The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-3/W12-2020, 2020
2020 IEEE Latin American GRSS & ISPRS Remote Sensing Conference (LAGIRS 2020), 22–26 March 2020, Santiago, Chile

EFFECTS ON STREAMFLOW CAUSED BY REFORESTATION AND DEFORESTATION IN A BRAZILIAN SOUTHEAST BASIN: EVALUATION BY MULTICRITERIA ANALYSIS AND SWAT MODEL

R. R. Gracelli [1], I. B. Magalhães [1], V. J. Santos [1], M. L. Calijuri [1] *

[1] Department of Civil Engineering, Federal University of Viçosa, 36570-900, Brazil, Minas Gerais, Viçosa.
Phone number: +5503138993098

KEY WORDS: Land Cover, Hydrology, Reforestation, Deforestation, Simulations

ABSTRACT:

Deforestation is a global concern due to its problematic consequences, which intensify natural phenomena such as floods. In the past century, Brazil lost large areas of forests due to agricultural and livestock development, mining activities, the construction of hydroelectric plants and the expansion of the urban-industrial sector. The recovery of forests is an alternative to mitigate impacts caused by floods, although it is not known for sure the extent of such mitigation. The objective of this study was to assess the flow behavior of the Velhas River, Southeast Brazil, under different reforestation and deforestation scenarios, through multicriteria analysis and hydrological modeling. The combination of these methods allowed for interesting results, showing that a reforestation in 34.3% of the watershed area would have effects on river flow behavior similar to a reforestation of 9.2%. A scenario of deforestation in 100% of the forest area showed that there would be an increase in flow peaks in the rainiest months.

1. INTRODUCTION

In Brazil reforestation has been a plausible and low cost solution to reduce surface runoff and control erosion. The areas defined as priorities are usually those with high slopes, soils which are easily eroded, intense and frequent rain events, watercourse banks and headwaters, in addition to areas with little or no vegetation cover (Nossack et al., 2014; Pinheiro, 2015; Santos, 2013; Sartori, Zimback, 2011).

The multicriteria analysis is commonly used for the definition of priority zones for reforestation (Nossack et al., 2014; Pinheiro, 2015; Santos, 2013; Sartori, Zimback, 2011), enabling the choice of variables and attribution of weights and values, giving priority to different options, and facilitating the decision making by presenting alternatives according to the proposed objective (Francisco et al., 2008). It is a tool used for the resolution of multiple problems. The analysis is based on the representation of a complex problem, structuring it hierarchically to prioritize factors in the analysis of several alternatives. It provides a hierarchical structure, facilitates the pairwise decomposition, reduces inconsistencies and generates priority vectors, in addition to reducing the subjectivity of the choice (Calijuri et al., 2002; Feizizadeh et al., 2014).

Other useful tools to assess the effects of reforestation on the attenuation of surface runoff are hydrological models. They evaluate the quantitative rainfall and flow rate data, simulating the hydrological response of the watershed to rain events. They also aid in environmental planning, since they provide important information for the management of soil and the maintenance of the quality of the water resources (Lelis, Calijuri, 2010). One of these models is the *Soil and Water Assessment Tool* (SWAT), which was developed to predict the effects of different scenarios of land use/land cover on the water quality, on the production of sediments and on the load of pollutants in the agricultural watershed (Srinivasan, Arnold, 1994).

Input data for simulating flow using SWAT are climate, hypsometry, pedology and land cover. The water management techniques focus on the latter, since it is easily modified by human action. By identifying areas with greater surface runoff potential, it is possible to manage them, and reforestation is one way to mitigate such phenomenon. Therefore, from the multicriteria analysis, alternative land cover scenarios can be designed, simulating the reforestation of priority areas; and the hydrological modeling would enable the evaluation of the effectiveness of forest recovery on the attenuation of surface runoff, as well as on the mitigation of problems such as floods and erosion.

The main advantage of using these models is the possibility of studying several scenarios in a quick manner, which significantly reduces research costs, especially in extensive and complex areas such as watersheds (Machado et al., 2003).

Thus the objective of this study was to assess the flow behavior of the Velhas River in different scenarios of reforestation and deforestation, using multicriteria analysis and hydrological modeling.

