Strategies for water quality reservoir assessment: Water Quality Index, Trophic State Index and Fuzzy Logic

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Among all the basic needs for human survival it is possible to highlight the vital importance of water in all processes. Thus, assessment of water quality, not only, the amount of water is required and should be made based on studies to characterize the quality in order to define their application and even its reuse. Some of these studies are represented mathematically by a Water Quality Index (WQI) and the Trophic State Index (TSI) which can classify water reservoirs, for example, according to the incidence of eutrophication process. In this work, there was the study of the water body of the dam Macela in Itabaiana, Sergipe, determining algebraically WQI and STI and using fuzzy logic.

Keywords: Water Quality Index; fuzzy logic; Trophic State Index.

1. INTRODUCTION

The phenomenological evaluation of a water system is made through physical, chemical and microbiological environmental parameters which are variables used to obtain quality indexes. Therefore, it is imperative that the data be obtained in a careful and adequate manner, because the water system is constantly altered by environmental factors such as temperature, pressure and anthropological characteristics of the environment under analysis.

The proposed mathematical methods define indexes which group the water classification parameters, numerically translating the phenomenon or process under analysis. However, some of these indexes require a considerable number of parameters which, at times, economic and social factors limit their attainment. Among the indexes for classification and identification of water body water quality are the Public Water Supply Index (IAP), the Water Quality Index for the protection of Aquatic Life (IAV) and the Quality Index more widely used. Also, for reservoirs, the Trophic State Index (TSI), which characterizes water in terms of eutrophication phenomena, is also highlighted. This phenomenon is very important and can happen naturally occurring in lakes and reservoirs, or as a consequence of human activities, by increasing the flow of nutrients to the water body, and consequently, causing serious environmental and social problems.

Among the different numerical strategies of environmental data analysis, fuzzy logic is a feature which has been used with a lot of success. In this context, its application in the understanding of the water quality indexes in reservoirs, IQA and STI, for example, stand out. In this type of application, the indexes are treated by assigning a range of interaction between water quality parameters to define the classification or use of the water environment. In addition to the Boolean logic which treats this interaction between good or bad, fits or does not, fuzzy logic allows to define between these extremes an infinity of values or premises (OLIVEIRA et al., 2014).

Although Brazil has some advantages over the availability of surface water relative to other countries, social problems, such as high poverty rates and disorderly population growth close to water sources, have been observed in all regions of the country, mainly in the Northeast region.

In this context, it is not only necessary to quantitatively assess water resources. This strategy has already been overcome, mainly because of this high population growth near the river banks, of water reservoirs. The need today is to quantitatively and qualitatively assess water resources, as the quality of water is suffering serious consequences of population growth and industrial progress. Thus, this work aims at the application of numerical strategies, including fuzzy logic, to determine water quality indexes and trophic status, which can define the quality of a water body as a consequence of the variation of environmental parameters.

2. THEORETICAL FOUNDATION

2.1 Water Quality Index (WQI)

According to Oliveira et al. (2014), the first form of a water quality index (WQI) was developed by the National Sanitation Foundation (NSF), using the Delphi technique, based on the opinion of 142 experts to define the parameters used. For each parameter weights were assigned and curves were later elaborated to represent the variation of water quality varying by each parameter. A total of nine parameters and their weights were established: dissolved oxygen (DO) (17%), thermotolerant coliforms (15%), pH (12%), biochemical oxygen demand (BOD) (10%), Total phosphate (10%), nitrate (10%), temperature (10%), turbidity (8%) and total solids (8%). The curves representing these parameters are used to determine the concentrations of the parameters and the IQA is then calculated by the weighted output of the water quality corresponding to the variables which make up the index. The result of this production is the classification of water quality which varies from bad to good for the identified use.

