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Hydrological drought risk evaluation in context of climate-resilient water regulation, conservation and restoration of hydrographic basin biomes of Brazil

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Abstract

Understanding the role of forests in the global sustainable development agenda as well as the context of critical environmental and socioeconomic issues related to climate change are relevant aspects for the present day. Water scarcity and ecosystem restoration are major challenges on a local and global scale. This article attempts to address the main aspects of integrated water resources management, climate change and sustainable development in Brazil in recent decades. It is a fact that we need tools for climate-resilient water management approaches for the diverse biomes of the world. An analysis of the current model of the water-climate-forest nexus and an analysis of the integration of policies and governance in Brazil are presented with an emphasis on aspects of water regulation, conservation and restoration of hydrographic basin biomes.
In the last two decades, the Southeast and Northeast Brazil are experiencing one of its worst periods of severe drought. Multi-purpose uses reservoirs were constructed to alleviate water shortage problems via redistributing water resources with temporal variability and spatial heterogeneity. Thus, a resilient approach to drought risk management, including reservoir operation methodologies for water scarcity situations, considering reliability, vulnerability and resilience are presented. The applicability of multi-seasonal streamflow generation models for hydrological drought risk evaluation is discussed. Five cases studies of reservoir operation rules as mitigation and adaptation strategies for building a green and resilient future with forests and watershed basins, belonging to three important biomes (savanna, caatinga and Atlantic Forest) are showed: the cases of Paraíba do Sul hydrographic basin (Rio de Janeiro), Cantareira reservoirs system (São Paulo) and the São Francisco river basin systems, including the Interbasin Water Transfer – PISF Project, the Piancó-Piranhas-Açu river basin and the Bocaina reservoir watershed.

Keywords: Adaptive and integrated management, Climate change, Economic development, Policies, Governance.

Introduction and objectives

Understanding the role of forests in the global sustainable development agenda as well as the context of critical environmental and socioeconomic issues related to climate change are relevant aspects for the present day. Water scarcity and ecosystem restoration are major challenges on a local and global scale. Extreme events, such as droughts and floods, are climate severities present in every region of the globe, with much varied effects, most of them with heavy impacts on society and the eco-systems. Recent developments on the matter is to make governments aware of the need to tackle the drought issue with a proactive approach, on one side, and on the other, to integrate all stakeholders (scientists, users, managers, etc.) in different fora allowing the enhancement of the response and mitigating capacity of services and societies confronted with droughts. One important activity is the promotion of integrated land and water use.

This article attempts to address the main aspects of integrated water resources management, climate change and sustainable development in Brazil in recent decades. It is a fact that we need tools for climate-resilient water

management approaches for the diverse biomes of the world. The caatinga biome, prevailing in the Brazilian semiarid region, the savanna and Atlantic Forest, in Southeast Brazil will be impacted by climate change.

Drought impacts in Northeast Brazil, which tend to intensify due to climate change and overexploitation of the caatinga biome, have over many decades brought famine, mass migration and social conflicts. Drought prediction and monitoring, however, remain a central research theme (Freitas, 2010). Marengo (2006), Salati et al. (2007), Brito et al. (2017) conducted studies on the impacts of global climate change for many areas of Brazil, as Brazilian Amazon, Northeast, Pantanal and the Prata River Basin, showing precipitation and temperature anomalies, and water balance for the XXI century. The semiarid northeastern presenting short but crucially important rainy season in the current climate could, in a warmer climate in the future, become arid.

Methodology

The analysis of the current model of policies that comprise the water-climate-forest nexus, as well as the integration of these policies and governance aspects in Brazil, revealed that emphasis should be placed on aspects of water regulation, to reduce vulnerability and expand the resilience of water producing systems, as well as ensuring the conservation and restoration of hydrographic basin biomes (Freitas and Afonso, 2011).

