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Scientific Paper

Prospects for reducing the contribution of organic load in a water basin with significant urban occupation

Perspectivas de redução do aporte de carga orgânica em bacia hidrográfica com relevante ocupação urbana

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ABSTRACT

The prospects for reducing organic load in water basins must be evaluated considering the self-purification capacities of the water bodies into which the raw or treated effluent will be discharged. The aim of this work was to evaluate the reduction of the organic load contribution to the Poti River, a watercourse that crosses the city of Teresina, Piauí, Brazil, considering different conditions for the final disposal of domestic sewage. To estimate the levels of reduction of the organic load contribution, the Water Quality Model Qual-UFMG and Nonlinear Programming were used in a combined manner. Three scenarios of final effluent disposal were modeled. For the appropriation of the reductions in organic load contributions, two different optimization models were used, models that incorporated restrictions based on the environmental quality standards indicated by the Brazilian Environment Council (CONAMA) Resolutions No. 357/2005 and 430/2011. The results indicated that the estimated effort for removal of organic load based on the optimization model that does not employ an equity measure among discharges was lower, regardless of the scenario analyzed. Additionally, in the simulation scenarios in which the quality standards for effluent were not considered, the efforts for removing organic load were lower, regardless of the optimization model used.

Keywords: Nonlinear Programming; water quality model; computational simulation; sewage treatment; optimization model.

RESUMO

A perspectiva de redução de aporte orgânico em bacias hidrográficas deve ser avaliada com base na capacidade de autodepuração dos corpos d'água nos quais serão despejados os efluentes brutos ou tratados. O objetivo do presente trabalho foi a avaliação da redução do aporte de carga orgânica afluente ao rio Poti, curso d'água que corta o município de Teresina, Piauí, Brasil, considerando-se diferentes condições de disposição final de esgotos domésticos. Para a estimativa de níveis de redução do aporte de carga orgânica foram empregados, de maneira combinada, o modelo de qualidade de água Qual-UFMG e a Programação Não Linear. Foram modelados três cenários de disposição final de efluentes. Para a apropriação das reduções dos aportes de carga orgânica, dois diferentes modelos de otimização foram utilizados, modelos que incorporaram restrições baseadas nos padrões de qualidade ambiental estabelecidos pelas Resoluções do Conselho Nacional do Meio Ambiente (CONAMA) nº 357/2005 e nº 430/2011. Os resultados demonstraram que o esforço de remoção de carga orgânica estimado pelo modelo de otimização que não emprega medida de equidade entre lançamentos foi menor, independentemente do cenário de simulação analisado. Adicionalmente, nos cenários de simulação em que não foram considerados os padrões de qualidade para os efluentes, os esforços de remoção de carga orgânica foram menores, independentemente do modelo de otimização empregado.

Palavras-chave: Programação Não Linear; modelo de qualidade de água; simulação computacional; tratamento de esgoto; modelo de otimização.

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1. INTRODUCTION

Several factors can compromise the quality of water bodies, such as lack of basic sanitation, rivers and aquifers pollution, deforestation, agriculture and livestock advancement, urbanization and industrialization (ABBASS, *et al*., 2022; AKHTAR, *et al*., 2021; GIRI, 2021). The final disposal of raw sewage directly into water bodies is still a reality in many Brazilian cities, causing significant impacts on the receiving bodies, local imbalance, and compromising human health. In this context, the final disposal of raw or poorly treated sewage in water bodies is the main, if not the only, source of pollution of Brazilian water bodies (ANA, 2019).

Sewage treatment is generally the main way to control pollution and improve water quality in water bodies. In this scenario, cost is usually the most important factor in choosing treatment plants (ALMEIDA *et al*., 2022), and the water bodies' self-purification capacities help to reduce costs and implement pollution control measures since they complement the processes that occur in sewage treatment systems (BRINGER, REIS and MENDONÇA, 2018).

According to Von Sperling (2007), two situations can occur: the effluent to be released into the water body meets the release standards but does not meet the receiving body standards or the effluent does not meet the release standards but meets the receiving body standards. The first situation is related to receiving bodies with low assimilative capacity. In this condition, the release should present better quality characteristics than that corresponding to the release standard. The second situation refers to receiving bodies with good assimilative and dilution capacity. In this case, the environmental agency may authorize releases with parameters values above the release standards, provided that it corresponds to exceptional conditions, of significant public interest, resulting from environmental impact studies, and with compliance with the water bodies classification.

In this context, water quality mathematical models, which are technological tools that can be used to simulate the water bodies' self-purification processes, allow the evaluation and prediction of the impacts of the final discharge of pollutant loads and analysis of intervention and environmental control scenarios (CALMON *et al*., 2016; CANDIDO, *et al*., 2022; KEUPERS and WILLEMS, 2017; RODRIGUES *et al*., 2022; SALLA *et al*., 2013). Mathematical modeling of water quality therefore offers support to the process of choosing the minimum and most economical treatment levels that should be carried out by the stations.

However, although water bodies modeling separately constitutes a powerful tool, it is not the ideal solution for choosing effluent treatment systems within a watershed. In this way, studies have shown that the combination of water quality modeling and optimization techniques has been an interesting methodological approach to reach the optimal combination of treatment systems to be chosen (ALMEIDA *et al*., 2022).