Lopes and Magalhães Jr (2010) used the nine parameters established by the NSF and verified that despite the observed interference of the low natural pH values, possibly related to the decomposition of the organic matter present in the waters, the Water Quality Index (WQI) adopted for The Ribeirao de Carrancas presented values that ranged from regular to poor, during most of the monitored period, characterizing the degradation of the water quality in the studied basin, especially after the launch of sewage without previous treatment of the urban area.

2.2. Water Quality Index for Reservoirs (IQAR)

The Environmental Institute of Paraná (IAP) seeking an evaluation of the water quality in reservoirs created the IQAR. The selected variables were: dissolved oxygen deficit, total phosphorus, total inorganic nitrogen, chemical oxygen demand, transparency, chlorophyll a, residence time and mean depth. In addition to these variables, the phytoplankton community (diversity, algal bloom and amount of cyanobacteria) was included in the matrix due to its ecological importance in lentic ecosystems, yet, this parameter received a different treatment.

Ferreira et al. (2015) adapted and compared the Water Quality Index developed by the National Sanitation Foundation (NSF) to the physical, chemical and biological conditions of the water of an artificial reservoir in tropical semiarid climate region, as well as the temporal space variability of the same in the municipalities Of Orós, Quixelô and Iguatu, Ceará, Brazil. Using the nine parameters they proposed a way of calculating variable weights to portray the conditions of the region using Principal Component Analysis (PCA).

Medeiros et al. (2016) evaluated the quality of water consumed in two riverside communities in the municipalities of Abaetetuba, Maranhão and Barcarena communities, Vila do Conde community, State of Pará, Brazil, exposed to domestic and industrial pollutants. Sampling campaigns were carried out in both communities and pH, Total Solids, Chloride, Fluoride, Hardness and N-Nitrate were used for the calculation of the Water Quality Index (WQI).

Still according to Medeiros et al. (2016), the water used in the community of Maranhão, due to not receiving industrial contamination, adequate samples with improvement in the dry season; Already in Vila do Conde, because it was close to areas of industrial activities, both in the dry and in the rainy seasons presented an unacceptable quality of water for human consumption. The parameters which most affected the WQI were pH and N-Nitrate, with amounts ten times higher than those provided by law, which causes concern and a need for urgent governmental intervention.

Manoel and Carvalho (2013) evaluated the WQI in the two springs in the Caçula stream microbasin, in the municipality of Ilha Solteira, São Paulo, Brazil. The values obtained in spring 1 were 58.31, in the dry season, which means a good water quality for this spring. In the rainy season, yet, it presented a regular pattern with a value of 47.17 for the IQA. At spring 2, the IQA value calculated was 69.54 in the dry season, and the water was classified as good quality, the same occurred in the rainy season, with a value of 51.97.

Effendi and Wardiatno (2015) used WQI and a pollution index to assess the quality of the Ciambulawung river in Indonesia, located near a small hydroelectric power plant. The WQI calculation was based on the NSF parameters, excluding the fecal coliform parameter, causing a proportional redistribution in the weights. In the analyzes, three of the parameters were values that extrapolated the regulation, which were the pH, BOD and COD at collection points 1, 2 and 3, respectively. This fact was justified by the process of decomposition of organic matter of plants decomposed by microbes which consume dissolved oxygen.

Medeiros et al. (2016) carried out a study to characterize the water quality of the Riacho da Bica, in the city of Portalegre, Rio Grande do Norte, Brazil, from the IQA and a bathing analysis. This water body is used for recreation and domestic activities. The analysis was performed at three points during the dry season and in the rainy season. The authors observed that the results obtained for the WQI indicate that the quality of the water is impaired as the slope descends. In Point 1 the water remains with the reasonable class during the period of rain and drought, already in Point 2 and Point 3 water remains in the bad class in both periods. It was concluded that slope favors transport and the accumulation of contaminants at lower altitudes. In this sense, it is necessary an environmental program which educates both the population and the visitors of the basin.

