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RAINFALL INPUT FROM WRF-ARW ATMOSPHERIC MODEL COUPLED WITH MOHID LAND HYDROLOGICAL MODEL FOR FLOW SIMULATION IN THE PARAÍBA DO SUL RIVER - BRAZIL

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Abstract: The present work aimed at building the hydrological model for the Paraíba do Sul River watershed, using the MOHID Land model, in order to study channel flows considering six different precipitation inputs. First, two scenarios were created with temporal variation of rain from the precipitation measured by 17 automatic stations of the Brazilian National Institute of Meteorology (INMET) located in the watershed, and interpolated with the FillMatrix tool, by the Inverse Distance Weighting (TIN) and Triangulated Irregular Networks (IDW) methods. The other four scenarios were created from four experiments simulated in the atmospheric model WRF-ARW, corresponding to the spatial and temporal variation of precipitation. The hydrological model considered the Manning coefficients, Curve Numbers and cross sections extracted from the database of the Brazilian National Water Agency (ANA) together with the operation curve of the reservoirs extracted from the situation room on the Geographical and Geoenvironmental Information System of the Paraíba do Sul River Watershed (SIGA-CEIVAP) website. The analysis period corresponds to the month of January 2019 (01/01/2019 00 UTC and 01/02/2019 00 UTC), with hourly evaluation. The measured channel flow data used were extracted from the ANA fluviometric station, in the Campos dos Goytacazes city, State of Rio de Janeiro, and they were used for the statistical indices calculation, BIAS, MAE, MAPE, RMSE and Pearson's Correlation (R), in order to evaluate the model. The results showed that once the physical parameterization of better performance in the atmospheric model (WRF – Weather Research and Forecasting) was established, the use of the modeled rain yields a superior performance in comparison to the interpolated (observed) rain for implementation in the hydrological model (MOHID – MODagem HIDrodinâmica), with the aim to study the channel flows.

Keywords: Hydrological modeling; Rainfall simulation; Channel flow simulation; Physical geography; Geotechnologies.

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INTRODUCTION

The watershed is an area of natural water catchment, constituted of topographical divisors which direct, through a complex network of channels, the waters originated from the rains to a main course that will flow into a single point of lower altitude called outlet (Tucci, 2012; Yousuf and Singh, 2019). There are several components that compose the hydrological processes in a watershed, such as the slope, altitude, type of soil, infiltration, runoff, distribution of rainfall, which represents a natural complex system.

The water cycle includes processes originating from the atmosphere, land surface and subsurface. Precipitation falls from the atmosphere, but part of it is intercepted by vegetation and evaporates back into the atmosphere, even before it reaches the ground. The fraction of the rain that reaches the ground can run off superficially (runoff) depending on the slope for example, among other factors, until it finds a watercourse, or it can infiltrate in the soil. The infiltrating rainwater reaches the groundwater through percolation, and part of it joins the channel flow as a base flow. Total evaporation is the sum of the canopy evaporation, transpiration and evaporation of the soil, and evaporation of open water. The channel flow of the main river is the accumulation of runoff to the channel plus the contribution of groundwater (base flow). Effective rain, that is, the portion of rain that effectively becomes runoff is responsible for providing increased flow to water courses in the basin (Collischonn and Dornelles, 2013).

Understanding the dynamics of rainfall-channel flow in a watershed is extremely important regarding the planning and management of water resources, as the events of intense rain, and subsequently extreme flow, are associated with floods. On the other hand, the decrease in precipitation events and the increase in the water withdrawal processes for different uses, implies a reduction in flow rates, generating problems such as silting up along the course and the saline intrusion at the mouth, generating water availability problems. Within this context, the use of computational modeling is presented as a low-cost tool for the elaboration of studies with different scenarios, with this work focusing on the hydrological modeling for the Paraíba do Sul River watershed and the river flow study.

The hydrological model chosen for the development of this research is MOHID, acronym for Hydrodynamic Model (MOdelagem HIDrodinâmica, in Portuguese), specifically its MOHID Land model, having been chosen, due to a partnership between the Instituto Federal Fluminense (IFF) and the Universidade do Estado do Rio de Janeiro (UERJ), in Brazil, with the Instituto Superior Técnico (IST) at the Technology Research Center Marine and Environmental Sciences MARETEC from the Technical University of Lisbon (UL), in Portugal. The MOHID Platform can receive the precipitation inputs as a constant rainfall in space and time, as a timeseries with temporal variation of rainfall or a structured file with the spatial and temporal variation of rainfall (MOHID WIKI, 2020).

The constant rainfall method is used for specific conditions in which it is desired to analyze the hydrological behavior of a watershed in a particular condition of constant rain in space and time, may to be used for example as the design heavy rain condition for engineering works, such as dikes, dams and bridges, or for the assessment of extreme environmental events.

The condition of rainfall temporal variation may be taken into account with the insertion of a historical series, usually derived from data measured with pluviometry stations, causing it to vary over time. Thus, it is possible to evaluate the long-term hydrological behavior of a watershed by realizing how much the seasonality of rainfall influences other hydrological variables, as well as the response time of the watershed to increasing or decreasing rainfall. This method tends to be more effective in small watersheds where the homogeneity of precipitation events is verified, and does not represent large watersheds, as the spatial variation of rain implies great variations in hydrological behavior. The model allows the use of the Triangulated Irregular Networks (TIN) and Inverse Distance Weighting (IDW) interpolation methods, so that the historical series measured by the monitoring stations, which are dispersed in the watershed, can be used to estimate the precipitation values between the stations. However, for very large watersheds, this can mean large deviations, especially if the density of stations is small.

The spatial and temporal variation of rainfall input in the MOHID Platform is possible with the insertion a file of the type Hierarchical Data Format Version 5 (HDF5), which is widely used in scientific computing, it has been created to organize and store a large amount of data, usually originated from simulated data in atmospheric models. This approach allows a specialized representation of precipitation, which in turn will lead to a better representation of the channel flow, as it admits events of intense rain in certain areas of the watershed, as well as complete absence of rainfall in other areas, with the flow rate in the outlet being the resultant of these variations.

In view of the need for hydrological modeling of basins with a large extension, such as the Paraíba do Sul River watershed (62,074 km²), this work proposes the integration of the atmospheric model Weather Research and Forecast (WRF) with the MOHID Land hydrological model, in order to obtain the best representativeness of atmospheric variables, notably in precipitation events, which represents the biggest contributor to flow variations in the hydrological study of the basin, seeking a better adjustment in the hydrological model. Other atmospheric variables, such as wind direction and speed, relative humidity, solar radiation, and air temperature, are variables that serve as input for the hydrological model and are possible to simulate by using the WRF-ARW.

In the present work six scenarios of hydrological modeling were constructed with a particular focus on flow rate values assessment with different rainfall inputs. Four scenarios came from the WRF model rainfall outputs and two scenarios corresponding to the rainfall measured by the official monitoring stations of the Brazilian National Meteorological Institute (INMET) and interpolated with the methods TIN and IDW. After the simulation, the results were compared with the data measured from the fluviometric station of the Brazilian National Water Agency (ANA), in the Campos dos Goytacazes city, State of Rio de Janeiro, and used for statistical indices computations, BIAS, Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE) and Pearson's Correlation (R), to assess which method of rainfall input yields the best representation for the flow rate in the Paraíba do Sul River watershed, under the test conditions considered.

STUDY AREA

The methodology proposed in this work is evaluated with a case study in the Paraíba do Sul River watershed, which has an area of approximately 62,074 km², extending through the states of Rio de Janeiro (26,851 km²), São Paulo (14,510 km²), and Minas Gerais (20,713 km²), in Brazil, in addition to covering 184 municipalities, of which 88 are in Minas Gerais, 57 in the state of Rio de Janeiro and 39 in the state of São Paulo. Regarding the State of Rio de Janeiro, the watershed covers 63% of the total area of the state; in São Paulo, 5% and in Minas Gerais, only 4%. The highest altitude point is the "Pico das Agulhas Negras" with 2,787 meters (CEIVAP, 2019).

Located in the southeast region of Brazil, as shown in **Fig. 1**, the watershed is in a place of strong population density. According to data from the last census, it was estimated 5.5 million people living in the interior of the watershed, and over 8.7 million people in the metropolitan area of Rio de Janeiro, who use their waters through transpositions. In this sense, an estimated 14.2 million people are served by this basin, in the 184 municipalities (CEIVAP, 2020).

In an area previously covered by the Atlantic Forest biome, it is currently heavily modified by human occupation. It is one of the Brazilian hotspots, and it is estimated that it has only 11% of the original native forest (COHIDRO, 2014).

