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Papers

Impacts of land use and land cover on sediment production in a tropical peri-urban water source area

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Abstract

The change of natural landscapes by anthropic activities is the main reason for the erosion deepening. Thus, it is necessary to know the processes that determine the hydrological balance to avoid erosion in this context. Due to the complexity of a basin and the need of making predictions, the development of mathematical models is essential for decision making. Among the existing models, the Soil and Water Assessment Tool (SWAT) is one of the most utilized models worldwide. Thus, the present study aims to compare the land use between different periods and quantify the soil loss in a basin (Feijão River, in the Brazilian southeast), using the SWAT + model, as also to provide guidance to decision making by determining priority areas to improve water quality. The simulation was performed by dividing the basin into sub-basins and assigning multiple HRUs. The metrics used to analyze the model's efficiency indicate that the results were satisfactory, Nash-Sutcliffe (NSE) of 0.53 and 0.54 for calibration and validation of streamflow, respectively. The model represented in this study can help guide future planning for land use and occupation of the basin, enabling the forecast of different scenarios and their possible impacts on water production.

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INTRODUCTION

The challenges regarding water availability and environmental disasters related to land use and cover are worldwide concerns. In Brazil, disordered urban sprawl and without the adoption of technical criteria (COSTA et al., 2012), intensified the change in natural cover and land use, causing serious problems in the areas of water sources (ALVIM et al., 2015). In this sense, it is necessary to rationally occupy the river basins as a way to protect and recover these areas and their water resources (BAIHUA FU et al., 2019).

The effects of disordered space occupation in a hydrographic basin can modify soil cover, which is a major factor in controlling water erosion (DECHEN et al., 2015; FAO, 2015) and determinant in the hydrological changes of the basin (ZHANG et al., 2020), besides favoring the transport of sediments, causing silting of rivers and reservoirs (ANJINHO et al., 2021), as well as compromising the quantity and quality of water (ACCORSI et al., 2017).

The magnitude of erosive processes is determined by several factors, such as rainfall intensity, through the capacity of infiltration and surface runoff of the soil, up to the slope of the terrain (VEIGA, 2014). Some localized factors can also be determinant in the quantification of erosion and consequent sediment production in water bodies (CASADO et al., 2002).

Compaction and reduction of soil thickness reduces infiltration capacity, generating greater surface runoff and even higher erosion rates (COSTA et al., 2012; OLIVEIRA et al., 2020). Thus, sediments, fertilizers and agrochemicals are dragged into the watercourses potentiating the processes of eutrophication and siltation, reducing the flow section and compromising the perennity and quality of its waters, affecting its physical, chemical and biological characteristics (PINHEIRO, 2004; VANZELA et al., 2010).

On the other hand, the vegetation cover protects the soil against erosion and sediment loss (CUIABANO et al., 2017). In developing countries such as Brazil, agriculture and livestock are important sources of income, moving the economy, however, when they do not have good management, they generate adverse effects. Thus, water resources are affected, requiring studies that reduce the vulnerability associated with the impacts of land use and land cover, its management, and consequent erosive processes.

The knowledge and planning of the dynamics of land use and cover and the understanding of the processes that determine the sedimentological balance allow the integration of actions aimed at better utilization of the soil, improving the resilience of the ecosystem (KEESSTRA et al., 2018).

The complexity of a hydrographic basin encompasses the multiple uses of the soil and the diversity of the physical and biotic environment, influencing the hydrological behavior that is also controlled by climatic characteristics and human activities that will result in landscape changes (PORTO; PORTO, 2008).

This complexity and the need to make predictions about development scenarios have driven, since the 1970s on, the development of mathematical models that become important decision-making tools for sustainable land management.

Computational modeling is a way of representing the most complex natural and/or anthropic phenomena, with the objective of performing simulations that accurately important variables for the various environmental studies, collaborating with future decision-making actions.

In this perspective, the SWAT (Soil and Water Assessment Tool) model, developed by the U.S. Department of Agriculture (USDA) and Texas A&M Agrilife Research, manages to integrate Geographic Information System (GIS) techniques with the hydrological cycle and MUSLE equation, becoming one of the most widely used models (TAN et al., 2020; BRESSIANI et al., 2015; GASSMAN et al., 2014). The GIS modeling provides valuable data with finer resolution (ROUHOLAHNEJAD et al., 2012) becoming a fundamental tool for environmental studies.

The lack of monitoring environmental variables, with quality, precision and good spatial resolution makes it difficult to apply SWAT models in Brazil. In addition, much of the available data is in formats not usable by SWAT, determining the absence of some parameters. This requires adjustments and parameterization of the data, as in the specific case of soil water physical parameters, which requires Pedo-Transfer functions to estimate missing parameters. These restrictions and the difficulty of finding a time series of data to perform the model, imposes on the modeler having to adapt information by evaluating the available data needed for the basin that will be studied (BRESSIANI et al., 2015).

