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COMPARATIVE STUDY ON EFFECT OF EXTREAME WEATHER AND URBANIZATION TO FLOOD OF TYPICAL RIVERS IN JAPAN

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ABSTRACT

The impact of extreme rain, urbanization and snow amount variability in typical rivers in Hyogo prefecture as a microcosm of Japan is investigated. In Mukogawa River, urbanization greatly advanced around Sanda, but its influence on the outflow process was relatively small at Sanda in the main stream and large in a tributary of Nagano River. Therefore, when evaluating the influence of urbanization on the outflow of rivers, it is necessary to pay attention to the rate of change of land use in the entire catchment. In the Kishidagawa River, it was found that there was a big difference in the amount of snow water in the watershed in the spring season between the year of much snow and the year of little snow. In the years with little snow, it turns out that the use of stable snow melting water cannot be expected. Based on these results, we considered that the risk of water problems in the river basin of Japan will further increase with the change of climate and life style. From now on, what kind of action will be taken according to the risk and how to inform people of the risk will be a problem.

Keywords: Water resources; climate change impact; urbanization impact; flood; snow.

1 INTRODUCTION

Recently, urbanization has changed run-off process of rivers and river basins, especially in rivers running through urban area. Moreover, climate change reduces the amount of snow in the northern part of Japan where snow is the most dominant water resources of pacific urban area like Tokyo, Osaka and Kobe that the situation is similar as California. Urbanization and climate change raise the frequency of localized heavy rain, increasing the risk of inundation in urban area. In other words, urbanized area changed to be running out of water in average, but increasing the risk of inundation in case of heavy rain. However, it is difficult for us to realize the change.

The objectives of the present study are to find out the flood risk increased by urbanization as well as to capture the amount of snow as water resources in early spring, to point out the most vulnerable area in the basin against water related disaster.

The authors selected three typical river basins in Hyogo prefecture, which people assume as "microcosm of Japan". One is Mukogawa River where urbanization has proceeded heavily and accumulation of population, wealth and asset has been very high. Mukogawa River shows typical urban river in Japan. The second one is Ibogawa River where high altitude mountain in the upper river basin and paddy field extends lower river basin. The upper river basin has snow every year. The third one is Kishidagawa River basin where snow is usually heavy in winter and the river passes through paddy field.

Distributed hydrological model developed by a grid-cell based distributed flood runoff model (Kojima and Takara, 2003) with historical land use maps of 1976, 1987, 1991, 1997, 2006 and 2009 published by Ministry of Land Infrastructure and Transport, Tourism (MLIT) of Japan has been used for the present study. Inundated water movement is calculated by two-dimensional shallow water model with corresponding roughness ratio with land use.

2 DISCHARGE CALCULATION USING THE XRAIN DATA OF KANTO AND TOHOKU HEAVY RAIN

Kanto and Tohoku heavy rain in 2015 reminded Japanese people of flood risk in urban area. Kanto and Tohoku heavy rain took place in the area where almost 500km away from Hyogo prefecture, however a similar heavy rainfall may happen. Therefore, it is reasonable to calculate discharge in Mukogawa River and Ibogawa River using the radar data at that time. The radar data collected by XRAIN meteorological network using X-band MP radar with high resolution in time of one minute and space of 250m.

Thus, in each basin, the same rainfall situation, such as Kanto-Tohoku heavy rain, was simulated in Mukogawa River and Ibogawa River. The simulated result is summarized by the discharge at Koububashi point, which is the discharge control point of Mukogawa River and at Yamazakidaini, which is the discharge control point of Ibogawa river, as shown in Table 1.

Table 1. Summary of discharge calculation in Mukogawagawa River and Ibogawa River.

Location name	Koububashi ↖ Mukogawa River↗	Yamazakidaini ↖ Ibogawa River↗
Design Flood (m^3/s)	3700	3000
Discharge calculation using the XRAIN data of Kanto and Tohoku heavy rain (m^3/s)	3622↖ Calculated value↗	3323↖ Calculated value↗
Historical maximum discharge (m^3/s) since 1986	2900↖ Estimated value↗ ↖ Typhoon No. 23 in 2004↗	3045↖ Observed value↗ ↖ Typhoon No. 19 in 1990↗

In the discharge calculation using the XRAIN data of Kanto and Tohoku heavy rain, the discharge at Koububashi (Mukogawa River) is almost same as the design flood (3700m^3/s) there, and the discharge at Yamazakidaini↖ Ibogawa River↗ exceeds estimated the design flood (3000m^3/s) there. Moreover, both of the simulated discharge exceeded the historical maximum discharge since 1986. The historical maximum discharge bought damage in the river basins.

