

Response of Streamflow to Climate Changes within a Mountainous Catchment

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Abstract. Climate changes combined with alteration in landuse, alter the hydrological processes and has increased flood risk in urban area. A better understanding of how the climate alter streamflow in the catchment of city surrounding area would help to reduce urban flood risk. In the present study, we assessed the response of streamflow to climate changes in a mountainous catchment of city surrounding area, Dashi River catchment, China. The Distributed Hydrology-Soil-Vegetation Model (DHSVM) was used to simulate the streamflow in different scenarios of climate and landuse changes. Results showed that: (i) DHSVM showed suitable performance in terms of calibration and validation periods; and (ii) Streamflow increased/decreased with increasing/decreasing precipitation, while decreased with increasing air temperature. And the increases or decreases in precipitation can directly lead to the significant corresponding directional changes in the streamflow, especially in summer season. The results would help to understand streamflow response to changes in climate and landuse, and help to reduce the flood risk in the urban regions.

1 Introduction

Climate combined with landuse changes has dramatically altered the hydrological processes (Chien *et al.*, 2013; Niraula *et al.*, 2015). Climate changes/variability resulting in temperature rises, changes in precipitation and altering the evapotranspiration, thereby affecting the volume, peak rate, and timing of streamflow (Niraula *et al.*, 2015; Pourmokhtarian *et al.*, 2016). Therefore, with the intensification of global warming, extreme hydrological events are generally showing an increasing trend (Goswami *et al.*, 2006), which have led to extreme hydrological disasters occur frequently, *e.g.*, flood, drought (Kourgialas *et al.*, 2015; Zhang *et al.*, 2015). Especially, in the catchments of city surrounding area where rapidly urbanization has increased the impermeable area and weakened the capability of water storage, that resulted in an increasing trend in extreme hydrological events and a more significant threaten to urban water security (Peng *et al.*, 2015; Bellu *et al.*, 2016). Consequently, our objectives are: (i) to explore the parameter sensitivity, and assess the performance of DHSVM in a small mountainous catchment of city surrounding area; and (ii) to estimate the streamflow response to climate and landuse changes scenarios in the Dashi River catchment, China. The results should help to understand the

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response of streamflow to climate changes in the catchment of city surrounding area and help to address the flood risk in the city.

2 Study site and methodology

2.1 Study site

Dashi River is a tributary of Juma River in the Haihe River Basin, which originates from Xiayunling of Fangshan District in Beijing, China. The total length of Dashi River is 129 km, and the catchment area is 1,280 km². Dashi River catchment is located in the southwest of Beijing. Dashi River Catchment belongs to semi-humid continental monsoon climate, which is hot and rainy in summer, cold and dry in winter. The mean annual temperature is 9 - 11 °C, while the mean annual precipitation (1956 to 2004) is 587.6 mm and concentrated in summer (June to August). The upper catchment, the mountainous area above hydrological station, was selected as a study area (Figure 1) which total area is 664 km². Due to influenced by extreme hydrological event, Dashi River catchment have suffered an extraordinary rainstorm in July 21, 2012, which was the strongest rainstorm in northern China since detailed meteorological records began in 1951 and also caused the greatest number of casualties and economic losses (Su *et al.*, 2015).

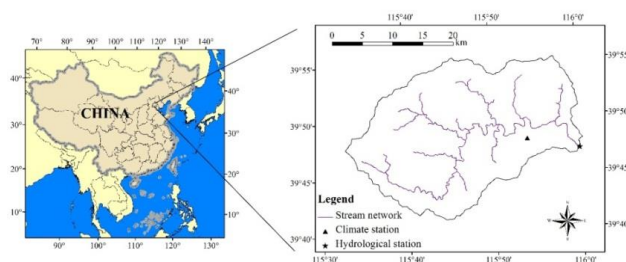


Fig. 1. Geographical location of Dashi River catchment, China.

