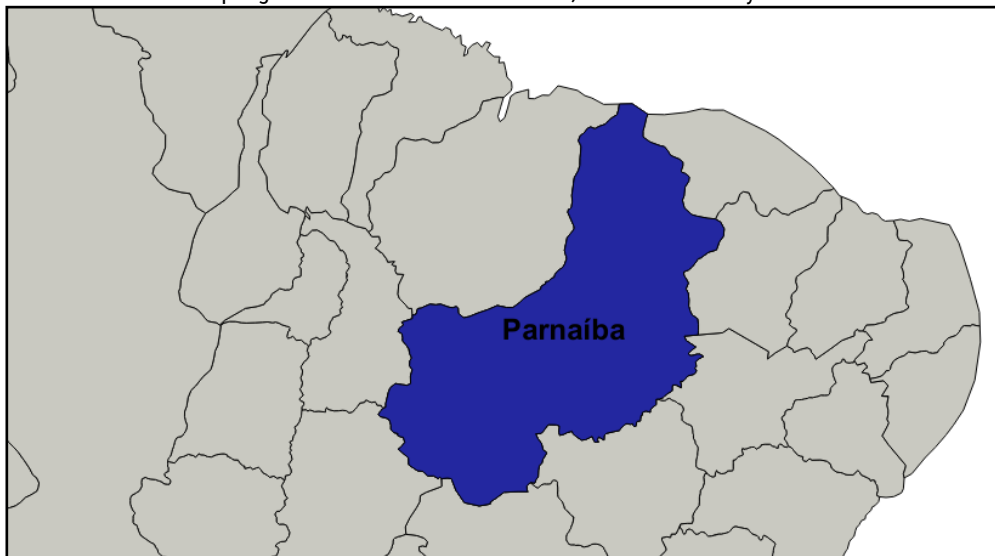
• CF calculation

The CF is calculated by the three different EF models.

Variables	AEF_j	MEF_j	LEF_j
Meaning	Average effect factor	Marginal effect factor	Linear effect factor
Units	$m^3 \cdot kg P^{-1}$	$m^3 \cdot kg P^{-1}$	$m^3 \cdot kg P^{-1}$
Value	$1.10 \cdot 10^4$	$4.05 \cdot 10^2$	$6.74 \cdot 10^2$
Source	Calculated by the equation $AEF_{AI} = \frac{PNOF_{AI}}{C_{AI}}$	Calculated by the equation $MEF_{AI} = PNOF_{AI} \cdot (1 - PNOF_{AI}) \cdot \frac{1}{C_{AI} \cdot \beta \cdot \ln(10)}$	Calculated by the equation $LEF_{AI} = \frac{0.5}{10^\alpha}$
Variables	ACF_j	MCF_j	LCF_j
Meaning	CF calculated by the AEF model	CF calculated by the MEF model	CF calculated by the LEF model
Units	-day	day	day
Value	$8.30 \cdot 10^{-5}$	$3.25 \cdot 10^4$	$5,41 \cdot 10^4$
Source	$CF = FF \cdot EF$	$CF = FF \cdot EF$	$CF = FF \cdot EF$

• **Parnaíba subwatershed**

Parnaíba is located at the northeast of Brazil and in a megathermal rainy zone, which has an average temperature from 16° C to 32° C. Approximately 4.152.865 inhabitants live in this region. Parnaíba subwatershed is not connected to any subwatersheds, because all the rivers spring at the subwatershed. Therefore, the income rate by advection is zero.



• **FF calculation**

Applying the Subwatershed model FF takes 31.10 days. The process calculations are detailed below.

- Calculation of $k_{ret,j}$

The water volume at Parnaíba was calculated the same way as Alto Iguaçu. The flow rate of Parnaíba River is base level so the removal rate of phosphorus is 0.012 day^{-1} (ALEXANDER et al., 2004).

Variables	$k_{ret,j}$	$V_{tot,j}$	A_j	P_j	$k_{ret,riv,j}$
Meaning	Outcome rates by retention of Parnaíba subwatershed	Total water volume of Parnaíba subwatershed	Water surface area of Parnaíba subwatershed	Average depth of Parnaíba River	Removal rate of phosphorus of Parnaíba subwatershed
Units	day ⁻¹	km ³	km ²	km	day ⁻¹
Value	9.52 10 ⁻³	5.64	1.11 10 ³	5.09 10 ⁻³	0.012
Source	Calculated by the equation 3 $k_{ret,j} = \frac{1}{V_{tot,j}} (V_{riv,j} \cdot k_{ret,riv,j} + v_f \cdot (A_{lak,j} + A_{res,j}))$	Calculated by the equation below. $V_{tot,j} = A_j \cdot P_j$	(BOLETIM,2016)	(CPRJ, 2006)	ALEXANDER et al, 2004
Qualitative analysis					
Year/Period	-	-	2016	2006	2004
Especial differentiation	-	-	River, lake and reservoir	River	River
Representativeness	-	-	High (Estimated by GIS)	Medium (Average depth is considered)	Low (The same rate for all regions)
Method	-	-	Sum	Average	Average
Available region	-	-	Brazil	Parnaíba	Global