Even so, SWAT was applied in several Brazilian watersheds for the most different purposes, highlighting: flow studies, land management and sediment transport, water quality and climate change (NETO, 2017; BRESSIANI et al., 2015;CARVALHO, 2014; LOPES, 2008). Several studies have also been developed applying this tool to analyze the effects of land use and cover changes on hydrological flows (ZHANG et al., 2020; PASSOS, 2017; BRESSIANI et al., 2015; PERAZZOLI et al., 2013; BLAINSK et al., 2011).

Water resources are public goods and strategic reserves for public supply and can be compromised in the face of land uses and cover, constituting a serious risk to public health and environment. Therefore, knowing the behavior of the basin in the face of land use is essential to guide studies and decision-making that ensure the protection of surface and groundwater quality and soil functionalities.

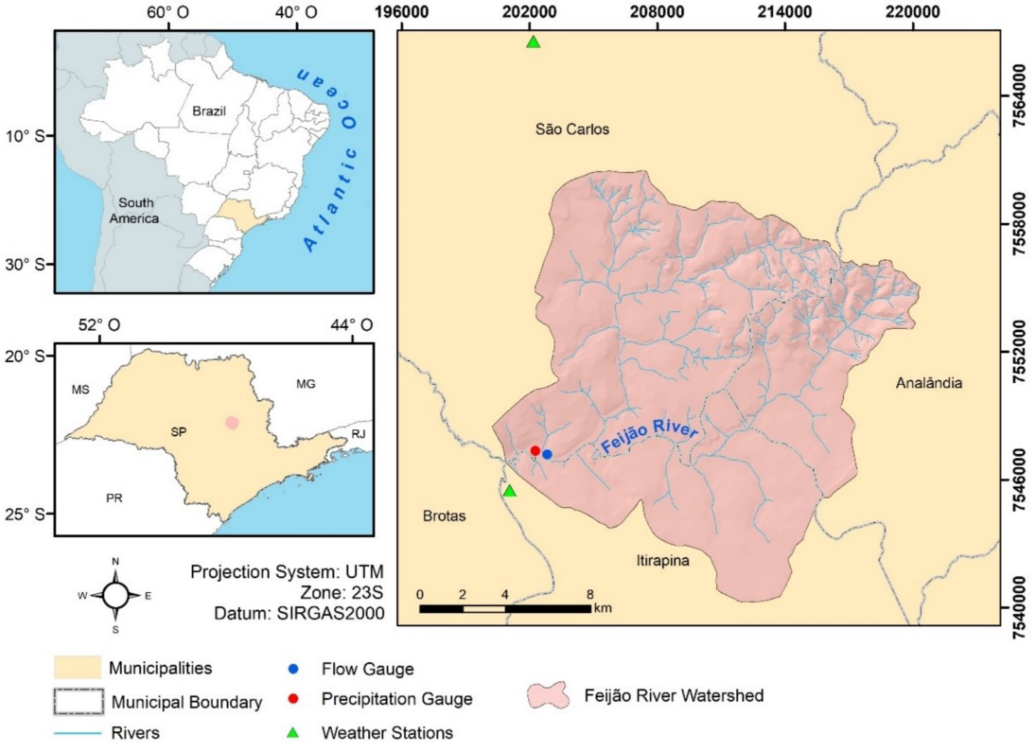
In this context, the objective of this work is to compare the land use in the Feijão River Hydrographic Basin from 2011 to 2020; estimate the flow and sediment generation of the hydrographic basin through hydrological modeling with the new SWAT + model; and establish priority areas in the basin for conservation according to current land use and simulated sediment production. This work aims to contribute as a guide for studies of land use and cover planning, enabling the prevention of negative impacts on water and soil.

MATERIALS E METHODS

Study Area

The Feijão River Basin, located in the state of São Paulo, covers the municipalities of São Carlos, Analândia and Itirapina, Figure 1, has an area of 243,16 km². It is responsible for supplying part of the city of São Carlos with 243,000 inhabitants, representing 27% of the supply. The other municipalities have smaller populations, Analândia has 4,789 and Itirapina 17,377 inhabitants (IBGE, 2017).

Figure 1. Feijão River Basin (SP-Brazil), of the climatological, fluviometric and pluviometry stations.



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Source: The authors (2021). Geographic basis extracted from: JAXA/METI (2011); IBGE (1971); IBGE (2020).

The occupation of the basin is predominantly rural, also having considerable areas of forest and Cerrado, livestock farming is a characteristic activity and practiced extensively, followed by sugarcane and orange crops, in addition to the presence of planted forests of *Pinus sp* and *Eucalyptus sp*.

The climate of the region is characterized as tropical with humid summer and dry winter, being among the Cwa and Aw classifications, according to the Köppen classification (ALVARES et al., 2013). The highest volumes of precipitation occur between October and March, with January being the wettest month, while the period with the lowest rainfall occurs between April and September (INMET, 2019). The average temperature is around 21°C, with an average annual rainfall of 1404 mm (CLIMATE.DATA.ORG, 2020).

The basin is located in a recharge area of the Guarani Aquifer, the most important and developed hydrogeological reserve in the southeast region of Brazil. The Feijão River is an affluent of the Jacaré-Guaçu River flowing into the Tietê River, being located in the region between the Tietê-Jacaré Hydrographic Basins, in São Paulo State.

