Edição especial – 9º INOVAGRI International Meeting

ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

INTERAÇÕES ENTRE SERES HUMANOS – RECURSOS HÍDRICOS E A DEGRADAÇÃO DA QUALIDADE DA ÁGUA EM UMA DENSA REDE DE RESERVATÓRIOS

JOSIANA DO NASCIMENTO ALVES FEITOSA[1]; PEDRO HENRIQUE AUGUSTO MEDEIROS [2] E ANTÔNIO ALVES MEIRA NETO[3]

[1]*Departamento de Pós-Graduação em Engenharia Agrícola, UFC, Brasil,* josinascimento1997@gmail.com , *https://orcid.org/0009-0005-7695-2280*
[2] *Professor do Instituto Federal de Educação, Ciência e Tecnologia do Ceará, IFCE Fortaleza, Brasil, phamedeiros@ifce.edu.br, https://orcid.org/0000-0002-4879-3148*
3 Professor da Colorado State University, Fort Collins, Colorado, EUA, A.Alves_Meira_Neto@colostate.edu, https://orcid.org/0000-0002-7508-8241

1 RESUMO

A expansão da infraestrutura hídrica foi uma estratégia de adaptação às secas no semiárido brasileiro, mas trouxe impactos negativos a médio e longo prazo. O objetivo do trabalho foi identificar os efeitos sócio-hidrológicos da expansão dos reservatórios na qualidade da água da Bacia do Alto Jaguaribe (BAJ), Ceará. Com base em referências bibliográficas e relatórios técnicos, observou-se um pico de construção de açudes na década de 1990, com uma média anual de 0,7 reservatórios (1980–2004) caindo para 0,1 entre 2005 e 2015. Essa expansão resultou na estabilização da capacidade de armazenamento, em quase o dobro do escoamento médio anual, contribuindo para a degradação da qualidade da água, especialmente em períodos secos. Entre 2012 e 2017, por exemplo, houve um aumento considerável das concentrações de fósforo total nos açudes, ultrapassando o limite de 0,05 mgL^{-1} (limite superior ao estado mesotrófico). Portanto, o adensamento da rede de reservatórios na BAJ agravou a degradação da qualidade da água à medida que aumentou a retenção de nutrientes e intensificou o fenômeno da eutrofização.

Palavras-Chave: seca, socio-hidrologia, poluição hídrica.

FEITOSA, J. do N. A.; MEDEIROS, P. H. A.; MEIRA NETO, A. A.
INTERACTIONS BETWEEN HUMANS-WATER RESOURCES AND WATER QUALITY DEGRADATION IN A DENSELY POPULATED NETWORK OF RESERVOIRS

2 ABSTRACT

The expansion of water infrastructure was a strategy for adapting to droughts in the semiarid region of Brazil, but it had negative effects in the medium and long term. The objective of this study was to identify the sociohydrological effects of reservoir expansion on the water quality in the Upper Jaguaribe Basin (BAJ), Ceará. On the basis of bibliographic references and technical reports, a peak in dam construction was observed in the 1990s, with an annual average of 0.7 reservoirs (1980–2004) falling to 0.1 between 2005 and 2015. This expansion resulted in

Recebido em 05/11/2025 e aprovado para publicação em 10/12/2025
DOI: http://dx.doi.org/10.15809/irriga.2025v30p70-77

the stabilization of storage capacity at almost 2-fold the average annual runoff, contributing to the degradation of water quality, especially during dry periods. Between 2012 and 2017, for example, there was a considerable increase in the concentrations of total phosphorus in the reservoirs, exceeding the limit of 0.05 mg L^{-1} (upper limit for mesotrophic status). Therefore, the growth of the reservoir network in the BAJ aggravated the degradation of water quality, as it increased nutrient retention and intensified the phenomenon of eutrophication.

Keywords: drought, socio-hydrology, water pollution.

