Sensitivity Analysis of Heihe River Runoff to LUCC and Climate Change: Postprint

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Date: 2018-06-10T00:00:00+00:00

Abstract

To quantitatively assess the sensitivity of runoff to land use change (LUCC) and climate change and its spatiotemporal variability, the sensitivity of Heihe River runoff to LUCC and climate change was quantitatively evaluated using the SWAT model combined with statistical methods, based on land use, soil, digital elevation (DEM), meteorological, and measured runoff data. The results show that: the sensitivity value of watershed runoff to LUCC from 1980 to 2009 was 0.020 mm·km ². The sensitivity of runoff to LUCC, from largest to smallest, was the upper reaches (0.108 mm·km ²), middle reaches (0.004 mm·km ²), and lower reaches (0.001 mm·km ²). A 1 mm change in precipitation caused water yield changes of 0.49–0.288 mm, 0.006–0.038 mm, and 0–0.002 mm in the upper, middle, and lower reaches, respectively. A 1°C change in temperature caused water yield changes of 13.413–78.902 mm, 1.105–6.500 mm, and 0.461–2.710 mm in the upper, middle, and lower reaches, respectively. The sensitivity of runoff to temperature was far higher than its sensitivity to precipitation. In terms of temporal trends, the sensitivity of runoff to LUCC showed a decreasing trend; the upper reaches exhibited a decreasing trend, while the lower reaches exhibited an increasing trend. The sensitivity of watershed runoff to temperature showed an increasing trend.

Full Text

Sensitivity Analysis of Runoff to LUC C and Climate Change in the Heihe River Basin

Abstract: To quantitatively assess the sensitivity of runoff to climate and land use/cover change (LUC C) in the Heihe River Basin during 1980–2009, multiple data sources (including land-use digital elevation data, soil, and weather) spanning from 1980 to 2016 were applied to drive the SWAT model, and observed runoff data was used for calibration and validation. The results indicate that the sensitivity value of runoff to LUC C is 0.020 mm · km ², which means that when land use changes by 1 km^2, the runoff will change by 0.114 mm. Meanwhile, the changes in runoff caused by a 1 mm variation in precipitation in the upstream, midstream, and downstream were 0.49–0.288 mm, 0.006–0.038 mm, and 0–0.002 mm, respectively, and the variation caused by a 1°C change in temperature in the upstream, midstream, and downstream were 13.413–78.902 mm, 1.105–6.500 mm, and 0.461–2.710 mm, respectively. We further found that the sensitivity of runoff to temperature is much higher than that of precipitation. The sensitivity of runoff to LUC C from large to small is upstream (0.108 mm · km ²), middle reaches (0.004 mm · km ²), and downstream (0.001 mm · km ²) from 1980 to 2009. Temporally, the sensitivity of runoff to LUC C in the whole basin shows a downward trend; the upstream region shows a decreasing trend, while the downstream shows an increasing trend. The sensitivity of basin runoff to temperature is increasing during 1980–2009.

Keywords: runoff; climate change; land use change; sensitivity; SWAT model; Heihe River

1 Study Area

The Heihe River Basin is located in northwestern China (38°–42°N, 98°–101°E) [Figure 1: see original paper]. The basin covers an area of 14.31×10 km^2 with total water resources of 34.43×10 m^3. The elevation ranges from 879 to 5573 m. The basin exhibits a continental climate characterized by significant spatial heterogeneity. Annual precipitation in the upstream mountainous area is 300 mm, with temperatures ranging from -2.9 to 1.5°C and evaporation of 2000–3000 mm. In the midstream region, annual precipitation is 50–200 mm, with temperatures of 7.2–9.6°C and similar evaporation rates. The downstream area receives only 40–50 mm of annual precipitation, with temperatures around 10.32°C and evaporation of 2300–3800 mm [17].

