

## Chapter 2

# Modeling the Effects of Land Use Change and Climate Change on Stream Flow Using GIS and a Hydrological Model

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**Abstract** This paper reports our research effort aiming to investigate the applicability of integrating a hydrological model and the Hydrological Predictions for the Environment (HYPE) model with a geographic information system (GIS) to examine the effect of land use change and climate change on stream-flows with the Kamo River basin (KRB) located in the central Honshu island, Japan as a case study. The goal of this study was to provide important information for understanding water discharge variations as a basis to guide water resource managers in environmental change decisions in this river basin. This goal was accomplished by two steps (i) comparing HYPE-generated hydrographs for various meteorological data from history to present at current land use (S1 and S2); and (ii) comparing HYPE-generated hydrographs for historical and current land use scenarios at current climate (S3 and S4). The calibration and validation results suggest that HYPE performs well in the case study site for daily simulations. The results of S1–S2 indicate that with the impact of climate change, the trend of annual and seasonal stream flows at the Kamo River Basin outlet would decrease. However, there is no evidence to indicate that the flood risk would be decreasing. The results of S3–S4

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show that the conversion of forest, grass and agriculture (FGA) into urban area would induce high peak flows, a reduction in annual evaporation and an increase in annual surface runoff.

**Keywords** Land use change • Climate change • Hydrologic modeling • HYPE • GIS • Kamo River basin

## 2.1 Introduction

In the last decades, the relentless usage of fossil fuel, growth of population, migration to urban areas and consequent global climate change, land use transition not only induce hydrological cycle variation and increase the risk of water-related disasters also bring challenges to the current water management and planning efforts. Water authorities in many places have paid special attention to water management in order to mitigate the disaster risk. Understanding hydrological processes, especially in the context of climate change and land use change is necessary for water resources sustainable management.

A number of studies have been conducted on the impact of climate and land cover variations on water resources balance at catchments (Cuo et al. 2013; Cornelissen et al. 2013; Öztürk et al. 2013; Arheimer et al. 2012; Chu et al. 2012; Zhang et al. 2012; Delpla et al. 2009). Cuo et al. (2013) found that the upper Yellow River Basin hydrological regimes had undergone changes over the past decades as reflected by a decrease in wet and warm season stream flow, and annual stream flow due to climate change and human activity. Öztürk et al. (2013) showed the water budget was most sensitive to variations in precipitation and conversion between forest and agricultural lands but was less sensitive to the type of forest stands in the Bartın spring watershed, Turkey. However, hydrological responses to climate and land-use changes are different from place to place. It is necessary to conduct a study of hydrological variation under climate and land-use changes on the regions with few previous studies to provide valuable information for water management.

The basin of interest in this study, Kamo River basin (KRB), is the political and socioeconomic center of Japan in history and also a famous tourist attraction with about 1.5 million residents nowadays. The riverbank of Kamo River is popular with tourists and residents for many activities such as sightseeing during Sakura blooms (cherry blossoms), fishing and walking. These activities are sensitive to stream flow changes. To date, there has been limited research on discharge variation in this basin. Luo et al. (2014a) took a palaeoflood simulation in KRB and found that lower discharge and earlier peak discharge time were exhibited under historical land use. However, to what degree water discharge has been altered under climate and land use changes certainly merits further investigation.

Rainfall-runoff dynamics are a complex process affected by various factors: rainfall, temperature, vegetation etc. Many methods have been used to quantify hydrological variations to all kinds of driving factors in river basins (Swank and Crossley 1988; Singh and Gosain 2011; Beskow et al. 2012; Dixon and Earls 2012;

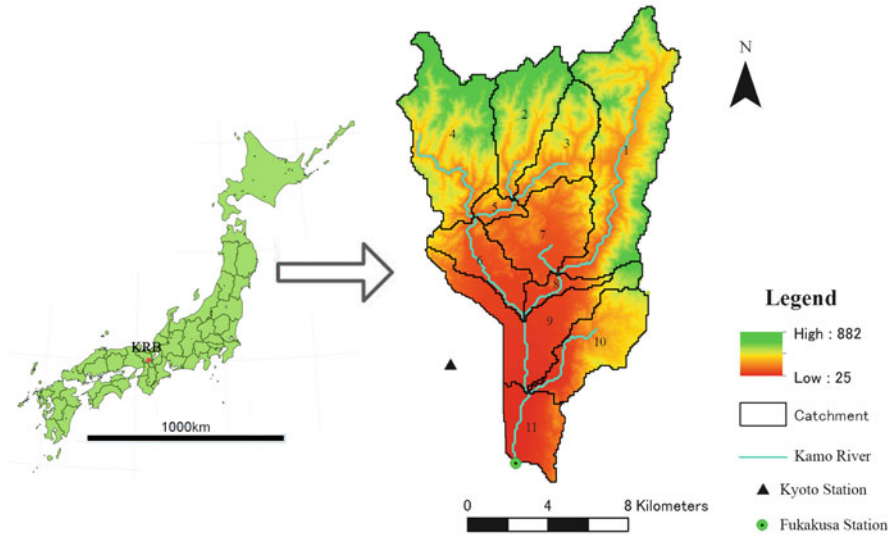
Dechmi et al. 2012; Koch et al. 2013). Swank and Crossley (1988) studied hydrological responses of deforestation and forestation from an early age using comparative tests method. Dixon and Earls (2012) examined the effects of land use change on a stream flow with a hydrological model. Hao et al. (2008) reports the variations of surface runoff under climate change and human activities in the Tarim River Basin by trend analysis of meteorological, socioeconomic and hydrological data. Among them, hydrological simulation is the most widely used method and modelling can be looked upon as an objective and repeatable method with which to interpolate and extrapolate knowledge in time and space between observations (Strömqvist et al. 2012). Also, the modelled data can be widely used by water authorities where measured data are not available for expert judgments.