2.2 Methodology and data description

The Distributed-soil-vegetation model (DHSVM) is a physically based distributed hydrologic model developed for mountainous watersheds (Wigmosta *et al.*, 1994), which has been widely used to assess the impacts of climate changes on hydrological processes (Wigmosta *et al.*, 1994; Safeeq and Fares, 2012; Cuo *et al.*, 2009; Dickerson-Lange and Mitchell, 2014). One-factor-at-a-time (OFAT) were used to analyze sensitive parameters in DHSVM while examined using Bias and root mean square error (RMSE); and the Nash-Sutcliffe efficiency coefficient (NSE) (Nash and Sutcliffe, 1970) and the coefficient of determination (R^2) were used to evaluate the model performance at simulating.

To construct the DHSVM in Dashi River catchment, a model database was compiled using meteorological data (*e.g.*, precipitation, wind speed, maximum and minimum temperature) and topographical data (consisting of a digital elevation map, landuse and soil map). The Meteorological data, including precipitation, temperature, wind speed, used for DHSVM calibration and validation were taken from Xiayunling climate station (Figure 1).

The DHSVM requires the digital elevation model (DEM), soil and vegetation maps to simulate the hydrological cycle. The DEM was obtained from USGS/NASA Shuttle Radar Topography Mission

(SRTM) data; the soil map (100 m resolution) was adapted from the world soil database (Harmonized World Soil Database). The vegetation map (100 m resolution) was generated based on the land cover data of Beijing in 1980 provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. Furthermore, 8 climate change scenarios were used to assess the impacts of climate changes on streamflow with the precipitation changes of +10% (scenario 1), +20% (scenario 2), -10% (scenario 3), and -20% (scenario 4), and air temperature changes increased 1 °C (scenario 5), 2 °C (scenario 6), 3 °C (scenario 7), and 4 °C (scenario 8).

3. Results

3.1 Parameter sensitivity and model validation

In the sensitivity analysis, 13 soil parameters and 20 vegetation parameters of the DHSVM underwent sensitivity analyses to determine the optimal model parameters. Among these parameters, the maximum infiltration, porosity, field capacity and wilting point are the most sensitive soil parameters; while leaf area index and vegetation height are the most sensitive vegetation parameters. DHSVM was manually calibrated taking into account daily and monthly streamflow by adjusting these sensitive parameters.

During both the calibration and validation periods, simulated daily and monthly streamflow agreed reasonably with the observed streamflow for both time steps (Figure 2), the NSE values for daily streamflow simulations during calibration and validation period were 0.62 and 0.71, respectively; and were 0.79 and 0.88 of monthly time step for the three-year calibration and validation, respectively. The R^2 of monthly time step reached up to 0.84 and 0.89 for the calibration and validation period, respectively.

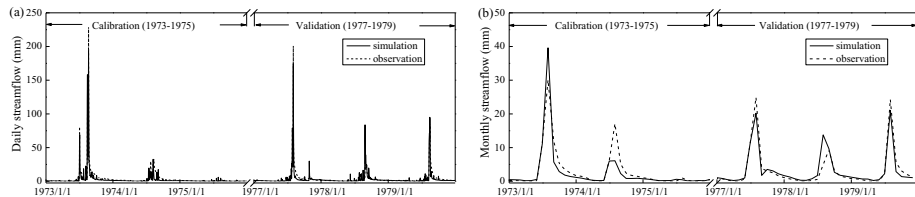


Fig. 2. Observed and simulated streamflow during the calibration (Jan. 1, 1973-Dec. 31, 1975) and validation (Jan. 1, 1977-Dec. 31, 1979) period: (a) daily streamflow; (b) monthly streamflow.

3.2 Response of streamflow to climate changes

Figure 3 showed the response of streamflow to climate changes: (i) as expected, the mean annual streamflow steadily increased (or decreased) with precipitation increasing (or decreasing); (ii) the precipitation scenarios have notable differences from the baseline, especially in the summer season; and (iii) the mean annual streamflow slightly decreased with air temperature increased.