In the last two decades, Brazil is experiencing one of its worst periods of severe drought. Multi-purpose uses reservoirs were built, over the last 50 years, to alleviate water shortage problems via redistributing water resources with temporal variability and spatial heterogeneity. These reservoirs were projected and were being operated based only on reliability criteria. Thus, the main instruments of the water resources policy are also based only on reliability criteria, namely: the granting of the right to use water; charging for water use and river basin plans. Thus, a resilient approach to drought risk management is presented (SIGES - Drought Management System), including reservoir operation methodologies for situations of water scarcity, considering not only reliability, but also vulnerability and resilience (Freitas et al., 2019). And in this sense, it is very important that the reservoirs operation optimization use climate information, and that the participative water allocation mechanisms (Negotiated Water Allocation), and resilience strategies were implemented.

Strategic Management

As part of the strategic component, several models for predicting droughts and floods using statistical-probabilistic tools and artificial neural networks were developed. As well as using existing global climate models. Such models serve as input for rainfall-runoff models, synthetic streamflow generation models, etc. Aiming at drought monitoring, several indices, such as Rainfall Anomaly Index (RAI), Bhalme & Mooley Drought Index (BMDI), were adapted and incorporated into a drought basic characteristic monitoring system (duration, severity and intensity), so that mitigating actions could be implemented in accordance with the event classification. Several of those indices have been incorporated into the Brazilian Drought Monitor (Nóbrega et al., 2019). Finally, new adaptive reservoir operation strategies for water scarcity are presented and discussed.

Tatic Management: Reservoir Operation Optimization using Climate Information, Negotiated Water Allocation and Resilience Strategies

Due to the scarcity of fluviometric data, it is often necessary to obtain a series of affluent flows into the reservoir using rainfall-runoff or streamflow generation models. For the generation of synthetic flowrates in intermittent rivers typical of semiarid regions, Freitas (1995, 2010) presented the SAGE system - Stochastische AbflussGEnerierungsmodelle.

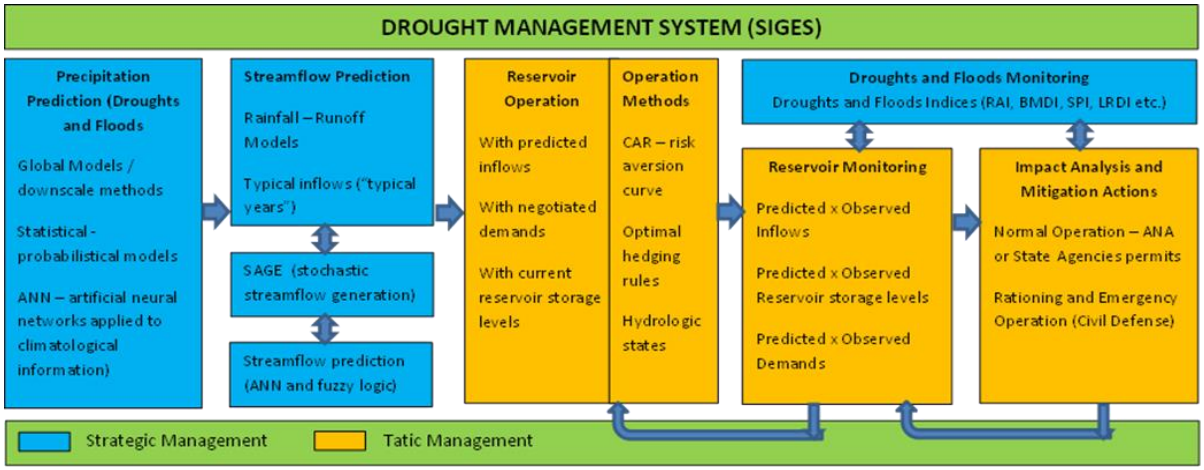

Fig. 1: Drought Management System - SIGES (Freitas, M. A. S. et al., 2019)

Water deficits as result of non-sustainable water resources development, are the main reason for water related conflicts in water scarcity affected regions, especially due to strong competition between the different water users. Non-conventional water resources, such as treated wastewater, brackish or imported water needs to be part of an integrated strategy for IWRM implementation (Rusteberg and Freitas, 2018).

