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Impacts of reforestation on soil and soil organic carbon losses

Impactos do reflorestamento nas perdas de solo e de carbono orgânico do solo

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ABSTRACT

Water erosion is a serious environmental problem that causes soil degradation, compromises its fertility and causes soil organic carbon (SOC) losses. Reforestation, encouraged by Brazilian environmental legislation, is a way to reduce water erosion. However, in tropical and subtropical regions, there is little information on the impact of reforestation on soil loss rates and SOC. Therefore, this study aimed to apply the Erosion Potential Method, combined with multitemporal data from soil samples collected in situ, to estimate and spatialize soil and SOC losses in a predominantly agricultural Brazilian watershed that showed high rates of reforestation in the period studied from 2011 to 2019. The determination of the EPM parameters was carried out with the aid of a Geographic Information System and the soil loss estimate was validated with information from a hydrosedimentological collection station. The results showed that between 2011 and 2019 water erosion was reduced by 27.5%, while carbon losses were reduced by 32.7%. Among the evaluated crops, corn showed the highest soil and SOC losses, while coffee and forest areas exhibited the lowest rates. Reforestation of the basin is the main factor responsible for the reduction of soil losses. This process was initiated seeking to meet the requirements of the Brazilian Forest Code, which highlights the positive role that public policies can play in environmental conservation when respected and well applied.

Index terms: Erosion potential method; soil conservation; water erosion.

RESUMO

A erosão hídrica é um grave problema ambiental que provoca a degradação do solo, compromete sua fertilidade e causa perdas de carbono orgânico do solo (SOC). O reflorestamento, incentivado pela legislação ambiental brasileira, é uma forma de reduzir a erosão hídrica. Porém nas regiões tropicais e subtropicais, há pouca informação sobre o impacto do reflorestamento nas taxas de perda de solo e SOC. Portanto, o presente trabalho teve como objetivo aplicar o Método de Erosão Potencial (EPM), combinado com dados multitemporais de amostras de solo coletadas in situ, para estimar e espacializar as perdas de solo e carbono orgânico do solo em uma bacia hidrográfica brasileira, predominantemente agrícola que apresentou altas taxas de reflorestamento no período estudado de 2011 a 2019. A determinação dos parâmetros do EPM foi feita com auxílio de Sistema de Informação Geográfica e a estimativa de perda de solo foi validada com informações de uma estação de coleta hidrossedimentológica. Os resultados mostraram que entre 2011 e 2019 a erosão hídrica foi reduzida em 27,5%, enquanto a perdas de carbono foi reduzida em 32,7%. Entre as culturas avaliadas, o milho apresentou as maiores perdas de solo e SOC, enquanto as áreas de café e floresta exibiram as menores taxas. O reflorestamento da bacia é o principal fator responsável pela redução das perdas de solo. Esse processo foi iniciado buscando atender as exigências do Código Florestal Brasileiro, o que destaca o papel positivo que as políticas públicas podem desempenhar na conservação ambiental quando respeitadas e bem aplicadas.

Termos para indexação: Método de erosão potencial; conservação do solo; erosão hídrica.

INTRODUCTION

Water erosion is a process that, although occurring naturally, is increased by human activities such as improper agricultural practices. This has adverse impacts on agriculture, such as the compromise of soil fertility and losses of soil organic carbon (SOC), consequently increasing greenhouse gas emissions and thus being a factor in environmental degradation (Lal, 2004).

In tropical and subtropical regions, changes in land use and land cover, especially the expansion of improper agricultural practices, intensify erosive processes (Didoné; Minella; Evrard, 2017; Deváty et al., 2019). In this context, the conversion of degraded pastures and agricultural areas into conservation and reforestation areas can reduce soil vulnerability to erosion, and surface runoff, consequently, increase carbon sequestration and decrease nutrient losses

(Smith et al., 2016; Korkan, 2018; Tiwari et al., 2019). Although reforestation is the object of intense investigation in several studies, few have direct investigated the consequences of increased reforestation on SOC losses (Anh et al., 2014; Yao et al., 2019).

The modeling of soil losses, using Geographic Information Systems (GIS) environments as support, is a simple and effective way to monitor the erosive process, as well as the losses of nutrients and SOC, in their spatiotemporal variations (Cunha; Bacani; Panachuki, 2017; Imamoglu; Dengiz, 2017). Furthermore, modeling allows for overcoming the limitations imposed by the need for field experiments that consume time and resources (Efthimiou; Lykoudi; Karavitis, 2017; Vanwalleghem et al., 2017).

Currently, a number of models are used to estimate water erosion, such as the Universal Soil Loss Equation (USLE) (Wischmeier; Smith, 1978), Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), Water Erosion Prediction Model (WEEP) (Laflen; Lane; Foster, 1991), Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), and the Erosion Potential Method (EPM) (Gavrilovic, 1962). These models require different input variables and present distinct ways of processing the information (Krasa et al., 2019).

