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Articles

Impact of the climate change and the land use/land cover change in the hydrological and water erosion response in the Quiscab River subbasin

Impacto del cambio climático y cambio de uso/cobertura de la tierra en la respuesta hidrológica y erosión hídrica en la subcuenca del río Quiscab

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Abstract

The following study determines the impact of climate change and the land use/land cover change in the hydrological and water erosion response in the Quiscab sub-basin, its approximate area is 149.7 km^2. The SWAT (Soil and Water Assessment Tool) model is used. It is considered a baseline (1994-2015); a Climate change scenario RCP 8.5, HadGEM2-ES model up to 2050; and two hypothetical scenarios of the land use/land cover change (-80 % forest and +50 % forest). With the SWAT-CUP program, calibration is done in two sites. The site with the least intervention shows a food hydrological performance (NS = 0.77; KGE = 0.87). The site of the most intervention shows a non-satisfactory hydrological performance (NS = -5; KGE = -0.8). Based on the evaluated scenarios, it is predicted that the highest impact in the hydrological and water erosion response will be caused by climate change. The production of water and water erosion is predicted to be reduced up to 40 and 20 %, respectively. Even though the observed data is limited, temporarily and spatially, it was possible to simulate the hydrological cycle and estimate the water erosion, highlighting the importance of the spatial instrumentation and temporary of the national basins.

Keywords: Hydrological modeling, simulation, hydrological response, water erosion, SWAT model, climate change.

Resumen

Este estudio determina el impacto del cambio climático y cambio de uso/cobertura de la tierra en la respuesta hidrológica y erosión hídrica de la subcuenca Quiscab, su área aproximada es 149.7 km^2. Se usa el modelo SWAT (Soil and Water Assessment Tool). Se considera una línea base (1994-2015); un escenario de cambio climático RCP 8.5, modelo HadGEM2-ES al 2050; y dos escenarios hipotéticos de cambio de uso/cobertura (-80 % bosque, y +50 % bosque). Con el programa SWAT-CUP se hace la calibración en dos puntos. Los puntos de calibración presentan comportamiento hidrológico distinto entre caudales simulados y observados. El punto con menor intervención el ajuste hidrológico fue muy bueno (NS = 0.77; KGE = 0.87). El punto en sector de mayor intervención el ajuste hidrológico no fue satisfactorio (NS = -5; KGE = -0.8). Bajo los escenarios evaluados se prevé que el mayor impacto en la respuesta hidrológica y erosión hídrica será ocasionado por el cambio climático. La producción de agua y erosión hídrica prevé reducirse hasta un 40 y 20 %, respectivamente. Si bien los datos observados son limitados, temporal y espacialmente, se logró simular el ciclo hidrológico

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y estimar la erosión hídrica; resalta la importancia de la instrumentación espacial y temporal de las cuencas nacionales.

Palabras clave: modelación hidrológica, simulación, respuesta hidrológica, erosión hídrica, modelo SWAT, cambio climático.

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Introduction

Water plays roles in different processes and it is complicated to define it in a specific category of ecosystem service (Vörösmarty *et al*., 2005); therefore it could be considered a cross-cutting ecosystem service, given its ability to establish the sustaility of living ecosystems (Ripl, 2003).

The Quiscab River subbasin is one of the two main rivers draining into Lake Atitlán (MAGA-DIGEGR, 2013), and is within the Lake Atitlán

Basin Multiple Use Reserve (CONAP, 2007). This lake is one of the most important lakes in the world (Rejmánková, Komárek, Dix, Komárková, & Girón, 2011), which was formed by a cycle of eruptions called Los Chocoyos (Newhall, 1987). Lately, Lake Atitlán has presented problems of increased water pollution due to the load of contaminants that negatively impact and accelerate eutrophication (Dix, Fortin, & Medinilla, 2003; Hernandez *et al*., 2011; Komárek *et al*., 2013; Rejmánková *et al*., 2011).

Imbach, Molina, Locatelli, and Corrales (2010) states that at the Mesoamerican level, the production of drinking water is vulnerable because of reduced rainfall in the future, affecting access to the hydrological ecosystem services due to the possible impact of climate change. This is a result of probable alterations in the hydrological conditions of the place (Zhang, Srinivasan, & Hao, 200). It is estimated that climate change will continue to advance and one must be prepared to adapt and be resilient (Locatelli, 2014). Guatemala is projected to increase its temperature by 1 – 3 °C, from 2010 to 2060, with changes of up to 75 mm of precipitation (Oglesby & Rowe, 2014).

On the other hand, there is evidence that both climate change and land use/cover change are direct drivers of change in ecosystems, causing changes in the rate of ecosystem service delivery (Carpenter *et al*., 2009; MEA, 2005). Land cover change plays an important role in the hydrological cycle, as processes such as evapotranspiration depend on the type of cover, climate, available plant water capacity, among others (Fitts, 2012; McNaughton & Jarvis, 1983; Zhang, Dawes, & Walker, 2001; Zhang, Walker, & Dawes, 1999), and it can increase or decrease surface runoff. In this context, it is necessary to understand the dynamics of the hydrological cycle and water erosion in the Quiscab River subbasin in the face of future changes in climate and land use/cover.

This study aims to determine the hydrological response and water erosion to climate change and land use/cover change in the Quiscab River subbasin, Guatemala. For this purpose, the SWAT model (Arnold, Srinivasan, Muttiah, & Williams, 1998; Neitsch, Arnold, Kiniry, Williams, & King, 2005) was used, which can incorporate climatic anomalies and coverage changes in the simulation process (Neitsch *et al*., 2005). It is an operational or conceptual model (Arnold *et al*., 1998; Zhang, 2014) semi-distributed (Arnold *et al*., 2012) and continuous-time basin scale, operating in daily time intervals; was developed to evaluate and predict the impact of soil management practices on the generation of water, sediment, nutrients and agricultural chemicals Arnold *et al*., 2012; Arnold *et al*., 1998; Gassman, Reyes, Green, & Arnold, 2007; Neitsch *et al*., 2005).

Arnold *et al*. (1998) mention that the SWAT model does not require calibration to meet its predictive objective, this is a reality in basins with poor instrumentation. The SWAT model simulates the hydrological processes in two stages, the first is the terrestrial phase of the hydrological cycle (quantity) and based on the mass balance equation, and the second stage consists of the routing or conduction of the loads simulated in the terrestrial phase, to the water network or reservoirs (Arnold *et al*., 2012; Neitsch *et al*., 2005; Zhang, 2014).

Methods

Study area

The Quiscab River subbasin (14º 48' 32.9" N, 91º 13' 51.89" W), belongs to the Lake Atitlan basin of the Pacific slope, and has an area of 149.7 km^2; which represents 28 % of the lake basin in question (Figure 1).