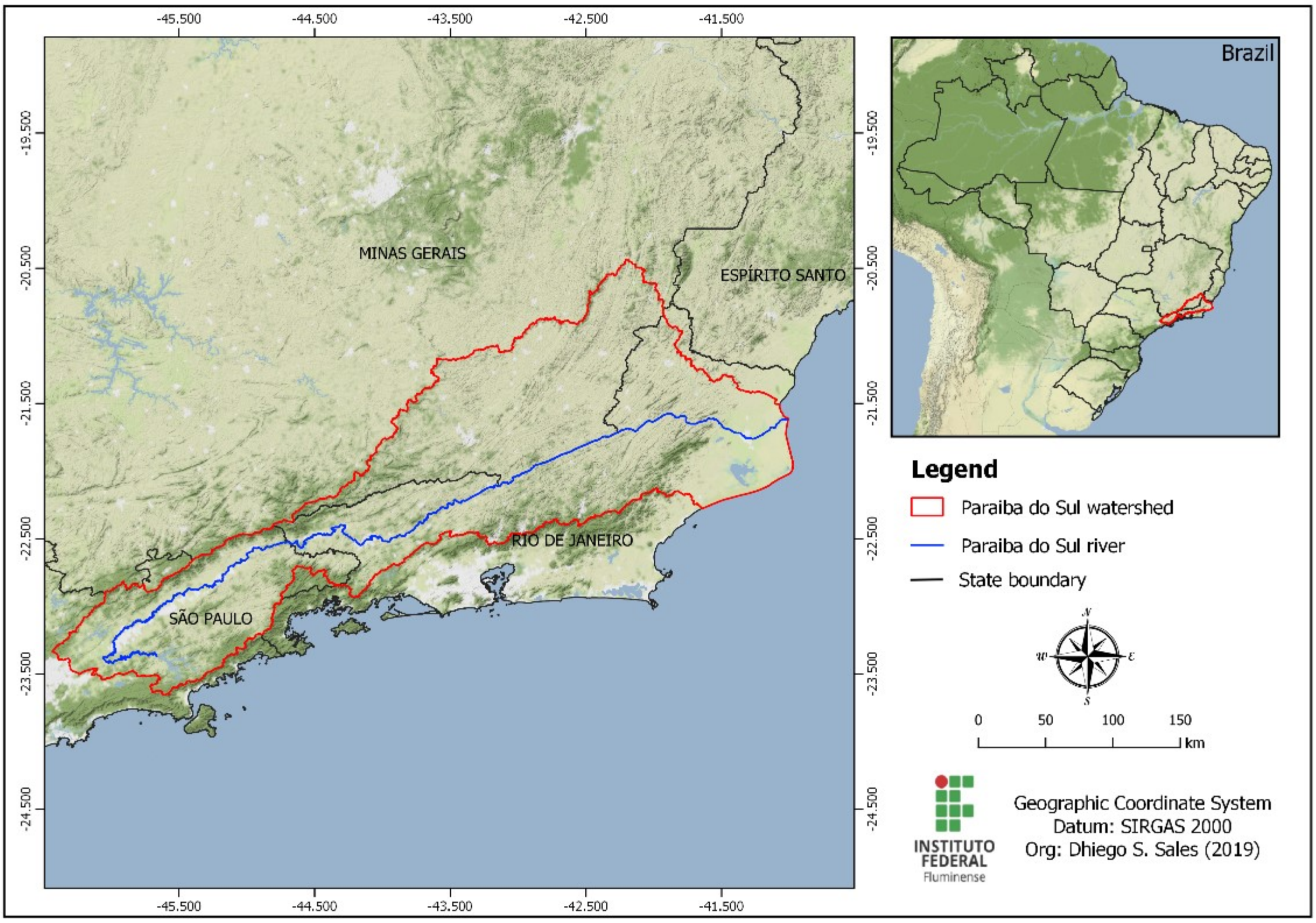


Fig. 1 Location of the Paraiba do Sul River watershed.

METHODOLOGY

Atmospheric modeling: WRF model

The WRF (Weather Research and Forecasting) is a public domain model, distributed free of charge by the National Center for Atmospheric Research (NCAR), from the United States, having been the result of collaborations established between universities since the early 1990s. It is composed of two dynamic solvers for the equations used to model the relevant phenomena in the atmosphere, being composed by the WRF–ARW (WRF Advanced Research) and the WRF–NMM (Nonhydrostatic Mesoscale Model) programs. In the present research, the version 4 of the WRF–ARW was used. The representation of the surface of the domain of interest is implemented in the model by means of a global data set of static variables, such as soil layers, land use category, terrain altitude, average annual soil temperature, monthly vegetation fraction and monthly albedo available for download on the WRF website (http://www2.mmm.ucar.edu/wrf/users/download/get_sources_wps_geog.html). Some of the datasets are available in only one resolution, but others are available for download both in high or low resolution.

Although the model has been designed for regional analysis, it has the flexibility to be used in local studies. For this purpose, it allows multiple domains (nesting) for the downscaling process, minimizing errors (Warner, 2010).

The initial and lateral boundary conditions can be obtained from several global models, such as: Interim reanalysis data (ERA), North American Model (NAM), Rapid Update Cycle (RUC), AGRMET (Agricultural Meteorology from the Air Force Weather Agency - AFWA), the products of analysis of the Global Forecasting Model - GFS (Global and Forecast System), among others, as described by Wang *et al.* (2019).

The computational system consists of two main modules with applications as follows:

i. The WPS (WRF Pre-processing System) module has the purpose of preparing the input for the real.exe program, which consists of three applications (WANG *et al.*, 2019): (a) "geogrid.exe": defines the domains and interpolates static geographic data, made available in binary WPS format for grids; (b) "ungrib.exe": extracts the meteorological data referring to the initial and lateral boundary conditions, distributed in the GRIB (GRIdded Binary) format; (c) "metgrid.exe": horizontally interpolates the meteorological data extracted by ungrib.exe to the grid defined by "geogrid.exe".

ii. The WRF module is divided into two programs. The first is "real.exe", which performs a vertical interpolation of atmospheric data, horizontally interpolated by "metgrid.exe", thus completing the pre-processing step. The second program to be executed is "wrf.exe" which is responsible for using all the data prepared in the previous programs, performing the simulation from the definition of the physical parameterizations informed in the file "namelist.input" (Wang *et al.*, 2019). All simulated variables are organized in a hierarchical file in the standard WRF format, type netCDF, where it is possible to organize many variables in an equally large number of time layers.

Currently atmospheric models are executed in general from a sophisticated set of physical parameterizations that seek to consider atmospheric physics processes in an increasingly detailed way (Jacobson, 2005; Liu, 2018). These schemes are simplified formulas instead of complex theoretical models to solve the terms associated with turbulent flows of momentum, heat and humidity. These are important components of numerical models and have a decisive role in determining the model's behavior (GUNWANI and Mohan, 2017). The WRF has seven physical parametrizations for implementation: microphysics, long-wave radiation, short-wave radiation, cumulus, planetary boundary layer, surface layer and model of the earth's surface, which are briefly described next.

- Microphysics includes explicit water vapor, cloud and precipitation processes.
- The radiation schemes (long and short wave) deal with atmospheric heating due to the divergence of radiative flux and radiation of long waves and short surface waves for the calculation of soil heating.
- The cumulus scheme is responsible for the sub-grid effects, convection and vertical distribution of moisture and heat.
- The surface layer schemes calculate the friction speeds and the exchange coefficients.
- Earth surface schemes provide heat and humidity flows over land and sea ice points (in our region of interest there are no ice points).
- Planetary boundary layer schemes are responsible for turbulent mixing across the entire column (SKAMAROCK *et al.*, 2019).

Each of these parameterizations has a wide variety of possible schemes, and they can be used in free associations, generating many combinations. The combination with the best representativeness will depend on the region of study, and can be obtained either through sensitivity studies or by searching the literature

WRF experiment design and data

The model was configured with two nested domains where, the external domain (D1) is composed of a grid of 62 x 51 cells with spatial resolution of $\Delta x = \Delta y = 15$ km, while the internal domain (D2) is composed of a grid of 123 x 90 cells with spatial resolution of Δx=Δy= 5 km. The coordinates of the central point of both domains are 43.52° W/22.084° S, with the nesting arrangement being constructed in such a way that the finer mesh covers the entire length of the Paraíba do Sul River watershed. The projection used was that of Mercator, and the nesting of the domains can be seen in **Fig 2**.

The vertical profile of the model was configured for 35 "sigma" layers at 5000 Pa at the top of the atmosphere, thus establishing the vertical boundary condition for integration of the model. The integration time interval was 90 s, and the model output was configured to generate data at every hour. Static data is a standard high-resolution option provided by the model. The initial and lateral boundary conditions for the experiments were obtained from the global numerical prediction model, GFS, from the analysis data provided by the National Centers for Environmental Prediction (NCEP), which has information on the atmosphere in a 6-hour temporal resolution, and spatial resolution of 0.25° (ds084.1 dataset).

Hydrological modeling: MOHID Land

MOHID Land is a 3D model capable of simulating the different phases of the water cycle, spatially distributed in a constant or variable way. The solver is open source, freely distributed, and its graphical interface, MOHID Studio, is not open, being commercialized by Bentley®. In the present research, the version of MOHID Studio 2016 was used, made available for academic purposes by the developer in partnership with Instituto Federal Fluminense (IFF) and the Universidade do Estado do Rio de Janeiro (UERJ). **Fig. 3** indicates the equations solved by the model in its different phases of the water cycle, where the drainage network is one-dimensional, the runoff is two-dimensional, and the infiltration process is three-dimensional.

The model uses a finite volume approach, which admits that each control volume (or grid cell), which consists of a defined and constant volume, has all its homogeneous properties and are referenced in the center of each cell, being the flow and speed calculated at the interface of each cell (Bernard-Jannin *et al.*, 2016). MOHID Land processes are based on the mass conservation and movement continuity equation (IONA, 2013).

