DIFERENTES ESCALAS DE DADOS E MÉTODOS DE PROPAGAÇÃO DE VAZÃO NA MODELAGEM HIDROLÓGICA DA BACIA HIDROGRÁFICA DO RIO PARDO

Rodrigo Lacerda Brito Neto[1], Cristiano Tagliaferre[2], Lorena Júlio Gonçalves[3], Bismarc Lopes da Silva[4], Lorena Lima Ferraz[5], Rosilene Gomes de Souza Pinheiro[6]

RESUMO: O MGB-IPH é um modelo distribuído que possibilita a utilização dos métodos Muskingum-Cunge e Inercial para simular a propagação da vazão na rede de drenagem. Assim, este estudo propõe avaliar o desempenho da modelagem hidrológica pelo modelo MGB-IPH para três estações fluviométricas da bacia hidrográfica do rio Pardo, utilizando os métodos Muskingum-Cunge e Inercial de propagação de vazões, tanto em escala diária, quanto mensal. Para isto, os resultados da calibração e validação do modelo foram avaliados por meio dos coeficientes de eficiência NSE e NSEloge do o erro percentual de volumes, que indicaram o desempenho do modelo ao comparar os dados simulados e observados de vazão diária e total mensal para os diferentes métodos de propagação. Os resultados indicaram ao comparar o desempenho pelos métodos Muskingum-Cunge e Inercial somente 11.11% dos resultados exibiram alteração, já para os resultados utilizando dados diários e mensais, 55.56% dos valores demonstraram alteração da classe. Foi possível concluir que poucas foram as diferenças ao utilizar os diferentes métodos de propagação de vazões e que existe uma melhoria geral no desempenho da modelagem ao utilizar dados totais mensais.
PALAVRAS-CHAVE: MGB. Desempenho. Simulação.

DIFFERENT DATA SCALES AND FLOW ROUTING METHODS FOR HYDROLOGICAL MODELING OF PARDO RIVER BASIN, BRAZIL

ABSTRACT: The MGB-IPH is a distributed model that enables the use of Muskingum-Cunge and Inercial methods to simulate flow routing in a drainage network. Thus, this study

[1]Engenheiro Florestal, mestre em Ciências Florestais, UESB, Vitória da Conquista, BA.
[2]Prof. Dr, Departamento de Engenharia Agrícola e Solos, UESB, Vitória da Conquista, BA.
[3]Engenheira Agrônoma, mestranda em Fitotecnia UESB, Estrada do Bem Querer, Km 4, CEP – 45083-900, Vitória da Conquista, BA. Fone (77) 991003132. E-mail: lorenagoncalves.agro@gmail.com.
[4]Engenheiro Agrônomo, mestrando em Fitotecnia, UESB, Vitória da Conquista, BA.
[5]Engenheira Ambiental, mestranda em Desenvolvimento Regional e Meio Ambiente, UESC, BA.
[6]Engenheira Agrônoma, mestranda em Fitotecnia, UESB, Vitória da Conquista, BA.

proposes to evaluate the performance of hydrological modeling by the MGB-IPH model for daily and monthly data from three fluviometric gaging stations of the Pardo river basin, using the Muskingum-Cunge and Inertial flow routing methods. Results from validation and calibration of the model were evaluated using the NSE and NSElog efficiency coefficients, as well as the percentage volume error, which indicated the performance of the model when comparing simulated to observed data of daily and total monthly flow using different flow routing methods. The results indicated that in comparing the performance by the Muskingum-Cunge and Inertial methods, only 11.11% of the results showed class change, whereas for the results using daily and monthly data, 55.56% of the values showed class change. It was concluded that there were few differences when using the different flow routing methods and there is a general improvement in modeling performance when using monthly total data.
KEYWORDS: MGB. Performance. Simulation.

INTRODUCTION

A river basin is an area that is topographically delimited, drained by an interconnected system of watercourses in such a way that all effluent flow is discharged into a single point known as the outlet (Tucci, 2004), which is the basic unit of hydrological studies.

Hydrological modeling represents mathematically various physical processes in soil-plant-atmosphere interactions; thus, it is regarded as a powerful tool for analyzing water resources, such as the impact of water and land use on river flow and real-time forecasting and estimating of flow for sites missing hydrological data.

Distributed models allow representing temporal and spatial variability of hydrological characteristics by dividing the watershed into sub-basins (Paz et al., 2011). These models take into account different regions composing the river basin that have similar hydrological behavior, i.e., similar hydrological response units (HRUs), and they structurally consist of at least two components: water balance and flow routing through a drainage network.