2. MATERIAL AND METHODS

2.1 Study Area

The Velhas River Watershed (VRW) (Figure 1) is located in the state of Minas Gerais (MG), Southeast Brazil. The Velhas River is the largest tributary to the São Francisco River, with a drainage area of 27,851 km², corresponding to 4.4% of the drainage area of the São Francisco River Watershed (SFRW), according to the Velhas River Watershed Committee (CBH Rio

* Corresponding authors: rafaelagracelli@gmail.com and iarabmagalhaes@yahoo.com.br

das Velhas, 2014). Velhas contributes nearly 11.2% (an average of 320.5 m³/s) of the São Francisco river flow, being the third largest contributor (DAMG, 2009; Pereira et al., 2007).

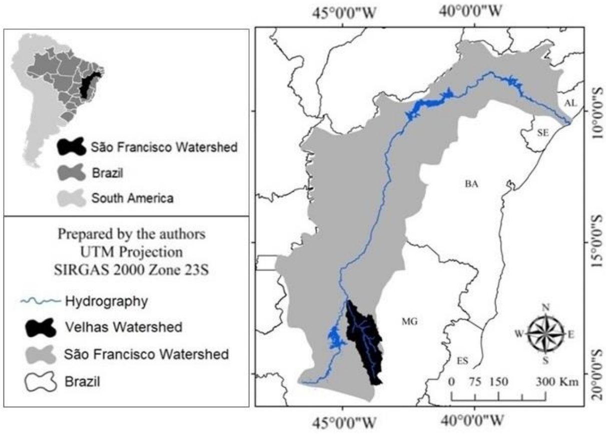

Figure 1. Location of the Velhas River Watershed

The Velhas River presents an important contribution to the flow of the São Francisco, which is, in turn, responsible for 70% of the water resources of Brazil's Northeast. This region has nearly 1/3 of the Brazilian population, but water availability is only 3% of that of the country, with great irregularity in the distribution of such resources. Thus, the protection and conservation of the tributaries of the São Francisco River, such as the Velhas River, is important for the maintenance of the main river that crosses the Northeast (Brasil, 2006; Castro, 2009).

2.2 Preparation of reforestation and deforestation scenarios

The reforestation scenarios were designed from preliminary mappings carried out using data available through governmental and research institutes, in addition to methods available in the literature and specific geoprocessing softwares (Table 1 and 2).

Criteria	Definition
Erodibility	Soil erosion ratio
Slope	Surface inclination with respect to the horizontal
Erosivity	Potential capacity of water to cause erosion
Distance to arboreal vegetation	Areas close to arboreal vegetation are considered more suitable for forest recovery
Distance to hydrography	Areas close to hydrography are considered suitable for forest recovery (riparian forest)
Distance to roads	Revegetation of areas closer to roads
Distance to urban areas	Distant forest recovery, since forest areas are more easily affected by urban sites

Table 1. Criterias definition to designed reforestation scenarios

The design of the scenarios was carried out using the *Multicriteria Evaluation – MCE of software Idrisi Selva* 17.0, through the *Analytic Hierarchy Process.* The suitability scales of the factors used in the analysis were standardized using a diffuse function where the factors have suitability values ranging from zero (lowest suitability) to 255 (greatest suitability) (Eastman, 2012; Feizizadeh et al., 2014).

Constraints were used in some classes of the land cover mapping (Table 3). The classes selected as constraints were: Rock Outcrop, Water, Urban Area and Arboreal Vegetation; the first three classes consist of areas which are difficult for growing trees and the latter is already occupied by forests. The choice of the covers to be replaced comes from the idea that the less vegetated and more exposed the soils, the higher the chance of occurrence of surface runoff with higher intensity, which may result in intensive erosive processes (El Swaify et al., 1982; Labrière et al., 2015).