This study, by applying a rigorously calibrated and validated process-based, integrated semi-distributed hydrology model over the KRB aims to identify the variations of stream flow at the outlet of the basin and to estimate the effects of climate change and land use transition on stream flow changes. The ultimate goal of this study is to provide important information for understanding water discharge variation, and guide water resource managers in environmental change decisions in the KRB.

## 2.2 Methodology

### 2.2.1 Study Area

The KRB is in the central part of the island of Honshu, Japan. The length of the river is about 31 km, flowing into Katsura River. The area of the basin is 210 km<sup>2</sup>, ranging in elevation from 25 to 882 m, with average slope angles of about 25.7°. There is no weather station in the basin and the nearest station is Kyoto station (shown in Fig. 2.1). The annual precipitation from 1978 to 2008 at the Kyoto station is 1,491 mm and 84.3 % of precipitation is concentrated from March to October. The daily temperature ranges from -3.2 to 32.8 °C and annual mean temperature from 1978 to 2008 is about 16 °C.



**Fig. 2.1** Location of the study site: The Kamo River Basin (KRB) and a digital elevation model (DEM)

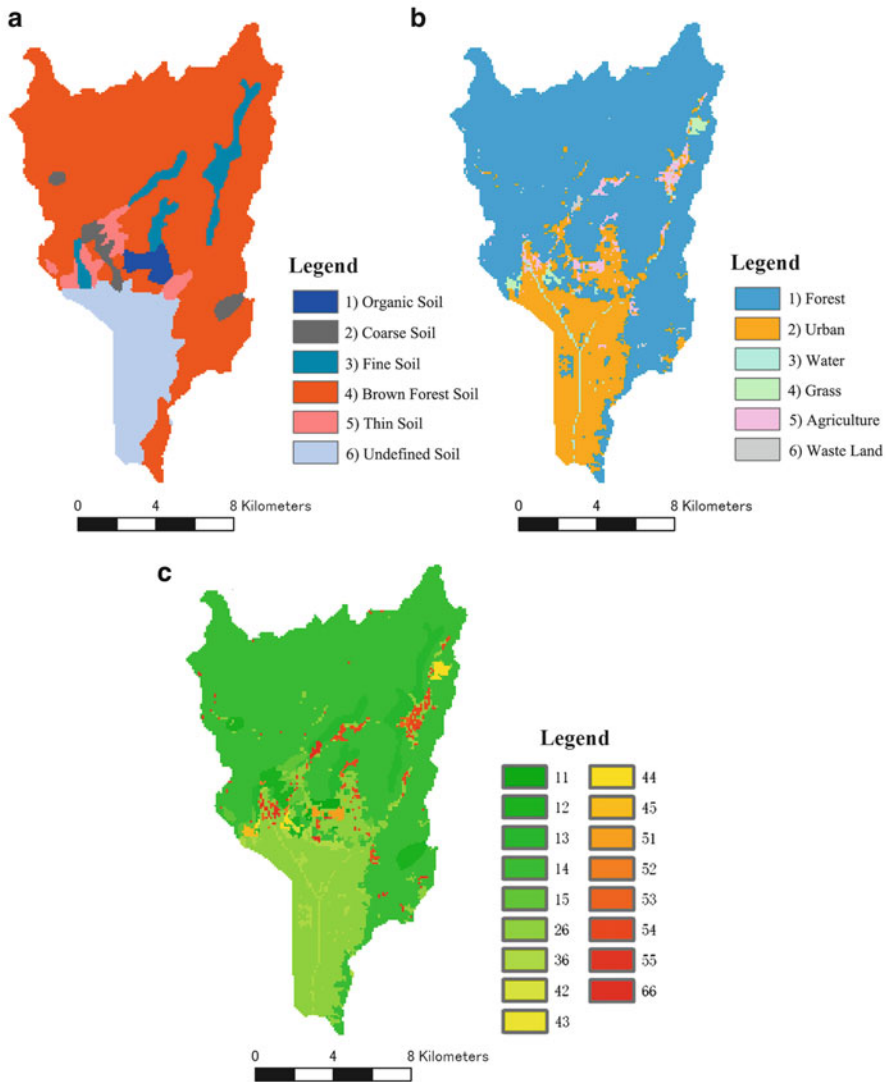
## 2.2.2 Model Description

The Hydrological Prediction for the Environment model (HYPE) was employed to investigate and understand the influences of climate and land use changes on KRB hydrology. HYPE is a process-based, temporally continuous, semi-distributed hydrology model, which integrates landscape elements and hydrological components along the flow paths (Lindstrom et al. 2010; Strömqvist et al. 2012). It has been applied in some regions of the world in a range of climate conditions and resolutions and existing studies have shown that it performed well in simulating stream flow (Strömqvist et al. 2009, 2012; Lindstrom et al. 2010; Arheimer et al. 2012; Jiang et al. 2013; Jomaa et al. 2013; Donnelly et al. 2014).

HYPE shares some similarities to the HBV (Bergström 1976), VIC (Liang et al. 1994) and SWAT (Arnold et al. 1998). The model partitions a basin into multiple sub-basins, which are further subdivided into a set of hydrological response units (HRUs) (Flügel 1995). HRU is determined by land use and soil type or other landscape characteristics such as elevation and slope. In this study HRUs are the combinations of land use and soils. Flows generated from each HRU in a sub-watershed are summed and routed through channels. HYPE model is based on the water balance in the soil profile and the simulating processes mainly include snowmelt, infiltration, surface flow, evapotranspiration, percolation, tile drainage, macro-pore flow and groundwater flow. The detailed calculation methods of each model component can be found in literature (Lindstrom et al. 2010).