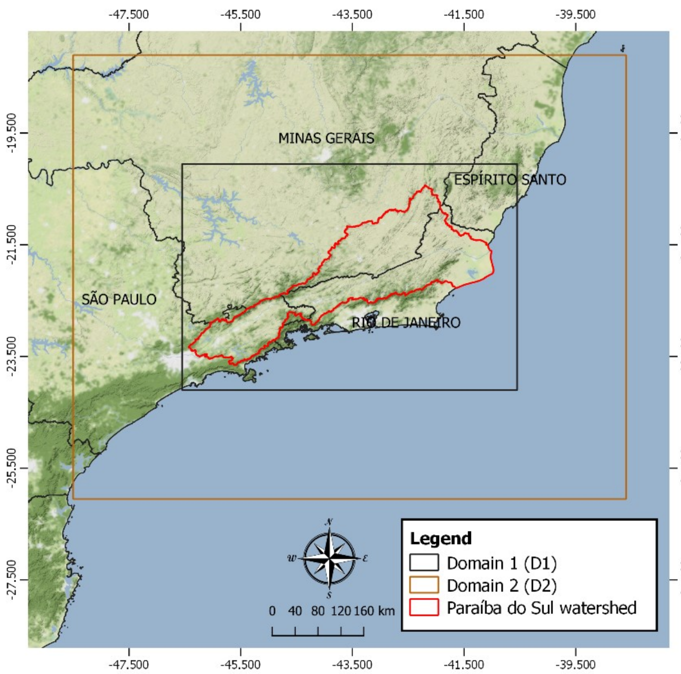


Fig. 2 Computational domains representation.

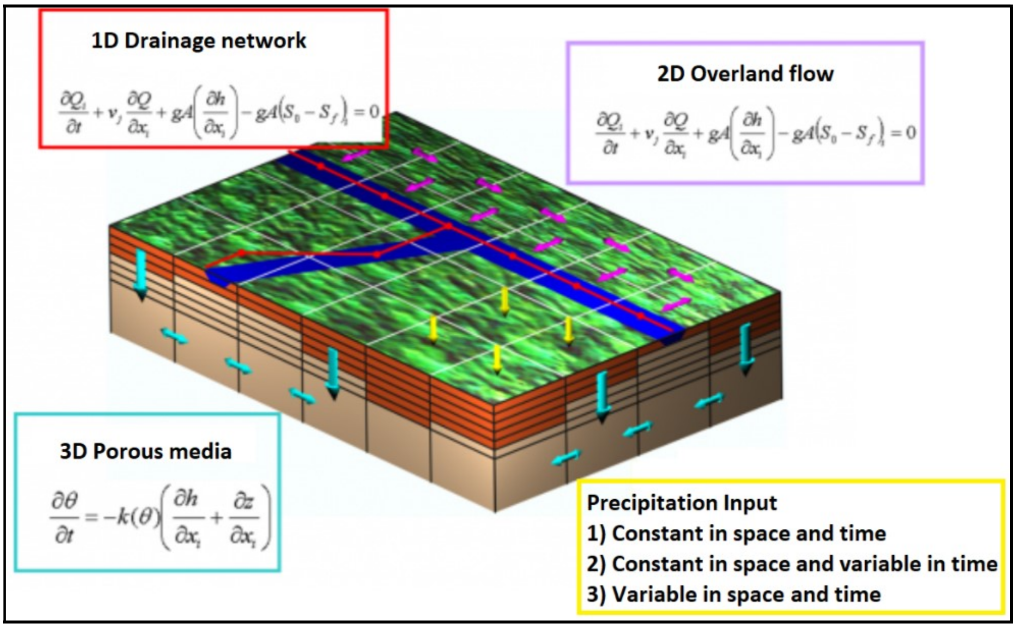


Fig 3 Equations solved by MOHID Land, in the different phases of the water cycle. Source: adapted from MOHID Wiki (2020).

Creation of topography, delimitation of the watershed and drainage network

To delimit the watershed and define the drainage network it is necessary to implement altimetry information of the study area in MOHID Land, through a Digital Elevation Model (DEM). A DEM can be defined as a structured model of rows and columns (matrix), georeferenced, which has altimetric records in each pixel that makes up the image (Paz *et al.*, 2006, Valeriano, 2012).

The altimetry input data was obtained from a mosaic of files of the Topodata project, which covers the entire area of interest, available for download at the INPE (Brazilian National Institute for Space Research) website (INPE, 2014). This DEM is available in geotiff format and is a rescaling for a spatial resolution of 30 m, from the SRTM radar mission (Shuttle Radar Topography Mission), performed with the aim of obtaining global elevation data, originally at a spatial resolution of 90 m. To generate the topography spatial discretization used in MOHID Land was $\Delta x = \Delta y = 0.05°$ (~5km), and a mesh of 120 x 81 cells of ~5.5 km.

After the topography was generated, the Remove Depression tool was used, which consists of the mathematical correction of the terrain irregularities, in order to allow the creation of water accumulation lines, which allows the construction of the model's drainage network. Then, the Delineate Basin tool from MOHID Land was used to design the watershed and the drainage network. The accuracy of the flow simulation is sensitive to the chosen discretization, which, in this case, was ~ 5.5 km due to the large size of the Paraíba do Sul River watershed, and to the fact that this was the discretization used in the rainfall simulation performed in the atmospheric model WRF-ARW. As expected, the higher the spatial resolution, the higher the computational cost associated with the simulation. Therefore, it must be first assessed which spatial resolution as capable of providing a reasonable representation of the phenomenon modeled.

The northern part of the state of Rio de Janeiro presents low quotas, being in some regions, lower than the Paraíba do Sul River course, as well as to the ocean. Therefore, it was opted that the watershed modeled in the MOHID Land disregards this great coastal lowland region, since precipitation in this region tends to provide flooding and drainage directed to other areas than the Paraíba do Sul River course. For this purpose, the exutory of this modeled watershed was considered to be close to the urban perimeter of the city of Campos dos Goytacazes, on the municipal iron bridge, downstream from the mouth of the Muriaé River, with the purpose of concentrating at this point the behavior of the entire watershed upstream, disregarding only the great coastal plain of Campos dos Goytacazes, the so called Baixada Campista. It is important to emphasize also that this point coincides with ANA's fluviometric station in Campos dos Goytacazes, which contributes to the model accuracy assessment.

The drainage network is generated by the tool, defining the point of the exutory, and in this way the algorithm maps, according to the altimetry, the entire delineated area generating the drainage network. Since the Paraíba do Sul River watershed is composed of a complex drainage network, it was opted to simplify the channel network to a hierarchical pattern of dendritic channels of order 3, the main course being the Paraíba do Sul River. This is necessary to use the available information from ANA database about the cross sections, that is, they are limited to Strahler order number 3. The modeled drainage network, although simplified, proved to be very close to reality, when compared with the courses of rivers present in the official survey available at the ANA website. The modeled watershed can be seen in **Fig. 4**.

Cross-section adjustment

The channel volumetric flow rate calculation is obtained with the product of the flow velocity by the cross-sectional area. So, MOHID Land requires that the cross sections for each node of the drainage network be implemented in order to obtain the flow rate (MOHID WIKI, 2020). The standard geometry of the cross section is trapezoidal, where it is possible to implement a section for each channel order.

The cross-sections implemented in the model were extracted from ANA's public database, using the Hidro 1.3 application, available for download on the HidroWeb portal (http://www.snirh.gov.br/hidroweb/download). Since the real cross-section is irregular, the equivalent area of each real section was established and converted into the trapezoidal geometric shape for insertion into the model by approximation, preserving the depth and width of the river at the station site. Eleven different cross sections were implemented, where two are of order 3, eight are of order 2, and one of order 1. The identification of the stations used, the order that each one represents in the model, and the calculated dimensions of the sections can be seen in **Table 1**.

From the values shown in **Table 1** the average values for the trapezoid dimensions (long base, short base and height), that are calculated for each order. The results are shown in **Table 2**.