Maps	Data used	Data source	Methodology used
Slope	Images of the *Shuttle Radar Topography Mission* (SRTM), spatial resolution of 30 meters	https://earthexplorer.usgs.gov/	*Slope* tool of the *software ArcGIS* 10.3
Land cover	Images of the OLI sensor of the satellite *Landsat* 8 with spatial resolution of 30 meters	http://www.dgi.inpe.br/catalogo/	Brasileiro et al. (2016); Cechim Junior et al. (2017); Souza et al. (2011)
Erodibility	Shapefiles containing the mapping of the soils of the state of Minas Gerais, clipped to the shape of the VRW	http://www.dps.ufv.br/?page_id=742	Durães e Mello (2016); Serio et al. (2008); Silva et al. (2009)
Erosivity	Daily rainfall data, between 1986 and 2015, from 21 rainfall stations	http://www.snirh.gov.br/hidroweb/	Nearing et al. (2017)
Distance to water courses	Shapefiles containing the hydrography map of the São Francisco Watershed, clipped to the shape of the VRW	Provided by the Company of Development of the Valleys of São Francisco and Parnaíba (CODEVASF)	*Distance* tool of *software Idrisi Selva* 17.0
Distance to roads	Shapefiles containing the roads map of the São Francisco Watershed, clipped to the shape of the VRW	Provided by the Company of Development of the Valleys of São Francisco and Parnaíba (CODEVASF)	*Distance* tool of *software Idrisi Selva* 17.0
Distance to arboreal vegetation	Created from the land cover map	-	*Distance* tool of *software Idrisi Selva* 17.0
Distance to urban area	Created from the land cover map	-	*Distance* tool of *software Idrisi Selva* 17.0

Table 2. Data and methodology used for designing the preliminary mappings

Criteria	Function		Interval of values		Points of control			
	Shape	Type	Min	Max	a	b	C	D
Erodibility	MI*	Linear	0	0.05	Scale (0-255)			
Slope	MI	Linear	0	75	Scale (0-255)			
Erosivity	MI	Linear	0	1290	Scale (0-255)			
Distance to arboreal vegetation	MD **	Linear	0	98,500 m	-	-	0	1,000 m
Distance to hydrography	MD	Linear	0	98,500 m	-	-	0	30 m
Distance to roads	MD	Linear	0	98,500 m	-	-	0	1,000 m
Distance to urban areas	MI	Linear	0	112,000 m	0	1,000 m	-	-

*Monotonically increasing **Monotonically decreasing
Table 3. Factors selected, functions chosen and values established to identify the priority areas for reforestation using the WLC-MCE method

This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLII-3-W12-2020-225-2020 | © Authors 2020. CC BY 4.0 License.
Primary publication at IEEE Xplore: https://doi.org/10.1109/LAGIRS48042.2020.9165666

2.3 Hydrological modeling

For the hydrological modeling of the VRW, secondary data available from research and governmental institutions were used (Table 4).

Information	Data used	Data source	Method used
Land Cover Map	Images of the OLI sensor of the *Landsat* 8 with spatial resolution of 30 meters in 2016	http://www.dgi.inpe.br/catalogo/	Brasileiro et al. (2016); Cechim Junior et al. (2017)
Soils Type Map	Shapefiles containing the mapping of the soils for the State of Minas Gerais, clipped to the shape of the VRW	http://www.dps.ufv.br/?page_id=742	C*lip* tool of the *software ArcGIS* 10.3
Digital Elevation Model	Images *Shuttle Radar Topography Mission* (SRTM) with spatial resolution of 30 meters	https://earthexplorer.usgs.gov/	*Extract By Mask* tool of the *software ArcGIS* 10.3
Rainfall	Daily rainfall data between 1986 and 2015, from 21 rainfall stations	http://www.snirh.gov.br/hidroweb/	Data organization for input in *ArcSWAT*
Climatology	Daily temperature data, relative moisture, solar radiation , wind speed, dew point, between 1986 and 2013, simulated for 55 points within and around the VRW	https://globalweather.tamu.edu/	Data organization for input in *ArcSWAT*
Flow	Daily flow data between 1986 and 2015, from a fluviometric station near the Velhas River mouth	http://www.snirh.gov.br/hidroweb/	Data organization for input in *SWAT-Cup*

Table 4. Data and methods used to prepare and organize the preliminary data for the hydrological modeling of the VRW

This stage consisted of data entry and flow simulation using the *software ArcSWAT*. The *software SWAT-Cup* was used to carry out the sensitivity analysis of the parameters used to calibrate and validate the model, in addition to the analysis of the modeling uncertainty. The land cover, pedology and slope maps, in addition to climate data from the VRW, were entered into the *ArcSWAT* to simulate the flows at the location of the fluviometric station used in the research. The objective of this stage was to compare simulated and observed data, and thus enable the calibration and validation of the model in the *SWAT-Cup*. The hydrological simulation was carried out using the 2016 Land cover Map, as well as flow and rainfall data from the period between 1986 and 2015, with 10 years of warm-up period.