Examples of works that use the association between water quality modeling and optimization techniques are Aghasian *et al*. (2019), Almeida *et al*. (2022), Bringer, Reis and Mendonça (2018), Fantin, Reis and Mendonça (2017), Rocha *et al*. (2021), Sá *et al*. (2019) and Santoro, Reis and Mendonça (2016). The optimization models suggested by these authors were built through the combination of different objective functions and sets of constraints. They were created with the incorporation of goals such as minimizing the implementation and operating costs of the treatment plants, maximizing the organic load discharge, minimizing inequalities between different discharges, among others.

In this context, the main purpose of the study was to estimate the reduction of organic load contribution associated with domestic sewage through the combined use of conventional optimization technique and water quality model within a watershed that has a significant urban occupation.

2. STUDY AREA

Although the methodology employed in this work is applicable to any watershed, a portion of the Poti river watershed was constituted as the study area (**Figure 1**). The portion under analysis covers 36.8 km of the Poti river, in a section that includes rural and urban areas of the city of Teresina, the capital of the state of Piauí, Brazil.

According to Brazilian Institute of Geography and Statistics, the city of Teresina had, in 2010, a population density of 584.94 inhab.km^{-2}, with a population of 814,230 inhabitants, 94.27% of which lived in urban areas and 5.73% in rural areas. The activities of government, trade and service provision constituted the basis of the city's economy.

The Poti river, one of the largest tributaries of the Parnaíba river, has its source in the eastern foothills of the Ibiapaba plateau, in the state of Ceará, at an approximate altitude of 600 m. Its entire course is defined by the geological structure, fitting into regional fractures and faults (LIMA, 1982). The flow of the Poti river becomes permanent in its lower course, from the city of Prata do Piauí, when it receives its largest tributary, the Berlengas river (OLIVEIRA FILHO and LIMA NETO, 2018).

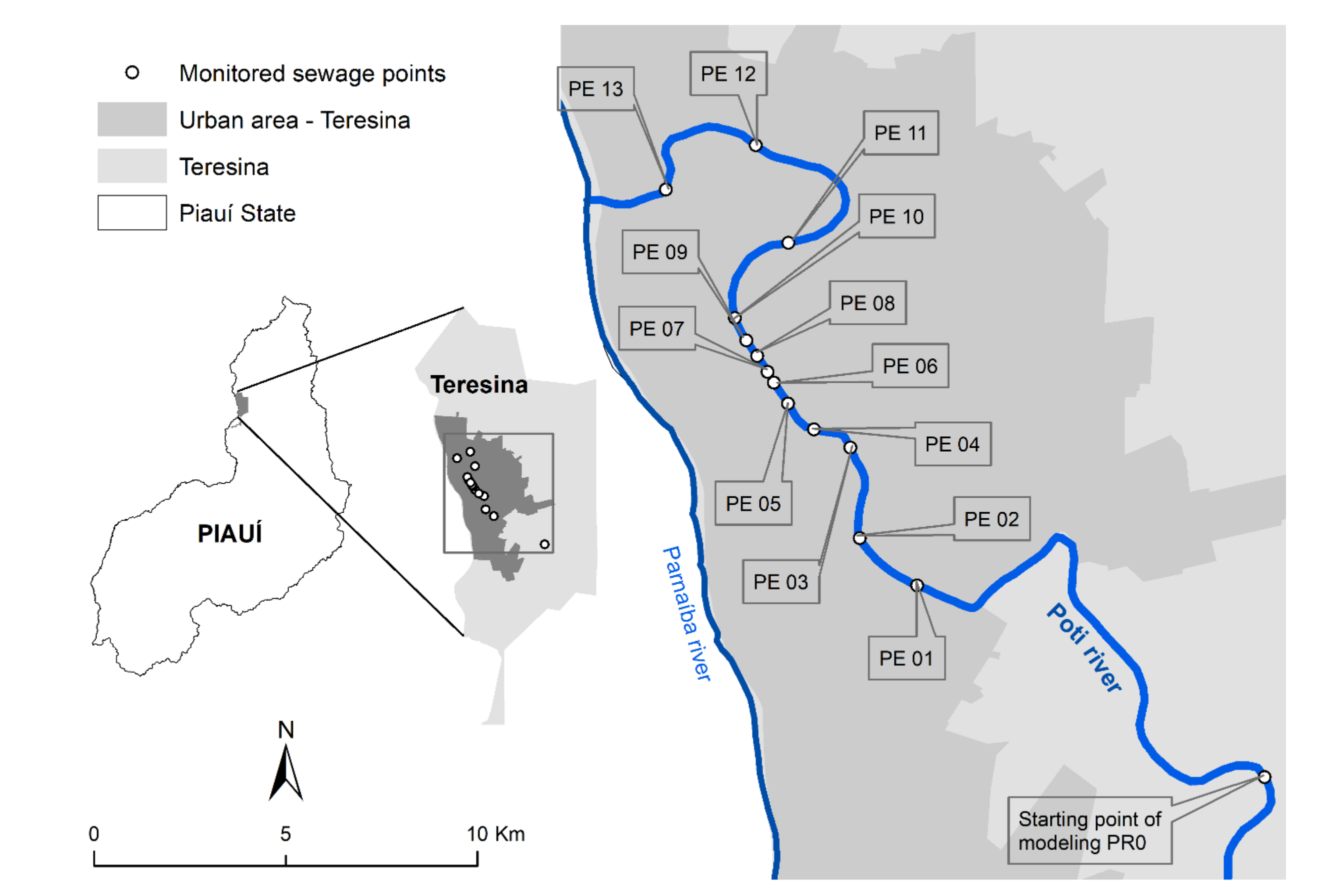
In 2014, the city of Teresina had a low coverage of sanitation services, serving approximately 19% of its population. Currently, it is estimated that 36% of the urban population is served with sanitation (SNIS, 2022). This level of coverage leads the inhabitants to use alternatives for the sanitation of their homes, such as septic tanks and discharging raw sewage into public streets, connected to the urban drainage galleries, with the subsequent discharge of these effluents into watercourses (OLIVEIRA FILHO and LIMA NETO, 2018).