Roughness coefficient adjustment

Considering its simplicity and satisfactory results in practical applications, the Manning roughness coefficient has been widely used in hydrodynamic modeling (Lyra *et al.*, 2010; Tavares *et al.*, 2019). Its formulation can be seen as below (used in MOHID Land model),

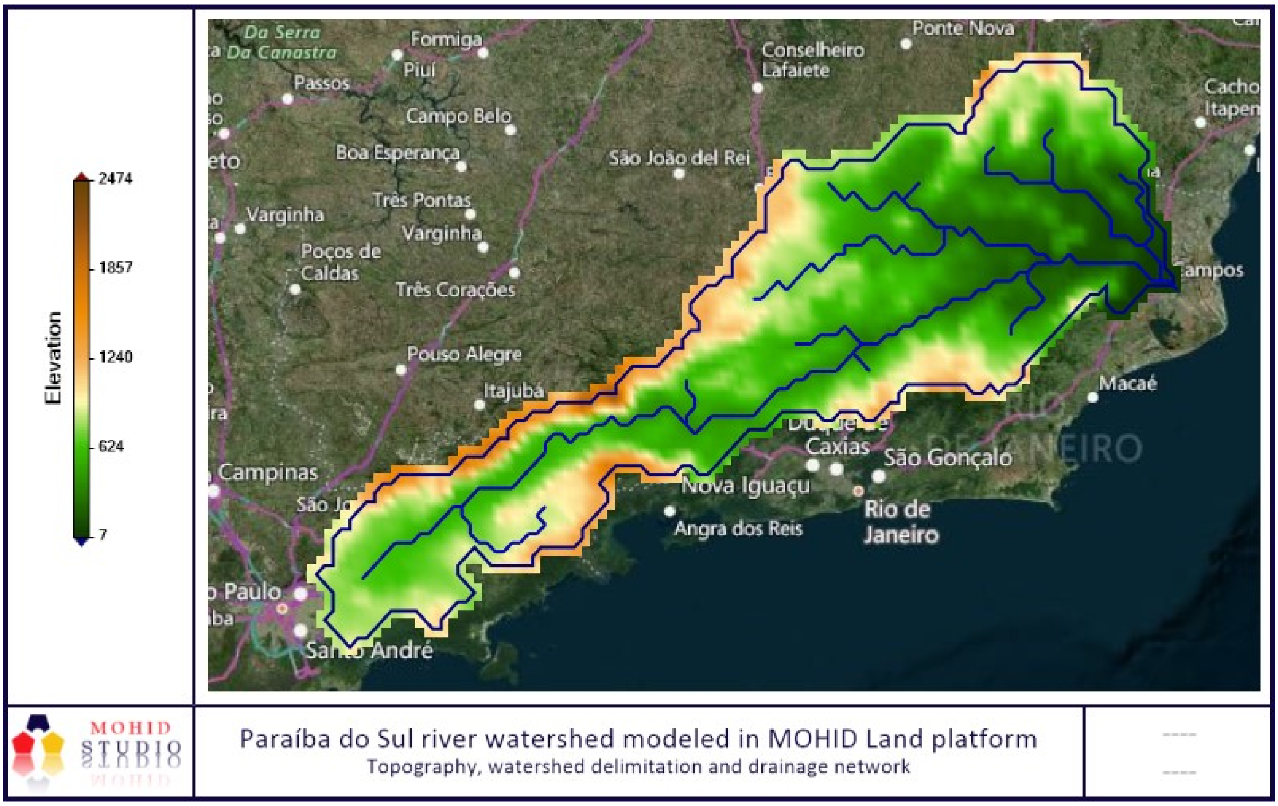


Fig. 4 Paraíba do Sul River watershed generated at the MOHID Studio interface

$$Q = \frac{1}{n} . A . R_h^{2/3} . S^{1/2} \quad (1)$$

where Q is the volumetric flow rate (m³/s), A is the cross-section area (m²), n is the Manning roughness coefficient (s.m$^{-1/3}$), R_h is the hydraulic radius (m) and S is the slope (m/m). The adjustment of this coefficient is one of the most important variables for the flow calculation.

For the river channel, the Manning coefficient of 0.035 was adopted, as described in the paper by Tavares *et al*. (2019). For the watershed, the coefficient was estimated using the methodology described by Chow (1959), combined with the 2016 land use survey performed by the Brazilian Institute of Geography and Statistics (IBGE), on a scale of 1: 250.000, which is available for download (ftp://geoftp.ibge.gov.br/informacoes_ambientais/cobertura_e_uso_da_terra/). The coefficient values were assigned for each land use class. All data processing was performed using the QGIS 3.8.0 geoprocessing software. The spatialization of the Manning coefficient implemented in the model, as well as the criteria adopted in the estimation of the model, by class of land use, can be observed in **Fig. 5** and **Table 3**, respectively.

Table 1. Cross sections from the Brazilian National Water Agency (ANA) used for implementation in MOHID Land.

ANA ID	Place	River	Order	Cross-section date	Total area (m²)	Long base (m)	Short base (m)	Height (m)
58920000	Patrocínio do Muriaé	Muriaé	1	February 26th, 2015	655.89	110.00	21.18	10.00
58235100	Queluz	Paraíba	2	March 15th, 2014	499.35	78.00	17.11	10.50
58242000	UHE Funil Jusante	Paraíba	2	October 27th, 2006	659.38	140.00	62.88	6.50
58315100	Vargem Alegre	Paraíba	2	July 13th, 2018	753.00	190.00	61.00	6.00
58380001	Paraíba do Sul	Paraíba	2	March 18th, 2015	451.25	75.00	7.05	11.00
58790002	Santo Antônio de Pádua	Pomba	2	December 3rd, 2014	1090.00	180.00	110.67	7.50
58792100	Aperibé	Pomba	2	September 29th, 2018	937.25	255.00	24.78	6.70
58940000	Itaperuna	Muriaé	2	February 3rd, 2015	686.81	182.20	22.82	6.70
58960000	Cardoso Moreira	Muriaé	2	February 7th, 2014	905.75	125.00	74.72	9.07
58974000	Campos	Paraíba	3	October 4th, 2017	1610.00	190.00	102.73	11.00
58880001	São Fidélis	Paraíba	3	June 17th, 2015	3893.50	460.00	296.02	10.30

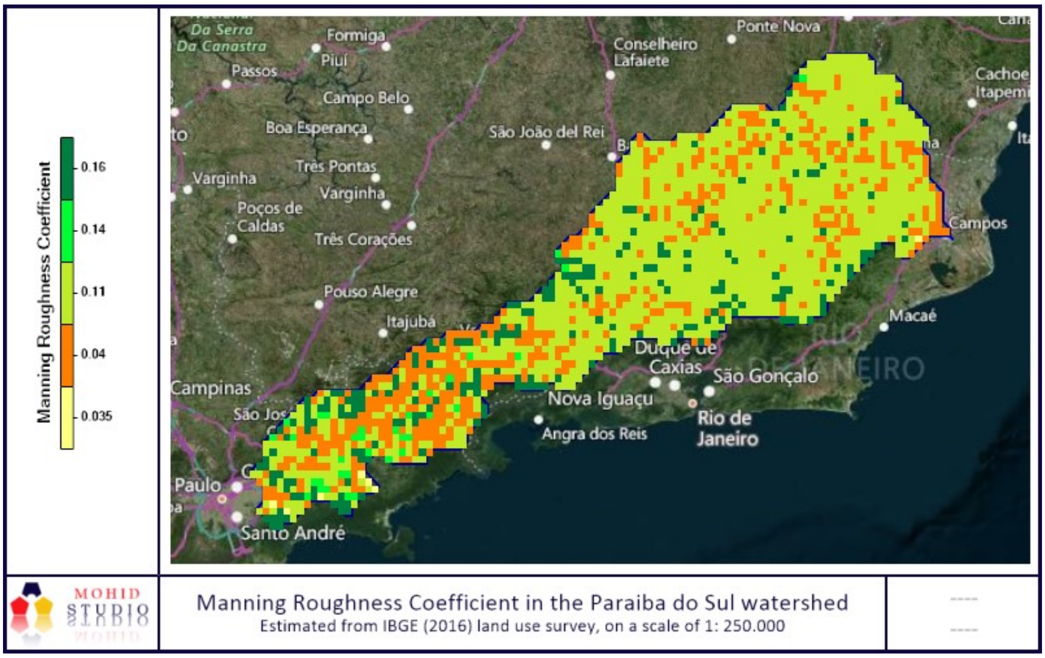


Fig. 5 Estimate of the Manning Coefficient generated at the MOHID Studio interface.

Table 2. Cross-sections defined for each order and implemented in MOHID Land.

Modeled order	Long base (m)	Short base (m)	Height (m)
1	110.00	21.17	10.00
2	153.15	47.62	7.99
3	325.00	199.37	10.65

Table 3. Manning coefficient values assigned to each IBGE Land Use class (2016).

IBGE Land Use Class	**Manning**
Artificial Area	0.04
Agricultural Area	0.04
Pasture	0.04
Mosaic of Occupations in Forest Area	0.11
Silviculture	0.14
Forest	0.16
Underwood	0.04
Mosaic of Occupations in Underwood	0.04
Water	0.035

Source: Adapted from Chow (1959).

Infiltration process adjustment

The MOHID Land model allows the use of the Porous Media module, which has the purpose of modeling the 3D infiltration and subsurface flows. They generate the base flow in the channel, through texture and granulometry information of each soil that constitutes the soil. According to Barão *et al.* (2010) the water contained in the soil can be transferred in all layers by advection or removed by transpiration or evaporation on the surface, thus generating the vertical transfer of water to the water table and, therefore, the river channels. Since for the simulation of the infiltration process it is necessary to insert in the model the characteristics of all soils presented in the extensive Paraíba do Sul River Basin, in this paper we sought to simplify these processes with, the infiltration being simulated by adjusting the Curve Number (CN) method.

The CN method allows MOHID Land to remove part of the water from the runoff, simulating then the infiltration process. However, this portion of water that corresponds to the infiltration, will not feed the water table and, therefore, will not return in the form of base flow in the channel trough. The CN is one of the simplest methods to calculate the effective rain, or the part of the precipitation that effectively turns into runoff. This method was developed by the US National Resources Conservation Center (formerly Soil Conservation Service – SCS) and is known as SCS-CN (Kowalik and Walega, 2015, Bartlett, 2016).