2.3. Trophic Status Index (TSI)

The trophic state is a fundamental action for the classification of water systems, that is, to evaluate the water quality regarding the eutrophication process, as emphasized by Sulis et al. (2011) when they developed a linear model for estimating water quality based on the TSI. The trophic state of a reservoir can be evaluated through established indices, through equations using limnological parameters.

The Carlson IET (1977) allows a fairly close limnological evaluation of the level of nutritional enrichment of an aquatic body and covers only three parameters, which are water transparency, chlorophyll a and total phosphorus concentration. It is a simple way of analyzing a multidimensional concept which involves criteria of oxygenation, transparency, eutrophic nutrients, biomass, composition and concentration of phyto and zooplankton, among other data (Von SPERLING, 1994 apud MAIA et al. (2015)).

Araújo et al. (2013) developed a methodology to calculate the risk of eutrophication in a reservoir, based on the fuzzy logic and the mechanisms used to determine the modified Trophic State Index. They used data from a reservoir in the state of Ceará, Brazil, obtained from 2001 to 2006. For the calculation of the risk, the Modified Trophic State Index (MTSI) was transformed into pertinence functions based on set theory Diffuse. The authors concluded that the risk of eutrophication is dynamic in time and space, that is, the process of eutrophication can increase in one period and decelerate in another, causing the water of that reservoir to recover rapidly.

Maia et al. (2015) analyzed the water of the Lower São José dos Dourados River, São Paulo, Brazil for the determination of the STI using the trophic state indices proposed by Toledo et al. (1983) developed for reservoirs of tropical environments and also by the method of Lamparelli (2004).

Maia et al. (2015) also observed that the Lamparelli method (2004) presented greater susceptibility to the changes, increasing, in this way, the level of the trophic classifications; Although the method of Toledo et al. (1983) presents lower levels of classification, its numerical variation is larger, being able to detect much smaller concentrations. Although they presented different classifications during the analyzes, it was concluded that there is a small degradation in the the study area, that is, low degree of eutrophication.

Recently, Lobato et al. (2015) classified a trophic state in a hydroelectric plant using fuzzy logic. They observed human actions in the Brazilian Amazon region which cause serious damages to the environment, such as the construction of dams that cause radical environmental changes to occur. The hydrological systems have been impaired and an increase in the concentration of ions is observed, as well as changes in physical and chemical parameters in an abrupt way. The authors comment that effluents from urban and industrial areas contribute critically to an increase of the trophic level of these systems.

In addition to the work of Lobato et al. (2015), statistical analyzes using fuzzy logic were proposed to evaluate the IQA and the trophic state index (STI) in reservoirs in the Amazon region. The Carlson and Lambert STI methods were used to compare to the proposed fuzzy model. Lobato et al. (2015) concluded that the methods Carlson and Lamparelli did not make a correct estimation of the parameters for that reservoir, since both did not evaluate the trophic state correctly. The proposed fuzzy solution, based on several statistical techniques, showed greater reliability in the characterization of the studied hydrological regime, being, therefore, ideal in the search for relevant factors which cause eutrophication and consequent decision making.

Andrietti et al (2016) evaluated the Caiabi River, Mato Grosso, Brazil, through the STI and WQI. These authors used trophic degrees according to ANA (2016): ultraoligotrophic (EIT ≤ 47), oligotrophic (47 <EIT ≤ 52), mesotrophic (52 <EIT ≤ 59), eutrophic (59 <EIT ≤ 63), supereutrophic (63 <EIT ≤ 67) and hypereutrophic (ETI> 67). It was found that there was a low risk of eutrophication in the Caiabi River, since the STI did not exceed the limit of 47. The environment can be classified as ultraoligotrophic. The WQI value was considered and this is due to the preservation of the native vegetation and the dilution effect motivated by the addition of tributaries along the river stretch.

Still, according to Andrietti et al. (2016), the analysis of variance of the monitored parameters showed that the monitoring of the water quality can be performed considering only two annual collections, one in the dry period and the other in the rainy season, in two points, which are sufficient to describe the behavior of water quality in the basin for most of the parameters, provided that the conditions of use and occupation of the soil of the basin are not modified.