Variables	$V_{riv,j}$	$A_{riv,j}$	P_j	v_f	$A_{lak,j}$	$A_{res,j}$
Meaning	Volume of Parnaíba do Sul River	Water surface area of Parnaíba do Sul River	Average depth of Parnaíba River	Phosphorus uptake velocity at Parnaíba subwatershed	Lake surface area of Parnaíba subwatershed	Reservoir surface area of Parnaíba subwatershed
Units	km ³	km ²	km	km·day ⁻¹	km ²	km ²
Value	2.55	5.02 10 ²	5.09 10 ⁻³	3.80 10 ⁻⁵	2.37 10 ²	3.69 10 ²
Source	Calculated by the equation below. $V_{riv,j} = A_{riv,j} \cdot P_j$	(DISPONIBILIDADE HIDRICA, 2016)	(CPRJ, 2006)	(ALEXANDER et al., 2004)	(DISPONIBILIDADE HIDRICA, 2016)	(DISPONIBILIDADE HIDRICA, 2016)
Qualitative analysis						
Year/Period	-	2016	2006	2004	2016	2016
Especial differentiation	-	River	River	River	Lake	Reservoir
Representativeness	-	High (Estimated by GIS)	Medium (Average depth is considered)	Low (The same rate for all regions)	High (Estimated by GIS)	High (Estimated by GIS)
Method	-	Sum	Average	Average	Sum	Sum
Available region	-	Brazil	Parnaíba	Global	Brazil	Brazil

Calculation of $k_{use,j}$

$k_{use,j}$ is $-1.18 \cdot 10^{-3} \text{ day}^{-1}$ and it is calculated by the equation 7. The same consideration made for Alto Iguaçú is used for Parnaíba subwatershed.

Variables	$k_{use\ dom,j}$	$f_{WTA,j}$	$f_{DITW\ dom,j}$	$k_{adv,j}$	f_{TS}
Meaning	Removal rate by water use of Parnaíba subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for domestic purposes at Paraíba do Sul subwatershed	Removal rate by advection at Parnaíba subwatershed	Fraction of P removed by sewage treatment.
Units	day ⁻¹	Dimensionless	Dimensionless	day ⁻¹	Dimensionless
Value	$-1.83 \cdot 10^{-3}$	0.8	0.31	$4.83 \cdot 10^{-3}$	0.15
Source	Calculated by the equation 9 $k_{use\ dom,j} = f_{WTA,j} \cdot f_{DITW\ dom,j} - (1 - f_{NTS,j})$	(SPERLING M., VON, 1996)	(ABASTECIMENTO URBANO, 2016)	Calculated by the equation 5 $k_{adv,j} = \frac{Q_j}{V_{tot,j}}$	It is calculated by the equation 10 $f_{TS} = t \cdot r$
Qualitative analysis					
Year/Period	-	1996	2016	-	-
Especial differentiation	-	River	subwatershed	-	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	-
Method	-	Average	Sum	-	-
Available region	-	Global	Alto Iguaçú subwatershed	-	-

Variables	t	r	f_{NTS}	d	$C_{P\ river}$	$C_{P\ TS}$
Meaning	Percentage of treated sewage at Parnaíba subwatershed	Percentage of phosphorus removed at effluent treatment	Fraction of P transferred to the water body by dumping non-treated sewage	Fraction of P non-treated sewage	P concentration at Parnaíba river	P concentration at non-treated sewage
Units	Dimensionless	Dimensionless	Dimensionless	Dimensionless	mg/L	mg/L
Value	0.21	0.71	-0.66	-0.83	0.08	14
Source	(TRATA BRASIL, 2016)	(CONAMA, 2011)	It is calculated by the equation 11 $f_{NTS} = (1 - t) \cdot d$	Calculated by the equation below. $d = \frac{(C_{P\ river} - C_P)}{C_{P\ TS}}$	(INCT, 2016)	(CONAMA, 2011)
Qualitative analysis						
Year/Period	2016	2011	-	-	2016	2011
Especial differentiation	Parnaíba subwatershed	Brazil	-	-	Paraíba river	Brazil
Representativeness	Medium (Percentage estimate of treated sewage)	Low (The same rate for all regions)	-	-	Low (Average of 3 samples)	Low (The same rate for all regions)
Method	Average	Average	-	-	Average	Average
Available region	Parnaíba subwatershed	Brazil	-	-	Paraíba river	Brazil

