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SARDIM – UMA PLATAFORMA DE ACOMPANHAMENTO HIDROLÓGICO EM TEMPO REAL DOS RIOS DA AMÉRICA DO SUL

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Trabalho de Conclusão de Curso apresentado à Comissão de Graduação do Curso de Engenharia Civil da Escola de Engenharia da Universidade Federal do Rio Grande do Sul, como parte dos requisitos para obtenção do título de Engenheiro Civil

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O presente documento apresenta um artigo técnico-científico realizado no contexto de elaboração do trabalho de conclusão do curso de Engenharia Civil, o qual será posteriormente enviado para submissão à Revista Brasileira de Recursos Hídricos - ABRHidro. O estudo foi liderado pelo aluno de graduação Gustavo Gabbardo dos Reis, com orientação do Prof. Rodrigo Cauduro Dias de Paiva, e contou com a fundamental colaboração dos pesquisadores João Paulo Lyra Fialho Brêda e Vinicius Alencar Siqueira.

SARDIM - A real-time hydrological monitoring platform of South American rivers

SARDIM - Uma plataforma de acompanhamento hidrológico em tempo real dos rios da América do Sul

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ABSTRACT

Due to the frequent occurrence of extreme hydrological events in the South American flow river regimes, this work aims to develop a hydrological monitoring platform open to the public, with a wide and intuitive access, using resources of an online geographical information system, in order to contribute to a better understanding of the behavior of these natural disasters. SARDIM (South America River Discharge Monitor) was built with the aid of programming resources in languages such as Python and JavaScript. The platform data are derived from results of a continental scale hydrological simulation model (MGB - South America) that uses, among other information, precipitation data from GPM (Global Precipitation Measurement) mission and from MSWEP (Multi-Source Weighted Ensemble Precipitation) product. After a statistical analysis of the model results, the platform is updated daily and in an operational way, with new data on flow duration and the return period of river flows, allowing the identification, monitoring and evaluation of the intensity of extreme hydrological events in South America.

Keywords: SARDIM; Platform; Hydrologic Modelling; MGB; South America.

RESUMO

Devido à frequente ocorrência de eventos hidrológicos extremos nos regimes de escoamento dos rios da América do Sul, o presente trabalho tem como objetivo o desenvolvimento de uma plataforma de monitoramento hidrológico aberta ao público, com um acesso amplo e intuitivo, utilizando recursos de um sistema de informação geográfica online, com o intuito de contribuir para um melhor entendimento acerca do comportamento desses desastres naturais. A plataforma de acompanhamento hidrológico dos rios da América do Sul (SARDIM - *South America River Discharge Monitor*) foi construída com auxílio de recursos de programação em linguagens como Python e Javascript. Os dados da plataforma são provenientes de resultados de um modelo de simulação hidrológica de escala continental (MGB - *South America*) que utiliza, entre outras informações, dados de precipitação da missão GPM (*Global Precipitation Measurement*) e do produto MSWEP (*Multi-Source Weighted Ensemble Precipitation*). Após uma análise estatística das informações resultantes do modelo, a plataforma é atualizada diariamente de forma operacional com novos dados de permanência e tempo de retorno das vazões dos rios, permitindo a identificação, o acompanhamento e a avaliação da intensidade de eventos hidrológicos extremos na América do Sul.

Palavras-chave: SARDIM; Plataforma; Modelagem Hidrológica; MGB; América do Sul.

INTRODUCTION

In the year of 2021 the Brazilian population faced the worst period of drought in almost a century. The socio-economic impacts linked to the current scenario were worrisome, considering the dependence of the country's economy on water use. One of the main sectors affected is the power generation, since, according to data from the National Operator of the Electric System (ONS), approximately 65.2% of the electric energy used in the country comes from hydroelectric power plants (BEN, 2021). In addition, the agricultural sector has also been heavily affected in recent years, since it is responsible for about 66,1% of the flow consumed in the country (ANA, 2020).

