Nativa, Sinop, v.6, n. 5, p. 480-485, set./out. 2018.
Pesquisas Agrárias e Ambientais
DOI: http://dx.doi.org/10.31413/nativa.v6i5.5719
http://www.ufmt.br/nativa

ISSN: 2318-7670

Climate change and water resource sustainability index for a water-stressed basin in Brazil: the case study of Rio Verde Grande basin

Mônica Carvalho de SÁ[1], Edson de Oliveira VIEIRA[1*], Flavia Mazzer RODRIGUES[1], Lorrana Cavalcanti ALBUQUERQUE[1], Núbia Ribeiro CALDEIRA[1]

[1]Instituto de Ciências Agrárias, Universidade Federal de Minas Gerais, Montes Claros, MG, Brasil.
*E-mail: eovieira@ica.ufmg.br

Recebido em outubro/2017; Aceito em março/2018.

ABSTRACT: The Rio Verde Grande basin is a water-stressed basin, which is 87% in the northern part of Minas Gerais and 13% in Bahia, Brazil. It has a semi-arid climate with long and intense periods of drought. This climatic directly affects the availability of water resources and the development of the main activities in the region. There are presently no studies that evaluate the effect of climate change on the availability of water in the Rio Verde Grande basin and the sustainability of high water demand activities. The objective of this study was to analyze future changes in the availability of water in the Rio Verde Grande basin, and the sustainability of water for the major water users. This was done using a synthetic series generated through climatic and hydrological modeling programs. This study performed climate projections using the Global Climate Models of the Coupled Model Intercomparison Project Phase 5. The calculation of sustainability indexes and a comparison between current and future scenarios, it was observed that even if all the interventions proposed by the Water Resources Plan of the Rio Verde Grande basin are implemented, there will still be a reduction in the sustainability of water resources in some sub-basins, due to climate change.
Keywords: CMIP5, WEAP model, vulnerability.

Mudanças climáticas e a sustentabilidades dos recursos hídricos em bacia hidrográfica com escassez hídrica no Brasil: o caso da bacia de Rio Verde Grande

RESUMO: A bacia de Rio Verde Grande está localizada 87% na parte norte do estado de Minas Gerais e 13% no estado da Bahia, em uma região com clima semiárido, apresentando longos e intensos períodos de seca. Esta característica climática afeta diretamente a disponibilidade de recursos hídricos e, conseqüentemente, o desenvolvimento das principais atividades da região que são pecuária e agricultura irrigada. Não há estudos que avaliem o efeito das mudanças climáticas na disponibilidade de água e na sustentabilidade de atividades com alta demanda de água na bacia de Rio Verde Grande. O objetivo deste estudo foi analisar as mudanças prováveis na disponibilidade de água na bacia de Rio Verde Grande e a sustentabilidade dos recursos hídricos para as atividades usuárias de água, utilizando séries sintéticas geradas através de programas de modelagem climática e hidrológica. Este estudo realizou as projeções climáticas utilizando os Global Climate Models do Coupled Model Intercomparison Project Phase 5. Com base nos cálculos dos índices de sustentabilidade e na comparação dos cenários atuais e futuros, observou-se que, mesmo com todas as intervenções propostas pelo Plano de Recursos Hídricos da Bacia Rio Verde Grande implementadas, houve uma redução na sustentabilidade da água Recursos em algumas sub-bacias devido à mudança climática.
Palavras-chave: CMIP5, modelo WEAP, vulnerabilidade.

1. INTRODUCTION

Climate change has been a matter of global concern since the 1980s. The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 with the aim of gathering and evaluating research in this field. According to the IPCC (2007) and Schlenker et al. (2007), some projections indicate that the average global surface temperature will increase by up to 5.8 °C in the next hundred years. This will directly affect patterns of precipitation and will be reflected in an increase of extreme events such as droughts and floods. In many places in the world climate change will compromised water availability.

In Brazil, climate change may make access to water even more difficult. A lack of rainwater due to protracted periods of low rainfall (combined with high temperatures and evaporation rates) and competition for water resources could lead to a potentially catastrophic crisis. The most vulnerable will be members of the agricultural sector, especially in Brazil's semi-arid region (MARENGO, 2008a).