The calibration process was carried out for the period between 1996 and 2010, and the validation from 2011 and 2015. The same interval of values of the parameters used to calibrate the model was used for validation. A total of 6 iterations with 200 simulations were carried out for calibration and only 1 iteration with 200 simulations was carried out for validation, using the *SUFI-2* method.

The results of calibration and validation for the flow simulation of the Velhas River were evaluated by statistical analysis, in order to verify if the flow behavior presented by the model is compatible with the data obtained in the field. For that, three statistical criteria were used: the Determination Coefficient (R^2), the Nash–Sutcliffe Efficiency (NSE) and the Percentage of Bias (PBIAS) (Moriasi et al., 2007). In general, the model can be considered satisfactory when NSE > 0.4, $R^2 > 0.5$ and PBIAS ± 25% for simulations related to flow (Welde, Gebremariam, 2017).

2.4 Simulation of flow for the designed scenarios

After the preparation of the scenarios and elaboration of the hydrological modeling for the VRW, flow simulations were carried out, in which the parameters used to simulate the flows of the scenarios had the same values found during the model calibration and validation. This process enabled the verification of the flow behavior, in the case of reforestation or deforestation in the watershed.

In order to show the influence of reforestation and deforestation on the flows of the Velhas River, a more recent period of rainfall and flow data was selected, with continuous series, i.e., without gaps throughout monitoring and that comprised both the rainy and the dry seasons. The period chosen was from February 2012 to June 2013 (rainy season from 2011/2012 – rainy season 1, dry season of 2012 – dry season 1, rainy season from 2012/2013 – rainy season 2, and the beginning of the dry season in 2013 – dry season 2).

3. RESULTS

3.1 Reforestation and Deforestation Scenarios

The mapping resulting from the multicriteria analysis showed that the suitability for reforestation in the VRW ranged between 30 and 244. The continuous scale was divided into equal parts, resulting in five suitability classes (Figure 2).

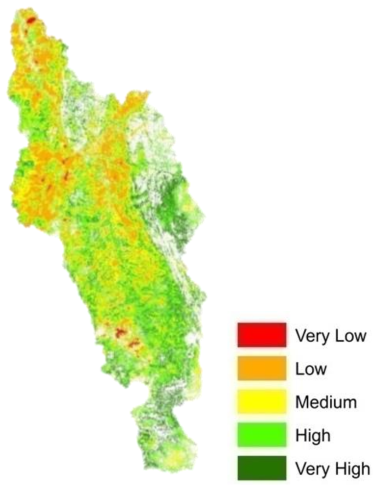

Figure 2. Suitability map for the reforestation of the VRW

The class with the greatest representativity was the High Suitability Class, with 6,983.4 km² (37%), followed by the Medium Suitability Class, with 4,956.3 km² (26%) and the Low Suitability Class, with 4,398.2 km² (23%). The least representative classes are those of the extremes, the Very Low Suitability Class, with 111.3 km² (>1%) and the Very High Suitability with 2,570.1 km² (14%).

The most indicated locations for reforestation (Very High Suitability) are in the South, Southeast and East of the watershed. In these areas, there is still remaining arboreal vegetation, facilitating the expansion of forest areas. In these locations, there are also steep hillsides (slopes over 45º) occupied by pasture or bare soil. These hillsides present easily erodible soils (litholic soils) and are located where rainfall indices are more intense. The river banks and hillsides with high slopes (but not as steep as the ones previously mentioned) were considered suitable for reforestation (High Suitability), because they are on Cambisols (soils with a shallow B horizon and susceptible to erosion) and are occupied by pasture.

Areas occupied by agriculture were considered less suitable (Low and Very Low Suitability), since they consist of more plain terrains with soils less prone to erosion (Red and Red-Yellow Latosols and the Red-Yellow Argisols). Also, in these areas, West, Northwest and North of the watershed, the rainfall indices are the lowest.