According to data from EM-DAT (The Emergency Events Database, 2021) released for the period of 1900-2021, about 90 million people were affected by drought events recorded in South America, accumulating a total loss of approximately USD 21 billion. Concerning the flood events for the same period, about 71 million people were affected, including 49,000 deaths recorded and a total loss of USD 38 billion.

Aiming at the regular and periodic monitoring of the drought situation in Brazil, the National Agency of Waters and Sanitation (ANA) began to provide monthly consolidated information on the evolution of drought events through an online platform called "Monitor de Secas", in English “Drought Monitor” (Martins et al., 2015). The development of such system was driven by the successive drought events that occurred in 2012, at the height of an extremely dry period in the Northeast region of the country.

Tools with similar technologies that aim to monitor and analyze hydrological events through online platforms are being increasingly explored by the scientific community. The United Nations University - Institute for Water, Environment and Health (UNU-INWEH) in Canada recently launched a tool that generates instant, accurate street-level resolution maps of floods worldwide since 1985, available on https://floodmapping.inweh.unu.edu/. (Meehmood et al., 2021). Another example of a tool where data is made available using a WebGIS platform is the GEOGloWS - ECMWF (Global Water Sustainability - European Centre for Medium-Range Weather Forecasts) flow forecasting system (https://geoglows.ecmwf.int/) which provides daily flow forecast data for a period of up to 15 days and historical information relating to hydrological simulations for a period of 40 years for every river in the world (Souffront et al., 2019).

Easily accessible monitoring tools can play an important role in improving the coexistence of the population with the recurring events of droughts and floods in rivers. Therefore, the aim of the present work was to develop an online platform of hydrological information in real time of South American rivers, called SARDIM (South America River Discharge Monitor), using a geographic information system applied to the web, in order to contribute with a better understanding of extreme hydrological events, both by the technical-scientific community and by society in general. Unlike traditional databases, SARDIM platform enables the user to have a more interactive access to the provided information, allowing the observation of hydrological results such as streamflow, percentages of flow duration and return periods related to the rivers through informative tables, dynamic maps, and other associated search elements in the platform.

MATERIAL AND METHODS

Model description

In order to develop the SARDIM platform, it was necessary to use a tool which allowed the calculation of river flows, as these values serve as background information for the estimation of statistical metrics, such as flow duration and return period of drought and flood events. Having regard to the continental scale of the SARDIM platform, it was found that only the use of observed data would not be sufficient to adequately represent the hydrological situation in South America, given the large disparity between the number of discharge gauge stations that are currently in operation, in relation to the number of reaches that compose the continent’s main drainage network. Thus, the present study opted for the use of a computational modelling tool for the calculation of river flows. The hydrological data available by SARDIM platform comes from the application of the continental MGB model version developed for South America (MGB-SA) (Siqueira et al., 2018).

MGB is a conceptual, semi-distributed hydrological model developed for applications in large basins (Collischonn et al., 2007). To simulate the soil water balance, the current version of the model divides the basin into unit-catchments, which are subdivided into hydrological response units (HRUs), according to the type of soil and vegetation cover. Thus, it is possible to represent the spatial variation of physical characteristics in watersheds, which is one of the major challenges on distributed hydrological models’ application. Evapotranspiration from soil, vegetation and canopy to the atmosphere is estimated by the Penman-Monteith equation. To represent the damping and attenuation effects of the flow generated within the unit-catchment, the model uses a linear reservoirs system to propagate surface and groundwater runoff to the stream network. Hydrodynamic propagation in rivers is based on the Saint-Venant formulations, solved explicitly, and approximated by despising the terms of convective acceleration in the dynamic equation, according to a study presented by Pontes et al. (2015).

In the MGB-SA version, the pre-processing of the databases was carried out with the help of the GIS (Geographic Information System) package IPH-Hydro Tools (Siqueira et al., 2016), resulting in the discretization of 33,749 unit-catchments, considering a threshold of 1,000 km² to delimit the beginning of the drainage network. For numerical stability of the model, such a network was segmented into reaches with similar lengths of approximately 15 km.

