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REGIONALIZATION OF CHARACTERIZATION FACTOR IN BRAZIL: FRESH WATER EUTROPHICATION CATEGORY

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ABSTRACT

OLIVEIRA, Jéssyca M. Regionalization of characterization factor in Brazil: fresh water eutrophication category, 2017. Monograph (master's degree in mechanical engineering) – Programa de Pós-Graduação em Engenharia Mecânica, Universidade Tecnológica Federal do Paraná. Curitiba, 2017

Brazil is privileged to have the most important natural resource in its territory, but currently, the increased concentration of phosphorus (P) affects the water quality. The phosphorus has two main routes to get into aquatic environmental: 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 (LCIA) 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, the goal of this study is to calculate a more coherent freshwater CF to Brazilian subwatersheds.

Moreover, the model proposed by Azevedo (2013) regionalized and used to calculate the CF for Alto Iguaçu, Paraíba do Sul, Parnaíba, Litorânea do Ceará and Litorânea Alagoas Pernambuco subwatersheds. Paraíba do Sul and Parnaíba's CF are the highest, 8.83 10^5.and 4.04 10^5. $m^3.KgP^{-1}$ day respectively. The CF of Litorânea Pernambuco Alagoas is 1.19 10^4. $m^3.KgP^{-1}$ day and Litorânea do Ceará is 8.30 10^{-2}. $m^3.KgP^{-1}$ day. The P present in the water used to supply the domestic and agricultural sector is the most relevant rate. At Alto Iguaçu is the advection rate and its CF is 7.43 10^3. $m^3.KgP^{-1}$ 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. An important part of the study was to find the necessary data, due to data unavailability in underdeveloped countries.

Key words: Eutrophication, regionalization, LCIA

RESUMO

OLIVEIRA, Jéssyca M. Regionalização do fator de caracterização no Brasil: categoria de eutrofização de água doce, 2017. Monografia (mestrado em engenharia mecânica) - Programa de Pós-Graduação em Engenharia Mecânica, Universidade Tecnológica Federal do Paraná. Curitiba, 2017

O Brasil tem o privilégio de ter o recurso natural mais importante em seu território, mas atualmente, o aumento da concentração de fósforo (P) esta afetando a qualidade da água. O fósforo tem duas rotas principais de entrada no meio aquático: através do despejo de esgotos não tratados e escoamento de fertilizantes. O excesso de P pode promover a eutrofização, um processo caracterizado por crescimento descontrolado de microalgas, afetando vários parâmetros de água doce. Devido às grandes diferenças nas regiões brasileiras, as metodologias atuais de avaliação do impacto do ciclo de vida (AICV) não são capazes de avaliar adequadamente o impacto da eutrofização no Brasil. O maneira mais viável para obter um modelo mais adequado é regionalizá-lo estimando o fator de caracterização (FC). Portanto, o objetivo deste estudo é calcular uma FC de água doce mais coerente para as sub-bacias brasileiras.

Portanto, o modelo proposto por Azevedo (2013) foi regionalizado e utilizado para calcular o FC para as sub-bacias do Alto Iguaçu, Paraíba do Sul, Parnaíba, Litorânea do Ceará e Litorânea Alagoas Pernambuco. O FC da Paraíba do Sul e Parnaíba são os mais altos, 8,83 10^5. e 4,04 10^5. m^3.KgP^{-1} dia, respectivamente. O FC da Litorânea Pernambuco Alagoas é 1,19 10^4. m^3.KgP^{-1} dia e Litorânea do Ceará é 8,30 10^{-2}. m^3.KgP^{-1} dia. O P presente na água utilizada para abastecer o setor doméstico e agrícola é a taxa mais relevante. No Alto Iguaçu é a taxa de advecção e sua FC é 7.43 10^3. m^3.KgP^{-1} dia. Por essa razão, a mesma quantidade de fósforo emitido promove um maior potencial de eutrofização na Paraíba do Sul e Parnaíba do que outras bacias. Estimando a taxas de entrada de fósforo é possível conhecer a origem de sua contribuição mais significativa. Com base nessa informação, os recursos financeiros podem ser melhor utilizados. A dificuldade do estudo foi encontrar os dados necessários, devido à indisponibilidade de dados em países subdesenvolvidos.

Palavras-chave: Eutrofização, regionalização, AICV

ACRONYMS

AI: Alto Iguaçu
ACF: Average Characterization Factor model
AEF: Average Effect Factor model
CF: Characterization factor
DP: Dissolved Phosphorus
DIP: Dissolved Inorganic Phosphorus
DOP: Dissolved Organic Phosphorus
EF: Effect Factor
FF: Fate Factor
LC: Litorânea do Ceará
LCA: Life Cycle Assessment
LCIA: Life Cycle Impact Assessment
LCF: Linear Characterization Factor model
LEF: Linear Effect Factor model
LPA: Litorênea Pernambuco e Alagoas
MCF: Marginal Characterization Factor model
MEF: Marginal Effect Factor model
N: Nitrogen
P: Phosphorus
PIP: Particulate Inorganic Phosphorus
PNOF: Potential not occurring fraction
PP: Particulate Phosphorus
POP: Particulate Organic Phosphorus
PR: Paraíba do Sul
PN: Parnaíba
TSI: Trophic State Index

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Summary

1 INTRODUCTION

Water is one of the natural resources responsible to maintain life; around 13.7% of the world's freshwater availability is in Brazil's territory. However, just quantity is not enough to promote life quality and economic development; it is also required good water quality (TUNDISI; TUNDISI, 2006). Nowadays, the increase in the phosphorus compounds (P) emission in water bodies is responsible for poor quality water. P is a nutrient, but in excess it becomes a contaminant.

The excess of P accelerates the cyanobacteria and aquatic plants growth. This phenomenon is called eutrophication (ESTEVES, 1998).The microalgae uncontrolled growth causes extensive damage to the waterbody, because the light passage is restricted causing organisms death. A part of cyanobacteria produces toxins, which are potentially toxic and have killed many people around the world (ANDREOLI, 2005; GALLI; ABE, 2006; CARMICHAEL; LI, 2006).

There are two different types of measures to control the eutrophication: preventive and corrective. Preventive measures are based on avoiding eutrophication. Therefore, they are more effective and cheaper than corrective measures (ANDREOLI, 2005). If the potential impact at hydrographic regions is known, it is possible to direct financial resources to prioritize preventive actions, such as sanitation and environmental education programmes at regions with a high eutrophication potential.

Eutrophication potential can be estimated by the Life Cycle Assessment (LCA) methodology. However, in order to obtain a realistic impact caused by phosphorus compounds emission it is necessary to regionalize the impact. The eutrophication effects are restricted to an emission region and these regions are not affected equally; it depends on the phosphorus transportation and some waterbody characteristics (TUNDISI; TUNDISI, 2006).

The most viable method to regionalize the impact is with the Characterization Factor (CF). Although this regionalization should consider the particularities of Brazilian watershed, it is common a watershed is divided in subwatersheds fatherly (WULCA, 2015).

This study aims to regionalize a Life Cycle Impact Assessment (LCIA) method and calculate characterization factors category for Brazilian subwatersheds.

It is divided into five chapters. The first chapter contextualizes the eutrophication problem. The second chapter presents the bibliographic review, explains the phosphorus cause-effect chain and the described objectives.The third chapter relates to the work methodology and details the LCIA method classification. This chapter also explains the fate factor regionalization and the effect factor model. The fourth and last chapters present the results, conclusion and learning process, respectively.

2 LITERATURE REVIEW

In this section, eutrophication process and LCIA methods for this category are discussed. Additionally, the eutrophication in Brazil is addressed.

2.1 EUTROPHICATION

For many centuries the water was synonymous for life, purity, and renewal. Although as water was perceived, mistakenly, as an infinite resource, it did not receive proper attention. Due to fast industrialization and unbridled population growth the environmental landscape is changing; water consumption is increasing and the water quality is getting worse (MINISTÉRIO DA SAÚDE, 2006).

One of the reasons for poor quality water is the discharge of phosphorus compounds into the waterbodies (MENDONÇA, 2004).

Phosphorus is the tenth most abundant element on Earth. It can be obtained in phosphate rocks (SHRIVER, D. F.; ATKINS, 2008) and it is a constituent of bones and teeth, cell membranes, nucleotides, and nucleic acids. This element is normally found in nature as a phosphate ion, but many of these ions have the tendency to form poor soluble compounds, associated with metal cation clays, decreasing its availability and becoming a limiting nutrient (ROLAND, F.; CESAR, D.; MARINHO, 2005).

In aquatic environments P the fundamental fractions are:

- Particulate Phosphorus (PP): involves particles larger than 1.6 micrometers. The Particulate Organic Phosphorus (POP) fraction is usually an aggregate, which is absorbed into mineral particles, living organism cells and debris (biomass). The Particulate Inorganic Phosphorus (PIP) consists on minerals phosphates, and it is absorbed on metal complexes or clays.
- Dissolved Phosphorus (DP): particles between 1.0 to 1.6 micrometers. The Dissolved Organic Phosphorus (DOP) is a result of planktonic excretion, decomposition and photoxidation of particulate organic matter. The Dissolved Inorganic Phosphorus (DIP) consists mainly of orthophosphates , essential for the phytoplankton's organism metabolism and other primary producers (ROLAND, F. et al, 2005).

Orthophosphate concentration, solubility, and availability in the aquatic compartment depend on several parameters, such as pH, oxygen concentration and thermal stratification. However, factors like redox potential, metal cation concentrations, organic matter content, rainfall, light and wind also affect indirectly the nutrient availability (ANDREOLI, 2005).

The P excess promotes accelerated growth of cyanobacteria and aquatic plants. This phenomenon is called eutrophication (ESTEVES, 1998).

Natural eutrophication or “waterbodies aging” is a slow and continuous process, the result of nutrients intake by rain and soil erosion. This process can take around 100 years. However, the dump of P compounds ends this natural process, causing a higher impact. The domestic and industrial effluents and agricultural activities are the main sources of anthropogenic phosphorus. A great amount of sewage is released to waterbodies without any treatment and part of fertilizers percolate into the ground achieving aquifers; another portion is carried by irrigation and rain water to rivers and lakes (ESTEVES, 1998).

Several factors influence eutrophication: waterbody initial trophic state, depth average, residence time, climatic factors and luminosity. Hypertrophic waterbodies are more capable to support nutrients increase than oligotrophic. Moreover, this condition slows the process. The waterbody depth interferes at nutrients dilution; in shallow waterbodies the nutrient is more concentrate and they are more susceptible to the eutrophication. If the nutrient has long residence time, it will be available for a long time, promoting phytoplankton proliferation. The light and temperature are fundamental to achieve optimal conditions for primary production, thus these factors increase contribute to accelerate the eutrophication (TUNDISI; TUNDISI, 2006).

Extensive damage may occur to the environment due to phytoplankton uncontrolled growth and cyanobacteria proliferation: water color and odor change, pH increase, and cyanotoxins production (ANDREOLI, 2005). These toxins are potentially toxic and they are responsible for several people’s death around the world (GALLI ABE, 2006; CARMICHAEL; LI, 2006). Light passage is also restricted, hindering photosynthesis at the waterbody bottom, causing the death of autotrophic organisms and then heterotrophy, impairing the biodiversity. The oxygen pattern also changes: the concentration on the surface is very high due to elevate respiration rates, and very low at the bottom, because of decomposition rates (ANDREOLI, 2005).

Furthermore, the use of eutrophicated water is restricted. In some cases, it is not used for supply, recreation, irrigation and energy production due to its high treating cost. The coagulation and flotation processes become very difficult, filters clog easily and more chlorine for disinfection is required (ANDREOLI, 2005).

There are two different measures to control the eutrophication: preventive and corrective. Corrective measures require time and money to treat the water. Some of the solutions are (ANDREOLI, 2005):

1) Artificial circulation of water column, making phosphorus assimilation difficult;

2) Dredging and blocking the sediment, removing accumulated nutrients;

3) Phosphorous precipitation and inactivation by coagulation and flocculation;

4) Algal bloom control, using chemical (herbicides and algaecides), biological (other species inclusion to compete for resources) or mechanical (material removal) solutions.

Preventive measures are more effective and cheaper than the corrective measures (ANDREOLI, 2005):

1) Effluent treatment;
2) Restriction on the fertilizers use;
3) Phosphorus control in the animal's diet;
4) Land use control;
5) Environmental education.

Working with preventive measures to evaluate freshwater eutrophication potential impact is a very efficient measure. If the potential impact of hydrographic regions is known, it is possible to direct financial resources (private or public) to prioritize preventive actions, such as sanitation and environmental education programmes in regions with a high eutrophication potential.

Eutrophication potential can be estimated by the Life Cycle Assessment (LCA) methodology. According to ISO 14040 (2006), LCA compiles input and output data to evaluate potential environmental impacts of a process or activity throughout all its life cycle. This methodology is divided into four phases: scope definition, inventory analysis, impact assessment and interpretation.

The LCIA phase analyses the potential environmental impact. The impact is divided in categories and the eutrophication takes part in these midpoint categories (ISO14040, 2006).

Several LCIA methods have been proposed to assess the eutrophication impact category.

2.2 LCIA METHODS

LCIA is a technical process, quantitative and/or qualitative, to identify, characterize and evaluate the potential environmental impacts of human activity at the product, process or activity life cycle (ISO14040, 2006).

LCIA methods of freshwater eutrophication evaluate the potential impact of P compounds emission in a determined region. In order to do this, the cause-effect chain should be known. The cause-effect chain is a description of environmental mechanisms (physical, chemical and biological system processes) regarding the impacts category (ISO14040, 2006). The objective to describe the nutrients path is to understand which nutrient path step needs to be modeled (ILCD HANDBOOK, 2010).

Phosphorus enters into the aquatic ecosystem mainly by fertilizers runoff and dumping of untreated sewage. Inside the water, the P content can be transported and/or removed. Only a fraction of the P issued to the waterbody will promote eutrophication effect, because part of it is unavailable due to transport or removal.

The P share that remains in the aquatic compartment increases its exposure limit and promotes algae growth. The algae excess reduces the oxygen concentration at deep layers, causing change in the biodiversity. Consequently, the freshwater system is impaired. Figure 1 summarizes the aquatic eutrophication cause-effect chain (ILCD HANDBOOK, 2010).

LCIA methods are reported according to their position in the cause-effect chain. Methods that provide intermediate results are called midpoints and restrict quantitative modeling at relatively early stages in a cause-effect chain, in order to minimize uncertainties. Endpoint methods try to model the cause-effect chain using the damage on the watersheds, but high uncertainty values are added (ISO14040, 2006).

The damage to the ecosystem due to chemicals or physical interventions is expressed by the species Potentially Disappeared Fraction (PDF). It can be interpreted as the species fraction that has a higher probability of non-occurrence in a region due to unfavorable conditions (ILCD HANDBOOK, 2010).

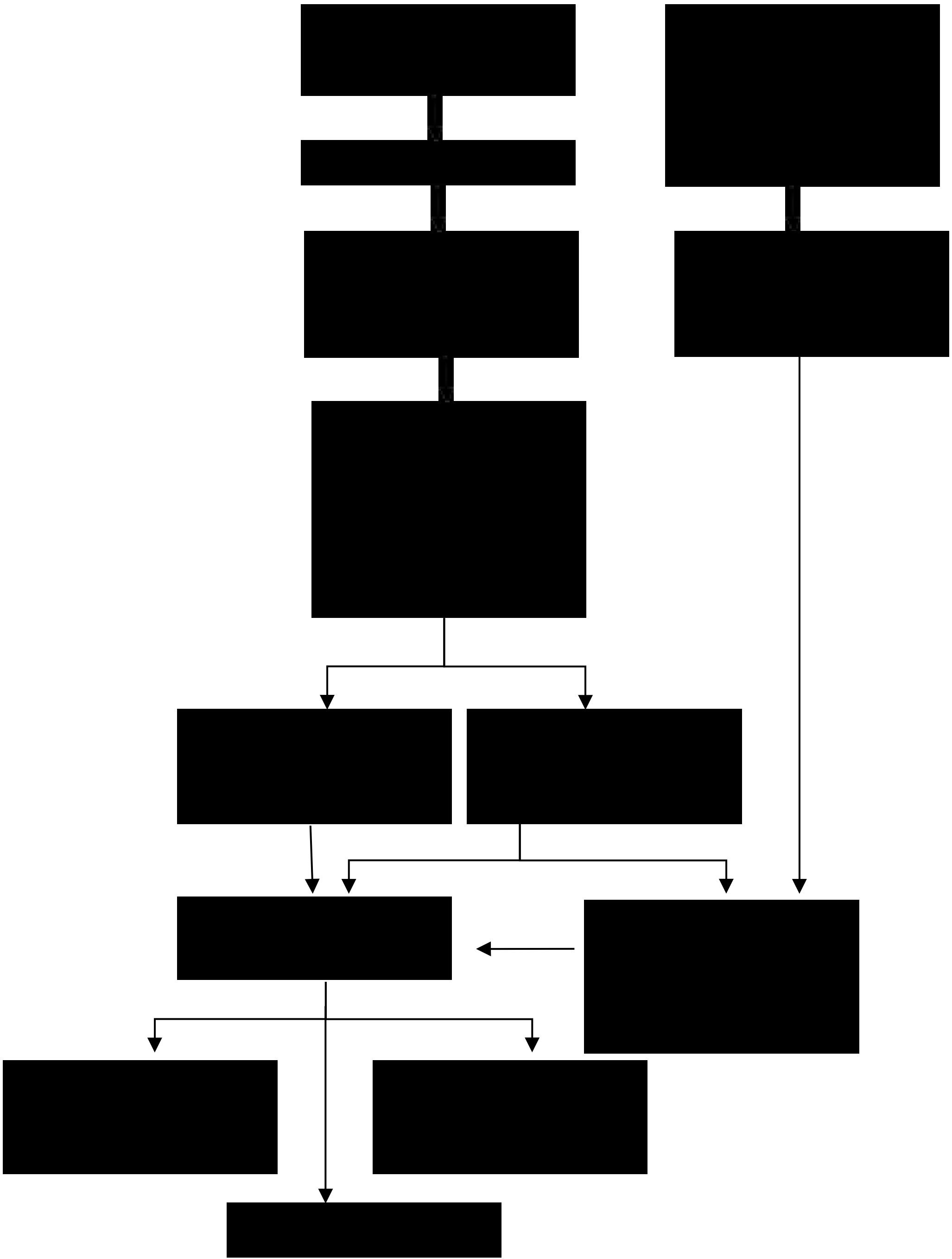

Figure 1. Aquatic eutrophication cause-effect chain
Source: ILCD HANDBOOK, 2010.