According to Lopes and Freitas (2007) and Freitas (2009), water allocation in Brazil, historically, is characterized by a strong intervention of the public sector. It can be understood as a measure that aims to provide water to current and future users of the water resources system, matching water supply and demand, even meeting environmental demands, being in line with strategic management objectives.

Results and Discussion

Five cases studies of reservoir operation rules as mitigation and adaptation strategies for building a green and resilient future with forests and watershed basins, belonging to three important biomes (savanna, caatinga and Atlantic Forest) are showed. The first one, the Paraíba do Sul River basin, where 5 million inhabitants live, has about 57,000 km² and extends across the states of São Paulo, Rio de Janeiro and Minas Gerais. Approximately 2/3 of its waters are transferred to the Guandu basin, supplying another 8 million inhabitants of the metropolitan region of Rio de Janeiro, in addition to producing energy and supplying water to the region's industries. Through Law No. 9,984/2000, the National Water Agency - ANA was created, having among its attributions, to define the operating conditions for hydroelectric reservoirs in conjunction with the National Electric System Operator - ONS.

Foreseeing a future problem of water scarcity at the end of the dry period in 2003, studies (Figure 2) were carried out through simulations to modify the operating rules of the basin's reservoirs in force until then. Those rules had been established by the DNAEE Ordinance No. 022/1977 and by Decree No. 81.436/1978. Freitas (2004) presents a synthesis of the simulations carried out using the flow network model, called AcquaNet (Azevedo et al., 1997), and later discussed within the scope of the Basin Committee, resulting in the edition of Resolution No. 211/2003, providing for the rules to be adopted for the operation of the Paraíba River hydraulic system do Sul, which comprises, in addition to the reservoirs located in the basin, also the structures for transposing the waters of the Paraíba do Sul River to the Guandu System.

After articulation with the ONS and with the Paraíba do Sul River Basin Committee - CEIVAP and Guandu River Basin Committee, Resolution No. 211/2003, was published, which provides for the rules to be adopted for the operation of the Paraíba do Sul River hydraulic system.

In 2008, the Master Plan for the Use of Water Resources for the Macrometropolis of São Paulo included, among the studied options, the possibility of transposing water from the Paraíba do Sul basin to reinforce the supply of the Metropolitan Region of São Paulo. With the crisis beginning in 2014, which affected both the Cantareira system and the Paraiba do Sul basin, the state of São Paulo began the construction of the interconnection of the basins, connecting the Jaguari to the Itibainha reservoir. A series of conflicts and negotiations broke out.

In 2015, an Interinstitutional Group, composed of the federal government, the three States and basin representation, completed the preparation of the evaluation report, with emphasis on new operating rules for the Paraíba do Sul Hydraulic System, which would replace ANA Resolution No. 211/2003. The Joint Resolution ANA/DAEE/INEA/IGAM No. 1.382/2015 was published, which enters into force in December/2016. In October/2017, ANA Resolution No. 1,931, with the operational rules for the transposition of São Paulo was published. As a result of all this long process, there was the strengthening of the shared management in the basin, of the relationship between the Committee, the State management bodies and ANA. In addition, these new operating rules ensured more water security for both metropolitan regions.