The EPM is a model that has gained ground in tropical regions because it requires a minimum of input data and the determination of its parameters is simple, allowing its use in areas where there is low availability of pedological and climatic data (Gavrilovic, 1962; Efthimiou; Lykoudi; Karavitis, 2017; Dragičević et al., 2019; Lense et al., 2019; Lense et al., 2020). Furthermore, combining spatialized SOC content data with the model results helps in understanding the dynamics of nutrient transportation (Lense et al., 2021).

Thus, this work aimed to apply the EPM, combined with multitemporal data from soil samples collected in the field, to estimate and spatialize soil and SOC losses in a predominantly agricultural Brazilian watershed that presented high reforestation rates over the studied period from 2011 to 2019.

MATERIAL AND METHODS

Study site description

This study was carried out in the Coroado Stream watershed, with 559.5 ha, located in the Capoeirinha Farm (45°55'55" to 45°54'14" W, and 21°31'32" to 21°33'5" S, Datum SIRGAS 2000), a coffee producer, owned by the company Ipanema Agrícola SA, in southeastern Brazil.

The predominant soil type in the study area is Latosols, with a moderate-grade granular structure with a medium size, clayey texture, and medium organic matter content (2.56 dag kg^{-1}) (Lense et al., 2019). According to the Köppen-Geiger climate classification, the region's climate is the Cwb type, characterized by dry winters and mild summers (Alvares et al., 2013). Altitudes vary in the study area between 795 and 922 m, with a maximum slope of 44.7% (Figure 1).

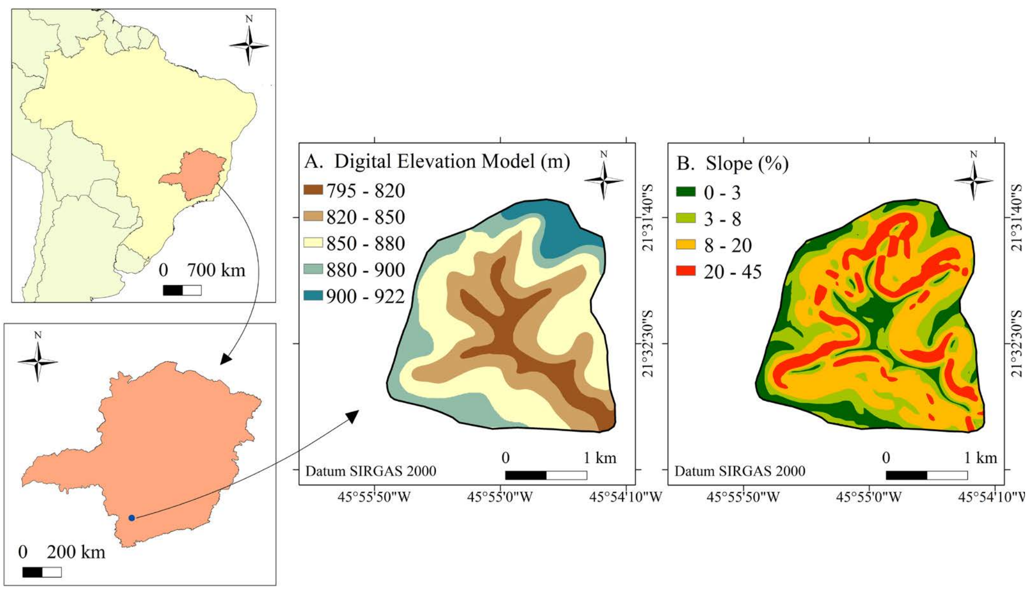

Figure 1: Localization, Digital Elevation Model (A), and Slope Map (B) of the Coroado Stream watershed, Alfenas municipality, south of Minas Gerais state, Brazil.

The slope map (Figure 1B) was prepared from the Digital Elevation Model (Figure 1A) of 10 m resolution obtained from the topographic map of Alfenas (Instituto Brasileiro de Geografia e Estatística - IBGE, 1970).

The land-use/land-cover (LULC) maps for 2011 and 2019 (Figure 2) were produced through photointerpretation of true-color compositions and vectorization of classes based on images from the Landsat 5 TM and Landsat 8 OLI satellites, respectively. Orbit/point 219/75 images were obtained at the "Divisão de Geração de Imagens" of the "Instituto Nacional de Pesquisas Espaciais" (Instituto Nacional de Pesquisas Espaciais - INPE, 2021). The slope map and the LULC map were generated in ArcMap 10.5 (Environmental Systems Research Institute - ESRI, 2016).

In 2011, the land use classes in the Coroado Stream watershed were: coffee (48.9%), forest (18.5%), corn (12.6%), eucalyptus (12.4%), watercourses (3.1%), sugarcane (2.7%) and facilities (1.8%). In 2019, the land use classes remained the same, but there were changes in the percentage of areas of coffee (39.6%), forest (34.9%), corn (11.8%) and eucalyptus (6.1 %).

The coffee-growing fields, the farm's main economic activity (Figure 2), were renovated between 2011 and 2019 with more productive genotypes. In addition, 91.7 ha previously occupied by eucalyptus and corn was reforested. In 2011, the coffee, sugarcane, and reforestation areas were already established, so there were no open spaces planned for new crops.