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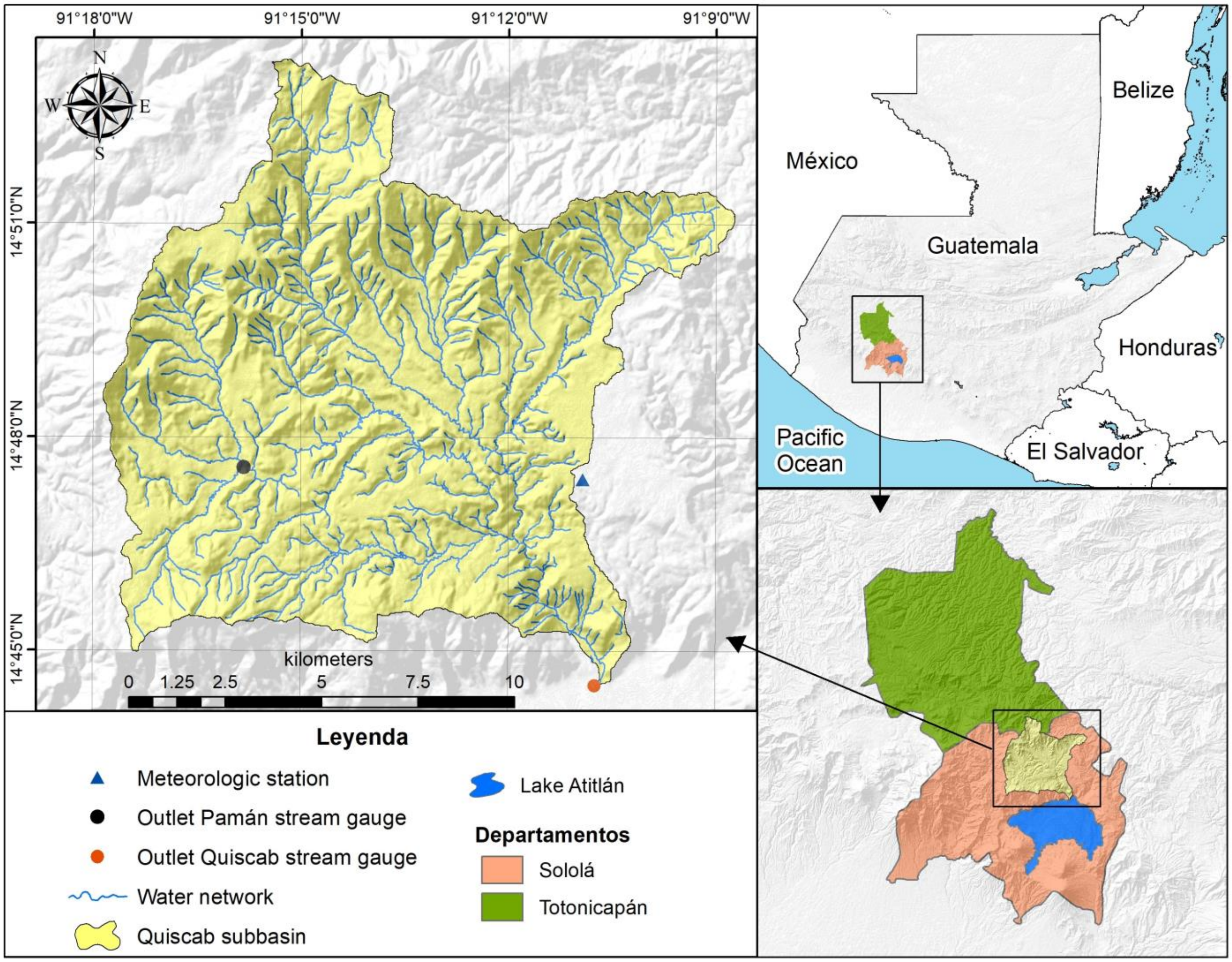

Figure 1. Location of the study area, Quiscab River subbasin, Lake Atitlán basin, Guatemala.

Its climate, according to Thornthwaite, ranges from humid cold to very humid semi-warm (MAGA-DIGEGR, 2013; UPGGR-MAGA, 2009). It comprises three Holdridge life zones: very humid Subtropical Montane

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Forest (bmh-M); very humid Subtropical Low Montane Forest (bmh-MB); and the humid Subtropical Low Montane Forest (bh-MB). Thirty-five percent of its area corresponds to the forest, 38.6 percent to basic grains, 4.8 percent to vegetables, 1.3 percent to grasses, shrubs, and places with little vegetation with 18.3 percent and 0.1 percent, respectively (GIMBUT, 2014; INAB & CONAP, 2015; MAGA-DIGEGR, 2015).

Data for the SWAT model

The simulation with the SWAT model required climate and biophysical information that was obtained from different sources (Table 1). Local use/coverage was reclassified according to the SWAT database. The soil variables were completed with the *Soil Water Characteristic* programs developed by Saxton and Rawls (2006), and NumCur to estimate soil variables not contained in the cited sources. The statistics of the climatic variables were calculated with Macro 4.1 of Microsoft Excel®. The topographic, coverage, soil, climate, and flow information were systematized and analyzed to configure the SWAT model.

Table 1. Data was used to configure the SWAT model.

Variable	Information	Source
Topography	Digital elevation model (1:50 000), spatial resolution 20 m	MAGA, 2010
Land use/land cover	Map of forests and land use 2012 (1:50,000), forest map by forest type and subtype (1:50,000), and map of vegetation cover and land use of the Republic of Guatemala (1:50,000)	GIMBUT, 2014; INAB & CONAP, 2015; MAGA-DIGEGR, 2015
Soil type	Semi-detailed study of the soils of the department of Sololá (1:50,000)	MAGA-DIGEGR, 2013
Weather	El Tablón weather station, rainfall, and temperature variables (minimum and maximum). Period 1994 to 2015.	(INSIVUMEH, 2016)
Monthly streamflow	Gauging data of Quiscab River and Pamán. Periods: 15 months (between 2013 and 2014) and 12 months (between 2007 and 2008)	URL-UNR-UVG-DRI-UCD, 2014; Xicay, 2011
Climate Change	MarkSim® platform, RCP 8.5 climate change scenario, and HadGEM2-ES model for the year	Jones & Thornton, 2013

	2050 Monthly precipitation and temperature anomalies.	

Configuration and simulation SWAT model

The study was conducted with the ArcSWAT 2012.10 extension (Winchell, Srinivasan, Di-Luzio, & Arnold, 2013) for the ArcGis® version 10.2 program (Esri Inc., 2014). Seven micro-basins were defined for the Quiscab River subbasin and a three-year heating period. The unique overlap of topography, soil, and vegetation generated the hydrological response units (HRU); the slope was categorized according to the FAO classification (FAO, 2009). Thus, the SWAT model, considering the two levels of spatial heterogeneity, subbasins, and HRU (Zhang, 2014), simulates the hydrological cycle in each of these units and then combines them to calculate the water balance in each basin. The hydrological cycle is simulated according to the equation given below, which defines the final water content in the soil as a function of the initial water content in the soil (SW_0), time (t), precipitation (R_{day}), runoff (Q_{surf}), evapotranspiration (E_a), percolation in the soil profile (w_{seep}), and return flow (Q_{gw}); all the above in daily scale and in millimeters (Neitsch *et al*., 2005):

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$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

Water erosion is calculated with the modified universal soil loss equation (MUSLE) by Williams (1975a):

$$SYLD = 11.8 * \left(Q_{surf} * q_{peak} * area_{urh}\right)^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG$$

Where $SYLD$ is the erosion on a given day (ton); Q_{surf} is the surface runoff (mm H2O ha-1); q_{peak} is the maximum rate of runoff (m^3 s^{-1}); $area_{urh}$ is the area of the HRU (ha); K_{USLE} is the USLE factor of soil erodability; C_{USLE} USLE factor of coverage and management; P_{USLE} is the support practice USLE factor; LS_{USLE} is the topographic USLE factor, and $CFRG$ is the macro fragment factor. Soil conservation practices were not considered.