The rain database used as the main forcing on the MGB-SA model comes both from MSWEP (Multi-Source Weighted

Ensemble Precipitation) product and from GPM (Global Precipitation Measurement) mission. The MGB-SA model was originally calibrated using MSWEP data, a product that combines estimates of rainfall by satellite, reanalysis and observed precipitation (Beck et al., 2017). The MSEWP data was used in the hydrological model simulations perfomed from 1980 to 2014. For the most current simulations performed from 2015, the model uses the GPM mission data processed by IMERG (Integrated Multisatellite Retrievals for GPM) Early Run algorithm, which allows the distribution of precipitation data in near real time, with approximately 4 hours of latency. On the GPM data, a bias correction is applied to reduce systematic differences in relation to the rain base originally used by the MGB-SA model.

The choice to use the MGB-SA model was also motivated by its high accuracy in the representation of South American river flows regimes. In a comparative analysis, the MGB-SA model was even more accurate than other global scale models, such as HTESSEL/CaMA-Flood, LISFLOOD, and WaterGAP3 (Siqueira et al., 2018). The model was calibrated for the period from 1990 to 2010, and presented high performance mainly in the Southern and Southeastern regions of Brazil, in addition to Central Amazon. The calibration stage was performed from the analysis of more than 600 discharge gauge stations, presenting for daily flow the Kling-Gupta and Nash-Sutcliffe efficiencies greater than 0.6, respectively, for 70% and 55% of the gauges (Siqueira et al., 2018).

Statistical analysis

In order to estimate the hydrological parameters that are fundamental to monitoring rivers, the flow data resulting from the application of the MGB-SA model are analyzed statistically, enabling the calculation of the percentages of flow duration and return periods of recent flood and drought events simulated.

The flow duration of a reach is obtained by analyzing its duration curve. This curve graphically indicates how often the flow rate of a given magnitude is equaled or exceeded during the flow recording period. In the case of the SARDIM platform, the analyzed period corresponds to the period between 01/01/1980 and the most recent update of the platform. Three parameters are calculated to estimate the percentage of flow duration in each reach in the SARDIM platform. The “current flow duration” refers to the most recent simulated flow. The “maximum or minimum flow duration in the last 30 days” refers to the most extreme flood or drought event occurring in that reach in the last month analyzed. Finally, “the current seasonal flow duration” calculates, in a similar way, the flow duration of the most recent flow simulated in relation to the date of update of the platform. However, such parameter is based solely on the historical flow data for the month under analysis, making it possible to consider the seasonality factors of flow river regimes.

The return period is the estimated time interval in years, on average, in which a given event is expected to occur or to be exceed. The analysis of the return period of the simulated flows is given considering the extreme values of both minimum and maximum streamflow for all reaches, in order to identify the possible incidence of a drought or flood phenomenon that may be occurring in the present time. This analysis is performed by selecting minimum and maximum annual flow values and distributing them according to a statistical function that adjusts a determined return period for each flow value. In this study, the minimum values were adjusted following the Weibull distribution, while the maximum values followed the Gumbel distribution. As documented by Tucci (1993), both distributions are commonly applied for statistical analysis of historical series of hydrological variables such as precipitation and flow. Distribution adjustments are not applicable to all reaches in the stream network, as in some cases the distribution function may not satisfactorily represent the selected annual values. In these cases, when the mean quadratic error of the adjustment was greater than 50%, it was considered that the return period of the event had an undetermined value. The return period values were calculated for the most recent flows according to the latest platform update and for the highest or lowest flows of the last 30 days. In this way, it is possible to evaluate which were the most extreme simulated results in the month and to highlight on the platform map the occurrence of a drought or flood event throughout this period.

Programming and updating

The SARDIM platform was developed by using JavaScript language programming resources, in conjunction with an API (Application Programming Interface) distributed by ESRI (Environmental Systems Research Institute) through the ArcGIS Developer platform, which offers a complete set of development tools and location services at building mapping solutions.

The updating of the data available for visualization on the map is possible thanks to the hosting and data storage services on ArcGIS Online servers. Python programming language offers several features that can be used to facilitate the access to this hosted data, allowing them to be updated remotely via simple Python scripts.