If extreme rainfall exceeds expected design flood, residents near the river should be aware of the safe location from hazard maps made by municipalities. Moreover, it is necessary to bear in mind the possibility that unexpectedly more flood damage than the municipalities' "assumption" when rainfall exceeds the "expected" maximum amount.

3 URBANIZATION AND OUTFLOW PROCESS IN MUKOGAWA RIVER BASIN

The progress of urbanization has increased rainfall impermeable area and run-off response speed with decreasing rainwater retention capacity so that the total discharge and peak discharge has increased and arrival time of peak discharge has been reduced. Therefore, the change of urbanization and outflow process by taking Mukogawa River basin (Figure 1), which took place remarkable urbanization has been investigated in the present study.

Figure 2 shows the results of the simulated discharge using land use data of 1976 (before urbanization) and 2014 (after urbanization). Rainfall of Typhoon No. 23 in 2004 was used for the simulation. Difference between the discharge at city of Sanda, which locates along the main stream of Mukogawa River and area of Naganogawa in a small tributary, has been compared. The simulated results show that the peak discharge at Naganogawa increased after the urbanization.

From the simulation, the influence on urbanization outflow process raise 28.5% of peak discharge after urbanization in a relatively small catchment where ratio of developing area is dominant in the catchment, whereas the discharge in large catchment consisting of forest, paddy field as well as highly developed urban area does not change so drastically.

Therefore, when evaluating the influence of urbanization on the outflow of rivers, it is necessary to pay attention to the rate of change of land use in the entire catchment.

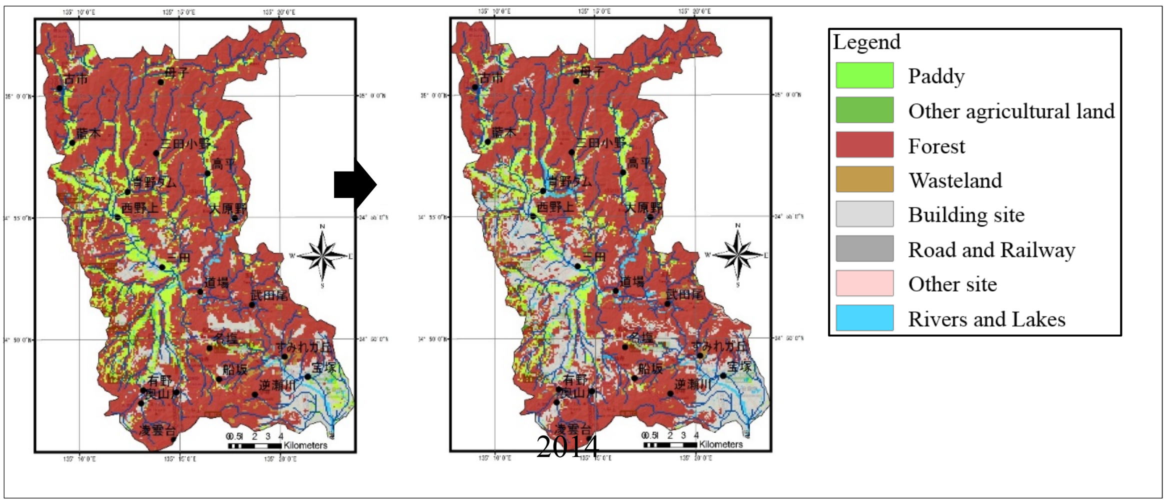

Figure 1. Changes in land use in the Mukogawa river basin.

