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Effect of the Substitution of Agricultural Uses by Forest on the Hydrological Processes in a Tropical Watershed. Analysis through Hydrological Simulation

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Abstract *— Forests play an important role in watershed hydrology, regulating the transfer of water within the system. Their role in maintaining the hydrological regime of watersheds is still a controversial issue. Due to the uncertainty, our first objective was to identify, through GIS techniques, "Environmentally Sensitive Areas" (ESAs) in the Pinhal watershed, subsequently, to simulate land use scenarios with the Soil and Water Assessment Tool model. In one of these scenarios, we considered these areas as protected by forest cover. This scenario we compared to the current scenario regarding watershed sediment yield and hydrological processes. The results showed a reduction in sediment yield of 54% between the two scenarios, whereas watershed water yield was reduced by 19.3%.*

Keywords— hydrologic modelling; land use change; reforestation; SWAT, surface runoff; water yield.

I. INTRODUCTION

Abandonment of former agricultural and pasture land has led to spontaneous regeneration and active planting of new forests (Molin, 2014). Forests has many diverse environmental functions and knowledge on how forests affect the various aspects of water is essential to assess the role of forest cover on watersheds' hydrological regime (Lima, 2012). Forests are often regarded as effective to stabilize and maintain the river flow rates and this is one of the reasons why revegetation is repeatedly recommended to recover watersheds (Wei & Zhang, 2010). Some of the hydrological functions usually ascribed to forests, however, such as increase rivers water availability, are disputable and lack a technical and scientific basis. We observe, however, that this is still a worldwide controversy, especially regarding the establishment of water conservation and sustainable use of natural resources policies.

In this line of research, a large collection of data in the scientific literature, resulting from the systematic monitoring of catchments all over the world. Catchment studies may be grouped broadly into three main types (Bosch & Hewlett, 1982): (a) correlation studies in which the streamflow is compared between different catchments, (b) single catchment studies and of which (c) paired catchment experimental studies stands out (Bosch & Hewlett, 1982; Cosandey, 1995; Brown, 2005, Bart & Hope, 2010; Webb & Jarrett, 2013; Rodríguez-Martínez & Santiago, 2017). Some works with paired catchment showed the effect of forest cover on water yield, where natural vegetation has been removed and/or replaced by planted forests (Bosch & Hewlett, 1982; Bruijnzeel, 1990, 2004; Buytaert et al., 2006). The paired catchment technique would be arguably the best methodology to evaluate the hydrological functions normally assigned to forests, applicable to basins with very similar characteristics (Bosch & Hewlett, 1982; Brown, 2005). It is always preferable that paired catchment should be as near as possible, to have similar physical aspects, climate, vegetation and use and occupation (Best et al., 2003). Despite the advantages of using paired catchment to study the impact of vegetation changes on water yield, this kind of study takes time, since a watershed's hydrological response to tree cutting or reforestation is a medium to long-term process. It is also impossible to test other configurations of land management and use, and according to Zhang et al. Zhang et al (2017), the results from small catchment (e.g. paired catchment studies) cannot always be extrapolated to large basins.

Another option to predict the impact of land-use changes on the quantity and quality of water in a watershed, e.g., vegetation replacement, is the use of hydrological models. According to Sun et al. (2006), mathematical models are probably the best tools to analyze complex non-linear relationships between the water yield of forests and major environmental factors.

The large number of existing models applied to watersheds shows the advancement of this technology. There are many hydrological models that simulate the quality and quantity of streamflow, each one with strengths and weaknesses that must be considered according to the user's needs and the characteristics of the study area. As an example, the Soil and Water Assessment Tool (SWAT) model allows great flexibility when configuring watersheds (Abbaspour et al., 2015). The model was developed to predict the effect of different management scenarios in the quality and quantity of water, sediment yield and pollutant loads in agricultural watersheds (Srinivasan & Arnold, 1994; Peterson & Hamlett, 1998). SWAT discretize watersheds in subbasins based on relief, soil and land use, preserving thus spatially distributed parameters of the entire watershed and homogeneous characteristics within the watershed (Srinivasan & Arnold, 1994).

The SWAT model is internationally recognized as a solid interdisciplinary watershed-modeling tool, as demonstrated in annual international conferences and papers submitted to scientific journals (Kuwajima et al., 2011). SWAT's many uses have shown promising results, e.g., hydrological assessments, impacts of climate change, evaluation of best management practices, estimation of pollutant load, determining of the effects of land-use change, sediment yield, etc (Machado & Vettorazzi, 2003; Machado et. al. 2003; Koch et al., 2012; Lessa et al., 2014; Abbaspour et al., 2015; Dechmi & Skhiri, 2013; Liu et al., 2015; Zhang et al., 2014; Rocha et al., 2015; Lin et al., 2015, Tuo et al., 2018; Wang et al., 2018; Mutenyo el al., 2013; Sajikumar & Remya, 2015; Giri el al., 2018).

Due to the uncertainty of forests' role in the quantity and quality (sediment loading) of water resource and the possibility of creating different scenarios that are difficult to test at watershed level, this paper's objective is first to identify "Environmentally Sensitive Areas" (ESAs) in the watershed under study and, subsequently, to simulate land use scenarios comparing them regarding sediment yield and hydrological processes. The Pinhal watershed is important as supply of drinking water for the Limeira city and it is in state of environmental degradation (e.g., improper land use, areas severely eroded and soil loss). The results of this study will provide valuable information for future implementing the Payments for Ecosystem Services (PES) in the watershed.

II. METHODOLOGY

2.1. Study Area

Pinhal watershed is located in State of São Paulo, Brazil. It consists of approximately 300 square kilometers (Fig. 1). It has a humid subtropical climate – Cwa, according to the Köeppen classification, with a hot and humid summer and cold and dry winter, and average annual temperature of 25°C. Average annual precipitation is approximately 1400 mm.

Sugarcane cultivation occupies most of the watershed area (42.3%), whereas citrus cultivation occupies approximately 30% of the area. Much of the original forest vegetation has been destroyed in the process of land use and occupation, now scattered along the streams (9%). The urban area occupies 6.7%, located at the western side of Pinhal watershed. The predominant soils in watershed are ferralsols (72%) and cambisols (19%).

The Pinhal watershed is important as supply of drinking water and due to it is state of environmental degradation. In addition, the initiative taken by City Council of Limeira to reverse the degradation of forest and the adverse effect of land use changes is implementing the Payments for Ecosystem Services (PES).