In this way, the operation of the SARDIM platform can be understood from three basic steps. 1) Download of GPM mission data and obtaining flow data from the hydrological simulations performed by the MGB-SA model. 2) Statistical analysis of flow data, aiming at obtaining hydrological parameters such as percentages of flow duration and return periods of flood and drought events. 3) Updating data relating to shapefile which is hosted on ArcGIS Online servers and connected to the platform via an external code written in Python. This script is responsible for replacing the information of each attribute of the shapefile of the rivers with the new information generated by the most recent hydrological simulation. These 3 operation steps aim to ensure that the SARDIM platform will be properly updated, and for this, all of them are scheduled to be held daily and at a predetermined time of the day. Figure 1 shows the flowchart of the operational steps related to the platform updating process.

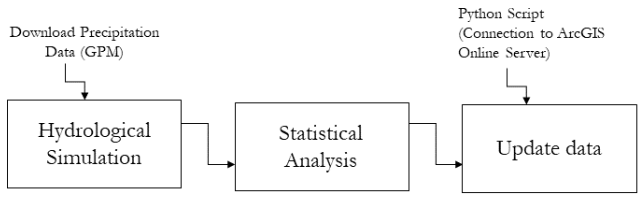

Figure 1 . Platform update operation steps.

User survey

Aiming to collect information from SARDIM platform users, it was conducted a survey with 18 professionals who work in various areas of activity. It was found that almost 90% of the participants worked in engineering consulting sectors or in government agencies, mainly in the areas of water resources, environment, natural disasters, and sanitation. The survey also collected other relevant information, such as the main motivations of users for using the platform and suggestions for new features that would make the tool more useful and effective for their applications.

RESULTS AND DISCUSSION

Platform functionalities

The home page of the SARDIM platform can be accessed from any browser on: https://sardim.herokuapp.com. In the main menu it is possible to see basic information on the functioning of the platform and the related publications in "about" and "publications" buttons. Note that the most recent version of the platform is available in four languages: English, Spanish, French and Portuguese. In the top-right corner the date of the platform update is highlighted from which the last hydrological simulation was made.

The results of the SARDIM platform can be viewed by selecting the reach where you want to obtain the information on the map. The main hydrological parameters of each reach are presented in a summary table, as shown in Figure 3, highlighting information such as the accumulated upstream catchment area, current flow duration, current seasonal flow duration, maximum or minimum flow duration on the last 30 days, current return period, maximum or minimum return period in the last 30 days, in addition to the numerical code of the respective unit-catchment of the MGB-SA model that includes the selected reach. Together with the summary table of hydrological information, a graph showing the average weekly streamflow of the last two months is also presented, as shown in Figure 4. The results of flow duration and return period are also presented on the map by configuring a predefined color scale for the rivers. As shown in Figure 2, it is possible to select one of the five available result options using the layer list tool to view the color variation in the rivers according to the chosen attribute. Reaches in blue highlight events of different flood scales, while red reaches highlight drought events. Reaches in gray represent events of low intensity, which cannot be classified either as flood or a drought.

Figure 2. Flow duration results categorized by a color ramp on the map.

SARDIM - South America River Discharge Monitor

Accumulated catchment area (km^2)	59 678,30
Current flow duration (%)	80,8
Current seasonal flow duration (%)	41,8
Flow duration (max/min) - Last month (%)	99,1
Current return period (years) - Drought + Flood	-1 to -2
Return period (max/min) - Last month (years) - Drough + Flood	-10 to -20
Catchment	29427

Figure 3. Example table summary of available hydrological information.

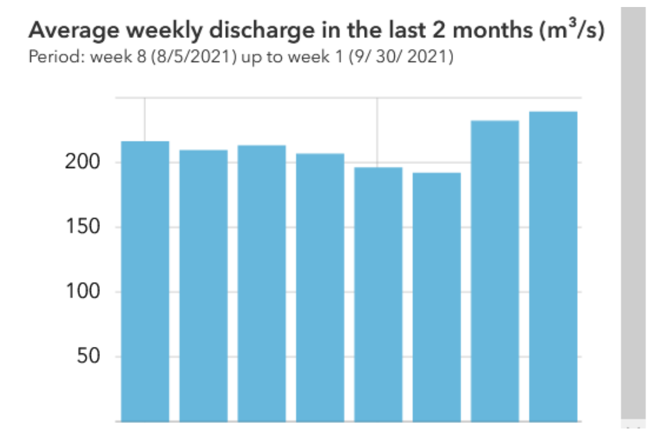

Figure 4. Example chart of average weekly discharge.