For the impact assessment methodology reflect regarding the region reality, the cause-effect chain must address the main connection on the phosphorus cycle and should allow the regionalization, in other words, it should allow regional data input. To achieve this, CF calculation is an efficient method to promote the spatial differentiation (GALLEGO et al., 2010; CIVIT et al., 2012; SEPPÄLÄ et al., 2006; AZEVEDO, 2013; HELMES et al., 2012).

The characterization factor converts a result from the Life Cycle Inventory analysis to the common unit of the category indicator (ISO14040, 2006). For freshwater eutrophication category, CF is expressed in PO_4^{3-} equivalents (ILCD HANDBOOK, 2010), because any form of phosphorus present in natural waters, either in ionic or in complex form, is in a phosphate form. Thus, the term phosphate should be used to refer to different forms of phosphorus in the aquatic environment (ESTEVES, 1998).

The following equation shows CF calculation (JRC, 2010).

$$\square_{\square,\square,\square} = \square\square\ .\ \square\square \qquad (1)$$

Where: $\square\square_{\square,\square,\square}$: substance characterization factor, at the compartment m, that is transferred to the receiving environment; $\square\square$: Fate factor; and $\square\square$: 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 et al., 2007).

CF depends on FF and EF; therefore, the CF is influenced by the nutrients mass change in the waterbody. It other words, nutrients increment, transport and removal are a significant factor to obtain a representative CF (GALLEGO et al., 2010; CIVIT et al., 2012; SEPPÄLÄ et al., 2006;HELMES et al., 2012).

In the past, impact assessment methods were proposed with the goal to evaluate freshwater eutrophication at endpoint and midpoint environmental level. The JRC European commission (2011) held a compilation of the life cycle impact assessment method published until 2007. The methods CML 2002; EDIP 2003; ReCiPe; EPS 2000 and IMPACT 2002+ were developed based on European reality, TRACI for United States and LIME for Japan (JRC EUROPEAN COMMISSION, 2011). A part of the LUCAS method was proposed for Canada current proposals (TOFFOTETTO et al., 2006).

EPS (Environmental Priority Strategy) 2000 is an endpoint method, which assesses the damage to freshwater. The CF is estimated using an empirical method. The phosphorus fate for aquatic emissions is considered, but it is not modeled, because a fixed global value is assumed for P distribution. The nutrients removal rates are not modeled, hence, this method does not permit any regionalization (STEEN, 1999).

The CML (Centre of Environmental Science) 2002 is a midpoint method and also provides CF for organic material. Phosphorus content dumped into the waterbody is analyzed, but it does not allow regionalization and the phosphorus fate is not considered (GUINÉE et al., 2001).

The IMPACT 2002+ proposes CF calculation for midpoint and endpoint, but at that time there wasn't enough information to evaluate the EF in terms of Potentially Disappeared Fraction. Therefore, it is not possible to calculate CF for ecosystem quality and for aquatic eutrophication the CF is estimated exactly like CML 2002 (JOLLIET et al., 2003).

The midpoint TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) evaluates increased exposure of aquatic ecosystem. It is based on CML 2002, but some improvement was made in this method. Phosphorus transport is assessed and modeled using hydrological transport. Initially, nutrients release and its removal rate in aquatic compartment were not studied. Therefore TRACI allows regionalization at phosphorus transport in aquatic compartment (NORRIS, 2003).

The midpoint LUCAS (LCIA method used for a Canadian-specific context) developed the aquatic eutrophication based on IMPACT 2002+, but allowed regionalization estimating a vulnerability factor, in other words, the region degree of sensitivity. The considered regional characteristics are topsoil vulnerability, aquifer type, unsaturated zone thickness and groundwater age (TOFFOTETTO et al., 2006).

The EDIP 2003 is also a midpoint method, which expresses maximum exposure of aquatic systems that phosphorus can cause. Phosphorus inputs (from fertilize and municipal wastewater discharge) are modeled by CARMEN model (Cause Effect Relation Model to Support Environmental Negotiation). This model presents a fixed phosphorus removal rate, which makes it impossible to model this type of nutrient transport. Nevertheless, it is possible to insert local data of phosphorus inputs (POTTING; HAUSCHILD, 2006).

ReCiPe 2008 also uses CARMEN model, but with some adaptation. Nutrients transport from agricultural manure, fertilizers and surface runoff are modeled allowing regionalization of phosphorus inputs and transport data. This method analyzes the phosphorus content increase in aquatic compartment (midpoint) and also can express the result in terms of the damage to freshwater ecosystems (endpoint) (GOEDKOOP et al., 2009). Table 1 summarizes characteristics of LCIA methods.

Table 1. Characteristics of LCIA method

Methods	Characteristics
EPS 2000	• Aquatic emissions are considered • Factor by biochemical oxygen demand (BOD) • It does not permit any regionalization
CML 2002	• Aquatic emissions are considered • Factor by biochemical oxygen demand (BOD) • It does not permit any regionalization
IMAPAC 2000+	• CF is estimated exactly like CML 2002
TRACI	• Allows regionalization in the transport of phosphorus (hydrological transport)
LUCAS	• Allows regionalization (vulnerability factor)
EDIP 2003	• Phosphorus inputs are modeled (CARMEN model)
RECIPE 2008	• Phosphorus inputs are modeled (CARMEN model adapted) • Allows regionalization of phosphorus inputs and transport data.

Current studies are being developed aiming to expand the traditional models relevance. A consensus among them is the need to consider regions characteristics, regarding their direct influence on the results. The most viable solution is to estimate the CF, since obtaining specific regional data is simpler and cheaper than making a regional phosphorus inventory. This may guarantee more accuracy to the model, because the error implied when adopting the CF from another zone is excluded. Using a regional CF enables to calculate a more real and precise eutrophication impact for a specific region (GALLEGO et al., 2010;CIVIT et al., 2012; SEPPÄLÄ et al., 2006; AZEVEDO, 2013;HELMES et al., 2012).

2.3 EUTROPHICATION IN BRAZIL

According to the Brazilian National Waters Agency (“*Agência Nacional de Águas*” [ANA]), watershed consists in a drained area by a main stem, its tributaries and sub-tributaries, forming a hydrographic network. Brazil is divided in twelve hydrographic regions: Amazônica, Atlântico Leste, Atlântico Nordeste Ocidental, Atlântico Nordeste Oriental, Atlântico Sudeste, Atlântico Sul, Paraguai, Paraná, Parnaíba, São Francisco, Tocantins-Araguaia and Uruguai (MMA/ANA, 2017). Table 2 presents some of these regions characteristics.

Table 2. Main characteristics of each hydrographic region.
Source: ANA, 2016.

Characteristics	**Amazônica**	**Atlântico Leste**	**Atlântico Nordeste Ocidental**
Extension (Brazilian surface %)	42%	4%	3%
Temperature	24º C to 26º C	22º C to 32º C	22º C to 32º C
Precipitation (mm/year)	2,512	2,400	1,738
Climate type	tropical rainy	tropical	megathermal rainy
Population (Brazilian population %)	4.5%	8%	3,3%
Characteristics	**Atlântico Nordeste Oriental**	**Atlântico Sudeste**	**Atlântico Sul**
Extension (Brazilian surface %)	3%	2.7%	2%
Temperature	24º C to 26º C	17º C to 22º C	18º C to 22º C
Precipitation (mm/year)	2,700	1,352	1,573
Climate type	subtropical	tropical altitude	tropical rainy
Population (Brazilian population %)	12.7%	15.1%	6.8%
Characteristics	**Paraguai**	**Paraná**	**Parnaíba**
Extension (Brazilian surface %)	4.6%	10%	3.9%
Temperature	22.5 to 26.5 ºC	16º C to 22º C	22º C to 32º C
Precipitation	1,398		1,726
Climate type	tropical savanna	tropical	megathermal
Population	1%	32%	1.6%
Characteristics	**São Francisco**	**Tocantins-Araguaia**	**Uruguai**
Extension (Brazilian surface %)	8%	11%	2%
Temperature	22º C to 32º C	16°C	16º C to 20º C
Precipitation	1036	1869	1784
Climate type	transition from wet to dry	Tropical	seasoned
Population	8%	4.7%	2.3%

As presented in table 2 there are several different characteristics among the Brazilian watershed, as temperature average and precipitation. According to Tundisi; Tundisi (2006) the eutrophication is influenced by those watershed characteristics and, in order to estimate realistic impacts, these proprieties should be analyzed (TUNDISI; TUNDISI, 2006). Table 2 also details many differences among the Brazilian watersheds, especially the water availability. More than 73% of the available freshwater is at the Amazon watershed, where less than 5%

of the Brazilian population lives. Only 27% of water is available to other regions. The hydrological availability is especially important since it is directly proportional to phosphorus compounds emission (BICUDO et al., 2010).

In Brazil, ANA is responsible to evaluate water quality. The analysis of phosphorus fractions are performed using “Standard methods for water and wastewater examination” (WPC, 2005) and then the waterbody is classified according to the total phosphorus concentrated by the Trophic State Index (TSI), as presented in table 3. This index is expressed in milligrams of total phosphorus per liter of water (MMA/ANA, 2016b).

Table 3. Trophic State Index
Source: ANA, 2016b

TSI	Trophic State	Characteristics
= 47	Ultratrophy	Clear water, very low concentration of nutrients.
47<TSI = 52	Oligotrophy	Clear water, low concentration of nutrients.
52 <TSI = 59	Mesotrophy	Water moderately clear, the nutrients influenced water quality, but in acceptable levels.
59<TSI=63	Eutrophy	High concentration of nutrients. The water transparency is reduced, the water quality is impaired.
63<TSI=67	Supereutrophy	High concentration of nutrients. The water transparency is low, the water quality is impaired, sporadic algal blooms.
> 67	Hypereutrophy	High concentration of nutrients. The water transparency is very low, the water quality is severely damaged, algal blooms are common, causing organisms’ death.

The most eutrophic, supereutrophic and hypereutrophic waterbodies are at the Brazilian coastline, particularly in Paraná, Atlântico Nordeste Oriental, Atlântico Leste and the Atlântico Sudeste watersheds (Figure 2), where the majority of the population lives (Figure 3).

The untreated sewage in Brazil has a total phosphorus concentration of 6 to 10 mg of phosphorus per liter. The fecal organic matter and powder detergents used domestically in large scale are the main sources of phosphorus (CETESB, 2009). Around 46% of the Brazilians don’t have sewage network (MMA/ANA, 2007), but the most alarming information is that only 20% of collected sewages is treated, the remainder is dumped "*in natura*". In other words, 80% of the collected sewage is discarded without any treatment into rivers, lakes and the sea (KELMAN, 2001).

Brazil fertilizer consumption represents 6% of the world total; 10.1 million tons of nutrients were used in 2010. Brazil is the fourth largest consumer, after China, India and the United States (ANDA, 2016).

Every day, a huge amount of phosphorus arrives to the Brazilian waterbodies culminating in an environmental degradation process, but this phenomenon is different at each watershed because of their own characteristics. Therefore, some of the subwatersheds can be more impacted than others for the same amount of phosphorus. Consequently, it is very important to regionalize the eutrophication potential impact by a regionalized LCIA method; as a result the peculiarities of each subwatershed are evaluated providing more realistic information about local impact to enable support to strategic decisions.

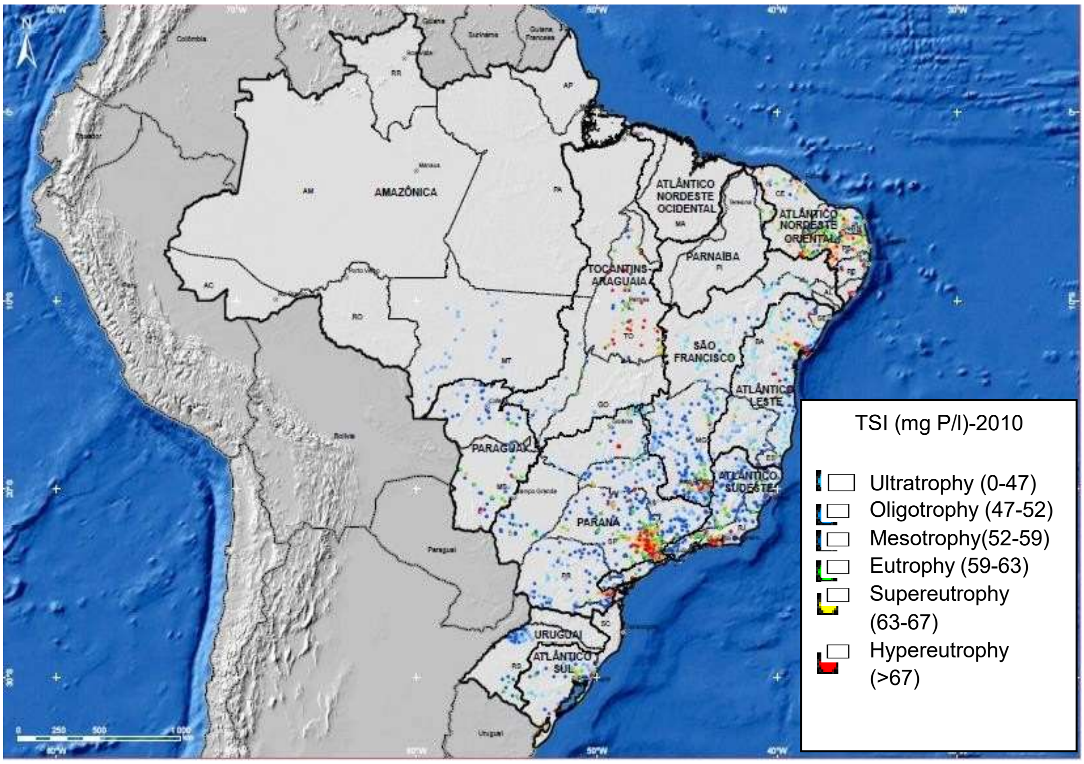

Figure 2. Water bodies trophic State Index
Source: ANA, 2016

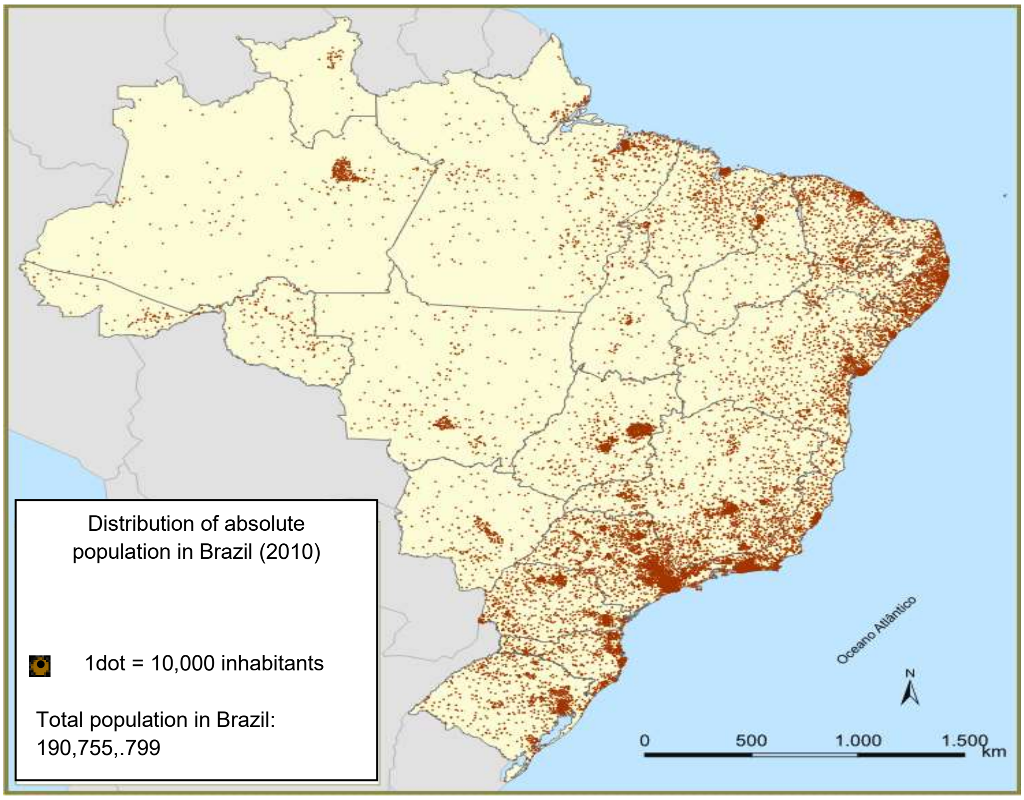

Figure 3. Brazilian population distribution.
Source IBGE,2010

It is possible to assess the eutrophication impact by the LCIA methods, but because Brazil is a developing country there aren’t Brazilian methods to evaluate the eutrophication yet. Due to scarce database it became unfeasible to develop a new method. Consequently, the most viable option is to regionalize already developed methods, incorporating different characteristics of the Brazilian watershed. Therefore, the characterization factor should be regionalized and calculated. Table 4 summarizes the literature review critical analysis.

The study challenges are:

1. Evaluate the eutrophication regarding the Brazilian watersheds diversity without a Brazilian LCIA method
2. Identify and regionalize the LCIA to the most suitable method for the Brazilian reality
3. Brazilian watersheds data collection

In regard to the challenges the objective of this study is to regionalize a LCIA method and calculate the eutrophication freshwater characterization factor more coherent than the present methodologies for the Brazilian subwatersheds.

Therefore, the specific objectives are:

- Check LCIA methods adequacy and feasibility.
- Regionalize an LCIA method and calculate characterization factors for freshwater eutrophication.