### 2.2.3 Data Preparing and Model Setup

The meteorological data at Kyoto station is obtained from Japan Meteorological Agency and the daily data from 1979 to 2008 is used as input data to the model. The 100 m DEM of KRB and 100 m mesh land use data sheet of 2006 are from the Nation and Regional Planning Bureau of MLIT. The 1927 land use stems from the research of Luo et al. (2014b) (Shown in Table 2.2). The soil map of the KRB (from MLIT) is presented in Fig. 2.2a and there are six types and the percentage



**Fig. 2.2** (a) Soil type map (b) Land use map of 2006 (c) Hydrological response units (HRUs) map of 2006

distribution is: (1) Organic Soil (1.7 %), (2) Coarse Soil (2.4 %), (3) Fine Soil (5.4 %), (4) Brown Forest Soil (72.1 %), (5) Thin Soil (3.2 %), and (6) Undefined Soil (15.2 %). At the outlet of the basin, there is a monitoring station called Fukakusa station, which has discharge data of several years from 1991 to 1995 and from 2002 to 2005. The observed discharge data are used to calibrate and validate the model.

The DEM, land use and soil type data were processed in ArcGIS. Based on the DEM data and hydrological analysis tools of ArcGIS, the basin was divided into 11 sub-basins (Fig. 2.1). Hydrological response units were created by the combination land use and soil type maps using the tool of raster calculation. Figure 2.2c shows the distribution of HRUs in 2006. There are 18 HRUs in KRB. Each HRU is named with double-digit. The first digit means land use type and the second digit means the soil type.

After pre-processing in ArcGIS, the database files were prepared including meteorological, geographical, hydrological data, etc. And some parameters without observed data were set manually in general agreement with hydrological knowledge and literature values in the process of calibration and a HYPE project was built.

## 2.2.4 Model Calibration

The initial conditions used for the hydrologic models strongly influence the values of the parameters and predicted outcome (Flügel 1995; Dixon and Earls. 2012). In order to reduce the uncertainties over initial conditions, the beginning date of the simulation in the model is 1978.1.1 under calibration, validation and all scenarios. The model is calibrated and validated by comparing the simulated stream flow and observed stream flow on a daily basis for two different 3-year periods. The calibration period is from 2003.1.1 to 2005.12.31 and the validation period is from 1993.1.1 to 1995.12.31. Calibration of the model was carried out automatically with an aim of obtaining a good calibration results fit, but with the constraint that parameters should be in general agreement with hydrological knowledge and literature values. In these processes, Monte Carlo simulation method is used. The performance of the calibrated parameters was evaluated by Nash-Sutcliff efficiency (NSE). The NSE is commonly used in hydrological modeling. It measures the efficiency of a model by relating the errors to the variance in the observations. A perfect fit corresponds to  $NSE = 1$ , whereas a naive model that uses the mean value results in  $NSE = 0$ . The NSE efficiency is usually evaluated over a certain time period ( $n$  time steps) for one basin at a time. The equation for NSE is as follows:

$$NSE = 1 - \frac{\sum_{i=1}^n (O - S)^2}{\sum_{i=1}^n (O - \bar{O})^2} \quad (2.1)$$

where  $O$  and  $S$  are the observed and simulated data, respectively, and  $n$  is the total number of data records.

Monte Carlo simulation is a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results; typically one runs simulations many times over in order to obtain the distribution of an unknown probabilistic entity. In the structure of HYPE, there is a module of Monte Carlo simulation. The work of modelers is to assign the intervals and tolerance values of calibrated parameters. Then the parameters are automatic calibrated in the model with the task of Monte Carlo simulation.

### 2.2.5 Climate Trends Analysis

The Mann Kendall test (MKT) was applied in this study to analyze the monotonic trend of annual and monthly precipitation and mean temperature from Kyoto station. MKT is a non-parametric statistical procedure used to test for trends in time series data (Yu et al. 1993). The null hypothesis in the Mann-Kendall test is that the data are independent and randomly ordered, i.e. there is no trend or serial correlation structure in the time-series (Hamed and Rao 1998). For independent and randomly ordered data in a time-series  $x_i$   $\{x_i, i = 1, 2, \dots, n\}$ , the null hypothesis  $H_0$  is tested on the observations  $x_i$  against the alternative hypothesis  $H_1$ , where there is an increasing or decreasing monotonic trend (Yu et al. 1993). According to the condition of  $n \geq 10$ , the S variance is described according to Eq. 2.2 below:

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^e (t_i-1)(2t_i+5)}{18} \quad (2.2)$$

where  $e$  is the number of tied groups and  $t_i$  is the number of data values in the  $i_{\text{th}}$  group.

The statistical S test is given as follows:

$$S = \sum_{e=1}^{n-1} \sum_{i=e+1}^n \text{sgn}(x_i - x_e) \quad (2.3)$$

where

$$\text{sgn}(\varphi) = \begin{cases} 1 & \varphi > 0 \\ 0 & \varphi = 0 \\ -1 & \varphi < 0 \end{cases} \quad (2.4)$$

The normal approximation Z test by using the statistical value  $S$  and the variance value  $\text{Var}(S)$  is written in the following form:

$$Z = \begin{cases} \frac{S - 1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (2.5)$$

For the normal approximation Z test and the cumulative standard normal distribution  $\phi$ , if  $|Z| \leq Z_{\alpha/2}$  and  $\phi(Z_{\alpha/2}) = \alpha/2$ , then the  $H_0$  hypothesis is adopted. Where  $\alpha$  is the probability level of rejecting the null hypothesis  $H_0$  when it is true? The value of Z shows the statistical trend. If  $Z < 0$ , it indicates a decreasing trend and if  $Z > 0$  it indicates an increasing trend (Luo et al., 2011).