Variables	$k_{use\ irrig,j}$	$f_{WTA,j}$	$f_{DITW\ irri,j}$	$f_{soil,j}$	R	$k_{TOT,j}$
Meaning	Income rate of P by water used for domestic purpose at Parnaíba subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for irrigation at Parnaíba subwatershed	Fraction of total phosphorus emissions transferred at Parnaíba subwatershed	Runoff rate at Parnaíba subwatershed	Income rate of P by water used at Parnaíba subwatershed
Units	day ⁻¹	Dimensionless	Dimensionless	Dimensionless	mm.year ⁻¹	day ⁻¹
Value	-4.57 10 ⁻³	0.8	0.58	3.05	371.39	-6.41 10 ⁻³
Source	$k_{use\ irrig,j} = f_{WTA,j} \cdot f_{DIT} - f_{soil,j}$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $f_{DIP} = \frac{0.29}{\left(1 + \left(\frac{R}{0.85}\right)^{-2}\right)}$ $f_{DOP} = 0.01 \cdot R^{0.95}$	(ATALAS, 2016)	Calculated by the equation below. $k_{TOT,j} = k_{use\ dom} - k_{use\ irrig}$
Qualitative analysis						
Year/Period	-	1996	2016	-	1950-2000	-
Especial differentiation	-	River	subwatershed	-	0.5°x0.5°	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	High (Estimated by GIS)	-
Method	-	Average	Sum	-	Average	-
Available region	-	Global	Alto Iguaçu subwatershed	-	Global	-

- EF calculation

TP concentration is the average value measured between March and August 2010.

Variables	$PNOF_j$	C_j	α	β
Meaning	Potentially non-occurring fraction	TP concentration at Parnaíba River	Coefficient α of streams	Coefficient β of streams
Units	Dimensionless	kg .m ³	Dimensionless	Dimensionless
Value	1	8,00 10 ⁻⁵	-3.13	0.426
Source	Calculated by the equation $PNOF_{AI} = \frac{1}{1 + \exp\left(\frac{-(\log C_{AI} + 0.54)}{0.63}\right)}$	(INCT, 2016)	(AZEVEDO et al, 2013b)	(AZEVEDO et al, 2013b)
Qualitative analysis				
Year/Period	-	2016	2013	2013
Especial differentiation	-	River	0.5°x0,5°	0.5°x0,5°
Representativeness	-	Low (Average of few samples)	Low (European context)	Low (European context)
Method	-	Average	Average	Average
Available region	-	Parnaíba River	Europe	Europe

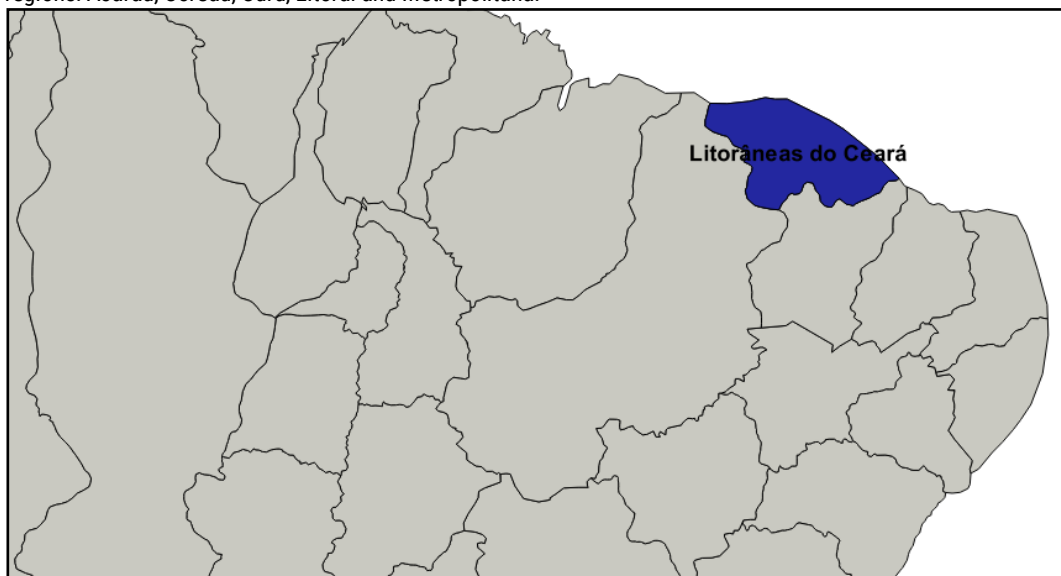
• CF calculation

CF is calculated using three different EF models.