Table 4. Literature review **summary**

Literature review	Main results	Critical analysis
(ESTEVES, 1998) (TUNDISI; TUNDISI, 2006) (ANDREOLI, 2005) (GALLI; ABE, 2006) (CARMICHAEL; LI, 2006) (MMA, 2006) (MENDONÇA, 2004)	Eutrophication concepts	The eutrophicated water is a problem around the world.
(SHRIVER, D. F.; ATKINS, 2008)	Fundamental limiting nutrients	Nitrogen and phosphorus are limiting nutrients, in excess they become pollutants
(ISO, 2006) (ILCD HANDBOOK, 2010)	LCA and LCIA principles	It is fundamental to comprehend the concepts to understand the CF model.
(GALLEGO et al., 2010) (CIVIT et al., 2012) (SEPPÄLÄ et al., 2006) (AZEVEDO, L. B. ET AL, 2013) (HELMES et al., 2012) (ROSENBAUM et al., 2007) (JRC EUROPEAN COMMISSION, 2011) (TOFFOTETTO et al., 2006) (STEEN, 1999) (GUINÉE et al., 2001) (JOLLIET et al., 2003)	CF models	LCIA evaluates the eutrophication impact, but none of existing LCIA methodologies is capable to consider the Brazilian watersheds particularities.

(POTTING; HAUSCHILD, 2006) (GOEDKOOP et al., 2009)		
(MMA/ANA) (MMA/ANA, 2016) (BICUDO et al., 2010)	Brazilian watershed situation	In Brazil the coast concentrates the largest amount of eutrophicated waterbodies
(IBGE, 2010)	Brazilian population	The most affected areas by eutrophication are those with the highest population concentration
(CETESB, 2009) (MMA/ANA, 2007) (KELMAN, 2001)	Sewage treatment in Brazil	The Brazilian watersheds have totally different sanitation conditions, so effluent treatment must be analyzed
(ANDA, 2016)	Fertilizer consuming	Brazil consumes a large amount of fertilizers, and its runoff should be analyzed

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3 METHODOLOGY

This chapter describes the work structure and the methodology to assess quantitatively the eutrophication impact assessment methods established by the Brazilian Life Cycle Impact Assessment Network.

An indirect and descriptive research methodology was used to estimate a reliable freshwater eutrophication CF for Brazilian subwatersheds.

3.1 WORK METHODOLOGY

Traditional methods (recognized by scientific community) and more recent methodologies, which evaluate freshwater eutrophication category, were detected by systematic research in the time span from 2010 to 2015. The eutrophication methods were studied and classified according to the criteria established by the Brazilian LCIA Network (UGAYA et al., 2016), based on JRC (2011).

Afterwards, a study of eutrophication concepts and Brazilian watershed characteristics was implemented and used to regionalize the selected LCIA model. The next step was to identify and collect data to calculate the CF for the Brazilian watersheds.

3.2 LCIA METHODS CLASSIFICATION

It describes the method used to classify the LCIA methods. In order to facilitate the understanding their classification results are divided into two groups: traditional methods (recognized by the scientific community) and latest methods.

JRC (2011) classifies LCIA models developed until 2008 according to five criteria: scope completeness; environmental relevance; scientific robustness and certainty; documentation, transparency and reproducibility; applicability; stakeholder acceptance.

If the criteria are complied accordingly, they receive score A, complied in all essential aspects score B, complied in some aspects score C, little compliance score D and no compliance score E. Based on these scores the model is classified into three levels:

I: recommended and satisfactory

II: recommended but in need of improvement

III: recommended, but to be applied with caution

UGAYA et al. (2016) adapted this criteria in four to evaluate the method and the feasibility to adapt: scope; scientific robustness; characterization factors evaluation and adaptation feasibility.

Differently from JRC (2011) the scope is based on four aspects: geographical coverage; elementary flow; covered compartments definition; location in the environmental mechanism. As for the characterization factors, two important aspects are evaluated: regionalization feasibility and Brazilian characterization factors existence.

It was regionalized based on eutrophication concepts and characteristics of subwatersheds -watershed volume, water flow rate, sewage treatment and fertilizers runoff rate.

Each method is also scored according to the scientific robustness and adaptation feasibility criterion. The score comprises a number from1to 5, where 5 represents the best possibility and 1, the worst. The model which has the highest score average is the most suitable model for the Brazilian reality.

- Scope: refers to the method's general considerations, with the coverage level concerning the following aspects: geographical coverage; elementary flow included; compartments included; and location in the environmental mechanism.
- Geographical coverage;

Topography and climate influence the eutrophication (TUNDISI; TUNDISI, 2006) and Brazilian watersheds shelter a huge geographic diversity (MMA/ANA,2017). As a result, the geographical coverage should be the most specific as possible, not to homogenize the Brazilian geography. Therefore, a score of 5 is given to the method that presents geographical differentiation in subwatersheds or in a grid; a score of 4 for region, watersheds or biomes; a score of 3 for national coverage; a score of 2 for continents and a score of 1 for a global scale.

- Elementary flow included;

In Brazil, untreated sewage dump and agriculture fertilizers runoff are the main phosphorus inputs into water bodies. It is not only the phosphorus amount that promotes eutrophication, transport or/and removal rate caused by advection, biomass assimilation and water withdrawal can also cause eutrophication (ESTEVES, 1998).

Methods regarding both phosphorus inputs (untreated sewage dump and agriculture fertilizers) and the three main outputs (precipitation, organisms assimilation and removed by water use) receive highest scores. Each output or input disregarded by the method results in a lower score.

- Definition of covered compartments;

In the analyzed compartments, the impact methods that include the aquatic ecosystem and differentiate between freshwater and marine compartment receive a score of 5, and the ones that don't receive score of 1.

- Location in the environmental mechanism;

Impact methods can evaluate different phases of the cause-effect chain. When the damage on the environment is evaluated, the real impact on the ecosystem is better represented, because the effect at aquatic ecosystem is considered. Hence, endpoint methods receive a score of 5, midpoints located at the end of cause-effect chain receive a score of 3 and midpoints located at the beginning of the chain receive a score of 1.

- Scientific robustness: evaluates reliability level and method transparency based on the characterization model used.

The method is considered robust if the cause-effect chain, equations and data are accessible and provide transparency. If the method meets these requirements it receives a score of 5. In case it does not meet the requirements, the data is not easily obtained and does not present a cause-effect chain, it scores 1; and it scores 3 if data is not easily obtained, but presents cause-effect chain and equations.

- Characterization factors evaluation: analyzes the national characterization factors and the geographic level. Two aspects are evaluated: regionalization and the Brazilian characterization factors

- Regionalization

This method should allow CF regionalization in order to obtain a Brazilian CF. If the method allows it, it scores 5, in case it does not it scores 1.

- The Brazilian characterization factors

Nowadays eutrophication assessment has been extensively studied. Therefore, methods which do not belong to studies endorsed by scientific community cannot be belittled, since progress in this area is recent. If the method presents a CF for Brazil it scores 5, if it does not, it scores 1.

- Adaptation feasibility: this evaluation criterion follows the standard model which allows indication of existing data to feed models that were considered regionalized in the previous item.

Methods receive a score of 5, 3 and 1 respectively for easily adaptable methods, adaptable methods and methods difficult to adapt. Table 5 summarizes the requirements of each score.

Table 5. Score to assess quantitatively the methods of eutrophication impact assessment

Principles		**Scope**			
		Geographical coverage	**Elementary flow**	**Covered compartments**	**Location in the environmental mechanism**
Score	**5**	Watershed or a grid	All inputs and outputs are considered	Differentiates between freshwater and marine	Endpoint
	4	Region or biome	All inputs and outputs are considered	-	-
	3	National	All inputs and outputs are considered	-	Midpoint located at the end of the cause-effect chain
	2	Continental	All inputs and outputs are considered	-	-
	1	Global	All inputs and outputs are considered	Don't differentiate or don't contemplate freshwater	Midpoint located at the beginning of the cause-effect chain
Principles		**Scientific robustness**	**CF evaluation**		**Adaptation possibility**
			Regionalization	**Brazilian CF**	
Score	**5**	Equations and data are accessible	Allows regionalization	Specifies the Brazilian CF	Easily adaptable
	4	-	-	-	-
	3	Data is not easy to obtain	-	-	Adaptable
	2	-	-	-	-
	1	Equations and data are not accessible	Doesn't allow regionalization	Doesn't specify the Brazilian CF	Adaptation is difficult

3.3 FF model

Helmes et al. (2012) proposes the calculation of three processes to estimate the FF: income rate by advection, outcome rate by retention and water use at geographic differentiation of 0.5°x0.5° grid covering the globe. These processes are regionalized in Brazil at subwatershed due to data availability. Moreover, the sewage treatment was included, which was not modeled in Helmes et al (2012).

- Income rate of P by advection from upstream grid ($□_{□□□,□}$)

Originally, the model estimates P transference from upstream grid (□) to downstream grid (□) through the water flow by the equation 2. Table 11 describes the variables of the original model and explains the assumption to regionalize them.

$$□_{□□□,□} = \frac{□_{□}}{□_{□□□,□}} \tag{2}$$

Table 6. Regionalization of income rate by advection

Variables	***Units***	***Original model***	***Assumptions***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square_{\square\square\square,\square}$:	day^{-1}	Income rate by advection from the upstream grid	Data is available at subwatersheds geographic differentiation	Income rate by advection from the upstream subwatersheds	Subwatersheds
$\square_{\square}$:	$m^3 . day^{-1}$	Water flow rate from upstream grid	Only stream water contributes to the advection process and, in a watershed, secondary rivers flow to the main river, so the water flowing of the river base level represents the advection from upstream subwatersheds	The flow rate of the main river of upstream subwatershed	River
$\square_{\square\square\square,\square}$:	m^3	Total water volume at upstream grid	$\square_{\square\square\square,\square}$ is calculated adding the volume of rivers, lakes and reservoirs of upstream subwatershed	Total water volume of upstream subwatershed	Rivers, lakes and reservoirs

- Outcome rate of P by retention ($\square_{\square\square\square,\square}$)

Originally, $\square_{\square\square\square,\square}$ evaluates the P that was removed by precipitation and organism assimilation at downstream grid by the equation 3, which is explained at table 12.

$$\square_{\square\square\square,\square} = \frac{1}{\square_{\square\square\square,\square}} (\square_{\square\square\square,\square} \, . \, \square_{\square\square\square,\, \square\square\square,\square} + \square_{\square} . (\square_{\square\square\square,\square} + \square_{\square\square\square,\square})) \quad (3)$$

Table 7. Regionalization of outcome rate by retention

Variables	***Units***	***Original model***	***Assumption***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square_{\square\square\square,\square}$	day^{-1}	Removal rate by retention at downstream grid	Data is available at subwatersheds geographic differentiation	Removal rate by retention at downstream subwatershed	Subwatersheds
$\square_{\square\square\square,\square}$	km^3	Total water volume at downstream grid	$\square_{\square\square\square,\square}$ is calculated adding the volume of rivers, lakes and reservoirs of upstream subwatershed	Total water volume at downstream subwatershed	Rivers, lakes and reservoirs
$\square_{\square\square\square,\ \square\square\square,\square}$	day^{-1}	Removal rate of phosphorus at the river at downstream grid	The literature factor is used (ALEXANDER et al., 2004)	Removal rate of phosphorus at main river of downstream subwatershed	0.5x0.5° grid
$\square_{\square\square\square,\square}$	km^3	Rivers volume at downstream grid	There is no information of affluent rivers, therefore the river volume at downstream subwatershed is equal to the main river volume	Main river volume at downstream subwatershed	River
$\square_{\square}$	km $\cdot$day^{-1}	Phosphorus uptake velocity	The literature factor is used (ALEXANDER et al., 2004)	Phosphorus uptake velocity	River
$\square_{\square\square\square,\square}$	km^2	Lake surface area at downstream grid	Sum of lakes surface area at downstream subwatershed	Lake surface area at downstream subwatershed	Lakes
$\square_{\square\square\square,\square}$	km^2	Reservoir surface at downstream grid	Sum of reservoirs surface area at downstream subwatershed	Reservoir surface area at downstream subwatershed	Reservoirs

- Outcome rate of P by water use ($\square_{\square\square\square,\square}$)

The water is used to supply three sectors, industrial, domestic and agricultural. In the model proposed by Helmes et al. (2012), just the agricultural sector is modeled. Due to the massive difference at the Brazilian sanitation to model the water use to supply domestic needs is extremely relevant. As the original model the industry sector is not modeled.

To calculate the P removed by withdrawing water to agricultural sectors, the equation 4 is used. Table 13 shows the adaptations to regionalize $□_{□□□,□}$.

$$□_{□□□,□} = □_{□□□,□} . (1 - □_{□□□□,□}). □_{□□□,□} . (1 - □_{□□□□,□}) \tag{4}$$

Table 8. Regionalization of income rate by water use for agricultural sector.

Variables	***Units***	***Original model***	***Assumptions***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$□_{□□□,□}$	day^{-1}	Removal rate of P by water used for agricultural at downstream grid.	Data is available at subwatersheds geographic differentiation. Just the irrigation is considered at the agricultural purpose.	Removal rate of P by water used for irrigation at downstream subwatershed.	subwatershed
$□_{□□□,□}$:	Dimensionless	Fraction of water returned to downstream grid after being used for agriculture at downstream grid	The same fraction of domestic is considered, because the amount of water, which returns to the waterbody after industrial and agricultural use varies greatly.	Fraction of water returned to downstream grid after being used for irrigation at subwatershed.	subwatershed
$□_{□□□□ □□□□,□}$	Dimensionless	Share of the total water use that is used for domestic and industrial purposes at downstream grid	At the equation the term $□_{□□□,□} = □_{□□□,□}.(1- □_{□□□□,□}). □_{□□□,□} . (1 - □_{□}$ represents the share of the total water use that is used for agricultural purpose. Just the water used for irrigation is considered	Share of the total water use that is used for agricultural purposes at downstream subwatershed	subwatershed
$□_{□□□,□}$:	day^{-1}	Outcome rate by advection at downstream grid	Data is available at subwatersheds geographic differentiation. It is calculated by the equation 5	Outcome rate by advection at downstream subwatershed	subwatershed
$□_{□□□□,□}$:	Dimensionless	Fraction of total phosphorus (TP) emissions transferred from soil to waterbody at downstream grid	Originally TP is calculated by adding DIP, DOP and particulate P, but in the Subwatershed model the particulate fraction is not considered because of its low reactivity. It is calculated by the equations 6 and 7	Fraction of total phosphorus emissions transfer from soil to the water body at downstream subwatershed	subwatershed

The P outcome rate by advection is calculated by the equation 5, which is further explained at table 14.

$$\square_{\square\square\square,\square} = \frac{\square_{\square}}{\square_{\square\square\square,\square}} \qquad (5)$$

Table 9. Regionalization of outcome rate by advection

Variables	***Units***	***Original model***	***Assumption***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square_{\square\square\square,\square}$	day^{-1}	Outcome rate by advection at downstream grid	Data is available at subwatersheds geographic differentiation	Outcome rate by advection at downstream subwatershed	Subwatershed
$\square_{\square}$	m^{3}. day^{-1}	Water flow rate from downstream grid	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	The flow rate of the main stem base level of downstream subwatershed	River
$\square_{\square\square\square,\square}$	m^{3}	Total water volume at downstream grid	$\square_{\square\square\square,\square}$is calculated by adding the volume of rivers, lakes and reservoirs of upstream subwatershed	Total water volume of downstream subwatershed	rivers, lakes and reservoirs

Total phosphorus emissions transferred from soil ($f_{soil,j}$) are estimated adding DIP and DOP fraction which are calculated by the following equations. Table 15 clarifies the variable of these equations.

$$\square_{\square\square\square} = \frac{0.29}{(1+(\frac{\square}{0.85})^{-2})} \qquad (6)$$

$$\square_{\square\square\square} = 0.01.\square^{0.95} \qquad (7)$$

Table 10. Regionalization of income rate by runoff

Variables	***Units***	***Original model***	***Assumption***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square_{\square\square\square}$	day^{-1}	Fraction of inorganic phosphorus transferred from soil to waterbody at downstream grid	Data is available at subwatersheds geographic differentiation	Fraction of inorganic phosphorus transferred from soil to waterbody at downstream subwatershed	subwatersheds
$\square$	mm.yr^{1-}	Runoff rate at downstream grid	Data is available at subwatersheds geographic differentiation	Average runoff rate at downstream subwatershed	subwatersheds
$\square_{\square\square\square}$	day^{-1}	Fraction of organic phosphorus transferred from soil to waterbody downstream grid	Data is available at subwatersheds geographic differentiation	Fraction of organic phosphorus transferred from soil to waterbody downstream subwatershed	subwatersheds

So at the subwatershed model the removal rate of P by water used for irrigation is calculated by the equation 8.

$$\square_{\square\square\square\ \square\square\square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square\square\ \square\square\square\square,\square} \cdot \square_{\square\square\square,\square} \cdot (1 - \square_{\square\square\square\square,\square}) \qquad (8)$$

The sewage treatment is not modeled to improve these flaws. The model suggested by Gallego et al. (2010) is used to estimate fraction of total phosphorus removed by the sewage treatment and the fraction transferred to water body by the non-treated sewage.