[Figure 1: see original paper] Location of the Heihe River Basin

2 Methods

2.1 Data Collection

Meteorological data from 1980 to 2016 were obtained from 12 national meteorological stations within and surrounding the basin (http://cdc.cma.gov.cn/). Land use/cover data for the same period were sourced from the Chinese Academy of Sciences Resource and Environment Data Cloud Platform (http://westdc.westgis.ac.cn/). Soil parameters were derived from the Harmonized World Soil Database (HWSD) V1.1, including bulk density (SOL_BD), available water capacity (SOL_AWC), saturated hydraulic conductivity (SOL_K), and the USLE soil erodibility factor (USLE_K). The SOL_BD, SOL_AWC, and SOL_K parameters were calculated using the SPAW (Soil Plant Atmosphere Water) and SWCT (Soil-Water Characteristics) models, while USLE_K was computed using the Universal Soil Loss Equation (USLE).

Topographic data were obtained from the ASTER Global DEM (ASTER GDEM) with a spatial resolution of 30 m. All spatial data were resampled to a consistent resolution and projected to the same coordinate system for SWAT model input.

2.2 SWAT Model Setup

The Soil and Water Assessment Tool (SWAT) was employed to simulate hydrological processes in the basin. The model was configured using the collected meteorological, land use, soil, and topographic data. Model calibration and validation were performed using observed runoff data from three hydrological stations: Zamashk, Yingluoxia, and Zhengyixia.

2.3 Experimental Design

To isolate the impacts of climate change and LUC C on runoff, we designed a series of modeling experiments based on the principle of variable control. The general framework is expressed as:

$$Y = F(L, C, O_1, O_2, ..., O_i)$$

where Y represents runoff, L denotes land use/cover, C represents climate variables, and O_i represents other factors.

For the 1980s and 1990s: We conducted paired experiments using land use and climate data from different decades (Table 1). The difference between simulations (Y -Y)-(Y -Y)-(Y -Y) quantifies the individual contributions of LUC C and climate change.

For the 2000s: Due to significant land use changes during 2000–2016, we divided this period into two sub-periods (2000–2008 and 2009–2016) and performed separate analyses (Table 2).

[Figure 2: see original paper] Comparison of simulated and observed runoff at Zamashk, Yingluoxia, and Zhengyixia hydrological stations

Performance of the Soil and Water Assessment Tool (SWAT)

2.4 Sensitivity Analysis

We conducted sensitivity analysis to quantify the response of runoff to changes in precipitation, temperature, and land use. The sensitivity coefficient was calculated as the ratio of runoff change to the forcing variable change.

Precipitation Sensitivity: For a 1 mm change in precipitation, runoff sensitivity varied by region and period (Table 8). In the 2000s, the sensitivity range was 0.057-0.357 mm · mm ¹ in the upstream, 0.002-0.010 mm · mm ¹ in the midstream, and 0–0.002 mm · mm ¹ in the downstream. Over the entire 1980–2009 period, the upstream showed the highest sensitivity (0.49–0.288 mm · mm ¹), followed by midstream (0.006–0.038 mm · mm ^{1}) and downstream (0–0.002 mm · mm ^{1}).

Temperature Sensitivity: For a 1°C temperature change, runoff sensitivity was substantially higher than for precipitation (Table 7). The sensitivity ranged from 13.413–78.902 mm · °C ^{1} in the upstream, 1.105–6.500 mm · °C ^{1} in the midstream, and 0.461–2.710 mm · °C ^{1} in the downstream during 1980–2009.

Land Use Sensitivity: The sensitivity of runoff to LUC C was 0.020 mm · km ^{2} at the basin scale (Table 9). Spatially, the sensitivity decreased from upstream (0.108 mm · km ^{2}) to midstream (0.004 mm · km ^{2}) to downstream (0.001 mm · km ^{2}). Temporally, basin-wide sensitivity to LUC C showed a decreasing trend from 1980 to 2009, with the upstream decreasing and the downstream increasing.

List of modeling experiments to evaluate LUC C and climate impacts in the 1980s and 1990s

List of modeling experiments to evaluate LUC C and climate impacts in the 2000s

Mean temperature in each decade in the Heihe River Basin during 1980–2009

Land use change in the Heihe River Basin (1980s–2010)

Sensitivity of mean temperature (mm · °C ^{1})

Sensitivity of precipitation (mm · mm ^{1})

Sensitivity of land-use change (mm · km ^{2})

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Note: Figure translations are in progress. See original paper for figures.