Before calibration, parameter adjustments were made to achieve the best reference or initial simulation. The method of Hargreaves and Samani (1985) was defined for potential evapotranspiration. The initial number (CN) curve was varied according to local vegetation conditions (hydrological conditions) and soil hydrological group (Cronshey, 1986). Manning's roughness coefficient (n) for surface flow was modified for each cover category according to Engman (1986). Finally, the main channel and tributary roughness was modified by Manning's tabular method

(Chow, 1994). This established the initial simulation, which was later calibrated with the average monthly flow variable as described in the following section.

Calibration and uncertainty analysis

Sensitivity analysis, calibration, and uncertainty analysis were performed with the SUFI-2 algorithm (Abbaspour, Johnson, & Van Genuchten, 2004; Abbaspour *et al*., 2007) included in the SWAT-CUP program (Abbaspour, 2015). This algorithm performs semi-automated inverse modeling and combines optimization (calibration and sensitivity analysis) and uncertainty analysis (Abbaspour *et al*., 2004; Abbaspour *et al*., 2007) which quantifies the uncertainty of the model outputs with the 95 % uncertainty prediction band (95 PPU) at two queues, through sampling by Latin hypercube method. To measure the calibration goodness of fit, it uses the P-factor and R-factor rules, the first one being the fraction of the observed data plus its error contained in the 95 PPU band, varying from 0 to 1. The second one is the fraction between the mean distance of the minimum and maximum values of the 95 PPU band and the standard deviation of the observed data (Abbaspour *et al*., 2004; Abbaspour *et al*., 2015; Abbaspour *et al*., 2007).

The calibration was done with the monthly flow variable; and it was done at two points, one at the Pamán River and the other at the mouth of the Quiscab River. At the first point, the calibration period was from April 2014 to August 2015, and for the mouth of the Quiscab River, in addition to the same period for the Pamán River, another record was added (September 2007 to August 2008). The objective function used to evaluate the hydrological adjustment of the calibration was the Kling-Gupta criterion (Gupta, Kling, Yilmaz, & Martinez, 2009):

$$KGE = 1 - ED$$

$$D = \sqrt{(r-1)^2(\propto -1)^2 + (\beta - 1)^2}$$

Where ED is the Euclidean distance from the ideal point; β is the quotient between the average of the simulation and the average of observed values, it represents the bias; $\propto$, quotient between the standard deviations of the simulation and the observed data, represents the variability; r linear correlation coefficient between simulated and observed data (Abbaspour, 2015; Gupta *et al*., 2009). Other adjustment statistics were calculated: Nash-Sutcliffe (NS); percentage of bias (PBIAS); and the ratio RSR or root mean square error standardization.

600 simulations were calculated in two iterations and the overall sensitivity method was used to define the most sensitive variables in the flow rate calibration. The 12 calibration parameters were defined based on a literature review (Abbaspour, 2015; Abbaspour *et al*., 2015; Arnold *et al*., 2012; Marcinkowski, Piniewski, Kardel, Giełczewski, & Okruszko, 2013; Me, Abell, & Hamilton, 2015; Rostamian *et al*., 2008; Santhi, Kannan, Arnold, & Di-Luzio, 2008; Singh, Bankar, Salunkhe, Bera, & Sharma, 2013) and the overall sensitivity (Table 2).

Table 2. Parameters used for two-point calibration of the Quiscab subbasin.

Parameter	**Description**	**Calibration range**
r__CN2.mgt	Number curve for humidity condition II.	-0.17 a 0.03
r__SOL_AWC().sol	Available water capacity on the floor, mm/mm floor.	-0.15 a 0.03
v__GW_REVAP.gw	Coefficient of return of water from the aquifer to the root zone	0.07 a 0.24
v__ALPHA_BF.gw	The alpha factor of the deep aquifer groundwater recession curve, 1/day	0.34 a 1.0
v__GW_DELAY.gw	Delay time for aquifer recharge, days	0.00 a 243.97
v__ESCO. URH	Soil Evaporation Compensation Factor	0.20 a 0.75

v__CH_N2.rte	Manning's "n" coefficient for the main channel	0.14 a 0.30
r__SOL_K().sol	Saturated hydraulic conductivity, mm/h	-0.80 a -0.0066
v_CH_K1.sub	Effective hydraulic conductivity in the tributary channel, mm/h	17.18 a 55.32
v_RCHRG_DP.gw	Coefficient of percolation of the deep aquifer	0.40 a 1.00
r_SLSUBBSN. URH	Average slope length, m	0.09 a 1.00
r_SOL_BD().sun	Apparent soil density, g/cm^3	-0.10 a 0.14

Climate change and land use/land cover change scenario

After calibration, prospective scenarios were incorporated, one for climate change and two for land use/land cover change; these were compared with the base scenario (1994-2015) and considered relative changes and associated variability. For each scenario, the following SWAT model

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configuration was not modified: topography, soil type, and watershed division.

The climate change scenario assumes that the spatial distribution of precipitation, temperature, and land use are constant. While the spatial distribution of precipitation does not change. This is how the RCP 8.5 scenario is evaluated to the year 2050. This scenario was selected for the following criteria: it is the most critical of the CMIP5 (Cubasch *et al*., 2013), similarity in radiative forcing (Meinshausen *et al*., 2011), and in temperature anomaly with the other scenarios (RCP 4.5 and RCP 6.0) (Collins *et al*., 2013); to the year 2050. In addition, the last year of the base simulation was the hottest year on the global surface of the earth (Hansen, Sato, Ruedy, Schmidt, & Lo, 2016; WMO, 2016) and in Guatemala, by 2015 it is reported that the monitored stations presented higher frequencies (days) with average daily temperatures above the average for the period 1981-2010 (Amador, Hidalgo, Alfaro, Durán-Quesada, & Calderón, 2016).

The HadGEM2-ES (Hadley Centre Global Environmental Model version 2, Earth System Model) General Circulation Model (GCM) was used (Collins *et al*., 2011; Jones *et al*., 2011; Martin *et al.*, 2011) with downscaling by the MarkSim® platform statistical method (Jones & Thornton, 2013).

The choice of this model is because it is in the third of models with the highest magnitude (> 66 %) of the temperature anomaly, considering the 17 MarkSim® models; being likely that the anomalies of this model will happen (Stocker *et al*., 2013). The HadGEM2-ES model includes components of the atmosphere, ocean, stratosphere, and the Earth system (Earth-System, ES); the latter contains the dynamics of vegetation, ocean biology, and atmosphere chemistry (Jones *et al*., 2011; Martin *et al*., 2011).

