

Maximum streamflow: brief description of concepts and methods of regionalization

Vazões máximas: breve descrição de conceitos e métodos de regionalização

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Abstract

One of the main problems in the development of hydrological studies is the scarcity of measured data. In Brazil, because of its great water availability, and due to its territorial extension, the costs of implementing and maintaining hydrometric stations is a challenge, compromising hydrological monitoring and data collection. Therefore, developing methods that contribute to the estimation and transfer of information is essential for better integrated management of water resources, highlighting the importance of maximum streamflow data on issues such as flood mitigation. In order to solve this problem, streamflow regionalization models appear as tools to estimate hydrological data in ungauged sites, that is, it allows the transfer of measured or simulated information between homogeneous basins. In view of this, this article has the objective of investigate and describe the main methodologies developed and disseminated in the literature on hydrological regionalization, especially in relation to maximum streamflow, by means of a brief literature review. In short, it can be observed that different methods are applied and tested in order to obtain regionalization results associated with lower uncertainties, and there is no standardized method, once there are hydrological specificities of different locations.

Keywords: Streamflow estimation; Data series; Simulation; Drainage basin

Resumo

Um dos principais problemas encontrados na elaboração de estudos hidrológicos é a escassez de dados medidos. No Brasil, por abrigar um enorme patrimônio hídrico, e devido à extensão territorial, os custos de implementação e manutenção das estações hidrométricas se tornam um desafio, comprometendo o monitoramento hidrológico e a obtenção de dados. Portanto, desenvolver métodos que contribuam para a estimativa e transferência dessas informações é essencial para uma melhor gestão integrada dos recursos hídricos, destacando a importância de dados de vazões máximas em questões como mitigação de efeitos de enchentes. Visando equacionar essa problemática, os modelos de regionalização de vazões surgem como ferramentas capazes de estimar dados hidrológicos em regiões não monitoradas, isto é, permite a transferência de informações entre bacias homogêneas a partir de séries de dados de vazões medidas ou simuladas. Em vista disso, o presente artigo teve como objetivo descrever metodologias difundidas sobre regionalização hidrológica, principalmente no que se refere a vazões máximas, por meio de uma breve revisão da literatura. Em suma, observa-se que os diversos métodos são aplicados e testados a fim de se obter resultados de regionalização associados a menores incertezas, não existindo um método padronizado, uma vez consideradas as especificidades hidrológicas de diferentes localidades.

Palavras-chave: Estimativa de vazões; Série histórica de dados; Simulação; Bacias hidrográficas

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1 Introduction

Brazil, due to its wide territorial extension, geographical location and its natural characteristics, is one of the countries with the largest water availability in the world. The annual average river streamflow represents approximately 12% of all water availability on the Earth (National Agency of Water, 2018).

The rich hydrographic network is fundamental to guarantee the economic and social development of the country, in addition to maintaining the integrity of all Brazilian biodiversity. However, despite being beneficial, this large number of water systems is associated with many problems of water monitoring management, especially regarding the measurement and acquisition of hydrological data.

Hydrological information is crucial for management of water resources, since, for example, it is possible to characterize the water availability of river basins and to plan an efficient and sustainable way to ensure the multiple uses of water, as provided by Federal Law 9.433 / 1997 (Brazil, 1997), which instituted the National Policy on Water Resources. Therefore, it is essential to know the hydrological operation of river basins, which demands an intense process of data collection and interpretation (Ibiapina et al., 1999).

The number of hydrometeorological monitoring stations in Brazil is scarce, and these are concentrated mainly in populated areas, economically developed and with high hydroelectric potential, and are often financed and maintained by companies in the electricity sector (Brusa, 2004). National Agency of Water (2019) states that there are 14,822 hydrometeorological stations registered in all Brazilian territory, which represents a station every 756.30 km², demonstrating the lack of a significant monitoring network in the country, considering the vast territorial dimension of Brazil.

Thus, in order to guarantee the water conservation and availability in all Brazilian territory, it is necessary to have more hydrological information that supports water planning and management, with the purpose of serving as a foundation for the implementation of both structural and non-structural actions.

Scarcity or lack of basic primary information is one of the main problems in hydrological studies. According to Tucci (2009), the hydrometric network will hardly cover all hydrographical space gaps, emphasizing the importance of developing methods that allow estimation of these data (Wolff, 2014).

The regionalization of streamflow is a very important tool for the management of water resources since, through statistical procedures and methods, it is possible to estimate the hydrological variables of regions where there is a lack of information, based on instrumented hydrographic basins. Regionalization allows, in a relatively fast and economical way, the transfer of hydrological information between homogeneous river basins (Tucci, 2009).