### ***2.2.6 Impact Assessment of Meteorological Variation***

To evaluate the effects of climate change, the meteorological data from 1979.1.1 to 2008.12.31 was selected. Coupling the meteorological data and land use map of 2006, two scenarios were established (as follows). The influences of climate variations were quantified by the trend analysis of the simulation results from 1979 to 2008 and comparing the simulation results of two scenarios.

S1: 1979–1988 climate and 2006 land use

S2: 1999–2008 climate and 2006 land use

### ***2.2.7 Impact Assessment of Land Use Variation***

To evaluate the effects of land use change, the meteorological data from 2003.1.1 to 2005.12.31 was selected. Coupling the meteorological data and land use maps of 2006 and 1926, two scenarios were established (as follows). The influences of land use changes were quantified by comparing the simulation results of the two scenarios.

S3: 1927 land use and 2003–2005 climate

S4: 2006 land use and 2003–2005 climate



**Table 2.1** Trend analysis for precipitation and temperature

Item	Period	Mann-Kendall	
		Z	P
Precipitation	Annual	-0.91	N
	Dry seasonal	0.61	N
	Flood seasonal	-1.2	N
Temperature	Annual	3.35	Y
	Dry seasonal	1.75	Y
	Flood seasonal	3.25	Y

Z is statistics of MKT; Y means significant at the level of  $P = 0.05$

## 2.3 Results

### 2.3.1 Variations of Precipitation and Temperature

The trend analysis was carried out for the annual, flood (from March to October) and dry (from November to next February) seasonal rainfall and mean temperature. The annual and seasonal results were shown in Table 2.1. The annual and flood seasonal rainfall trended to decrease and dry seasonal rainfall trended to increase during 1979–2008. However, the trend is statistically insignificant. Whereas annual and seasonal mean temperature increased significantly.

### 2.3.2 Land Use Changes

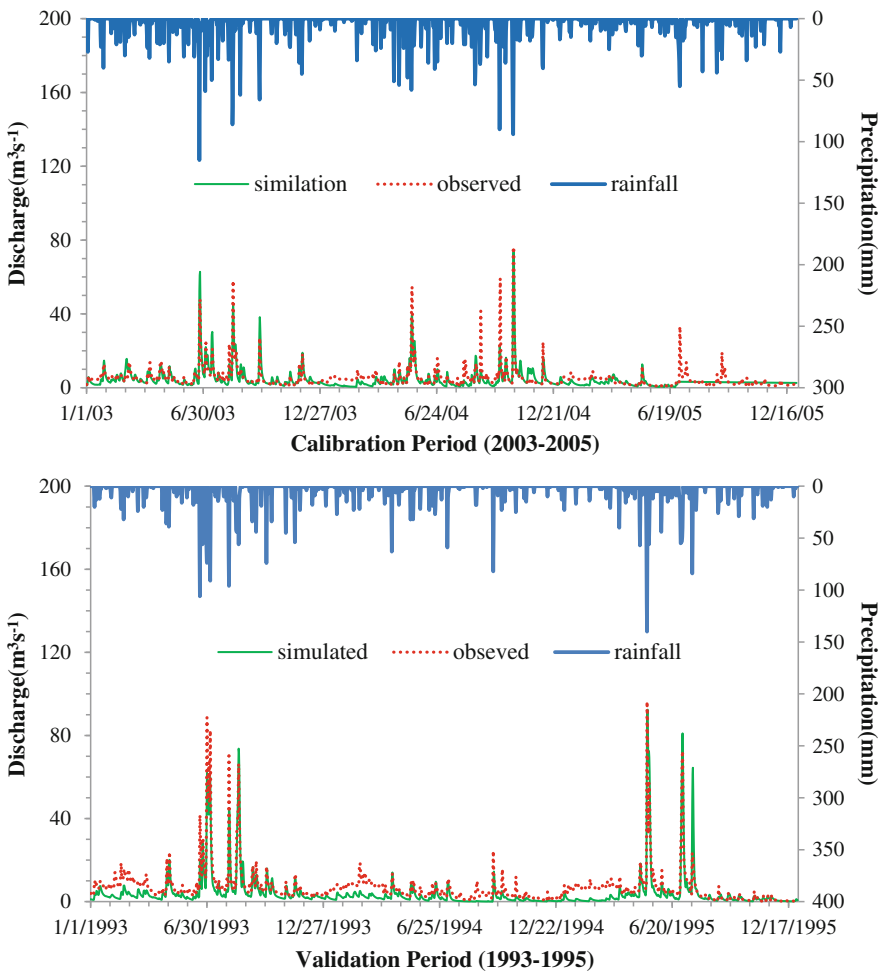
Table 2.2 exhibited the land use types of KRB in 2006 and 1927. From 1927 to 2006, the trend is forestland, grassland and farmland converted into urban areas. The city sprawled twice larger (from 10.7 % of total area to 21.3 %). Rising rate is almost up to 100 %. The decreased areas of forest, grassland and farmland are 4.3 km<sup>2</sup>, 5.56 km<sup>2</sup> and 9.09 km<sup>2</sup>, respectively. However, since the proportions of grass and agriculture field in KRB are small, there are 80.6 % of grass and 69.1 % of agriculture field disappeared.