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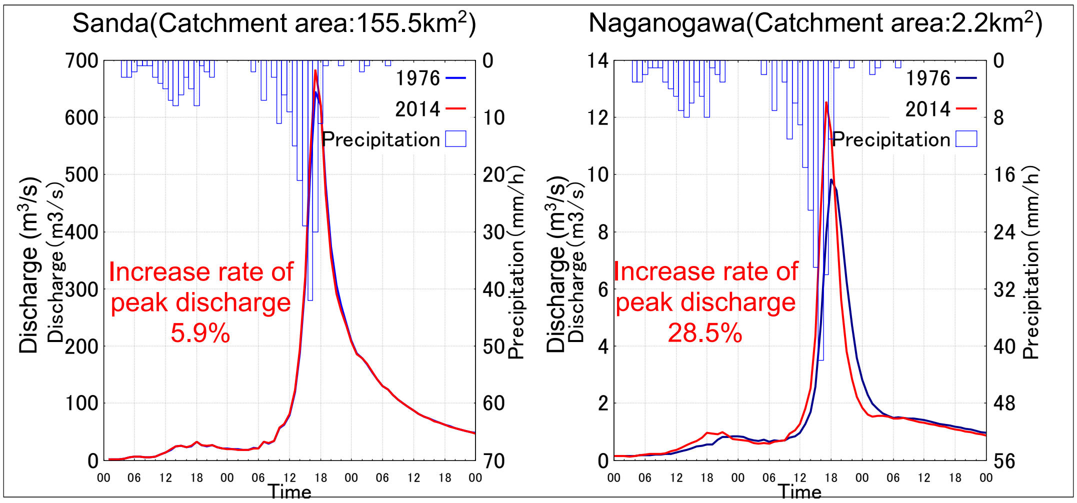

Figure 2. Results of discharge analysis using case of Typhoon No. 23 in 2004.

4 SNOWFALL, SNOWMELT AND OUTFLOW PROCESS IN THE KISHIDAGAWA RIVER BASIN

In the northern area of Hyogo prefecture like Kisidagawa river basin, snow is water resources in spring and early summer when farmers use plenty of water for paddy field. Therefore, the accumulated snow amount and snow melting process are simulated by numerical snowfall and snowmelt model that is modified from the result of Kozan et al. (2003) in Kishidagawa river basin located in the northern part of Hyogo Prefecture. They had much snow in the 2011 – 2012 seasons and a little snow in the 2015 – 2016 seasons.

Figure 3 shows the discharge at the Hamasaka observation point with simulated result. There are two types of simulations in this section. One is simulation calculated by only discharge model without the snowfall and snowmelt model in order to consider the contribution of snow to store the water resources. The other is simulation with the snowfall and snowmelt model.

By introducing the snowfall and snowmelt model, the accuracy of runoff analysis improved as compared to the result of only discharge model. In the year of much snow (left figure of Figure 3), water resources in January and February are stored as snow, which is released from March to May as melted water. However, it was not seen in the year of little snow.

Table 2 shows the amount of water resources due to snow in the Kishidagawa river basin in the spring. In the Kishidagawa river basin, the amount of snow water is totally different between the year of much snow and the year of little snow. In the year of much snow, the stored water in April meets up to 20 years of water for the population in the Kishidagawa river basin, but in the year of little snow, 0.7 months of water is stored.

In the future, snow may attract attention as a water resource, but recently snow is not assumed as stable water resources. The present study shows the stored water resources as snow differs almost 800 times year by year.