The Rio Verde Grande basin is located in a semi-arid region. The distribution of rainfall in the basin throughout the year is characterized by clearly differentiable drought and humid seasons.

According to Marengo (2008b), water resource management in semi-arid regions depends heavily on climate variability. One of the outcomes of climate change in the Rio Verde Grande basin is an increase in climatic variability, which compromises the availability of water. The main activity in this region is irrigated agriculture; thus, it is extremely important to guarantee the sustainability of water resources in the basin so that water is available for this activity.

Current knowledge of the impact of climate change on water resources in this region is insufficient for future planning. It is, therefore, necessary to conduct a deeper study to better evaluate and quantify the impacts of climate change and ensure the sustainable use of water resources. For this, both hydrological and climatological models have been used as tools to simulate the behavior of watersheds and climate, allowing to analyze future scenarios (MACHADO ET AL., 2017; YUNUS ET AL., 2017).

The objective of this study was to analyze the likely changes in water availability in the Rio Verde Grande basin and the sustainability of water resources for water users.

2. MATERIALS AND METHODS

2.1. Basin characterization

The Rio Verde Grande basin has an area of 31,410 km², of which 87 % (27 219 km²) is located in the State of Minas Gerais and 13 % (4,191 km²) in the State of Bahia (Agência Nacional de Águas - ANA, 2016)(Figure 1). The basin was subdivided into eight sub-basins to assist in the management of the Water Resources Plan of the Rio Verde Grande basin (WRPVG). The sub-basins are as follows: Alto Verde Grande (AVG), Médio Verde Grande-Trecho Alto (MVG-TA), Médio Verde Grande-Trecho Baixo (MVG-TB), Alto Gorutuba (AG), Médio Baixo Gorutuba (MBG), Alto Verde Pequeno (AVP), Baixo Verde Pequeno (BVP), and Baixo Verde Grande (BVG). The Médio Baixo Gorutuba (MBG) sub-basin represents the largest area, accounting for 25 % (7,715 km²) of the total area. The Baixo Verde Grande (BVG) sub-basin is the smallest, consisting of only 6 % of the area (1,934 km²) (ANA, 2016).

The WRPVG proposes a series of studies. These studies will, through a climatological system, predict the occurrence of extreme events, such as droughts and floods. In addition, the climate systems proposed by the Water Plan will analyze the effects of climate change on the hydrological regime (ANA, 2016).

2.2. Climate Modeling

The IPCC is a scientific body whose purpose is to assess global climate change. In order to do so, researchers from all over the world come together to share advances in climate change science and to reach a consensus on the trends of these changes. This consensus is made official by the scientific community through reports that have current information on climate change research (MARENGO; SOARES, 2003 & TUCCI, 2002). The Coupled Model Intercomparison Project Phase *5* (CMIP5) consists of more than 50 climate models working with climate change simulations, both past and future (ZHAO et al. 2014). The MarkSim climate modeling program has 17 of the general circulation models used by CMIP5, but only four of these models were used in this study (Table 1).

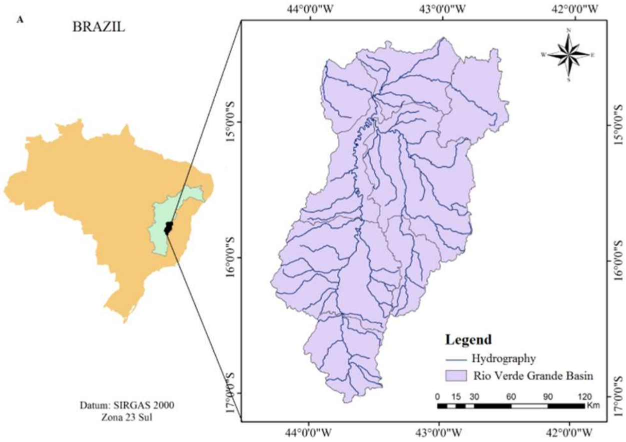

Figure 1. Location of the Rio Verde Grande Basin.
Figura 1. Localização da Bacia do Rio Verde Grande.