On a continental geological scale, the studied area is located in the Structural Province of Paraná, located on the northeast flank of the Paraná Sedimentary Basin. From the lithostratigraphic point of view, lithological representatives ranging from the Mesozoic Era (sandstone from the Botucatu and Itaqueri formations and basic intrusives rocks of the Serra Geral formation) to the Cenozoic (alluvial sediments) (ZUQUETTE, 1981; NISHIYAMA, 1991).

The predominant soil in the basin is the Quartzarenic Neosol, a very deep soil, very permeable and with low nutritional potential, being common the presence of the primary vegetation represented by the Cerrado (OLIVEIRA, 1984), in addition to the Red-Yellow Latosol with texture ranging from sandy to clayey. In areas of rich soils and clayey texture the semideciduous forests become more present. Along the bank of the Feijão River, the hygrophiles fields predominate in hydromorphic soils (COSTA et al., 2018).

With the transformations that occurred in the basin, primary vegetation was replaced due to the advance of pastures, common in poor soils and sandy texture, as well as the cultivation of artificial forests that occurs in these areas. In claysoils and more productive, it is trivial to advance agricultural practices, such as the cultivation of sugarcane, coffee, corn and orange.

Multitemporal Analysis of Land Use and Cover

The land use and cover map for 2011 was obtained from Costa (2017), which was elaborated from GeoEye satellite images with spatial resolution of 0.5m. Then, the map was processed in ArcGIS and the classes of the different land uses were grouped into 10 classes.

For the elaboration of the 2020 land use and cover map, images from the Sentinel-2A Satellite, MSI sensor (Multispectral Instrument), RGB color compositions (4.3,2) and false color (8,4,3) with spatial resolution of 10m were used (EUROPEAN SPACE AGENCY, 2020). Based on the knowledge of the area and the high-resolution images of Google Earth and sentinel-2A satellite, the manual polygonal classification and vectorization of the land uses on screen (JENSEN, 2009) was performed; (LONGLEY et al., 2013) of the basin at ArcGIS (CUNHA, 2021; JOVINO, 2021). Finally, the land use and cover map were obtained for the year 2020.

Hydrological Modeling

SWAT was initially developed by Dr. Jeff Arnold for the Agricultural Research Service (ARS) of the USDA (NEITSCH et al., 2009), undergoing continuous improvements over the years with the contribution of several studies and researchers (ARNOLD et al., 1995; NEITSCH et al, 2004; 2005). Given the major modifications and improvements that SWAT has undergone, a completely revised version of the model was generated, SWAT +, which was used in this work. The SWAT+ is much more flexible, although the algorithms used to calculate model processes remain the same, the structure and organization has changed considerably (BIEGER et al., 2016).

SWAT is able to diagnose the impact of soil use, type and management changes on sediment runoff, erosion and production, pollutant transport and water quality in watersheds, in addition to including plant growth and soil management details (GASSMAN et al, 2007). Regardless of the type of problem to be diagnosed, the water balance needs to be in accordance with the watershed under study. With this, the model is based on the equation of water balance (in days):

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_i + Q_{sup} + E_i + P_i + Q_{ret}) \tag{Equation 1}$$

Where:
SWt represents the final volume of water in the soil on the day (mm);
SW0 is the initial volume of water in the soil on the day (mm);
Ri is the precipitation on the day (mm);
Qsup is the surface runoff on the day (mm);
Ei is the evapotranspiration on the day (mm);
Pi is percolation (mm),

i.e. water infiltration into the soil profile on the day;
Qret is the return flow (mm), i.e. the capillary rise in the soil on the day.

Model and data set

The model requires topographic data, soil type, land use and coverage and climate (Table 1). The information and data for the construction of the model were collected on the web, provided by government agencies and research agencies. Daily meteorological data were obtained from the National Institute of Meteorology (INMET, 2019) for the years 1988 to 2019; and the Center for Water Resources and Environmental Studies of the University of São Paulo (CRHEA, 2020). The monthly historical data related to the flow of Feijão River were obtained from the National Agency for Water and Basic Sanitation (ANA,2012) for the years 1977 to 2013.