For the dynamics of land use/land cover change (LULCC), two hypothetical scenarios were proposed, these are: a) reduction (80 %, LULCC 1); and increase (50 %, LULCC 2) of the forest area. In the configuration of the SWAT model, the climate was not modified. These scenarios are represented by the dynamics between forest and grassland, shrubland, and low vegetation sites; this conversion was established by spatial proximity. The use of hypothetical land use/land cover change and climate change scenarios is applied in several studies using the SWAT model (Chen, Ale, Rajan, Morgan, & Park, 2015; Gassman *et al*., 2007; Morán-Tejeda *et al*., 2015; Qi, Sun, Wang, McNulty, & Myers, 2009; Zhang, Nan, Xu, & Li, 2016).

Results

Calibration of the SWAT model

Of the two calibration points, the best calibration strength and uncertainty evaluation was presented by the Pamán River, given its P-factor value close to 70 % recommended by Abbaspour *et al*. (2015) for the discharge variable. Also, the NS, RSR, and PBIS criteria presented very good values according to the scale proposed by Moriasi *et al*. (2007) and the Kling-Gupta criterion had very good behavior, given that its three components bias, variability, and linear correlation were close to their optimal value (1) (Figure 2).

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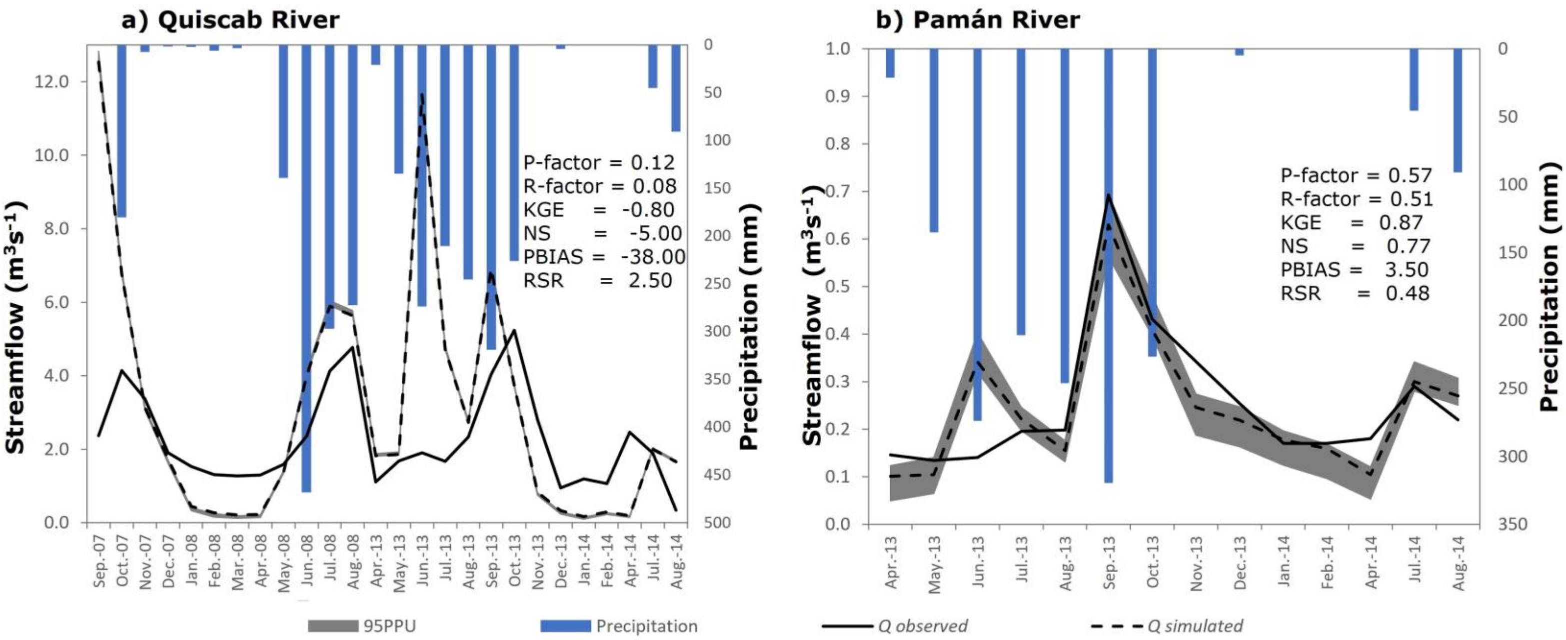

Figure 2. SWAT model calibration in Quiscab River subbasin.

Regarding the sensitivity of the parameters subject to calibration, eight of the twelve showed the highest sensitivity ($p \leq 0.05$) to discharge adjustment, these are: saturated hydraulic conductivity, number curve, effective hydraulic conductivity of the tributary channel, compensation factor for soil evaporation, deep aquifer percolation coefficient, average slope length, available water capacity in the soil, and soil bulk density.

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Effect of climate change on hydrological response and water erosion

During the baseline scenario (1994-2015) in the Quiscab River subbasin, the mean annual contribution of rainfall was equal to 1,472 ± 276.4 mm. Meanwhile, the water production of 696 ± 224.2 mm, surface runoff 234 ± 113.5 mm, lateral flow 316 ± 74 mm, baseflow 61 ± 31.2 mm, percolation 150 ± 75.3 mm, and the median of the actual evapotranspiration estimated is 749.6 mm (724.4-781.0). On the other hand, water erosion is 26.8 ± 15 t ha^{-1} year-^{1}. Meanwhile, the mean annual simulated streamflow at the outlet of the Quiscab River subbasin is 3.3 m^3 s^{-1}.

In the Quiscab River subbasin in 2050 under the climate change scenario RCP 8.5 of the HadGEM2-ES model, annual changes of -23, -6, -40, and -51 % are suggested for rainfall (PRECIP), current evapotranspiration (ET), water production (WYLD) and percolation (PERC), respectively. Water recharge (GW_RCHG) would decrease by 48 %, and water erosion (SYLD) is expected to experience a 20 % annual reduction. On a multi-year monthly scale, the greatest change in the hydrological variables PRECIP, ET, and WYLD is predicted at -100, -19, and -68 %, respectively (Figure 3). Water recharge and erosion are expected to change the most by -86 and -100 %, respectively.