3. METHODOLOGY

3.1. Water quality modeling

In this work, with the aid of the Qual-UFMG water quality model, the profiles of dissolved oxygen (DO) concentrations and biochemical oxygen demand ($BOD_{5,20}$) associated with the final disposal of raw effluent in the Poti River were established. Besides this, concentration profiles considering different scenarios of removal of organic loads were drawn. The simulation of $BOD_{5,20}$ concentrations was based on the phenomenon of deoxygenation resulting from the oxidation of organic matter. The simulation of DO concentrations, in turn, involved atmospheric reaeration and deoxygenation produced by the oxidation of organic matter. The kinetic coefficients that, in the quality simulations conducted, regulated the processes of atmospheric reaeration (K_2) and decomposition of organic matter (K_1, K_d) are gathered in **Table 1**.

The functional relationships among the velocity, depth and flow rate of the watercourse (Equations 1 and 2), values of domestic sewage flow rate, average altitude of the basin, temperature and saturation of DO in the watercourse were obtained from Oliveira Filho and Lima Neto (2018). The flow rate



Source: elaborated by the authors.

Figure 1 - Poti River watershed.

Table 1 - Kinetic constants for Poti River.

Kinetic coefficient	Value (day^{-1})
K_1	0,40
K_2	2,40
K_d	0,85

Table 2 - Initial data entry for Poti river headwater.

Variable (Unit)	Value
Flow ($m^3.s^{-1}$)	39.0
DO ($mg.L^{-1}$)	7.9
$BOD_{5,20}$ ($mg.L^{-1}$)	2.7
Temperature (°C)	29.0
DO saturation ($mg.L^{-1}$)	7.5

and quality conditions associated with the beginning of the simulated stretch are presented in **Table 2**. The average flow rate of domestic effluents relative to the urban population of the city of Teresina in the 13 (thirteen) points of final sewage disposal monitored by the concessionaire Águas e Esgotos do Piauí S. A. (AGESPISA) and the positions of these monitoring points in relation to the headwaters of the simulated stretch are presented in **Table 3**. To appropriate the raw inflows, also gathered in **Table 3**, a per capita load of 54 $gBOD.hab^{-1}.day^{-1}$, a return coefficient of 0.80, per capita water consumption and urban population served in the municipality of Teresina were assumed according to the National Sanitation Information System.

$$U = 0.1593 \,.\, Q^{0,3173} \quad (1)$$

$$H = 0.2094 \,.\, Q^{0,4552} \quad (2)$$

3.2. Optimization models

The optimization models used for estimating wastewater treatment efficiencies were selected based on a review of current technical literature. The following aspects were considered in choosing the models used:

- Minimizing the sum of $BOD_{5,20}$ removal efficiencies regarding the different final disposal points of effluent identified in the hydrographic basin.
- Maintaining equity among the different final disposal points of effluent identified in the hydrographic basin, imposing higher levels of $BOD_{5,20}$ removal for those points that receive higher organic loads.
- Maintaining the environmental quality standards established for bodies of water by CONAMA Resolutions 357/2005 and 430/2011 (BRASIL, 2005, 2011).

Table 3 – Teresina city urban population domestic effluent flows, raw influent loads and positions of monitoring points.

Monitored points	Position (km)	Sewage flow (m³.s-1)	Raw influent load (kg.d⁻¹)
PE 01	14.3	0.210	8,116
PE 02	16.2	0.021	812
PE 03	19.5	0.100	3,865
PE 04	21.0	0.084	3,246
PE 05	21.6	0.040	1,546
PE 06	22.0	0.082	3,169
PE 07	22.2	0.170	6,570
PE 08	22.3	0.010	387
PE 09	22.9	0.213	8,232
PE 10	23.1	0.021	812
PE 11	26.2	0.129	4,986
PE 12	31.5	0.040	1,546
PE 13	35.0	0.156	6,029

In this context, optimization models were selected with the following objective functions:

- In Optimization Model 1, originally proposed by Valory, Reis and Mendonça (2016), the objective function seeks to minimize the sum of efficiencies within a watershed (Equation 3).

$$\text{Minimize } f(E) = \sum_{i=1}^{n} E_i \quad (3)$$

- Optimization Model 2 establishes an objective function that imposes the minimization of the inequality measure between treatment systems (Equation 4), as originally proposed by Burn and Yuliant (2001).

$$\text{Minimize } f(E) = \sum_{i=j}^{n} \left| \left(\frac{Load_{eff.\,i}}{E_i}\right) - \left(\frac{\overline{CargaLoad_{eff.}}}{\bar{E}}\right) \right| \quad (4)$$

In Equations 3 and 4, E_i represents the minimum estimated treatment efficiency for discharge point i, $\bar{E}$ is the average efficiency for the set of discharges, $Load_{eff.}$ is the organic load associated with discharge i, and $\overline{Load_{eff.}}$ is the average load for the set of discharges. The minimum treatment efficiencies allowed the appropriation of removed organic loads, leaving organic loads, and an average removal efficiency within the Poti river watershed.