Variables	AEF_{AI} :	MEF_{AI} :	LEF_{AI} :
Meaning	Average effect factor	Marginal effect factor	Linear effect factor
Units	$m^3 \cdot kg P^{1-}$	$m^3 \cdot kg P^{1-}$	$m^3 \cdot kg P^{1-}$
Value	$1.30 \cdot 10^4$	$-5.13 \cdot 10^2$	$6,74 \cdot 10^2$
Source	Calculated by the equation $AEF_j = \frac{PNOF_j}{C_j}$	Calculated by the equation $MEF_{AI} = PNOF_{AI} \cdot (1 - PNOF_{AI}) \cdot \frac{1}{C_{AI} \cdot \beta \cdot \ln(10)}$	Calculated by the equation $LEF_{AI} = \frac{0.5}{10^\alpha}$
Variables	ACF_{AI} :	MCF_{AI} :	LCF_{AI} :
Meaning	CF calculated by the AEF model	CF calculated by the MEF model	CF calculated by the LEF model
Units	-day	day	day
Value	$4.04 \cdot 10^5$	$-1.60 \cdot 10^4$	$2.10 \cdot 10^4$
Source	$CF = FF \cdot EF$	$CF = FF \cdot EF$	$CF = FF \cdot EF$

• Litorânea do Ceará

Litorânea do Ceará is also located at the northeast of Brazil and is not connected with any subwatersheds. It is divided in five regions: Acaraú, Coreaú, Curú, Litoral and Metropolitana.



• FF calculation

Applying the Subwatershed model FF takes 5.00 days. The process calculations are detailed below.

- Calculation of $k_{ret,j}$

Litorânea do Ceará (LC) $k_{ret,j}$ is $3,28 \cdot 10^{-3}$. Its water volume is calculated adding the volume average of each region, which is estimated multiplying the average percentage storage capacity by the maximum volume. Consequently, the water volume of LC subwatershed is $6,30 \cdot 10^2 km^3$.

LC water flow rate is the sum of the average values of the five main stem flow rates ($96,68 m^3/s$). Therefore, the phosphorus removal rate is $0.012 day^{-1}$ (ALEXANDER et al., 2004). More details can be found at the table 4.

The main stem volume is estimated using the shapefile of water availability.

The lake and reservoir surface areas are calculated using GIS, as described before at Alto Iguaçu's topic.

Variables	$k_{ret,j}$	$V_{tot,j}$	$k_{ret,riv,j}$	$V_{riv,j}$
Meaning	Outcome rates by retention of LC subwatershed	Total water volume of LC subwatershed	phosphorus removal rate LC subwatershed	Volume LC do Sul River
Units	day ⁻¹	km ³	day ⁻¹	km ³
Value	3.28 10 ⁻³	6,30 10 ²	0.012	1.69 10 ²
Source	Calculated by the equation 3 $k_{ret,j} = \frac{1}{V_{tot,j}} (V_{riv,j} \cdot k_{ret,riv,j} + v_f \cdot (A_{lak,j} + A_{res,j}))$	(HIDRO, 2016)	(ALEXANDER et al, 2004)	Estimated by the water flow rate. (DISPONIBILIDADE HIDRICA, 2016)
Qualitative analysis				
Year/Period		2015 to 2016	2004	2009/2015
Especial differentiation	-	River, lakes and reservoir	River	River
Representativeness	-	Medium (Mean water bodies are considered)	Low (The same rate for all regions)	High (Estimated by GIS)
Method	-	Sum	Average	Sum
Available region	-	LC subwatershed	Global	LC subwatershed

Variables	v_f	$A_{lak,j}$	$A_{res,j}$
Meaning	Phosphorus uptake velocity at LC subwatershed	Lake surface area of LC subwatershed	Reservoir surface area of LC subwatershed
Units	km·day ⁻¹	km ²	km ²
Value	3.80 10 ⁻⁵	1.42 10 ²	6.84 10 ²
Source	(ALEXANDER et al., 2004)	(DISPONIBILIDADE HIDRICA, 2016)	(DISPONIBILIDADE HIDRICA, 2016)
Year/Period	2004	2016	2016
Especial differentiation	River	Lake	Reservoir
Representativeness	Low (The same rate for all regions)	High (Estimated by GIS)	High (Estimated by GIS)
Method	Average	Sum	Sum
Available region	Global	Brazil	Brazil