### 2.3.3 Calibration and Validation of the HYPE Model

The HYPE model was calibrated for a 3-year period from 2003 to 2005 using the land use of 2006 and the resulting parameters were kept constant for the validation step for a different period from 1993 to 1995. Figure 2.3 provides observed and HYPE simulated daily stream flow at the KRB outlet for calibrated and validated periods. Simulations during the calibration period captured the observed evolution well for daily time scales and in general, the observed peak flow was higher than the modelled peak flow. Deficiencies in HYPE simulations included mismatched peak flows for some days of extreme rainfall and underestimation of base flow, which

**Table 2.2** Classification and the area for each land use type for 2006 and 1927

ID	Name	Land use area (km <sup>2</sup> )		Changed area from 1927 to 2006 (%)	Rising rate from 1927 to 2006 (%)
		1927	2006		
1	Forest	138.21	133.91	-2.4	-3.1
2	Urban	19.3	38.35	10.6	98.7
3	Water	1.67	1.911	0.1	14.4
4	Grass	6.9	1.34	-3.1	-80.6
5	Agriculture field	13.16	4.07	-5	-69.1
6	Waste Land	1.12	0.78	-0.2	-30.4



**Fig. 2.3** Observed and simulated daily streamflows at the outlet of the KRB and rainfall data over the calibration and validation periods

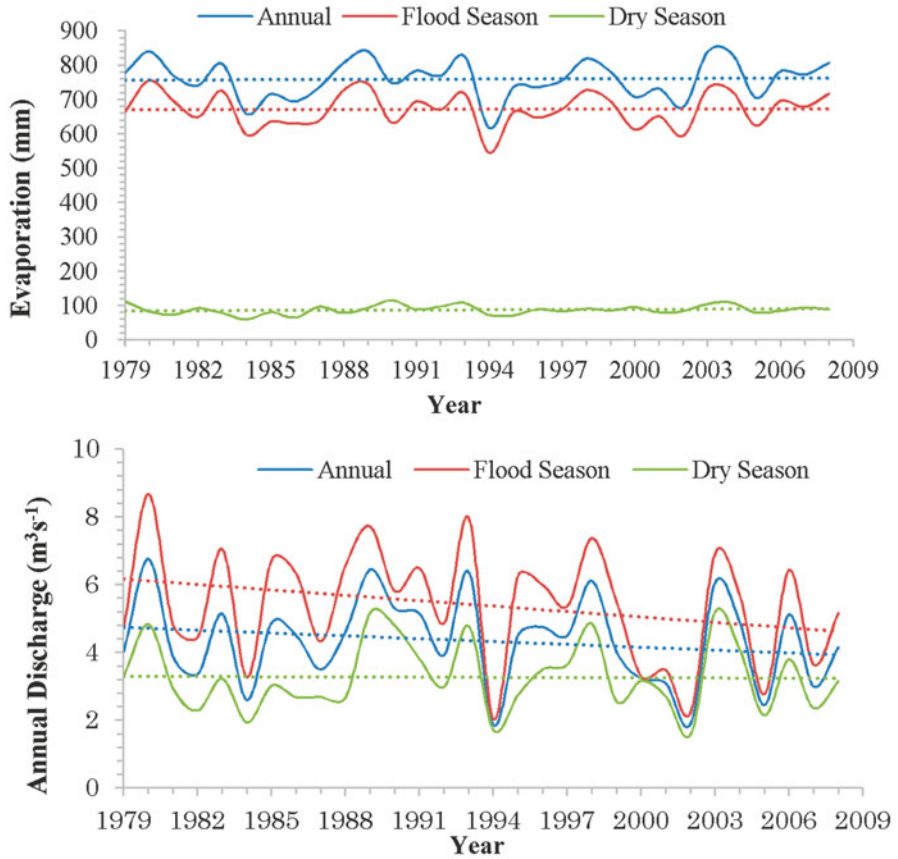


Fig. 2.4 Simulated annual and seasonal evaporation and outlet stream flows in the KRB

was most due to errors in rough soil data. There is no initial soil observed data (field capacity, wilting point, etc.). During the calibration period, correlation coefficients and NSE were 0.87 % and 0.72, respectively.

During the validation period, simulated daily stream flow at the outlet of the KRB also captured the observed evolution well. Peak flow simulations improved in comparison to the calibration period. However, base flow still was underestimated. Correlation coefficients and NSE were 0.83 % and 0.69, respectively.

### 2.3.4 Climate Change Impact

Figure 2.4 displays simulated annual and seasonal evaporation and outlet stream flow at the KRB. The figure illustrates that linear trends occurred in evaporation and

**Table 2.3** Differences of mete-hydrology between S1 and S2 in the KRB

		Precipitation	Temperature	Surface runoff	Evaporation
S1	Annual	1,519.2	15.3	361	754.3
	Flood season	1,320.8	19.6	327.7	672.2
	Dry season	198.4	6.5	33.4	82.1
S2	Annual	1,388.1	16.2	314.8	763.4
	Flood season	1,142	20.6	261.2	672.9
	Dry season	246.1	7.4	53.7	90.7
S2–S1	Annual	−131.1	0.9	−46.2	9.1
	Flood season	−178.8	1	−66.5	0.7
	Dry season	47.7	0.9	20.3	8.6

**Table 2.4** Simulated daily stream flow at the outlet of KRB for two scenarios

Stream flow	S1	S2
AAMD ( $\text{m}^3\text{s}^{-1}$ )	69.7	54.8
MD ( $\text{m}^3\text{s}^{-1}$ )	102.2	104.5

stream flow. Annual and flood seasonal stream flows trended to decrease from 1979 to 2008, whereas dry seasonal stream flow had rising trends. Annual and seasonal evaporation seemed to increase. In addition, stream flow and evaporation have same trends as precipitation and temperature (Table 2.1 and Fig. 2.4), respectively.