The choice of models used in this study was based on their availability to MarkSim (2017). Of the models available in MarkSim, only those with the smallest scales were selected; these models could be regionalized using the downscaling technique, which would guarantee more satisfactory results. MarkSim also works with the Representative Concentration Pathways (RCP) found in the fifth IPCC report. The RCP present four scenarios that consider changes in radiative forcing in the year 2100. These scenarios are called RPC2.6, RPC4.5, RPC6.0, and RPC8.5. From these scenarios, climate projections analyze different conditions as a reflection of different sources of radiative forcing, such as greenhouse gas concentrations, emission of aerosols and chemical gases, and land use and occupation. These analyses allow projections on climate change to also consider human actions, which makes the scenarios more realistic (TAYLOR et al., 2012; TUNDISI, 2008). For this study, the RCP6.0 scenario was adopted. This represents a radiative forcing of 6 Wm^{-2}, and considers climate stabilization to occur after the year 2100. This scenario also stabilizes the CO_2 emissions and foresees stabilization of the emissions of greenhouse and air polluting gases.

With our chosen parameters (the models and the scenario), MarkSim was able to generate a future synthetic series, where each sub-basin produced monthly averages of precipitation, minimum temperature, and maximum temperature for each year studied until the year 2050.

Table 1. Global Climate Models (GCM) used in this work (adapted from MarkSim DSSAT weather file generator, 2017).
Tabela 1. Modelos Climáticos Globais utilizados neste trabalho.

	Model	Institute	Resolution (Latitude x Longitude)	References
1	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organization and the Queensland Climate Change Centre of Excellence	1.875 x 1.875	Collier et al. (2011)
2	HadGEM2-ES	Met Office Hadley Centre, UK	1.2414 x 1.875	Collins et al. (2011)
3	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo) and the National Institute for Environmental Studies	1.4063 x 1.4063	Watanabe et al. (2010)
4	MRI-CGCM3	Meteorological Research Institute, Japan	1.125 x 1.125	Yukimoto et al. (2012)

2.3. Hydrological Modeling

This study used the WEAP (Water Evaluation and Planning) model for hydrological modeling in the Rio Verde Grande basin. The calibration and verification of the model was based on historical data from basin's meteorological stations. In its future scenarios, the WRPVG considered some changes in the basin by the year 2030. The plan predicted a reduction in the demand for water due to a smaller loss in the water systems. The WRPVG predicts greater control of losses due to urban supply and the implementation of measures to improve the availability of water in the basin. This could include the building of new dams, the import of water and use of delivered water (ANA, 2016).

Three scenarios were presented by the water plan: Baseline, Normative 1, and Normative 2. In this study, the Baseline and Normative 2 scenarios were used. The Baseline scenario considers the increase of water supply by interventions previously proposed or in progress. Normative 2 considers a water management scheme that aims to increase water supply by importing water from the Congonhas River, through water diversion from the São Francisco River, and the construction of five dams. It also includes preventive and adaptive actions, such as increasing the efficiency of water use (ANA, 2016).

The calibration to validate the WEAP model was done using the interventions provided for in the WRPVG. The types of demand on water resources were also determined. These were found to be: irrigated agriculture, livestock farming, the urban population (Urban Pop.), and the rural population (Rural Pop.). Once the WEAP was calibrated and validated, this study used the future synthetic series obtained in the MarkSim climate modeling program as input data for the hydrological model. Thus, the performance criteria and the sustainability index could be calculated.

The hydrological model generated future scenarios (climate scenario) that represent changes in the behavior of the water users in the basin and, consequently, the sustainability of the available water resources.

According to Sandoval-Solis et al. (2011) performance criteria can be used to evaluate water management policies and allow comparison with alternative water management measures. The performance criteria reliability, resilience, vulnerability and maximum deficit were chosen for this study. These performance criteria are based on a "water supplied deficit" (D_t^i) (Equation 1).

$$D_t^i = \begin{cases} X_{Target,t}^i - X_{Supplied,t}^i, & \text{If } X_{Target,t}^i > X_{Supplied,t}^i \\ 0, & \text{If } X_{Target,t}^i = X_{Supplied,t}^i \end{cases} \qquad \text{(Eq.1)}$$

(D_t^i) is the difference between the water demand ($X_{Target,t}^i$) and the water supplied ($X_{Supplied,t}^i$) for each time period t, for a determined ith water user.