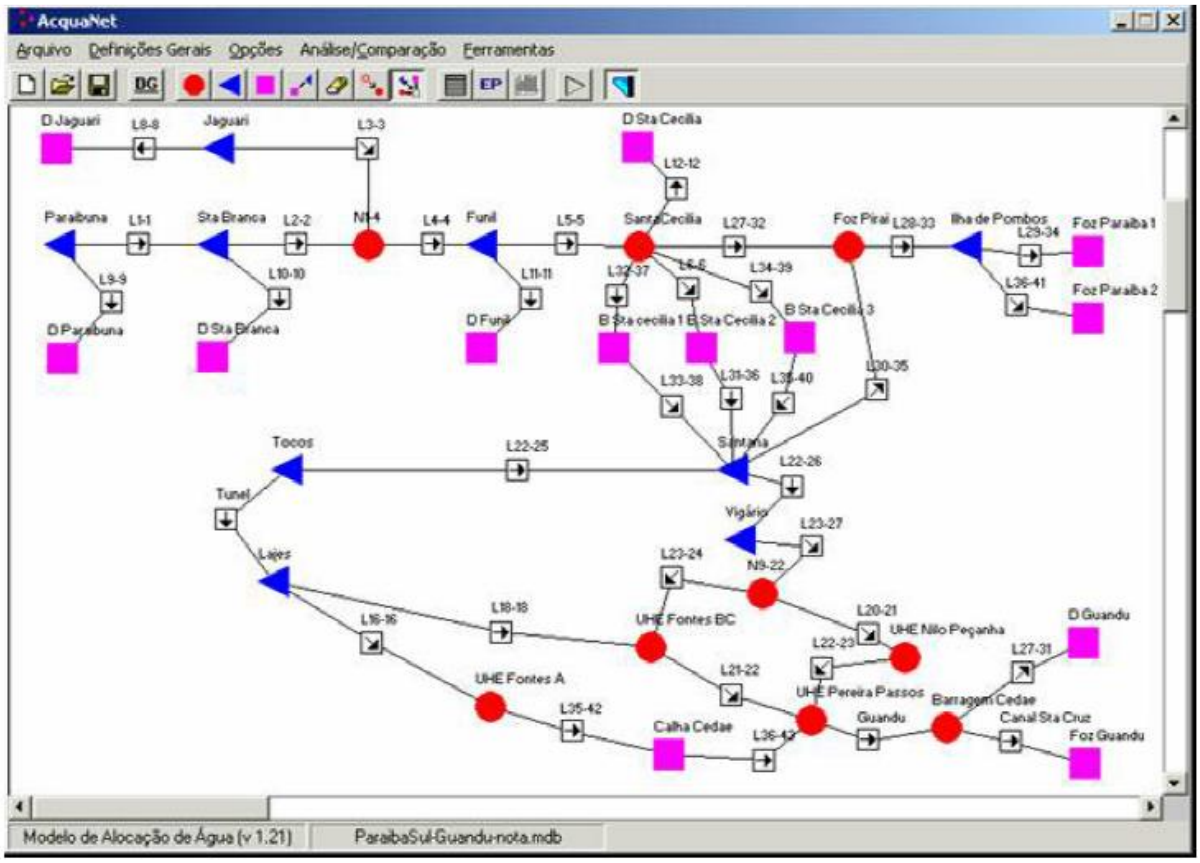

Fig. 2: AcquaNet System for the Paraíba do Sul River basin (Freitas, 2004)

Cantareira reservoirs system

According to Gondim Filho et al. (2005) and Oliveira et al. (2015) the Cantareira System is one of the most important water producing systems in the Metropolitan Region of São Paulo composed by a series of reservoirs, tunnels and channels that diverse water from the Piracicaba river basin to Alto Tiete basin. The system designed in the late 60's began to operate on the following decade. The authorization to diverse up to 33m³/s of water

was given to the Sanitation Company of São Paulo State (Sabesp) by the Ordinance MME nº 750/1974, with a term of 30 years. The authorization for another 10 years was given by Ordinance DAEE nº 1213/2004, according to the operating conditions determined by the Joint Resolution ANA/DAEE nº 428/2004. Due to the low water flows observed on the first semester of 2014, which values were smaller than the minimum registered since 1930, and to allow consider this exceptional hydrological scenario on the studies that will be done to renew the authorization, ANA and DAEE issued the Joint Resolution ANA/DAEE nº 910/2014 extending until October 31, 2015 the authorization to diverse water from the Piracicaba river basin.