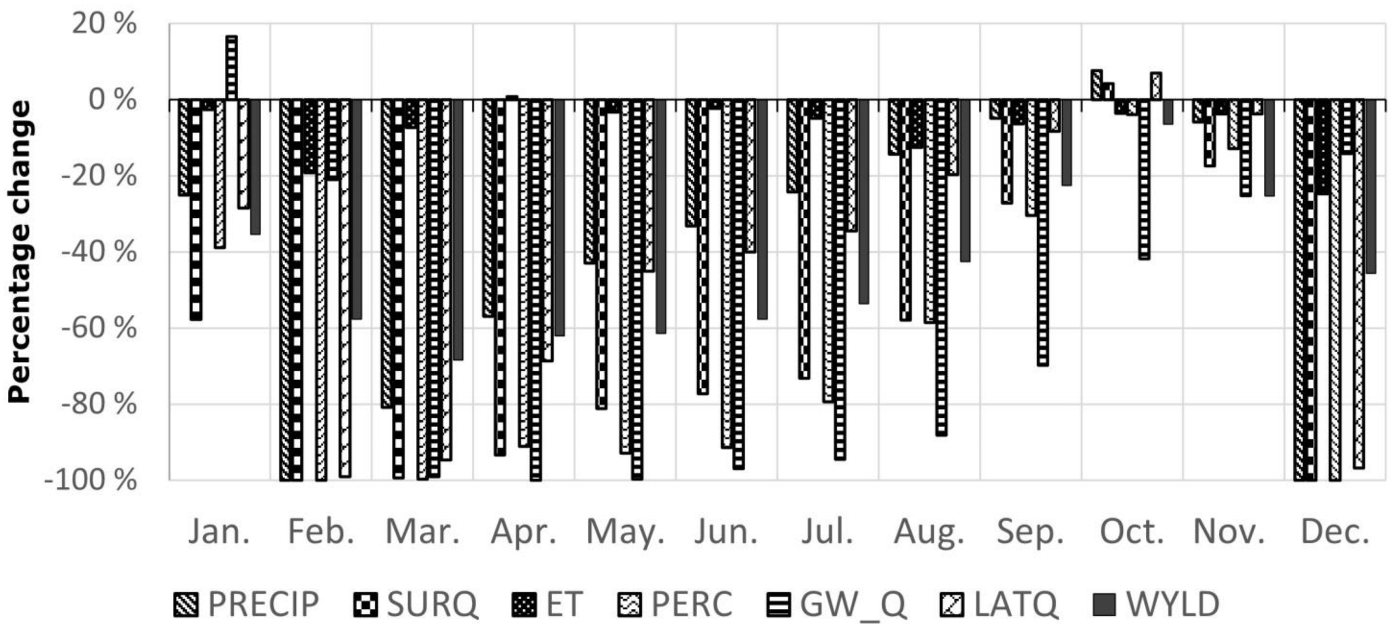

Figure 3. Average monthly percentage change of water balance fractions in the face of climate change in 2050.

Throughout the year with the RCP 8.5 scenario to 2050, variability is expected to increase slightly for ET, PRECIP, and lateral flow (LATQ) (6-15 %), moderately for surface runoff (SURQ), WYLD, and GW_RCHG (between 15 and 35 %) and severely for PERC, baseflow (GW_Q) and SYLD (> 35 %), all with respect to the baseline. While the spatial change of the components of the water balance, water production, and water erosion is presented in Figure 4, where the effect of the climate change scenario is expected to be a general reduction of these hydrological variables and water erosion.

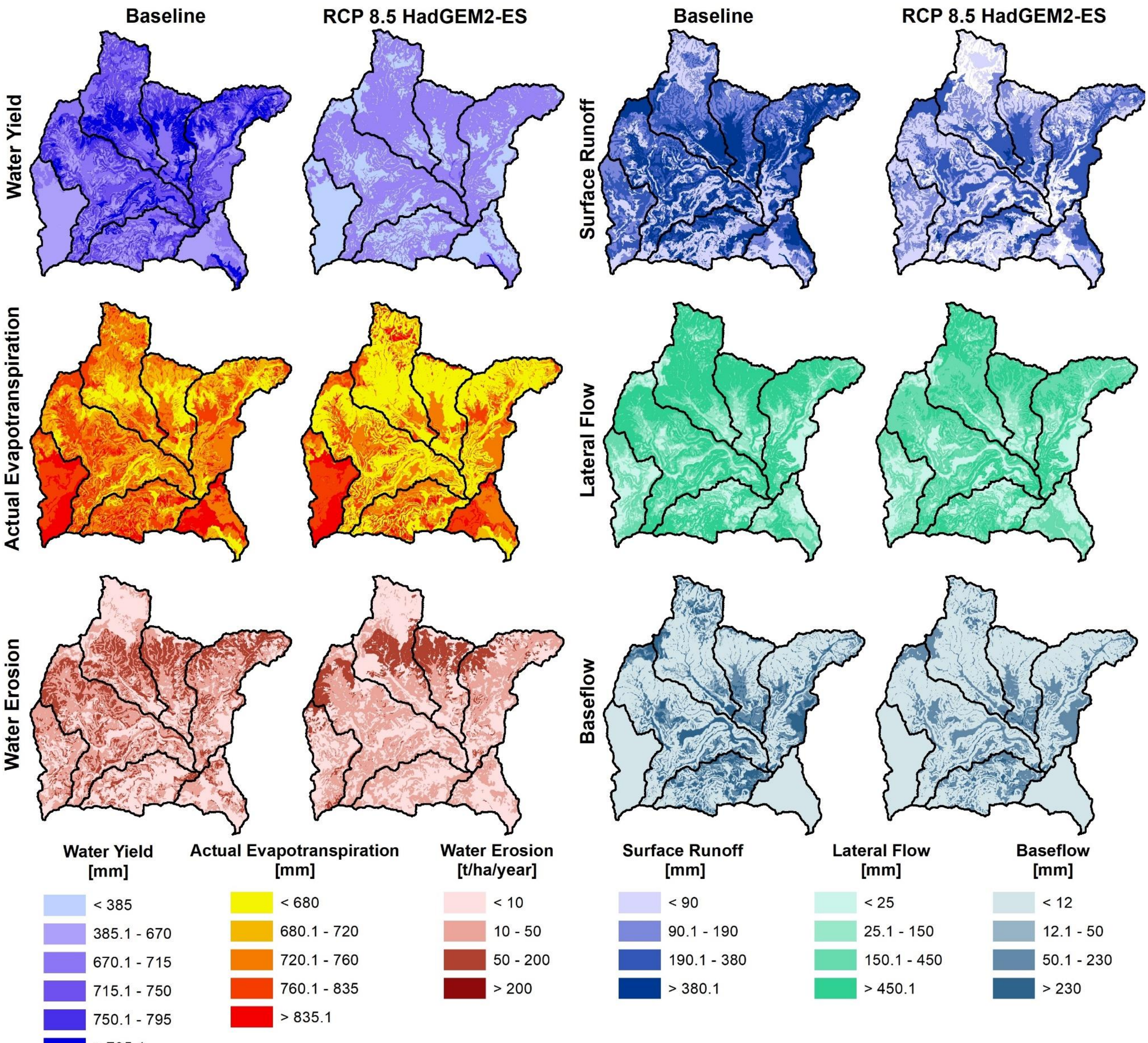

Figure 4. Hydrological response and water erosion to climate change in the Quiscab River subbasin.

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Effect of land use/land cover change on hydrological response and water erosion

The possible annual change under the LULCC 1 scenario (-80 % forest) would be -3 % for ET, while WYLD, SURQ, LATQ, GW_Q, water recharge, and erosion are projected to change +3, +4, -1, +10, -1, and +10 %, respectively. On a multi-year monthly average, the largest changes for the variables ET, WYLD, SURQ, GW_Q will be -36, +5, +8, and +24 %, respectively (Figure 5). Water recharge and erosion suggest their greatest changes in the order of +10 and +61 %, respectively. Variability (coefficient of variation) throughout the year will present very slight changes (< 6 %) for the variables SURQ, PERC, GW_Q, LATQ, WYLD, and GW_RCHG. Slight changes for ET (between 6 and 15 %), and moderate for water erosion (between 15 and 35 %).