The main purpose of the regionalization models is to estimate streamflow at locations without fluviometric

measurements, and is not recommended for regions with data availability, since the estimated data are less reliable and do not replace information collected in situ in the water channels sections (Silva Júnior et al., 2002 apud Novaes et al., 2007). The application of methods that fit the dynamics of each basin and result in reliable values is the objective of streamflow regionalization studies, being extremely important the effort to execute models that generate less uncertainties.

According to Tucci (2009), the regionalization models can be elaborated to obtain, among other applications, statistical functions such as the probability curve of maximum, average or minimum streamflow. There are several methods for regionalization of maximum streamflow. Among the most used methods, we highlight those based on linear interpolations, regression correlations and hydrological simulations.

Maximum streamflow data is essential for the elaboration of engineering projects of water resources. The various anthropic changes in the natural landscapes in river basins, without correct territorial planning, alter the dynamics of the hydrological cycle, by means of an excessive increase of the surface flow, which, in turn, can generate or intensify the occurrence of extreme events, such as floods, causing environmental and socioeconomic negative impacts.

In this context, the main objective of this article is to investigate and describe, by means of a brief bibliographic review, the main concepts and applications related to maximum streamflow and regionalization studies, aiming to describe the main characteristics, applications, potentialities and difficulties of the analyzed aspects.

2 Methodology

The present article deals with a brief bibliographical review of the literature on studies of maximum streamflow and regionalization of this hydrological parameter.

In the bibliographic research phase, were considered current studies, but counting with the classical and pioneering works in what concerns the hydrological regionalization; covering studies carried out in Brazil, since these are usually elaborated according to regional characteristics, as well as international studies.

In the first stage, research was carried out on the subject, with reference to the main Brazilian authors and institutions relevant to hydrological and regionalization studies (Tucci, 2009; Tucci, 2005, Euclides 2001 and Natural Environment Research Council, 1985).

The research was conducted in the main databases: Scielo, Scopus and Web of Science, using the descriptors "estimation of maximum streamflow", "streamflow regionalization", "hydrological regionalization", among others. Master dissertations and doctoral theses were also considered.

After the classical works, articles, dissertations and theses were selected, the main characteristics were analyzed in a critical and systematic way, so the studies presented in this work could be efficient in approaching the proposed theme.

3 Maximum streamflow

The quantitative characterization of the runoff in a basin is made by the reference flows values that represent the river behaviour during periods of drought (minimum flows), flood events (maximum flows), long periods (mean flows) and statistical analysis, such as permanence flow rate curves.

The maximum streamflow are hydrological quantities applied mainly to the design of hydraulic works, such as spillways for dams, canals, conduits, culverts, galleries and other urban drainage devices. In addition, they are used as a management tool in the prevention of extreme hydrological events (Araújo, 2008).

Flood events are recurrent problems in certain areas (Marciano et al., 2018), because even though they are known natural events, the population finds, in these affected areas, places of easy establishment. Thus, the natural event becomes an environmental, economic and social problem, which demands an effort from the scientific community and public agencies to be controlled.

The most characteristic recurrence intervals of the maximum streamflow are 2 years, which represent, in most cases, the occupation of the main channel of the river; and the 500 years, considered in the elaboration of hydraulic projects of great magnitude. This parameter is important for territorial planning or planning to coexist with flood events.

The actions to control floods can be structural, which aim to soften the peak of maximum flow, such as rectification of rivers, meanders, reforestation, buses, dikes, among others; or non-structural, such as monitoring programs, urban planning, flood insurance, analysis applied in Geographical Information Systems, among others (Canholi, 2014; Ferreira, Barbassa and Moruzzi, 2018).

The non-structural control actions require an estimation of maximum streamflow in short term, in which there is a real-time monitoring of the precipitation. Structural control, through hydraulic works, demands statistical calculations for the estimation of the maximum flow (Tucci, 2009).

The necessary hydrological studies in several works of water resources engineering, as well as in the planning and management of multiple uses of water, depend directly on the knowledge of the aspects related to maximum streamflow. In this way, the maximum flow rate must be estimated so the projects and studies are reliable representations of the basin dynamics, for different recurrence intervals.

4 Maximum streamflow estimation

4.1 Extrapolation of historical series

Hydrological studies, including, obviously, maximum streamflow studies, require a representative historical data series. A period of at least 20 years is usually adopted so the hydrological behaviour is statistically well represented; and, from the historical series, the extrapolation of the data allows to infer maximum values for recurrence

intervals beyond the historical series dates.

The directly estimation of streamflow, when data from historical series of fluviometric stations is available, is calculated from the adjustment of these data to a probability distribution. The distributions of log-Normal and Pearson type III are the most used to represent maximum events (Langat, Kumar and Koech, 2019).

