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Original Research Article

Assessing sediment yield in Kalaya gauged watershed (Northern Morocco) using GIS and SWAT model

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ABSTRACT

An efficient design for erosion-control structures of any watershed in the world is entrusted with the delicate forecasting of sediment yields. These outlook yields are usually inferred by extrapolations from past observations. Because runoff, as the transporting vehicle, is more closely correlated with sediment yields than any other variable. So, calibration as well as validation of process-based hydrological models are two major processes while estimating the sediment yield in watershed. The actual survey is fulfilled with the aim of developing a trustworthy hydrologic model simulating stream flow discharge and sediment concentration with least uncertainty among the parameters picked out for calibration so as to verify the effect of the scenarios on the spatial distribution of sediment yield (sediments transported from sub-basins to the main channel during the step of time). Soil and Water Assessment Tool (SWAT, version 2012) model integrated with Geographic Information System (GIS, version 10.1) was used to simulate the stream flow and sediment concentration of Kalaya catchment situated in north of Morocco for the period from 1971 to 1993. Model calibration and validation were performed for monthly time periods using Sequential Uncertainty Fitting 2 (SUFI-2, version 2) within SWAT-CUP using 16 parameters. Our calibration outputs for monthly simulation for the period from 1976 to 1984 showed a good model performance for flow rates with NSE and PBIAS values of 0.76 and −11.80, respectively; also a good model performance for sediment concentration with NSE and PBIAS values of 0.69 and 7.12, respectively. Nonetheless, during validation period (1985–1993) for monthly time step, the NSE and PBIAS values were 0.67 and −14.44, respectively for flow rates and these statistical values were 0.70 and 15.51, respectively for sediment concentration; which also means a good model performance for both. Following calibration, the inclusive effect of each parameter used was ranked using global sensitivity function in SWAT-CUP. From our analysis, the effective hydraulic conductivity in main channel alluvium (CH_K2), USLE support practice factor (USLE_P) and manning's "n" value for the main channel (CH_N2) were found to be the most sensitive parameters during different iterations with different number of simulation but with the same inputs. The least sensitive parameter were found to be different in either cases unlike the most sensitive parameters. As a result, the global evaluated soil erosion rate in the study area varied from 20 to 120 t/ha/yr. It was summarized that the entire knowledge of the hydrologic processes happens within the watershed and the consciousness about acceptable meaningful range of the parameters is crucial while developing reliable hydrologic model.

1. Introduction

Of all the gifts of nature, none is more essential to man than soil (Singh & Saika, 1990; Singh, 2002). The soils play a major role in the provision of services and goods provided by ecosystems to humans. Located at the interface between the atmosphere, lithosphere, hydrosphere and biosphere, they participate in great cycles necessary for life on Earth: the water cycle and major nutrients (carbon, nitrogen, phosphorus…). They support most agricultural, forestry and pastoral production systems and contribute to climate regulation (controlling emissions of greenhouse gases and carbon sequestration). Meanwhile, they have always faced the problem of erosion which is a process of the surface soil alteration and relief

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modifications successively involving the detachment of soil particles, their transportation by the action of various agents (water, wind, work tools ground, gravity, glaciers…) and then, their deposition at a distance varying from less than a meter to several thousand kilometers. Critical environmental, ecological and economic troubles worldwide can be caused by soil erosion (Pimentel et al., 1995; Portenga & Bierman, 2011; Wu & Chen, 2012; Yang, Kanae, Oki, Koike, & Musiake, 2003) and has become a challenging issue, menacing chiefly the Mediterranean territories (Grimm, Jones, & Montanarella, 2002; Yaalon, 1997) especially in north of Morocco (Briak, Moussadek, Derradji, Aboumaria, & Mrabet, 2016; Raclot, Inoubli, Moussa, Habaieb and Bissonnais, 2015). In fact, Mediterranean climate is identified by seasonal contrast, where the soil erodibility can be affected by the dry and warm summer climate (Le Bissonnais et al., 2007), and where the soil erosion can be affected by the concentration of precipitation events, particularly in the fall (Ramos & Martínez-Casasnovas, 2009). This event may lead to serious degradation of the hill slopes with further negative damage on natural resources (Cerdà & Robichaud, 2009; Smith, Sheridan, Lane, Nyman, & Haydon, 2011; Stoof et al., 2015). Yet, both climate changes and also human interventions are responsible for the dramatic reductions in runoff and sediment load (Gao, Mu, Wang, & Li, 2011; Zuo et al., 2016).