Large basin hydrological model developed by Instituto de PesquisasHidráulica of the Federal University of Rio Grande do Sul, Brazil (MGB-IPH) is a distributed hydrological model that uses two different methods for simulating flow routing: Muskingum-Cunge (MC), which is a kinematic wave method (Collischonn&Dornelles, 2013); and Inertial model, which, unlikely the latter, computes water levels, allows lateral exchange between sub-basins and therefore simulates the influence of flood plains, and allows the inclusion of downstream effects; however, this model needs a higher computational power.

Using a model for a given region is indispensable to calibrate it for later validation of the model's parameters for different periods aiming at the best approximation of a real-world system. Tucci (2005) mentions that the model's parameters are values that characterize the system and fluctuate with time and space; thus, it is possible to quantify its performance on different scales (Silva, 2011; Pimentel, 2017) or using different methodologies (Pontes et al., 2015; Lopes, 2015; Pontes et al., 2017).

Therefore, this study aimed to evaluate the performance of hydrological modeling using the model MGB-IPH for three gaging stations located at Pardo river basin, using MC and Inertial methods for flow routing, both daily and monthly.

MATERIAL AND METHODS

Pardo river basin has a drainage basin measuring approximately 32,649 km^2. The source of its main river, Pardo river, is in the municipality of Montezuma, Minas Gerais state, and its estuary in Canavieiras, Bahia state, both in Brazil. Mean annual rainfall ranges from 703.72 mm, at the central region of the basin, to 1,325.05 mm, occurring closer to the estuary. For this study, the basin was divided into three sub-basins, monitored by the following gaging stations: 53540001 (A), 53650000 (B) and 53880000 (C), which are located downstream the main river and monitor a catchment area of 10,791.721 km^2, 18,439.686 km^2 and 29,284.012 km^2, respectively (Figure 1). These stations were chosen due the availability of observed data.

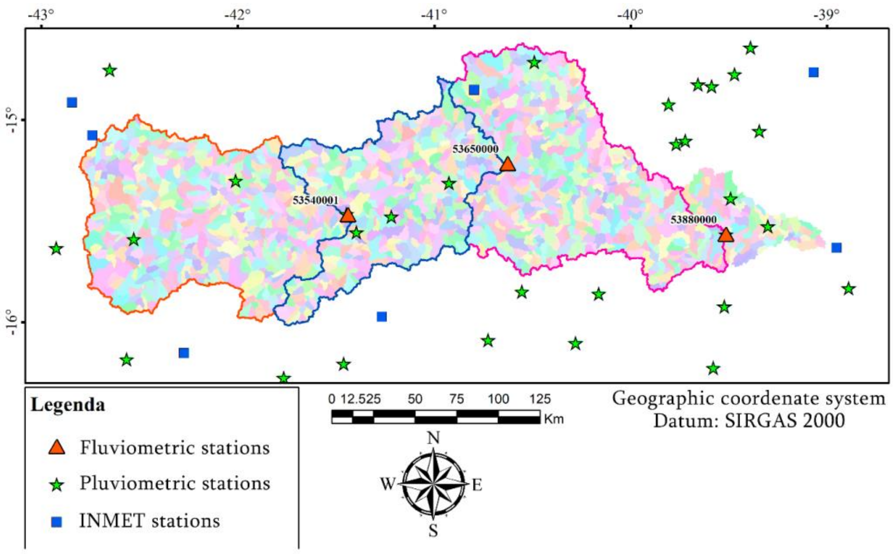

Figure 1. Map of Pardo river basin and the stations used in the model.

Using the plug-in IPH-Hydrotools for MapWindows GIS, a digital altimetry model, information on soil types and land use was used as input data for creating nine HRUs: deep soil forest, shallow soil forest, animal/crop farming on deep soil, animal/crop farming on shallow soil, no vegetation on deep soil, no vegetation on shallow soil, and water. Afterwards, using the plug-in MGB-IPH version 4.1 for QGIS Desktop, centroids were created for the sub-basins; rainfall, discharge and climate data were prepared; vegetation and soil parameters were defined; and projects for calibration and validation were created.

Calibration took place between Jan 2000 and Dec 2005, at first, manually changing the following soil parameters: water storage; relationship between saturation and storage of the model used for soil water balance; subsurface and underground runoff; soil pore size; upstream flow of the aquifer; soil water balance considering that groundwater can return by upward flow to the surface layer and adjustment coefficients for the delay time of linear reservoirs in the sub-basins. These parameters were changed for each sub-basin until the best fit was obtained. The same parameter setting was used as input for the automatic calibration of MGB-IPH. The validation of the model was done after the calibration process and consisted of maintaining the same parameters for the automatic calibration for the period between Jan 2006 and Dec 2010.