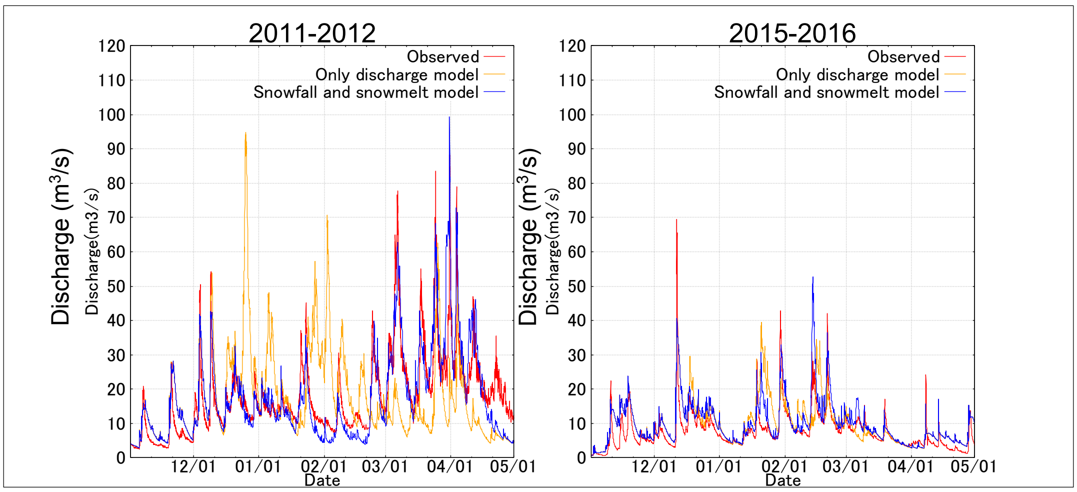

Figure 3. Results of winter discharge analysis using snowfall and melting snow model.

Table 2. Water resources due to snow in the Kishidagawa river basin in spring.

	March 15		**April 1**	
	2011-2012	2015-2016	2011-2012	2015-2016
Amount of snow water！(m^3)	5.8×10^7	2.7×10^6	2.5×10^7	6.9×10^4
Conversion of water usage of population (month)	576.4	26.9	243.7	0.7

5 CONCLUSIONS

In this study, the influence of extreme weather and urbanization on outflow process is investigated taking typical rivers in Hyogo prefecture as examples.

As a result, we understand as followed.

1) In the future, if rain falls beyond the designed assumption, flood discharge becomes unexpected;
2) The urbanization in small catchment changes the discharge amount;
3) Snow is no longer stable water resources.

All over the world, climate variability takes place and population is rapidly concentrating in urban areas. This trend keeps continue in the future.

In this way, the water problem in the river basin of Japan is considered to further increase as the climate variability and life change. From now on, it can be said that how to anticipate the risk in advance, take actions according to the risk and how to inform people of the risk.

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UNCERTAINTY FROM LAND USE AND CLIMATE CHANGE IN FUTURE STREAMFLOW SIMULATIONS

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ABSTRACT

Quantification of uncertainties in projecting the impacts of land use and climate change on future streamflow simulations is of paramount importance for sustainable water resources management. Uncertainties may arise from different sources such as input data, hydrologic models and/or natural variability of the hydrologic system. In this paper, we address uncertainty in streamflow simulations due to future projections of land use and climate. Although there are several studies reported in literature where uncertainty due to climate projections arising from the use of General Circulation Models (GCMs) in streamflow simulations is quantified in detail, there is dearth of studies where land use projections are considered as a source of uncertainty. In this paper, several plausible combinations of land use and climate projections are used to obtain multiple streamflow simulations. The investigation is carried out over the Upper Ganga Basin (UGB) in India using a semi-distributed Variable Infiltration Capacity (VIC) hydrologic model. The VIC model is coupled with Parameter ESTimation (PEST) algorithm to obtain the optimum set of model parameter values. Uncertainty in the streamflow projections is addressed by obtaining the best representative of future estimate for the streamflow along with its bounds using reliability ensemble averaging approach. Results from the case study indicate that the streamflow from the UGB may reduce significantly in future.

Keywords: Land use; climate projections; PEST; VIC; ensemble average.

1 INTRODUCTION

Changes in land use (LU) and climate are known to significantly influence water resources and hydrology of a region (Vörösmarty et al., 2000; Oki and Kanae, 2006). Quantifying the implications of LU and climate change under future scenarios is critical for sustainably managing the water resources. In this regard, several studies have been carried out in past that address effect of either of these factors on hydrological processes (Wagner et al., 2013). Amongst these, a few studies have focused on the integrated effects of LU and climate change on streamflow (Chawla and Mujumdar, 2015). However, impacts of projected LU change – along with ongoing climate change – on water resources is neglected in most of the above-mentioned studies.