Considering the estimation of maximum flow values requires a consistent database, regardless of the procedure, it is important to have a series of data that, besides being representative temporarily, is: independent, not correlating with other series; and stationary, in which the characteristics of the basin did not change over time, avoiding the change in the measured values (Tucci, 2009).

The data series of the maximum streamflow are composed of the highest annual or monthly flow value. This value is obtained from the database, which usually consists of two daily values, and these values of the daily readings do not necessarily represent the highest value of the day (Tucci, 2002).

The fluviometric stations that have these two daily measurements present a series of data with a daily maximum flow value different from the instantaneous value, especially in basins with small concentration time, where the hydrographs have quick answers to the precipitation events. This difference implies an error, which may alter the estimation result. In this sense, Silva and Tucci (1998) present methodologies to determine the coefficient of relation between the maximum daily flow rate and the maximum instantaneous flow rate, so the errors are minimized. These techniques are necessary to reduce the uncertainties of studies that require maximum flow series. However, it is worth mentioning that a large part of the current fluviometric monitoring network is composed of continuous measurements and a telemetry system, which consists of real time data transmission.

4.2 Regionalization

The hydrological regionalization consists of a set of tools that exploit the available data to the maximum, performing the transfer of information, to estimate hydrological variables in places with no data or with insufficient data (Tucci, 2009). In the context of minimizing uncertainties, regionalization studies require data series that are representative in time and space; however, as already mentioned, the scope of the current monitoring system is limited.

In relation to data series, the quality of the regionalization study is often compromised due to the quality of the primary data. Besides the difficulty in spatial representativeness, the temporal representativeness of the data is another challenge, since the continuity of measurements in the existing stations often still depends on human resources, being these responsible for the annotations, which may be the cause of many errors in data series (Tucci, 2002).

According to Silva Junior et al. (2003), the Brazilian hydrometric network is installed in order to monitor large basins, making the regionalization studies, which target small basins, often under uncertainties due to the limitations of extrapolation of the existing data.

The spatial transfer of information from the historical data series can be done by means of usual techniques - flow proportional to the drainage area or linear interpolation between two or more stations proportionally to the respective areas, if the place of interest is close to, at least, one measuring station; or by the application of hydrological regionalization techniques, if there are no measuring stations near the place of interest (Bazzo et al., 2017).

The linear interpolation method consists in regionalizing the maximum streamflow through a linear function of proportionality. The maximum flow rate is directly related to an explanatory variable, such as the drainage area upstream of the study section (Lima et al., 2017). This method consists in a simple analysis, as it does not require long series of data; however, it should be applied in neighbouring areas, that is, the measurement sections should not be at a great distance from the section to be regionalized. According to Novaes et al. (2007), this proportionality between the specific flows of the drainage area should be considered when the relationship between the drainage areas of the sections is less than three.

The procedures presented by Tucci (2002) and Tucci (2009) are classified as traditional regionalization methods, presented by Eletrobrás (1985 apud Novaes et al., 2007). These consist of regionalizing a variable or function, such as the probability curve, of one or more stations with available data series from hydrologically homogeneous regions. The dependent variable of this statistical distribution is determined as a function of the independent variables that best explain the hydrological phenomenon, and the significance of this regression relation is tested statistically (Piol et al., 2019). The explanatory independent variables, in the case of streamflow, can be annual mean precipitation, partial period mean precipitation, drainage area, length of drainage channels, slope or drainage density.

According to Tucci (2009), the regionalization of the probability curve of the maximum streamflow can be done by the method of the selected values, by the method of the parameters or by the method of the non-dimensional curve; this last one, using the mean flow rate as a factor for the non-dimensional analysis. Each of these methods using the regression technique has difficulties in determining the primary probability curve for the study; however, all result in a regionalized probability curve.

Wolff et al. (2014) present a new methodology for regionalization in the state of São Paulo, compared to the methodology already used by the Department of Water and Electric Energy (DAEE) since 1980. The justification for the new methodology is given by the change in the capacity of geoprocessing techniques. The determination of homogeneous regions for regionalization is an unnecessary link of this new methodology and is pointed out as a relevant advantage, since this practice can obtain subjective conclusions.

4.3 Simulation

A series of flow data for a given section can be obtained by means of hydraulic simulations, which refer to the flow-flow models applied in channels; or hydrolo-

gical simulations, that seek to model the dynamics in a basin between rainfall-flow events (Marinho Filho et al., 2013). According to Brewer et al. (2018), the Hydrologic Engineering Center (HEC-RAS) and the Soil & Water Assessment Tool (SWAT) are the most used hydraulic and hydrological models, respectively.

The indirect flow estimation, which uses rainfall data, is based on empirical methods, such as the unit hydrograph, information transformation methods based on the drainage area, or by means of rainfall-flow mathematical models, which should be calibrated (Tucci, 2005). The need to calibrate the model in a location with no data available, causes the model to be calibrated with data from another region; thus, achieving the transfer of results (Saraiva et al., 2011).