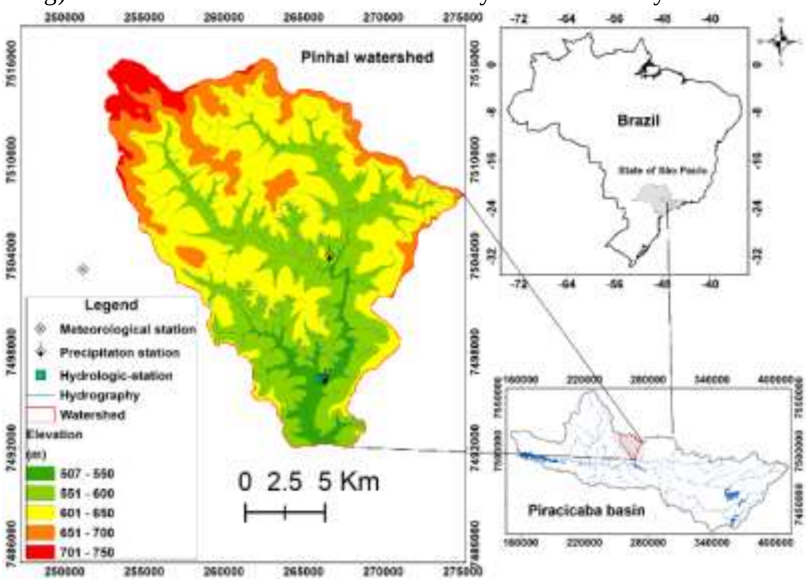

Fig. 1. Locations of the Pinhal watershed and gauging stations.

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2.2. The SWAT model and input data

SWAT, version 2012, was used in the simulation of the Pinhal watershed's scenarios. The model requires as input data daily precipitation, maximum and minimum air temperatures, solar radiation, wind speed and relative humidity. These data were obtained from UNICAMP's School of Technology's weather station, located in Limeira, state of São Paulo, at UTM coordinates 251,145 m (W) and 7,503,161 (S). Rainfall data were obtained from two other rainfall stations (Fig. 1). Other data include Digital Elevation Model (DEM), land use and soil maps. Land use properties were obtained directly from the SWAT model database and the physical-hydrological soil parameters of Agronomic Institute of Campinas (IAC). Table 1 summarizes the input data used for the current study. Inputting data into SWAT is made via an interface developed between SWAT and GIS ArcGis (Arnold et al., 2012). The interface divides the watershed in subbasins from the DEM. We discretized the Pinhal watershed in 25 subbasins up to the hydrologic station localized at UTM coordinates 266,175 m (W) and 7,496,308 (S) (Fig. 1).

Table.1: Data sources for the Pinhal watersheds and input data for SWAT model.

Input data	Data description	scale	Data sources
Land use	Land-use classification - agricultural land, forest, pasture, urban and water	25,000	Secretary of the Environment of the State of São Paulo, 2013 (http://www2.ambiente.sp.gov.br/cpla/mapa-de-uso-e-ocupacao-da-terra-ugrhi-5-pcj/)
Soil	Soil types and physical properties	100,000	São Paulo Forest Institute (http://iflorestal.sp.gov.br/2017/09/26/mapa-pedologico-do-estado-de-sao-paulo-revisado-e-ampliado/)
Topography	Digital Elevation Model (DEM)	10,000	Geographic and Cartographic Institute of São Paulo (IGC)
Hydrological and Meteorological	precipitation, minimum and maximum temperature, solar radiation, wind speed	Daily	ANA (http://www.snirh.gov.br/hidroweb/publico/mapa_hidroweb.jsf) UNICAMP (https://www.ft.unicamp.br/dadosmeteorologicos)

2.3. Model evaluation

The warm-up, calibration, validation and uncertainty analyses of the SWAT model was done in the period 2010 to 2014 in the SWAT-CUP 2012 program with the SUFI-2 (Sequential Uncertainty Fitting) calibration algorithm. The SUFI-2 algorithm has the capability to account for all sources of uncertainty within the parameter ranges such as uncertainty in driving variables (e.g. rainfall), conceptual model, parameters, and measured data (Abbaspour et al., 2007). Based on the relevant literature, parameters related to management/soil [CN2 (dimensionless), SOL_K (mm/h), SOL_AWC (mm/mm), SOL_ALB (dimensionless)]; groundwater parameters [ALFHA_BF (1/day), GW_DELAY (day), GWQMIN (mm), SURLAG (dimensionless), GW_REVAP (dimensionless), REVAPMN (mm)]; subbasins/HRU parameters [ESCO (dimensionless), EPCO (dimensionless), SURLAG (days), SLSUBBSN (m), CANMX (mm H2O)] and main channel parameters [CH_N2 (dimensionless), CH_K2 (mm/hr)], were submitted to the sensitivity analysis to parameterize the most sensitive and make necessary adjustments in their values. This step was performed iteratively, according to the calibration procedure (Abbaspour et al., 2015). The Nash-Sutcliffe model's efficiency coefficient (NSE - Equation 1) was used to evaluate the simulation's results. NSE can range from -∞ to 1, where 1 is the optimal value. Values above 0.75 can be considered very well (Moriasi et al., 2007. The PBIAS (Equation 2) also was used to evaluate the simulation's results (Gupta et al., 1999).

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{OBSi} - Q_{SIMi})^2}{\sum_{i=1}^{n}(Q_{OBSi} - \overline{Q}_{OBS})^2} \quad (1)$$

$$PBIAS[\%] = \left(\frac{\sum_{i=1}^{n}(Q_{OBSi} - Q_{SIMi})}{\sum_{i=1}^{n}(Q_{OBSi})}\right) * 100 \quad (2)$$

Where, Q_{OBSi} and Q_{SIMi} correspond to the observed and simulated streamflow, respectively, on day i (m^3/s), and $\overline{Q}_{OBS}$ corresponds to the observed average streamflow, in (m^3/s), and n corresponds to the number of events. The calibrated SWAT model was used to simulate monthly average hydrological processes under land use change scenarios.

2.4. Identification of Environmentally Sensitive Areas (ESAs)

The concept of "Environmentally Sensitive Areas" (ESAs) was created approximately 30 years ago due to increased soil and water degradation and the degree of severity of degradation (Rubio, 1995). ESAs are areas that contain natural or cultural features important for a

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functioning ecosystem (Ndubisi et al., 1995; Gourlay, 1998).

To identify ESAs in the Pinhal watershed within the context of environmental degradation, we reclassified the results from Adami et al. (2012) and identified three types of ESAs: Critical, Fragile and Potential according to Rubio (1995). Adami et al. (2012) made an agroenvironmental analysis of the Pinhal watershed via a Geographic Information System (GIS). They used indicators of relief (slope, which was sliced into categories and fragility degrees), soil (ranking of soil classes according to their fragility) and land use and cover (reclassified according to their protection degree, with higher grades given to classes with greater soil cover) to determine the capacity of natural resources and environmental fragility. The empirical analysis was used to identify areas that require more attention for improving environmental conditions. The results of the procedures employed by the authors in their study are shown in Fig. 2. Additional information in Adami et al. (2012).

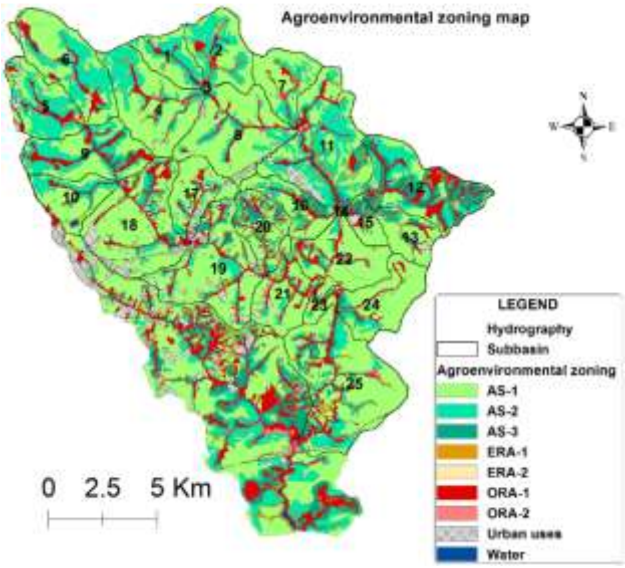

Fig. 2. Map of the agroenvironmental zoning of the Pinhal watershed by Adami et al. (2012).