From this mapping, two reforestation and one deforestation scenarios were created. The first two were designed as follows: i) one replaces the current land cover by arboreal vegetation in the areas considered of Very High Suitability, i.e., a reforestation of 9.2% of the watershed area (Scenario I); ii) the other one was designed by replacing the current land cover by arboreal vegetation in the areas considered of Very High and High Suitability, i.e., a reforestation of 34.3% of the watershed area (Scenario II). The deforestation scenario was prepared by replacing all arboreal vegetation by underbrush (Scenario III) (Figures 3 and 4).

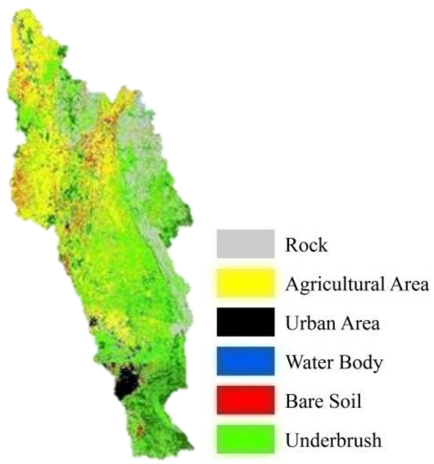

Figure 3. Current Scenario of Land Cover and Land Use

a) Scenario I *b) Scenario II* *c) Scenario III*

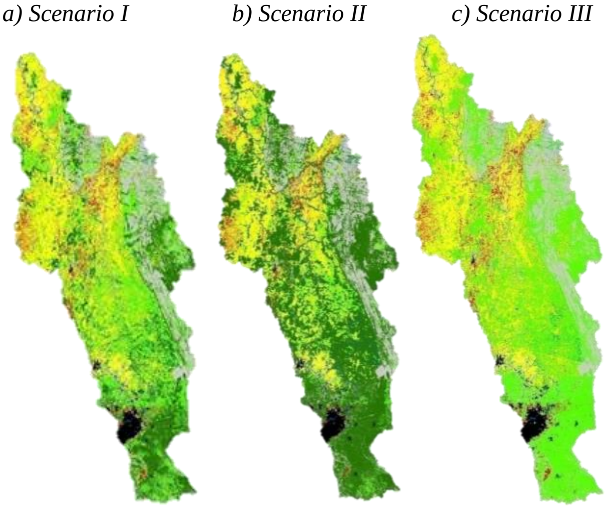

Figure 4. a and b) Reforestation Scenarios (Scenarios I and II, respectively); c) Deforestation Scenario (Scenario III)

The changes from the current scenario to Scenario I were more significant in the underbrush, with a loss of 2,280 km² (29%); in agricultural areas, with a decrease of 203 km² (2.7%); and in bare soils, with a reduction of 87 km² (7%). There was an increase of 2,570 km² (45%) of arboreal vegetation.

From the current scenario to Scenario II, the most significant reductions were in the underbrush, of 6,801 km² (213%); in agricultural areas, of 2,243 km² (40%); and in bare soils, with 508 km² (63%). There was an increase of 9,552 km² (75%) of the arboreal vegetation.

From the current scenario to Scenario III, there was a replacement of 3,008 km² of arboreal vegetation by underbrush, representing a deforestation of 100% of the forests of the watershed.

3.2 Hidrological Modeling

The statistical tests for calibration resulted in values of 0.75 for NS, 0.76 for R^2 and +5.4% for PBIAS. For validation, the values were 0.54 for NS, 0.65 for R^2 and -14.4% for PBIAS. These results show that the efficiency of the model was satisfactory in both the calibration and validation processes.

The hydrograms related to calibration and validation (Figure 5) showed that during calibration, the model had a good fit between observed and simulated monthly average streamflows, satisfactorily representing the rainy and dry seasons, even though it underestimated the flows for the rainiest months.