General Circulation Models (GCMs) are currently considered to be the most credible tool for simulating climate change projections. However, each GCM utilizes different boundary condition resulting into disagreement between model realizations for a particular climate variable across different GCMs. As a consequence, GCMs are considered to be associated with significant amount of model and scenario based uncertainty (Wilby and Harris, 2006). In addition to GCMs, LU projections may also contribute towards input data uncertainty in impact assessment studies. Projections for future LU are generally obtained by using information from the past and selecting driving variables (such as road network, stream network, proximity to existing urban area, etc.) that may cause change in the LU of the region. Selection of driving variables is quite subjective which introduces uncertainty to the LU projections of future time period. Therefore, future projections of LU and climate may impart uncertainties to the streamflow projections that may make the results unrealistic (Beven, 2001; Bastola et al., 2011). Therefore, in order to establish confidence in the projected impacts of LU and climate change on water resources, it is necessary to perform these studies within the uncertainty framework.

In the past decade, attempts have been made to address uncertainties in climate change projections by considering ensemble of GCM simulations (Giorgi and Mearns, 2002; Ghosh and Mujumdar, 2009); however, the uncertainty in LU predictions is mostly ignored. In the present paper, input data uncertainty pertaining to both LU and climate is addressed by considering combined information provided by several plausible projections of LU and climate change.

Impact assessment studies are usually carried using physically based hydrologic models. Executing hydrologic models require a challenging task of estimating parameter values which contribute immensely towards model parameter uncertainty (Brath et al., 2004; Goegebeur and Pauwels, 2007). Model parameters can be obtained manually which can turn out to be a cumbersome task. Therefore, hydrologic models are often driven along with an optimization algorithm to obtain best set of parameter values. In the present paper, a semi-distributed Variable Infiltration Capacity (VIC) model coupled with Paramter ESTimation (PEST) algorithm is executed to obtain streamflows projections. Details corresponding to the structure and functioning of the VIC model can be obtained from Liang et al. (1994), Liang et al. (1996), Nijssen et al. (1997) and Lohmann et al. (1996; 1998a; b).

With this background, this study aims at identifying the integrated impacts of land use and climate change on future streamflow simulations within the uncertainty framework.

2 DATA AND METHODOLOGY

2.1 Study area and observed data

Analyses is carried out over the upper part of the Ganges River basin in India, hereafter termed as Upper Ganga Basin (UGB). UGB covers approximately 100,000 sq. km within the latitude 25°30'N – 31°30'N and longitude 77°30'E – 80°E (Figure 1). The basin includes origin place of the Ganges river in India and therefore any change in this part of the basin has influence over the hydrological regime of the entire basin. This makes this region an important area to study. Elevation information of the region is derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data. UGB exhibits significant variation in the topography (Figure 1) and consequently in the LU pattern and the climatology. Based on this variation, the region is subdivided into upstream, midstream and downstream reaches and considered independently for hydrologic modelling. Upstream region of the UGB is highly undulating, with elevations ranging from 300 m to 7800 m a.m.s.l and dominated by mountainous landscape which are covered by glaciers and dense forests throughout the year. Midstream region is slightly lower in elevation with values ranging between 75 m to 3000 m a.m.s.l and as a result supports scrub forests and crop land areas. Downstream region is mostly plain with approximate elevation of 100 m a.m.s.l and is covered by crop lands.