Definitions: ***AS****: Agricultural subareas - these subareas are all sites identified and mapped with agricultural activities, as long as they are compatible with the conditions of protection of the water resources.* ***ERA****: Environmental Recuperation Area - are areas with usage or occupations that are compromising the quantity and quality of water, requiring urgent corrective interventions.* ***ORA****: Occupation Restriction Area - they are those defined as permanent preservation according to the Federal, State and Municipal legislation, within the limits of the Protection and Recuperation Area of Water Resources (PRAWR). These areas should be considered of private preservation of fauna and flora remaining in the watershed. Priorities should be given for the production of water, through investments and the application of economic instruments and compensation provided by the current legislation. Thus, we reclassified ORA 1, 2 and ERA 1, 2 as Critical ESAs; AS 2, 3 in Fragile ESAs and AS 1 in Potential ESAs.*

2.5. Scenario simulation

We made two scenario simulations using the SWAT model interfaced with GIS ArcGis, aiming to verify the effect of land use change on sediment yield (sediment transported from subbasins to the main channel over time, ton/ha) and the hydrological processes (surface runoff (mm), evapotranspiration (mm), soil water content (mm), water yield (mm). Where the water yield (WYLD) is the net amount of water that leaves the sub-basin and contributes to streamflow in the reach during the time step (WYLD= SURQ + LATQ + GW_Q – TLOSS – pond abstractions). SURQ is the surface runoff contribution to streamflow during time step (mm H2O). LATQ is the lateral flow contribution to streamflow during time step (mm H2O). GW_Q is the groundwater contribution to streamflow (mm). Water from the shallow aquifer that returns to the reach during the time step. TLOSS is the average daily rate of water loss from reach by transmission through the streambed during time step (m^3/s) (Arnold et al., 2012).

In a scenario, we did Critical and Fragile ESAs with forest cover and overlapping on the land use map. This scenario was compared to the baseline scenario. Thus, these simulations illustrate the application and integration of hydrological and water quality models with GIS to evaluate watershed management scenarios, modifying only land use layer and management practices.

We used the change of the analysed events as statistical criterion to evaluate sediment yield and compare the hydrological behavior of the watershed in different scenarios, Equation 3:

$$Change\,[\%] = \left(\frac{\sum_{i=1}^{n}(S_{ESA} - S_{CU})}{\sum_{i=1}^{n}(S_{CU})}\right) * 100 \qquad (3)$$

Where, S_{ESA} the results of the alternative scenario (Critical and Fragile ESAs with forest cover) and S_{CU} represents current scenario events (baseline) in the period. For this method, the higher the value of change (+ or -), the greater the difference in sediment yield and changes in hydrological processes between scenarios.

III. RESULTS AND DISCUSSION

3.1. Model evaluation

The purpose of the model calibration is to better parameterize a model to a given set of local conditions, thus to improve the simulation accuracy. Model validation is to check whether the model can predict flow for another range of time periods or conditions than those for which the model was calibrated (Li et al., 2015).

From the definition of the parameters to be calibrated and validated, SWAT-CUP defines the parameters most sensitive. It required 4 iterations of 500 simulations each to achieve the final optimization. The most sensitive parameters were SOL_AWC, CN2, SOL_K and ALPHA_BF (Table 2). Unlike studies of Strauch et al. (2012, 2013) for another Brazilian watershed, CN2 was not the most sensitive parameter. In the Pinhal watershed predominates Oxisol soil (72%) that has high permeability and, therefore, the sensitive parameters were those related to soil (SOL_AWC, SOL_K, ESCO) and groundwater (ALPHA_BF, GW_DELAY). These fitted values were used to adjust the model inputs for the scenario's simulation.

The Fig. 3 shows the monthly streamflow simulated and observed data in the calibration (2012-2013) and validation (2014) period. The graphic shows a pattern of variation similar between simulated e observed. The peak streamflow reflected the greatest precipitation events, but the base streamflow simulated were underestimated when the rainfall volume decreased. The NSE was 0.90 for calibration and 0.88 for validation period. Validation at the Pinhal watershed also indicates a good performance of the model. NSE values between 0.7 and 1 indicate a very good performance of the model Moriasi et al (2007).

As for the PBIAS result for the flow values, the model underestimated the flows by 3.1% in the calibration and 3.8% in the validation. PBIAS $\leq \pm 10$ indicates a very good accuracy of the model (Van Liew et al., 2007). These results show that the model after calibration and validation can accurately simulate the sediment yield and hydrological processes in the Pinhal watershed for two scenarios.

Table 2. Parameters used in the sensitivity analysis.

Parameters	Sensitivity	t-Stat	P-Value	Fitted Value
R__SOL_AWC	1	8.35	0.00	-0.01
R__CN2	2	6.45	0.00	0.03
R__SOL_K	3	-3.45	0.00	-0.10
V__ALPHA_BF	4	1.74	0.08	1.00
V__EPCO	5	-1.20	0.23	0.81
V__GW_DELAY	6	-1.06	0.29	47.06
V__ESCO	7	-1.00	0.32	0.12
V__CH_K2	8	-0.90	0.37	110.94
R__SOL_ALB	9	0.73	0.46	0.14
R__SLSUBBSN	10	-0.72	0.47	0.35
V__CH_N2	11	0.63	0.53	0.13
V__GWQMN	12	-0.60	0.55	4816.90
V__REVAPMN	13	0.45	0.65	295.98
V__GW_REVAP	14	-0.44	0.66	0.05
V__SURLAG	15	-0.20	0.84	0.38
V__CANMX	16	0.03	0.98	8.14

Parameter definitions: **SOL_AWC**: Available water capacity of the soil layer; **CN2**: Initial SCS runoff curve number for moisture condition II; **SOL_K**: Saturated hydraulic conductivity of soil layer; **ALPHA_BF**: Baseflow alpha factor; **EPCO**: Plant uptake compensation factor; **GW_DELAY**: Groundwater delay; **ESCO**: Soil evaporation compensation factor; **CH_K2**: Effective hydraulic conductivity in main channel alluvium; **SOL_ALB**: Moist soil albedo of soil layer; **SLSUBBSN**: Average slope length; **CH_N2**: Manning's "n" value for the main channel; GWQMN: Threshold depth of water in the shallow aquifer for return flow to occur; **REVAPMN**: Groundwater "revap" coefficient; **GW_REVAP**: Groundwater "revap" coefficient; **SURLAG**: Surface runoff lag time; **CANMX**: Maximum canopy storage.

R__: the parameter was adjusted by multiplying by the existing value; V__: existing parameter value was replaced by the new value.