○ Calculation of $k_{use,j}$
 $k_{use,j} = 5.71 \cdot 10^{-5} \text{ day}^{-1}$. The same consideration for Alto Iguaçu is used for Litorânea do Ceará subwatershed

Variables	$k_{use\ dom,j}$	$f_{WTA,j}$	$f_{DITW\ dom,j}$	$k_{adv,j}$	f_{TS}
Meaning	Removal rate by water use of LC subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for domestic purposes at LC subwatershed	Removal rate by advection at LC subwatershed	Fraction of P removed by sewage treatment.
Units	day ⁻¹	Dimensionless	Dimensionless	day ⁻¹	Dimensionless
Value	$-2.22 \cdot 10^{-5}$	0.8	0.41	$4.92 \cdot 10^{-5}$	0.25
Source	Calculated by the equation 9 $k_{use\ dom,j} = f_{WTA,j} \cdot f_{DITW\ dom,j} - (1 - f_{NTS})$	(SPERLING M., VON, 1996)	(ABASTECIMEN TO URBANO, 2016)	Calculated by the equation 5 $k_{adv,j} = \frac{Q_j}{V_{tot,j}}$	It is calculated by the equation 10 $f_{TS} = t \cdot r$
Qualitative analysis					
Year/Period	-	1996	2016	-	-
Especial differentiation	-	River	subwatershed	-	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	-
Method	-	Average	Sum	-	-
Available region	-	Global	Alto Iguaçu subwatershed	-	-

Variables	t	r	f_{NTS}	d	$C_{P\ river}$	$C_{P\ TS}$
Meaning	Treated sewage percentage at LC subwatershed	Removed phosphorus percentage at effluent treatment	Fraction of P transferred to the water body by dumping non-treated sewage	Fraction of P non-treated sewage	P concentration at Acaraú river	P concentration at non-treated sewage
Units	Dimensionless	Dimensionless	Dimensionless	Dimensionless	mg/L	mg/L
Value	0.36	0.71	-0.61	-0.96	0.17	14
Source	(TRATA BRASIL, 2016)	(CONAMA, 2011)	It is calculated by the equation 11 $f_{NTS} = (1 - t) \cdot d$	Calculated by the equation below. $d = \frac{(C_{P\ river} - C_P)}{C_{P\ TS}}$	(OLIVEIRA U. C., 2014)	(CONAMA, 2011)
Qualitative analysis						
Year/Period	2016	2011	-	-	2014	2011
Especial differentiation	LC subwatershed	Brazil	-	-	Acaraú river	Brazil
Representativeness	Medium (percentage estimate of treated sewage)	Low (The same rate for all regions)	-	-	Low (Average of 3 samples)	Low (The same rate for all regions)
Method	Average	Average	-	-	Average	Average
Available region	LC subwatershed	Brazil	-	-	Paraíba river	Brazil

Variables	$k_{use\ irrig,j}$	$f_{WTA,J}$	$f_{DITW\ irrig,J}$	$f_{soil,J}$	R	$k_{TOT,j}$
Meaning	Income rate of P by water used for domestic purpose at LC subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for irrigation at LC subwatershed	Fraction of total phosphorus emissions transferred at LC subwatershed	Runoff rate at LC subwatershed	Income rate of P by water used at LC subwatershed
Units	day ⁻¹	Dimensionless	Dimensionless	Dimensionless	mm.year ⁻¹	day ⁻¹
Value	-3.49 10 ⁻⁵	0.8	0.39	3.28	403.69	-5.71 10 ⁻⁵
Source	$k_{use\ irrig,j} = f_{WTA,J} \cdot f_{DITW} - f_{soil,J}$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $f_{DIP} = \frac{0.29}{\left(1 + \left(\frac{R}{0.85}\right)^{-2}\right)}$ $f_{DOP} = 0.01 \cdot R^{0.95}$	(ATALAS,2016)	Calculated by the equation below. $k_{TOT,j} = k_{use\ dom,j} - k_{use\ irrig,j} $
Qualitative analysis						
Year/Period	-	1996	2016	-	1950-2000	-
Especial differentiation	-	River	subwatershed	-	0.5°x0.5°	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	High (Estimated by GIS)	-
Method	-	Average	Sum	-	Average	-
Available region	-	Global	Parnaíba subwatershed	-	Global	-

• EF calculation

TP concentration is the average value measured at five locations of Caruarú River in 2014.