Erosion potential method parameters

The Erosion Potential Method was used to estimate soil losses in 2011 and 2019, according to Equation 1:

$$W_{yr} = \left(\sqrt[2]{\frac{t_0}{10} + 0.1}\right) . H_{yr} . \pi . \sqrt[2]{\left[Y . X_a . (\varphi + \sqrt[2]{I_{SR}})\right]^3} . Bd \quad (1)$$

where: W_{yr} = soil losses, in Mg ha^{-1} year^{1}; t_0 = average air temperature, in °C; H_{yr} = annual rainfall, in mm; Y = soil resistance to water erosion, dimensionless; X_a = use and management coefficient, dimensionless; φ = coefficient of the degree of erosive features, dimensionless; I_{sr} = slope of the area, in % and Bd = average bulk density of the soils, in kg dm^{-3}.

Soil resistance to water erosion (Y) is a parameter determined according to the soil type and it ranges from 0.2 to 2.0, where higher values indicate lower fragility. Considering the watershed characteristics and what was proposed by Gravilovic (1962) and Sakuno et al. (2020), we classified the area as 0.8. The map of declivity was useful to determine the topographic conditions of the area, mainly wavy relief (8-20%), and the average declivity (I_{sr}) was 13.5% (Figure 1B).

The coefficient of soil use and management (X_a) reflects the effect of land cover on erosion rates and ranges from 0 to 1, where lower values indicate a higher density of vegetal cover. The X_a parameter was determined for each land use class for the years 2011 and 2019 from the satellite images mentioned above, according to Sakuno et al. (2020). The coefficient of visible erosion features (φ) is related to the presence or absence of erosive features, as well as their intensity, and it varies from 0.1 to 1, increasing as the erosion increases. Through field surveys, it was verified that the occurrence of laminar erosion predominates in the Coroado Stream watershed, therefore, the value of 0.4 was adopted for the parameter throughout the region.

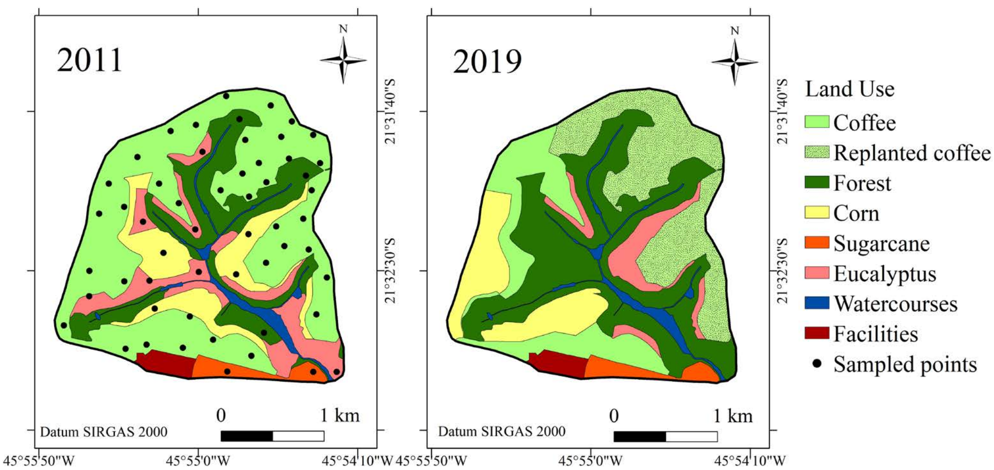

Figure 2: Land-use/land-cover map in the Coroado Stream watershed, Alfenas municipality, south of Minas Gerais state, Brazil, 2011 and 2019.

The annual precipitation (H_{yr}) and the average yearly temperature (t_0) correspond to the climatic factors required by the EPM, and they were acquired from the "Instituto Nacional de Meteorologia" database (INMET, 2021). The average bulk density (Bd) was defined according to Blake and Hartge (1986), utilizing sampled soil from all over the watershed in 2011 and 2019 (Figure 2). The EPM parameters are shown in Table 1.

Table 1: EPM parameter values from the Coroado Stream Watershed, Alfenas municipality, south of Minas Gerais state, Brazil, in 2011 and 2019.

Parameter	Year	
	2011	2019
Y (dimen.)	0.80	0.80
X_a (dimen.)	0.53	0.44
φ (dimen.)	0.40	0.40
t_0 (°C year^{-1})	20.11	20.62
H_{yr} (mm year^{-1})	1,618.27	1,559.11
Bd (kg dm^{-3})	1.25	1.22

Notes: Y = soil resistance to water erosion; X_a = Average coefficient of soil use and management; φ = Average coefficient of visible erosion features; Z = Average coefficient of erosion; t_0 = Mean air temperature; H_{yr} = Mean annual rainfall; Bd = Average of bulk density; dimen. = dimensionless.

All of the parameters were calculated and spatialized in ArcMap 10.5 (Environmental Systems Research Institute - ESRI, 2016) using the Raster Calculator tool.