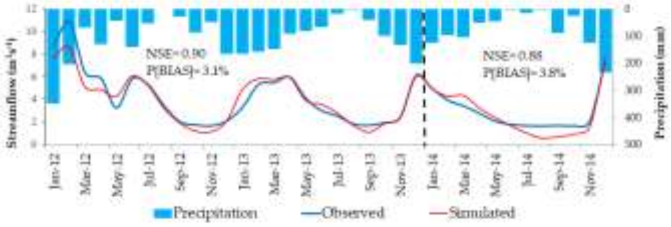

Fig. 3. Comparison of the observed and simulated streamflow in the Pinhal watershed. The calibration period was done in the years of the 2012-2013 and validation was done in the year of 2014.

3.2. Environmentally Sensitive Areas (ESAs)

ESAs identified in the Pinhal watershed are shown in Fig. 4. 16% of the watershed area is degraded due to improper land use. These areas are severely eroded and have high rates of surface runoff and soil loss (Adami et al., 2012). In this case, there may be higher peak streamflow and sedimentation of water bodies (Critical ESAs). In 25% of the area, we have identified regions where any change in the delicate balance between the environment and human activities may result in environmental degradation of the ecosystem (Fragile ESAs). 54% of the total watershed area is classified as Potential ESAs. Agricultural activities in these areas although following land use capability standards and requiring simple soil conservation practices to control erosion, care in the use of pesticides in sugarcane and citrus crops.

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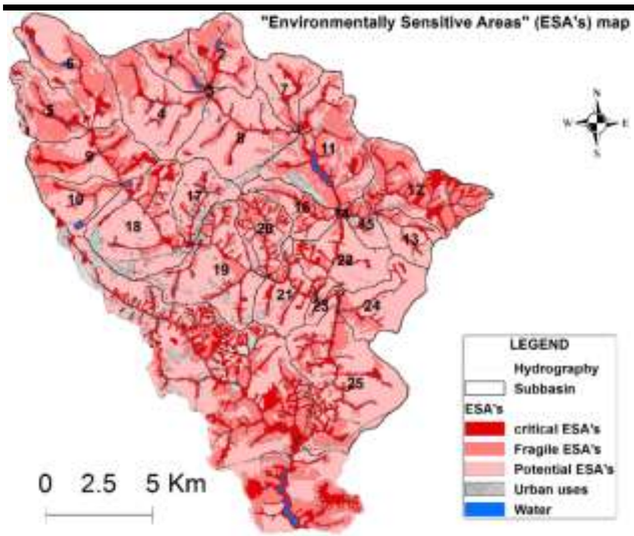

Fig. 4. ESAs (Environmentally Sensitive Areas) Map in the Pinhal watershed. 16% of the watershed area is critical ESAs and 25% is Fragile ESAs.

3.3. Land use change between scenarios

In this study, two different land use change scenarios, current and ESAs' scenarios were established to assess the impacts of the land use/cover change in the sediment yield and on hydrological processes.

Fig. 5 presents the land use map for the two scenarios and Table 3, the total and relative areas of occupation of each land cover in the Pinhal watershed for the current use scenario (baseline) and for the scenario of ESAs recomposed with forest vegetation. From the current scenario to the ESAs' scenario, there is a reduction of areas occupied with sugarcane, citrus and pasture and, consequently, an increase of areas occupied with forest vegetation. Sugarcane occupied the largest area in the watershed and in the ESAs' scenario; there was a reduction of 46.30% in this area. Orange occupies the second largest area in the current use scenario and in the new scenario, it was reduced by 18.8%, whereas pasture was reduced by 44.43%. The area for other uses has been reduced by 42.61%. Some subbasins increased forest cover compared to others: subbasins number 11, 12, 13, 14, 15 and 16.

Table 3. Land use and occupation change between the two scenarios (current use and ESAs) in the Pinhal watershed.

Land-use	Current use		ESAs scenario		Change	
	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)
Sugarcane	12566	42.2	6748	22.7	-5818	-46.30
Orange	8866	29.8	7199	24.2	-1667	-18.80
Pasture	2341	7.9	1301	4.4	-1040	-44.43
Forest	2662	8.9	12609	42.4	9947	373.67
Other uses	3337	11.2	1915	6.4	-1422	-42.61

We present in Fig. 6 the variation of land use change in subbasins scale between the two scenarios. The decrease in pasture and sugarcane areas, where soils are exposed to erosion during soil management, and the increase of forest vegetation area, which would exert significant impacts in the sediment yield and on water yield in watershed.

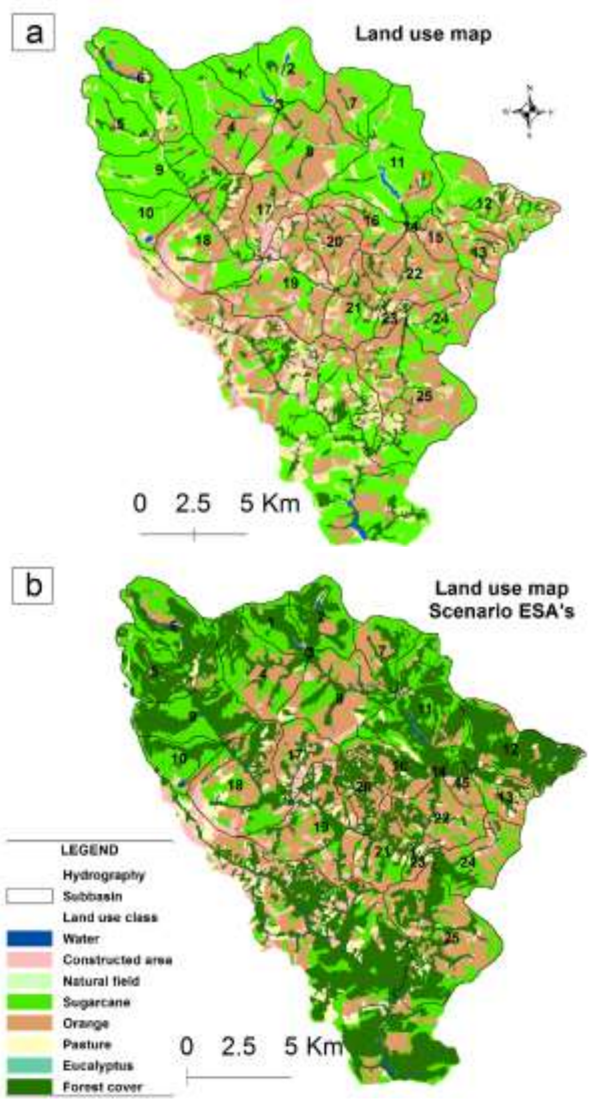

Fig. 5. Land use map: (a) current scenario and (b) ESAs' scenario - Critical and Fragile ESAs with forest cover overlapping current land use on the Pinhal watershed.