3.3. Optimization technique

For the resolution of optimization models established from the objective functions defined by Equations 3 and 4, nonlinear programming (NLP) was used, applied with the help of the Microsoft Excel spreadsheet solver supplement. The solver has specific solution methods for different types of functions, such as the Generalized Reduced Gradients (GRG) for nonlinear functions, the Simplex LP for linear functions, and the Evolutionary for functions whose results vary abruptly (ROCHA *et al.*, 2021). Based on the characteristics of the optimization models used in this study, the GRG solution method was used.

3.4. Scenarios for organic load reduction evaluation

From the water and effluent quality standards established by the CONAMA Resolutions 357/2005 and 430/2011, assuming the classification of the Poti River as class 2 watercourse (condition imposed by CONAMA Resolution No. 357/2005 for water bodies that were not classified), three analysis scenarios associated with organic load removal were analyzed:

- Scenario 1: Maximum concentration for $BOD_{5,20}$ in the treated effluent 120 $mg.L^{-1}$, and it was necessary to meet the quality standards for DO (minimum 5 $mg.L^{-1}$) and $BOD_{5,20}$ (maximum 5 $mg.L^{-1}$) in the watercourse. These standards constituted restrictions for appropriating the treatment efficiencies through the different optimization models employed.
- Scenario 2: Restrictions on the minimum $BOD_{5,20}$ removal efficiency of 60%, and it was necessary to meet the quality standards for DO and $BOD_{5,20}$ in the watercourse.
- Scenario 3: No imposition of a quality standard for the effluent, with the quality standards for DO and $BOD_{5,20}$ in the watercourse as restrictions.

A 90% $BOD_{5,20}$ removal efficiency was assumed as the operational limit for the treatment systems, which constituted an additional restriction for the optimization models.

4. RESULTS AND DISCUSSION

The DO and $BOD_{5,20}$ concentrations profiles, established from the perspective of the final disposal of raw effluents, are presented in **Figure 2**. In this figure (and in similar figures presented in subsequent sections) the red line indicates the quality standards for DO and $BOD_{5,20}$ defined for class 2 watercourses.

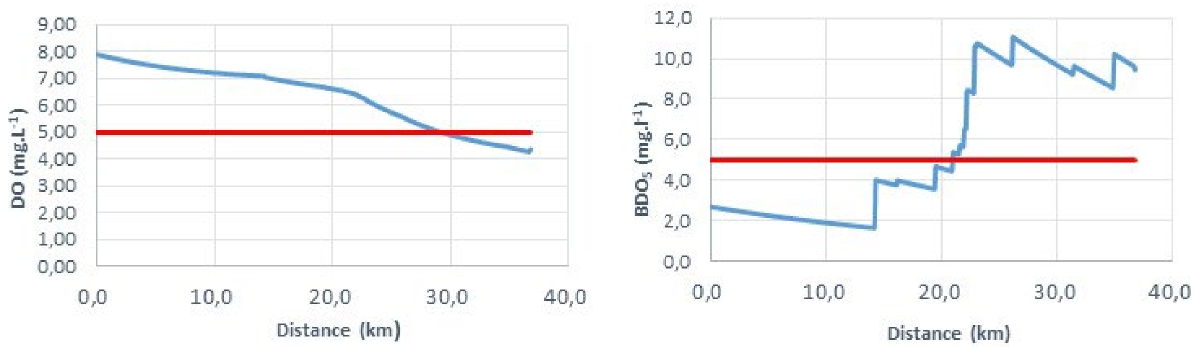
From a simple inspection of **Figure 2**, it is possible to observe that, starting at kilometer 22, the concentration of $BOD_{5,20}$ increases significantly in the Poti river, exceeding the environmental quality standard. As a result of the significant increase in organic matter concentration, the DO concentration decreases progressively, presenting values below the environmental quality standard in the vicinity of kilometer 29. This condition is established based on the series of discharges starting from kilometer 20, close and with high organic loads, as summarized in **Table 3**.

Table 4 presents, for each simulation scenario, the estimates of removal of organic loads and the percentages of removal obtained with the aid of Optimization Model 1.

Figures 3 to 5 show the DO and $BOD_{5,20}$ profiles after the incorporation of organic matter removal as indicated in Table 4.

From the results summarized in **Table 4** and the simple inspection of **Figures 3 to 5**, the following considerations are relevant:

- The imposition of a maximum concentration of 120 $mg.L^{-1}$ for effluent disposed in the Poti river (Scenario 1) called for a higher treatment effort than that involved in adopting a minimum removal efficiency of 60% for $BOD_{5,20}$ (Scenario 2). **Figure 4** graphically represents this condition, with $BOD_{5,20}$ and DO profiles further away from the quality standards set for class 2 rivers.
- Analysis of the results associated with Scenario 3 highlights the relevance of incorporating the self-purification capacity of the watercourse when evaluating the treatment effort of sewage in the context of a watershed. This scenario did not incorporate quality standards for the effluent, assuming only the quality standards for the watercourse as restrictions. As a result, the