Performances of calibration and validation were verified using the Nash Sutcliffe model efficiency coefficient (NSE), logarithmic Nash Sutcliffe coefficient of the flow (logNSE) and volume error percentage (VE%), as described and classified by Moriasi et al., (2007) (Table 1).

Table 1. Classification of performance indexes

Classification	NSE e logNSE	VE (%)
Very good	0.75 <NSE e NSElog ≤ 1.00	VE (%) < ± 10
Good	0.65 <NSE e NSElog ≤ 0.75	± 10 ≤ VE (%) < ± 15
Satisfactory	0.50 <NSE e NSElog ≤ 0.65	± 15 ≤ VE (%) < ± 25
Unsatisfactory	NSE e NSElog ≤ 0.50	VE (%) ≥ ± 25

Source: Moriasi et al., (2007).

Performance was assessed for daily discharge as well as total monthly discharge.

RESULTS AND DISCUSSION

The best performance results for the calibration period were observed for station C. In comparing MC and Inertial methods for this period, it was possible to observe changes in the VE (%) only for station A. At this station, both monthly and daily data results decreased performance from very good to good (Table 2). Comparing the results using daily and monthly data in the calibration, it can be seen that there was no decrease in performance of all indexes in all stations for the MC and Inertial methods; rather, there was an increase in the performance of NSE and NSElog indexes in all stations.

Table 2. MGB-IPH performance indexes for the calibration period for three fluviometric stations located in the Pardo river basin, Brazil.

		Daily		Monthly	
Station	Index	MC	Inercial	MC	Inercial
A	NSE	0.42	0.41	0.62	0.60
	NSElog	0.30	0.25	0.61	0.55
	VE (%)	2.71	12.79	4.00	14.00
B	NSE	0.33	0.33	0.51	0.50
	NSElog	0.36	0.28	0.64	0.60
	VE (%)	8.19	0.67	7.00	2.00
C	NSE	0.64	0.64	0.81	0.80
	NSElog	0.72	0.73	0.85	0.83
	VE (%)	2.69	5.99	2.00	6.00

Just as in calibration, the best performance results for the validation period were observed for station C; when comparing MC method to Inertial method for this period, it was possible to observe a decrease in performance for VE (%) only in station A (Table 3). Performance improvements in NSE of stations B and C and NSElog of station C were observed by observing the differences between daily and monthly data for the validation period.

Table 3. MGB-IPH performance indexes for the validation period for three fluviometric stations located in the Pardo river basin, Brazil.

		Daily		Monthly	
Station	Index	MC	Inercial	MC	Inercial
A	NSE	0.12	0.11	0.20	0.08
	NSElog	-1.00	-0.75	-0.41	-0.30
	VE (%)	6.03	21.29	12.00	27.00

	NSE	0.24	0.25	0.56	0.56
B	NSElog	-0.33	-0.10	0.06	0.21
	VE (%)	8.04	4.40	6.00	6.00
	NSE	0.53	0.53	0.73	0.70
C	NSElog	0.65	0.66	0.84	0.82
	VE (%)	4.31	8.11	5.00	9.00

When comparing MC to Inertial methods, in general, only 11.11% of the results showed a change in class; all changes were for station A as to VE (%) in all situations, with the inertial model showing lower results than those of MC. Pontes et al. (2017) applying the MGB-IPH in 10 sub-basins of the Araguaia River concluded that the Inertial method led to similar NSE and VE (%) results and, sometimes, better than the MC method for the validation period. Pontes et al. (2015) using the MGB-IPH to assess the importance of river hydrodynamics for flow prediction in three river stations in the Paraná River watershed compared MC and Inertial methods for daily data; as a result, the NSE, NSElog and VE indexes (%) performed very well for both routing methods. Lopes (2015) when performing the integrated hydrological modeling of the Laguna dos Pato watershed using the MGB-IPH model verified similar performance of the two methods. The author explains that the similarity of the flow routing performance between the Muskingum-Cunge and Inertial methods for the rivers that they studied may be justified by the fact that these rivers do not have broad flood plains.

More significant changes between performance class indexes were observed when comparing the results using daily and monthly data. 55.56% of the values changed from one class to another, and 90% of them improved their performance when using monthly flow data. These results are consistent with Silva (2011), who applied the SWAT model to simulate river flow of Araranguá river basin in Santa Catarina state and verified a change in NSE from 0.724 with daily data to 0.919 with monthly data. Pimentel (2017) used a conceptual semi-distributed model (SWAT) for hydrological modeling for the Jucu river basin in Espírito Santo state and found 0.40 for NSE and 28.82 % for VE using daily data and 0.60 for NSE and 11.83% for VE using monthly data at calibration. These findings agree with data reported herein; however, unlikely the results of this study, both authors did not report improvements in performance during validation using monthly data.