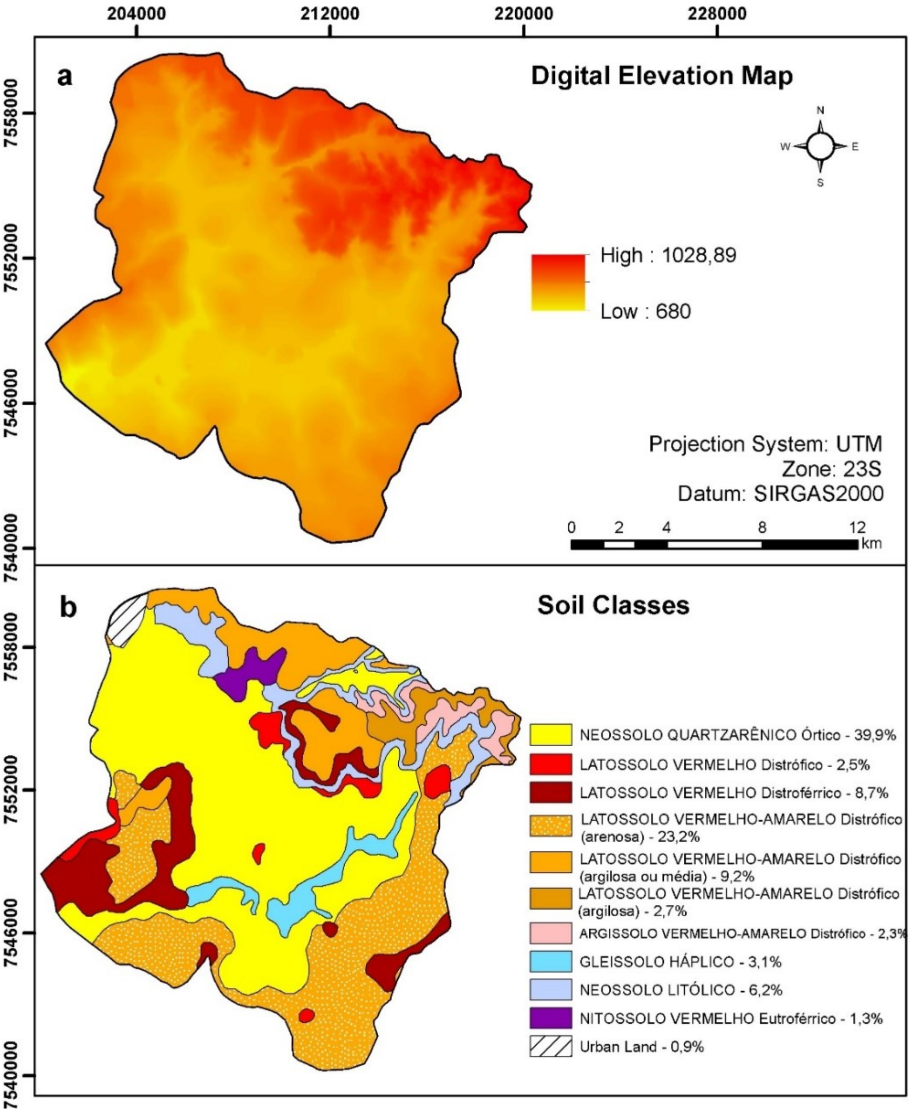
Table 1 - Description of the data needed to build the SWAT model for the Feijão River basin.

Data Type	Description	Resolution	Source
DEM	Digital Elevation Map	12,5m x 12,5m	JAXA/METI (2011)
Land use map 2020	Prepared by the first author and by (CUNHA, 2021) from Sentinel-2A satellite images.	10m	European Space Agency (2020) and Cunha (2021)
Soils map	Soil types	1:50.000[1]	Prado et al. (1981)
Soils characteristics	Soil depths, texture, and organic matter Hydrological group Other soil parameters were estimated based on Pedo-transfer functions	Horizons of soil types	Oliveira (1984) and Oliveira (1987) Sartori et al. (2005) Saxton; Rawls (2006)
Flow	Flow data from the river station Feijão River	Daily Mean ($m^3.s^1$)	ANA (2012)
Climate	Daily maximum and minimum temperatures, precipitation, wind speed, humidity and solar radiation.	Daily Mean	INMET (2019) and CHREA (2020)

Source: The authors (2021).[1]Although printed at a scale of 1:100,000, such mapping was carried out using a planimetric base at a scale of 1:50.000

The Digital Elevation Model (DEM) (Figure 2a) was obtained from the Alos Palsar satellite with a 12.5m x 12.5m pixel (JAXA/METI, 2011). The soil type map used was the São Carlos from the pedological survey of the São Paulo state (Figure 2b) (PRADO et al., 1981).

Figure 2 - (a) Digital Elevation Model; (b) Soil classes of the Feijão River Basin.



Source: The authors (2021). Geographic basis of: (a) JAXA/METI, (2011); (b) PRADO et al. (1981).

The land use and cover map applied was for the year 2020, elaborated from the sentinel-2A satellite image. The model was rotated in the daily time step, but the outputs were extracted in the monthly time step for the period from 1988 to 2013, with an initial heating period for the model of 3 years.

Calibration and Validation of the flow model

The calibration process consists of changing the input parameters of the model, considered more sensitive, so that the simulated values are as close to the observed values, within a significant range for the study. The calibration method chosen for this study was manual, and the model was calibrated for the monthly time interval and for variable flow. Thus, to evaluate the performance of the model during calibration, the following statistical metrics were used: Nash-Sutcliffe (NSE), Coefficient of Determination (R^2), Error/Bias percentage (PBIAS), Standard Deviation Ratio (RSR) and Kling-Gupta Efficiency Coefficient (KGE).