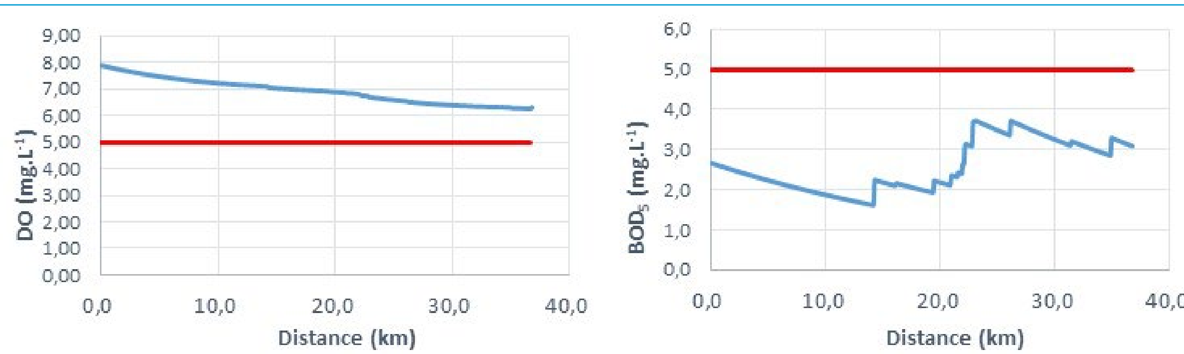


Source: elaborated by the authors.
DO: oxygen demand; $BOD_{5,20}$: biochemical oxygen demand

Figure 2 – Oxygen demand and biochemical oxygen demand concentration profiles for the Poti river considering raw effluent disposal.

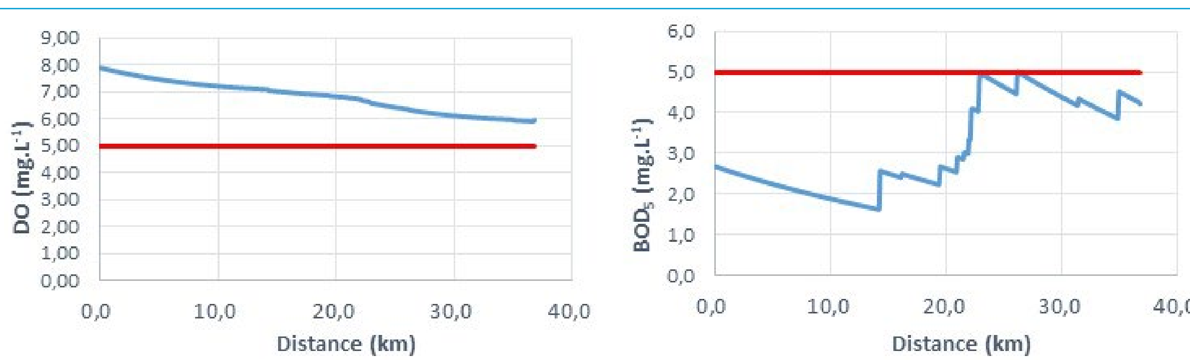
Table 4 – Organic loads and removal percentages per water quality simulation scenario of the Poti river — results associated with the use of Optimization Model 1.

Simulation scenarios	Organic loads ($kg.d^{-1}$)			Removal percentage (%)
	Raw load ($kg.d^{-1}$)	Load removed ($kg.d^{-1}$)	Remaining load ($kg.d^{-1}$)	
1	49,315	36,085	13,229	73
2	49,315	29,781	19,534	60
3	49,315	27,727	21,588	56



Source: elaborated by the authors.
DO: oxygen demand; $BOD_{5,20}$: biochemical oxygen demand

Figure 3 – Concentration profiles of oxygen demand and biochemical oxygen demand for the Poti river after reduction of organic loads estimated through the use of Optimization Model 1, Scenario 1.



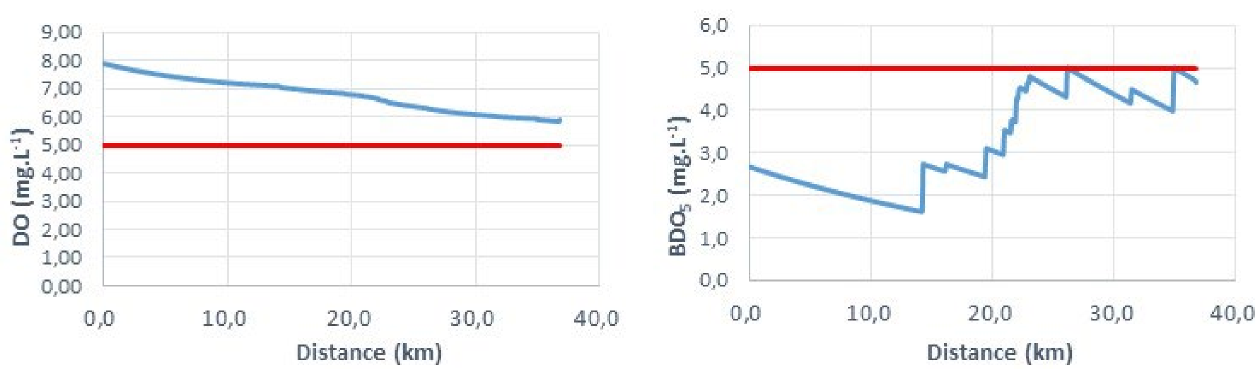
Source: elaborated by the authors.
DO: oxygen demand; $BOD_{5,20}$: biochemical oxygen demand

Figure 4 – Oxygen demand and biochemical oxygen demand concentration profiles for the Poti river after reduction of organic loads estimated through the use of Optimization Model 1, Scenario 2.

treatment efforts to remove organic loads were reduced. A similar behavior was observed by Bringer, Reis and Mendonça (2018), Rocha *et al.* (2021), Sá *et al.* (2019) and Valory, Reis and Mendonça (2016) when evaluating the final disposal of domestic effluents in the Pardo and Santa Maria da Vitória rivers, respectively. The authors emphasize the relevance of using the self-purification capacity of the watercourses as a way to reduce the treatment efforts for the rivers.