3 INTRODUCTION

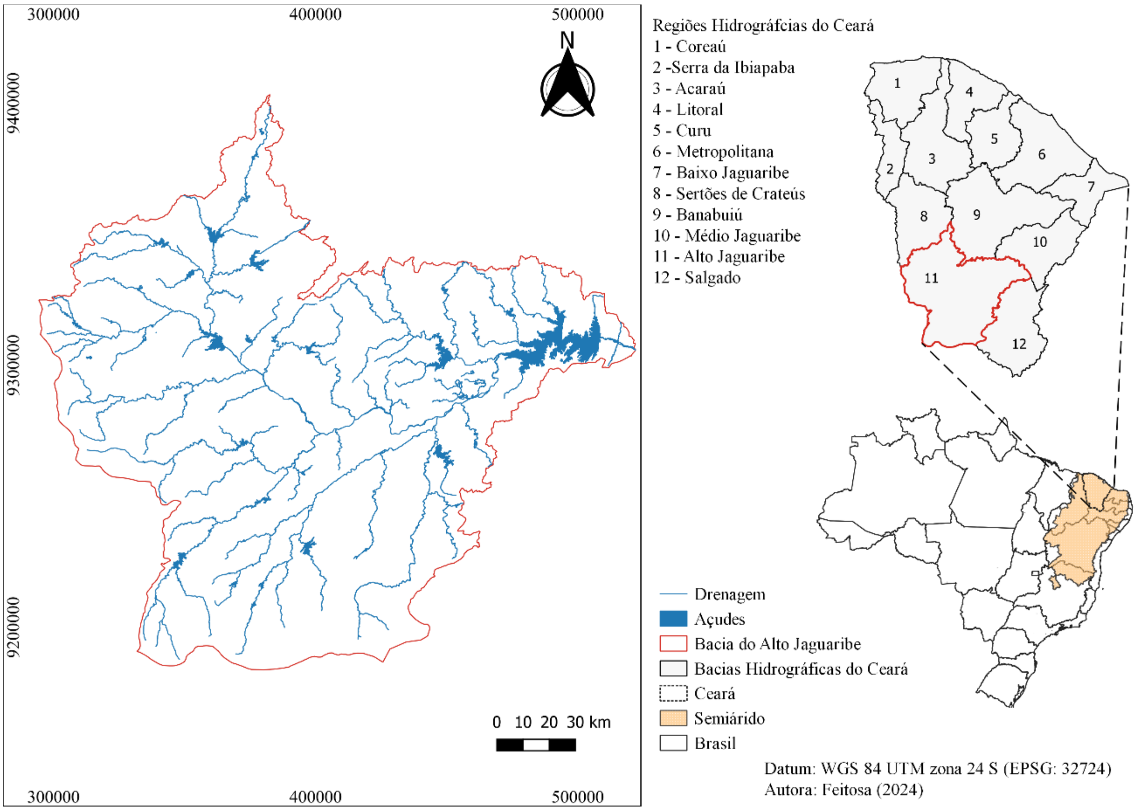
Drought is a natural phenomenon that has adverse effects on humans and hinders the achievement of the Sustainable Development Goals – SDGs (Di Baldassarre *et al*., 2019). To reduce human vulnerability, several adaptation strategies have been implemented over time, notably, the construction and expansion of a network of reservoirs in semiarid Northeast Brazil since the beginning of the 20th century, a measure that has contributed to promoting water security (Meira Neto *et al*., 2024). However, the evolution of water storage has resulted in undesirable consequences arising from interactions between society and water resources, such as nutrient retention and degradation of water quality due to eutrophication, negatively impacting the availability of this resource (Medeiros; Sivapalan, 2020).

This eutrophication process is driven primarily by the high input of phosphorus, a nutrient carried in sediment flows, which reaches water bodies (Lima Neto *et al*., 2022; Wang; Wang, 2009). Thus, analysis of the total phosphorus load is essential both for controlling eutrophication in these environments (Le Moal *et al*., 2019; Rattan *et al*., 2017; Silva *et al*., 2025) and for the sustainable management of water resources. In this context, sociohydrology stands out , an interdisciplinary science that analyzes the reciprocal interactions between societies and water and results from a variety of events in diverse regions of the planet and in varied contexts (Pereira *et al*., 2025; Sivapalan; Savenije; Blöschl, 2012). Therefore, this work aims to identify the sociohydrological effects of the expansion of water infrastructure in the Upper Jaguaribe Basin, Ceará, with emphasis on the water quality of the extensive and dense network of reservoirs.