Model Validation

The EPM makes it possible to estimate the fraction of eroded soil that reach watercourses, that is, the deposition of sediments in a given hydrographic basin. Sediment delivery was estimated according to Equation 2 (Gavrilovic, 1962):

$$SD = \frac{(O \cdot D)^{0.5}}{0.25 \cdot (L + 10)} \quad (2)$$

where: SD = sediment delivery rate; O = perimeter, in km; D = mean elevation difference, in km; L = main length of the watershed, in km.

The watershed presents a perimeter of 9.28 km (O). The area extension of 3.32 km (L) was calculated considering the watercourses, and the average difference in elevation (D) was computed using the average (861 m) and minimum (795 m) altitude. Based on the parameters O, D and L, we observed a sediment delivery rate (SD) of 0,118, which means that 11.8% of the transported soil reaches watercourses.

Sediment deposition in watercourses can be directly observed and measured in the field (usually at hydrosedimentological stations) and therefore can be used for validation of soil loss estimates. In this way the estimated sediment delivery rate (estimated SD) was compared with the observed sediment delivery rate (observed SD) which was calculated according to Beskow et al. (2009) and Batista et al. (2017).

To do that, it was necessary to build a discharge curve with data from a monitoring station of the "Instituto Mineiro de Gestão das Águas" (IGAM). The station chosen for data acquisition was located near the Coroado Stream outlet between 2007 and 2018 (coordinates 45°53'35" W and 21°39'55" S). The curve represents the relationship between the water discharge and the solids carried in it (Figure 3).

The observed SD was then determined considering the water discharge and the daily flow data obtained from the (Agência Nacional de Águas e Saneamento Básico - ANA, 2019) database from 2011 to 2019.

Estimates of SOC loss

The average SOC contents, obtained from the soil analysis, were used to estimate SOC losses by relating these outcomes to the soil loss estimates (Chen et al., 2019; Lense et al., 2021). The points where the soil samples were collected are shown in Figure 2. Both in 2011 and 2019 the samples were extracted at the same points (0 - 20 cm) and the organic matter content was determined according to (Empresa Brasileira de Pesquisa Agropecuária - Embrapa, 2011). Ordinary kriging was performed using the Geostatistic Wizard tool (Environmental Systems Research Institute - ESRI, 2016) to generate maps of soil organic matter (SOM) content. From these models, the SOM content was converted into SOC values using the van Bemmelen constant (0.58 kg C kg SOM^{-1}).

Finally, by relating the soil loss map and the map of the SOC content, it was possible to produce map of estimated losses of SOC. The process was carried out using the Raster Calculator tool (Environmental Systems Research Institute - ESRI, 2016).

RESULTS AND DISCUSSION

SOM contents

From 2011 to 2019, a decrease in SOC contents was observed over the watershed (Figure 4). In 2011, the SOM content ranged from 2.1-3.3%, and in 2019, they reached 2.0-3.0%.

The geostatistical analysis confirmed the spatial dependence of SOM. The adjustment of the spherical model achieved a coefficient of determination (R^2) that varied between 0.93 and 0.99. The residue sum of squares (RSS) of SOM for 2011 and 2019 was 0.17 and 0.27. For both years, the highest contents were present in the coffee-growing areas, which can be explained by the high volume of fertilizers (organic) applied, as well as the use of vegetable waste (coffee straw) between the rows (Figure 4).

The reduction in SOC content in the region can be explained by the fact of water erosion is an accumulative process whose long-term trend is the loss of nutrients, even in areas with low-intensity erosion. However, other factors can affect the nutritional dynamics of soils, such as the renovation of the coffee growing areas, which causes soil disturbance and exposure to climate agents and microbial enzymes, hence decreasing the SOC content (Lal, 2019). Other factors, such as the application of fertilizers and practices adopted in cultivation, can also interfere with this dynamic.

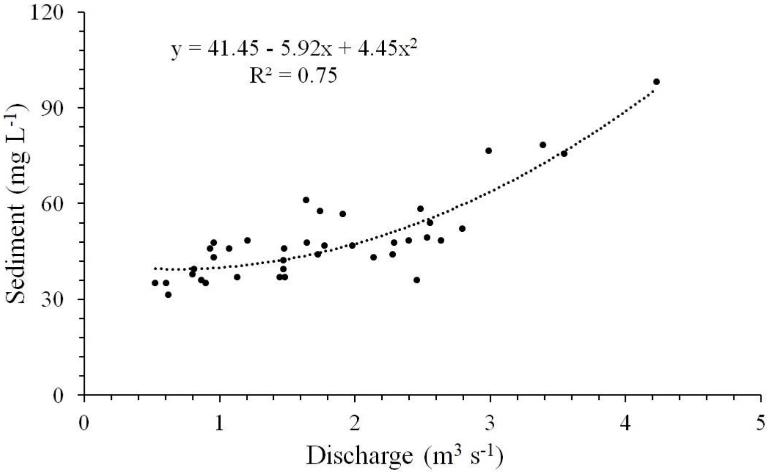

Figure 3: Water discharge curve (sediment transported × water discharge) of the Coroado Stream watershed, Alfenas municipality, south of Minas Gerais state, Brazil.