Table 5 summarizes the results associated with the use of Optimization Model 2. **Figures 6 to 8**, in turn, show the DO and $BOD_{5,20}$ concentration profiles after incorporating the $BOD_{5,20}$ removal perspectives gathered in **Table 5**.

The behavior of the concentrations of BOD and DO, considering the removal efficiencies estimated with the help of the Optimization Model 2, was similar to that observed when the appropriate treatment efficiencies were taken into account with the help of the Optimization Model 1. The largest demands for organic load removal were associated with the fixation of effluent quality standards. The perspective that these standards were ignored (Scenario 3), ensuring compliance with the quality standards defined for the watercourse, suggested lower organic load removal efforts.

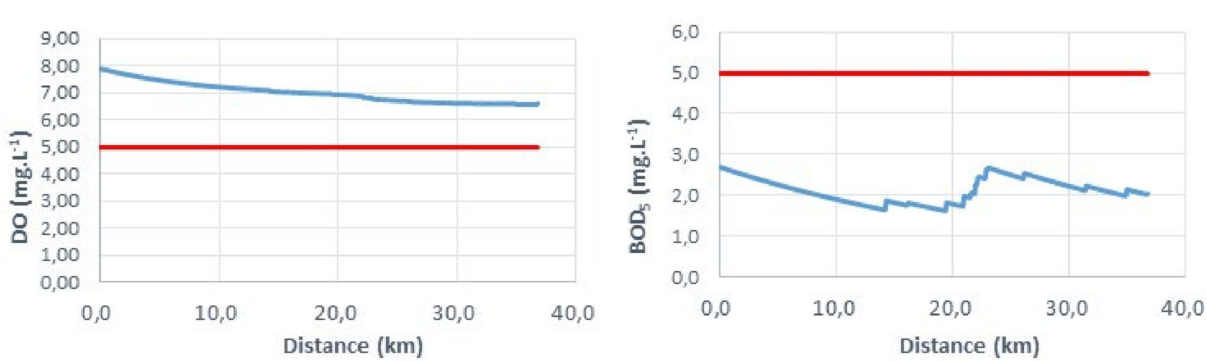


Source: elaborated by the authors.
DO: oxygen demand; $BOD_{5,20}$: biochemical oxygen demand

Figure 5 – Oxygen demand and biochemical oxygen demand concentration profiles for the Poti river after reduction of organic loads estimated through the use of Optimization Model 1, Scenario 3

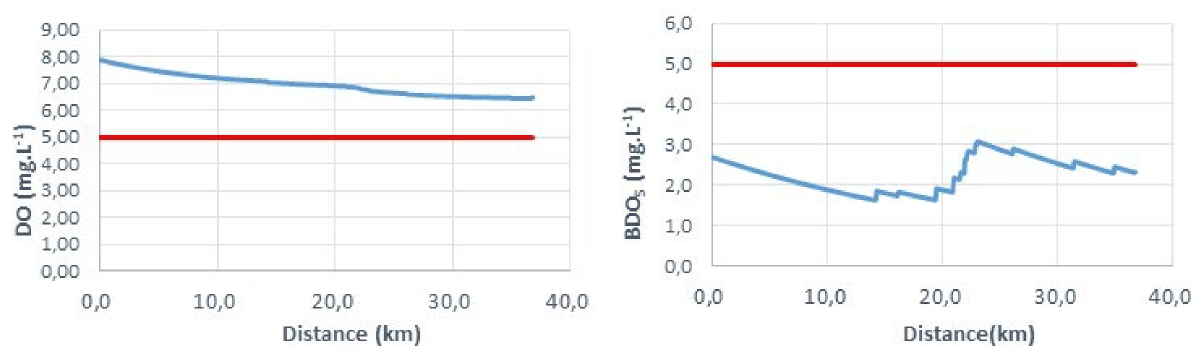
Table 5 – Organic loads and removal percentages per water quality simulation scenario of the Poti River — results associated with the use of Optimization Model 2.

Simulation scenarios	Organic loads ($kg.d^{-1}$)			percentage (%)
	Raw load ($kg.d^{-1}$)	Load removed ($kg.d^{-1}$)	Remaining load ($kg.d^{-1}$)	
1	49,315	42,129	7,185	85
2	49,315	40,425	8,890	82
3	49,315	29,670	19,644	60



Source: elaborated by the authors.
DO: oxygen demand; $BOD_{5,20}$: biochemical oxygen demand

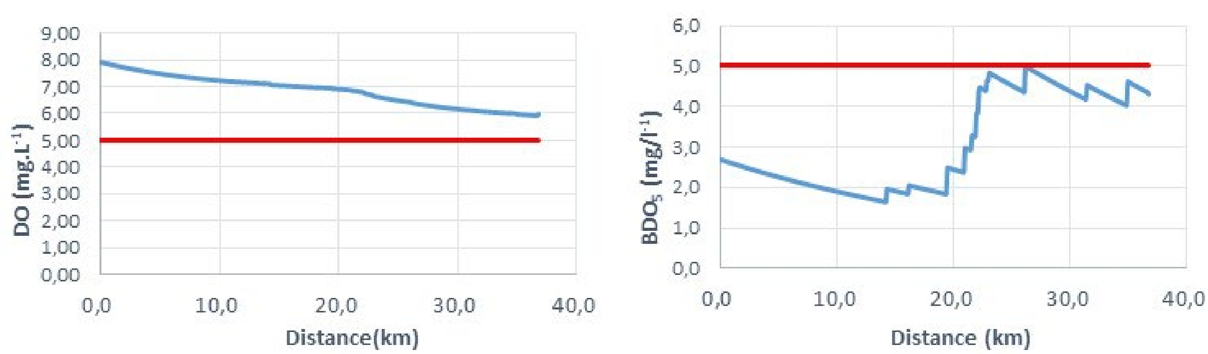
Figure 6 – Oxygen demand and biochemical oxygen demand concentration profiles for the Poti River after reducing the estimated organic loads through the use of Optimization Model 2, Scenario 1



Source: elaborated by the authors.