According to Joint Resolution ANA/DAEE No. 428/2004, the amounts to be released to Sabesp were stipulated in priority order, with a primary priority being the flow of 24.8 m^3/s and secondary priority being the flow of 6.2 m^3/s, which totals the possibility of withdrawing 31 m^3/s. For the Piracicaba, Capivari, Jundiai River Basin Committees (PCJ Committees), the total discharge flow was stipulated at 5 m^3/s, with the primary flow of 3 m^3/s and the secondary flow of 2 m^3/s being in the order of priority.

In addition to defining the flow limits to be released to users, operating guide curves were established, based on the concept of Risk Aversion Curves - CAR, which allows evaluating the future situation of the system in case a critical hydrological drought scenario occurs, maintaining a minimum reserve at the end of this period. In Cantareira, the CARs were defined considering the Jaguari-Jacareí, Cachoeira and Atibainha reservoirs (Equivalent System, corresponding to the reservoirs located in the Piracicaba river basin), a 5% strategic reserve and the hydrological scenario of the biannual period of minimum water availability, corresponding to the 1953/1954 biennium (Oliveira et al., 2015). A compensation mechanism, called "water bank" was created and it allows the storage of unused volume during the rainy season for use in critical dry periods.

During the period 2004-2014, the operational model of the Cantareira System was tested under different conditions. In 2014, the stock of accumulated volumes in the reservoirs rapidly reduced, causing the management bodies to issue the ANA-DAEE Joint Resolution No. 335/2014, which incorporated the Water Bank to the Equivalent System State, determined that the new withdrawal flows would be defined by the management bodies (since it would no longer be possible to apply the risk aversion curves) and established that the use of volumes below the levels operating minimums would depend on authorization.

São Francisco river basin system

Lopes and Freitas (2004) have been proposed a methodology for water allocation to supply multiple water resources uses in a watershed based on present and future water availability and demand. It was applied in the São Francisco river watershed using data from the watershed plan with satisfactory results. The application shows the methodology's ability to adapt to the modeling of complex systems. In this case, it was important to properly define the control points, compatible with the hydrological characteristics of the water system.

Freitas and Gondim Filho (2004) presents the determination of regulated flows (100% guaranteed) for the Reservoirs of Três Marias and Sobradinho, using the newly series of net evaporation and natural inflows to the reservoirs. These flows were used in the “Water Resources Master Plan”. Its purpose was to determine the reference flows for water allocation in parts of the river’s main stem located between the main reservoirs of the São Francisco River basin. An important finding was that the critical period (from a long series of historical flows starting in 1931) for the Sobradinho reservoir, which corresponded to the period from May-1952 to October-1955, had shifted to the end of the series, that is, April/1998-November/2001.

Piancó-Piranhas-Açu River Basin

Northeast Brazil experienced during the years 2012-2020 one of its worst periods of severe drought. This was largely due to the conditions of the El Niño phenomenon in the Pacific Ocean and the oceanographic and atmospheric conditions of the Atlantic Ocean.

This methodology was applied to mitigate the drought impacts. With the reduction of rainfall and the consequent tax flow to the main reservoirs, the operation of the reservoirs responsible for the main uses of the

region's water resources is shown to be of fundamental importance: irrigated agriculture; aquaculture; human and industrial supply, among others. Actions aimed at the rational use of water, monitoring and negotiated water allocation mechanisms, as well as communication were also carried out.