2.4. Fuzzy Logic

The applications of fuzzy logic in relation to water treatment analysis are increasingly common, due to their rapid response and the lack of infinity of experiments that prove the results, which can now be done at the level of comparison only. The physical, chemical and biological parameters taken into account in these analyzes should be very careful in order to portray the experiment in the most truthful way and in accordance with what is happening in the reservoir or studied water body.

Pereira et al (2012) compared the Water Quality Index (WQI) obtained by the application of the fuzzy sets with the method proposed by the National Sanitation Foundation (NSF). During two years samples of the Pimenta Bueno River in Rondônia were collected and the WQI values obtained were compared to the NSF standards. The sensitivity of the WQI using the fuzzy method has a greater sensitivity when observed the parameters which were evaluated, showing efficacy for analysis of large bodies of water.

Oliveira et al (2014) developed a study to evaluate crude water quality index using fuzzy logic. The ability to evaluate more accurately the uncertainties and non-linearity of water quality evaluation parameters has shown that fuzzy logic has a greater prominence than other models. A prediction of these indices is very complicated because of their complexity affected by geographic, climatic and ecological factors, which are interconnected making this assessment even more difficult. Eight parameters used to formulate the Raw Water Quality Index (RWQI) showed greater accuracy when fuzzy logic was used than the curves traditionally used by water utilities.

Gorai et al (2014) developed a groundwater analysis study using 11 physicochemical variables (alkalinity, dissolved solids, hardness, pH, Ca, Mg, Fe, fluoride, As, sulfate, nitrates) through the application of fuzzy logic. The study found that the fuzzy system improves the tolerance of inaccurate data and that, therefore, they believe that it can be an effective way to solve problems for governments in relation to drinking water.

Mourhir et al (2014) developed a fuzzy quality index combined with the Quebec and Moroccan methods of evaluation, following the legislation of the same, seeking the least possible interference from a specialist. This new index was applied to water bodies in Morocco using six parameters.

In this context, Mourhir et al. (2014) observed that there is a need for new legislation for the country, which aligns with the one presents in other countries in order to mitigate risks to water bodies. The conventional indexes do not reflect the alarming situation of the water bodies under analysis, and in addition, the new developed fuzzy index allows a better qualitative and quantitative interpretation.

Pessoa et al. (2015) compared the IQA proposed by the NSF with an IQAfuzzy developed for IQAFAL lotic environments in the Paraíba do Sul River, Rio de Janeiro. The data were evaluated by experts from the State Environmental Institute of Rio de Janeiro (INEA). In the comparison, the results showed that only the IQAFAL was sensitive to the influence of an isolated variable in poor condition, even when the others were in good condition. The work developed showed that the river quality evaluation bands were between "bad" and "very poor" for IQAFAL and "regular" for the WQI. The thermally tolerant coliforms were considered to have the greatest influence on the IQAFAL result.

Li et al (2016) used fuzzy logic to describe the water quality of the Qu river in China. In this work, the authors monitored four stations along the river between 2006 and 2010, determining DO, BOD, COD, total phosphorus and ammoniacal nitrogen parameters. The authors used the Princiapis Component Analysis technique to determine the most relevant parameters and emphasize that fuzzy logic produces a more accurate result than other indexes presented in the literature.

In general, the fuzzy logic presents some advantages in relation to other techniques to determine the water quality indexes, emphasizing the need not to determine weights for the environmental parameters. Therefore, for the development of this work, for both the WQI and the EIT, the fuzzy logic was implemented, enabling a better evaluation of the water body, in a faster and more precise way.

3. Macela Reservoir

The Macela reservoir (Figure 1), located in the city of Itabaiana-SE, was evaluated in this work as an important water source for the local population. The experimental data of the water collected in this reservoir were obtained by the Laboratory of Analytical Chemistry Laboratory (LQA), Department of Chemistry, Federal University of Sergipe. Analyzes were performed using the analytical procedure according to APHA (1998).