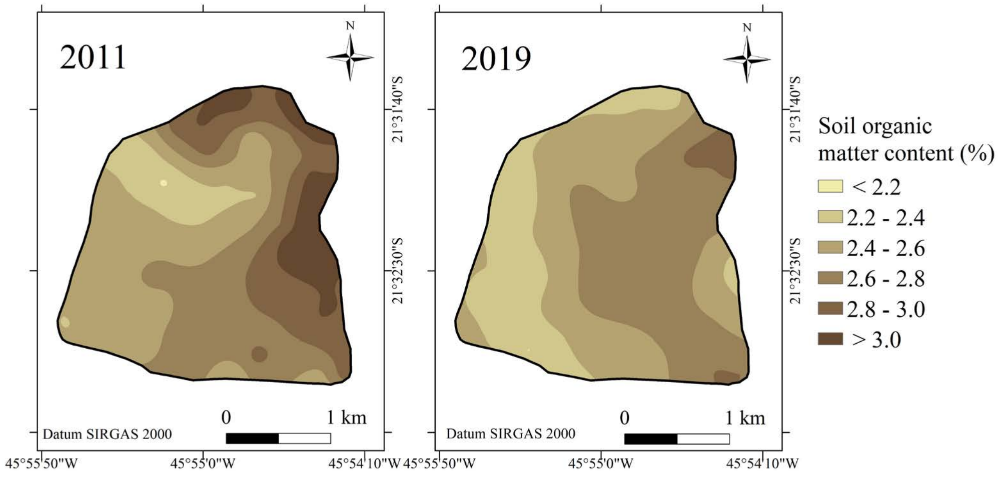

Figure 4: Spatial distribution of the soil organic matter content (SOM) of the Coroado Stream watershed, Alfenas municipality, south of Minas Gerais state, Brazil, in 2011 and 2019.

Despite this, due to the reforestation since 2011, the SOC levels are expected to increase over time, mainly because the new forest is still in the initial stage of development. Throughout the aging of the forest, the trend is the increased carbon sequestration (Guo; Gifford, 2002; Smith et al., 2016; Tiwari et al., 2019).

EPM modeling

The EPM estimated sediment delivery of 2.8 and 2.1 Mg ha^{-1} year^{-1} for 2011 and 2019, respectively. Conversely, the observed sediment delivery was 3.16 and 2.78 Mg ha^{-1} year^{-1} for the same years. Therefore, comparing the EPM results with the observed SD, it is noted that the modeling underestimated the soil losses by 11.4% in 2011 and by 24.4% in 2019. According to Bagarello et al. (2012), when used for more practical purposes, soil loss estimates can be considered acceptable if the forecast errors do not exceed the observed erosion by two or three times.

The errors observed may be mainly related to the difficulty of determining the parameters of the EPM model, mainly Y and X_a, which are factors that strongly interfere in the results of the model (Dragičević; Karleuša; Ožanić, 2017). In addition, the absence of a DEM with better spatial resolution and the uncertainties associated with an accurate determination of land use are also considerable sources of error for modeling (Beskow et al., 2009).

It is worth noting that the modeling is a representation of reality and not reality itself, and therefore is prone to errors, but regardless of errors, the estimation of soil losses should be interpreted as a tool to assess soil degradation and help in proposing and adopting conservation practices to reduce the negative impacts of erosion (Alewell et al., 2019).

Soil and SOC losses

Land-use and land-cover changes directly impact water erosion (Chen et al., 2019; Devátý et al., 2019), and this happened in the study area, where water erosion was reduced from 2011 to 2019 after the implementation of reforestation, a practice that promotes permanent soil cover due to the presence of forests. The total soil losses in the region was estimated at 13,361 Mg year^{-1} for 2011 and at 9,684 Mg year^{-1} for 2019. The loss of SOC was estimated at 358.6 and 241.5 Mg year^{-1} for 2011 and 2019, respectively. Thus, it was possible to determine that the actual soil losses in the watershed were reduced by 27.5% between 2011 and 2019, and the transportation of SOC was consequently reduced by 32.7%.

Considering the spatial distribution of soil losses and SOC losses (Figure 5) and the land use map (Figure 2), it is possible to notice a trend in the distribution of losses in the region according to each land use class. The highest soil losses and SOC losses were observed in areas occupied by maize and eucalyptus crops, especially in the steepest locations (Figure 6).

Coffee production areas had significantly lower erosion rates than crops cultivated conventionally or in steep areas, such as corn and eucalyptus (Table 2). Coffee production in the watershed is carried out by adopting conservationist agricultural practices, such as maintaining the vegetation between rows and level planting, actions that are efficient in reducing the intensity of the erosive process (Villatoro-Sánchez et al., 2015; Ramos-Scharrón; Figueroa-Sánchez, 2017), thus minimizing SOC losses.