Case studies

This topic presents two cases studies concerning flood and drought events that occurred in the year of 2020. The analysis of these events served to evaluate the functioning of the SARDIM platform, where it was possible to identify the location and magnitude of these hydrological events through the map of flow duration available on the platform.

The flood events analyzed occurred in the main river basins in the state of Rio Grande do Sul in July 2020. The basins of Taquari-Antas, Caí, Sinos and Uruguai Rivers were mainly affected. According to the data recorded in the monitoring stations operated by CPRM, it was possible to observe that many of these rivers reached historical levels at various points, as in the case of the Taquari river, where the water level reached 22 meters on July 8 in the city of Muçum, being the highest level recorded in the station also denominated "Muçum" since 1940 (Giacomelli et al., 2020).

Figure 6 shows the map provided by SARDIM platform on 19 July 2020, where although the elevation of many rivers has slowly declined, it was still possible to observe the high percentage of flow duration in these rivers, in addition to the floods that occurred later in the Baixo Jacuí basin and Guaíba lake after the flow contribution of its tributary rivers.

The drought event analyzed occurred in the Pantanal Matogrossense in the period between 2019 and 2021, with this extreme drought being the worst recorded in the last 50 years. This event was directly related to the increase in the number of wildfires in the region, which resulted in the loss of about 26% of the total area of the biome and affected at least 4.6 billion animals, of which at least 10 million ended up dying.

According to a survey conducted by the CEMADEN (National Center for Monitoring and Warning of Disasters), of the INPE (National Institute for Space Research), the main cause for the occurrence of this event can be explained by a phenomenon known as meteorological blocking, where the combination of lack of rain with high temperatures and very low relative humidity increased the risk of wildfires, which spread over the agricultural and natural areas of the biome (Marengo et al., 2021). Such a meteorological phenomenon is related to the emergence of a high-pressure area that halted the formation of rain throughout the Midwest region of South America.

Figure 7 shows the map provided by SARDIM platform in October 2020, where it is possible to visualize high values of flow duration in several reaches of the Paraguay River and other tributaries located in the area directly impacted by the drought in the Brazilian Pantanal.

Connecting the SARDIM platform to users

In general terms, the research presented positive feedback since many of the users considered as fundamental characteristics for their respective applications the ease of viewing results and the regularity of operation that are associated with the SARDIM platform. However, about 40% of users reported that access to the database would be extremely important for the applicability of the platform, something that is not yet fully available today.

Figure 5 presents a bar graph that indicates, according to the evaluation of the users, which are the most important characteristics of a hydrological monitoring platform, as in the case of the SARDIM platform.

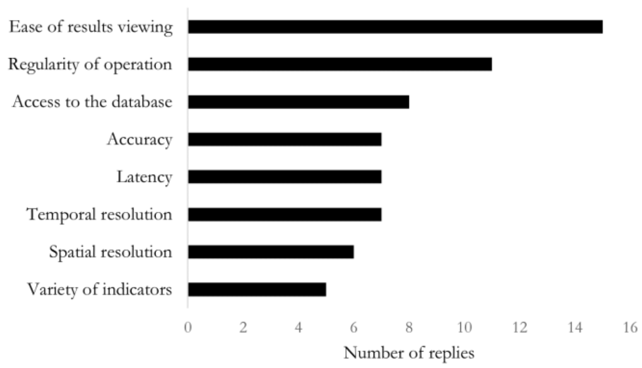

Figure 5. Most important characteristics of a hydrological monitoring platform.

Figure 6. Map of flow duration of rivers in the state of Rio Grande do Sul during the flood event occurred in July 2020.