The method is based on the water balance equation and two hypotheses. The first hypothesis states that the ratio between runoff and maximum potential runoff is equal to the ratio between the accumulated infiltration in the soil and the maximum potential accumulated infiltration. The second hypothesis states that the initial losses correspond to 20% of the maximum potential accumulated infiltration, with runoff occurring only when the rain is greater than the loss. The general formulation of the SCS-CN method can be seen below:

$$Q' = \frac{(P - 0.2 \times S')^2}{(P + 0.8 \times S')} \text{ when } P > Ia \quad (2)$$

$$S' = \frac{25400}{CN} - 254 \quad (3)$$

where Q' is the effective rain or runoff (mm), P is the precipitation occurring over the event (mm), Ia is the initial loss (mm), S' is the maximum potential accumulated infiltration (mm) and CN is the Curve Number.

The CN is a dimensionless parameter, which ranges from 0 to 100, with 0 representing a soil with infinite infiltration capacity and 100 corresponding to a completely impermeable soil (Collischonn and Dornelles, 2013, Bartlett, 2016). It is estimated from the joint analysis of the land use and pedology maps, considering the soil texture. The CN criteria assigned to each class of land use were based on the work by Cronshey (1986), and are shown in **Table 4**. For the soil texture, type A was agreed, where it represents the largest infiltration and D represents the largest runoff.

Base flow adjustment

In order to simulate the base flow in the channel, as the 3D flow mode was not activated (infiltration process adjustment), a constant discharge in a cell in the drainage network was attributed to the model, which was estimated from the flow separation of the 2018 hydrograph, observed at the ANA fluviometric station, in Campos dos Goytacazes, using Chapman's digital filter.

The water found in the ground originates from the rainwater that infiltrates into the soil and percolates into the deepest layers. In periods of drought, where rainfall declines, not feeding rivers through runoff, the natural flow of a river is maintained by the base flow, which can be defined as the groundwater contribution in the watershed. As the dry period extends, groundwater is consumed slowly as opposed to runoff which is fast. This slow consumption provides a significant reduction in river flow, and can be observed through the recession hydrograph with the behavior of a decreasing exponential function (Collischonn and Dornelles, 2013, Ladson *et al.*, 2013), as represented in the equation below,

$$Q_t = Q_0 * a \quad (4a)$$

$$a = e^{\frac{-t}{k}} \quad (4b)$$

where Q_t is the flow rate in an instant t, Q_0 is the flow rate in an instant t_0, a is the exponential parameter, k is the recession constant in days, and t is the time in days;

The greatest difficulty associated with the determination of the period of recession the proper identification of the beginning and end of the period, in order to estimate the recession constant k. It can be obtained from the visual analysis of the historical channel flow series measured at a known point (Novaes *et al.*, 2009). Changes in the start and end date promote changes in the parameter and, in turn, changes in the decreasing exponential. The recession constant k still depends on the physical characteristics of the watershed, especially its geological characteristics (Collischonn and Dornelles, 2013, Ladson *et al.*, 2013), since the porosity and ground arrangement interfere with the transport of these waters to the river channel. This is given by the following equation,

$$k = \frac{-\Delta t}{\ln\left(\frac{Q_{(t+\Delta t)}}{Q_t}\right)} \quad (5)$$

where Δt is the interval in days between the end and the beginning of the recession period, $Q_{(t+\Delta t)}$ is the end-of-recession flows, Q_t is the flow at the beginning of recession, and k is the constant in days.

Based on the determination of the recession constant, it is possible to estimate the base flow using digital filters. The application of filters is based on the premise that the flow is composed of two components, one of which is the surface flow and the second the underground flow, as stated in **Eq. (6a).** Among the several possible filters available in the literature, due to the simplicity of application and as the dependence only on the total registered flow, the Chapman filter was chosen (Chapman, 1999, Costa *et al.*, 2019; Balbin-Betancur, 2019) which is given by

$$y_i = f_i + b_i \quad (6a)$$

$$b_i = \frac{a}{2-a} * b_{i-1} + \frac{1-a}{2-a} * y_i \quad (6b)$$

$$\text{if } b_i > y_i, \text{ consider } b_i = y_i$$

where i represents the time interval, y is the total flow of the hydrograph at time t (m^3/s), f is the runoff (m3/s), b is the underground flow (m3/s). For the value of a, see **Eq. (4b)**.

Table 4 Curve Number assigned to each IBGE land use class (2016), considering a texture A soil.

IBGE land use class	Curve Number
Artificial Area	98
Agricultural Area	60
Pasture	39
Mosaic of Occupations in Forest Area	45
Silviculture	45
Forest	30
Underwood	39
Mosaic of Occupations in Underwood	39
Water	98

Source: Adaptaded from Cronshey (1986).

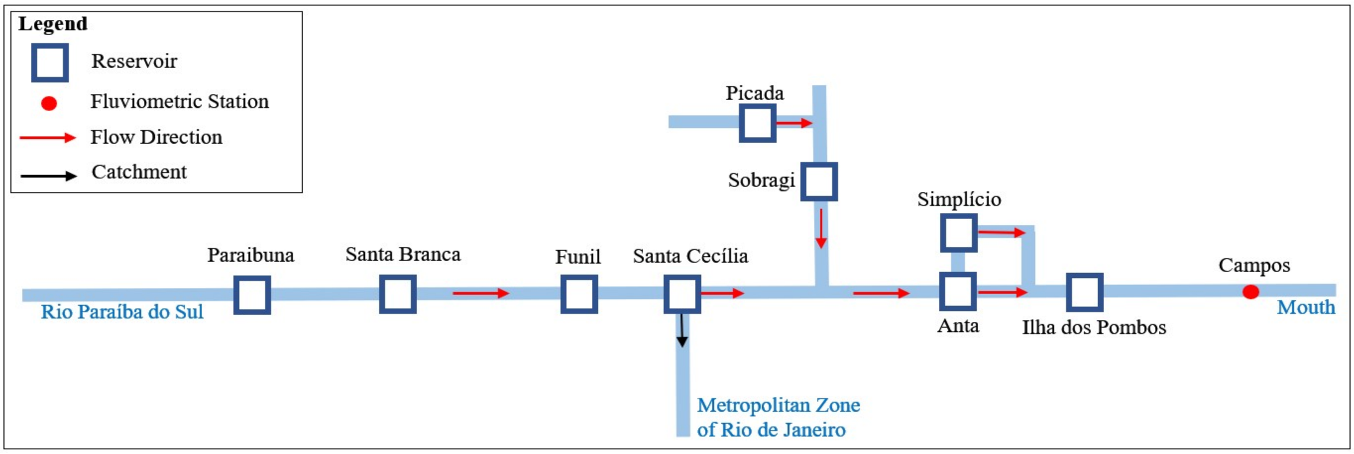


Fig. 6 Schematic representation of the reservoirs installed in the Paraíba do Sul River watershed. Source: adapted from SIGA-CEIVAP website http://sigaceivap.org.br/siga-ceivap/salaDeSituacao

Reservoirs implementation

For the correct representation of the channel flow variation, the reservoirs installed in the watershed were implemented in the model. The operating curves of the reservoirs, with a history of 365 days, are of public domain and available on the SIGA-CEIVAP website (http://sigaceivap.org.br/siga-ceivap/salaDeSituacao). In **Fig. 6** it is shown a schematic representation, with the indication of the scheme with the reservoirs implemented, as well as the flow direction. The operating curve for each reservoir was generated considering the difference between the outflow and inflow, with the objective of representing the decrease or increase in the flow downstream of each reservoir, at each time instant, in the form of a discharge point implemented in its coordinates.

It was considered in the model the capture related to the Santa Cecília reservoir, which implies a considerable decrease in the Paraíba do Sul River flow, due to the supply of the Metropolitan Zone of Rio de Janeiro. This is an important point to be considered when adjusting the model, as this capture corresponds to the average decrease in the order of 30% of the total flow of the Paraíba do Sul River. This flow is removed without return to the watershed, since the Metropolitan Zone of Rio de Janeiro is not inserted in the Paraíba do Sul river watershed.

Simulation scenarios

For the simulation of the volumetric flow rate at the mouth of the Paraíba do Sul River with the MOHID Land model, six different scenarios with variation in the precipitation implementation methodology were considered: four scenarios with rainfall modeled in the WRF-ARW, and two scenarios with rainfall observed in the official stations of the INMET distributed across watershed, The objective is to evaluate which method has the best rainfall-flow rate correspondence. The analysis period chosen in this paper corresponds to the month of January 2019 (01/01/2019 00 UTC and 01/02/2019 00 UTC), to assess the flow during the period of the river's flood, when the incidence of rain is more intense.

Rainfall scenarios modeled on WRF-ARW

In view of the various possibilities of inserting possible physical parameterizations in the WRF-ARW model, we opted for parameterizations based on the research work from Sales (2020), who based on sensitivity tests of free associations of seven microphysics schemes with seven cumulus schemes (totaling 49 experiments), defined for the same study region considered in the present work, four combinations of physical schemes, statistically similar, and that best represent the average rainfall across the watershed. These are described in **Table 5.**

The days December 30th and 31st, 2018 were added to the original simulation period to be used as a spin-up, in order to remove the instabilities from the beginning of the simulation.

Since the standard MOHID Land model format for hierarchical files is the HDF5 type, and the WRF-ARW model outputs are files in the netCDF format, it was necessary to use the tool available in the hydrological model called ConvertToHdf5, created with the objective of allocating atmospheric variables, and time layers associated with each variable, in a format compatible with the interpretation of MOHID Land.