DO: oxygen demand; $BOD_{5,20}$: biochemical oxygen demand

Figure 7 – Oxygen demand and biochemical oxygen demand ($BOD_{5,20}$) concentration profiles for the Poti River after reducing the estimated organic loads through the use of Optimization Model 2, Scenario 2.



Source: elaborated by the authors.

DO: oxygen demand; $BOD_{5,20}$: biochemical oxygen demand

Figure 8 – Oxygen demand and biochemical oxygen demand concentration profiles for the Poti River after reducing the estimated organic loads through the use of Optimization Model 2, Scenario 3.

Additionally, it is relevant to observe that the application of an optimization model that uses equity measure as the objective function (Optimization Model 2) produced higher organic load removal efforts in the Poti river watershed. The same trend was observed in the works produced by Rocha *et al.* (2021) and Santoro, Reis and Mendonça (2016). The absence of equity between discharges in the removal efforts of the organic load input in a watershed, as established by Optimization Model 1, may make users located in the downstream part of the watershed need to treat their effluent with higher efficiencies, since the river water usually reaches them with lower quality, due to discharges from upstream (ALBERTIN; MAUAD; DANIEL, 2006). There is also the possibility that the river presents a much higher flow than the upstream flow, due to increases from incremental flows and tributaries, which requires more rigorous organic load removals from users who are closer to the headwaters of the rivers, even if the sewage loads they discharge are similar to those discharged by the users downstream.

It is important to note that this work did not intend to implement local studies or define sewage treatment systems for the Poti river basin. What was sought, essentially, was to estimate the level of organic load removal, considering different possible treatment scenarios.

5. CONCLUSIONS

The present study aimed to evaluate the prospects of organic load removal in a watershed area through different optimization models, implemented using a combination of water quality model and optimization technique, with different possible combinations of environmental quality standards set for watercourses and effluents as restrictions. The conclusions drawn from this work can be summarized as follows:

- The combined use of the Qual-UFMG water quality mathematical model and PNL proved efficient in determining the minimum removal of organic load in a watershed, allowing the use of different optimization models in different simulation scenarios.
- From the current technical literature, two optimization models applicable to the determination of reducing the input of organic load in watersheds were selected. The first, Optimization Model 1, aimed to minimize the effort of removing the organic load within the watershed. The second, Optimization Model 2, in turn, aimed to appropriate the level of removal of organic load seeking to ensure equity in the removal effort of the different points of final disposal of effluents. The quality standards set by CONAMA Resolutions

357/2005 and 430/2011 for watercourses and effluent formed the restrictions of the employed optimization models.
- The perspective of maintaining equity between the final disposal points of effluents (basic assumption of Optimization Model 2) produced the highest efforts of removing organic load within the Poti river watershed.
- In the simulation scenario in which the effluent quality standards were not considered, seeking exclusively the satisfaction of the established quality standards for DO and $BOD_{5,20}$ in watercourses, the efforts of removing organic load were lower, regardless of the optimization model used.

REFERENCES

ABBASS, K.; QASIM, M.Z.; SONG, H.; MURSHED, M.; MAHMOOD, H.; YOUNIS, I.A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research International*, v. 29, n. 28, p. 42539-42559, 2022. https://doi.org/10.1007/s11356-022-19718-6

AGÊNCIA NACIONAL DE ÁGUAS (ANA). *Conjuntura dos recursos hídricos no Brasil 2019: informe anual*. Brasília: ANA, 2019.

AGHASIAN, K.; MORIDI, A.; MIRBAGHERI, A.; ABBASPOUR, M. A conflict resolution method for waste load reallocation in river systems. *International Journal of Environmental Science and Technology*, v. 16, n. 1, p. 79-88, 2019. https://doi.org/10.1007/s13762-018-1993-3

AKHTAR, N.; ISHAK, M.I.S.; BHAWANI, S.A.; UMAR, K. Various natural and anthropogenic factors responsible for water quality degradation: a review. *Water*, v. 13, n. 19, p. 2660, 2021. https://doi.org/10.3390/w13192660

ALBERTIN, L.L.; MAUAD, F.F.; DANIEL, L.A. Uso de simulação computacional para planejamento de um sistema hídrico: estudo de caso qualitativo e quantitativo. *Revista Brasileira de Recursos Hídricos*, v. 11, n. 4, p. 209-219, 2006.

ALMEIDA, K.N.; REIS, J.A.T.; MENDONÇA, A.S.F.; SILVA, F.G.B. Methodology to support the planning of sewage treatment systems within river basins International Journal of Environmental Science and Technology. *International Journal of Environmental Science and Technology*, v. 19, n. 5, p. 3741-3756, 2022. https://doi.org/10.1007/s13762-021-03387-y

BRASIL. Resolução CONAMA n°. 357, de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências. *Diário Oficial da União*, p. 58-63, 2005.