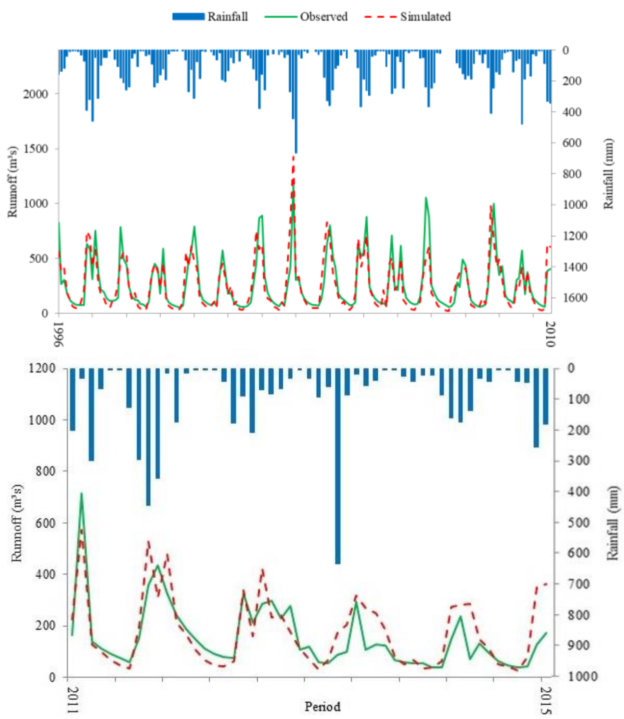

Figure 5. Hydrograms of calibration (A) and validation (B)

With respect to validation, there were higher inconsistencies when comparing observed and simulated data, with significant differences, especially overestimating flows in the months of higher average flows. The modeling had satisfactory results when simulating the flows of the Velhas River, according to the statistical tests.

3.3 Simulation of flows for the designed scenarios

The flow simulation for Scenario I showed that a reforestation of 9.2% of the watershed would result in a reduction of 33.6 m³/s (17.6%) in the average flow for the entire period assessed. The maximum flows would reduce by 18.6% and 16% in the rainy seasons 1 and 2, respectively, and the minimum flows would reduce by 26.6% and 22.6% in the dry seasons 1 and 2, respectively (Figure 6A).

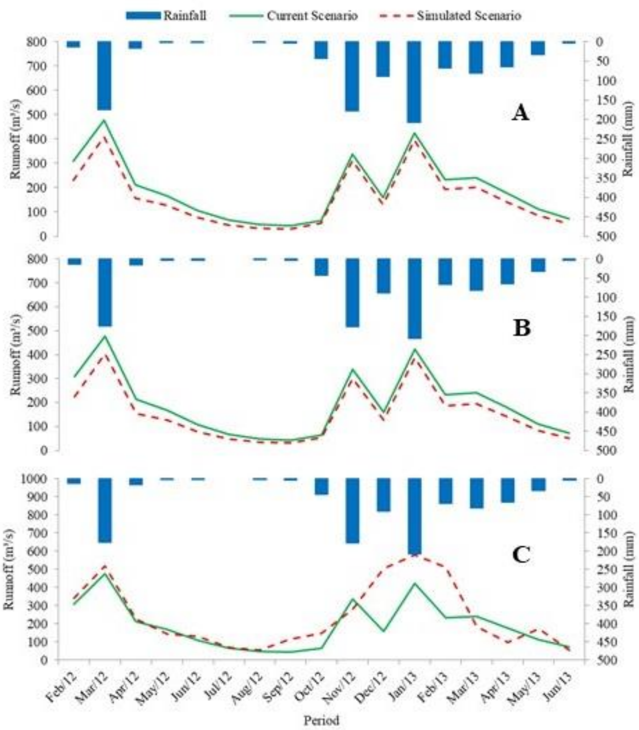

Figure 6 – Flow behavior for Scenarios I (A), II (B) and III (C) compared to the flows of the Current Scenario

The flow simulation for Scenario II showed that a reforestation of 34.3% of the watershed would reduce the average flow by 36.7 m³/s (19.2%) for the entire period assessed. The maximum flows would reduce by 19.8% and 14.3% in the rainy seasons 1 and 2, respectively, and the minimum flows would reduce by 26.8% and 24.3% in the dry seasons 1 and 2, respectively (Figure 6B).

The flow simulation for Scenario III showed that a deforestation of 100% of the remaining forests in the watershed would increase the average flow by 51.9 m³/s (27.1%). The maximum flows would increase by 9.4 and 51.4% in the rainy seasons 1 and 2, respectively, and the minimum flows would increase by 14.4% in the dry season 1 and decrease by 9.3% in the dry season 2 (Figure 6C).