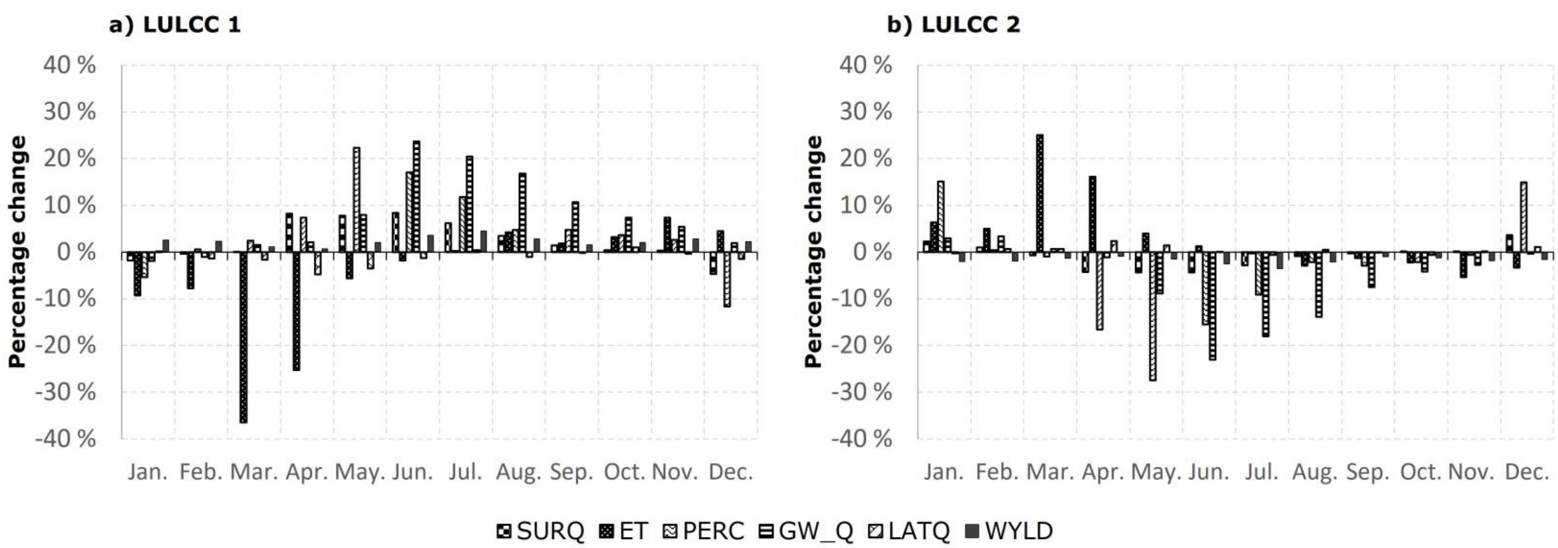

Figure 5. Average monthly percentage change of water balance fractions under two coverage changes scenarios.

Annual average changes are suggested under the LULCC 2 scenario (+50 % forest), where ET would increase 2, SURQ -2 %, GW_Q -8 %, and WYLD -2 %, water recharge and erosion -14 % and -1 %, respectively. LATQ would experience no change in the annual balance. With respect to the average monthly change (Figure 5), the greatest changes are predicted for the variables ET, WYLD, SURQ, LATQ, and GW_Q, at +25, -3, -4, -23, +2 %, respectively. Water recharge will show its biggest change of -28 % and water erosion by +34 %. The variability during the year of the fractions of the balance and the hydric erosion is suggested to present very slight changes (CV < 6 %).

The spatial dynamics of the components of the water balance, water production, and water erosion are presented for the two hypothetical land use/land cover change scenarios, where it is evident that the -80 % forest cover scenario (LULCC 1), would result in increased water production, surface runoff, baseflow, and water erosion. Actual evapotranspiration is reduced. The 50 % increase in forest cover scenario (LULCC 2) is projected to reduce surface runoff, baseflow, water production, and water erosion, with an increase in actual evapotranspiration (Figure 6).

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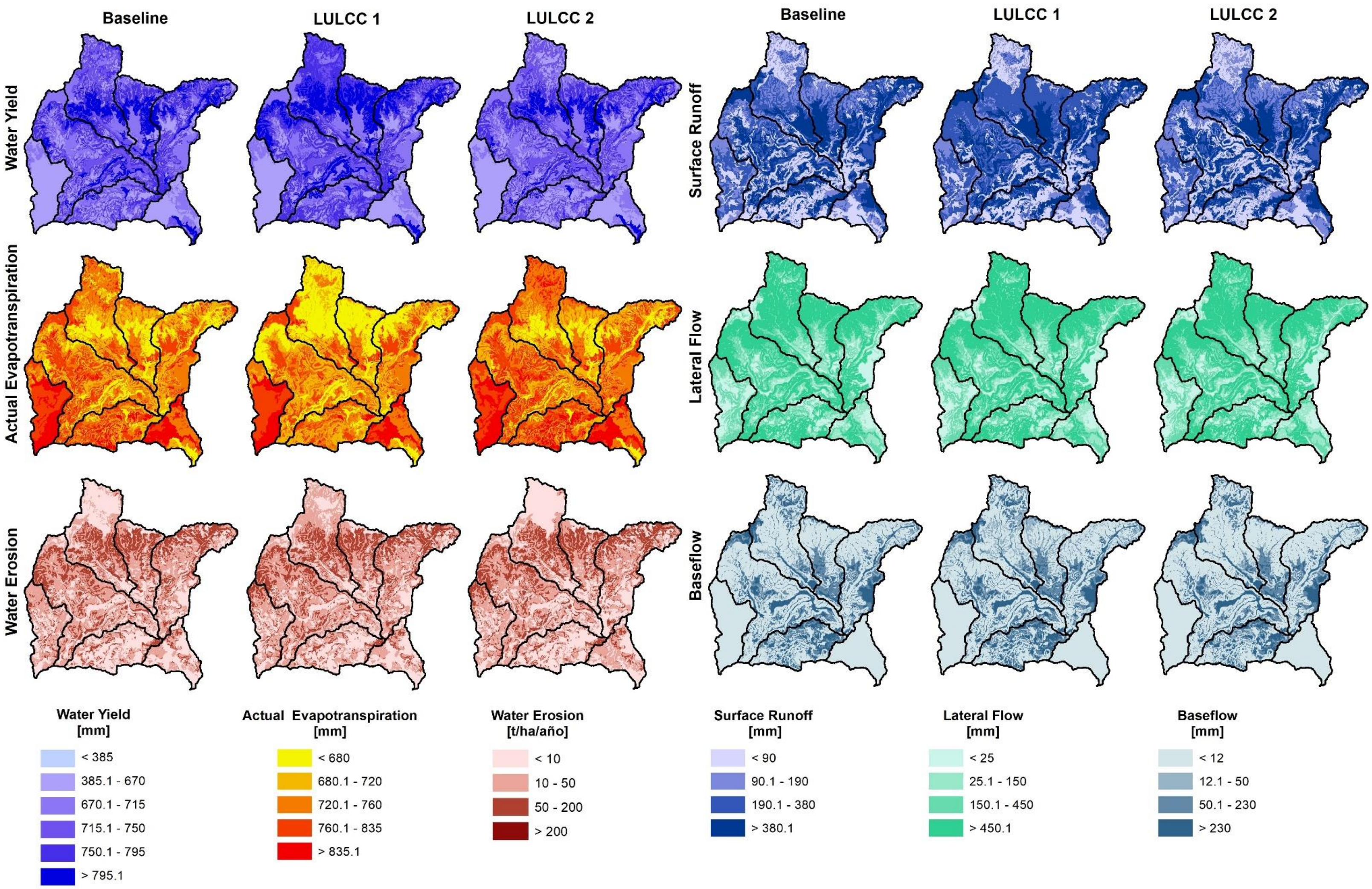