The water users were defined as the irrigated area (irrigated crop farmers), livestock (livestock farmers), urban population, and rural population. The reliability was calculated using Equation 2. The resilience (Res) is given by Equation 3.

$$Reliability = \frac{No.\ of\ times\ D_t^i = 0}{n} \qquad \text{(Eq. 2)}$$

$$\text{Res} = \frac{\text{No. times } D_t^i = 0 \text{ follows } D_t^i > 0}{\text{No. times } D_t^i > 0 \text{ ocurred}} \qquad \text{(Eq. 3)}$$

and vulnerability (Vul) is calculated by Equation 4,

$$\text{Vul} = \frac{\left(\frac{\sum_{t=0}^{t=n} D_t^i}{\text{No. of times } D_t^i > 0 \text{ occurred}}\right)}{X_{Target}^i} \qquad \text{(Eq. 4)}$$

The maximum deficit is given by Equation 5, where D_{annual}^i is the annual demand for water,

$$\text{Max. Deficit} = \frac{\max(D_{annual}^i)}{\text{Water demand}^i} \qquad \text{(Eq. 5)}$$

The calculation of the sustainability index for the water resources of the Rio Verde Grande basin allowed a comparison of the behavior of the basin between the Baseline and Normative 2 scenario. This made it possible to analyze the projected climatic changes and the changes that occurred in the basin once the interventions to improve water availability were implemented.

In order to process the data in the WEAP model, a time interval of 2000 to 2050 was used. Both historical data (2000-2014) and the future synthetic series generated in MarkSim (2015-2050) were considered. The Baseline and Normative 2 scenarios, established by the WRPVG, were compared by evaluating the changes in the sustainability index of the basin's water resources. In order to better understand the results generated, it was necessary to observe the behavior of the basin through performance criteria. These criteria were calculated by comparing the eight sub-basins and the different water use activities.

3. RESULTS

Reliability is shown in Figure 2; it indicates the probability that the water available in the sub-basins meets the demand during the simulated time interval. The resilience (shown in Figure 3) represents the ability of the system to adapt to changes imposed on it. The vulnerability performance criteria (Figure 4) describes the behavior of the sub-basins considering the maximum deficit in the system in a period of continuous failure, and measures the consequences of an undesirable situation and identifies their severity (ASEFA ET AL., 2014). Figure 5 shows the worst maximum annual deficit reported when water availability did not meet the required demand.

The sustainability index indicated the performance of alternative policies, in order to guarantee a lower vulnerability to the system (Figure 6).

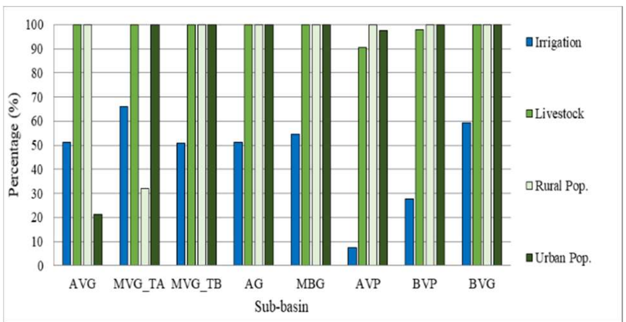

Figure 2. Reliability of water resources in the Rio Verde Grande Basin.

Figura 2. Confiabilidade dos recursos hídricos na Bacia do Rio Verde Grande.

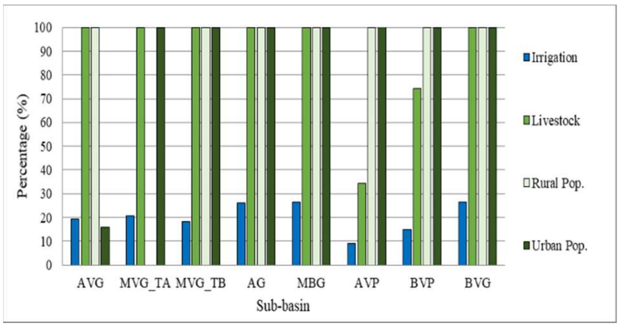

Figure 3. Resilience of water resources in the Rio Verde Grande Basin.
Figura 3. Resiliência dos recursos hídricos na Bacia do Rio Verde Grande.