4. DISCUSSIONS

The results of the simulations of monthly average streamflows for Scenarios I and II indicate that a reforestation of 9.2% (2,570 km²) or 34.3% (9,552 km²) will result in a decrease of 33.6 m³/s in the first case and 36.7 m³/s in the second, in the case of similar rainfall in the assessed period. From one scenario to another, there is a difference of 3.1 m³/s, which represents a 1.6% change. In the dry and rainy seasons, these changes were also not significant, with the difference no higher than 2% between the two scenarios. Although the simulation of the two scenarios suggests changes in the behavior of the monthly average flows with respect to the current scenario, there is no significant variation between Scenario I and II.

The literature that addresses the effects of reforestation on the water yield and flows shows that an increase in forest areas causes a reduction in such factors (Andréassian, 2004; Brown et al., 2005). Over a hundred results were compiled from the quoted studies showing that, despite the flow reductions that take place with reforestation, the hydrological responses of the watersheds are highly variable and most of the time, unpredictable. Most of these studies were carried out in watersheds smaller than 1,000 km². From the compilation of 162 studies on watersheds with more than 1,000 km², it was possible to see that the increase in forest areas also decreased the water yield (Li et al., 2017).

Also, the greater the changes in the forest areas, due to deforestation or reforestation, the higher the variations in water yield in large watersheds. However, the authors of these studies highlighted that despite the existing relationship between changes in forest cover and variations in water yield, there are other variables that interfere in this production, such as climate, soils, size and shape of the watershed, altimetry, and slopes, among other characteristics (Andréassian, 2004; Brown et al., 2005; Li et al., 2017).

With respect to Scenario III (100% of deforestation) and its comparison to the Current Scenario, there would be an increase of 51.87 m³/s in the monthly average flow of the assessed period. This difference would result in a flow of 124.81 m³/s in one of the rainy seasons. The results related to deforestation were compatible with those found in the literature, where the suppression of forests causes the increase in water yield, mostly due to the increase in runoff which directly contributes to river flows, in small or large watersheds (Andréassian, 2004; Brown et al., 2005; Li et al., 2017). Scenario III shows how important it is to protect and maintain the remaining arboreal vegetation, contributing to actions aimed at regulating the flows of the Velhas River, mitigating problems related to floods.

5. CONCLUSIONS

- Multicriteria analysis is an important methodology that aids in the management of the territory. This study allowed the identification of priority areas for reforestation in the VRW;
- The hydrological modeling was a method to complement the multicriteria analysis, verifying the behavior of the flows of the Velhas River from the scenarios created, helping in the identification of those that are more advantageous for the management of water resources;
- According to the hydrological simulations of the scenarios, the flows of the Velhas River do not follow a linear trend, where the larger the reforested area, the smaller the surface runoff. The multicriteria analysis and the hydrological modeling indicate that the physical characteristics of the watershed significantly influence the flow behavior, and that reforestation and deforestation should be carried out with caution. Thus, the results show that the combination of the multicriteria analysis and hydrological modeling provides assistance to planning and management with respect to modifications of forest areas, contributing to the policy related to the subject.

REFERENCES

Andréassian, V., 2004. Water and forests: from historical controversy to scientific debate. **J. Hydrol.** 291, 1-27.

Brasileiro, F.G., Oliveira, C.M.M., Rodrigues, R.A., Delgado, R.C., 2016. Orbital image classification for Maximum Likehood Method in Quixeramobim, Ceará, Brazil. Revista Geográfica Acadêmica 10, 81-92 (In Portuguese).

Brasil, 2006. Notebook of the San Francisco Hydrographic Region. Ministério do Meio Ambiente, Secretária de Recursos Hídricos, Brasília, DF, Brazil (In Portuguese).

Brown, A.E., Zhang, L., McMahon, T.A., Western, A.W., Vertessy, R.A., 2005. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. **J. Hydrol.** 310, 28-61.

Calijuri, M.L., Melo, A.L.O., Lorentz, J.F., 2002. Identification of areas for the implantation of sanitary landfills using strategic decision analysis. Informática Pública 4, 231-250 (in Portuguese).

Castro, C.N., 2009. São Francisco River Transposition. Repositório do Conhecimento do IPEA. (in Portuguese) (http://repositorio.ipea.gov.br/handle/11058/5477).

C.B.H. Rio das Velhas, 2014. The Velhas Watershed (in Portuguese) (http://cbhvelhas.org.br/a-bacia-hidrografica-do-rio-das-velhas/).