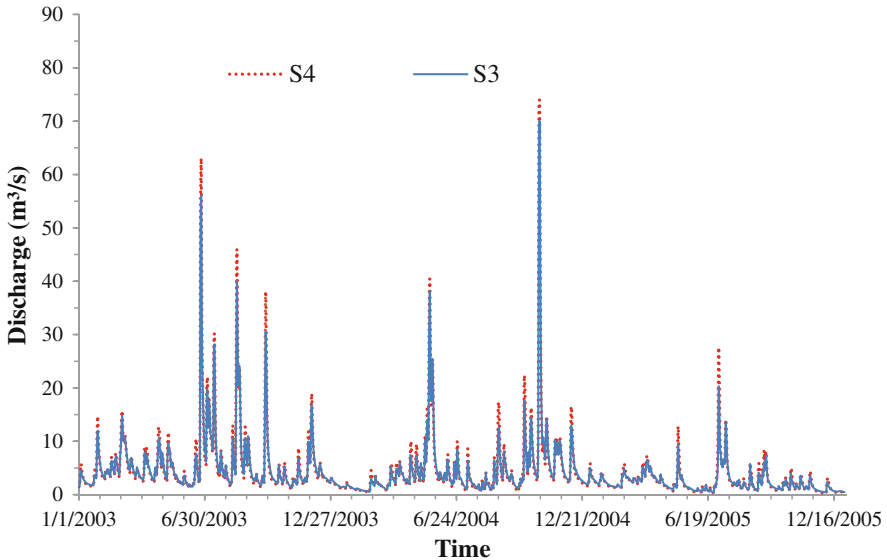
Table 2.3 shows average annual precipitation, mean temperature, stream flow, surface runoff and evaporation in two scenarios of S1 and S2. It reveals that annual and flood seasonal rainfall and surface runoff of S2 decreased 131.1 mm and 46.2 mm respectively in comparison to S1. Evaporation rose 9.1 mm and 0.7 mm, respectively. In arid season, however, rainfall, surface runoff and evaporation all increased.

In addition, the comparison of average annual maximum daily (AAMD) stream flows and maximum daily (MD) stream flows of S1 and S2 demonstrates that AAMD stream flow of S1 was higher, while MD stream flow of S2 was larger (Table 2.4).

### 2.3.5 Land Use Change Impact

Computed daily stream flows of scenarios 3 and 4 are shown in Fig. 2.5. There are large differences on peak flows. The peak flows of S4 are much higher than the ones of S3. It can be concluded that the conversion of forest, grass and agriculture (FGA) into urbanization would lead to high peak flow.

Furthermore, annual and monthly differences of surface runoff and evaporation between S3 and S4 were estimated (shown in Figs. 2.6 and 2.7). With respect to evaporation, the conversion of FGA into urbanization would result in a reduction of about 35 mm, 36 mm and 31 mm for the years of 2003, 2004 and 2005. Greatest



**Fig. 2.5** Simulated daily stream flows at KRB outlet according to S3 and S4

differences were presented in summer. On the contrary, the surface runoff increased about 39 mm, 35 mm and 23 mm for the years of 2003, 2004 and 2005 under the conversion of FGA into urbanization.

## 2.4 Discussion

### 2.4.1 Model Uncertainty

Model uncertainties are resulted from uncertainties in input data, model dynamics and physics and parameter values. To reduce uncertainties of the HYPE model and examine the suitability of HYPE for impact studies in the KRB, the model was calibrated and validated at the gauge of the basin outlet. The calibration and validation results showed that HYPE simulations matched observations well in various periods. Although this ensures that HYPE is applicable in this basin, it is recognized that HYPE displayed relatively large biases in terms of base flows that were most likely due to lack of soil hydrology data (field capacity, wilting point, etc.). These biases, however, should not compromise our analysis results since the analysis was based on the comparison of different simulated scenarios and was not focused on base flow.