To calculate the P added by withdrawing water to domestic sectors, the equation 9 is used, which is explained at the table 16.

$$\square_{\square\square\square\ \square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square\square\ \square\square\square,\square} \cdot \square_{\square\square\square,\square} \cdot (\square_{\square\square} - (1 - \square_{\square\square\square})) \qquad (9)$$

Table 11. Regionalized outcome rate by water use for domestic purpose

Variables	***Subwatershed model***
$\square_{\square\square\square\ \square\square\square,\square}$	Income rate of P by water used for domestic purpose at downstream subwatershed.
$\square_{\square\square\square,\square}$:	Fraction of water returned to downstream subwatershed after being used for domestic sector
$\square_{\square\square\square\square\ \square\square\square,\square}$	Share of the total water use that is used for domestic purposes at subwatershed
$\square_{\square\square\square,\square}$:	Outcome rate by advection at subwatershed. It is calculated by the equation 5
$\square_{\square\square}$	Fraction of P removed by sewage treatment. It is calculated by the equation 10
$\square_{\square\square\square}$	Fraction of P transferred to the water body by dumping non-treated sewage It is calculated by the equation 11

The fraction of total phosphorus removed by the sewage treatment ($\square_{\square\square}$) is calculated by multiplying the percentage of treated sewage at downstream subwatershed ($\square$) by percentage of phosphorus removed at effluent treatment ($\square$:), equation 10.

$$\square_{\square\square} = \square . \square \qquad (10)$$

The fraction of P transferred to the waterbody by dumping non-treated sewage is estimated by equation 11. The term $\square$ represents the fraction of P at non-treated sewage.

$$\square_{\square\square\square} = (1 - \square) . \square \qquad (11)$$

The regionalized equations of income and outcome rates, are used to estimate the phosphorus persistence at freshwater ($\square_{\square}$), and transported phosphorus ($\square_{\square,\square}$). The persistence is calculated by the inverse of the sum of outcomes rates, equation 12.

$$\tau_j = \frac{1}{\text{sum of outcame rates}} \qquad (12)$$

The transported phosphorus is calculated dividing the income by the outcome rates, equation 13.

$$\square_{\square,\square} = \frac{\square\square\square\ \square\square\ \square\square\square\square\square\square\ \square\square\square\square\square}{\square\square\square\ \square\square\ \square\square\square\square\square\square\square\ \square\square\square\square\square} \qquad (13)$$

FF is calculated multiplying τ_j by $\square_{\square,\square}$, equation 14.

$$\square\square_{\square} = \square_{\square,\square} . \square_{\square} \qquad (14)$$

To facilitate understanding the table 17 summarizes equations used to estimate the income and outcome rate at subwatersheds.

Table 12 Equations summary

Equation	Income/ outcome rate
$\square_{\square\square\square,\square} = \frac{\square_{\square}}{\square_{\square\square\square,\square}}$ Outcome rate by advection from upstream watershed equals to income rate by advection at downstream subwatershed	Income rate
$\square_{\square\square\square,\square} = \frac{\square_{\square}}{\square_{\square\square\square,\square}}$	Outcome rate
$\square_{\square\square\square,\square} = \frac{1}{\square_{\square\square\square,\square}}(\square_{\square\square\square,\square} . \square_{\square\square\square, \square\square\square,\square} + \square_{\square} . (\square_{\square\square\square,\square} + \square_{\square\square\square,\square}))$	Outcome rate
$\square_{\square\square\square\ \square\square\square\square\square,\square} = \square_{\square\square\square,\square} . \square_{\square\square\square\square\ \square\square\square\square,\square} . \square_{\square\square\square,\square} . (1 - \square_{\square\square\square\square,\square})$ $\square_{\square\square\square\ \square\square\square,\square} = \square_{\square\square\square,\square} . \square_{\square\square\square\square\ \square\square\square,\square} . \square_{\square\square\square,\square} . (\square_{\square\square} - (1 - \square_{\square\square\square})$ The water use can remove or add P at waterbody if the rate is negative. It is an income rate, if it is an outcome.	Income/ outcome rate

Firstly, the subwatershed 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 more six subwatersheds: Paraíba do Sul; Litorânea do Ceará; Litorânea Pernambuco e Alagoas; Parnaíba; Uruguai and Madeira.

Paraíba do Sul is selected because it is located at a populous region, as Alto Iguaçu, but with a lower rainfall index. Litorânea do Ceará and Litorânea Pernambuco e Alagoas are on the coast and suffer with water shortage. Parnaíba subwatershed has a very low rate of sewage treatment. Uruguai has one of the lowest annual average temperatures and Madeira the highest water availability. Unfortunately, it is not possible to estimate the FF of Uruguai and Madeira subwatersheds due to lack of data. Figure 5a presents the main eight watersheds and 5b presents the subwatershed location.

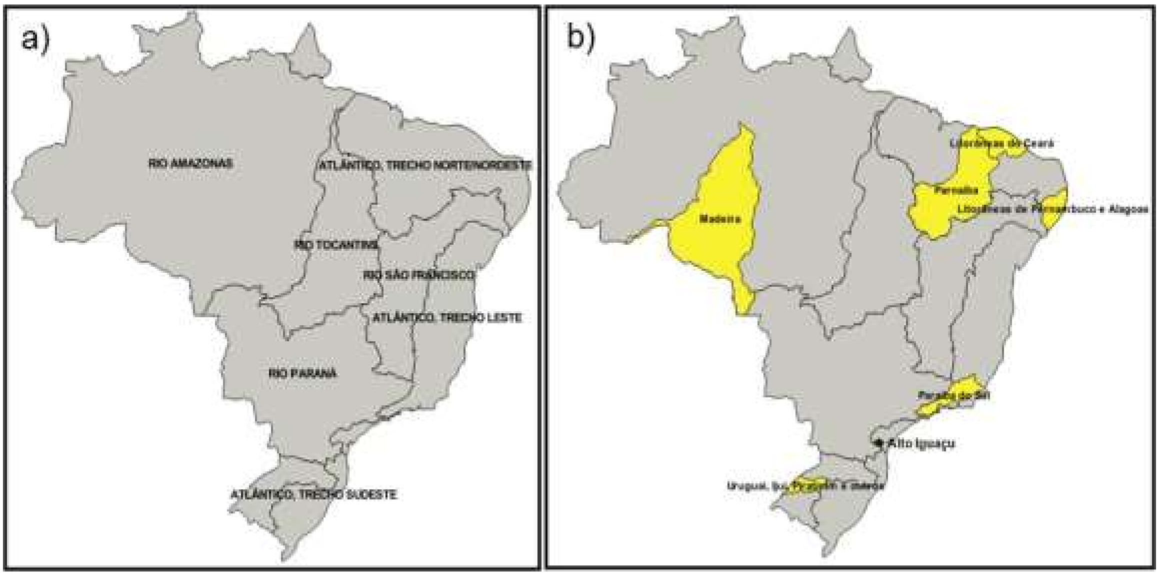


Figure 4. a) main eight watersheds. b) subwatershed location

3.4 EF model

Azevedo et al. (2013) developed three effect models to estimate the EF for fresh water also at 0.5°x0.5° grid geographic differentiation. They are based on log−logistic relationships between potentially non-occurring fraction[1] (PNOF) of heterotrophic species and total phosphorus concentration (TP), by the equation 15.

Originally these effect models were developed for the European context, where temperate climate predominates and the phosphorus concentration in the waterbodies is lower due to better sanitation conditions.

Table 23 describes the variables of the original calculation and explains the assumption to regionalize them into subwatersheds.

$$\square\square\square\square = \frac{1}{1+\square^{-\frac{(\square\square\square\square_{\square,\square}+0.54)}{0.63}}} \qquad (15)$$

Table 13. PNOF regionalization

Variables	***Units***	***Original model***	***Assumption***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square\square\square\square_{\square,\square}$	Dimensionless	Potentially non-occurring fraction in freshwater at downstream grid	Regionalized at subwatersheds geographic differentiation	Potentially non-occurring fraction in freshwater at downstream subwatershed	Subwatershed
$\square_{\square,\square}$	kg P·m⁻³	TP concentration fraction in freshwater at downstream grid	There is no information about affluent rivers, so TP concentration at downstream subwatershed equals to the main river TP concentration	The average of TP concentration at the main river	River

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 using the equation 16. Table 24 shows MEF regionalization.

$$\square\square\square_{\square,\square} = \frac{\square\square\square\square\square_{\square,\square}}{\square\square_{\square,\square}} = \square\square\square\square_{\square,\square}.(1-\square\square\square\square_{\square,\square}).\frac{1}{\square_{\square,\square}.\square_{\square}.\ln(10)} \qquad (16)$$

---

[1] Eutrophication causes the decrease in species richness, in other words, increases species PNOF due to TP concentration increase..

Table 14. MEF regionalization

Variables	***Units***	***Original model***	***Assumption***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square\square\square_{\square,\square}$:	kg $P^{-1} \cdot m^3$	Marginal Effect Factor model in freshwater at downstream grid	Regionalized at subwatersheds geographic differentiation	Marginal Effect Factor model in freshwater at downstream subwatershed	Subwatershed
$\square_{\square}$:	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. It describes the change from ideal stage (pollutant zero concentration) to the concentration affecting 50% of the organisms. LEF is calculated by the equation 17, which is better explained at table 25.

$$\square\square\square_{\square} = \frac{0.5}{10^{\alpha_w}} \qquad (17)$$

Table 15. LEF regionalization

Variables	***Units***	***Original model***	***Assumption***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square\square\square_{\square}$	kg $P^{-1} \cdot m^3$	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
α_w	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 the MEF, because it reflects the average distance between the current state and the preferred state of the environment. AEF is calculated by the equation 18, which is detailed at the table 26.

$$\square\square\square_{\square,\square} = \frac{\square\square\square\square_{\square,\square}}{\square_{\square,\square}} \tag{18}$$

Table 16. AEF regionalization

Variables	***Units***	***Original model***	***Assumption***	***Subwatershed model***	***Subwatershed model* geographic differentiation**
$\square\square\square_{\square,\square}$	kg $P^{-1}\cdot m^{3}$	Average Effect Factor model in freshwater at downstream grid	Regionalized at subwatersheds geographic differentiation	Average Effect Factor model in freshwater at downstream subwatershed	Subwatershed
$\square\square\square\square_{\square,\square}$	Dimensionless	Potentially non-occurring fraction in freshwater downstream the grid	Regionalized at subwatersheds geographic differentiation	Potentially non- occurring fraction in freshwater at downstream subwatershed	Subwatershed
$\square_{\square,\square}$	kg $P\cdot m^{-3}$	TP concentration fraction in freshwater at downstream grid	There is no information only of affluent rivers, so TP concentration at downstream subwatershed equals to the main stem volume	The average of TP concentration at the main stem	River

4 RESULTS

At this chapter the results of Alto Iguaçu FF and EF are detailed and the other watersheds results are presented and discussed.

4.1 Results of LCIA methods classification

- Traditional LCIA methods

Aquatic eutrophication is analyzed by eight traditional methods: EPS2000, CML2002, IMPACT 2002+, ReCiPe midpoint, ReCiPe endpoint, EDIP 2003,TRACI and LUCAS, each one was evaluated as previously described.

Table 6 and table 7 present, respectively, the traditional LCIA methods score and their score average.

Table 17. Score of LCIA traditional methods

Scope evaluation				
Methods	**Geographic scope**	**Elementary flow**	**Definition of covered compartments**	**Location in the environmental mechanism**
EPS 2000	2	1	5	5
CML 2002	1	3	5	1
IMPACT 2002+	1	3	5	1
ReCiPe midpoint	3	4	1	3
ReCiPe endpoint	3	4	1	5
EDIP 2003	4	3	1	3
TRACI	4	2	5	3
LUCAS	4	3	1	3
Methods	**Scientific robustness**	**Characterization factors evaluation**		**Adaptability**
		CF for Brazil	**Regionalization**	
EPS 2000	1	1	1	1
CML 2002	1	1	5	1
IMPACT 2002+	1	1	5	1
ReCiPe midpoint	3	1	5	3
ReCiPe endpoint	3	1	5	3
EDIP 2003	3	1	5	3
TRACI	4	1	5	1
LUCAS	3	1	5	3

Table 18. Score average of LCIA traditional methods

Methods	**EPS 2000**	**CML 2002**	**IMPACT 2002+**	**ReCiPe midpoint**	**ReCiPe endpoint**	**EDIP 2003**	**TRACI**	**LUCAS**
Score Average	2.125	2.250	2.250	3.125	2.875	3.375	3.675	2.875

The method EPS 2000 has the lowest average (2.125), because phosphorus destination is determined by an empirical method, a fixed nutrient global distribution is assumed and it has no spatial differentiation.

The CML 2002 method also has a low score (2.25) because it evaluates nutrient concentration at aquatic environment by converting main emissions of eutrophying substances to equivalent phosphate. The method uses nutrification potential (NP), which was developed based on the Redfield proportion. Although this method allows spatial differentiation, the CF does not consider many local characteristics and uses only phosphorus emissions data. In addition to that, the effect at aquatic system is not modeled.

Although IMPACT 2002+ has been developed with the purpose to provide an endpoint evaluation, this evaluation is not possible for aquatic eutrophication since there was a lack of adequate scientific information to determine the damage sufferedfor natural environment due to chemicals or physical interventions (ILCD HANDBOOK, 2010). The study time IMPACT 2002+ uses CML 2002 to estimate the CF for eutrophication category. Both methods have the same score.

TRACI is also based on CML, but some improvement was made, which results in a score increase (3.125). The nutrient transport is used to estimate the transport factor. It represents the P probability to achieve a particular waterbody. The nutrification factor is calculated as CML 2002.

The methods EDIP 2003, ReCiPe midpoint, and ReCiPe midpoint receive scores of 2.875; 3.375 and 3.625, respectively. These methods used the same process used by the CARMEN model to determine nutrient FF, but EDIP 2003 does not differentiate between fresh water and marine compartment.

CARMEN model regards phosphorus input from fertilizer runoff and untreated effluent, and a fix nutrient removal rate. It allows adding several local data, such as phosphorus load in watershed, number of inhabitants in the region, soil texture, rainfall intensity and land use.

ReCiPe endpoint evaluates the damage caused by phosphorus emission multiplying midpoint CF by damage factor (DF), which is given by curve slope of species total loss and phosphorus concentration.

LUCAS also uses CARMEN model. The vulnerability factor integrates regionalization, but it was developed only for groundwater. The surface freshwater CF is calculated by the EDIP 2003. LUCAS obtained the same score as EDIP 2003 (2,875).

In addition to the classical methods, more recent methods were studied.

- Latest LCIA models

To identify latest methods which assess aquatic eutrophication category, a systematic research was made using three different platforms, Google Scholar, Scielo and Periódicos Capes. At Scielo no study was found.

The keywords were chosen aiming to select studies which present methodology to develop the CF. The search was from 2010 to 2015 and the results are detailed at table 8.

Table 19. Literature review results

Keywords	Sources		Date
	Google scholar	Periódicos Capes	
Modeling, Characterization Factors, Aquatic Eutrophication, Fertilizers, Phosphorus, Nitrogen, Crops, Life Cycle Impact Assessment	4120	71	09/30/2015
Modeling, Characterization Factors, Aquatic Eutrophication, Phosphorus, Nitrogen, Livestock, Life Cycle Impact Assessment	5740	86	09/30/2015
Modeling, Characterization Factors, Aquatic Eutrophication, Animal Droppings, Phosphorus, Nitrogen, Livestock, Life Cycle Impact Assessment	1360	0	09/30/2015
Modeling, Regionalization, Characterization Factors, Aquatic Eutrophication, Phosphorus, Nitrogen, Livestock, Life Cycle Impact Assessment	236	5	09/30/2015
Modeling, Regionalization, Characterization Factors, Aquatic Eutrophication, Animal Droppings, Phosphorus, Nitrogen, Livestock, Life Cycle Impact Assessment	61	0	09/30/2015
Modeling, Regionalization, Characterization Factors, Aquatic Eutrophication, Fertilizers, Phosphorus, Nitrogen, Crops, Life Cycle Impact Assessment	139	3	09/30/2015
Modeling, Regionalization, Characterization Factors, Aquatic Eutrophication, Fertilizers, Phosphorus, Nitrogen, Crops, Life Cycle Impact Assessment	141	3	10/31/2015

Among 141 studies, only three of them develop new models to calculate CF or at least improve an existing method. Their scores are presented at table 9 and their score average at table 10.

Table 20. Score of Current LCIA model

Scope evaluation				
Methods	**Geographic scope**	**Elementary flow**	**Definition of covered compartments**	**Location in the environmental mechanism**
Gallego Alejandro, 2010	5	4	5	5
Helmes J. K. Roel, 2012	5	4	5	5
AzevedoLigia B., 2013	5	5	5	5
Methods	**Scientific robustness**	**Characterization factors evaluation**		**Adaptability**
		CF for Brazil	**Regionalization**	
Gallego Alejandro, 2010	5	1	5	1
Helmes J. K. Roel, 2012	3	1	5	3
AzevedoLigia B., 2013	3	1	5	5

Table 21. Average of Current LCIA model

Methods	Gallego Alejandro, 2010	Helmes J. K. Roel, 2012	AzevedoLigia B., 2013

Average	3.875	3.875	4.250

The common point among these models is the concern to evaluate phosphorus output to determine the real phosphorus fraction that will cause eutrophication. Consequently, two different models are proposed to estimate P transport (FF).

The model presented by Gallego et al. (2010) and Helmes et al. (2012) obtained the same score, 3.875, but the first author presents a simpler model, as the effluent treatment considers the only phosphorus output possible to include data about local sewage treatment, and constant EF is adopted.

The second author proposes FF calculation estimating three factors: input rate of P by advection ($\square_{\square\square\square,\square}$); output rate of P by retention ($\square_{\square\square\square,\square}$) and output rate of P by water use ($k_{use,j}$).

The advection mechanism is a consequence of the water flow, as stream water carries P to different regions affecting not only the region where it was emitted. But it is not the whole emitted amount that promotes eutrophication, as it was mentioned before. P is a nutrient, needed by aquatic organisms to grow. Therefore, part of P is assimilated by them and another share forms insoluble compounds precipitating at the bottom of the water body. These two unavailability process of P are estimated by$\square_{\square\square\square,\square}$. P is also removed from the aquatic compartment during the water removal to supply domestic, industrial or agriculture sectors and this factor is evaluated by $k_{use,j}$.

The FF model proposed by Helmes et al. (2012) indicates phosphorus persistence in the water body. It is calculated on a worldwide scale, at 0.5°x 0.5 grid and it also adopts a constant EF.

The model proposed by Azevedo et al. (2013) is considered the most complete, because it fulfills almost all established criteria, achieving a score of 4.25. It uses the model developed by Helmes et al. (2012) to calculate FF and proposes three models to estimate EF for the European context.

To calculate the CF of the Brazilians subwatersheds, the FF is estimated by Helmes et al. (2012) and EF by Azevedo et al. (2013).