Digital Atlas of Minas Gerais (DAMG), 2009. Contribution of the main tributaries of the Velhas basin, third ed. (in Portuguese).

Durães, M.F., Mello, C.R., 2016. Spatial distribution of the potential and current soil erosion for the Sapucaí River Basin, MG, Brazil. Eng. Sanit. Ambient. 21, 677-685 (In Portuguese).

Eastman, J.R., 2012. IDRISI Selva Manual, Version 17, Clark University, Worcester, Massachusetts, EUA.

El-Swaify, S.A., Dangler, E.W., Armstrong, C.L., 1982. Soil erosion by water in the tropics, first ed. University of Hawaii. Hawaii, EUA.

Feizizadeh, B., Roodposhti, M.S., Jankowski, P., Blaschke, T., 2014. A GIS-based extended fuzzy multi-criteria evaluation for landslide susceptibility mapping. Comput. and Geosci. 73, 208–221.

Francisco, C.E.S., Coelho, R.M., Torres, R.B., Adami, S.F., 2008. Watershed selection for environmental rehabilitation using multicriteria analysis. Ciência Florestal. 18, 1-13 (in Portuguese).

Labrière, N., Locatelli, B., Laumonier, Y., Freycon, V., Bernoux, M., 2015. Soil erosion in the humid tropics: a systematic quantitative review. Agric. Ecosyst. Environ. 203,127-139.

Lelis, T.A., Calijuri, M.L.A., 2010. Hydrosedimentological modeling of watershed in southeast Brazil, using SWAT. Ambi-Agua. 5, 158-174.

Li, Q., Wei, X., Zhang, M., Wang, Y., 2017. Forest cover change and water yield in large forested watersheds: a global synthetic assessment. Ecohydrology. 10:e1838.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., Veith, T.L., 2007. Model evaluation guidelines for systematic quantifications of accuracy in watershed simulations. Transactions of the ASABE. 50, 885-900.

Nearing, M.A., Yin, S., Borreli, P., Polyakov, V.O., 2017. Rainfall erosivity: an historical review. Catena. 157: 357-362.

Nossack, F.A., Zimback, C.R.L., Da Silva, R.F.B., Sartori, A.A.C., 2014. Application of multicriteria analysis to define priority areas for forest recovery. Irriga. 19, 612-625 (in Portuguese).

Pereira, S.B., Pruski, F.F., Da Silva, D.D., Ramos, M.M., 2007. Study of the hydrological behavior of São Francisco river and its main tributaries. Rev. Bras. Eng. Agríc. Ambient. 11, 615-622 (in Portuguese).

Pinheiro, J.A.C., 2015. Analysis of the landscape and priority areas for forest restoration in watershed from the Minas Gerais area. Doctoral dissertation. Federal University of Viçosa. Viçosa, MG, Brazil (in Portuguese).

Santos, J.B., 2013. Geotechnology and hydrologic modeling in the limits of priority areas in recomposition forest in sub-basin of Ribeirão Lavapés, Botucatu-SP. Master thesis. Paulista State University, Botucatu, SP, Brazil (in Portuguese).

Sartori, A.A.C., Zimback, C.R.L., 2011. Forest recomposition aiming the conservation of water resources in river Pardo watershed, SP. Energia na Agricultura. 26, 1-15 (in Portuguese).

Serio, J., Costa, C.A.G., Teixeira, A.S., Ortega, E., 2008. Application of USLE and SIG in the characterization of three small watersheds in Brazil. Rev. Acad. Agrár. Ambient. 6, 213-221 (In Portuguese).

Silva, R.M., Paiva, F.M.L., Santos, C.A.G., 2009. Evaluation of soil erodibility and soil loss in Capiá Basin based on Geographical Information System and Remote Sensing. Rev. Bras. Geogr. Fís. 2, 26-40 (In Portuguese).

Srinivasan, R., Arnold, J.G., 1994. Integration of a basin-scale water quality model with GIS. J. Am. Water Resour. Assoc. 30, 453-462.

Welde, K., Gebremariam, B., 2017. Effect of land use land cover dynamics on hydrological response of watershed: case study of Tekeze Dam watershed, northern Ethiopia. J. Soil Water Conserv. 5, 1-16.