To predict reliable quantity and rate of sediment transport from land surface into streams, rivers and water bodies, to identify erosion problem areas within a watershed and to propose the best management practices to reduce erosion impact, models are used (Yesuf, Assen, Alamirew, & Melesse, 2015). In this paper, Soil Water Assessment Tool model (SWAT; Arnold, Srinivasan, Muttiah, & Williams, 1998) has been applied to simulate the performance of a small-scale in the Kalaya river catchment in north of Morocco. The agro-hydrological model SWAT was used because it is a continuous-time, daily-based and semi-distributed watershed simulation model developed to predict hydrological and water quality processes (Arnold, Allen, & Bernhardt, 1993; Yen et al., 2014) and to seek good planning strategies, which strongly depend on integrated basin models (Collins & McGonigle, 2008; de Vente et al., 2013; Rickson, 2014). The definition and the quantification of uncertainty calibration in distributed hydrological modeling have become the subject of much research in recent years (Abbaspour, 2005). Multi-variable and multi-site approaches to calibrate and validate SWAT have been used through trial-and-error processes. Not only internal hydrological processes in the model have been evaluated, but also a number of subcatchments have been used in this calibration (Cao, Bowden, Davie, & Fenemor, 2006). Several worldwide studies have been done using the SWAT model, for example in America (Arnold et al., 2012; Havrylenko, Bodoque, Srinivasan, Zucarelli, & Mercuri, 2016; Jha & Gassman, 2014; Mbonimpa, Yuan, Mehaffey, & Jackson, 2012… etc.), but only a few studies have been realized by this model in Morocco (Fadil, Rhinane, Kaoukaya, Kharchaf, & Alami Bachir, 2011; Kharchaf, Rhinane, Kaoukaya, & Fadil, 2013). In this context, the interest of this approach lies in having a good spatialized hydrological stock of the basin which could be extended to similar watersheds where there is a lack of data in north of Morocco, knowing that it has never been sampled owing to the shortage of the stations scale in the studied area.

2. Methods and materials

2.1. Study area

The research area is the 3838 ha Kalaya catchment in north of Morocco (Fig. 1) located in the southern part of Tangier city. The study area has a Mediterranean climate sub-humid to wet, characterized by wet winters and dry summers. The annual average precipitation is 667 mm, while the annual average temperature is about 18 °C (Briak et al., 2016). The hydrological monitoring is ensured by the hydrometric station located at the outfall Kalaya (reservoir). The representation of relief chosen for this study is the ASTER - GDEM satellite with a spatial resolution of 30 m. Use of this resolution in watershed modeling is widely demonstrated (Hirt, Filmer, & Featherstone, 2010). Surroundings for the most part formed of little rough hills with comparatively low height.

2.2. SWAT model

Widely used over the world, Soil and Water Assessment Tool (SWAT) is a hydrological model to assess sediment, impact of land use, in-stream water quality, climate change and, water quality and quantity variation. SWAT can determine as well as river basin-scale, continuous-time model that operates on a daily or sub-daily time step, computationally efficient, and able to estimate long-term yields in large watersheds. The model is physically-based and uses readily available temporal and spatial data. It simulates water flows in soil and groundwater, crop growth, nutrient cycling, erosion, pesticides, bacteria, sediments, nutrients, and environmental impact of climate change (Arnold et al., 1998). The impact of climate change or land management practices on sediment transport and surface hydrological response over long periods of time for large complex watersheds that have differed soils, land use and management practices is anticipated by this model (Neitsch, Arnold, Kiniry, Williams, & King, 2005). Associated by a stream network, in the swat model the basin is subdivided into multiple sub-basins, each sub-basin is divided into hydrological response units (HRUs) that consist of unique combinations of homogenous soil and land use properties in each sub-basin (Arnold et al., 2012). The hydrological cycle is simulated by SWAT model according to the equation below of water balance (Neitsch et al., 2005):

$$SW_t = SW_0 + \sum_{n=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \tag{1}$$

where SW_t is the soil water content (mm), SW_0 is the water available to plants (mm), R_{day} is the precipitation (mm), Q_{surf} is the surface runoff (mm), E_a is the evapotranspiration (mm), W_{seep} is the percolation (mm), Q_{gw} is the low flow (mm) and t is the time (days).

2.3. SWAT-CUP model

The SWAT-CUP tool (SWAT Calibration and Uncertainty Procedures) is a program that interfaces with ArcSWAT, to perform calibration, validation and sensitivity analysis of the SWAT model. It was designed to bring more flexibility and performance as to the calibration of SWAT model to face out the limits of ArcSWAT calibration functions in the ArcGIS environment. Thus, the advantage of the application is its ability to give a large choice of functions and wider and generous interfaces for parameterization, calibration and validation of the model. The execution of the SWAT-CUP model involves the use of output files generated by SWAT model in ArcSWAT (Abbaspour, 2011). Five different algorithms procedures are associated to SWAT such as Generalized Likelihood Uncertainty Estimation "GLUE" (Beven & Binley, 1992), Particle Swarm Optimization "PSO" (Eberhart & Kennedy, 1995), Parameter Solution "ParaSol" (Alamirew, 2006), Mark chain Monte Carlo "MCMC" (Kassa & Foerch, 2007) and Sequential Uncertainty Fitting "SUFI-2" (Abbaspour et al., 2007; Abbaspour, Johnson, & van Genuchten, 2004). The SUFI-2 strategy is applied in this research since it can supply the widest marginal parameter uncertainty intervals of model parameters among the five approaches. The goodness of fit