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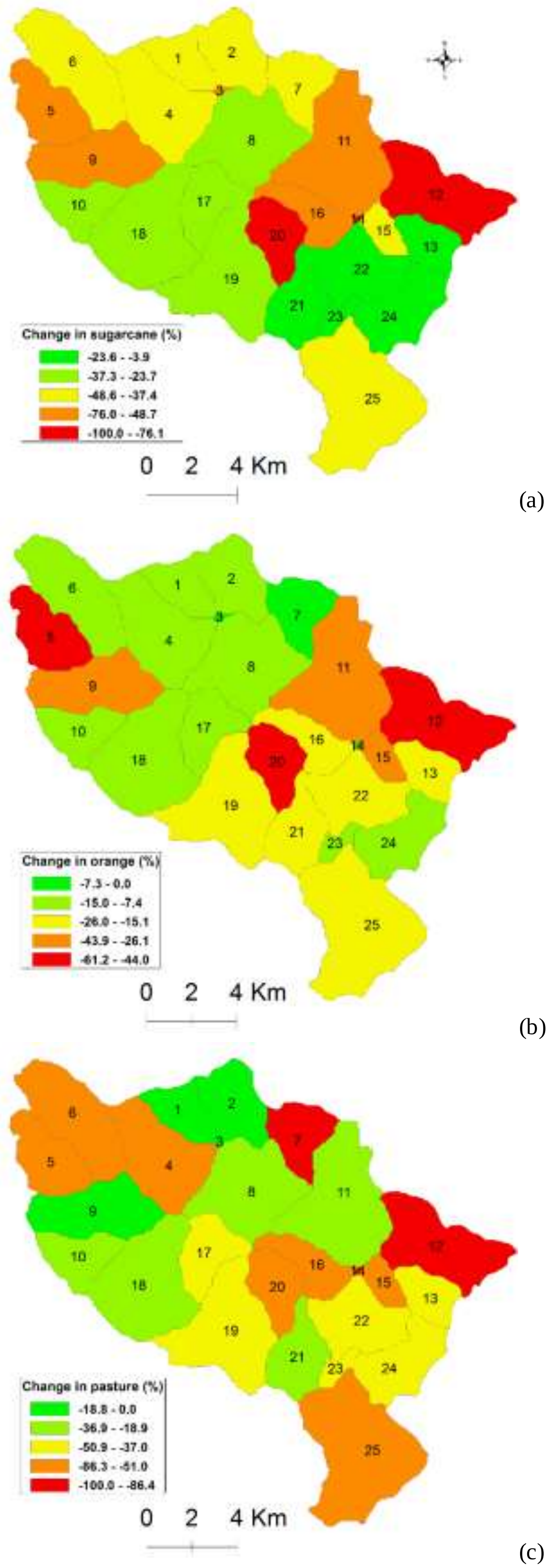

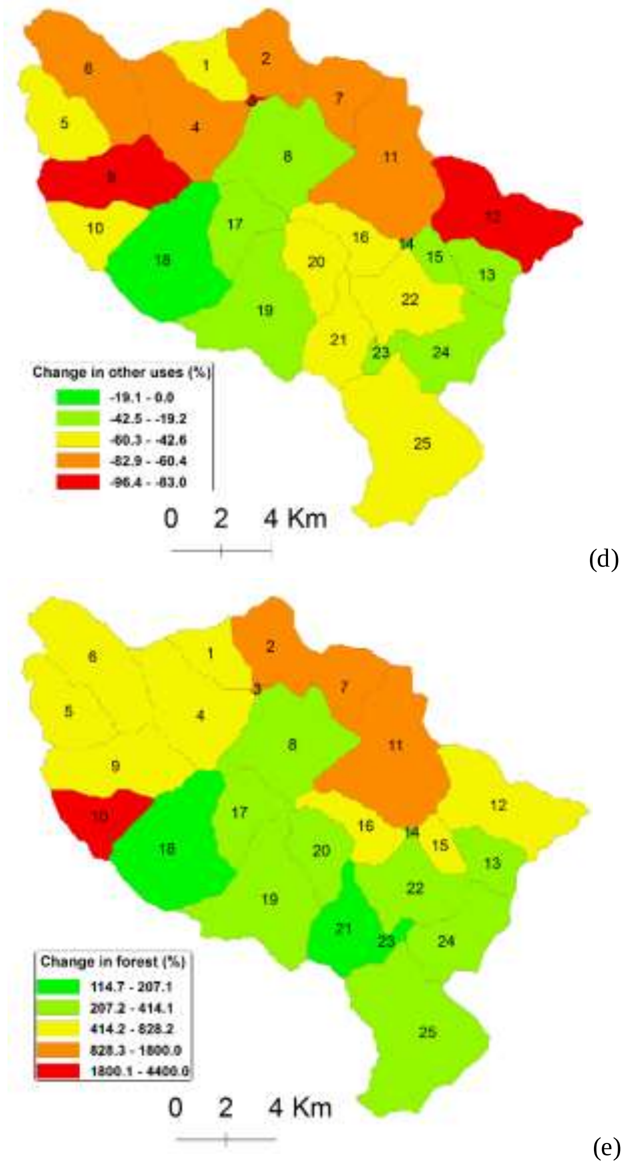

Fig. 6. Spatial variations of land use types at subbasins scale between two scenarios. (a) sugarcane; (b) orange; (c) pasture; (d) other uses; (e) forest.

3.4. . Sediment Yield

The results of the monthly sediment yield presented in Fig. 7 represent the erosion and sedimentation processes occurring throughout Pinhal watershed during the simulation period (2012 to 2014). With the scenario change, reduction in sediment yield was -54% (PBIAS) compared to the current use scenario. This reduction occurred mostly in subbasins located in leptosols and cambisols (Fig. 8). These are not deep soils. Cambisols in the watershed area occur in undulate relief. These are poorly developed soils, with incipient B horizon. One of cambisols' main features is their shallowness and often high content of gravel. High silt content and low depth are responsible for this low soil permeability (Teramoto, 1995). The biggest issue, however, is erosion risk. Cambisols have restrictions of agricultural use, for their

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high erodibility, high risk of degradation and poor trafficability. These soils occupy 19% of the watershed's total area. In the current use scenario, 22.4% of this soil area is being occupied with forest vegetation. In the ESAs' scenario, this percentage increased to 68.3% (Table 4). Leptosols occupy approximately 4% of the watershed's total area and are located in areas of greater declivity. They are in a geomorphologically unstable zone in which erosion affects soil development, and they are constantly renewed through superficial erosion (Teramoto, 1995; Oliveira, 1999). Extensive areas are occupied with sugarcane, pasture and orange (62.3%) cultivation on these soils. In the current scenario, 24.3% of the leptosols is covered with forest vegetation. In the ESAs' scenario, this percentage is 95.7% (Table 4).

The climatological regime has significant importance in the sediment yield in area cultivated with sugarcane in southeast Brazil. It is harvested from May to November and its growth period (December and January) coincides with the beginning of the rainfall season. The pastures in Brazil are generally poorly managed and degraded. Increased forest vegetation on both soils explains the 54% reduction (PBIAS) in sediment yield in the watershed, when we compare the two scenarios. The spatial location of agricultural areas in relation to relief, soil and climate is important to control erosion in watersheds (Grunwald & Frede, 1999).

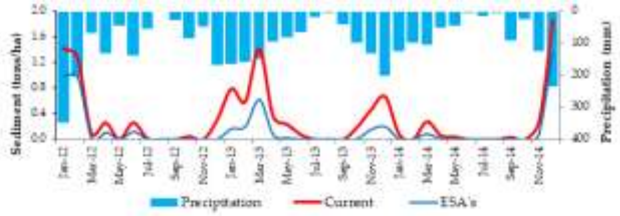

Fig. 7. Monthly Sediment yield between the two scenarios on the Pinhal watershed in the 2012-2014 period.