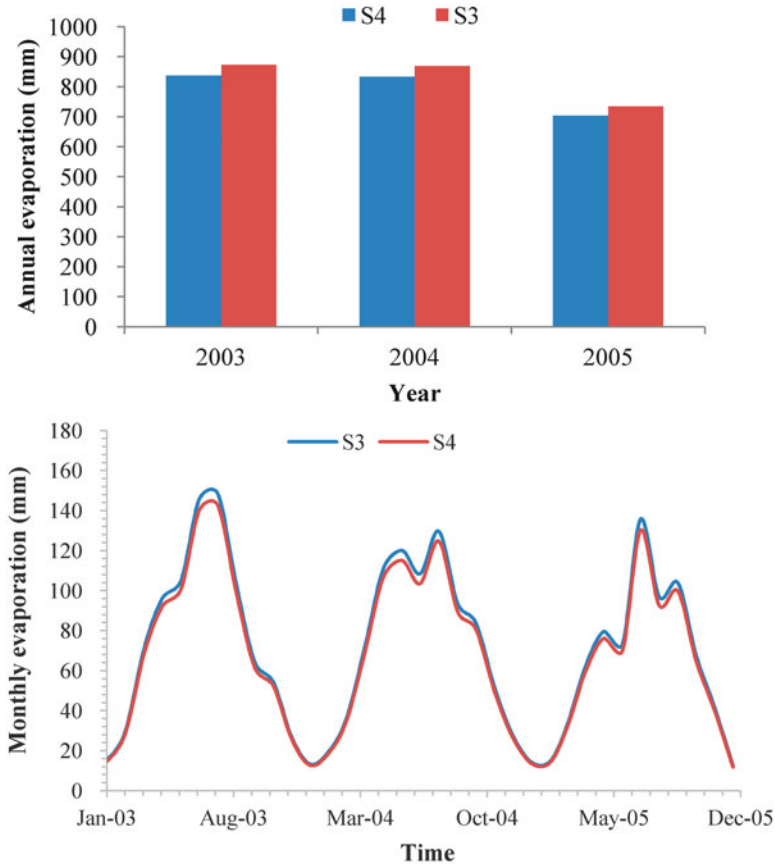


Fig. 2.6 Annual and monthly evaporation of S3 and S4 in the KRB

## 2.4.2 Results Discussion

As we know, runoff has positive correlation with rainfall and negative relation with evaporation. The simulated results of annual and flood seasonal stream flows demonstrate the relationships. In arid season, rainfall, evaporation and surface runoff had the same rising trends revealing that the contributions of rainfall to runoff were larger than these of evaporation to runoff. Similar results had been reported in some regions suffered homogeneous climate changes (Hao et al. 2008; Zhang et al. 2012). But, there is no evidence to prove the flood risk decreasing in the KRB since there is no decreasing trend in the MD stream flow in the two different periods, though AAMD stream flow decreased from S1 to S2 and annual stream flows seemed to reduce.

The results of stream flow variations under land use changes indicate that the conversion of FGA into urban area resulted in high peak flow, a reduction in annual

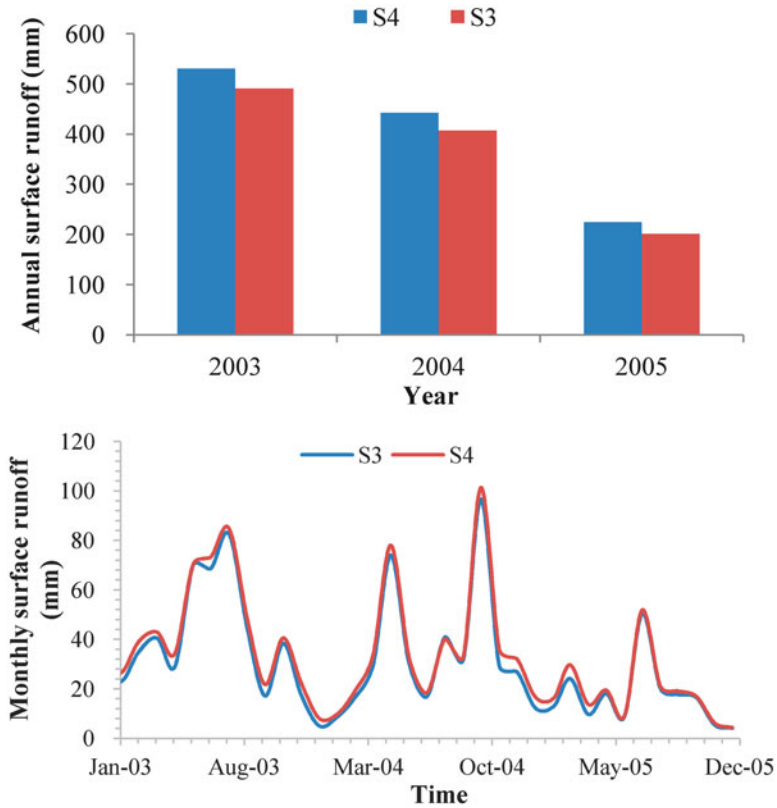


Fig. 2.7 Annual and monthly surface runoff of S3 and S4 in the KRB

evaporation and an increase in annual surface runoff. This phenomenon might be explained by different hydrological processes in different land-use types. With contrast to FGA area, infiltration in urban area is much smaller as most of urban areas are covered by impervious surface, which leads to quick runoff and reduce infiltration. Luo et al. (2014a) took a Palaeoflood research in KRB and found similar results that higher and earlier peak discharge was driven by urbanization. In addition, the conversion of FGA into urban area presented a greater effect on evaporation in summer. This phenomenon can be explained by the research of Tucci (2003) that precipitation distribution over the year allowed identification (if it exists) of water availability for evapotranspiration. As the temperature and precipitation in these months are the highest in a year in the KRB, there is water availability in the soil during periods with the greatest potential evapotranspiration. Beskow et al. (2012) reported the similar behavior that stream flows presented the greatest differences among different scenarios of land use in the wettest and hottest months like December, January, February, March, and April in Brazil. There are no apparent characteristics with respect to monthly surface runoff differences of S3

and S4, which are inconsistent with monthly evaporation changes. These might be due to the rainfall density and extreme rainfall and it requires more research.

## 2.5 Summary and Conclusion

In this study, the influences of climate and land use changes on stream flow in the KRB were estimated by an application of the HYPE model. The simulated stream flow and its components were shown to vary among different scenarios of climate and land use. Comparing the results of climate scenarios revealed that annual and flood seasonal stream flows had a decrease trend from 1979 to 2008, whereas dry seasonal stream flow trended to rise. However, there is no evidence to prove the flood risk decreased. The differences of simulated outputs between land use scenarios exhibited the conversion of FGA into urban area induced high peak flow, a reduction in annual evaporation and an increase in annual surface runoff. In general, the results of this study provide important information for understanding hydrology variation, and guide water resource managers to plan decisions associated with water environmental change.