4.2 FF results

Some dates used at this research are available at MMA/ANA (2016a) as shapefile format and some as literature. Due to data scarcity and limitations some assumptions are essential to conclude the study.

Only data about the mean rivers of each subwatershed was found, used to represent all basins, as consequence data representativeness is low.

The water flow which gets in the basin is the same as the mean river water flow rate at the basin entrance. The subwatershed volume is estimated multiplying rivers area by the mean river depth, which is estimated by the average of some depth measurements.

Alto Iguaçu micro watershed is part of Iguaçu subwatershed; it is located at Curitiba metropolitan region, where around 3.5 million inhabitants live (MMA/ANA, 2011). It is in the tropical zone, with average temperature from 16°C to 22°C (MMA/ANA, 2017). Iguaçu River is the main river of Alto Iguaçu; it flows only from Ribeira do Iguapé subwatershed and the flow rate by advection comes from Ribeira River (figure 6).

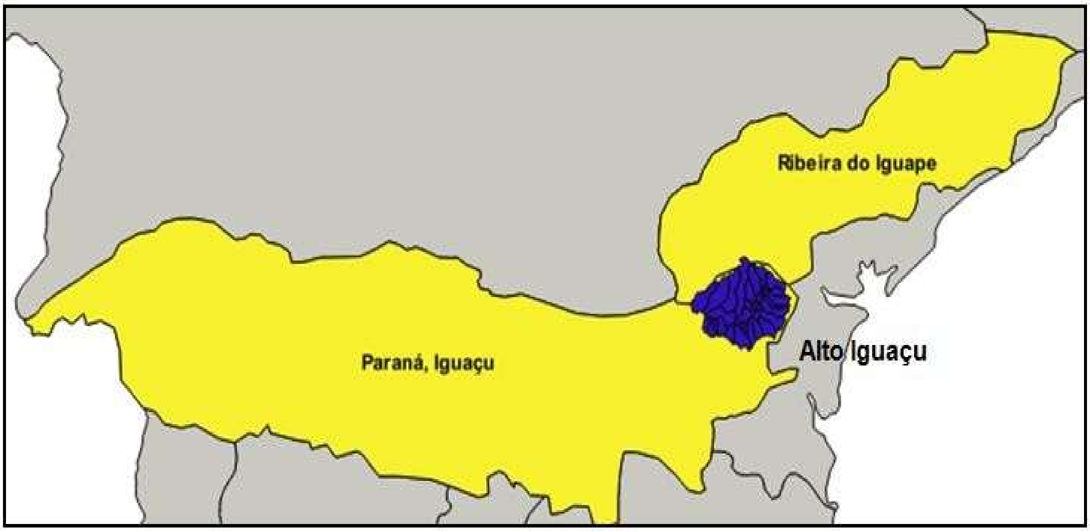


Figure 5. Location of Alto Iguaçu microwatershed

Applying the Subwatershed model, the FF value is 15.01 days. The process calculations are detailed below.

- Calculation of $\square_{\square\square\square,\square}$

The water flow rate of Ribeira River before it disembogues into Alto Iguaçu watershed is not available. Therefore, the Iguaçu River flow rate was used at the El Dorado station (basin entrance). The water volume at Ribeira was estimated multiplying the sum of the main stem, lake and reservoir area by the Ribeira depth average. The area was calculated through a shapefile provided by ANA using Qgis 2.16, Geographic Information Systems (GIS) programme.

$\square_{\square\square\square,\square}$ is 7.32 10^{-3} $days^{-1}$ and it is calculated using equation 2. Its calculation is explained at the table 18 as well as data collection and data quality.

Table 22. Income rate by advection calculation from Ribeira subwatershed

Variables	$\square_{\square\square\square,\square}$	$\square_{\square\square}$	$\square_{\square\square\square,\square}$	$\square_{\square}$	$\square_{\square}$
Meaning	Income rates by advection from Ribeira subwatershed	Iguaçu river flow rate at El Dorado station	Total water volume at Ribeira subwatershed	Water surface area of Ribeira subwatershed	Maximum depth of Ribeira River
Units	day^{-1}	m^3/day	m^3	m^2	M
Value	$7.32\ 10^{-3}$	$1.75\ 10^{-7}$	$2.39\ 10^{-9}$	$3.41\ 10^{8}$	7
Source	Calculated by the equation 2 $\square_{\square\square\square,\square} = \frac{\square_{\square}}{\square_{\square\square\square,\square}}$	(HIDRO MAPA, 2016)	$\square_{\square\square\square,\square} = \square_{\square} . \square_{\square}$	(DISPONIBILIDADE HIDRICA, 2016)	(TESSLER et al, 1996)
Qualitative analysis					
Year/Period	-	2016	-	2016	1996
Spatial differentiation	-	River	-	River, lake and reservoir	River
Representativeness	-	Low (only the mean river water flow is considered)	-	High (Estimated by GIS)	Low (Maximum depth is considered)
Method	-	Year Average	-	Sum	
Available region	-	Brazil	-	Brazil	Ribeira subwatershed

- Calculation of □□□□,□

□□□□,□ is 6.54 10^{-3} days and it is calculated by the equation 3. Table 20 details calculation and the data collected.

The water volume at Alto Iguaçu was calculated as the water volume at Ribeira. The lake surface area is also obtained by GIS and no data was found about reservoir surface area.

The P removal rate in rivers depends on the water flow rate, the higher water flow, the lower is the retention time, as detailed in table 19. The water flow average of Iguaçu River is 8.5 m^3/s, and its removal rate of phosphorus is 0.068day^{-1}(ALEXANDER et al., 2004). Its calculation is explained at the table 20.

Table 23. Removal rate of phosphorus at rivers
Source: ALEXANDER et al., 2004

Removal rate of phosphorus in rivers	Water flow
0.195day^{-1}	Q< 2.8 m^3 s^{-1}
0.068day^{-1}	2.8 m^3 s^{-1}<Q< 14.2 m^3 s^{-1}
0.012day^{-1}	Q> 14.2 m^3 s^{-1}

Table 24. Outcome rate by retention

Variables	$\square_{\square\square\square,\square\square}$	$\square_{\square\square\square,\square\square}$	$\square_{\square\square}$	$\square_{\square\square}$	$\square_{\square\square\square, \square\square\square,\square\square}$
Meaning	Outcome rates by retention at Alto Iguaçu subwatershed	Total water volume at Alto Iguaçu subwatershed	Water area surface of Alto Iguaçu subwatershed	Average depth of Iguaçu River	Removal rate of phosphorus at Alto Iguaçu
Units	day^{-1}	km^3	km^2	km	day^{-1}
Value	$6.54\ 10^{-3}$	$4.14\ 10^{-1}$	$8.27\ 10^{-2}$	$5\ 10^{-9}$	0.068
Source	Calculated by the equation 3 $\square_{\square\square\square,\square} = \frac{1}{\square_{\square\square\square,\square}}(\square_{\square\square\square,\square} . \square_{\square\square\square, \square\square\square,\square} + \square_{\square} . (\square_{\square\square\square,\square} + \square_{\square\square\square,\square}))$	$\square_{\square\square\square,\square\square} = \square_{\square\square} . \square_{\square\square}$	((AGUAS DO PARANÁ, 2016)	(MMA/ANA, 2011).	(ALEXANDER et al., 2004)
Qualitative analysis					
Year/Period	-	-	2016	2011	2004
Special differentiation	-	-	River, lake and reservoir	River	River
Representativeness	-	-	Medium (Reservoir isn't considered)	Medium (Average depth is considered)	Low (The same rate for all regions)
Method	-	-	Sum	Average	Average
Available region	-	-	Brazil	Alto Iguaçu	Global

Variables	$\square_{\square\square\square,\square\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square}$	$\square_{\square\square\square,\square\square}$	$\square_{\square\square\square,\square\square}$
Meaning	Iguaçu River volume	Water area surface of Iguaçu River	Average depth of Iguaçu River	Phosphorus uptake velocity at Alto Iguaçu subwatershed	Lake surface area at Alto Iguaçu subwatershed	Reservoir surface area at Alto Iguaçu subwatershed
Units	km^3	km^2	km	$km\cdot day^{-1}$	km^2	km^2
Value	$3.61\ 10^{-2}$	$7.22\ 10^{-3}$	$5\ 10^{-9}$	$3.80\ 10^{-5}$	6.6	0
Source	$\square_{\square\square\square,\square} = \square_{\square\square\square,\square} . \square_{\square\square\square,\square}$	(AGUAS DO PARANÁ, 2016)	(MMA/ANA, 2011)	(ALEXANDER et al., 2004)	(AGUAS DO PARANÁ, 2016)	Data not available, Therefore, the existence of reservoirs in this basin is disregarded
Qualitative analysis						
Year/Period	-	2016	2011	2004	2016	None
Especial differentiation	-	River	River	River	Lake	None
Representativeness	-	Medium (only the mean river is considered)	Low (Average depth is considered)	Low (The same rate for all regions)	Medium (only large lakes are considered)	Very low- (There is no data)
Method	-	Sum	Average	Average	Sum	None
Available region	-	Brazil	Iguaçu River	Global	Brazil	None

- Calculation of $\square_{\square\square\square,\square}$

$\square_{\square\square\square\ \square\square\square,\square}$ only regards the domestic use of water and, moreover, 0.8 is adopted for the water fraction that returns to the waterbody (M. Von Sperling, 1996).

Some assumptions are made to enable the fraction of P estimation removed by sewage treatment. The effluent at Alto Iguaçu watershed has 14mgP/l and this value is usually adopted for domestic effluents (M. Von Sperling, 1996). Around 71% of the sewage is collected (MMA/ANA, 2011) and treated in the region, and the treatment conforms with the CONAMA 430/2011 resolution, in other words, the water is returned to the waterbody with 4mg P/l, so 71,4% of P is removed. The outcome rate by advection is estimated at the last water station in the basin, Porto Amazonas station.

$\square_{\square\square\square\ \square\square\square,\square}$ is -3.25 10^{-4} days and it is calculated by the equation 10, which is better explained at the table 14. The negative value means this is an income rate of P, so the water use for the domestic sector returns to the water body with a higher concentration of P.

Only the dissolved organic and inorganic phosphorus are considered to estimate the fraction of total phosphorus emissions transferred from soil to the water, because the particulate phosphorus is much less reactive (ESTEVES, 1998).

$\square_{\square\square\square\ \square\square\square\square\square,\square}$ is -1.44 10^{-3} days and it is calculated by the equation 8, it is detailed at the table 21 and it is also an income rate.

Table 25. Calculation of income rate by water use for domestic purpose

Variables	$\square_{\square\square\square\ \square\square\square,\square}$	$\square_{\square\square\square,AI}$:	$\square_{\square\square\square\square\ \square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square}$	$\square_{\square\square\square,\square\square}$	$\square_{\square\square}$
Meaning	Income rate of P by water used for domestic purpose at Alto Iguaçu subwatershed	Fraction of water returned to downstream grid after being used for domestic sector at Alto Iguaçu subwatershed	Share of the total water use that is used for domestic purpose at Alto Iguaçu subwatershed	Outcome rate by advection of Alto Iguaçu subwatershed	Iguaçu river flow rate at Porto Amazonas station	Total water volume at Alto Iguaçu subwatershed	Fraction of P removed by sewage treatment at Alto Iguaçu subwatershed.
Units	day^{-1}	Dimensionless	Dimensionless	m^3/day	m^3/day	m^3	Dimensionless
Value	- 3.35. 10^{-4}	0.8	0.03	1.80 10^{-2}	1.80 10^{-2}	4.14 10^8	0.51
Source	Calculated by the equation 9 $\square_{\square\square\square\ \square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square\square\ \square} - (1 - \square_{\square\square\square}))$	(SPERLING M., VON, 1996) (SPERLING M., VON, 1996)	(ABASTECIMENTO URBANO, 2016)	Calculated by the equation 5 $\square_{\square\square\square,\square} = \frac{\square_{\square}}{\square_{\square\square\square,\square}}$	(COPEL, 2016)	Already estimated at $\square_{\square\square\square,\square\square}$	It is calculated by the equation 10 $\square_{\square\square} = \square.\ \square$
Qualitative analysis							
Year/Period	-	1996	2016	-	2016	-	-
Special differentiation	-	River	subwatershed	-	River	-	-
Representativeness	-	Low (The same rate for all regions)	High (Estimated by GIS)	-	Low (only the mean river water flow is considered)	-	-
Method	-	Average	Sum	-	Year Average	-	-
Available region	-	Global	Alto Iguaçu subwatershed	-	Brazil	-	-

Variables	□	□	$□_{□□□}$	□	$□_{□\ □□□□□□}$	$□_{□\ □□□}$
Meaning	Percentage of treated sewage at Alto Iguaçu 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 Iguaçu river	P concentration at non-treated sewage
Units	Dimensionless	Dimensionless	Dimensionless	mg/L	mg/L	mg/L
Value	0.72	0.71	0.28	-0.99	0,005	14
Source	(AGUAS DO AMANHÃ, 2011)	(CONAMA, 2011)	It is calculated by the equation 11 $□_{□□□} = (1 - □).□$	Calculated by the equation below. $□ = \frac{(□_{□\ □□□□□□} - □_{□\ □□□})}{□_{□\ □□□}}$	(KRAMER, 2012)	(CONAMA, 2011)
Qualitative analysis						
Year/Period	2011	2011	-	1996	2012	
Special differentiation	Alto Iguaçu subwatershed	Brazil	-		Iguaçu River	
Representativeness	Medium (treated sewage percenteage estimation)	Low (The same rate for all regions)	-		Low (Average of few samples)	
Method	Average	Average	-	Average		
Available region	Alto Iguaçu subwatershed	Brazil	-	Global		

Table 26. Calculation of income rate by water use for irrigation

Variables	$\square_{\square\square\square\ \square\square\square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square\square\ \square\square\square\square,\square}$	$\square_{\square\square\square\square,\square}$	$\square$	$\square_{\square\square\square,\square}$
Meaning	Outcome rate of P by water used for domestic purpose at Alto Iguaçu subwatershed	Fraction of water that returns to the waterbody after domestic use	Share of the total water use that is used for irrigation at Alto Iguaçu subwatershed	Fraction of total phosphorus emissions transferred to Alto Iguaçu subwatershed	Runoff rate at Alto Iguaçu subwatershed	Income rate of P by water used
Units		Dimensionless	Dimensionless	Dimensionless	mm.year^{-1}	day^{-1}
Value	-1.44 10^{-3}	0.8	0.02	7.37	1000	1.76 10^{-3}
Source	Calculated by the equation 8 $\square_{\square\square\square\ \square\square\square\square\square,\square} = \square_{\square\square\square,\square}$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $\square_{\square\square\square} = \frac{0.29}{(1+(\frac{\square}{0.85})^{-2})}$ $\square_{\square\square\square} = 0.01.\ \square^{0.95}$	(ATLAS, 2016)	Calculated by the equation below. $\square_{\square\square\square,\square} = \lvert\square_{\square\square\square\ \square\square\square,\square}\rvert - \square_{\square\square\square\ \square\square\square\square\square,\square}$
Qualitative analysis						
Year/Period	-	1996	2016	-	1950-2000	-
Special 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	-

The other basins calculation are detailed at Appendix I and all of their FF result are presented at the figure 7, input process at the 8 and output at the figure 9.