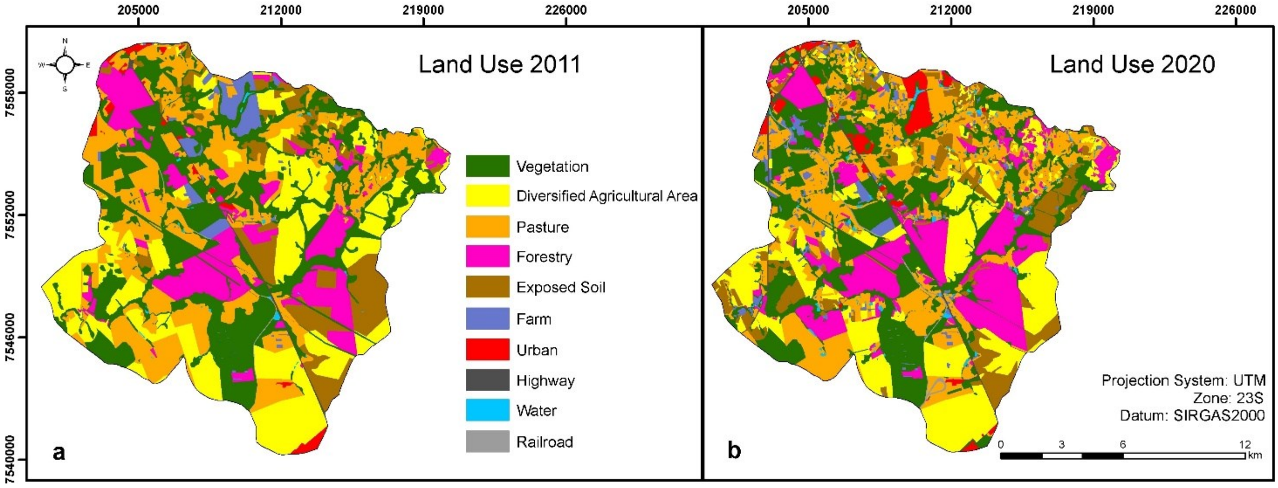
The final step was the validation of the model that consists of the process of verifying the performance of a model using the same parameters adopted in calibration and performing a comparison for an independent period. The results obtained are important to test whether the model is effective under different climatic conditions (ARNOLD et al., 2012). The performance evaluation criteria for validation were the same as those used in calibration. For sediments, no calibration was performed due to lack of monitored data.

RESULTS

Multitemporal Analysis of Land Use and Cover

The manual classification of land use generated ten classes that were grouped taking into account the different land uses of the basin: Vegetation (riparian forest and primary vegetation); Pasture (extensive cattle breeding, lots without vegetation or with undergrowth); Diversified agricultural area (sugarcane, citrus and other crops); Urban area (houses, allotments, industrial and commercial complexes, intermodal terminal); Forestry (eucalyptus and pine plantation); Exposed soil (soil in preparation for planting, dump, exposed soil and soil used for extraction of metallic minerals); Water (lakes, ponds and fish farming); Farms; Highway and Railway. Land use in 2011 and 2020 (Figure 3, Table 2) shows a low difference between the years.

Figure 3. Land uses and cover of the Feijão River Basin (a) for the year 2011; and (b) for the year 2020.



Source: The authors (2021).

Table 2. Land use and land cover classes for the Feijão River Watershed, in the years 2011 and 2020 and related differences.

Classes	2011		2020		Variation
	Area (km²)	%	Area (km²)	%	(%2020-%2011)
Vegetation	70,35	28,93	72,19	29,69	0,76
Pasture	52,46	21,58	52,62	21,64	0,06
Diversified agricultural area	56,64	23,29	45,73	18,80	-4,49
Exposed soil	23,35	9,60	19,26	7,92	-1,68
Forestry	27,59	11,35	34,13	14,04	2,69
Farm	7,06	2,90	10,57	4,35	1,45
Urban	2,58	1,06	5,21	2,14	1,08
Highway	1,82	0,75	1,91	0,79	0,04
Railroad	0,19	0,08	0,63	0,26	0,18
Water	1,12	0,46	0,91	0,37	-0,08
Total	243,16	100	243,16	100	—

Source: The authors (2021).

Hydrological modeling with SWAT + for the Feijão River Basin

The creation of the model resulted in the formation of 31 sub-basins and 5,898 Hydrological Response Units (HRU's), as no limit was defined for the creation of the HRUs, a relatively large number was obtained.

The parameters used to calibrate the model flow (Table 3) were altered and simulated several times in order to achieve satisfactory metric results.