4 MATERIALS AND METHODS

The Upper Jaguaribe Basin (BAJ, 24,500 km2) is located in the state of Ceará in the northeast region of Brazil and has 24 reservoirs monitored by the Ceará Water Resources Management Company (2025). Figure 1 , and 3478 nonstrategic strategies. According to the Köppen climate classification, the basin has a BSh-type climate—hot semiarid (Medeiros *et al*., 2014)—with an average annual precipitation of 700 mm $year^{-1}$ and an average annual potential evaporation of 2,100 mm $year^{-1}$ according to 30-year averages of the Climatological Normals of the National Institute of Meteorology (INMET) (Meira Neto *et al*., 2024). The region's precipitation has significant interannual and intraannual variability (concentrated in the months of January to March). Runoff coefficients in the region typically range between 5% and 10% and can be less than 1% (Figueiredo *et al*., 2016), while the rivers are mostly ephemeral or intermittent (Lima Neto *et al*., 2022; Mamede *et al*., 2018).

Figure 1. Location of the Upper Jaguaribe Basin (BAJ) and the reservoirs monitored by COGERH.



This work presents a qualitative and quantitative theoretical approach developed through a literature review. The objective was to identify evidence of the sociohydrological effect of the expansion of water infrastructure on the water quality of the BAJ, Ceará. For this study, scientific publications, journal articles, and technical reports from the Water Resources Management Company (2025) related to drought, human–water resource interactions, and water quality were consulted. The selection of sources prioritized journals in the areas of environmental and hydrological sciences, as well as studies published in the last 15 years.

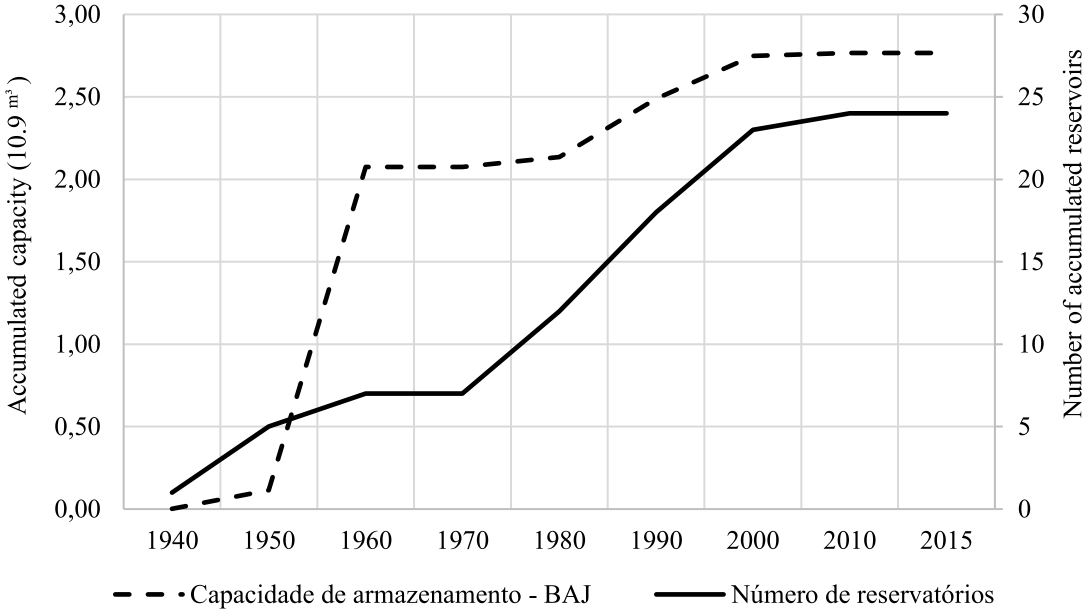
5 RESULTS AND DISCUSSION

Historically, reservoirs have been constructed to reduce the vulnerability of society to droughts (Di Baldassarre *et al.*, 2019). These water infrastructures experienced remarkable growth on a global scale in the 1960s (300%) and 1970s (130%) to meet the needs of populations, which increased by 15% and 25% during those periods, respectively (Di Baldassarre *et al.*, 2018), generating extensive reservoir networks. However, in recent decades, there has been an increase in water demand at the expense of a stable reservoir storage capacity, as well as a reduction in the availability of water in reservoirs due to siltation and eutrophication resulting from land use and cover patterns and societal adaptation measures (Di Baldassarre *et al.*, 2018; Gohari *et al.*, 2013; Medeiros; Sivapalan, 2020).