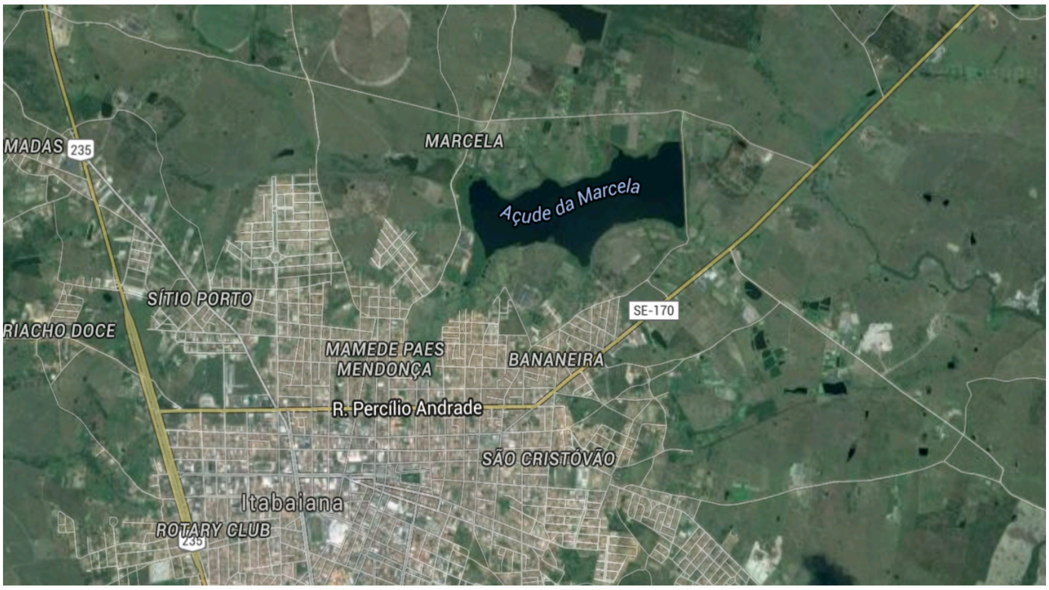

Figure 1 – Location of the Macela reservoir, Itabaiana-SE.
Source: Google Earth (2016)

4. Results and Discussions

To obtain the WQI, the mean values of the parameters, Table 1, allow the establishment of a comparison with the WQI calculations obtained for the Macela reservoir using the IQAR (IAP), O-WQI, PW-WQI and CPCB-WQI were equal to 6; 2.16; 9.49, 20.13, respectively. In this way, it was observed that the four indexes present the same conclusion about Macela reservoir which is a high level of eutrophication and is extremely polluted.

Table 1 - Parameters evaluated in Macela reservoir

Parameters	Mean	Stand. Dev.	CONAMA
Condutivity (mS cm^{-1})	1.67	0.63	-
Color (Pt-Co)	21.48	13.28	75 mg Pt-Co
pH	8.56	0.39	Between 6.0 and 9.0
TS (mg L^{-1})	1058.02	339.64	500
TDS (mg L^{-1})	23.06	24.79	-
DO(mg L^{-1})	5.32	2.85	5
N-NH_4 (µg L^{-1})	48.19	39.66	500 µg/L for pH > 8,5 and at most 2000 µg/L for 7,5 < pH ≤ 8,0
N-NO_2 (µg L^{-1})	146.92	146.31	1000
N-NO_3 (µg L^{-1})	1255.96	615.88	10000
N Total (mg L^{-1})	4.52	3.32	1.27
P Total(mg L^{-1})	415.14	200.3	0.05
Clorophyll-a (µg L^{-1})	59.28	63.2	30
Temperature (^{o}C)	28.23	1.82	-

For the evaluation of the IQARfuzzy the 4 parameters already mentioned were used, Total Nitrogen, Total Phosphorus, DO and chlorophyll-a. IQARfuzzy was compared to IQAR (IAP) in its classification ranges. The IQARs obtained served to establish, then, the validity of the calculated IQARfuzzy.