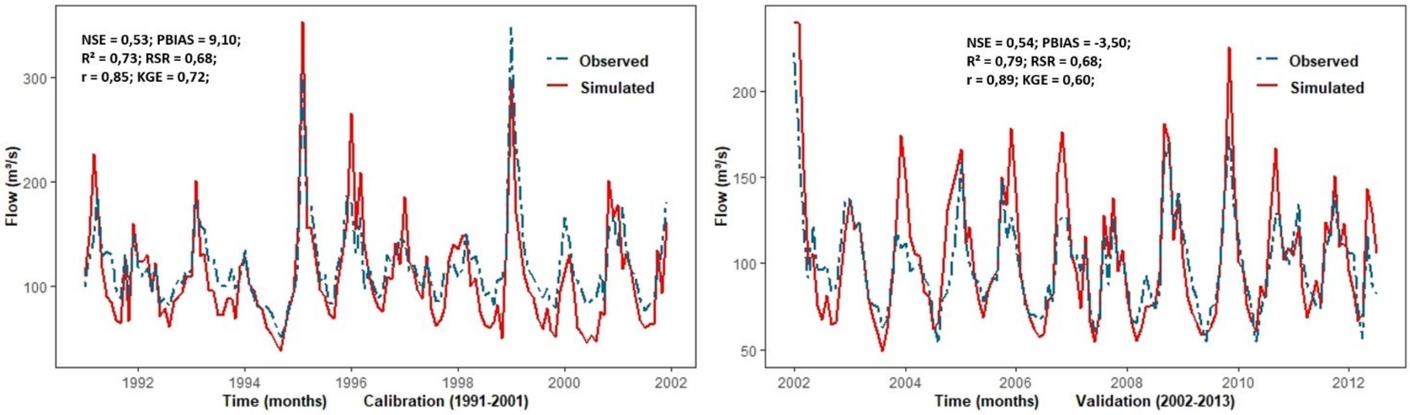
Table 3 - Calibrated parameters in modeling with SWAT+. R: relative change in percentage; S: Replace the existing value of the parameter with the new value.

Parameter	Description	Type of Change	Default value	Calibrated value
RCHRG_DP	Aquifer percolation coefficient (mm)	S	0,05	0,70
CN2	SCS curve number (moisture condition II)	R	Vary	-25%
SOL_K	Saturated hydraulic conductivity (mm/h)	R	Vary	+50%
ESCO	Soil evaporation compensation coefficient (dimensionless)	S	0,95	0,90
REVAP	Threshold depth of water in the shallow aquifer for "revap" to occur	R	0,02	0,20
PERCO	Fraction of water percolated into the soil	S	1	0,350
SLOPE	Average slope of the basin	R	Vary	+50%
MANN	Manning's "n" value for the main channel	S	0,05	0,070
LAT_TTIME	Lateral flow travel time (days)	S	0	180

Source: The authors (2021). Descriptions of parameters from (ARNOLD, 2012).

The simulated, calibrated and validated flow rate with the SWAT+ model for the Feijão River Hydrographic Basin in the monthly time step, as well as the observed flow rate for the period and statistical evaluation metrics are presented in Figure 4.

Figure 4 - Calibrated and validated flow on the monthly timescale with its metric metrics.



Source: The authors (2021).

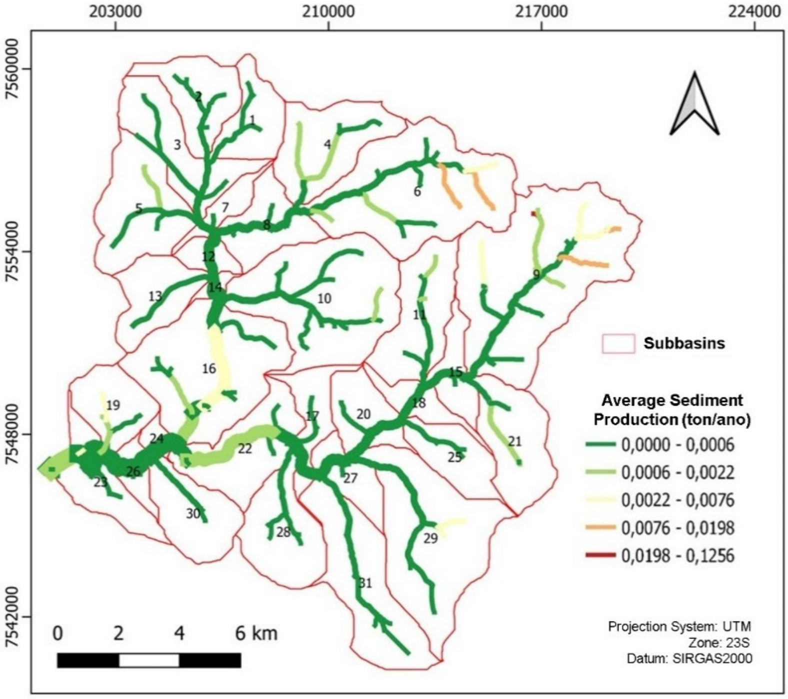
Based on the performance and statistics classification for the monthly time interval (MORIASI et al., 2007), the NSE value was classified as satisfactory (NSE=0.53), for calibration, the same for the RSR statistic. For PBIAS the result was considered very good for calibration. In addition, the KGE, which has been widely used in hydrological models (LIU, 2020), presented satisfactory results with a value above 0.5. Some studies published using SWAT used this statistical metric to evaluate the efficiency of the model and presented good results (BRIGHENTI et al., 2017; FRANCO, 2017).

The statistical metrics for the validation period were considered satisfactory, obtaining for the NSE = 0.54, RSR = 0.68 and KGE = 0.60, indicating the efficiency of the model in the simulation of the basin flow. The results continued to be considered "very good" for the other metrics, in detail, the coefficient of determination (R^2) = 0.79, Pearson coefficient (r) = 0.89 and PBIAS = -3.5%. The negative PBIAS value for validation indicates a small overestimation of the flow during the years 2002 to 2013.