BRASIL. Resolução CONAMA nº 430/2011, de 13 de maio de 2011. Dispõe sobre as condições e padrões de lançamento de efluentes, complementa e altera a Resolução nº 357, de 17 de março de 2005, do Conselho Nacional do Meio Ambiente-CONAMA. *Diário Oficial da União*, p. 89-89, 2011.

BRINGER, L.M.; REIS, J.A.T.; MENDONÇA, A.S.F. Wastewater treatment systems selection inside watersheds by using multiobjective analysis. *Revista Brasileira de Recursos Hídricos*, v. 23, 2018. https://doi.org/10.1590/2318-0331.231820170140

BURN, D.H.; YULIANTI, J.S. Waste-load allocation using genetic algorithms. *Journal of Water Resources Planning and Management*, v. 127, n. 2, p. 121-129, 2001. 10.1061/(ASCE)0733-9496(2001)127:2(121)

CALMON, A.P.S.; SOUZA, J.C.; REIS, J.A.T.; MENDONÇA, A.S.F. Uso combinado de curvas de permanência de qualidade e modelagem da autodepuração como ferramenta para suporte ao processo de Enquadramento de cursos d'água superficiais. *Revista Brasileira de Recursos Hídricos*, v. 21, n. 1, p. 118-133, 2016. https://doi.org/10.21168/rbrh.v21n1.p118-133

CANDIDO, L.A.; COÊLHO, G.A.G.; MORAES, M.M.G.A.; FLORÊNCIO, L. Review of decision support systems and allocation models for integrated water resources management focusing on joint water quantity-quality. *Journal of Water Resources Planning and Management*, v. 148, n. 2, p. 03121001, 2022. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001496

FANTIN, L.L.D.O.; REIS, J.A.T.; MENDONÇA, A.S.F. Proposal of a methodology for pre-selection of sewage treatment systems within watersheds. *Revista Brasileira de Recursos Hídricos*, v. 22, e12, 2017. https://doi.org/10.1590/2318-0331.011716079

GIRI, S. Water quality prospective in Twenty First Century: Status of water quality in major river basins, contemporary strategies and impediments: a review. *Environmental Pollution*, v. 271, p. 116332, 2021. https://doi.org/10.1016/j.envpol.2020.116332

KEUPERS, I.; WILLEMS, P. Development and testing of a fast conceptual river water quality model. *Water Research*, v. 113, p. 62-71, 2017. https://doi.org/10.1016/j.watres.2017.01.054

LIMA, I. M. M. F. *Caracterização Geomorfológica da Bacia Hidrográfica do Rio Poti*. 1982. 162 f. Dissertação (Mestrado em Geografia) – Instituto de Geociências, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 1982.

OLIVEIRA FILHO, A.A.; LIMA NETO, I.E. Modelagem da qualidade da água do rio Poti em Teresina (PI). *Engenharia Sanitária e Ambiental*, v. 23, n. 1, p. 3-14, 2018. https://doi.org/10.1590/S1413-41522017142354

ROCHA, L.G.; ALEIDA, K.N.; REIS, J.A.T.; MENDONÇA, A.S.F.; SILVA, F.D.G.B. Sewage treatment efficiencies estimation for urban areas located in the River Pardo's watershed by associating nonlinear programming and water quality modeling. *Brazilian Journal of Environmental Sciences (Online)*, v. 56, n. 1, p. 65-75, 2021. https://doi.org/10.5327/Z2176-947820200731

RODRIGUES, M.B.; ALMEIDA, K.N.; SÁ, G.L.N.; REIS, J.A.T.; MENDONÇA, A.S.F. Perspectivas para revisão do enquadramento da bacia hidrográfica do rio Benevente a partir do emprego de curva de permanência e modelagem da qualidade da água. *Engenharia Sanitaria e Ambiental*, v. 27, p. 831-843, 2022. https://doi.org/10.1590/S1413-415220210295

SÁ, G.L.N.; REIS, J.A.T.; MENDONÇA, A.S.F.; SILVA, F.G.B. Methodology for minimum nitrogen compounds removal efficiencies estimation and wastewater treatment systems pre-selection: a watershed approach. *Revista Brasileira de Recursos Hídricos*, v. 24, e41, 2019. https://doi.org/10.1590/2318-0331.241920180173

SALLA, M.R.; PEREIRA, C.E.; ALAMY FILHO, J.E.; PAULA, L.M.; PINHEIRO, A.M. Estudo da autodepuração do Rio Jordão, localizado na bacia hidrográfica do Rio Dourados. *Revista Engenharia Sanitária e Ambiental*, v. 18, n. 2, p. 105-114, 2013. https://doi.org/10.1590/S1413-41522013000200002

SANTORO, M.C.; REIS, J.A.T.; MENDONÇA, A.S.F. Avaliação de modelos de otimização aplicáveis à determinação de eficiências de tratamento de efluentes no âmbito de uma bacia hidrográfica. *Revista Brasileira de Recursos Hídricos*, v. 21, n. 4, p. 694-706, 2016.

SISTEMA NACIONAL DE INFORMAÇÕES SOBRE SANEAMENTO (SNIS). *Diagnóstico Temático Serviços de Água e Esgoto*. Brasília: MDR/SNS, 2022.

VALORY, J.P.L.; REIS., J.A.T.; MENDONÇA, A.S.F. Combining genetic algorithms with a water quality model to determine efficiencies of sewage treatment systems in watersheds. *Journal of Environmental Engineering*, v. 142, p. 04015080, 2016.

VON SPERLING, M. *Estudos e modelagem da qualidade da água de rios*. Belo Horizonte: DESA/UFMG, 2007.