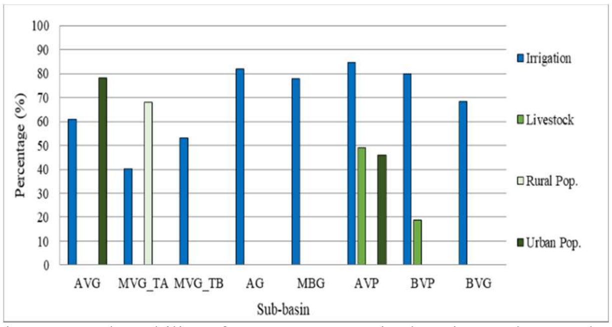

Figure 4. Vulnerability of water resources in the Rio Verde Grande Basin.
Figura 4. Vulnerabilidade dos recursos hídricos na Bacia do Rio Verde Grande.

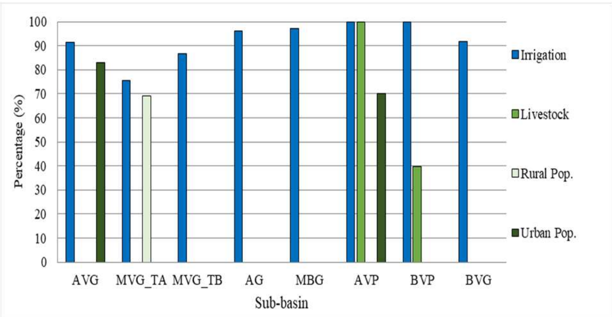

Figure 5. Maximum Deficit of water resources in the Rio Verde Grande Basin.
Figura 5. Déficit Máximo dos recursos hídricos na Bacia do Rio Verde Grande.

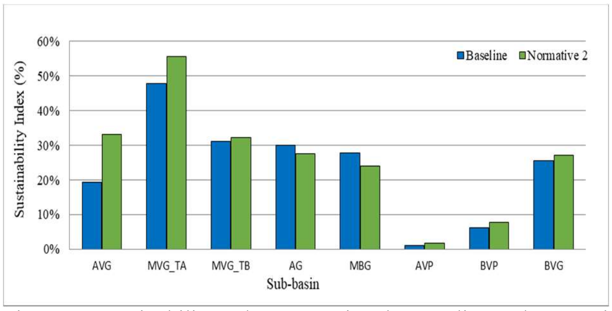

Figure 6. Sustainability Index comparing the Baseline and Normative 2 scenarios.
Figura 6. Índice de Sustentabilidade comparando os cenários Referencial e Normativo 2.

4. DISCUSSION

Figure 2 shows that the urban population (Urban Pop.) of the AVG sub-basin has the highest water demand in relation to the other sub-basins, but it has a very low reliability. The high demand is due to the population density; half the population of the entire Rio Verde Grande basin is located in this sub-basin, mainly in the city of Montes Claros.

All types of water use (irrigation, livestock, urban population, and rural population) in the BVG sub-basin had a high level of reliability. This sub-basin has the highest surface water availability of the entire basin, due to its high cumulative mean flow. Among the water users' activities, irrigation has a very variable reliability, which can be explained by the different demands in the eight sub-basins of the Rio Verde Grande basin. In some sub-basins water consumption for irrigation exceeds 90% of the total demand. Grafton and Hussey (2011) report that climate change can increase water demand for irrigation, affected with warmer temperatures.

Figure 3 shows that the MVG-TA sub-basin does not have a recovery capacity for the rural population. This sub-basin has a large rural population in a region with low drainage density. In contrast, despite having the largest rural population of any sub basin, the MBG had a high resilience for water users. This can be attributed to its location, since most of the basin's water bodies are located in this sub-basin, as is the dam at Bico da Pedra. This increases its drainage density and, consequently, its resilience. Irrigation activity had a low level of resilience in all of the sub-basins, never exceeding 30 %. Lane et al. (2015) analyzing water management in the Rio Grande/Bravo showed that a single optimal policy changing the timing (but not quantity) of reservoir releases can improve specified environmental objectives while maintaining or improving human objectives of basin. Policy like that can be apply in MBG to increase their performance criteria indexes.