Sediment production estimation for the Feijão River Basin

For the 2020 land use scenario used in this model, the average sediment production results for the entire simulated period indicate a low sediment production in most of the channels present in the Feijão River basin (Figure 5).

Figure 5 - Estimated annual average production of sediments (tons/year) for the entire period simulated in SWAT+ for the Feijão River Basin.

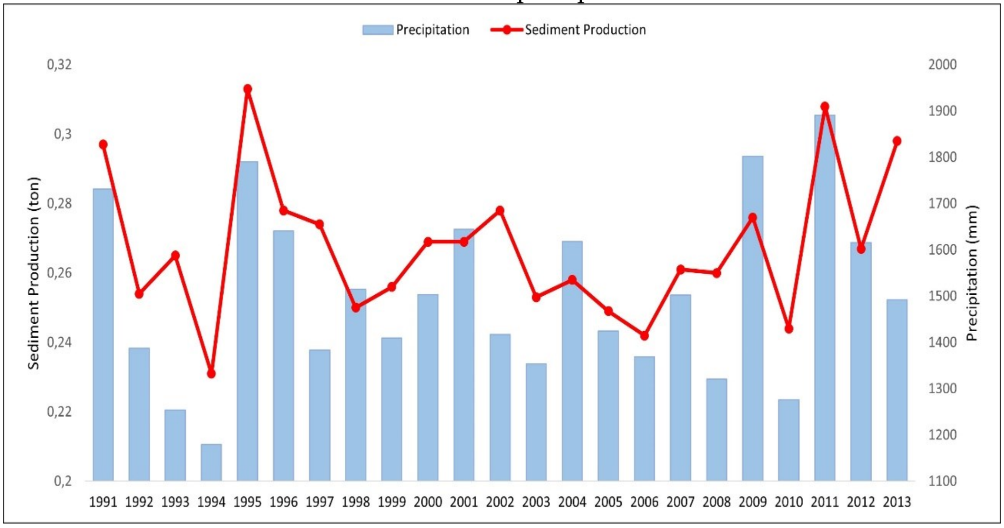


Source: The authors (2021).

The annual average of sediments that are carried to the rivers of the basin ranged around 0.27 tons, with a minimum of 0.231 tons and a maximum of 0.313 tons per year, with a sediment production of approximately 0.025 ton/km².

Precipitation is also an influence factor for sediment transport, and it is observed that the highest amount of sediment production was in the wettest years (Figure 6). Pearson's correlation coefficient obtained for precipitation and sediment production was 0.56.

Figure 6 - Relationship between the total annual sediment production (tons/year) carried to the rivers with the total annual precipitation in the basin.



Source: The authors (2021).

The model was applied in an area with no sediment data available, which made it impossible to perform calibration and validation for sediment production. Thus, the results presented above are of uncalibrated simulations for sediment production.

DISCUSSION

Multitemporal Analysis of Land Use and Cover

The differences in land use between 2011 and 2020 (Figure 3) are not drastic (Table 2). One of the most changed categories of use from 2011 to 2020 was the urban area, with an increase of approximately 50%, and farmhouses with more than 100%. The occupation of the basin (2011) is characterized mainly by vegetation composed of riparian forest and primary vegetation (28.9%), diversified agricultural area (23.3%) and pasture (21.6%). Despite the urban increase, it has been also observed an increase in natural areas and artificial forests as a result of environmental recovery activities already taking place in the basin, with forestry increasing 23,70%.

Hydrological modeling with SWAT + for the Feijão River Basin

Throughout the calibration performed manually and using the objective functions (NSE, KGE and R²) to evaluate the efficiency of the model, the parameters CN2 (Number of the SCS Curve), RCHRG_DP (Coefficient of percolating the water from the root zone to the deep aquifer) and LAT_TTIME (Lateral Flow Displacement Time) had great influence when changed in the calibration, significantly improving the metrics used. For the flow simulation, the simulated data were being overestimated in the rainy season and underestimated in the dry season.

During calibration, a decrease in surface runoff and an increase in water infiltration and storage rates in soils were observed, and can be explained by the presence of Latosols, which are characterized by their depth, high permeability and hydraulic conductivity, in addition to the increase in vegetation area in the basin.

One of the challenges to achieve satisfactory results in hydrological modeling with SWAT and SWAT+ is the range of data and information needed to insert into the model in order to better represent reality, as well as the amount of parameters that can be changed, in addition to the large amount of interactions during calibration for the results converge with the observed data, demanding a high processing time.

In this particular model, some important information impacting the physical processes of the watershed could not be incorporated and considered due to lack of access, time required for processing or the lack of data that better demonstrated the local reality. For example, the management of agricultural crops, application of agrochemicals and amount of water used for irrigation, in addition to the internal parameters for crops that have not been changed. Nevertheless, the results were considered satisfactory (Figure 4) and can be used and improved for future work and simulations of scenarios for decision making.