Variables	$PNOF_j$	C_j	α	β
Meaning	Potentially non-occurring fraction	TP concentration LC subwatershed	Coefficient α of streams	Coefficient β of streams
Units	Dimensionless	kg .m ³	Dimensionless	Dimensionless
Value	1.49 10 ⁻⁵	1.72 10 ⁻⁴	-3.13	0.426
Source	Calculated by the equation $PNOF_{AI} = \frac{1}{1 + \exp\left(\frac{-(\log C_{AI} + 0.54)}{0.63}\right)}$	(OLIVEIRA U.C., 2014)	(AZEVEDO et al 2013b)	(AZEVEDO et al 2013b)
Qualitative analysis				
Year/Period	-	2014	2013	2013
Especial differentiation	-	River	0.5°x0,5°	0.5°x0,5°
Representativeness	-	Low (Average of few samples)	Low (European context)	Low (European context)
Method	-	Average	Average	Average
Available region	-	Acaraú river	Europe	Europe

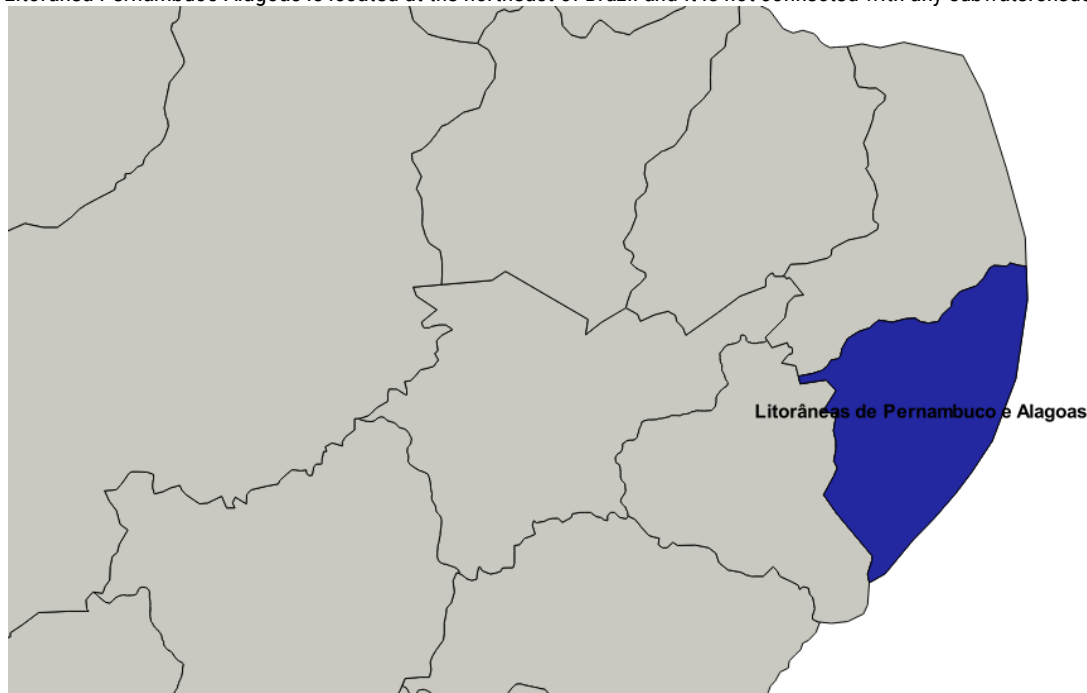
- CF calculation

CF is calculated by three different EF models.

Variables	AEF_j	MEF_j	LEF_j
Meaning	Average effect factor	Marginal effect factor	Linear effect factor
Units	$m^3 \cdot kg P^{1-}$	$m^3 \cdot kg P^{1-}$	$m^3 \cdot kg P^{1-}$
Value	$4.06 \cdot 10^{-2}$	$4.14 \cdot 10^{-2}$	$6,74 \cdot 10^2$
Source	Calculated by the equation $AEF_{AI} = \frac{PNOF_{AI}}{C_{AI}}$	Calculated by the equation $MEF_{AI} = PNOF_{AI} \cdot (1 - PNOF_{AI}) \cdot \frac{1}{C_{AI} \cdot \beta \cdot \ln(10)}$	Calculated by the equation $LEF_{AI} = \frac{0.5}{10^\alpha}$
Variables	ACF_j	MCF_j	LCF_j
Meaning	CF calculated by the AEF model	CF calculated by the MEF model	CF calculated by the LEF model
Units	-day	day	day
Value	$8.30 \cdot 10^{-2}$	$8.46 \cdot 10^{-2}$	$1.58 \cdot 10^3$
Source	$CF = FF \cdot EF$	$CF = FF \cdot EF$	$CF = FF \cdot EF$

- Litorânea Pernambuco Alagoas

Litorânea Pernambuco Alagoas is located at the northeast of Brazil and it is not connected with any subwatersheds.