With respect to the BAJ (Figure 2), it was found that from 1940—when the first strategic reservoir, Do Coronel, with a storage capacity of 0.002×10^{9} m^{3}, was implemented—until 1970, when the rate of dam construction corresponded to 0.2

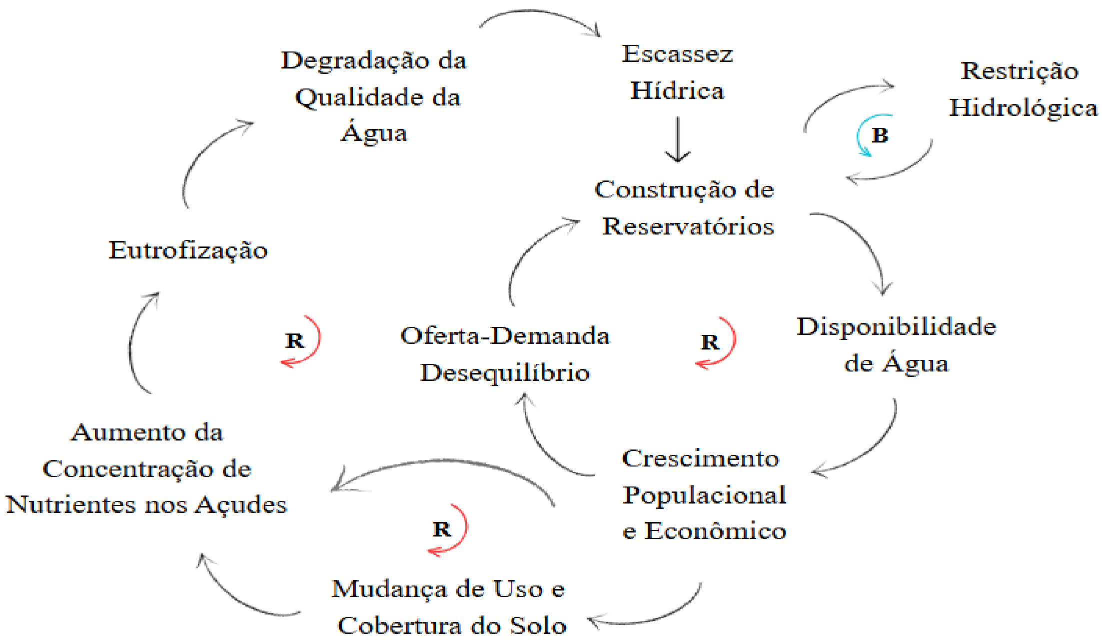
reservoirs per year. This rate peaked in the 1990s, with an average of 0.7 reservoirs per year implemented from 1980 to 2004. However, during the period from 2005 to 2015, the rate fell to 0.1 dams per year. Furthermore, the water storage capacity increased over time: in 1940, it was 0.002 × 10^9 m³, and in 2015, it reached 2.77 × 10^{9} m³. Notably, in the 1960s, the capacity substantially increased because of the implementation of the Orós reservoir (1.94 × 10^9 m³).

Figure 2. Evolution of the number of strategic reservoirs and storage capacity of the Upper Jaguaribe Basin.