Figure 4 shows that irrigation farming is highly vulnerable in all sub-basins. This is a consequence of this activity's high water demand. Therefore, when only considering surface water availability and climate changes effects, irrigation agriculture is likely the activity with the highest risk in the entire basin.

The AVP and BVP sub-basins had very high vulnerability for livestock farming. The land use and vegetation cover for livestock in these sub-basins is high; however, the surface water availability in both sub-basins is low, which results in higher vulnerability.

The analysis showed a highly vulnerable urban population in the AVG sub-basin; this region has the highest population concentration. The WRPVG projects a population growth of 1.95 % per year for the AVG sub-basin, which may lead to high vulnerability in this sub-basin by 2050.

Figure 5 shows a high maximum deficit in all sub-basins for irrigation agriculture. This indicates that for the simulated time frame, the implementation of the strategies in WRPVG will not meet the growth in water demand.

Sustainability index demonstrated the adaptability of the system. It can be seen that, even once all of the interventions proposed in the basin plan have been implemented, there was only an increase in the sustainability index in some of the sub-basins (Figure 6). In others, sustainability was reduced. This was likely due to the influence of climate change on the basin. The AVG sub-basin had a considerable increase in the sustainability index due to the import of water from the Congonhas River and the implementation of two dams. This development is intended to guarantee the water supply to the urban population of Montes Claros City. But after structural implementation both reliability and resilience of AVG sub-basin keep very low. This development is intended to guarantee the water supply to the urban population of Montes Claros City. But after structural implementation both reliability and resilience of AVG sub-basin keep very low. Similarly of the study of Safavi et al. (2015) that found very low reliability and resilience while high vulnerability of the Zayandehrud Dam, located center of Iran (SAFAVI and ALIJANIAN 2010), in very critical conditions period after withdrawing of water to irrigation, industries, animal farming and municipal supply.

The MVG-TA and MVG-TB sub-basins also had an improvement in sustainability levels. Both sub-basins are located near the AVG and make use of the main channel of the Rio Verde Grande. Thus, they will also benefit from the interventions made in the AVG sub-basin.

The MBG, BVG, AVP, and BVP sub-basins will not benefit from the water inputs to the AVG sub-basin. Even when other measures are implemented in these sub-basins, Figure 6 shows that some sub-basins have an increase in their sustainability indices and some did not. The interventions proposed by the WRPVG will be heavily affected by climate change. Thus, they will not been sufficient to significantly improve the sustainability index performance in BVG, AVP and BVP. Similarly, AG and MBG sub-basins had a reduction in sustainability, even with the proposed interventions modeled in Normative 2 scenario; this demonstrates the strong influence of climatic change on the behavior of the water management of the basin.

5. CONCLUSIONS

The results in this study showed that despite the interventions proposed by the WRPVG, climatic change may negatively affect water users in the basin. The results observed demonstrate that:

i) Among the water use activities analyzed, irrigation farming had the worst performance criteria This means that this activity is highly vulnerable to the climate change scenario predicted in this work.

ii) Even considering the interventions proposed by the WRPVG to increase the water supply, climate change may still directly influence the basin's water availability, reducing the sustainability index for some sub-basins.

iii) For the sustainability index of water resources to be guaranteed in the basin, more efficient adaptive measures that consider these climate changes must be included in the interventions planned by the WRPVG.