- FF calculation

- Calculation of $k_{ret,j}$

Litorânea Pernambuco Alagoas (LPA) $k_{ret,j}$ is $1.44 \cdot 10^{-2} \text{ day}^{-1}$. Its water volume is estimated multiplying the average percentage storage capacity by the maximum volume. LC water flow rate is the sum of the average values of the five main stem flow rates ($110.4 \text{ m}^3/\text{s}$). Therefore, the removal rate of phosphorus is 0.012 day^{-1} (ALEXANDER et al., 2004). More details can be found at the table 4.

The main stem volume is estimated using the shapefile of water availability. The lake and reservoir surface areas are calculated by GIS, as described before at Alto Iguaçu's topic.

Variables	$k_{ret,j}$	$V_{tot,j}$	$k_{ret,riv,j}$	$V_{riv,j}$
Meaning	Outcome rates by retention of LPA subwatershed	Total water volume of LPA subwatershed	Removal rate of phosphorus LPA subwatershed	Volume LPA do Sul River
Units	day ⁻¹	km ³	day ⁻¹	km ³
Value	1.44 10 ⁻²	3,48	0.012	3,48
Source	Calculated by the equation 3 $k_{ret,j} = \frac{1}{V_{tot,j}} (V_{riv,j} \cdot k_{ret,riv,j} + v_f \cdot (A_{lak,j} + A_{res,j}))$		(ALEXANDER et al., 2004)	Estimated by the water flow rate. (DISPONIBILIDADE HIDRICA, 2016)
Qualitative analysis				
Year/Period		F ro2015 to 2016	2004	2009/2015
Especial differentiation	-	River, lakes and reservoir	River	River
Representativeness	-	Medium (Mean water bodies considered)	Low (The same rate for all regions)	High (Estimated by GIS)
Method	-	Sum	Average	Sum
Available region	-	LC subwatershed	Global	LC subwatershed

Variables	v_f	$A_{lak,j}$	$A_{res,j}$
Meaning	Phosphorus uptake velocity at LPA subwatershed	Lake surface area of LPA subwatershed	Reservoir surface area of LPA subwatershed
Units	km·day ⁻¹	km ²	km ²
Value	3.80 10 ⁻⁵	107.86	114.57
Source	ALEXANDER et al., 2004	(DISPONIBILIDADE HIDRICA, 2016)	(DISPONIBILIDADE HIDRICA, 2016)
Qualitative analysis			
Year/Period	2004	2016	2016
Especial differentiation	River	Lake	Reservoir
Representativeness	Low (The same rate for all regions)	High (Estimated by GIS)	High (Estimated by GIS)
Method	Average	Sum	Sum
Available region	Global	Brazil	Brazil

o Calculation of $k_{use,j}$

Variables	$k_{use\ dom,j}$	$f_{WTA,j}$	$f_{DITW\ dom,j}$	$k_{adv,j}$	f_{TS}
Meaning	Removal rate by water use of LPA subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for domestic purposes at LPA subwatershed	Removal rate by advection at LPA subwatershed	Fraction of P removed by sewage treatment.
Units	day ⁻¹	Dimensionless	Dimensionless	day ⁻¹	Dimensionless
Value	$8.64 \cdot 10^{-4}$	0.8	0.26	$2.74 \cdot 10^{-3}$	0.16
Source	Calculated by the equation 9 $k_{use\ dom,j} = f_{WTA,j} \cdot f_{DITW\ dom,j} - (1 - f_{NTS})$	(SPERLING M., VON, 1996)	(ABASTECIMEN TO URBANO, 2016)	Calculated by the equation 5 $k_{adv,j} = \frac{Q_j}{V_{tot,j}}$	Calculated by the equation 10 $f_{TS} = t \cdot r$
Qualitative analysis					
Year/Period	-	1996	2016	-	-
Especial differentiation	-	River	subwatershed	-	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	-
Method	-	Average	Sum	-	-
Available region	-	Global	Alto Iguaçu subwatershed	-	-