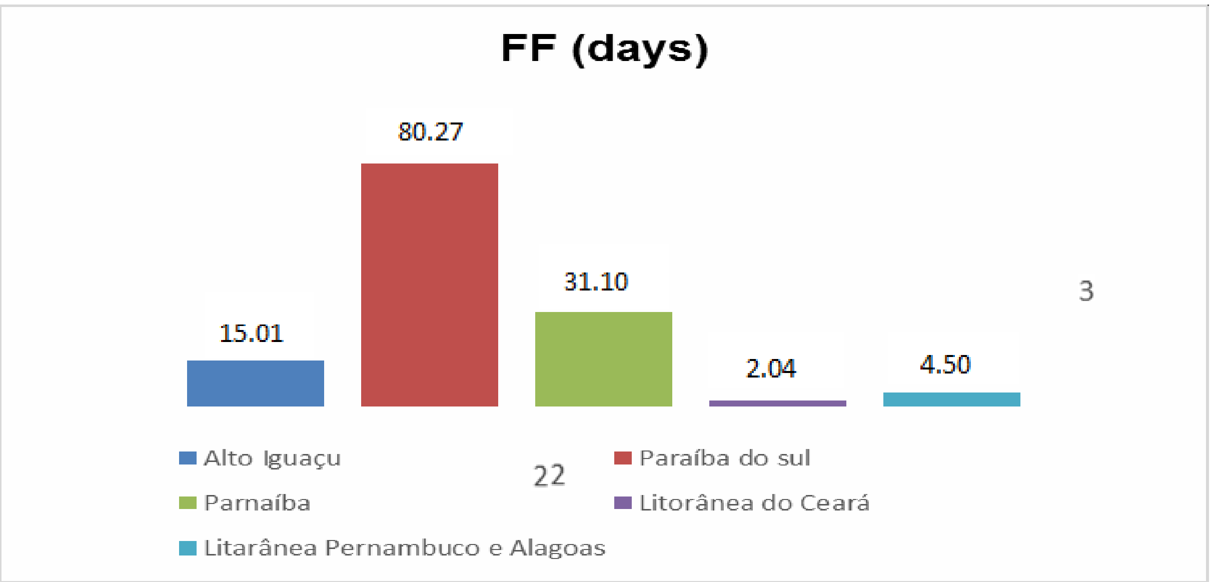


Figure 6: Subwatershed FF

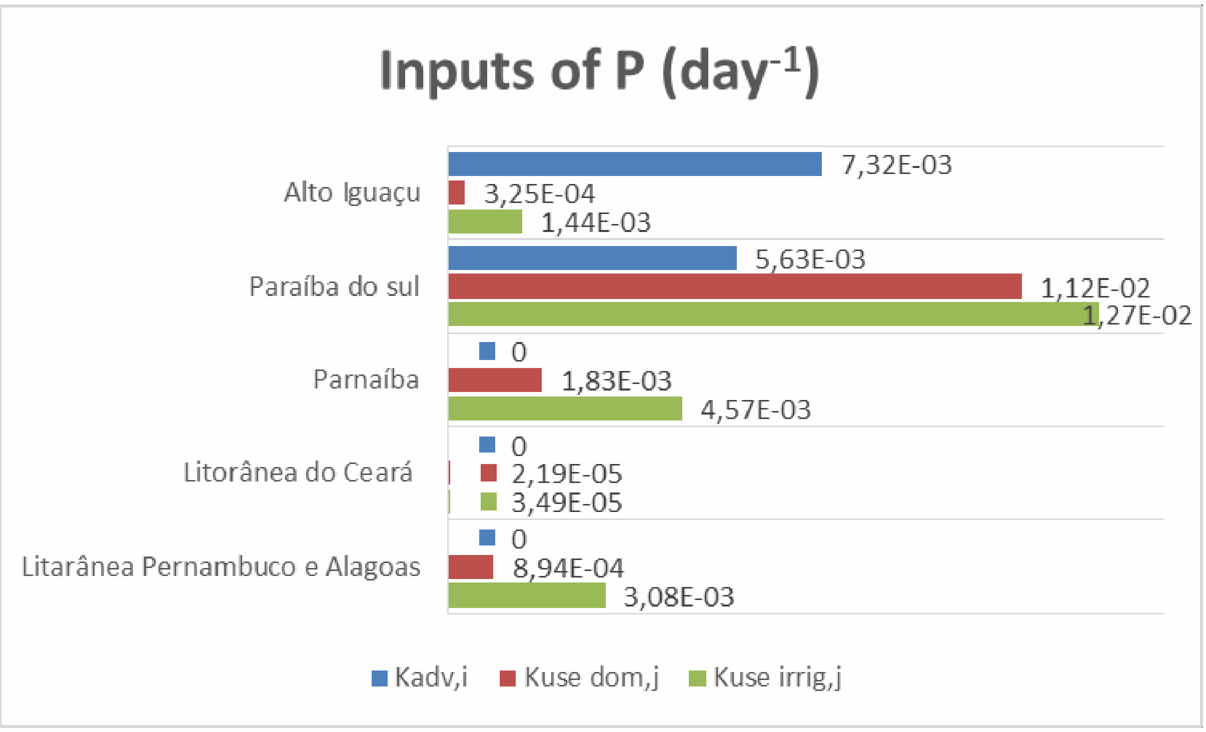


Figure 7. Subwatershed input rates

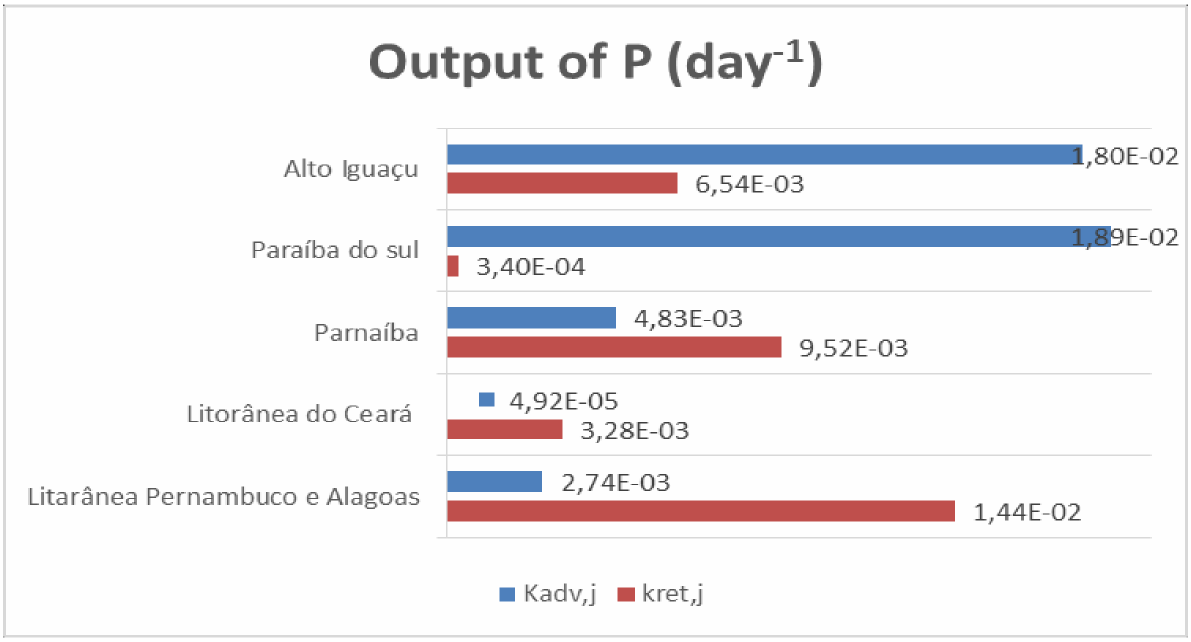


Figure 8. Subwatershed output rates

Helmes et al. (2012) estimate the FF of Alto Iguaçu between 30-300 days. According to the subwatershed model it is 15.01 days. Therefore, it is smaller than the estimated range. The dominant input process is □□□□,□ so the water from Ribeira River contributes substantially to the eutrophication at Alto Iguaçu. This region has a good sanitation reflected at □□□□,□□□,□ , which is very low.□□□□,□□□□□,□ is relevant, in spite of this basin location at an urban area. The amount of irrigation water is very low compared to the amount used for domestic supply.

The advection is also the most important output process. □□□□,□is significant, because the water flow from Iguaçu River to Alto Iguaçu is low, around 86 m^3/s, and this increases the P retention time appropriating 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 at Alto Iguaçu.

Parnaíba do Sul FF calculated by original model is also between 30-300 days and by the subwatershed model is 80.27 days. The FF of Parnaíba, Litorânea do Ceará and Litorânea Pernambuco Alagoas expected range is 3-10 days. By the subwatershed model the FF is 31.10, 2.04, 4.50 days. None of them is within the range.

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 the tropical altitude zone and the average temperature is from 17°C to 22°C (MMA/ANA). Paraiba 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 Parnaiba only 21%, the situation in Paraiba do Sul is worse, because it is located at a populous region, so the □□□□,□□□,□ and □□□□,□□□□□,□ are extremely high .

Furthermore, Paraíba River’s water flow is high, approximately 1120 m^3/s; consequently, $\square_{\square\square\square,\square}$ is lower and $\square_{\square\square\square,\square}$ is the highest. The $\square_{\square\square\square,\square}$ from Bacia Grande and Bacia Doce (1.13 10^{-3} and 4.51 10^{-3} days $^{-1}$ respectively) is quite relevant; therefore, to improve the eutrophication at Paraiba do Sul it is not enough to expand the sewage treatment. It is also necessary to invest at the effluent treatment of Bacia Grande and Bacia Doce. Industrial activity is very intense in this region, but the subwatershed model does not model it, so the FF should be worse than the estimated

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

For those three subwatersheds, $\square_{\square\square\square,\square}$ is zero because the spring rivers are located inside the basin; therefore, there is no income rate from upstream watershed and their dominant input rate is $\square_{\square\square\square,\square\square\square\square\square,\square}$. At the coast a large amount of sewage is dumped at the sea, the subwatershed model does not model the marine eutrophication and this can be the explanation of very low results of $\square_{\square\square\square,\square\square\square,\square}$ besides their poor sanitation.

Those three basins are located at a region with optimal temperature conditions for microalgae development and $\square_{\square\square\square,\square}$ is the dominant output process. At Litorânea Pernambuco Alagoas and Litorânea do Ceará suffer with water shortage resulting in low rates of $\square_{\square\square\square,\square}$

4.3 EF results

At Alto Iguaçu micro watershed TP concentration data of affluent rivers is not available, so the four collected values average at Iguaçu River is adopted. The coefficients α and β are used for stream water, because rivers volume are much bigger than the lake and the reservoir. The table 27 presents the data for Alto Iguaçu micro watershed, and the table 28 the result of Average, Marginal and Linear effect factor.

Table 27. Alto Iguaçu data to calculate EF

Variables	$\square\square\square\square_{\square\square}$:	$\square_{\square\square}$:	**α**	**β**
Meaning	Potentially non-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 by the equation $\square\square\square\square_{\square\square} = \frac{1}{1+\square\square\square^{\frac{-(\square\square\square\square_{\square\square}+}{0.63}}}$	(KRAMER, R. D. 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 28. EF results

Variables	$\square\square\square_{\square\square}$:	$\square\square\square_{\square\square}$:	$\square\square\square_{\square\square}$:
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 by the equation $\square\square\square_{\square\square} = \frac{\square\square\square\square_{\square\square}}{\square_{\square\square}}$	Calculated by the equation $\square\square\square_{\square\square} = \square\square\square\square_{\square\square} . (1 - \square\square\square\square_{\square\square}). \frac{1}{\square_{\square\square}. \square. \ln(10)}$	Calculated by the equation $\square\square\square_{\square\square} = \frac{0.5}{10^{\square}}$

Figure 10 details EF results obtained by the three models. The calculation and quality data are detailed at Appendix I.

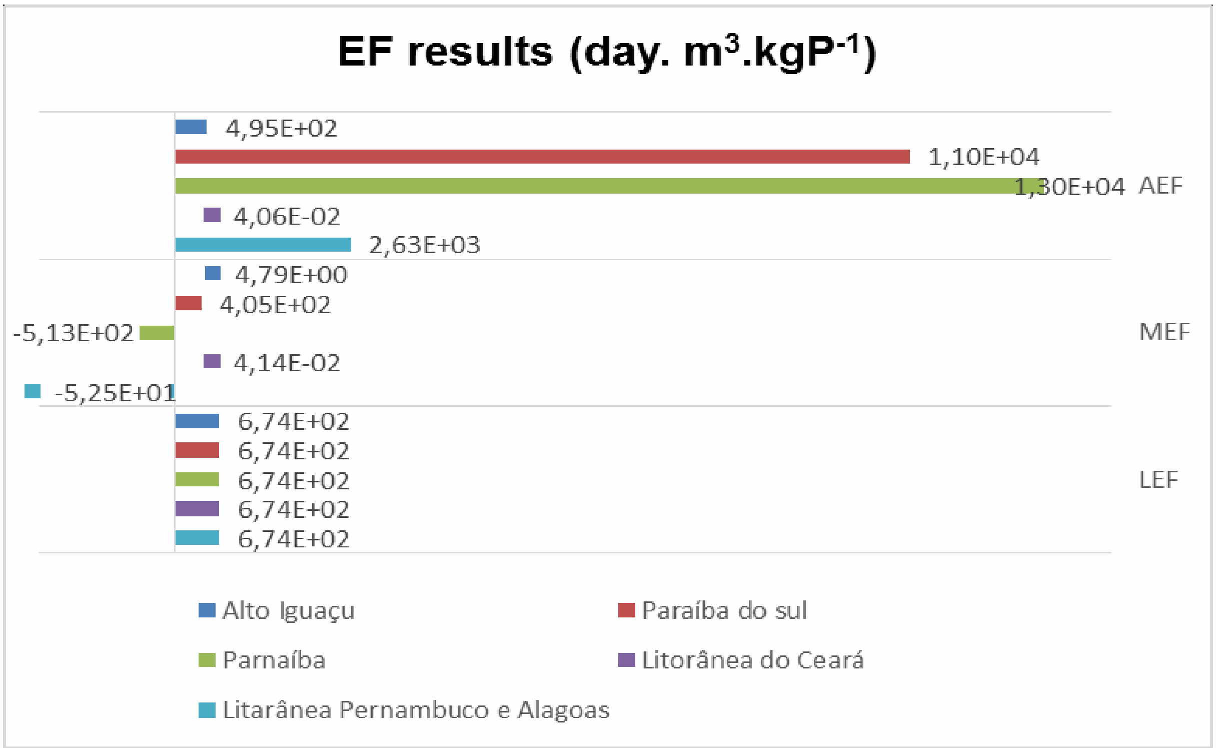


Figure 9. EF model results

LEF is used to estimate the effect if the concentration of P is unknown. It does not depend on TP concentration, and since there is not Brazilian data to estimate coefficient for stream water, the same α_w from literature is used for all subwatersheds. Moreover, LEF results in the same value for EF, what makes impossible to evaluate the effect by this model.

MEF measures small changes on TP concentration at waterbodies, 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.

Therefore, the AEF evaluates better the Brazilian subwatersheds. According to the AEF model, the same amount of dropped P affects more species richness at Alto Iguaçu, Parnaíba and Paraíba do Sul.

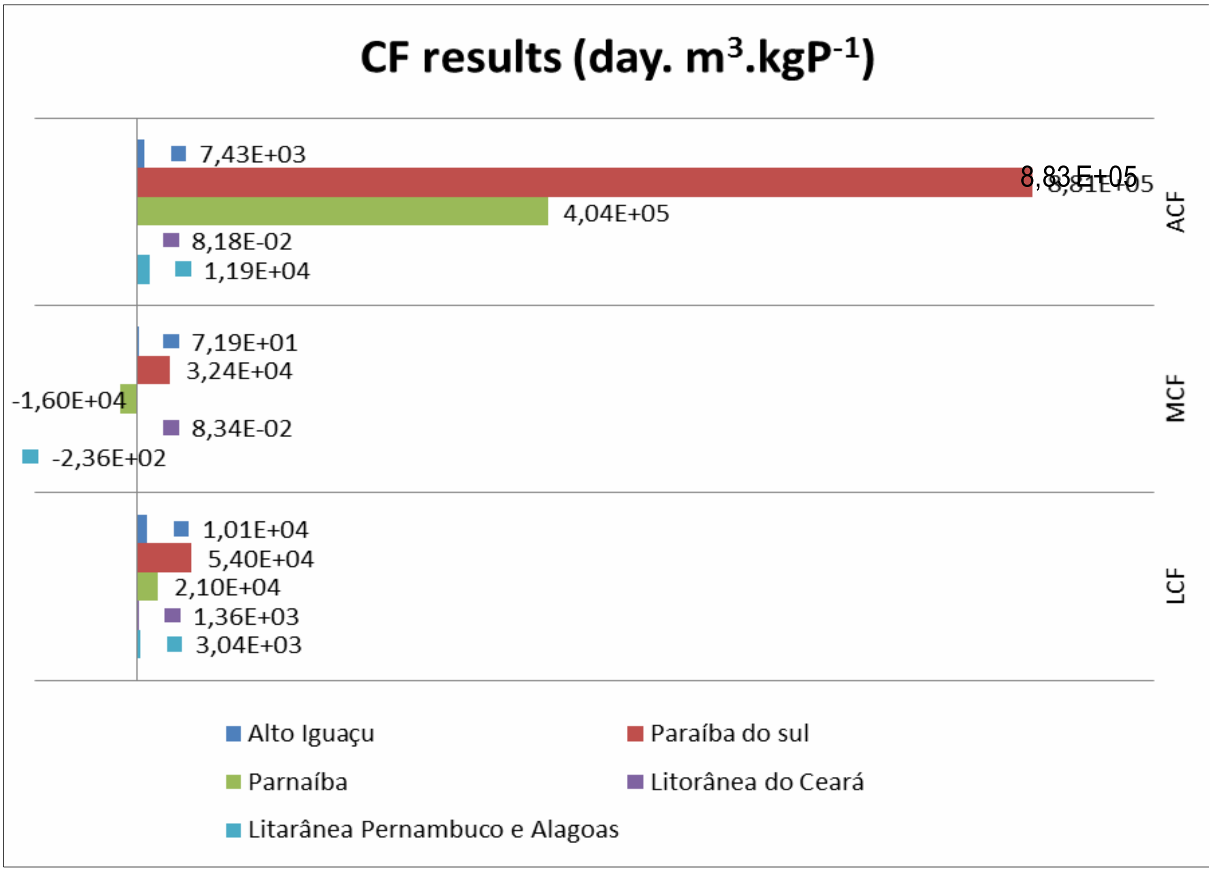
4.4 Characterization Factor results

Alto Iguaçu CF is calculated by three different EF models detailed at the table 29. ACF is the CF calculated by the Average EF model, MCF by the Marginal model and LCF by the Linear model.

Other basins CF calculations are detailed at the Appendix I and CF results are presented at the figure 11.

Table 29. CF results

Variables	□□□□□:	□□□□□:	□□□□□:
Meaning	CF calculated by the AEF model	CF calculated by the MEF model	CF calculated by the LEF model
Units	day.m^3 Kg^{-1}	day.m^3 Kg^{-1}	day.m^3 Kg^{-1}
Value	6.18 10^3	5.97 10^1	8.41 10^3
Source	□□ = □□.□□	□□ = □□.□□	□□ = □□.□□



‘**Figure 10.** CF results

LCF does not present good results. As mentioned before it is not capable to evaluate the effect at the subwatershed. MCF considers the waterbody initial trophy state (the P concentration is contemplated) but it presents negative values for regions which have a poor sanitation, making impossible to be used for the Brazilian context. The best CF is the ACF, because it allows watersheds comparison. Figure 12 presents the map of ACF.

Comparing figure 12 to figure 2 presented at topic 3.4, there is high concentration of hypereutrophy waterbodies at Paraíba do Sul and Alto Iguaçu, with a high eutrophication potential. At Parnaíba subwatershed is not possible to compare, because no waterbody at this basin was analyzed by ANA, but many of them should be hypereutrophy due to this region eminent CF..

According to figure 2 at the northeast coast the eutrophication is also concerning, at the Litorânea Pernambuco Alagoas and Litorânea do Ceará region. The Litorânea Pernambuco Alagoas presents higher CF than Alto Iguaçu, but Litorânea do Ceará has the lowest eutrophication potential. This apparent contradiction can be explained by low water availability and dump of untreated sewage at ocean.

Figure 11: CF map (day.m^3.kg P^{-1})

Comparing the map of the European CF (Figure 13) to the map of the Brazilian CF (Figure 14), the subwatershed model is quite coherent.

In Europe the lowest CF is in the north and at the cost, due to the low temperature of this regions and because a share of effluent is dumped at the ocean. The highest CF is at the south, where the temperature average is higher. The situation is similar in Brazil, except for the Litorânea do Ceará, which has a very low CF in spite of having tropical climate.