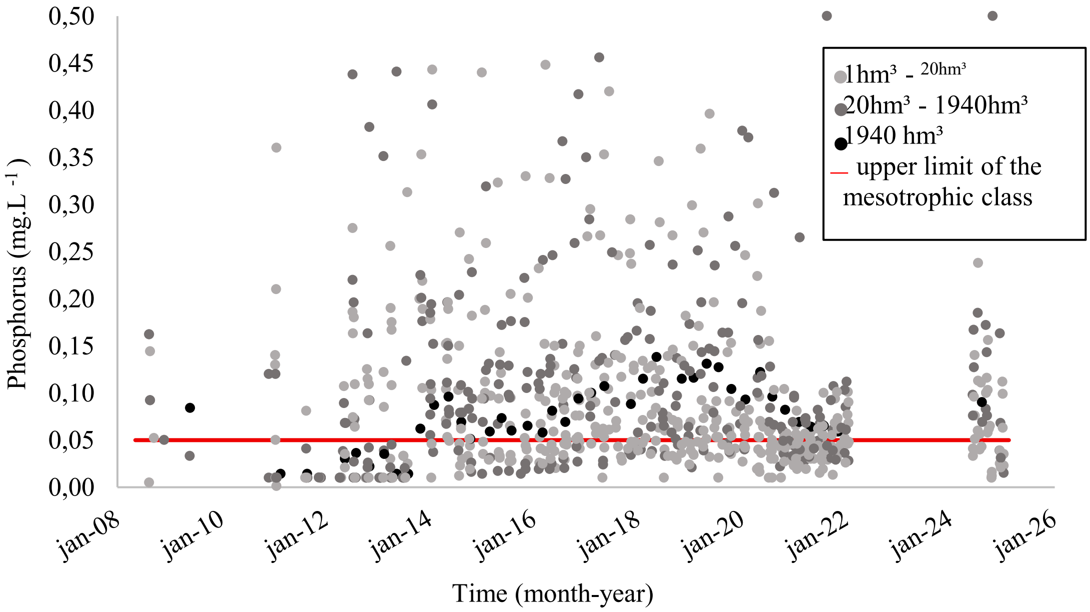
The expansion of reservoirs in the BAJ (Baía de Arrasco) resulted in two effects: i) the stabilization of storage capacity (at almost double the average annual flow) due to limited inflow, i.e., hydrological constraints; and ii) the degradation of water quality due to nutrient accumulation, intensified by the increased residence time of water in the water storage structures, accelerating the eutrophication process and causing greater water deterioration. This led to the implementation of new reservoirs (supply–demand effect), which reinforced a negative feedback loop. A loop diagram that allows visualization of these effects is shown in Figure 3.

Figure 3. Causal loop diagram: R: reinforcing loop; B: balancing loop



This degradation is significant and more pronounced during periods of low water storage (Wiegand *et al.*, 2021). The phosphorus values (mgL^{-1}) for different reservoir sizes for 2008 to 2025 according to the classification proposed by Meira Neto *et al. are shown in Figure 4*. (2024). From 2012 to 2017 (drought period), there was a significant increase in total phosphorus (TP), especially for reservoirs with lower storage capacities, which negatively impacted water availability.

Figure 4. Total phosphorus values for different storage capacities of reservoirs in the Upper Jaguaribe Basin for 2008 to 2025.



According to Silva *et al*. (2025), PT values exceeding the limit of 0.05 mg. L^{-1} (red line in Figure 4), which corresponds to the upper limit of the mesotrophic state—water bodies with intermediate productivity, with possible impacts on water quality but at acceptable levels in most cases, according to the Brazil Water Project (2013)—can be considered a condition of water unavailability for human supply because of poor quality. Thus, for almost the entire period and for almost all reservoirs, water is unsuitable for human consumption.

6 CONCLUSION

Human-induced changes to hydrological systems have allowed us to address the temporal variability in water availability and scarcity. However, the intensification of these interventions has led to undesirable effects, generating unintended feedback loops and producing sociohydrological impacts. Among the negative impacts of water management measures on the hydrological system, the effects on water quality were analyzed in this study. The degradation of water quality worsened in the Upper Jaguaribe Basin with the densification of the reservoir network, which caused an increase in the residence time of water in the water storage structures and, consequently, greater nutrient retention and accelerated eutrophication. In this sense, understanding the bidirectional interactions between humans and water is fundamental to seeking sustainable measures focused on recovering the water quality of reservoirs rather than exclusively structural measures.

7 ACKNOWLEDGEMENTS

The authors thank the National Council for Scientific and Technological Development (CNPq) for granting a doctoral scholarship to the first author, grant 140976/2024-8.

8 REFERENCES

Water Resources Management Company. **Ceará Hydrological Portal** . Fortaleza: COGERH, 2025. Available at: http://www.hidro.ce.gov.br/ . Accessed on: June 21, 2025.

DI BALDASSARRE, G.; SIVAPALAN, M.; RUSCA, M.; CUDENNEC, C.; GARCIA, M.; KREIBICH, H.; KONAR, M.; MONDINO, E.; MARD, J.; PANDE, S.; SANDERSON, MR; FUGIANGTIAN, T.; VIGLIONE, A.; WEI, J.; WEI, Y.; YU, DJ; SRINIVASAN, V.; BLÖSCHL, G. Sociohydrology: Scientific challenges in addressing the sustainable development goals. **Water Resources Research** , Washington, DC, vol. 55, no. 8, p. 6327-6355, 2019. DOI: https://doi.org/10.1029/2018WR023901. Available at: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2018WR023901. Accessed on: June 20, 2025.