Variables	t	r	f_{NTS}	d	$C_{P\ river}$	$C_{P\ TS}$
Meaning	Percentage of treated sewage at LPA subwatershed	Percentage of phosphorus removed at effluent treatment	Fraction of P transferred to the waterbody by dumping non-treated sewage	Fraction of P non-treated sewage	P concentration at Acaraú river	P concentration at non-treated sewage
Units	Dimensionless	Dimensionless	Dimensionless	Dimensionless	mg/L	mg/L
Value	0.23	0.71	-0.75	-0.90	0.387	14
Source	(NETO G. S. A., 2011)	(CONAMA, 2011)	Calculated by the equation 11 $f_{NTS} = (1 - t) \cdot d$	Calculated by the equation below. $d = \frac{(C_{P\ river} - C_{P\ TS})}{C_{P\ TS}}$	(NETO A. G.S., 2012)	(CONAMA, 2011)
Qualitative analysis						
Year/Period	2011	2011	-	-	2012	2011
Especial differentiation	LPA subwatershed	Brazil	-	-	Paraíba do Norte river	Brazil
Representativeness	Medium (percentage estimate of treated sewage)	Low (The same rate for all regions)	-	-	Low (Average of 3 samples)	Low (The same rate for all regions)
Method	Average	Average	-	-	Average	Average
Available region	LPA subwatershed	Brazil	-	-	Paraíba do Norte river	Brazil

Variables	$k_{use\ irrig,j}$	$f_{WTA,j}$	$f_{DITW\ irri,j}$	$f_{soil,j}$	R	$k_{TOT,j}$
Meaning	Income rate of P by water used for domestic purpose at LPA subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for irrigation at LPA subwatershed	Fraction of total phosphorus emissions transferred at LPA subwatershed	Runoff rate at LPA subwatershed	Income rate of P by water used at LPA subwatershed
Units	day ⁻¹	Dimensionless	Dimensionless	Dimensionless	mm.year ⁻¹	day ⁻¹
Value	3.08 10 ⁻³	0.8	0.64	3.20	392.94	3.94 10 ⁻³
Source	$k_{use\ irrig,j} = f_{WTA,j} \cdot f_{DITW} - f_{soil,j}$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $f_{DIP} = \frac{0.29}{\left(1 + \left(\frac{R}{0.85}\right)^{-2}\right)}$ $f_{DOP} = 0.01 \cdot R^{0.95}$	(ATALAS, 2016)	Calculated by the equation below. $k_{TOT,j} = k_{use\ dom,j} - k_{use\ irrig,j}$
Qualitative analysis						
Year/Period	-	1996	2016	-	1950-2000	-
Especial differentiation	-	River	subwatershed	-	0.5°x0.5°	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	High (Estimated by GIS)	-
Method	-	Average	Sum	-	Average	-
Available region	-	Global	LPA subwatershed	-	Global	-

• EF calculation

Variables	$PNOF_j$	C_j	α	β
Meaning	Potentially non-occurring fraction	TP concentration LPA subwatershed	Coefficient α of streams	Coefficient β of streams
Units	Dimensionless	kg .m ³	Dimensionless	Dimensionless
Value	1	3,87 10 ⁻⁴	-3.13	0.426
Source	Calculated by the equation $PNOF_{AI} = \frac{1}{1 + \exp\left(\frac{-(\log C_{AI} + 0.54)}{0.63}\right)}$	(NETO A. G.S., 2012)	(AZEVEDO et al, 2013b)	(AZEVEDO et al, 2013b)
Qualitative analysis				
Year/Period	-	2012	2013	2013
Especial differentiation	-	River	0.5°x0,5°	0.5°x0,5°
Representativeness	-	Low (Average of few samples)	Low (European context)	Low (European context)
Method	-	Average	Average	Average
Available region	-	Paraíba do Norte river	Europe	Europe

- CF calculation

CF is calculated by three different EF models.

Variables	AEF_j	MEF_j	LEF_j
Meaning	Average effect factor	Marginal effect factor	Linear effect factor
Units	$m^3 \cdot kg P^{1-}$	$m^3 \cdot kg P^{1-}$	$m^3 \cdot kg P^{1-}$
Value	$2.63 \cdot 10^{-3}$	$-5.25 \cdot 10^{-1}$	$6,74 \cdot 10^2$
Source	Calculated by the equation $AEF_{AI} = \frac{PNOF_{AI}}{C_{AI}}$	Calculated by the equation $MEF_{AI} = PNOF_{AI} \cdot (1 - PNOF_{AI}) \cdot \frac{1}{C_{AI} \cdot \beta \cdot \ln(10)}$	Calculated by the equation $LEF_{AI} = \frac{0.5}{10^\alpha}$
Variables	ACF_j	MCF_j	LCF_j
Meaning	CF calculated by the AEF model	CF calculated by the MEF model	CF calculated by the LEF model
Units	-day	day	day
Value	$1.19 \cdot 10^{-4}$	$-2.36 \cdot 10^2$	$3.04 \cdot 10^3$
Source	$CF = FF \cdot EF$	$CF = FF \cdot EF$	$CF = FF \cdot EF$