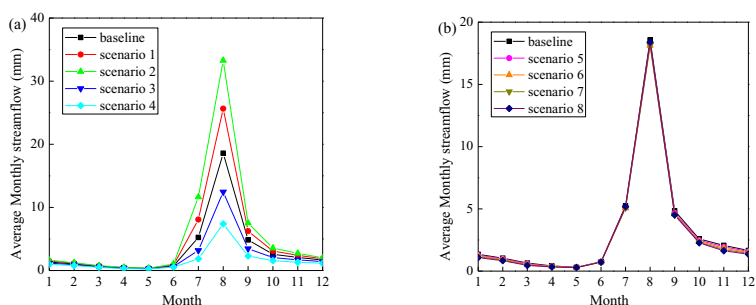


Fig. 3. Simulated streamflow in different climate change scenarios: (a) streamflow changed with precipitation change scenarios 1 to 4 correspond to the precipitation changed +10%, +20%, -10% and -20%; and (b) streamflow changed with air temperature scenarios, scenario 5 to 8 correspond to the air temperature increased 1 °C, 2 °C, 3 °C and 4 °C. Increase in precipitation contribute magnitude to changes in streamflow, e.g., annual streamflow increased about 32.73% and 68.18% with precipitation increased 10% and 20%, respectively; while it decreased about -28.69%, and -52.17% when precipitation decreased -10% and 20%, respectively. Similar results for the changes in streamflow also can be found in maximum changes of streamflow. For air temperature, streamflow will decrease with increase in air temperature due to its complex effects on hydrological processes, and interestingly sensitivity of streamflow reduced with the increase in air temperature, e.g., 1°C warming will cause streamflow increase -2.79% in scenarios, while it just will cause an increase in streamflow with -2.01, -1.13 and -0.19%, between scenario 5 and 6, scenarios 6 and 7, and scenarios 7 and 8, respectively.

4. Discussion

Climate changes/ variability (e.g., temperature rises and changes in precipitation) have significant impacts on regional streamflow (Chen *et al.*, 2006; Huo *et al.*, 2008). The Haihe River Basin have been intensified by the decreasing precipitation and steadily declining streamflow due to climate change and increasing human activity during the past decades (Yang and Tian, 2009). Bao *et al.* (2011) concluded the streamflow would increase as precipitation increased but would decrease as temperature increased, which is similar with our result. Results of sensitivity analysis showed that changes in streamflow are more sensitive to increase in precipitation in contrast with decrease in precipitation, e.g., streamflow can increase 32.73% or decrease 28.69% with 10% increase or decrease in precipitation. Streamflow response to changes in precipitation is consistent with results provided by Qi *et al.* (2009). Interestingly, increase rate of streamflow decreased with increase in air temperature, e.g., streamflow was reduced by 2.01% when 1 °C increased compared with baseline condition, while it was reduced by 1.13% when 2 °C increased compared with 1 °C increase. The reasons for that mainly lay that streamflow will be reduced by increase in evaporation when other meteorological variables keep in normal condition. In fact, changes of streamflow resulted from increasing air temperature reflected complex interaction between meteorological variable. Especially, explanations for “evaporation paradox” have enhanced the understanding of hydrological mechanism for increasing air temperature (Liu and McVicar, 2012; Szilagyi, *et al.*, 2017).

5 Conclusion

This study investigated the response of streamflow to the changes in climate and landuse within a

mountainous catchment of city surrounding area, Dashi River catchment. The DHSVM have been established in the study area, and run in different climate and landuse change scenarios. Several conclusions can be drawn as followed:

(i) The parameters sensitivity analyze of DHSVM in this area have been examined. And the most sensitive soil parameters are the maximum infiltration, porosity, field capacity and wilting point, while leaf area index and vegetation height are the most sensitive vegetation parameters. The DHSVM was suitable performance to simulate the streamflow with NSE and R^2 values of 0.88 and 0.89 in monthly scale, respectively.

(ii) Changes of streamflow was more sensitive to increasing in precipitation than that resulted from the decrease in precipitation. For air temperature, streamflow decrease with increase in air temperature, and increase rate in streamflow presented decreasing trend with the increase in air temperature, streamflow was reduced by 2.01% when 1 °C increase compared with baseline condition, while it was reduced by 1.13% in 2 °C increase when compared with 1 °C increase.

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