When reproducing the mean values of the parameters used in the Macela reservoir, it is observed that the developed program resulted in an IQARfuzzy of 6.3, which means that this reservoir is in an extremely polluted condition, a conclusion also obtained by the analysis of the environmental parameters.

Table 2 presents a comparative analysis between the IQA calculations performed in this work. It should be noted that although the applied fuzzy method took into account only four of the quantified variables, this one is quite representative presenting similar responses to the others with use of other variables in each calculated index, since the chosen parameters, P, N, OD and chlorophyll -a, for the evaluation of a reservoir are the indicators of the eutrophication phenomenon.

Table 2 - Water Quality Indexes for Macela reservoir

INDEXES	Marcela reservoir	Classification
IQAR (IAP)	6.00	Extremely polluted
O-WQI	2.16	Very bad
PW-WQI	9.49	Minimum quality
CPCB-WQI	20.13	Very bad
$IQAR_{fuzzy}$	6.3	Extremely polluted

The trophic state of a reservoir represents, mainly, the entrance of nutrients, through the discharge of domestic sewage. In this item, the TSIs of Carlson and Simpson (1996) and the TSIfuzzy were calculated, to define the trophic conditions of the Macela reservoir.

The calculation of the TSI proposed by Carlson and Simpson (1996) was performed using chlorophyll a, total phosphorus and total nitrogen. For each variable, the frequency with which the oligotrophic, mesotrophic, eutrophic and hypereutrophic classification appeared in each of the 119 samples from the Macela reservoir was calculated. The collected samples presented a high level of total phosphorus, which shows that the medium has a considerable amount of nutrients for the algal growth and consequent eutrophication. Nitrogen presented in more than 70% of the samples classification of hipereutrophic, ratifying that there is a considerable amount of nutrients. The amount of chlorophyll a present in the medium was well diversified for each sample, because some points collected as in the bottom of the reservoir have a smaller amount of it.

The reservoir can be considered as hypereutrophic, then, after calculating the total STI which presented a value of 79.76. This value shows that significant plant growth due to eutrophication may interfere with the use of water for human consumption or recreation.

Table 3 - EIT and percentage for each trophic state - Macela Reservoir

	TSI	Oligotrophic	Mesotrophic	Eutrophic	Hipereutrophic
Clorophyll a	65.77	-	44.54%	21.85%	33.61%
Ptotal	100.09	-	-	-	100.00%
Ntotal	73.43	-	7.02%	21.93%	71.05%
Total TSI	79.76				

Due to the high amount of chlorophyll-a, it can be stated that the presence of cyanobacteria in the reservoir, which leaves this water unfit for consumption, emphasizes that educational measures with the population using this reservoir must exist, since there is the risk of contracting diseases.

4.1. TSI_{fuzzy}

Fuzzy logic was used to calculate an TSI using the same parameters used by Carlson and Simpson (1996). The fuzzy inference method was the Mamdani method and for the defuzzification step the center of gravity (Centroid) method was used. Twenty-eight fuzzy rules were implemented according to the degree of importance or pertinence of the system response, in accordance with the definitions of the experts. The output variable was the trophic state index of the water, classifying the system into four trophic levels of the system.

It is important to emphasize that the higher the number of input variables the greater the number of rules, which makes the system more dependent on the knowledge of the specialists in the integration between the rules. A simulation performed with the mean values of the chlorophyll-a, nitrogen and total phosphorus parameters presented a TSI equal to 0.505 indicating that the system can be classified in the hypereutrophic linguistic term in accordance with that one calculated with the Carlson and Simpson (1996) method.