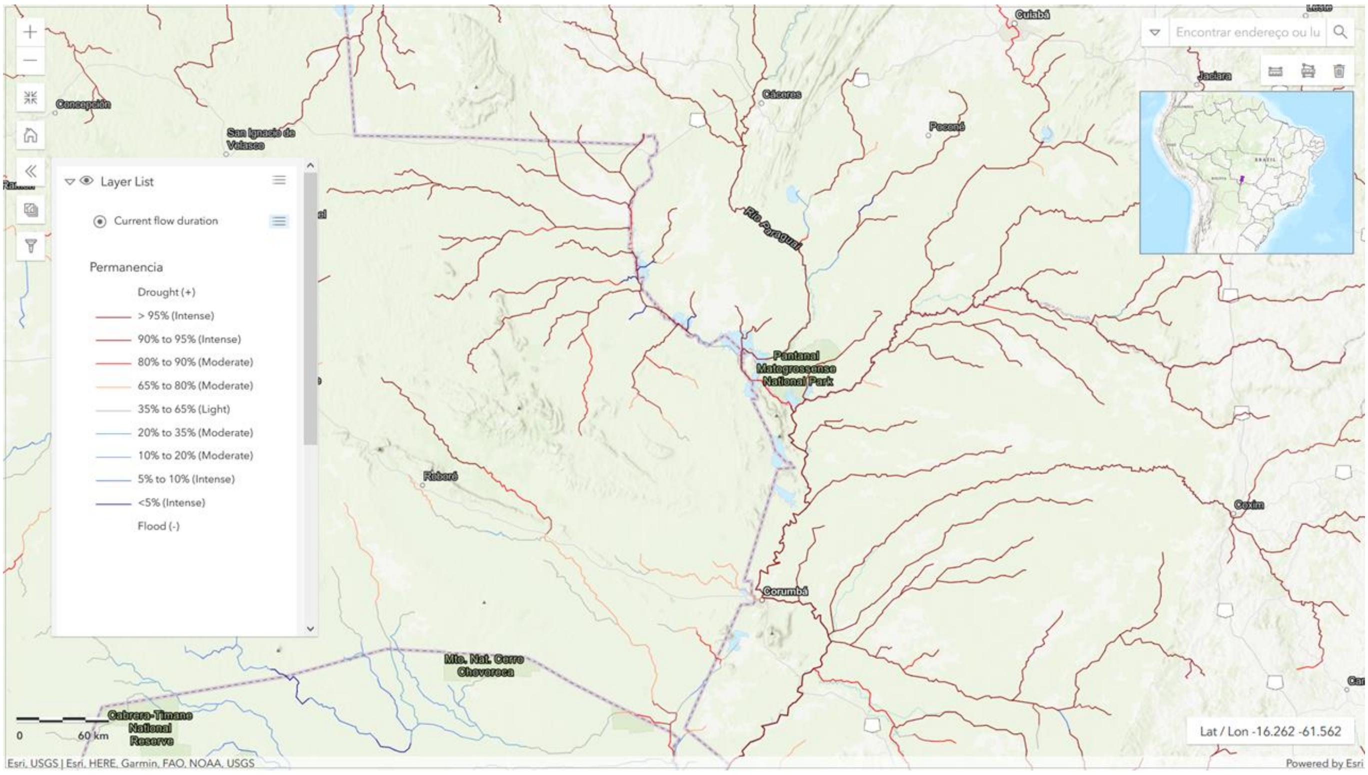

Figure 7. Map of flow duration of rivers in Brazilian Pantanal during the drought event occurred in 2020.

CONCLUSIONS

In the present study, it was shown that real-time monitoring of the hydrological situation of the major rivers in South America is a tool with great potential for application on a national and regional scale. Given the ease with which information can be accessed and interpreted on the platform, it is a tool for the use not only of professionals, researchers, and technicians in the field of hydrology, but also of other sectors of the general public. Having regard to the analysis of drought and flood events that took place in 2020, which have been widely publicized and documented by the Brazilian press, the study presented strong evidence that the platform showed coherent results and allowed a good representation of the real situation of river flows, enabling the visualization of the occurrence, location and magnitude of flood and drought events in the South American continent.