Rainfall scenarios measured at the official INMET stations

Precipitation data from 17 INMET automatic stations, distributed in the watershed and shown in **Fig. 7**, were used as the measured data. There are 19 stations located in the watershed. However, the Santa Maria Madalena and Nova Friburgo stations, both in the state of Rio de Janeiro, did not have the rain data for the second half of

January/2019. In this sense, it was decided to use only the stations that had the complete data series. The data registered at these stations are in the public domain and available at the INMET web page (http://www.inmet.gov.br/portal).

Once the precipitation data is obtained for the 17 stations, MOHID Land model allows, with the FillMatrix tool, the interpolation of the historical series of these stations, in order to spatialize the rainfall. Two interpolation methods are available in this tool, the TIN and the IDW, already implemented in the model, allowing the evaluation of, verify, which one presents greater deviation. The premise used in the algorithm developed assumes the estimation of precipitation values between the coordinates of the stations by means of interpolation methods. In this sense, a temporal variation is constructed, with the available hourly values, as well as an estimate of these values with spatial variation, for the same period of interest in the simulations. **Table 6** presents the summary of the scenarios implemented in the MOHID Land model for the study of flows.

Analysis metrics

The analysis methodology is based on the use of statistical metrics to assess the rain scenario that best represents the channel flow at the mouth of the modeled watershed, which coincides with the location of the ANA fluviometric station, in Campos dos Goytacazes (58974000). This station's data are in the public domain and available for download from the HidroWeb portal (http://www.snirh.gov.br/hidroweb/).

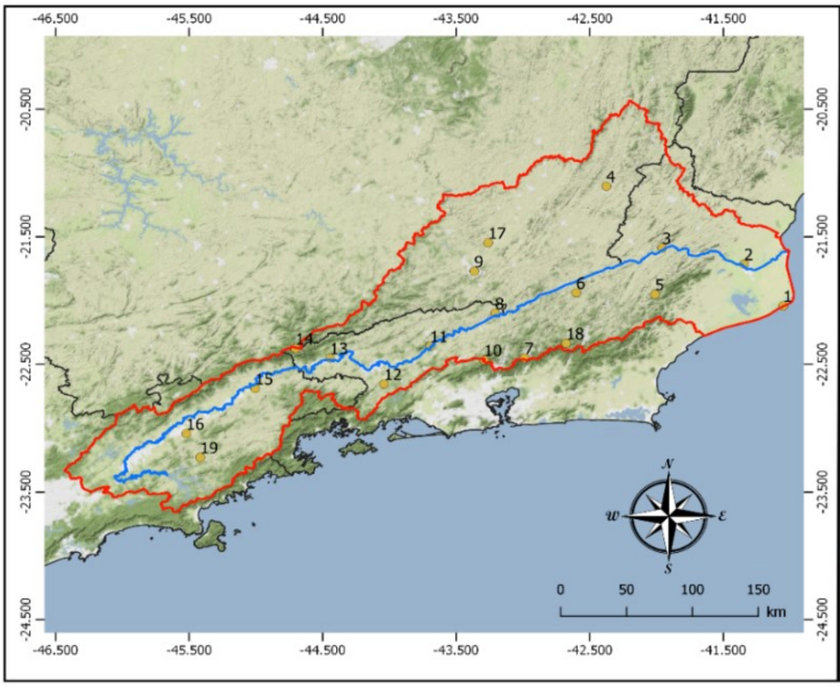
Table 6 Rain scenarios proposed for the study of flows in the modeled mouth of the Paraíba do Sul river.

Scenarios	Description
1	Modeled rain in WRF-ARW experiment 1
2	Modeled rain in WRF-ARW experiment 2
3	Modeled rain in WRF-ARW experiment 3
4	Modeled rain in WRF-ARW experiment 4
5	Rain measured at 17 INMET stations, interpolated with the IDW method
6	Rain measured at 17 INMET stations, interpolated with the TIN method

Table 5 Physical parameterizations used in the WRF-ARW per experiment.

Experiment	Microphysics	Cumulus	Planetary Boundary Layer	Surface Layer	Land-surface Option	Longwave radiation	Shortwave radiation
1	Goddard	Grell 3D	MYJ	ETA - Similarity Scheme	NOAH land surface model	RRTM	Dudhia
2	WSM5	Grell 3D	MYJ	ETA - Similarity Scheme	NOAH land surface model	RRTM	Dudhia
3	Purdue Lin	Grell 3D	MYJ	ETA - Similarity Scheme	NOAH land surface model	RRTM	Dudhia
4	WSM5	Grell-Freitas	MYJ	ETA - Similarity Scheme	NOAH land surface model	RRTM	Dudhia

Source: Adapted from Sales (2020).



ID	INMET Automatic Station	State	Latitude	Longitude
1	Campos - São Tomé	Rio de Janeiro	-22.041647	-41.051871
2	Campos dos Goytacazes	Rio de Janeiro	-21.714767	-41.344017
3	Cambuci	Rio de Janeiro	-21.587729	-41.958327
4	Muriaé	Minas Gerais	-21.104867	-42.375904
5	Santa Maria Madalena	Rio de Janeiro	-21.950592	-42.010489
6	Carmo	Rio de Janeiro	-21.938744	-42.600936
7	Teresópolis - Parque Nacional	Rio de Janeiro	-22.448922	-42.987146
8	Três Rios	Rio de Janeiro	-22.098391	-43.208574
9	Juiz de Fora	Rio de Janeiro	-21.769965	-43.364329
10	Petrópolis	Rio de Janeiro	-22.464889	-43.291505
11	Valença	Rio de Janeiro	-22.358094	-43.695656
12	Rio Claro (Passa Três)	Rio de Janeiro	-22.653579	-44.040916
13	Resende	Rio de Janeiro	-22.450924	-44.444786
14	Itatiaia - Parque Nacional	Rio de Janeiro	-22.373944	-44.703111
15	Cachoeira Paulista	São Paulo	-22.689001	-45.005444
16	Taubaté	São Paulo	-23.041668	-45.520841
17	Coronel Pacheco	Minas Gerais	-21.546728	-43.261029
18	Nova Friburgo	Rio de Janeiro	-22.334839	-42.676932
19	São Luis do Paraitinga	São Paulo	-23.228362	-45.417055

Fig. 7 Distribution of INMET's meteorological automatic stations within the Paraíba do Sul River watershed

Four error metrics were used for the representation of the degree of distance between the simulated values deviation from the observed values, plus Pearson's Correlation Coefficient, or R, as shown below:

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}\Phi_{i,p} - \Phi_{i,obs} \qquad (7)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|\Phi_{i,p} - \Phi_{i,obs}\right| \qquad (8)$$

$$MAPE = \frac{100\%}{N}\sum_{i=1}^{N}\left|\frac{\Phi_{i,p}-\Phi_{i,obs}}{\Phi_{i,obs}}\right| \qquad (9)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\Phi_{i,p} - \Phi_{i,obs}\right)^2\right]^{1/2} \qquad (10)$$

$$R = \frac{\sum_{i=1}^{N}(\Phi_{i,p}-\bar{\Phi}_{i,p})(\Phi_{i,obs}-\bar{\Phi}_{i,obs})}{\sqrt{\sum_{i=1}^{N}(\Phi_{i,p}-\bar{\Phi}_{i,p})^2}\cdot\sqrt{\sum_{i=1}^{N}(\Phi_{i,obs}-\bar{\Phi}_{i,obs})^2}} \qquad (11)$$

where: $\Phi_{i,p}$ represents the predicted volumetric flow rate values, $\Phi_{i,obs}$ represents the values observed in the ANA fluviometric station, and N represents the number of observations. In the case of the present study, it is used $N = 745$, referring to 31 simulation days with hourly simulation data plus the initial condition.

The BIAS represents the distance between the simulated flow in relation to the observations, where positive values imply that the model tends to overestimate the observed values, while negative values imply that the model tends to underestimate them. The Mean Absolute Error (MAE) represents the mean absolute deviation of the simulated flow in relation to the observations. The Mean Absolute Percentage Error (MAPE) represents in percentage terms the deviation between the simulated and observed flow. The Root Mean Square Error (RMSE) is a measure of the magnitude of the average error between the simulated and observed values, representing the standard deviation of the differences, a measure widely used in statistical tests on models. For all error measures, given by **Eqs. (7-10),** the best values are represented by their proximity to zero, which indicate a smaller gap between the simulated and observed values, which implies a better adjustment.

In order to verify the behavior of the modeled flow curve in relation to the observed one, Pearson's Correlation Coefficient, given by **Eq. (11),** was used. A linear dependence between two variables, is detected with values between -1 and 1 for R in **Eq. (11).** The sign indicates the direction, that is, whether the correlation is positive (direct) or negative (inverse). The interpretation (in module) of Pearson's coefficient can be seen in **Table 7**. All statistical tests were performed with the R platform that is available at the project website (https://cran.r-project.org/).

RESULTS AND DISCUSSION

Base flow estimation using the Chapman filter

From the visual analysis of the flow rate hydrograph of the Campos dos Goytacazes fluviometric station, for 2018, the start and end dates of the recession period were established as August 15th, 2018 (registered flow rate of 239.58 m³/s) and September 15th, 2018 (registered flow rate of 164.98 m³/s), respectively, the second being the lowest flow rate registered in the year. These dates were used for the application of **Eqs. (4-5).** Once the value of the constant k was established, the adjusted series was constructed, with the performance of the calculated recession curve observed in **Fig. 8**.