Figure 6. Hydrological response and water erosion to land cover changes in the Quiscab River subbasin.

Discussion

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Calibration of the SWAT model

The lack of adjustment between simulated and observed flows at a calibration point indicates a general lack of matching. A multi-site calibration approach was used (Cao, Bowden, Davie, & Fenemor, 2006), however, the observed flow data, also rain, available are of limited spatial detail, contrary to Zhang, Srinivasan, and Van Liew (2008) recommendation for this approach. This results in a limited spatial calibration (Arnold *et al*., 2012), masked model outputs (Takken *et al*., 1999) since the good fit at one point (Pamán River) was not reflected in the calibration at the Quiscab River output. Additionally, the temporal distribution of observed flows is poor. These spatial-temporal data, flow, and climate limitations lead to errors in the simulation models (Refsgaard & Storm, 1996), which is confirmed by the uncertainty assessment factors, which reflect the poor quality of the observed data (Abbaspour *et al*., 2007).

The morphometric conditions (drainage density, concentration-time) of the Quiscab subbasin favor its high efficiency in evacuating the rain it receives, given its low permeability and rapid hydrological response

(Horton, 1932), which is presented in high flow values in the rainy season. In addition, the high load of sediments transported in its bed during storm events makes it difficult to establish fixed gauging points (Hernández-Moreno, Álvarez-Nuñez, Girón, & Gutiérrez-López, 2011). When adding in the analysis the location of the gauging point, time of measurement, access to the gauging point, the uncertainty of the instrument and personnel makes it difficult to take data that properly reflect the natural discharge of the river; which results in recording errors of observed values (Refsgaard & Storm, 1996).

Although the SWAT conceptual model allows considering water extraction (Neitsch *et al*., 2005) and thus improving flow calibration, there is no historical record of gauging and monitoring points in the subbasin, a situation observed in the field trip. Extraction is a factor to be considered for monitoring since the main source of water access in this area is through rivers and springs (IARNA-URL, 2013).

Given the limitations of data observed for calibration, a typical characteristic of poorly instrumented basins, a good flow calibration adjustment was achieved at one point in the Quiscab subbasin. The positive aspect was to evidence the spatial variability of the flow variable, because in a micro-basin (Pamán) with little intervention, the calibration was satisfactory, a situation that did not occur in another point of high intervention. It is evident that information on use, consumption, and management is necessary for areas of high intervention.

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Effect of climate change on hydrological response and water erosion

By incorporating the climate, precipitation, and temperature anomaly, the other components of the water cycle would be expected to change, since precipitation is the main component of this cycle (Brutsaert, 2005; Davie, 2008; Han, 2010), and temperature is one of the components that govern evapotranspiration (Fitts, 2012), where the transpiration fraction is the process of greatest water loss in the basin (Fetter, 2000). The moderate to severe changes expected in the hydrological response and water erosion of the Quiscab subbasin is largely due to the reduction in the rate of evapotranspiration due to the decrease in the water capacity available in the soil and plant interception, ignoring the natural buffering capacity of the local ecosystem.

As for the variability of the annual regime of the components of the water, balance will increase, and with it, the changes in dry and rainy seasons may increase problems of water stress and water scarcity (Arnell, 2004; Revenga, Brunner, Henninger, Kassem, & Payne, 2000) change in agricultural aptitude (Bouroncle *et al*., 2016), impacts on drinking water (Imbach *et al*., 2010) and other hydrological services of the ecosystem.

Compared to other studies using the SWAT model, variable hydrological responses to the effect of climate change at other latitudes are revealed. For example, in the United States for two basins in Idaho, maximum flows are projected in the range of -198 m^3 s-1 and +106 m^3 s-1, and positive precipitation and temperature anomalies predominate; in one of the basins, forest cover predominates and in the other diverse cover (Jin & Sridhar, 2012). Chien, Yeh, and Knouft (2013) suggest an annual flow reduction between 41.1 and 45.2 % for the period 2051-2060 for four basins of the Mississippi River, where agricultural use predominates (> 68 %).

In the Blue Nile river basin, Koch and Cherie (2013) estimated that under scenario A2 the greatest changes in precipitation, water production, and evapotranspiration were -13, -45, and -2 %, respectively. Similarly, in Africa, Awotwi, Kumi, Jansson, Yeboah, and Nti (2015) showed that surface runoff, baseflow and evapotranspiration would increase by 26, 24, and 6 %, respectively, in the face of climate change. In India, Pandey, Gosain, Paul, and Khare (2016) quantified that in the face of climate change in the Armur basin, evapotranspiration and water production would increase by 28 and 49 %, respectively. In Chile, Stehr, Debels, Arumi, Alcayaga, and Romero (2010) modeled that in the face of climate change the flow of water in the Biobío river basin will decrease by 32 and 45 %.

The average annual erosion of the Quiscab subbasin is currently moderate according to the FAO classification (FAO, 1980). This category is largely due to the geomorphological and landscape characteristics of

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the study area (MAGA-DIGEGR, 2013). The average simulated erosion at the baseline, 26.8 ton ha-1 year-1, resembles the average between potential erosion and overuse potential erosion in the Quiscab sub-basin (24 ton ha-1 year-1) estimated by Pineda (2009). In the Quiscab subbasin, the combination of poor soil and vegetation conservation practices combined with inherent geomorphological characteristics exacerbate erosion in the area, without forgetting that the subbasin is about to reach the balance of the erosion cycle, according to Strahler's (Strahler, 1957) criteria.

In this subbasin, water erosion is expected to be reduced by 20 % because the decisive factors, rainfall, and surface runoff, decreased by 23 and 51 %, respectively, resulting in soil losses below the baseline (FFTC, 1995; Morgan, 1997). The decrease in surface runoff is key since the erosion estimation method used, MUSLE, uses this variable as an energy factor (Williams, 1975a; Williams, 1975b). The precipitation anomaly also plays an important role, given that the amount and intensity of rain are the factors that control erosion changes in the face of climate change (Nearing, Pruski, & O'neal, 2004).