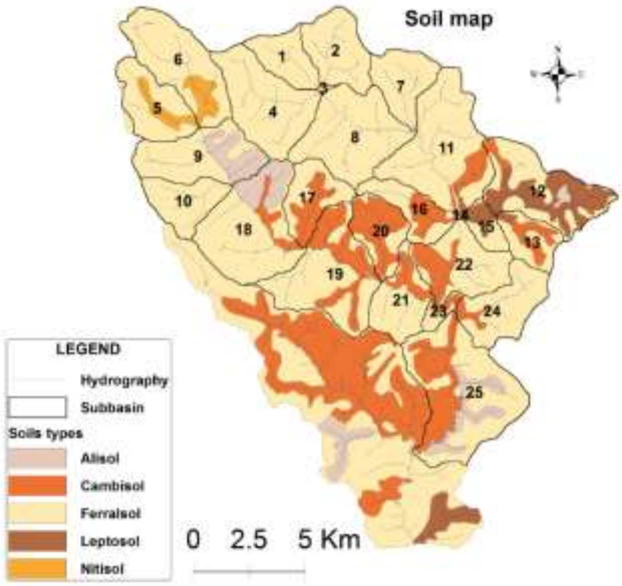

Fig. 8. Pinhal watershed's soil map (Source: Oliveira, 1999). Legend accord to WRB (World Reference Base for Soils Resources).

Table 4: Cross tab between scenarios and soils in the Pinhal watershed.

	Cambisols				Leptosols			
Land use type	**Current use**		**ESAs scenario**		**Current use**		**ESAs scenario**	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Forest	1278	22.4	3894	68.3	275	24.3	1089	95.7
Pasture	947	16.6	399	7.0	169	14.9	10	0.9
Sugarcane	997	17.5	142	2.5	350	30.9	8	0.7
Other uses	2476	43.5	1263	22.2	339	29.9	31	2.7
Total	5698	100	5698	100	1138	100	1138	100

Spatially analysis of sediment yield for 25 subbasins in the current use scenario showed a maximum of 80.2 t/ha, with an average of 14.6 t/ha (Fig. 9). Maximum sediment yield occurred in the upper Pinhal watershed, a more degraded area, whereas in the subbasins in the lower Pinhal watershed aggradation occurs, with lower sediment yield values. In the ESAs' scenario, replacement with forest vegetation in Environmentally Sensitive Areas lead to an average sediment yield of 5.2 t/ha per year, with a maximum of 14.2 t/ha. Average soil loss in subbasins was near tolerable soil loss rates, which according to Leinz & Leonardos (1977) is 7.9 ton/ha for alisols and 4.2 tons/ha for leptosol. According to Fig. 5, the lowest rates of sediment yield occurred in subbasins with greater forest cover. As the SWAT model simulates many processes in the watershed, some parameters may affect several processes (Arnold et al., 2012). With reduction of surface runoff in -45.8% (PBIAS) between scenarios (Table 5) due to greater soil protection, sediment yield has also been directly affected. Sediment yield change between the two scenarios is presented in Fig. 10. This difference is greater in upstream subbasins and in those with greater forest cover (subbasins 11, 14, 15 and 16), according to Fig. 5b.

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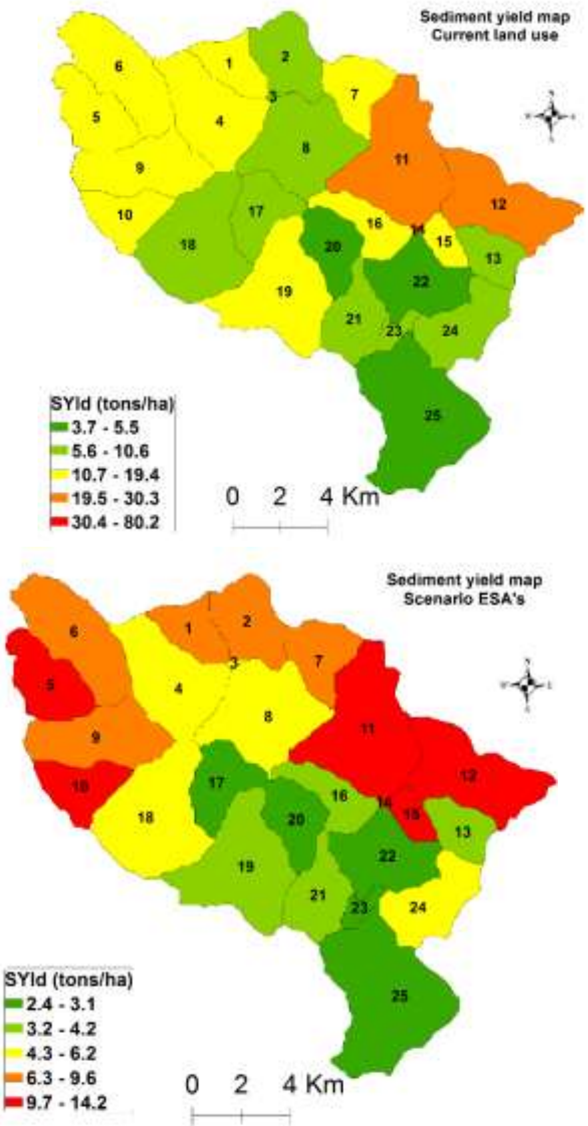

Fig. 9. Spatial distribution of average annual sediment yield at subbasins scale for the two scenarios: current and ESAs.

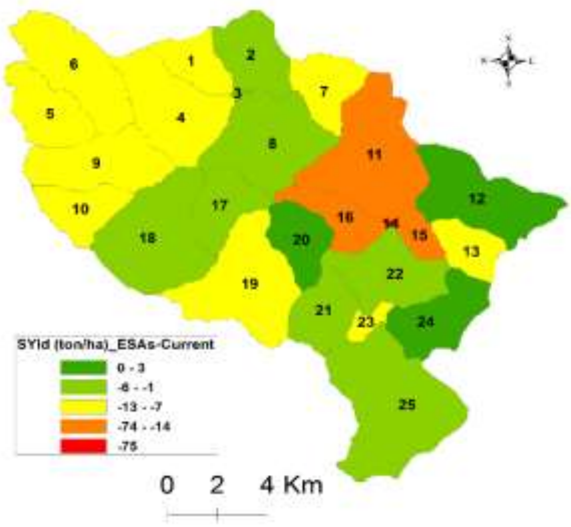

Fig. 10. Percent changes ((SESA-Scu)/Scu×100) of average annual sediment yield at subbasins scale between the two scenarios.

3.5. Hydrological processes

It is widely reported that land use and cover changes can affect the quantity and quality of water resources of a watershed. We analyzed the surface runoff (mm), water yield (mm), evapotranspiration (mm) and soil water content (mm) data to evaluate the impact of these changes on the watershed's hydrological processes. The results showed that the effects of land use/cover change on hydrological processes varied with the seasons and precipitation, and the variation trend was similar to that of the precipitation (Fig. 11).