The fuzzy logic for its characteristic of portraying phenomena often complicated to model, obtained in this application coherent results and in agreement with the WQI and STI of other mathematical models. However, it is necessary to observe that the representation of a smaller number of variables will necessarily imply a smaller number of rules and consequently requires that the expert has a great knowledge of the body of water to make the correct selection of the parameters. Thus, the correct definition of the number of variables makes it possible to reduce laboratory tests, as well as to promote a solution proposal for the problem which occurs in the water body under analysis.

5. Conclusion

Dissolved Oxygen (DO), Total Nitrogen, Chlorophyll a and Total Phosphorus for the Macela reservoir were above the limits defined by CONAMA nº 357/05. The study showed, mainly, that the amount of chlorophyll-a in the system is critical for the level of pollution. The reason for its development is the fact that the greater the concentration of chlorophyll-a in water means that algae and other microorganisms are having a significant source of nutrients, nitrogen and phosphorus, often arising from anthropic activities. Due to these factors, it can be seen that the level of eutrophication of these reservoirs is considerable.

An evaluation of the Macela reservoir Water Quality Index (WQI) indicates a high level of pollution. IQAR (IAP), O-WQI, PW-WQI, CPCB-WQI and IQARfuzzy converge to values which demonstrate the high level of pollution of these. In addition to the WQI, the Trophic State Index (TSI) was evaluated for the degree of eutrophication. Using the parameters chlorophyll a, total nitrogen and total phosphorus, the method of Carlson and Simpson (1996) indicated that the reservoir was in a state of hypereutrophy, that is, it has a nutrient load that favors the substantial growth of Plants and algae. This problem directly interferes with the use of water both for consumption and for human consumption, as well as for recreation.

The STI, too, was evaluated with fuzzy logic using the same parameters used in the method of Carlson and Simpson (1996). In addition, it is noted that the value of 0.503 indicates a state of hypereutrophy, which shows a similar and accurate result, such as the calculation using the method of Carlson and Simpson (1996).

Through the analysis of the numerical results, it is possible to conclude that the indices are determined in different ways and that the concept of water domain in question. By its perception and practicality, a fuzzy logic can be considered a precise and effective means of determining and evaluating complex environmental phenomena through the determination of environmental classification indexes.

REFERENCES

ANDRIETTI, G.; FREIRE, R.; AMARAL, A.G.DO; ALMEIDA, F.T.DE; BONGIOVANI, M.C.; SCHNEIDER, R.M. Índices de qualidade da água e de estado trófico do rio Caiabi , MT. **Ambiente & Água - An Interdisciplinary Journal of Applied Science** v. 11, 2016.

ARAÚJO, J. A .F. DE; SALES, R. J. DE M.; SOUZA, R. O. DE; Risco de eutrofização em reservatórios de regiões semiáridas com uso da teoria dos conjuntos difusos. **REGA** – Vol. 10, no. 1, p. 29-39, jan./jun. 2013.

CARLSON, R. E. e SIMPSON, J. **A coordinator's guide to volunteer lake monitoring methods.** North American Lake Management Society, p. 96, 1996.

EFFENDI, H.; WARDIATNO, Y. Water quality status of Ciambulawung River, Banten Province, based on pollution index and NSF-WQI. **Procedia Environmental Sciences**, v. 24, p. 228–237, 2015.

FERREIRA, Kássia Crislayne Duarte; LOPES, Fernando Bezerra; ANDRADE, Eunice Maia de; MEIRELES, Ana Célia Maia; DA SILVA, Gerlange Soares. **Revista Ciência Agronômica**. Adaptação do índice de qualidade de água da National Sanitation Foundation ao semiárido brasileiro. p. 1–14, 2015.

GORAI, A.K.; HASNI, S. A.; IQBAL, J. Prediction of ground water quality index to assess suitability for drinking purposes using fuzzy rule-based approach. Appl. Water Sci. **SPRINGER**. 2014.