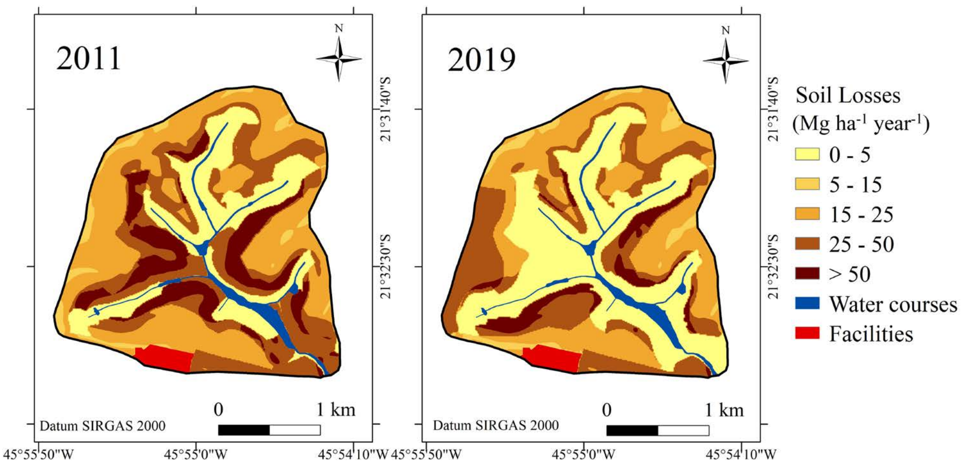

Figure 5: Soil losses in the Coroado Stream watershed, Alfenas municipality, south of Minas Gerais state, Brazil, in 2011 and 2019.

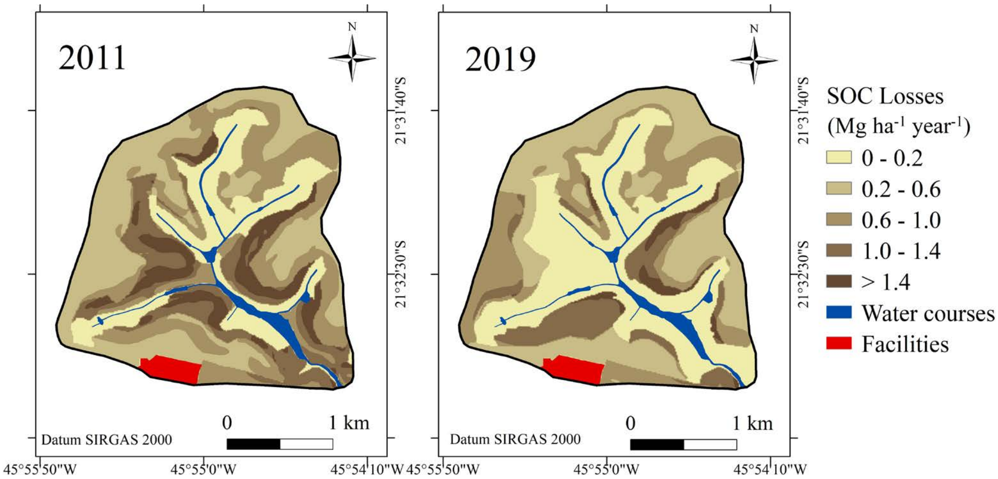

Figure 6: Soil organic carbon losses in the Coroado Stream watershed, Alfenas municipality, south of Minas Gerais state, Brazil, in 2011 and 2019.

Table 2: Average losses of soil and soil organic carbon (SOC) by land-use and land-cover class in the Coroado Stream watershed, Alfenas municipality, Minas Gerais state, Brazil.

Land Use	Average Soil Loss (Mg ha^{-1} year^{-1})		Average SOC Loss (Mg ha^{-1} year^{-1})	
	2011	2019	2011	2019
Coffee	21.5	20.1	0.58	0.49
Forest	0.6	1.0	0.04	0.03
Corn	53.7	43.0	1.42	1.04
Eucalyptus	44.2	48.5	1.17	1.30
Sugarcane	36.7	35.1	0.95	0.91

The forest areas had the lowest soil loss rates compared with the other cover classes (Table 2). In addition to protecting the soil against the impacts of raindrops, the forest areas, arranged alongside the water bodies, as illustrated in Figure 2, also act as a capture zone for the sediments coming from the other crop areas that make up a higher proportion of the watershed. Moreover, this barrier promotes lower SOC loss rates, as observed for the reforested areas.

Even though there was a reduction in soil losses from 2011 to 2019, better practices still need to be associated with crop production, such as corn, sugarcane, and eucalyptus. For corn and sugarcane, the adoption of agricultural practices that minimize soil disturbance, such as no-tillage, is recommended. For eucalyptus cultivation, terracing can help to reduce erosion, slowing runoff (Dai et al., 2018; Abdulkareem et al., 2019; Chen et al., 2019). Thus, an increase in riparian forest must be followed by other conservation practices throughout the entire watershed to expand the conservation of edaphic resources as much as possible.