Based on the qualitative analysis of collected data it is possible to affirm the data does not have good representativeness. Because only data about the mean river of each basin is available and no information about affluent river was found. Data about reservoir is not accessible and some coefficients exist just for the European context. Moreover, data periods have a lot of variability, many of them need update. Therefore, for the subwatershed model become more applicable, the data quality needs improvement.

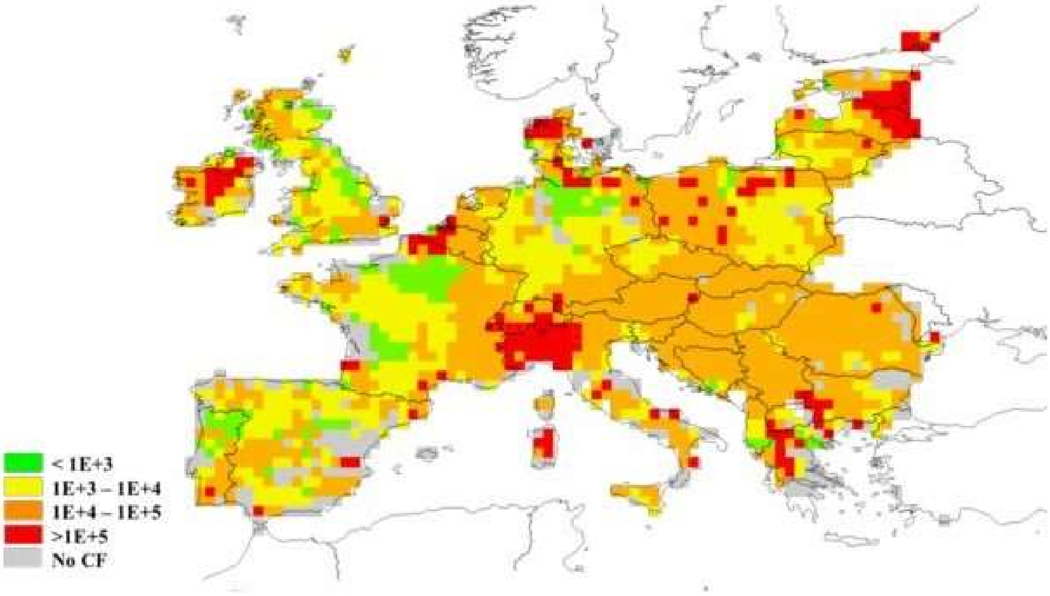


Figure 12: Europe CF

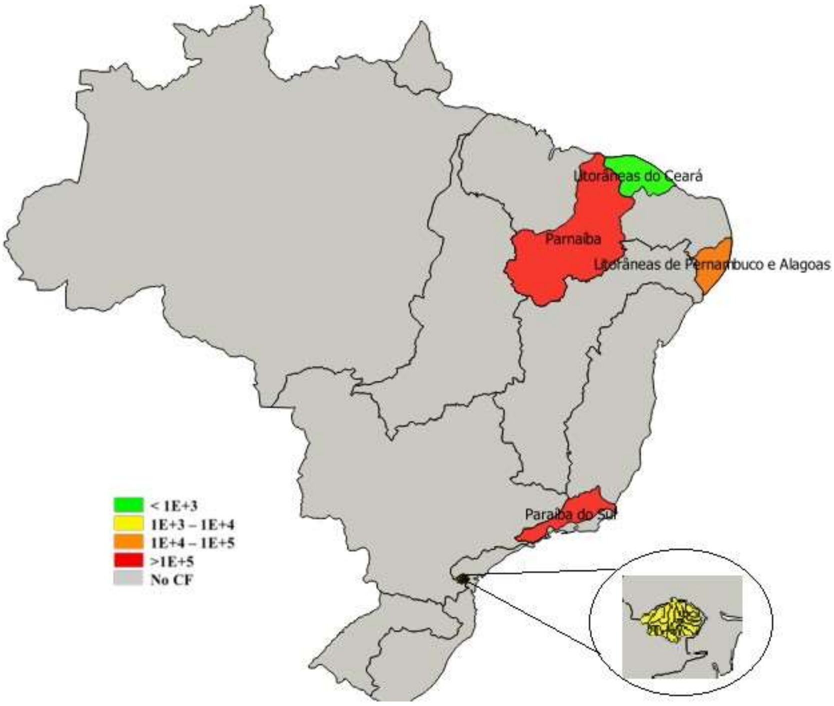


Figure 13: Brazil CF

5 CONCLUSION

The proposed goal to regionalize a LCIA method for the Brazilian reality was achieved. The adequacy and feasibility of the LCIA methods were checked. The most suitable method was to regionalize promoting a more coherent CF to the Brazilian subwatersheds. This is the first study that presents a subwatershed model to estimate the Brazilian CF for freshwater eutrophication.

Due to 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 them, Paraíba do Sul has the highest FF, 80.27 days^{-1}, the main reasons are the elevated income rate by water use of domestic agriculture sectors and the very low retention rate. Alto Iguaçu's FF is 15.01 days^{-1} and the phosphorus coming from the Ribeira by the advection contributes the most to this result.

Parnaíba, Litorânea do Ceará and Litorânea Pernambuco Alagoas have very bad sanitation, but unlike expected these subwatersheds have low FF, 31.10, 2.04 and 4.50 days^{-1} respectively. The reason is the effluent disposal at sea.

Assessing the advection, retention and water use processes it was possible to provide valuable information of each region and also promote more realistic FF, since the Brazilian sanitation is completely uneven, and the sewage treatment must be modelled to not overestimate or underestimate the FF.

The Average Effect Factor model evaluates better the effect caused by the phosphorus emission. The same amount of emitted phosphorus impacts more in Paraíba do Sul, which EF is 1.3 10^{4}. m^{3}.KgP^{-1}, then Parnaíba (1.1 10^{4}. m^{3}.KgP^{-1}), Litorânea do Ceará (2.63 10^{3} m^{3}.KgP^{-1}), Alto Iguaçu(4.95 10^{2} m^{3}.KgP^{-1}) and finally Litorânea Pernambuco Alagoas (4.06 10^{-4}. m^{3}.KgP^{-1}).

Paraíba do Sul and Parnaíba's CF are the highest, 8.83 10^{5}.and 4.04 10^{5}. m^{3}.KgP^{-1} day m^{3}. respectively. The CF of Litorânea Pernambuco Alagoas is 1.19 10^{4}. m^{3}.KgP^{-1} day, Alto Iguaçu is 7.43 10^{3}. m^{3}.KgP^{-1} day and Litorânea do Ceará is 8.30 10^{-2}. m^{3}.KgP^{-1} day.

Despite of the existence of a responsible committee to monitor the water quality at the basins to find the necessary data it was an important part of the study and the available data regards sub or micro watershed geographic differentiation. Consequently, it is complicated to apply the original model, where the geographic differentiation is 0.5°x 0.5°grid. Therefore, the subwatershed model is easier to work with and it promotes higher quality information, which can be used to make strategic decisions in order to avoid eutrophication impact.

Understanding the subwatershed reality, it becomes possible to direct financial resources to prioritize preventive actions, such as sanitation and environmental education programmes.

This was the first attempt to develop a Brazilian CF and some improvement needs to be done. Firstly, new studies ought to promote good data quality and affluent rivers data, such as lakes and reservoirs. Then the subwatershed model should be improved modeling industrial sewage treatment and, finally, CF needs to be calculated for all subwatersheds.

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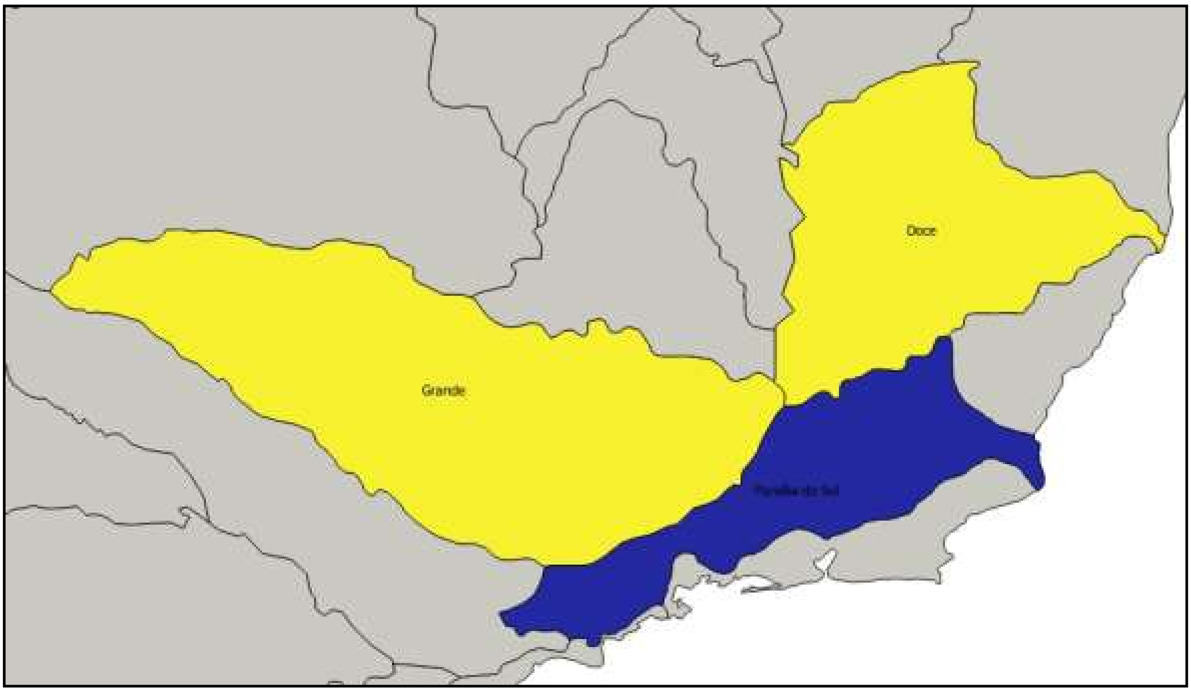
APPENDIX I

- **Paraiba do Sul subwatershed**

Paraiba 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). Paranaiba 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 □□□□,□

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 10^{-3} $days^{-1}$, which is the sum of the rate of both rivers.

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

Variables	$\square_{\square\square\square,\square\square\square\square\square\square\square}$	$\square_{\square\square\square\square\square\square\square}$	$\square_{\square\square\square,\square\square\square\square\square\square\square}$	$\square_{\square\square\square\square\square\square\square}$	$\square_{\square\square\square\square\square\square\square}$
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 $\square_{\square\square\square,\square} = \frac{\square_{\square}}{\square_{\square\square\square,\square}}$	(ATLAS DAS AGUAS, 2016)	Calculated by the equation below $\square_{\square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square,\square}$	(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	$\square_{\square\square\square,\square\square\square\square}$	$\square_{\square\square\square\square}$	$\square_{\square\square\square,\square\square\square\square}$	$\square_{\square\square\square\square}$	$\square_{\square\square\square\square}$	$\square_{\square\square\square,\square\square\square}$
Meaning	Income rates by advection of Bacia Doce subwatershed	Pomba river flow rate at the spring of Parnaiba 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 $\square_{\square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square,\square}$	(DISPONIBILIDADE HIDRICA, 2016)	(CPRJ, 2006)	$\square_{\square\square\square,\square\square\square} = \square_{\square\square\square,\square\square} + \square_{\square\square\square,\square\square}$
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 $□_{□□□,□}$

$□_{□□□,□}$ is 3.4 10^{-4}days^{-1}. Water volume data of Paraíba do Sul is available. P removal rate at rivers is 0.012 day^{-1} because Parnaíba do Sul flow rate is higher than 14.55 m^{3}/s(ALEXANDER et al., 2004).

Variables	$□_{□□□,□□}$	$□_{□□□,□□}$	$□_{□□□, □□□,□□}$	$□_{□□□,□□}$
Meaning	Outcome rates by retention of Parnaiba do Sul subwatershed	Total water volume of Parnaiba do Sul subwatershed	Removal rate of phosphorus Parnaiba do Sul River	Parnaiba do Sul River volume
Units	day^{-1}	km^{3}	day^{-1}	km^{3}
Value	3.4 10^{-4}	5.12	0.012	1.44 10^{-1}
Source	Calculated by the equation 3 $□_{□□□,□} = \frac{1}{□_{□□□,□}}(□_{□□□,□} . □_{□□□, □□□,□} + □_{□}.(□_{□□□,□} + □_{□□□,□}))$	(BOLETIM, 2016)	(ALEXANDER et al., 2004)	Calculated by the equation below $□_{□□□,□} = □_{□□□,□} . □_{□□□,□}$
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	$□_{□□□,□}$	$□_{□□□,□}$	$□_{□}$	$□_{□□□,□□}$
Meaning	Water surface area of Parnaiba do Sul River	Average depth of Parnaiba do Sul River	Phosphorus uptake velocity at Parnaiba do Sul subwatershed	Lake and Reservoir surface area at Parnaiba do Sul subwatershed
Units	km^2	km	$km \cdot day^{-1}$	km^2
Value	$9.58\ 10^{-2}$	$1.5\ 10^{-3}$	$3.80\ 10^{-5}$	$4{,}29\ 10^{-1}$
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 $□_{□□□,□}$

It is -1,44 10^{-2}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	$□_{□□□\ □□□,□}$	$□_{□□□,AI}$:	$□_{□□□□\ □□□,□}$	$□_{□□□,□}$	$□_{□□}$
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 10^{-2}	0.8	0.55	1.89 10^{-2}	0.26
Source	Calculated by the equation 9 $□_{□□□\ □□□,□} = □_{□□□,□} \cdot □_{□□□□\ □□□,□} \cdot □_{□□} - (1 - □_{□□□}))$	(SPERLING M., VON, 1996)	(ABASTECIMENTO URBANO, 2016)	Calculated by the equation 5 $□_{□□□,□} = \frac{□_{□}}{□_{□□□,□}}$	It is calculated by the equation 10 $□_{□□} = □.\ □$
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	$\square$	$\square$	$\square_{\square\square\square}$	$\square$	$\square_{\square\,\square\square\square\square\square}$	$\square_{\square\,\square\square}$
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 $\square_{\square\square\square} = (1 - \square).\square$	Calculated by the equation below. $\square$ $-\frac{(\square_{\square\square\square\square\square\square\square} - \square_{\square\,\square\square})}{\square_{\square\,\square\square}}$	(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	$\square_{\square\square\square\ \square\square\square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square\square\ \square\square\square\square,\square}$	$\square_{\square\square\square\square,\square}$	$\square$	$\square_{\square\square\square,\square}$
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	$\square_{\square\square\square\ \square\square\square\square\square,\square} = \square_{\square\square\square,\square} . \square_{\square\square\square\square\ \square\square\square\square,} - \square_{\square\square\square\square,\square})$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $\square_{\square\square\square} = \frac{0.29}{(1+(\frac{\square}{0.85})^{-2})}$ $\square_{\square\square\square} = 0.01. \square^{0.95}$	(ATALAS,2016)	Calculated by the equation below. $\square_{\square\square\square,\square} = \lvert\square_{\square\square\square\ \square\square\square,\square}\rvert - \square_{\square\square\square\ \square\square\square\square\square,\square}$
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	$\square\square\square\square_{\square\square}$:	$\square_{\square\square}$:	**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 $\square\square\square\square_{\square\square} = \frac{1}{1+\square\square\square^{\frac{-(\square\square\square\square_{\square\square}+0.54)}{0.63}}}$	(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

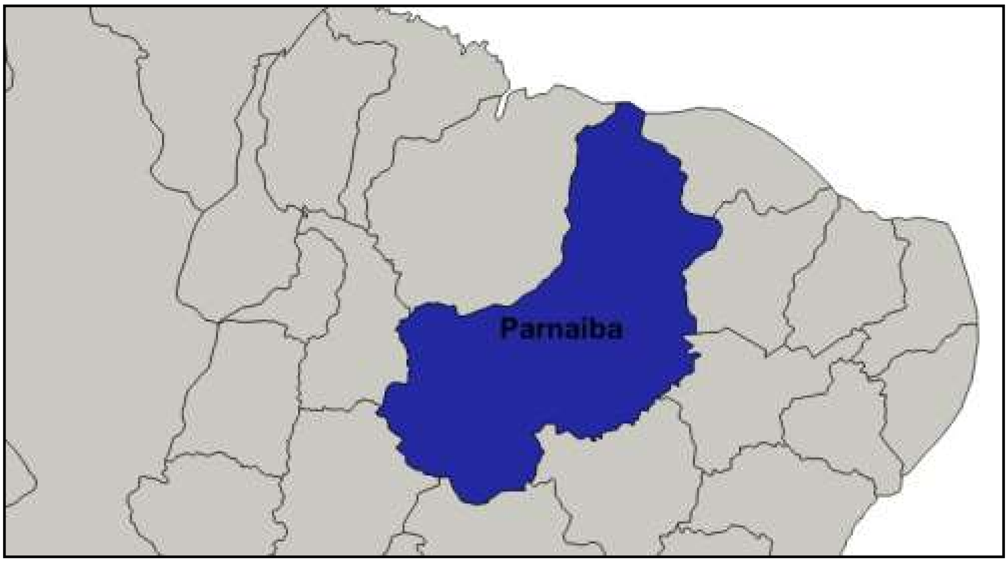
- CF calculation

The CF is calculated by the three different EF models.