LI, R.; ZOU, Z.; AN, Y.. Water quality assessment in Qu River based on fuzzy water pollution index method, **Journal of Environmental Sciences**, 2016 *in press*

LOBATO, C. *et al*. Science of the Total Environment Categorization of the trophic status of a hydroelectric power plant reservoir in the Brazilian Amazon by statistical analyses and fuzzy approaches. v. c, p. 613–620, 2015;

LOPES, Frederico Wagner de Azevedo; MAGALHÃES JR, Antônio Pereira. Influência das condições naturais de pH sobre o índice de qualidade das águas (IQA) na bacia do Ribeirão de Carrancas. v. 6, n. 2, p. 134–147, 2010.

MAIA, A. A. D.. **Determinação do grau de trofia no Baixo São José dos Dourados por meio da comparação entre dois diferentes índices de estado trófico**. Dissertação de 1Mestrado. Universidade Estadual Paulista. Faculdade de Engenharia de Ilha Solteira. 2011.

MANOEL, L.O.; CARVALHO, S.L. Avaliação Do Índice De Qualidade De Água (IQA) De Duas Nascentes No Município De Ilha Solteira-Sp. VII ENCONTRO DE CIÊNCIAS DA VIDA. UNESP – Campus de Ilha Solteira – SP. ANAIS. 2013

MEDEIROS, A. C.; LIMA, M. D. O.; GUIMARÃES, R.M. Avaliação da qualidade da água de consumo por comunidades ribeirinhas em áreas de exposição a poluentes urbanos e industriais nos municípios de Abaetetuba e Barcarena no estado do Pará, Brasil. **Ciência & Saúde Coletiva**, 21(3):695-708, 2016.

MEDEIROS, Samylle Ruana Marinho de; CARVALHO; Rodrigo Guimarães de; DI SOUZA, Luiz; BARBOSA, Antônio Helton da Silva. Índice de qualidade das águas e balneabilidade no Riacho da Bica, Portalegre , RN , Brasil. **Ambiente & Água - An Interdisciplinary Journal of Applied Science** v. 11, 2016.

MOURHIR, A.; RACHIDI, T.; KARIM, M. River water quality index for Morocco using a fuzzy inference system. Environmental Systems Research. **SPRINGER**. 2014

OLIVEIRA, Maria Dutra de; REZENDE, Oscar Luiz Teixeira de; OLIVEIRA, Sílvia Maria Alves Correa; LIBÂNIO, Marcelo. Nova abordagem do Índice de Qualidade de Água Bruta utilizando a Lógica Fuzzy. **Engenharia Sanitaria e Ambiental**, v. 19, n. 4, p. 361–372, 2014;

PEREIRA, A. A.; OCAZIONEZ, S. A. C.; TOMAZ, C. Avaliação da qualidade da água: Proposta de novo índice alicerçado na lógica fuzzy. **Bioscience Journal**, v. 28, n. 4, p. 667–677, 2012;

PESSOA, M. A. R.; DE AZEVEDO, J. P. S.; DOMINGOS, P. Comparação das respostas de dois índices de qualidade de água usando dados simulados e reais. **RBRH,** vol. 20 no .4. Porto Alegre. p. 905- 913. out./dez. 2015

SULIS, A.; BUSCARINU, P.; SECHI, G. M.. **Using reservoir trophic-state indexes in optimisation modelling of water-resource systems.** Environmental Modelling & Software,v 26, p. 731–738, 2011.

VON SPERLING, E. (1994) Avaliação do estado trófico de lagoas e reservatórios tropicais. *Revista Bio*, v.2, n.3, p.68-76., *apud* Maia, A.A.D.; Carvalho, S.L.; Carvalho, F.T. Comparação de dois índices de determinação do grau de trofia nas águas do Baixo Rio São José dos Dourados , São Paulo , Brasil. **Eng Sanit Ambient** .v.20 n.4 p. 613–622, 2015.