6. REFERENCES

ANA - Agência Nacional de Águas. **Plano de Recursos Hídricos da Bacia Hidrográfica do Rio Verde Grande**. Brasília: ANA, 2016. Disponível em: http://arquivos.ana.gov.br/servicos/planejamento/planoderecursos/20150902_PRH_Verde_Grande.pdf . Acesso em 25 abr. 2017

ASEFA, T.; CLAYTON, J.; ADAMS, A.; ANDERSON, D. Performance evaluation of a water resources system under varying climatic conditions: Reliability, Resilience, Vulnerability and beyond. **Journal of Hydrology**, v. 508, p. 53–65, 2014. DOI: http://dx.doi.org/10.1016/j.jhydrol.2013.10.043

COLLIER, M. A.; JEFFREY, S. J.; ROTSTAYN, L. D.; WONG, K. K-H.; DRAVITZKI, S. M.; MOSENEDER, C.; HAMALAINEN, C.; SYKTUS, J. I.; SUPPIAH, R.; ANTONY, J.; EL ZEIN, A.; ATIF, M. **The CSIRO-Mk3.6.0 Atmosphere-Ocean GCM: Participation in CMIP5 and data publication.** In: MODSIM 2011 - 19th International Congress on Modelling and Simulation - Sustaining Our Future: Understanding and Living with Uncertainty, 2011, December, p. 2691–2697.

COLLINS, W. J.; BELLOUIN, N.; DOUTRIAUX-BOUCHER, M.; GEDNEY, N.; HALLORAN, P.; HINTON, T.; HUGHES, J.; JONES, C. D.; JOSHI, M.; LIDDICOAT, S.; MARTIN, G.; O'CONNOR, F.; RAE, J.; SENIOR, C.; SITCH, S.; TOTTERDELL, I.; WILTSHIRE, A.; WOODWARD, S. Development and evaluation of an Earth-System model-HadGEM2. **Geoscientific Model Development**, v. 4, n. 4, p. 1051–1075, 2011. DOI: https://dx.doi.org/10.5194/gmd-4-1051-2011

GRAFTON, R. Q.; HUSSEY, K. **Water Resources Planning and Management.** Cambridge University Press, 2011. 800p.

LANE, B. A.; SANDOVAL-SOLIS, S.; PORSE, E. C. Environmental Flows in a Human-Dominated System: Integrated Water Management Strategies for the Rio Grande/Bravo Basin. **River Research and Applications**, v. 31, n. 9, p. 1053–1065, 2015. DOI: https://dx.doi.org/10.1002/rra.2804

MACHADO, A. R.; MELLO JUNIOR, A. V.; WENDLAND E. C. Avaliação do modelo J2000/JAMS para modelagem hidrológica em bacias hidrográficas brasileiras. **Engenharia Sanitária e Ambiental**, v. 22, n. 2, mar/abr. 2017. p.327-340. DOI: http://dx.doi.org/10.1590/S1413-41522016145177

MARENGO, J. A. Vulnerabilidade, impactos e adaptação à mudança do clima no semiárido do Brasil. **Parcerias Estratégicas,** v. 13, n. 27, p. 149–176, dez. 2008a.

MARENGO, J. A. Água e Mudanças Climáticas. **Estudos Avançados**, v. 22, n. 63, p. 83–96, 2008b. DOI: http://dx.doi.org/ 10.1590/S0103-40142008000200006

MARENGO, J. A.; SOARES, W. R. Impacto das Mudanças Climáticas no Brasil e Possíveis Futuros Cenários Climáticos: Síntese do Terceiro Relatório do IPCC 2001. In: TUCCI, C. E. M.; BRAGA, B. (Ed.). **Clima e recursos hídricos no Brasil**. Porto Alegre: ABRH, 2003. p. 209-242.

MARKSIM DSSAT weather file generator, 2017. Disponível em: http://gisweb.ciat.cgiar.org/MarkSimGCM/#. Acesso em 24 mar. 2017

PAINEL INTERGOVERNAMENTAL SOBRE MUDANÇA DO CLIMA (IPCC). **Mudança do Clima 2007: A Base das Ciências Físicas.** Contribuição do Grupo de Trabalho I ao Quarto Relatório de Avaliação do Painel Intergovernamental sobre Mudança do Clima. Sumário para os Formuladores de Políticas. Aprovado na 10ª sessão do Grupo de Trabalho I do IPCC, Paris, fevereiro de 2007. Disponível em: https://www.ipcc.ch/pdf/reports-nonUN-translations/portuguese/ar4-wg1-spm.pdf.