Similar to this study and with the use of the SWAT model, in Vietnam Khoi and Suetsugi (2013) project that in the face of climate change (scenario A1B) by 2050 the production of sediments will be reduced by 1.4 %. Similarly in China, Yu, Xie, and Meng (2017) predict a reduction of up to 1.4 Mt month^{-1}, in the period 2049-2064, under the models ESM2M, HadGEM2, and CM5A of the CMIP5. Conversely, in Vietnam, Khoi and Suetsugi (2013) indicate that by 2080 sediments will increase by 4.5 %, with an average temperature increase of 2.9 °C. Similarly, Thai, Thao, and Dieu (2017) estimate that soil loss will increase from 6.2 (2020-2039) to 25.5 % (2080-2100).

For water erosion, soil conservation practices can play a major role in controlling the erosive phases of landslides and soil transport (Morgan, 1997). As is the case with plant residues that cover the soil (Cogo, Moldenhauer, & Foster, 1984; Jin *et al*., 2008; Jordán, Zavala, & Gil, 2010), agronomic measures to maintain and increase the density of plant cover (Fullen, Guerra, Jorge, & Alexandre, 2014). Also, mechanical soil conservation methods, such as terraces, windbreaks, and protective barriers, among others (Fullen *et al*., 2014; Morgan, 1997).

Effect of use/coverage change on hydrological response and water erosion

In the hypothetical land use/cover change scenarios presented, there are nested changes in the components of the hydrologic cycle, such as actual evapotranspiration (ET), which is calculated by the SWAT model as a function of water evaporation intercepted by the canopy, and maximum rates of canopy transpiration and soil evaporation (Neitsch *et al*., 2005). Considering that ET is the key factor in understanding the effect of cover change on water production (Morán-Tejeda *et al.*, 2015) elements that constitute this flow should be understood, such as temperature, leaf area, radiation, surface albedo, among others (Fitts, 2012; McNaughton & Jarvis, 1983; Zhang *et al*., 2001; Zhang *et al*., 1999).

Consequently, by reducing forest cover by 80 %, the potential leaf area, leaf area index, and interception were reduced; thus, evapotranspiration was reduced. This occurs because the leaf area is related to interception, radiation and defines the leaf area available for evapotranspiration (Zhang *et al*., 1999). Therefore, the water that was stopped from evapotranspiration (-3 %) and an interception, favored the other flows of the water cycle, increasing surface runoff, baseflow, and consequently water production; since vegetation affects surface runoff by changes in interception and evapotranspiration (Zhang *et al*., 2001; Zhang *et al*., 1999).

Likewise, when there is a change in coverage, the curve number (CN) is also modified, and with it the runoff and water production change since in this study the CN method is used to generate runoff. As shown by Kundu, Khare, and Mondal (2017) the relationship between CN changes and water production.

Similar to the response expected in the Quiscab subbasin, in North Carolina Qi *et al*. (2009) show a reduction in evapotranspiration (7 %) and an increase in water production (14 %); in the face of a total change in forest cover to crops and pastures. Similarly, in India, Kundu *et al*.

(2017) conclude that the change in land use towards increased agriculture showed increased water production (up to 17.5 %) and decreased actual evapotranspiration (up to 8.4 %).

The 50 % increase in forest cover (LULCC 2) in the Quiscab subbasin showed a change in the balance flows in the opposite direction to those expected for LULCC 1. Where real evapotranspiration increased (+2 %) due to the increase in leaf area and by default the interception of precipitation increased; this caused a reduction in surface runoff, baseflow, and water production -2, -8, and -2 %, respectively.

In the same direction of increasing forest cover in the Aragon Basin of Spain, Moran-Tejeda *et al*. (2015) estimated a reduction in annual surface runoff of 7.4 %. Similarly, in Ecuador, increased evapotranspiration with reduced rapid flows (Crespo *et al*., 2008). Similarly, in China, Wei *et al*. (2016) showed the greatest increase in surface runoff and water production with an increase in forest cover of 30.39 %.

The dynamics of erosion due to change in coverage in the Quiscab subbasin is slight (+10 and -1 % for SCT 1 and 2, respectively), considering the high relative change in coverage. Similar findings to the STCU 2 scenario show Phan, Wu, and Hsieh (2011), in Vietnam, when the grassland area was converted to forest, as sediment load decreased by 6.08 %. Similarly in Brazil, Blainski, Porras, Garbossa, and Pinheiro (2017), in basins with reduced pasture area and increased forest showed a decrease in erosion, from > 20 ton ha^{-1} year-1 to 12.1-20 ton ha-1 year^{-1}.

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In addition, Li, Zhang, and Peng (2015) argue that forest and grassland have a similar erosion-reducing effect. Since both uses show similar infiltration capacity that reduces the erosive force of rain (Nunes, De-Almeida, & Coelho, 2011). Although the forest cover is more effective, if the herbaceous cover is dense it can have similar efficiency (Morgan, 1997). Erosion and sediment dynamics can be more sensitive when considering changes in forest or pasture cover towards agriculture (Alibuyog *et al*., 2009; Da-Silva, Silva, & Souza, 2016; Huang & Lo, 2015), since farmland is more prone to erosion than forest and soil movement is accelerated, mainly in places with pronounced relief (Bakker *et al*., 2008; Brooks, Ffolliott, & Magner, 2012).

Conclusions

With limited observed data, both temporally and spatially, the hydrological cycle and water erosion were simulated, where one calibration point was satisfactory (Pamán River), and another was not (Quiscab River); these differed by the intervention of the territory. The importance of hydrological monitoring is highlighted, as well as knowing the dynamics of water use and management to achieve better hydrological adjustments in areas of high intervention and increase the potential use of hydrological modeling as a planning tool.

Given the climate change scenario RCP 8.5 of the HadGEM2-ES model to the year 2050, a severe generalized reduction of the components of the water balance and water production is foreseen, on an annual and monthly scale, with slight to severe changes in the variability of the annual hydrological regime. A moderate to a severe reduction in aquifer recharge is expected. Similarly, water erosion will be reduced monthly and annually, and its annual variability will decrease severely.

Due to the cover change, the water balance flows (except for current evapotranspiration, lateral flow, and water recharge), water production, surface runoff, baseflow, and water erosion will increase annually under the scenario of 80 % forest reduction. Conversely, under the +50 % forest scenario, these components will decrease, and actual evapotranspiration will increase. Very slight to moderate changes are expected in the variability of the annual hydrological regime and water erosion for both scenarios.

The sensitivity of the components of the water balance and water erosion to the climate change scenario is higher than the hypothetical land use/land cover change scenarios. In the face of climate change, greater changes are expected at the monthly and annual scales, and in the variability of the annual regime.

The changes in water erosion estimated in the coverage change scenarios are determined to be slight to moderate, given the high relative change in the transition area. The coverages involved in the dynamics (forest, grasslands, and shrublands) are responsible for the lowest annual erosion rates compared to annual agriculture

In the Quiscab subbasin, the use/coverage of forest (conifer, broadleaf, and mixed) does not guarantee water production; however, its presence shows the regulation of hydrological balance flows and water erosion.

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