Monthly values for the 2012-2014 period were then compared between the two scenarios and the results showed increased forest cover in the watershed (+ 373.67%), decreased surface runoff (SR), soil water content (SW), water yield (WY) and increased evapotranspiration (ET) (Table 5). As shown in Fig. 11b, surface runoff reduced most significantly in wet season (October to March), when the precipitation is much more intensive. As both surface runoff and baseflow are the main components that contribute to water yield, we expected greater infiltration rate in the ESAs' scenario. Higher infiltration rate will increase baseflow, because in this scenario, areas previously occupied with other land uses were now occupied with forest. Infiltration rate in forest areas is greater than in other land covers, e.g., sugarcane and pasture areas (Liu et al., 2013). On the other hand, forest evapotranspiration will consume more water (Zhang et al., 2016; Morán-Tejeda et al., 2012) (change of evapotranspiration equal to +3.5%), because it is known that the forest is the surface with highest rates of evapotranspiration, higher than all the other vegetation types and also higher than a liquid's surface (Birkinshaw et al., 2011). Roots, especially of larger trees, increase water absorption from the baseflow and, consequently, decrease water yield in the watershed, as the water content in the soil decreased in the studied period (-14.1%). Studies conducted by Huang et al. (2003), Zhang et al. (2008), Cui et al. (2012) showed that the increased forest cover in watersheds decreased water yield. Differently, with the scenario change, this type of land cover provides greater resistance to surface runoff and, consequently, this component had a lower contribution to water yield in the watershed (-19.3%).

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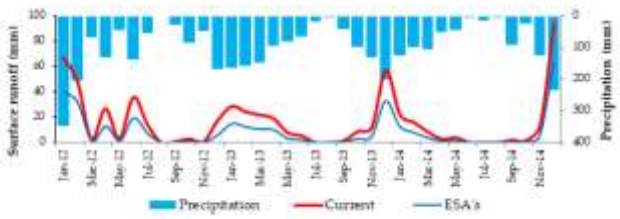
Table 5. Change of hydrological variables analyzed between the two scenarios (current use and ESAs) in the Pinhal watershed (2012-2014).

Variable	Current use	ESAs scenario	Change (%)	Change wet season (%)	Change dry season (%)
Surface runoff (mm)	570.4	309.1	-45.8	-44.0	-52.3
Evapotranspiration (mm)	1993.2	2062.3	+3.5	+1.3	+8.2
Soil water content (mm)	8279.8	7113.5	-14.1	-13.3	-14.9
Water yield (mm)	1471.4	1187.9	-19.3	-22.3	-14.7

We too analyzed the influence of land use change in the hydrological processes in the wet and dry seasons. Comparing evapotranspiration demand in the wet season (October to March) and dry period (April to September), the change between the two scenarios is even greater (Table 5, Fig. 12). The change was +1.3% (wet season). In the wet season, the available water in the soil (Table 5, Fig. 13a) compensates the increased evapotranspiration demand of vegetation, even with increased forest cover (ESAs' scenario). In the dry period, when soil water content is lower, change between scenarios was bigger (-14.9%) (Table 5, Fig. 13b). Change between scenarios for the evapotranspiration too was bigger (+8.2%, Table 5). Forest vegetation access more easily underground water than small-sized vegetation, having, therefore, greater evapotranspiration demand and reducing water yield in the watershed. Based on results obtained from more than 90 experimental catchment in different parts of the world, Bosch & Hewlett (1982) asserted that deforestation decreases evapotranspiration, which results in more water available in the soil and in streamflow. On the other hand, reforestation decreases streamflow at watershed scale. It is worth mentioning, however, that these results vary from place to place and are often unpredictable (Brown et al., 2005).

(a)



(b)

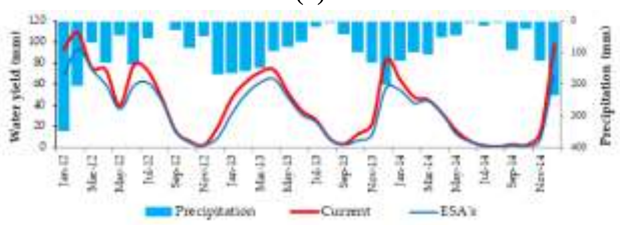
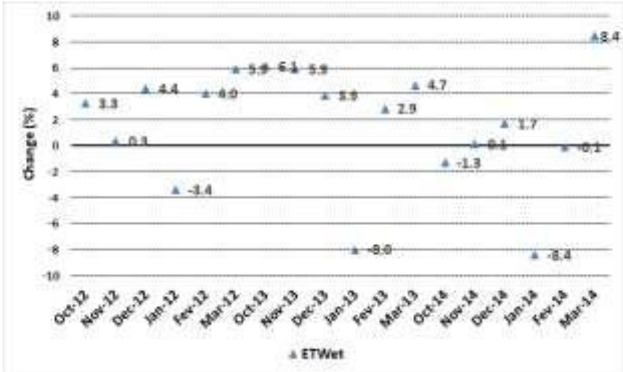


Fig. 11. Comparison of hydrologic processes between the two scenarios in the Pinhal watershed. (a) surface runoff; (b) water yield.

(a)



(b)

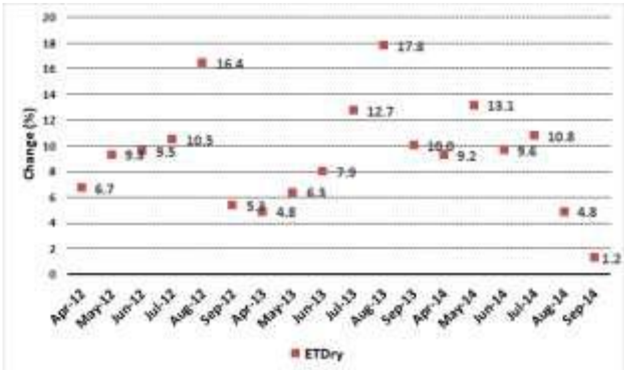
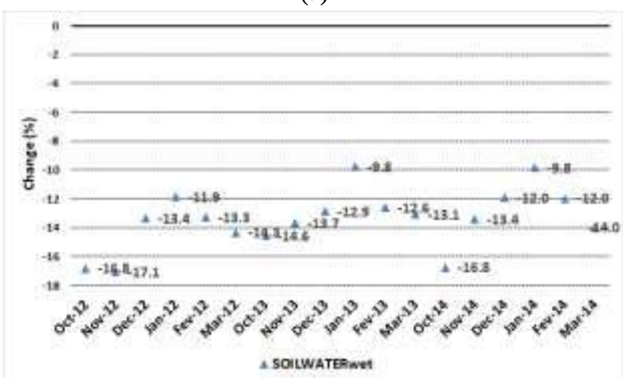


Fig. 12. Percent changes ((S_{ESA}-S_{cu})/S_{cu}×100) of evapotranspiration in the wet season (a) (ETWet - October to March) and dry season (b) (ETDry - April to September) for land use change scenarios in the 2012-2014 period.