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## References

- Arheimer B, Dahne J, Donnelly C (2012) Climate change impact on riverine nutrient load and land-based remedial measures of the Baltic sea action plan. *Ambio* 41(6):600–612
- Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrologic modeling and assessment part I: model development. *J Am Water Resour Assoc* 34(1):74–89
- Bergström S (1976) Development and application of a conceptual runoff model for Scandinavian catchments. Ph.D. thesis, SMHI reports RHO no. 7, Norrköping
- Beskow S, Norton LD, Mello CR (2012) Hydrological prediction in a tropical watershed dominated by oxisols using a distributed hydrological model. *Water Resour Manag* 27(2):341–363
- Chu JG, Zhang C, Wang YL, Zhou HC, Shoemaker CA (2012) A watershed rainfall data recovery approach with application to distributed hydrological models. *Hydrol Process* 26(13):1937–1948
- Cornelissen T, Diekkrüger B, Giertz S (2013) A comparison of hydrological models for assessing the impact of land use and climate change on discharge in a tropical catchment. *J Hydrol* 498:221–236
- Cuo L, Zhang Y, Gao Y, Hao Z, Cairang L (2013) The impacts of climate change and land cover/use transition on the hydrology in the upper Yellow River Basin, China. *J Hydrol* 502:37–52
- Dechmi F, Burguete J, Skhiri A (2012) SWAT application in intensive irrigation systems: model modification, calibration and validation. *J Hydrol* 470:227–238
- Delpla I, Jung AV, Baures E, Clement M, Thomas O (2009) Impacts of climate change on surface water quality in relation to drinking water production. *Environ Int* 35(8):1225–1233



- Dixon B, Earls J (2012) Effects of urbanization on streamflow using SWAT with real and simulated meteorological data. *Appl Geogr* 35(1–2):174–190
- Donnelly C, Yang W, Dahne J (2014) River discharge to the Baltic Sea in a future climate. *Clim Chang* 122(1–2):157–170
- Flügel W (1995) Delineating hydrological response units by geographical information-system analyses for regional hydrological modeling using PRMS/MMS in the drainagebasin of the River Brol, Germany. *Hydrol Process* 9:423–436
- Hamed KH, Rao AR (1998) A modified Mann-Kendall trend test for autocorrelated data. *J Hydrol* 204(1–4):182–196
- Hao XM, Chen YN, Xu CC, Li WH (2008) Impacts of climate change and human activities on the surface runoff in the Tarim River basin over the last fifty years. *Water Resour Manag* 22(9):1159–1171
- Jiang S, Jomaa S, Rode M (2013) Identification and uncertainty analysis of a hydrological water quality model with varying input data information content. EGU General Assembly Conference Abstracts
- Jomaa S, Jiang S, Rode M (2013) Effect of increased bioenergy crop production on hydrological response and nutrient emission in central Germany. EGU General Assembly Conference Abstracts
- Koch S, Bauwe A, Lennartz B (2013) Application of the SWAT model for a tile-drained lowland catchment in North-Eastern Germany on subbasin scale. *Water Resour Manag* 27(3):791–805
- Liang X, Lettenmaier DP, Wood EF, Burges SJ (1994) A simple hydrologically based model of land surface water and energy fluxes for general circulation models. *J Geophys Res Atmos* (1984–2012) 99(D7):14415–14428
- Lindstrom G, Pers C, Rosberg J, Stromqvist J, Arheimer B (2010) Development and testing of the HYPE (Hydrological Predictions for the Environment) water quality model for different spatial scales. *Hydrol Res* 41(3–4):295–319
- Luo P, He B, Takara K et al (2011) Spatiotemporal trend analysis of recent river water quality conditions in Japan. *J Environ Monit* 13:2819–2829
- Luo P, Takara K, Apip, He B, Nover D (2014a) Palaeoflood simulation of the Kamo River basin using a grid-cell distributed rainfall run-off model. *J Flood Risk Manag* 7(2):182–192
- Luo P, Takara K, Apip, He B, Nover D (2014b) Reconstruction assessment of historical land use: a case study in the Kamo River basin, Kyoto, Japan. *Comput Geosci* 63:106–115
- Öztiürk M, Coptý NK, Saysel AK (2013) Modeling the impact of land use change on the hydrology of a rural watershed. *J Hydrol* 497:97–109
- Singh A, Gosain AK (2011) Climate-change impact assessment using GIS-based hydrological modelling. *Water Int* 36(3):386–397
- Strömqvist J, Dahne J, Donnelly C, Lindström G, Rosberg J, Pers C, Yang W, Arheimer B (2009) Using recently developed global data sets for hydrological predictions. *IAHS Publ.* 333
- Strömqvist J, Arheimer B, Dahné J, Donnelly C, Lindström G (2012) Water and nutrient predictions in ungauged basins: set-up and evaluation of a model at the national scale. *Hydrol Sci J* 57(2):229–247
- Swank WT, Crossley DA (1988) *Forest hydrology and ecology at Coweta*. Springer, New York
- Tucci CEM (2003) Processos hidrológicos e os impactos do uso do solo. In: Tucci CEM, Braga B (eds) *Climae recursos hídricos no Brasil*. ABRH, Porto Alegre, pp 31–76
- Yu YS, Zou SM, Whittemore D (1993) Nonparametric trend analysis of water-quality data of rivers in Kansas. *J Hydrol* 150(1):61–80
- Zhang A, Zhang C, Fu G, Wang B, Bao Z, Zheng H (2012) Assessments of impacts of climate change and human activities on runoff with SWAT for the Huifa River Basin, Northeast China. *Water Resour Manag* 26(8):2199–2217