Variables	$\square\square\square_{\square}$	$\square\square\square_{\square}$	$\square\square\square_{\square}$
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	1.10 10^4	4.05 10^2	6.74 10^2
Source	Calculated by the equation $\square\square\square_{\square\square} = \frac{\square\square\square\square_{\square\square}}{\square_{\square\square}}$	Calculated by the equation $\square\square\square_{\square\square} = \square\square\square\square_{\square\square}.(1-\square\square\square\square_{\square\square}).\frac{1}{\square_{\square\square}.\square.\ln(10)}$	Calculated by the equation $\square\square\square_{\square\square} = \frac{0.5}{10^{\square}}$
Variables	$\square\square\square_{\square}$	$\square\square\square_{\square}$	$\square\square\square_{\square}$
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 10^{-5}	3.25 10^4	5,41 10^4
Source	$\square\square = \square\square . \square\square$-	$\square\square = \square\square . \square\square$	$\square\square = \square\square . \square\square$

- **Parnaiba subwatershed**

Parnaiba is located at the northeast of Brazil and in a megathermal rainy zone, which has an average temperature from 16º C to 32° C. Approximately 4.152.865 inhabitants live in this region. Parnaiba 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 $□_{□□□,□}$

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	$□_{□□□,□}$	$□_{□□□,□}$	$□_{□}$	$□_{□}$	$□_{□□□, □□□,□}$
Meaning	Outcome rates by retention of Parnaiba subwatershed	Total water volume of Parnaiba subwatershed	Water surface area of Parnaiba subwatershed	Average depth of Parnaiba River	Removal rate of phosphorus of Parnaiba 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 $□_{□□□,□} = \frac{1}{□_{□□□,□}}(□_{□□□,□} . □_{□□□, □□□,□} + □_{□}.(□_{□□□,□} + □_{□□□,□}))$	Calculated by the equation below. $□_{□□□,□} = □_{□} . □_{□}$	(BOLETIM,2016)	(CPRJ, 2006)	ALEXANDER et al, 2004
Qualitative analysis					
Year/Period	-	-	2016	2006	2004
Especial differentiation	-	-	River, lake and reservoir	River	River
Representativenes s	-	-	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	$\square_{\square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square}$	$\square_{\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square,\square}$
Meaning	Volume of Parnaiba do Sul River	Water surface area of Parnaiba do Sul River	Average depth of Parnaiba River	Phosphorus uptake velocity at Parnaiba subwatershed	Lake surface area of Parnaiba subwatershed	Reservoir surface area of Parnaiba subwatershed
Units	km^3	km^2	km	$km \cdot day^{-1}$	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. $\square_{\square\square\square,\square} = \square_{\square\square\square,\square} . \square_{\square}$	(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 $□_{□□□,□}$

$□_{□□□,□}$ is -1.18 10^{-3}day^{-1}and it is calculated by the equation 7. The same consideration made for Alto Iguaçu is used for Parnaíba subwatershed.

Variables	$□_{□□□ □□□,□}$	$□_{□□□,□}$:	$□_{□□□□ □□□,□}$	$□_{□□□,□}$	$□_{□□}$
Meaning	Removal rate by water use of Parnaiba 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 Parnaiba subwatershed	Fraction of P removed by sewage treatment.
Units	day^{-1}	Dimensionless	Dimensionless	day^{-1}	Dimensionless
Value	-1.83 10^{-3}	0.8	0.31	4.83 10^{-3}	0.15
Source	Calculated by the equation 9 $□_{□□□ □□□,□} = □_{□□□,□} \cdot □_{□□□□ □□□,□} \cdot □_{□□} - (1 - □_{□□□}))$	(SPERLING M., VON, 1996)	(ABASTECIMENTO URBANO, 2016)	Calculated by the equation 5 $□_{□□□,□} = \frac{□_{□}}{□_{□□□,□}}$	It is calculated by the equation 10 $□_{□□} = □.□$
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	$\square$	$\square$	$\square_{\square\square\square}$	$\square$	$\square_{\square\ \square\square\square\square\square}$	$\square_{\square\ \square\square}$
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 $\square_{\square\square\square} = (1 - \square).\square$	Calculated by the equation below. $\square = -\frac{(\square_{\square\square\square\square\square\square\square} - \square_{\square\ \square\square})}{\square_{\square\ \square\square}}$	(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	$\square_{\square\square\square\ \square\square\square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square\square\ \square\square\square\square,\square}$	$\square_{\square\square\square\square,\square}$	$\square$	$\square_{\square\square\square,\square}$
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	$\square_{\square\square\square\ \square\square\square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square\square\ \square\square\square\square,\square} \cdot - \square_{\square\square\square\square,\square})$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $\square_{\square\square\square} = \frac{0.29}{(1 + (\frac{\square}{0.85})^{-2})}$ $\square_{\square\square\square} = 0.01.\ \square^{0.95}$	(ATALAS,2016)	Calculated by the equation below. $\square_{\square\square\square,\square} = \lvert\square_{\square\square\square\ \square\square\square,\square}\rvert - \square_{\square\square\square\ \square\square\square\square\square,\square}$
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	$\square\square\square\square_{\square}$	$\square_{\square}$	**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 $\square\square\square\square_{\square\square} = \frac{1}{1+\square\square\square^{\frac{-(\square\square\square\square_{\square\square}+0.54)}{0.63}}}$	(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

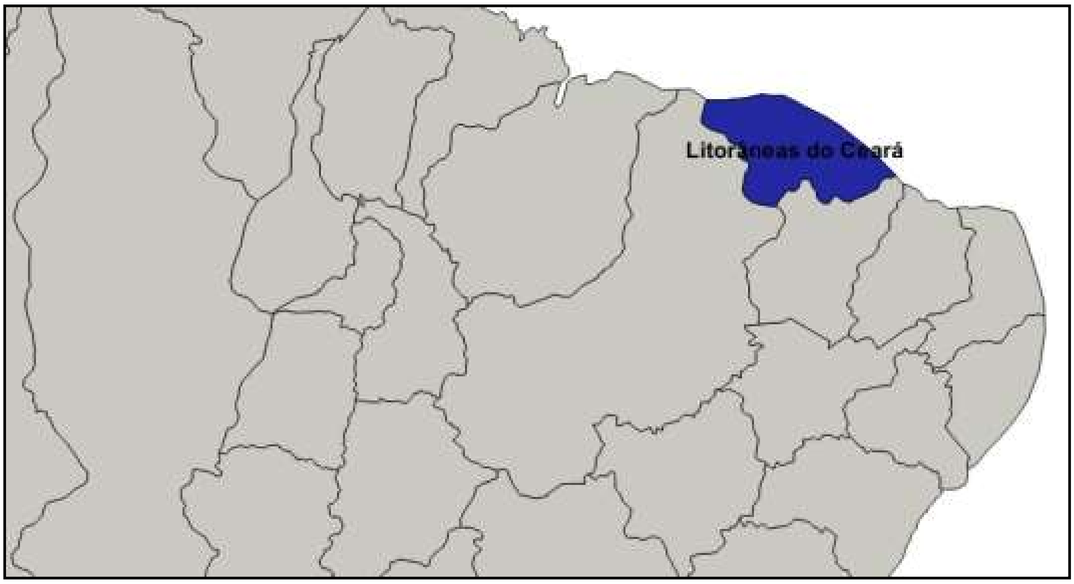
- CF calculation

CF is calculated using three different EF models.

Variables	$\square\square\square_{\square\square}$:	$\square\square\square_{\square\square}$:	$\square\square\square_{\square\square}$:
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	1.30 10^4	-5.13 10^2	6,74 10^2
Source	Calculated by the equation $\square\square\square_{\square} = \frac{\square\square\square\square_{\square}}{\square_{\square}}$	Calculated by the equation $\square\square\square_{\square\square} = \square\square\square\square_{\square\square} .(1 - \square\square\square\square_{\square\square}). \frac{1}{\square_{\square\square}. \square. \ln(10)}$	Calculated by the equation $\square\square\square_{\square\square} = \frac{0.5}{10^{\square}}$
Variables	$\square\square\square_{\square\square}$:	$\square\square\square_{\square\square}$:	$\square\square\square_{\square\square}$:
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 10^5	-1.60 10^4	2.10 10^4
Source	$\square\square = \square\square . \square\square$-	$\square\square = \square\square . \square\square$	$\square\square = \square\square . \square\square$

- **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 $\square_{\square\square\square,\square}$

Litorânea do Ceará (LC) $\square_{\square\square\square,\square}$ is 3,28 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 10^{-2} km^3.

LC water flow rate is the sum of the average values of the five main stem flow rates (96,68m^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	$\square_{\square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square,\ \square\square\square,\square}$	$\square_{\square\square\square,\square}$
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 $\square_{\square\square\square,\square} = \frac{1}{\square_{\square\square\square,\square}}(\square_{\square\square\square,\square} \cdot \square_{\square\square\square,\ \square\square\square,\square} + \square_{\square}.(\square_{\square\square\square,\square} + \square_{\square\square\square,\square}))$	(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	$\square_{\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square,\square}$
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 $□_{□□□,□}$

$□_{□□□,□}$ -5.71 10^{-5} day^{-1}. The same consideration for Alto Iguaçu is used for Litorânea do Ceará subwatershed

Variables	$□_{□□□\ □□□,□}$	$□_{□□□,□}$:	$□_{□□□□\ □□□,□}$	$□_{□□□,□}$	$□_{□□}$
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 10^{-5}	0.8	0.41	4.92 10^{-5}	0.25
Source	Calculated by the equation 9 $□_{□□□\ □□□,□} = □_{□□□,□} \cdot □_{□□□□\ □□□,□} \cdot □_{□□} - (1 - □_{□□□}))$	(SPERLING M., VON, 1996)	(ABASTECIMENTO URBANO, 2016)	Calculated by the equation 5 $□_{□□□,□} = \frac{□_{□}}{□_{□□□,□}}$	It is calculated by the equation 10 $□_{□□} = □.\ □$
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	$\square$	$\square$	$\square_{\square\square\square}$	$\square$	$\square_{\square\,\square\square\square\square\square\square}$	$\square_{\square\,\square\square}$
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 $\square_{\square\square\square} = (1 - \square).\square$	Calculated by the equation below. $\square$ $-\frac{(\square_{\square\square\square\square\square\square\square} - \square_{\square\,\square\square}}{\square_{\square\,\square\square}}$	(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	$\square_{\square\square\square\ \square\square\square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square\square\square\ \square\square\square\square,\square}$	$\square_{\square\square\square\square,\square}$	$\square$	$\square_{\square\square\square,\square}$
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	$\square_{\square\square\square\ \square\square\square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square\square\ \square\square\square\square,\square} \cdot - \square_{\square\square\square\square,\square})$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $\square_{\square\square\square} = \frac{0.29}{(1 + (\frac{\square}{0.85})^{-2})}$ $\square_{\square\square\square} = 0.01.\ \square^{0.95}$	(ATLAS,2016)	Calculated by the equation below. $\square_{\square\square\square,\square} = \lvert\square_{\square\square\square\ \square\square\square,\square}\rvert - \square_{\square\square\square\ \square\square\square\square\square,\square}$
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	Parnaiba subwatershed	-	Global	-

- EF calculation

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

Variables	$\square\square\square\square_{\square}$	$\square_{\square}$	**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 $\square\square\square\square_{\square\square} = \frac{1}{1+\square\square\square^{\frac{-(\square\square\square\square_{\square\square}+0.54)}{0.63}}}$	(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

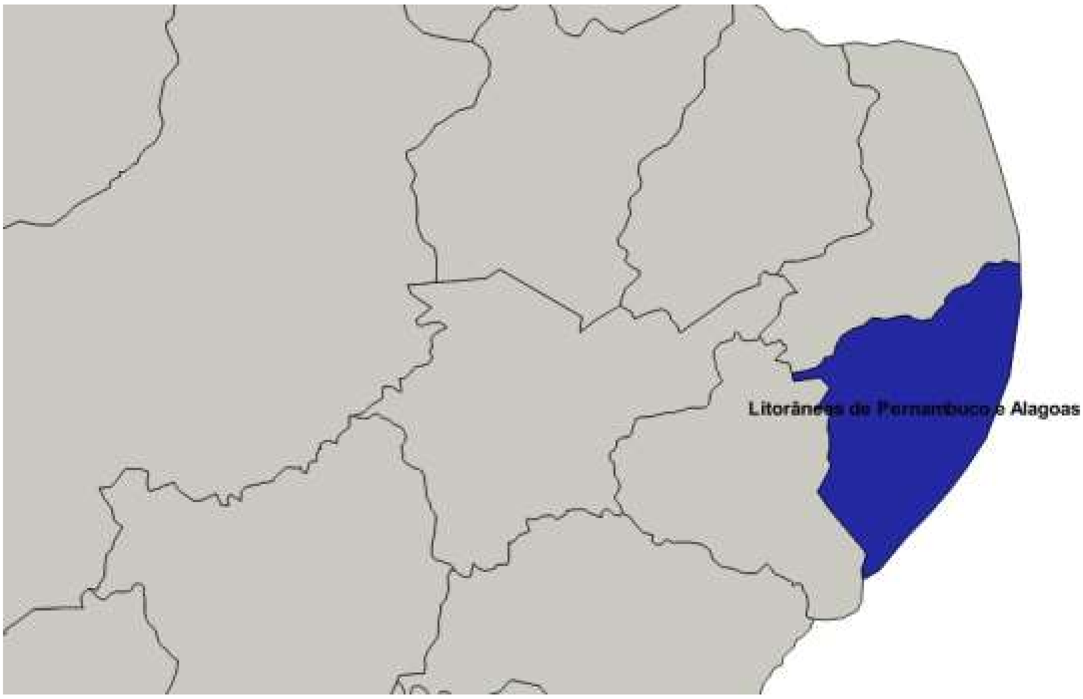
- CF calculation

CF is calculated by three different EF models.

Variables	$□□□_{□}$	$□□□_{□}$	$□□□_{□}$
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	4.06 10^{-2}	4.14 10^{-2}	6,74 . 10^{2}
Source	Calculated by the equation $□□□_{□□} = \frac{□□□□_{□□}}{□_{□□}}$	Calculated by the equation $□□□_{□□} = □□□□_{□□} .(1 - □□□□_{□□}). \frac{1}{□_{□□}. □. \ln(10)}$	Calculated by the equation $□□□_{□□} = \frac{0.5}{10^{□}}$
Variables	$□□□_{□}$	$□□□_{□}$	$□□□_{□}$
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 10^{-2}	8.46 10^{-2}	1.58 10^{3}
Source	$□□ = □□ . □□$-	$□□ = □□ . □□$	$□□ = □□ . □□$

- **Litorânea Pernanbuco Alagoas**

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



- FF calculation
    - Calculation of $\square_{\square\square\square,\square}$

Litorânea Pernambuco Alagoas (LPA) $\square_{\square\square\square,\square}$ is 1.44 10^{-2} 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 68m^3/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	$□_{□□□,□}$	$□_{□□□,□}$	$□_{□□□,□□□,□}$	$□_{□□□,□}$
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 $□_{□□□,□} = \frac{1}{□_{□□□,□}}(□_{□□□,□} \cdot □_{□□□,□□□,□} + □_{□}.(□_{□□□,□} + □_{□□□,□}))$		(ALEXANDER et alL, 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	$□_{□}$	$□_{□□□,□}$	$□_{□□□,□}$
Meaning	Phosphorus uptake velocity at LPA subwatershed	Lake surface area of LPA subwatershed	Reservoir surface area of LPA subwatershed
Units	$km \cdot day^{-1}$	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

- Calculation of $\square_{\square\square\square,\square}$

Variables	$\square_{\square\square\square\ \square\square\square,\square}$	$\square_{\square\square\square,\square}$:	$\square_{\square\square\square\square\ \square\square\square,\square}$	$\square_{\square\square\square,\square}$	$\square_{\square\square}$
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	$-8.64\ 10^{-4}$	0.8	0.26	$2.74\ 10^{-3}$	0.16
Source	Calculated by the equation 9 $\square_{\square\square\square\ \square\square\square,\square} = \square_{\square\square\square,\square} \cdot \square_{\square\square\square\square\ \square\square\square,\square} \cdot \square_{\square\square} - (1 - \square_{\square\square\square}))$	(SPERLING M., VON, 1996)	(ABASTECIMENTO URBANO, 2016)	Calculated by the equation 5 $\square_{\square\square\square,\square} = \frac{\square_{\square}}{\square_{\square\square\square,\square}}$	Calculated by the equation 10 $\square_{\square\square} = \square.\ \square$
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	$\square$	$\square$	$\square_{\square\square\square}$	$\square$	$\square_{\square\,\square\square\square\square\square}$	$\square_{\square\,\square\square}$
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 $\square_{\square\square\square} = (1 - \square).\square$	Calculated by the equation below. $\square - \frac{(\square_{\square\,\square\square\square\square\square} - \square_{\square\,\square\square}}{\square_{\square\,\square\square}}$	(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	$□_{□□□\ □□□□□,□}$	$□_{□□□,□}$	$□_{□□□□\ □□□□,□}$	$□_{□□□□,□}$	$□$	$□_{□□□,□}$
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	$□_{□□□\ □□□□□,□} = □_{□□□,□} \cdot □_{□□□□\ □□□□,} - □_{□□□□,□})$	(SPERLING M., VON, 1996)	(IRRIGAÇÃO, 2016)	Calculated summing the equations 8 and 9 $□_{□□□} = \frac{0.29}{(1 + (\frac{□}{0.85})^{-2})}$ $□_{□□□} = 0.01.\ □^{0.95}$	(ATALAS,2016)	Calculated by the equation below. $□_{□□□,□} = \|□_{□□□\ □□□,□}\| - □_{□□□\ □□□□□,□}$
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	$\square\square\square\square_{\square}$	$\square_{\square}$	**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 $\square\square\square\square_{\square\square} = \frac{1}{1+\square\square\square^{\frac{-(\square\square\square\square_{\square\square}+0.54)}{0.63}}}$	(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	□□□$_{□}$	□□$_{□}$	□□□$_{□}$
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	2.63 10^{-3}	-5.25 10^{-1}	6,74 . 10^{2}
Source	Calculated by the equation $□□□_{□□} = \frac{□□□□_{□□}}{□_{□□}}$	Calculated by the equation $□□□_{□□} = □□□□_{□□} .(1-□□□□_{□□}). \frac{1}{□_{□□}. □. \ln(10)}$	Calculated by the equation $□□□_{□□} = \frac{0.5}{10^{□}}$
Variables	□□□$_{□}$	□□□$_{□}$	□□□$_{□}$
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 10^{-4}	-2.36 10^{2}	3.04 10^{3}
Source	□□ = □□ . □□-	□□ = □□ . □□	□□ = □□ . □□