The sustainability of such a fundamental resource for human survival, the soil, can only be guaranteed by the adoption of good agricultural practices in all areas of production, even in crops with a tendency of low soil losses. Moreover, the decrease in SOC content is a threat to ecosystems because it generates water, air, and soil pollution, aggravating the emission of greenhouse gases at all stages of the erosive process, both in the breakdown of particles and in their deposition (Lal, 2019).

We highlight that the reforestation over the studied area was driven by Brazilian environmental legislation (Brazilian Forest Code), which requires that at least 20% of rural properties located in the Atlantic Forest biome be used as preservation areas (Brasil, 2012). This is a good example of how public policies can impact environmental conservation as a whole, and they benefit ecosystems and societies.

Finally, the world is experiencing a new trend in which sustainability in agricultural production has also become a factor capable of adding market value. Coffee production, which is the main activity of the Coroado Stream watershed, must be followed with attention to environmental, social, and economic aspects, which are quickly becoming international demands.

CONCLUSIONS

Soil losses were reduced in the Coroado Stream watershed by 27.5% from 2011 to 2019, which led to decreases of 32.7% in losses of soil organic carbon. Reforestation of the area is the main factor responsible for reducing soil losses. The reforestation of the Coroado Stream watershed was initiated seeking to comply with the Brazilian Forest Code, which highlights the positive role that public policies can play in environmental conservation when respected and well applied.

AUTHOR CONTRIBUTION

Conceptual Idea: Lense, G.H.E.; Mincato, R.L.M., Methodology design: Lense, G.H.E.; Servidoni, L.E.; Mincato, R.L.M., Data collection: Lense, G.H.E.; Parreiras, T.C., Data analysis and interpretation: Lense, G.H.E.; Parreiras, T.C., and Writing and editing: Lense, G.H.E.; Parreiras, T.C.; Servidoni, L.E.; Mincato, R.L.M.

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REFERENCES

ABDULKAREEM, J. H. et al. Prediction of spatial soil loss impacted by long-term land-use/land-cover change in a tropical watershed. Geoscience Frontiers, 10(2):389-403, 2019.

ALEWELL, C. et al. Using the USLE: Chances, challenges and limitations of soil erosion modelling. International Soil and Water Conservation Research, 7(3):203-225, 2019.

ALVARES, C. A. et al. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, 22(6):711-728, 2013.

AGÊNCIA NACIONAL DE ÁGUAS E SANEMANETO BÁSICO - ANA. Sistema nacional de informações sobre recursos hídricos, 2019. Available in: <https://www.snirh.gov.br/hidroweb/apresentacao>. Access in: July, 27, 2021.

ANH, P. T. Q. et al. Linkages among land use, macronutrient levels, and soil erosion in northern Vietnam: A plot scale study. Geoderma, 232-234:352-362, 2014.

ARNOLD, J. G. et al. Large-area hydrologic modeling and assessment: Part I model development. Journal of the American Water Resources Association, 34(1):73-89, 1998.

BAGARELLO, V. et al. Estimating the USLE soil erodibility factor in Sicily, South Italy. Applied Engineering in Agriculture, 28(2):199-206, 2012.

BATISTA, P. V. G. et al. Modelling spatially distributed soil losses and sediment yield in the upper Grande River Basin - Brazil. Catena, 157:139-150, 2017.

BESKOW, S. et al. Soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. Catena, 79(1):49-59, 2009.

BLAKE, G. R.; HARTGE, K. H. Bulk density. In: KLUTE, A. Methods of soil analysis. 2. ed. Madison: American Society of Agronomy, v. 1, p.363-375, 1986.

BRASIL. Lei Federal. Código Florestal Brasileiro - Lei nº 12.651, DF: Congresso Federal. 2012. Available in: <https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm>. Access in: August, 20, 2021.

CHEN, Z. et al. Land-use change from arable lands to orchards reduced soil erosion and increased nutrient loss in a small catchment. Science of the Total Environment, 648:1097-1104, 2019.

CUNHA, E. R.; BACANI, V. M.; PANACHUKI, E. Modeling soil erosion using RUSLE and GIS in a watershed occupied by rural settlement in the Brazilian Cerrado. Natural Hazards, 85(2):851-868, 2017.

DAI, C. et al. Exploring optimal measures to reduce soil erosion and nutrient losses in southern China. Agricultural Water Management, 210(1):41-48, 2018.

DEVÁTÝ, J. et al. Effects of historical land use and land pattern changes on soil erosion – Case studies from Lower Austria and Central Bohemia. Land Use Policy, 82(1):674-685, 2019.

DIDONÉ, E. J.; MINELLA, J. P. G.; EVRARD, O. Measuring and modelling soil erosion and sediment yields in a large cultivated catchment under no-till of Southern Brazil. Soil and Tillage Research, 174(1):24-33, 2017.

DRAGIČEVIĆ, N.; KARLEUŠA, B.; OŽANIĆ, N. Erosion potential method (Gavrilović Method) sensitivity analysis. Soil & Water Research, 12(1):51-59, 2017.