DI BALDASSARRE, G.; WANDERS, N.; AGHAKOUCHAK, A.; KUIL, L.; RANGECROFT, S.; VELDKAMP, TIE; GARCIA, M.; VAN OEL, PR; BREINL, K.; VAN LOON, AF Water shortages worsened by reservoir effects. **Nature Sustainability** , London, v. 1, no. 11, p. 617-622, 2018. DOI: https://doi.org/10.1038/s41893-018-0159-0 . Available at: https://www.nature.com/articles/s41893-018-0159-0. Accessed on: 02 Jun. 2025.

FIGUEIREDO, JV; ARAÚJO, JC de; MEDEIROS, PHA; COSTA, AC. Runoff initiation in a preserved semiarid Caatinga small watershed, Northeastern Brazil. **Hydrological Processes** , Hoboken , v. 30,

n. 13, p. 2390-2400, 2016. DOI: https://doi.org/10.1002/hyp.10801 . Available at: https://onlinelibrary.wiley.com/doi/10.1002/hyp.10801. Accessed Date : May 15, 2025.

GOHARI, A.; ESLAMIAN, S.; MIRCHI, A.; ABEDI-KOUPAEI, J.; BAVANI, AM; MADANI, K. Water transfer as a solution to water shortage: A fix that can Backfire. **Journal of Hydrology** , Amsterdam, v. 491, n. 1, p. 23-39, 2013. DOI: https://doi.org/10.1016/j.jhydrol.2013.03.021 . Available at: https://www.sciencedirect.com/science/article/pii/S0022169413002217?via%3Dihub. Accessed : May 21 , 2025.

LE MOAL, M.; GASCUEL-ODOUX, C.; MÉNESGUEN, A.; SOUCHON, Y.; ÉTRILLARD, C.; LEVAIN, A.; MOATAR, F.; PANNARD, A.; SOUCHU, P.; LEFEBVRE, A.; PINAY, G. Eutrophication: A new wine in an old bottle? **Science of the Total Environmental** , Amsterdam, v. 651, no. 1, p. 1-11, 2019. DOI: https://doi.org/10.1016/j.scitotenv.2018.09.139 . Available at: https://www.sciencedirect.com/science/article/pii/S0048969718335836?via%3Dihub. Access on : May 31 , 2025.

LIMA NETO, I. E; MEDEIROS, PHA; COSTA, AC; WIEGAND, MC; BARROS, ARM; BARROS, MUG Assessment of phosphorus loading dynamics in a tropical reservoir with high seasonal water level changes. **Science of The Total Environmental** , Amsterdam, v. 815, no. 152875, p. 1-10, 2022. DOI: https://doi.org/10.1016/j.scitotenv.2021.152875 . Available at: https://www.sciencedirect.com/science/article/pii/S0048969721079547?via%3Dihub. Access on : May 10 , 2025.

MAMEDE, GL; GUENTNER, A.; MEDEIROS, PHA; ARAÚJO, JC de; BRONSTERT, A. Modeling the effect of multiple reservoirs on water and sediment dynamics in a semiarid catchment in Brazil. **Journal of Hydrologic Engineering,** Reston, v. 23, n. 12, p. 05018020-1-05018020-13, 2018. DOI: https://doi.org/10.1061/(ASCE)HE.1943-5584.0001701 . Available at: https://ascelibrary.org/doi/10.1061/%28ASCE%29HE.1943-5584.0001701. Accessed on: August 12, 2025.

MEDEIROS, PHA; ARAÚJO, JC de; MAMEDE, GL; CREUTZFELDT, B. GÜNTNER, A.; BRONSTERT, A. Connectivity of sediment transport in a semiarid environment: a synthesis for the Upper Jaguaribe Basin, Brazil. **Journal of Soils and Sediments** , Heidelberg, v. 14, n. 12, p. 1938-1348, 2014. DOI: https://doi.org/10.1007/s11368-014-0988-z. Available at: https://link.springer.com/article/10.1007/s11368-014-0988-z. Accessed on: August 20, 2025.