Improvements in performance using monthly rather than daily data can be explained by minimizing potential failures when totaling flow data. It is a procedure that increases performance, but decreases the number of data and limits the studies to monthly scale, and should be used according to the purpose. Performance improvements using monthly data in hydrological modeling were also observed in Spruill, Workman and Taraba (2000), Coffey et al. (2004), Moriasi et al. (2007) and Ghosh (2016).

CONCLUSIONS

Overall, it was observed that station C was the one with the best overall results for both calibration and validation, with no index showing poor performance.

For both daily and monthly data, few differences were found when using the flow routing methods: Muskingum-Cunge and Inercial.

The use of monthly total flow data provided an improvement in hydrological modeling performance through the MGB-IPH when compared to the use of the daily data scale. Performance improvement in daily data usage involves using a series consistent with minimal failures.

REFERENCES

COFFEY, M. E.; WORKMAN, S. R.; TARABA, J. L.; FOGLE, A. W. Statistical procedures for evaluating daily and monthly hydrologic model predictions. **Transactions of the ASAE**, v. 47, n. 1, p. 59, 2004.

COLLISCHONN, W.; DORNELLES, F. **Hidrologia para Engenharia e Ciências Ambientais.** Porto Alegre: Associação Brasileira de Recursos Hídricos (ABRH), 2013. 350p.

GHOSH, M. **Application of SWAT model to assess the impact of land use changes on daily and monthly streamflow of Subarnarekha River Basin**. 2016. 68 f. Dissertação (Mestrado em Engenharia de recursos hídricos), National Institute of Technology Rourkela, 2016.

LOPES, V. A. R. **Modelagem hidrológica integrada da bacia hidrográfica da Laguna dos Patos e seus complexos lagunares usando o modelo MGB-IPH com propagação inercial de vazões**. 2015. 84 f. Monografia (Graduação em Engenharia Ambiental) - Universidade Federal do Rio Grande do Sul, Porto Alegre, 2015.

MORIASI, D. N.; ARNOLD, J. G.; VAN LIEW, M.W.; BINGNER, R. L.; HARMEL, R. D.; VEITH, T.L. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. **Transactions of the ASABE**. v. 50, n. 3, p. 885-900, 2007.

PAZ, A. R.; BUARQUE, D. C.; COLLISCHONN, W.; VICTORIA, D. C.; ANDRADE, R. G. Discretização de modelos hidrológicos de grande escala: grade regular x mini bacias. In: XIX Simpósio Brasileiro de Recursos Hídricos, 2011, Maceió. **Anais** do XIX SBRH, 2011.

PIMENTEL, S. M. **Modelagem hidrológica da bacia do rio Jucu sob diferentes cenários de cobertura florestal**. 2017. 79 f. Dissertação (Mestrado em Ciências Florestais) – Universidade Federal do Espírito Santo, Espírito Santo, 2017.

PONTES, P. R. M.; FAN, F. M.; FLEISCHMANN, A. S.; DE PAIVA, R. C. D.; BUARQUE, D. C.; SIQUEIRA, V. A.; JARDIM, P. F.; SORRIBAS, M. V.; COLLISCHONN, W. MGB-IPH model for hydrological and hydraulic simulation of large floodplain river systems coupled with open source GIS. **Environmental modelling & software**, v. 94, p. 1-20, 2017.

PONTES, P. R.; FAN, F. M.; COLLISCHONN, W.; MACHADO, A.; GOMES, G. V.; BUARQUE, D. C.; TUCCI, C. E. A. A importância da hidrodinâmica fluvial para previsão de vazão. In: Simpósio Brasileiro de Recursos Hídricos, 21., 2015, Brasília. ***Anais***... Brasília: Associação Brasileira de Recursos Hídricos, 2015.

SILVA, P.G. **Simulação do fluxo hídrico e da produção de sedimento da bacia do rio Araranguá, SC, a partir da aplicação do modelo hidrológico SWAT**. Itajaí: Universidade do Vale do Itajaí, 2011. Monografia (Bacharelado em Oceanografia), Universidade do Vale do Itajaí, 2011.

SPRUILL, C. A.; WORKMAN, S. R.; TARABA, J. L. Simulation of daily and monthly stream discharge from small watersheds using the SWAT model. **Transactions of the ASAE**, v. 43, n. 6, p. 1431-1439, 2000.

TUCCI, C. E. M. (Org.). Hidrologia: ciência e aplicação. Porto Alegre: Editora da UFRGS/ABRH, 2004. 943p.

TUCCI, C. E. M. **Modelos hidrológicos**. 2 ed. UFRGS, Porto Alegre-RS, 2005. 680 p.