The adjustment provided by the decreasing exponential curve, calculated from the combination of **Eqs. (4)** and **(5)**, presented a correlation coefficient R = 0.84, a value higher than the one in the work by Balbin-Betancur (2019), in which R = 0.63 ± 0.12 for a group of watersheds with different physiographic characteristics, indicating that it is observed indeed a strong correlation between the recession curve calculated in this work with the measured data, thus establishing the recession coefficient k.

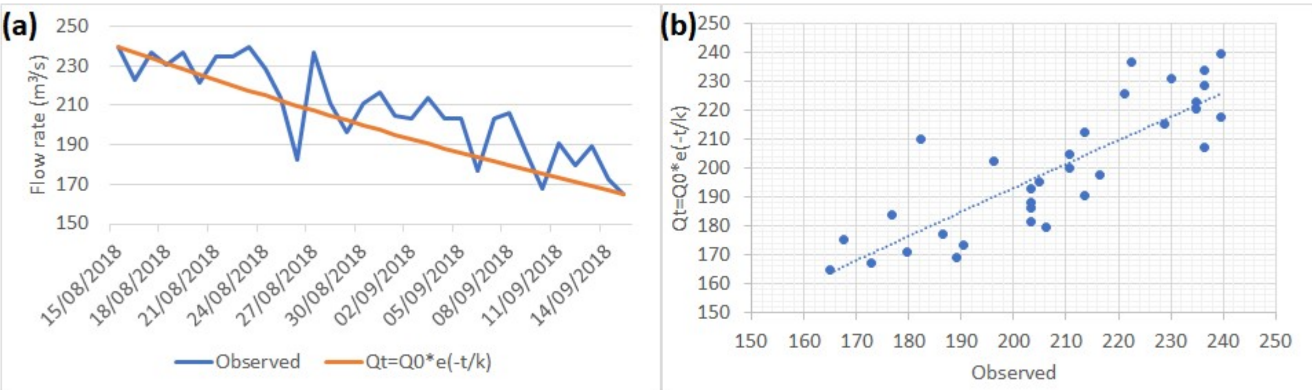


Fig. 8 Performance of the recession curve for the Paraíba do Sul watershed from the recession constant estimation k. (a) Comparison Observed x Adjusted by the recession equation. (b) Point dispersion Observed x Adjusted by the recession equation.

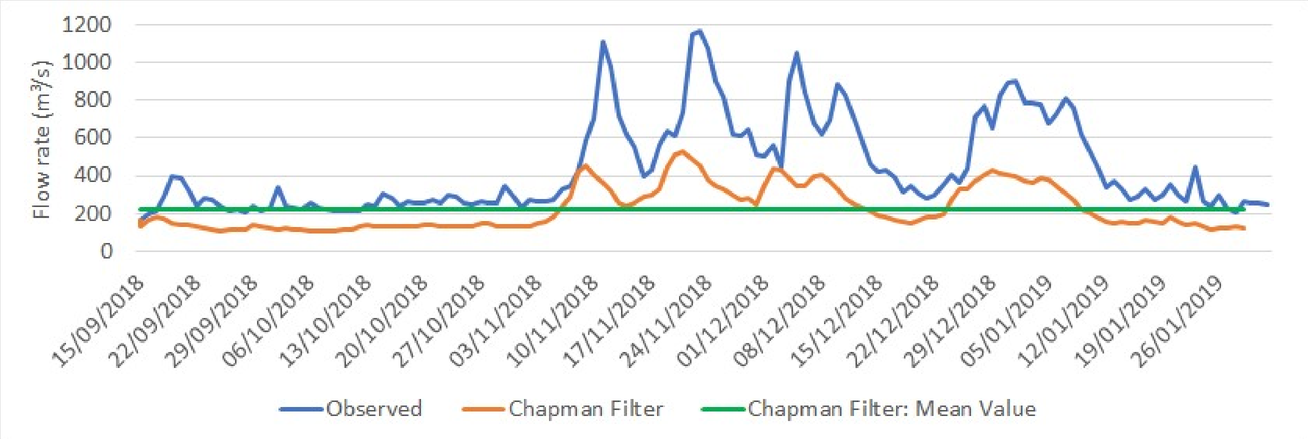


Fig. 9 Separation hydrograph of the observed flow and the representation of the base flow by the Chapman Filter.

Table 8. Scenarios results comparison with the statistical metrics

Simulations performed with the MOHID Land model	BIAS	MAE	MAPE	RMSE	R
Scenario 1: simulated rain in WRF - Experiment 1	-29.1	133.93	0.33	171.84	0.76
Scenario 2: simulated rain in WRF - Experiment 2	-87.17*	96.97*	0.25*	119.31*	0.90*
Scenario 3: simulated rain in WRF - Experiment 3	-85.67	98.86	0.26	123.35	0.87
Scenario 4: simulated rain in WRF - Experiment 4	540.76	556.30	1.54	616.49	0.58
Scenario 5: measured rain interpolated by the IDW method	-140.94	150.03	0.38	175.67	0.80
Scenario 6: measured rain interpolated by the TIN method	0.65	157.40	0.36	264.28	0.67

* Best result. For the identification of the experiments see **Table 5.**

Table 7 Interpretation of the correlation coefficient.

Correlation coefficient $\|R\|$	Interpretation
0.00–0.10	Insignificant correlation
0.10–0.39	Low correlation
0.40–0.69	Moderate correlation
0.70–0.89	Strong correlation
0.90–1.00	Very strong correlation

Source: adapted from Schober *et al*. (2018)

Once determining the recession constant k and the parameter a, described in **Eq. (4)**, Chapman's digital filter (Chapman, 1999, Costa *et al*., 2019; Balbin-Betancur, 2019), widely used in hydrological studies, was applied. The base flow estimate rate as of September 15th, 2018, which was the day with the lowest flow rate measured in 2018 (164.98 m³/s). The result of applying the filter can be seen in **Fig. 9**.

Based on the series of base flow calculated with the Chapman Filter application, which results are represented graphically by **Fig. 9**, the value of 224.21 m³/s was applied into the hydrological model, for all scenarios. This value corresponds to the mean value of the calculated base flow rate.

Flow simulation with the proposed rain scenarios

The hydrological modeling of the Paraíba do Sul River watershed was carried out in the MOHID Land model in six scenarios, with variation in rainfall, as described in Table 6. A simulation period of three months (October to December 2018) was added, that was used as a spin-up of the hydrological model, with the purpose of removing the instabilities from the beginning of the simulation. For this period, the precipitation was considered constant over time and space, a value of 1.5 mm/h was used, which represented the initial river flow rate for the period of interest.

Two analyzes were proposed, one quantitative through statistical evaluation metrics and another qualitative, with the analysis of graphical curves representation. The statistical results obtained metrics computation can be seen in **Table 8**.

Two analyzes were proposed, one quantitative through statistical evaluation metrics and another qualitative, with the analysis of graphical curves representation. The statistical results obtained metrics computation can be seen in **Table 8**.

The BIAS metrics, intended to indicate the overestimation or underestimation of results, indicated that only in scenarios 4 and 6 the model tended to overestimate the measured flow, while in all others it underestimated. Calvetti (2014), when analyzing the flow rate by coupling the WRF-ARW to the TOPMODEL hydrological model, for the União da Vitória/PR Iguaçu River watershed, identified a different behavior once the data were overestimated. It is worth noting that the author established only one physical parameterization in the WRF model, limiting the precipitation behavior to just one scenario. Santos (2019), in a study in the Paraíba do Meio river watershed/AL, observed a similar trend to the present paper, in the sense of underestimating the flow rate using the SCS / HMS hydrological model, with rain data from the WRF-ARW, having been made by the author a proposal for the association of physical parameters of three microphysics and three cumulus. The obtained results indicate that the tendency to overestimate or underestimate the flow is directly related to the rainfall input adopted, evidencing a need to perform a sensitivity test of the physical parameters in the atmospheric model WRF-ARW, for the correct representation of the precipitation, which suffers direct influence of latitude and altitude.

To assess the behavior of the curves and their variability, Pearson's correlation coefficient was used. Considering the interpretation described in **Table 7**, it was observed that only scenario 2 presented a very strong correlation representing the result with the best performance. As a performance evaluation, it is possible to make a comparison with the results obtained by Santos (2019), who obtained in two of his sub-watershed in the state of Alagoas values of R = 0.75 and 0.76, as well as with the results by Rodrigues (2012), which for the same points studied by Santos (2019), obtained results of R = 0.42 and 0.55. As shown in **Table 8**, scenarios 3, 5 and 1, showed a strong correlation, and, in this order, the best performances. Scenarios 4 and 6 showed a moderate correlation, with scenario 4 having the worst performance. It is worth mentioning that only the analysis of the Pearson Correlation Coefficient does not indicate the best performance of the model, as the curves can follow the same pattern and, therefore, have a low variability, but the deviations can be large, being necessary, to associate them with the error metrics evaluation.

Considering the RMSE, which is widely used for model tests and indicates the magnitude of the error, the evaluated scenarios 2, 3, 1, 5, 6 and 4, are ranked in decreasing order of performance. When the MAE, MAPE and RMSE tests were analyzed together, it was possible to observe that the smallest deviation remains with scenario 2, using the results from the rain modeled in the WRF-ARW, thus leading to the understanding that this was the scenario that produced the smallest deviation, when analyzing the total errors in the time period of analysis.