The maximum streamflow estimation by means of simulation can be considered the most complex method, since it requires the input of a significant number of parameters. The work of hydrological simulation in basins without fluvimetric monitoring, by Saraiva et al. (2011), uses the rainfall-flow model SMAP. The parameters of the models are calibrated and regionalized, and it is pointed out that for this procedure, extensive data series are necessary, and the regionalization of these data is done by regression or interpolation methods.

However, with the constant development of technologies involved in the means of computing and geoprocessing, it is possible to use more and more parameters as independent variables of the processes, enabling the achievement of increasingly satisfactory results (Parajka, 2005; de Lavenne, 2016).

5 Reference studies and the maximum streamflow

The Flood Studies Report, published in 1975, is a widely used reference in regionalization studies by the traditional regression method, which presents two methods for estimating flood events at non-measurement sites, one of which is based on a rainfall-flow model that uses regionalized data for input into the simulation. The Natural Environment Research Council report (1985) aims to review the parameters of the regression equations, which could be updated due to the 10 years of data added between the two studies, obtaining more accurate results in flood event predictions. The update of this report generated the Flood Estimation Handbook (of the Centre for Ecology & Hydrology, in United Kingdom), which encompasses all the advances obtained in these years, in the aspect of data acquisition, computational processing and statistical formulations.

The Hidrotec Project, which has as one of its products the digital ATLAS of the waters of Minas Gerais - a tool for the planning and management of water resources, has developed a computer program of hydrological regionalization, which synthesizes the methodology of regionalization, currently in version RH4.0.

The methodology used was based on the descriptive, hydrological and physical data analysis of the basin. In the regionalization of the maximum streamflow, the

independent variable is the precipitation of the wet semester or the annual maximum daily precipitation for a given recurrence interval. Next, the mean precipitation in the basin is calculated by the method of Thiessen, and then, the hydrologically homogeneous areas are identified. Finally, flow regionalization methods using multiple regression equations are applied.

In Euclides et al. (2001), as part of the Hidrotec Project, two methodologies of regionalization are presented, which include: the traditional method and a method that considers the spatial precipitation in the hydrographic basin. For the annual maximum daily flow, the most adequate explanatory variables were drainage area and slope of the main water course.

Novaes et al. (2007) presents a study comparing five different methods of regionalization. Although the application of the methods does not involve the maximum flows, it is interesting to present the methods considered, being these: traditional method, linear interpolation method, method of Chaves et al. (2002), modified linear interpolation method and modified Chaves method.

The traditional and linear interpolation methods were applied according to the basic literature. The method of Chaves et al. (2002) is based on interpolation and spatial extrapolation, considering the use of Geographic Information Systems (GIS). Finally, the modified methods consisted in introducing the precipitation parameter in the analysis, which only considered previously the drainage area.

The article presented by Barbosa et al. (2005) shows how the methodology used by the authors after the processing of the terrain data and the hydrological data series consisted of applying the regionalization by mathematical models based on non-linear regressions for maximum, minimum and average flows of several recurrences between 2 and 100 years. In the studies, the methodology of hydrological regionalization proposed by the computational model RH3.0 (previous version to RH4.0 mentioned, of the Hidrotec Project) is basically employed. Regarding the maximum flow rate, Pearson type III distribution was the best fit, and from that, the corresponding flow rates of different recurrence intervals were generated. The best regression models were the linear and the potential, and for the maximum flows, the best correlations were with the area, the drainage density and the total annual rainfall and the wet season.

6 Final considerations

The studies presented in this work were adequate in relation to the objective of describing the main concepts and applications related to maximum streamflow and techniques for estimating hydrological information in places with restrict or no data availability.

It is noted that the representativity of the data series it is of great importance to the quality of the regionalization study, which may have minimized uncertainties when the primary data are consistent.

The traditional methods of regionalization and the simulations are dependent on the temporal represen-

tativeness of the data series. The methods by linear interpolation are not based on large data series, however they are restricted to the application between physically close sections.

The hydrological simulation presents an advantage for regionalization, since it is not required the existence of a data series. From precipitation data, which are more available compared to fluviometric data, and other basin physical variables, it is possible to simulate streamflow series and, after calibration, to transfer this information to locations with no data.

In hydrographic regions where the planialtimetric data are already in digital form, the use of GIS, through the application of digital elevation models in the estimation of parameters and hydrological variables, optimizes the regionalization process.

Finally, it is important that the regionalization method itself best represent the behaviour of the regions where it is applied. For this, all the considerations and methods must be analyzed, but not limited to the ones presented in this work, since hydrological studies are susceptible to significant specificities.

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