DRAGIČEVIĆ, N. et al. Effect of source-varying input data on erosion potential model performance. Geocarto International, 34(10):1109-1122, 2019.

EFTHIMIOU, N.; LYKOUDI, E.; KARAVITIS, C. Comparative analysis of sediment yield estimations using different empirical soil erosion models. Hydrological Sciences Journal, 62(16):2674-2694, 2017.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Manual de métodos de análise do solo. 2. ed. rev. Rio de Janeiro: Embrapa Solos, 2011. 225p.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE - ESRI. ARCGIS Professional GIS for the desktop version 10.5**.** Redlands, Califórnia, Software, 2016. Available in: <https://desktop.arcgis.com/en/arcmap/10.5/get-started/setup/arcgis-desktop-quick-start-guide.htm>. Access in: July, 27, 2021.

GAVRILOVIC, S. A method for estimating the average annual quantity of sediments according to the potency of erosion. Bulletin of the Faculty of Forestry, 26(1):151-168, 1962.

GUO, L. B.; GIFFORD, R. M. Soil carbon stocks and land use change: A meta analysis. Global Change Biology, 8(4):345-360, 2002.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. Carta topográfica do Município de Alfenas (FOLHA SF 23-1-1-3), 1970. Available in: <https://mapas.ibge.gov.br/bases-e-referenciais/bases-cartograficas/cartas.html>. Access in: July, 27, 2021.

IMAMOGLU, A.; DENGIZ, O. Determination of soil erosion risk using RUSLE model and soil organic carbon loss in Alaca catchment (Central Black Sea region, Turkey). Rendiconti Lincei, 28:11-23, 2017.

INSTITUTO NACIONAL DE METEOROLOGIA - INMET. Estações pluviométricas convencionais. Ministério da Agricultura, Pecuária e Abastecimento (MAPA), 2021. Available in: <http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep>. Access in: July, 27, 2021.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS - INPE. Divisão de geração de magens (DIDGI). Ministério da Ciência, Tecnologia, Inovações e Comunicações, 2021. Available in: <http://www.dgi.inpe.br/catalogo/>. Access in: July, 27, 2021.

KORKAN, S. Y. Effects of the land use/cover on the surface runoff and soil loss in the Niğde-Akkaya Dam Watershed, Turkey. Catena, 163:233-243, 2018.

KRASA, J. et al. Soil erosion as a source of sediment and phosphorus in rivers and reservoirs - Watershed analyses using WaTEM/SEDEM. Environmental Research, 171:470-483, 2019.

LAFLEN, J. M.; LANE, L. J.; FOSTER, G. R. A new generation of erosion prediction technology. Journal of Soil and Water Conservation, 46(1):34-38, 1991.

LAL, R. Soil carbon sequestration to mitigate climate change. Geoderma, 123(1-2):1-22, 2004.

LAL, R. Accelerated Soil erosion as a source of atmospheric CO_2. Soil and Tillage Research, 188:35-40, 2019.

LENSE, G. H. E. et al. Estimates of soil losses by the erosion potential method in tropical latosols. Ciência e Agrotecnologia, 43:e012719, 2019.

LENSE, G. H. E. et al. Effects of deforestation on water erosion rates in the Amazon region. Revista Brasileira de Ciências Agrárias, 15:e8500, 2020.

LENSE, G. H. E. et al. Modeling of soil organic carbon loss by water erosion on a tropical watershed. Revista Ciência Agronômica, 52(1):e20207257, 2021.

RAMOS-SCHARRÓN, C. E.; FIGUEROA-SÁNCHEZ, Y. Plot-, farm-, and watershed-scale effects of coffee cultivation in runoff and sediment production in western Puerto Rico. Journal of Environmental Management, 202:126-136, 2017.

RENARD, K. G. et al. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Washington: United States Department of Agriculture, 1997. 384p.

SAKUNO, N. R. R. et al. Adaptation and application of the erosion potential method for tropical soils. Revista Ciência Agronômica, 51(1):e20186545, 2020.

SMITH, P. et al. Global change pressures on soils from land use and management. Global Change Biology, 22:1008-1028, 2016.

TIWARI, S. et al. Land use change: A key ecological disturbance declines soil microbial biomass in dry tropical uplands. Journal of Environmental Management, 242:1-10, 2019.

VANWALLEGHEM, T. et al. Impact of historical land use and soil management change on soil erosion and agricultural sustainability during the Anthropocene. Anthropocene, 17:13-29, 2017.

VILLATORO-SÁNCHEZ, M. et al. Temporal dynamics of runoff and soil loss on a plot scale under a coffee plantation on steep soil (Ultisol), Costa Rica. Journal of Hydrology, 523:409-426, 2015.

WISCHMEIER, W. H.; SMITH, D. D. Predicting rainfall erosion losses. A guide to conservation planning. Supersedes agriculture handbook. Washington: United States Department of Agriculture, 1978. 67p.

YAO, X. et al. Effects of soil erosion and reforestation on soil respiration, organic carbon and nitrogen stocks in an eroded area of Southern China. Science of The Total Environment, 683:98-108, 2019.