Sediment production estimation for the Feijão River Basin

Sub-basins 6, 9 and 16 (Figure 5) presented the highest production of sediments carried for the springs. They are areas where there was a greater predominance of pasture and agricultural use, present in Latosols that are deep and well drained. In the rainy season, these soils have a higher susceptibility to erosion, besides requiring frequent corrective fertilization for agricultural uses cultivated in this area. Sub-basins 6 and 9 are also bedside and have greater slope and therefore greater susceptibility to erosion. In a flatter area is sub-basin 16, receiving many of the eroded sediments.

In agricultural areas there is a greater supply of nutrients, such as in the cultivation of sugarcane, which are also carried and can cause a decrease in the water quality of the springs, representing risks to public and environmental health.

In the areas of Quartzarenic Neosol, a low sediment production was observed, and the depth and good infiltration capacity characteristics of this type of soil, which contributes to a lower surface flow (FURQUIM, 2002), besides being in relief areas with lower slope. Despite this, it is also a soil vulnerable to erosion (IAC, 2016), the presence of primary vegetation and artificial forest in these areas are factors that influenced lower soil losses.

It is important to consider that the land use and cover used in the modeling was related to the year 2020, which presented an increase in the area of vegetation and artificial forest. This contributes positively, because soil cover conditions are determining factors for estimating the transport and detachment of soil particles that reach the channels of the basins.

In the Feijão River basin, vegetation areas increased, comparing the years 2011 and 2020, however, the use by agribusiness activities remains intense. Adequate soil management and less impactful uses would mitigate erosive processes, reducing soil losses and transporting pollutants that degrade river water quality. In addition to the predominant agricultural uses of the basin requiring a large amount of water for irrigation, they are activities that generate pollutants, affecting the water used for public supply. In a study on the expansion of urban area in the Feijão River, it was found that the spring is located among the growth vectors of this spot (COSTA, 2010) alerting to the need for studies such as this to better plan the use and occupation of the soil in the region and its possible effects.

The production and supply of water in the region of São Carlos (SP) is an essential activity and service that needs to be maintained. Thus, it is necessary to minimize as much as possible the production of sediments that reaches the channels in order not to compromise this service. For this it is necessary that the areas of vegetation continue to increase and less "aggressive" crops are planted into the soil. Municipal Law No. 13,944 of 12/12/2006, which provides the regulations for the Water Supply and Recovery Areas of the Municipality of São Carlos (SÃO CARLOS, 2006) was created with the aim of preserving and recovering the banks of rivers and streams, maintaining the region's water production.

Áreas de Presevação Permanente (APPs) are natural protected areas, with rigid limits of exploitation, that is, direct economic exploitation is not allowed. APPs are protected by law, and it is necessary to take good practices for soil and water conservation. Thus, it is necessary to have supervision and adequate planning so that these areas are not unduly occupied from economic interests. Protection is fundamental to the ecological interest of the population of São Carlos who depend on the source to obtain water for their consumption (COSTA,2017).

Payment for Environmental Services (PES) is a way to offset the income of rural producers by replacing their agricultural and livestock activities with land use and cover that represents less degradation and sediment production. The financial resources would come from the collection for the use of water, another measure to protect the proper use of water resources. The implementation of programs and public policies to encourage rural producers for possible changes in the activities and land cover of their lands is a form of greater acceptance and interest for the protection of the basin springs. Dupas (2001) proposed the PSA to encourage farmers to transform their land into less "aggressive" crops, and could make the region's farms water production areas.

The priority areas for the application of the PSA would be sub-basins 6 and 9, mainly in the current land uses by pasture, minimizing the amount of sediments that reach the basin springs. The PSA allied with Municipal Law No. 13,944 of 12/12/2006 would be a way to prioritize areas that are negatively impacting, predicting the recovery and protection of springs.

FINAL CONSIDERATIONS

Sediment production in the basin varied around 0.27 tons per year. The areas with the highest sediment production were in sub-basins 6, 9, and 16, with pasture and agricultural production, uses. Therefore, these areas would be a priority for implementing the PSA since it would minimize the transport of sediment to the rivers, protecting the springs.

The models' uncertainties are generally because of simplifications, such as the non-inclusion of hydrographic processes, management plans, irrigation, and agrochemicals use. Although the limitation and lack of monitored data is also a problem, the availability of this data with high resolution for free is essential for constructing models. In Brazil, better availability would make the models' projections more accurate and minimize uncertainties.

The model represented with SWAT for the Feijão River basin can be used as a water resource management tool used in other springs and future studies and planning. The tool allows to simulate different land use and occupation scenarios and verify their impacts on the production of water and sediments.

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AUTHORS' CONTRIBUTION

Estephania Silva Jovino, Ronaldo Angelini and Carlos Willmer Costa conceived the study and hypotheses. Estephania Silva Jovino collected the data and ran the models. Danielle de Almeida Bressiani revised the model and its parameterizations. Karina Patrícia Vieira da Cunha provided the soil parameters. Estephania Silva Jovino and Carlos Willmer Costa made the maps. Estephania Silva Jovino, Ronaldo Angelini and Carlos Willmer Costa started the preparation of the manuscript, which was later revised by Danielle de Almeida Bressiani and Karina Patrícia Vieira da Cunha.