ANA Resolution No. 687/2004 provided for the Regulatory Framework for the management of the so-called Curema-Açu System and established parameters and conditions for issuing preventive grants and the right to use water resources (Freitas and Gondim Filho, 2007). First, the Risk Aversion Curves - CAR were proposed for the Curema-Mãe D'água and Armando Ribeiro Gonçalves reservoirs. Afterwards, several changes were made in the way of operating the reservoirs to incorporate flow release rules depending on the state or level of water accumulation in each reservoir. The Piancó-Piranhas-Açu River Basin will receive part of the transposed water from the São Francisco River basin, through the so-called Interbasin Water Transfer – PISF Project (Freitas, 2021).

Guaribas River Basin

The Bocaina dam (State of Piauí), with a capacity of 106 hm^3 of water, was built with the objective of regularizing the Guaribas River, among other uses (Freitas, 2010). The area estimated by the viability studies of the Bocaina Reservoir reached 2,000 (two thousand) irrigable hectares. Over the past three decades, use for irrigation and water supply in neighboring cities has increased significantly. The objective of this study is to analyze, by means of several multicriteria methods, the alternatives of operation of the afore mentioned reservoir to meet multiple uses. Five alternatives for reservoir operation, socioeconomic and environmental development were analyzed. For this, four different multicriteria techniques were used: i) weighted average method (WAM); ii) compromise programming (CP); iii) Promethee method with weighted averages (Promethee_WAM) and iv) Promethee method.

The decision-making process in water resources management currently involves multiple objectives and multiple decision-makers (river basin committees, consortia, etc.). In general, conflicts of interest are established between groups with different views about the goals to be adopted in the planning and management of water resources. The study of alternatives (A1 to A5) was carried out in two stages: i) Use of rainfall-runoff hydrological models, stochastic streamflow generation models (Freitas, 1995; Freitas and Freitas, 2019) and Monte Carlo analysis, as well as models for simulation / optimization of the reservoir operation; ii) Use of multicriteria techniques.

Conclusions

A resilient approach to drought risk management, including reservoir operation methodologies for water scarcity situations, considering reliability, vulnerability and resilience are presented. Five cases studies of reservoir operation rules as mitigation and adaptation strategies for building a green and resilient future with forests and watershed basins, belonging to three important biomes (savanna, caatinga and Atlantic Forest) are presented. With the application of this methodology, together with countless other management and communication actions, it was possible for the country to go through one of its worst severe droughts in history.

References

Azevedo, L.G.T.; Porto, R.L.L.; Zadeh Filho, K. – Modelos de Simulação e de Rede de Fluxo, in: Técnicas quantitativas para o gerenciamento de recursos hídricos, R. La Laina Porto (org.), Editora da Universidade UFRGS/ABRH, 1997.

Brito, S., Cunha, A. P., Castro, C., Alvala, R. Marengo, J., Carvalho, M. 2017. Frequency, duration and severity of drought in the Brazilian Semiarid region. International Journal of Climatology, doi: 10.1002/joc.5225.

Freitas, M.A.S. - SAGE (Stochastische AbflussGEnerierungsmodelle), Handbuch, Institut für Wasserwirtschaft, Hydrologie und landwirtschaftlichen Wasserbau, Universität Hannover, Alemanha, 1995.

FREITAS, M.A.S. 2004. Regras de operação dos reservatórios da bacia do rio Paraíba do Sul/Sistema Guandu. In: SEMINÁRIO INTERNACIONAL SOBRE REPRESAS Y OPERACIÓN DE EMBALSES, 2004, Puerto Iguazú. Anais... Buenos Aires: CACIER. v. 1.

Freitas, M. A. S. (2009). A Regulação dos Recursos Hídricos. 1. ed. Rio de Janeiro: CBJE, 2009. v. 1. 174p.

Freitas, M. A. S. (2010) Que Venha a Seca: Modelos para Gestão de Recursos Hídricos em Regiões Semiáridas. 1. ed. Rio de Janeiro: CBJE Editora, 413p.

Freitas, M. A. S. (2021) The Piancó-Piranhas-Açu Hydrographic Basin Face to the 2012-2020 Drought Event, Brazilian Journal of Animal and Environmental Research, Curitiba, v.4, n.1, p. 1033-1046 jan./mar. 2021.