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REFERENCES

ANA (Agência Nacional de Águas e Saneamento Básico). Conjuntura dos recursos hídricos no Brasil 2020. Brasília, 2020.

Beck, H. E., van Dijk, A. I. J. M., Levizzani, V., Schellekens, J., Miralles, D. G., Martens, B., & de Roo, A. (2017). 3-hourly 0.25° global gridded precipitation (1979–2015) by merging gauge, satellite, and reanalysis data. Hydrology and Earth System Sciences, 21(1), 589-615. http://dx.doi.org/10.5194/hess-21-589-2017

Collischonn, W., Allasia, D., Silva, B. C., & Tucci, C. M. (2007). The MGB-IPH model for large-scale rainfall: runoff modelling. Hydrological Sciences Journal, 52(5), 878-895. http://dx.doi.org/10.1623/ hysj.52.5.878

EPE (Empresa de Pesquisa Energética). Balanço Energético Nacional (BEN) 2021: Ano base 2020. Disponível em < https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-601/topico-588/BEN_S%C3%ADntese_2021_PT.pdf >.

EM-DAT. 2021. The OFDA/CRED International Disaster Database. Université Catholique de Louvain.

Giacomelli, L., Nectoux, M., Valente, C., Fan, F. M. Cheias Históricas Ocorridas no Rio Grande do Sul em Julho de 2020. Anais do II Encontro Nacional de Desastres (2020).

Marengo, J. A., Cunha, A. P., Cuartas, L. A., Deusdará Leal, K. R., Broedel, E., Seluchi, M. E., Michelin, C. M., De Praga Baião C. F., Chuchón Ângulo, E., Almeida, E. K., Kazmierczak, M. L., Mateus, N. P. A., Silva, R. C. and Bender, F. (2021) Extreme Drought in the Brazilian Pantanal in 2019–2020: Characterization, Causes, and Impacts. *Front. Water* 3:639204. doi: 10.3389/frwa.2021.639204

Martins, E., Nys, E., Molejón, C., Biazeto, B., Silva, R., Engle, N. (2015). Monitor de Secas do Nordeste, em busca de um novo paradigma para a gestão de secas. https://dx.doi.org/10.13140/RG.2.1.4238.8886

Mehmood, H.; Conway, C.; Perera, D. Mapping of Flood Areas Using Landsat with Google Earth Engine Cloud Platform. Atmosphere 2021, *12*, 866. https://doi.org/10.3390/atmos12070866

Pontes, P. R. M., Collischonn, W., Fan, M. F., Paiva, R. C. D., Buarque, D. C. (2015). Modelagem hidrológica e hidráulica de grande escala com propagação inercial de vazões. Revista Brasileira de Recursos Hídricos, 20(4), 888-904.

Siqueira, V. A., Paiva, R. C. D. D., Fleischmann, A. S., Fan, F. M., Ruhoff, A. L., Pontes, P. R. M., Collischonn, W. (2018). Toward continental hydrologic–hydrodynamic modeling in South America. Hydrology and Earth System Sciences, 22(9), 4815-4842.

Siqueira, V. A.; Fleischmann, A. S.; Jardim, P. F.; Fan, F. M.; Collischonn, W. IPH-Hydro tools: uma ferramenta open source para determinação de informações topológicas em bacias hidrográficas integrada a um ambiente SIG. Revista Brasileira de Recursos Hídricos, v. 21, n. 1, p. 274-287, 2016.

Souffront, Michael A., E. James Nelson, Kiran Shakya, Christopher Edwards, Wade Roberts, Corey Krewson, Daniel P. Ames, Norman L. Jones, and Angelica Gutierrez, "Hydrologic Modeling as a Service (HMaaS): A New Approach to Address Hydroinformatic Challenges in Developing Countries" Frontiers in Environmental Science: Freshwater Science, October 2019, doi: 10.3389/fenvs.2019.00158.

Tucci, Carlos E. M. Hidrologia: Ciência e Aplicação. 1ª Edição. UFRGS/ABRH., 1993.