MEDEIROS, PHA; SIVAPALAN, M. From hard-path to soft-path solutions: slow–fast dynamics of human adaptation to droughts in a water scarce environment. **Hydrological Sciences Journal** , Abingdon, v. 65, n. 11, p. 1803–1814, 2020. DOI: https://doi.org/10.1080/02626667.2020.1770258 . Available at: https://www.tandfonline.com/doi/full/10.1080/02626667.2020.1770258. Accessed on: June 26, 2025.

MEIRA NETO, AA; MEDEIROS, PH A; ARAÚJO, JC de; PEREIRA, BS; SIVAPALAN, M. Evolution of Drought Mitigation and Water Security Through 100 Years of Reservoir Expansion in Semi-Arid Brazil. **Water Resources Research** , Washington, v. 60, n. 9, p. 1-23, 2024.

DOI: https://doi.org/10.1029/2023WR036411. Available at: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023WR036411. Accessed on: May 26, 2025.

PEREIRA, BS; UCHÔA, JGSM; FREITAS, GS; MEIRA NETO, AA; ANACHE, JAA; WENDLAND, EC; MEASURING, IN; MEDEIROS, PHA Hydrological heritage: a historical exploration of human–water dynamics in northeast Brazil. **Hydrological Sciences Journal** , Abingdon, vol. 70, no. 4, p. 546–558, 2025. DOI: https://doi.org/10.1080/02626667.2024.2446272 . Available at: https://www.tandfonline.com/doi/full/10.1080/02626667.2024.2446272. Accessed on: October 5, 2025.

BRAZIL WATER PROJECT. *Research* . Available at: https://brasildasaguas.com.br/projetos/sete-rios-2006-2007/pesquisa/. Accessed on: January 15, 2026.

RATTAN, KJ; CORRIVEAU, JC; BRUA, RB; CULP, JM; YATES, AG; CHAMBERS, PA Quantifying seasonal variation in total phosphorus and nitrogen from prairie streams in the Red River Basin, Manitoba Canada. **Science of The Total Environmental** , Amsterdam, v. 575, p. 649-659, 2017. DOI: http://dx.doi.org/10.1016/j.scitotenv.2016.09.073. Available at: https://www.sciencedirect.com/science/article/pii/S0048969716319921?via%3Dihub. Accessed on: May 15, 2025.

SILVA, EMR; ALMEIDA, LG de; MEDEIROS, PHA; LIMA, GD; ANDRADE, EM de; ARAÚJO, J.C. de . Reservoir eutrophication in the Brazilian semiarid: modeling of sediment removal and control of external loads as remediation measures. **Environmental Science and Pollution Research** , Heidelberg, v. 32, n. 12, p. 7663-7679, 2025. DOI: https://doi.org/10.1007/s11356-025-36183-z . Available at: https://link.springer.com/article/10.1007/s11356-025-36183-z . Accessed on: May 18, 2025.

SIVAPALAN, M.; SAVENIJE HHG; BLÖSCHL, G. Sociohydrology: A new science of people and water. **Hydrological Processes** , Hoboken, v. 26, n. 8, p. 1270-1276, 2012. DOI: https://doi.org/10.1002/hyp.8426. Available at: https://onlinelibrary.wiley.com/doi/10.1002/hyp.8426. Accessed on : May 21 , 2025.

WANG, H.; WANG, H. Mitigation of lake eutrophication: Loosen nitrogen control and focus on phosphorus abatement. **Progress in Natural Science** , Beijing, vol. 19, no. 10, p. 1445-1451, 2009. DOI: https://doi.org/10.1016/j.pnsc.2009.03.009. Available at: https://www.sciencedirect.com/science/article/pii/S1002007109002391?via%3Dihub. Accessed on: 23 June. 2025.

WIEGAND, MC; NASCIMENTO, ATP; COSTA, AC; LIMA NETO, IE. Trophic state changes of semiarid reservoirs as a function of the hydroclimatic variability. **Journal of Arid Environments** , Amsterdam, v. 184, article 104321, p. 1-9, 2021. DOI: https://doi.org/10.1016/j.jaridenv.2020.104321. Available at: https://www.sciencedirect.com/science/article/pii/S0140196320302202?via%3Dihub. Accessed on: July 5, 2025.