(a)



(b)

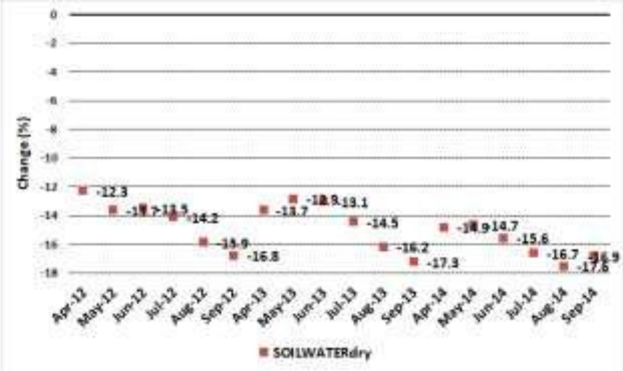
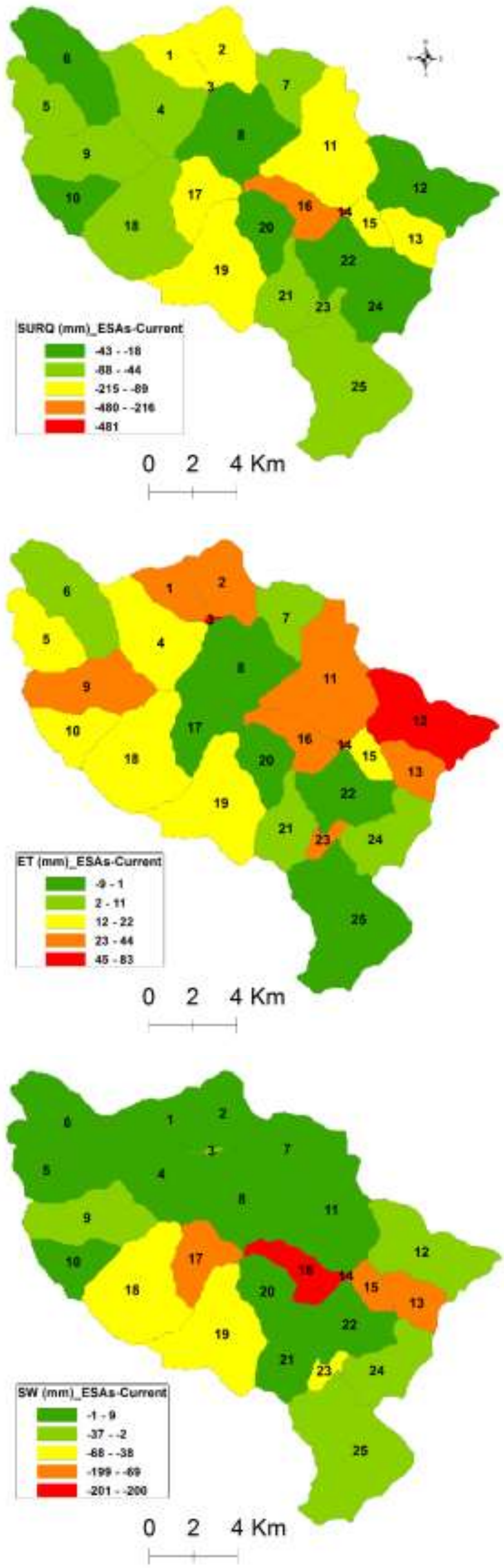


Fig. 13. Percent changes ($(S_{ESA}$-$S_{cu})/S_{cu}\times100$) in the soil water content between wet season (a) (SOILWATERwet - October to March) and dry season (b) (SOILWATERdry - April to September) for land use change scenarios in the 2012-2014 period.

Fig. 14 shows the change in mean annual hydrological processes (surface runoff, evapotranspiration, soil water content and water yields) at subbasins scale between scenarios. The percentage changes caused by land use changes range from -481% to 43%, from -9% to 83%, from -200% to -1% and from -412% to -8%, respectively. The influence of land-use change (Fig. 5) on the hydrological process is more visible in some of the subbasins than others. The dominant hydrological processes and associated drivers are variable across spatial scales (Zhang et al., 2017). Bigger variations occurred in subbasins with greater forest cover when compared the current scenario with the ESAs' scenario. The subbasins 11, 13, 14, 15 and 16, undergoes more pronounced hydrological processes variations than the other. In these subbasins undergoes more significant changes in land use between scenarios. At subbasin 12, change of land use was biggest (Fig. 5). Consequently, evapotranspiration change between scenarios was also higher (Fig. 14b). In this subbasin prevails leptosol soil (Fig. 8). It's shallow soil, with low water storage capacity. Therefore, the change in soil water content was not as pronounced as in the other subbasins with more significant changes in land use between scenarios (Fig. 14c).

According to Andreassian (2004), watersheds' hydrological processes is the result of complex interactions between climate (wet versus dry years), plants' physiological properties (e.g., leaf area and successional stages) and soil type. These and other factors together make hydrological effects of forests a markedly different scenario Singh & Mishra (2012).



(a)

(b)

(c)

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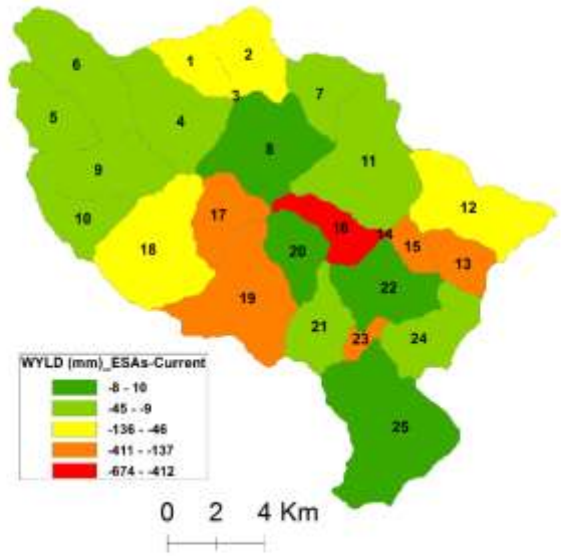

(d)

Fig. 14. Spatial change ((S_{ESA}-S_{cu})/S_{cu}×100) of the hydrological processes at subbasins between the two scenarios. (a) SURQ (surface runoff - mm); (b) ET (evapotranspiration - mm); (c) SW (soil water content - mm); (d) WYLD (water yield - mm).

IV. CONCLUSION

In this study, the ecohydrological SWAT model was used to simulate land use change scenarios and comparing them regarding sediment yield and hydrological processes. The performance of the model for the simulation of the streamflow was very good, indicating that the model was able to represent the hydrological processes of the basin under study, and can be used in scenarios analysis. Although reducing sediment yield from the simulation of land use change for the forest (PBIAS = -54%), for it offers the soil greater protection, its influence on increasing and maintaining streamflow is questionable, because the results obtained from this study also showed that increased forest cover decreased water yield in the watershed in -19.3% (PBIAS) due mostly to its greater evapotranspiration capacity (+3.5%). This demand being even greater during the dry season. Simulation results lead us to conclude that the impacts of land use change on hydrological processes are complex and their consequences are not equal in the subbasins with the same intensity. Thus, its application can help to determine the policies for land use at the Pinhal watershed, and for the management of water resources in the region. However, the hydrological responses to forest cover change between large and small watersheds can be quite different.

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