Combining all the statistical tests considered, it was possible to observe that scenario 2 was the one with the best performance, followed closely by scenario 3, both with inputs originated from the WRF-ARW model, and validating the hypothesis of the present paper, that for large watersheds it is more appropriate to take into account spatial and temporal variation of rainfall to feed precipitation data in hydrological models. It was also possible to verify that the variation in physical parameterizations in the atmospheric model (see **Table 5**) leads to great variations in the hydrological response of the watershed. In this sense, a prior sensitivity test is recommended for physical parameterization of rainfall simulated in atmospheric models, before its implementation in hydrological models, and subsequently testing among the physical parameters of better performance, in order to assess which method has the best hydrological correspondence.

Considering only the calculated flow rates obtained with the interpolated precipitation inputs, i.e. scenarios 5 and 6, it was possible to observe that the IDW method responded statically better to the variation of the flow rate in the river channel than the TIN method, indicating that the former tends to present better performance for rain interpolation, and later implementation, in the hydrological model. However, both provide greater deviations in the final calculated flow rates in comparison to those obtained considering as inputs the rainfall modeled with the WRF-ARW.

In **Fig. 10** are shown the curves generated for each of the flow simulations, allowing a qualitative assessment of the analysis scenarios. The measured flow rate curve indicates that the first 10 days of January 2019 resulted in higher flow values, due to the greater incidence of precipitation, since the flow of the channel in peak flow events comes mainly from surface runoff. All scenarios captured higher flow rate values in this period, as well as the beginning of the recession. Scenarios 1, 4 and 6 promoted large peaks between January 5th and 6th, 2019. The explanation of this fact, in cases 1 and 4, may be related to the error in the perception and distribution of rain by the WRF-ARW model, concentrating precipitation in points of the watershed, which promotes an overestimation in the runoff. In the case of scenario 6, it may be linked to the interpolation method, since the TIN method concentrates the triangulated values of the nearby stations in certain points. In this sense, the rain may have been concentrated in one point by the method, promoting a punctual overestimation, therefore increasing runoff.

When the behavior of the curves regarding the interpolated data is observed, i.e. scenarios 5 and 6, it appears that the peak of the IDW was in the same order of magnitude as the measured data, responding better in this condition when compared with the TIN. In conditions of low rainfall into the watershed, the curves tend to be closer when using TIN than with IDW.

Since rainfall intensity and distribution is the variable that most influences hydrological forecasts, especially in medium and large watersheds (Rodrigues, 2012), its correct representation has a decisive contribution in hydrological studies. Studies carried out by Paiva (2011) and Rodrigues (2012) concluded that measured rain data are more efficient than data simulated in WRF-ARW, despite recognizing model initialization problems, and the inadequate use of physical parameterizations, which do not respond satisfactorily to the particular conditions of each region.

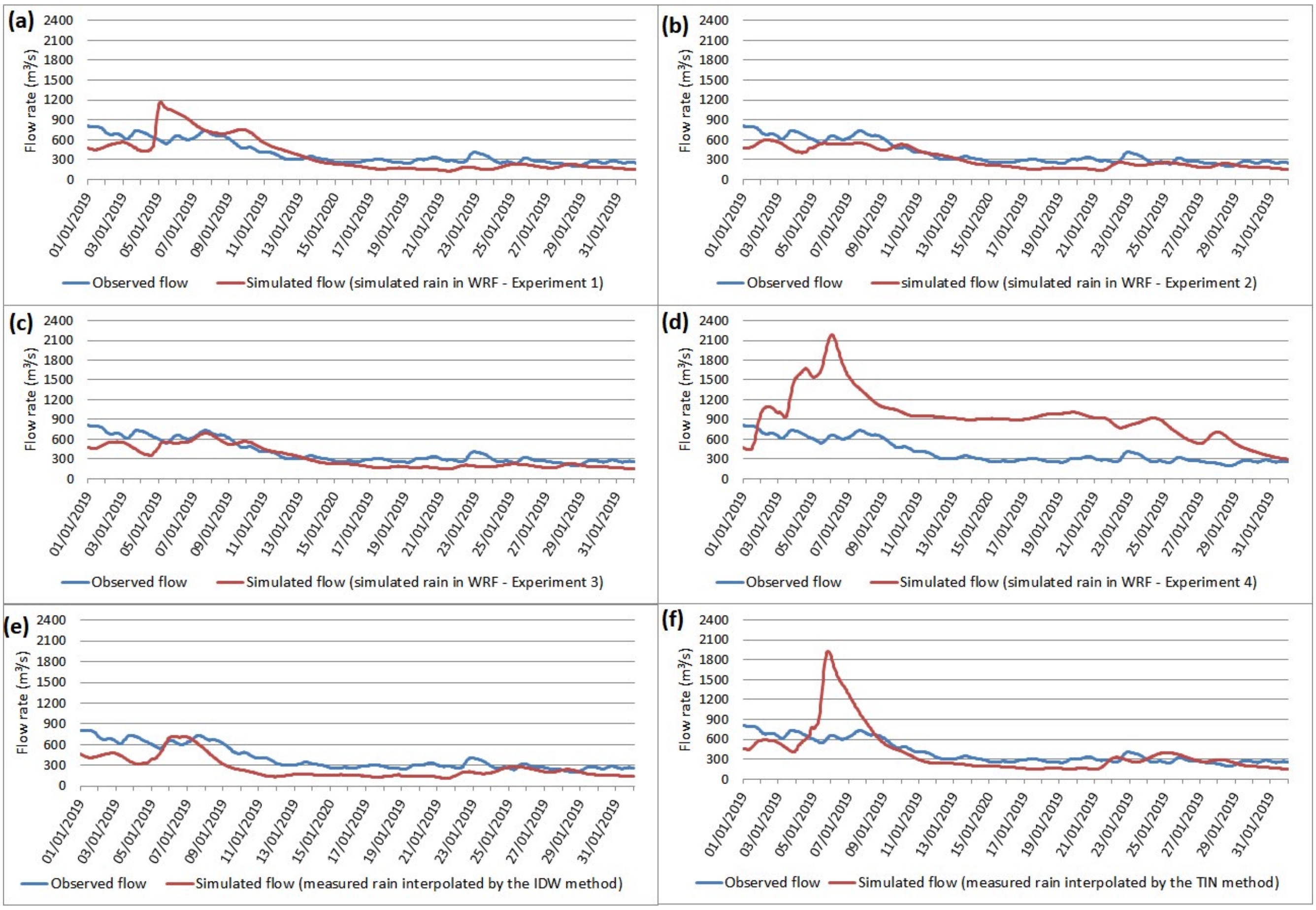


Fig. 10 Calculated and observed volumetric flow rates for the different scenarios. (a) Scenario 1 Hydrograph: simulated rain in WRF - Experiment 1. (b) Scenario 2 Hydrograph: simulated rain in WRF - Experiment 2. (c) Scenario 3 Hydrograph: simulated rain in WRF - Experiment 3. (d) Scenario 4 Hydrograph: simulated rain in WRF - Experiment 4. (e) Scenario 5 Hydrograph: measured rain interpolated by the IDW method. (f) Scenario 6 Hydrograph: measured rain interpolated by the TIN method. For the identification of the experiments see **Table 5**.

CONCLUSIONS

This paper aimed to carry out the hydrological modeling of the Paraíba do Sul River watershed with a focus on the evaluation of the methodology for implementing rain data in the MOHID Land hydrological model, which best represented the flow rate variation at the mouth of the Paraíba do Sul River.

From the data obtained it was possible to observe that the rain modeled in the atmospheric model WRF-ARW, that is, with spatial and temporal variation in a discretized grid, resulted in a better adjustment for channel flow modeling when compared to the implementation of rains obtained from real data, but spatially dispersed, from the official monitoring stations, interpolated with both the IDW and TIN methods.

It was possible to observe that the four physical parametrizations of better performance of the WRF-ARW model for the basin under study, as evaluated in the research performed by Sales (2020), and considered statistically similar, resulted in a significant variation in the hydrological response. The physical parameterizations of the WRF-ARW model that obtained the best performance in the representation of the average precipitation into the watershed, as well as in the hydrological representation for the Paraíba do Sul river watershed were the WSM5 microphysics and Grell 3dDconvective schemes, followed by the microphysics of Purdue Lin and convective Grell 3d. These were associated with MYJ planetary boundary layer, ETA similarity scheme for the surface layer, NOAH land surface model, RRTM longwave radiation and Dubhia shortwave radiation.

When only the interpolation methods were analyzed, it was possible to observe that the IDW presented the smallest deviation, indicating that in the event of not having access to atmospheric modeling, this method better represented the rain into watershed and, subsequently, the flow in the river trough.

Finally, it was possible to observe, supported by the statistical metrics evaluation and analysis of the hydrographs, that the hydrological model built in this paper responded satisfactorily for the month of January 2019, with respect to the representation of the flow in the watershed, achieving a better performance in comparison to the works by Calvetti (2014), Rodrigues

(2012) and Santos (2019), which despite being related to studies in different basins, used also the rain calculated with the WRF-ARW as an input to the hydrological models.

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