SAFAVI, H. R.; ALIJANIAN, M. A. Optimal crop planning and conjunctive use of surface water and groundwater resources using fuzzy dynamic programming. **Journal of Irrigation and Drainage Engeneering**, v. 137, n. 6, p. 383–397, 2010. DOI: https://dx.doi.org/10.1061/(ASCE)IR.1943-4774.0000300

SANDOVAL-SOLIS, S.; MCKINNEY, D. C.; LOUCKS, D. P. Sustainability Index for Water Resources Planning and

Management. **Journal of Water Resources Planning and Management**, v. 137, n. 5, p. 381–390, set/out. 2011. DOI: https://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000134.

SCHLENKER, W.; HANEMANN, W. M.; FISHER, A. C. Water Availability, Degree Days, and the Potential Impact of Climate Change on Irrigated Agriculture in California. **Climatic Change**, v. 81, n. 1, p. 19–38, 2007. DOI: https://dx.doi.org/10.1007/s10584-005-9008-z

WATANABE, M.; SUZUKI, T.; O'ISHI, R.; KOMURO, Y.; WATANABE, S.; EMORI, S.; TAKEMURA, T.; CHIKIRA, M.; OGURA, T.; SEKIGUCHI, M., TAKATA, K., YAMAZAKI, D., YOKOHATA, T.; NOZAWA, T.; HASUMI, H.; TATEBE, H.; KIMOTO, M. Improved Climate Simulation by MIROC5: Mean States, Variability, and Climate Sensitivity. **Journal of Climate**, v. 23, n. 23, p. 6312–6335, 2010. DOI: https://dx.doi.org/10.1175/2010JCLI3679.1

TAYLOR, K. E.; STOUFFER, R. J.; MEEHL, G. A. An overview of CMIP5 and the experiment design. **Bulletin of the American Meteorological Society**, v. 93, n. 4, p. 485–498, 2012. DOI: https://dx.doi.org/10.1175/BAMS-D-11-00094.1

TUCCI, C. E. M. Impactos da variabilidade climática e do uso do solo nos recursos hídricos. **Fórum Brasileiro de Mudanças Climática**. Agência Nacional de Águas – ANA, 2002. 150p.

TUNDISI, J. G. Recursos hídricos no futuro: problemas e soluções. **Estudos Avançados**, v. 22, n. 63, p. 7–16, 2008. DOI:http://dx.doi.org/10.1590/S0103-40142008000 200002

YUKIMOTO, S.; ADACHI, Y.; HOSAKA, M.; SAKAMI, T.; YOSHIMURA, H.; HIRABARA, M.; TANAKA, Y. T.; SHINDO, E.; TSUJINO, H.; DEUSHI, M.; MITUZA, R.; YABU, S.; OBATA, A.; NAKANO, H.; KOSHIRO, T.; OSE, T.; KITOH, A. A new global climate model of Meteorological Research Institute: MRI-CGCM3 – Model description and basic performance. **Journal of the Meteorological Society of Japan**, v. 90, p. 23–64, 2012. DOI: https://dx.doi.org/10.2151/jmsj.2012-A02

YUNUS, R. M., HASAN, M. M., RAZAK, N. A., ZUBAIRI, Y. Z., DUNN, P. K. Modelling daily rainfall with climatological predictors: Poisson-gamma generalized linear modelling approach. **International Journal of Climatology**, v. 37, n. 3, p. 1391–1399, 2017. DOI: https://dx.doi.org/10.1002/joc.4784

ZHAO, T.; CHEN, L.; MA, Z. Simulation of historical and projected climate change in arid and semiarid areas by CMIP5 models. **Chinese Science Bulletin**, v. 59, n. 4, p. 412–429. 2014. DOI: https://doi-org.ez27.periodicos.capes.gov.br/10.1007/s11434-013-0003-x

SAFAVI, H. R.; GOLMOHAMMADI, M. H.; SANDOVAL-SOLIS, S. Expert knowledge based modeling for integrated water resources planning and management in the Zayandehrud River Basin. **Journal of Hydrology**, v. 528, p. 773–789. 2015. DOI: http://dx.doi.org/10.1016/j.jhydrol.2015.07.014