Freitas, M. A. S.; Afonso, S. R. (2011) O Trinômio Água-Clima-Floresta: integração das políticas, governança e participação social no Brasil, Conference: V Congreso Forestal Latinoamericano – CONFLAT, June 2011.

Freitas, M. A. S.; Freitas, G. B. (2019): On the Applicability of Multiseasonal Streamflow Generation Models for Intermittent rivers. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 16, p. 36-44, 2019.

Freitas, M. A. S.; Silveira, P. B. M.; Freitas, G. B. (2019): A Resilient Drought Risk Management Approach in the Semiarid Northeast Brazil. International Journal of Current Research 11 (09), p. 6968-6974, 2019.

Freitas, M. A. S.; Gondim Filho, J. G. C. (2004). Disponibilidade hídrica do sistema formado pelos reservatórios de Três Marias e Sobradinho na bacia hidrográfica do rio São Francisco para fins de alocação de água, VII Simpósio de Recursos Hídricos do Nordeste, nov. 2004.

Freitas, M. A. S.; Gondim Filho, J. G. C. (2007). Curvas de Aversão ao Risco para os Reservatórios Armando Ribeiro Gonçalves e Curemas-Mãe D´água, in Anais do XVII Simpósio Brasileiro de Recursos Hídricos, 2007, São Paulo.

Gondim Filho, J. G. C., Sugai, M., Nobrega, M. T., Freitas, M. A. S. 2005 Implementação e Operação do Modelo de Alocação de Água do Sistema Cantareira - São Paulo. In: XVI Simpósio Brasileiro de Recursos Hídricos, 2005, João Pessoa. Anais do XVI Simpósio Brasileiro de Recursos Hídricos. Porto Alegre: Editora da ABRH, v. 1. p. 129-129.

Lopes, A. V.; Freitas, M. A. de S. (2004). Alocação de Água baseada nas ofertas e demandas hídricas, VII Simpósio de Recursos Hídricos do Nordeste, nov. 2004.

Lopes, A. V.; Freitas, M. A. de S. (2007). A alocação de água como instrumento de gestão de recursos hídricos: experiências brasileiras. Revista de Gestão de Água da América Latina (REGA) 4 (1), 6-28, 2007.

Marengo, J.A. 2006 Mudanças climáticas globais e seus efeitos sobre a biodiversidade: caracterização do clima atual e definição das alterações climáticas para o território Brasileiro ao longo do século XXI, Brasília – DF.

Nóbrega, M. T.; Freitas, M. A. S.; Júnior, F. V. (2019) Monitor de Secas, XXIII Simpósio Brasileiro de Recursos Hídricos, Foz do Iguaçu, Paraná, Available at: https://eventos.abrh.org.br/xxiiisbrh/pdf/nobrega-2019-msecas-sbrh2019-stand_da_ana.pdf; https://monitordesecas.ana.gov.br/

Oliveira, O. F.; Gondim Filho, J. G. C.; Freitas, M. A. S.; Meller, A. (2015) Avaliação da Operação do Sistema Cantareira entre 2004 e 2014, XXI Simpósio Brasileiro de Recursos Hídricos, 2015.

Rusteberg, B.; Freitas, M. A. S. (2018): IWRM Implementation in North-East Brazil (Results from WP 8). In: Abels, A., Freitas, M. A. S., Pinnekamp, J., Rusteberg, B. (Org.). Bramar Project - Water Scarcity Mitigation in Northeast Brazil. 1ed., Aachen: Department of Environmental Engineering (ISA), 2018, v. 1, p. 120-144.

Salati, E., Salati, E., Campanhol, T., Villa Nova, N. 2007 Tendências das Variações Climáticas para o Brasil no Século XX e Balanços Hídricos para Cenários Climáticos para o Século XXI. Brasília: MMA, 186 p.