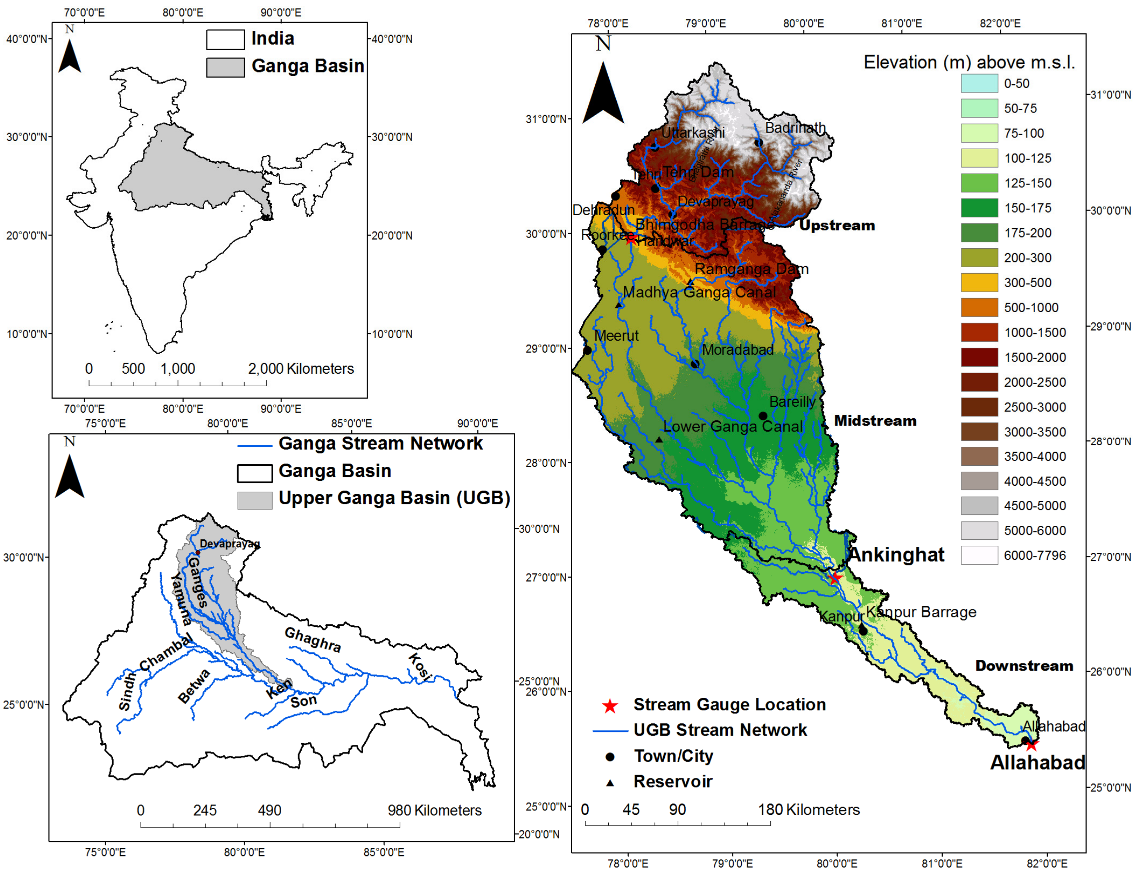

Figure 1. Details of the Upper Ganga Basin (UGB) study area (from Chawla and Mujumdar, 2015).

Observed rainfall and temperature data required to execute the VIC model is obtained from the Indian Meteorological Department (Rajeevan et al., 2006). However, information corresponding in the wind speed is procured from the Princeton University database (Sheffield et al., 2006). Climate data is brought to the VIC model execution resolution, which is 0.5° for the present work. Setting up a hydrological model over a region requires information related to the observed hydrological processes in the basin which is used for model calibration and validation. In the present work streamflow records from two stations: (a) Bhimgodha (1987-2011), and (b) Ankinghat (1977-2009) is considered for setting up the model at monthly scale. This data is obtained from the Uttar Pradesh Irrigation Department and Central Water Commission (CWC). The entire length of the Ganga River in this region has control structures which makes the obtained data unusable in the procured form. For model calibration and validation, the observed data, which essentially is regulated streamflow, is converted to natural streamflow by adding the data corresponding to various diversions to the observed records. This data is also obtained from the CWC. Digitized soil map is obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) to determine soil profile of the UGB which is given as an input to the VIC model.

2.2 Land use projections

In general, the LU models project change in future by empirically relating the variables that are expected to drive change in LU (driving variables) with the transitions of interest. LU projection models often use logistic regression or artificial neural network based approaches to establish the relationship between driving variables and LU transitions. Logistic regression based models can only model one LU transition (such as conversion from forest to crop land) at a time, whereas neural network based models can model multiple transitions together. Considering the above feature of LU models, a neural network based model is used in the paper for projecting LU of the UGB into the future. Digitized network of road, stream and urban areas are considered as primary set of LU change driving variables. In addition to this, due to hilly terrain of the region, it is assumed that elevation and slope may also play an important role in determining LU change. Based on this assumption, elevation and slope are also considered as LU change driving variables in the present work.

The main goal of LU modelling is to project the LU for the year *t*+1, given the LU for the time period *t* and *t*-1. Within the framework of neural network, aforementioned driving variables are provided as input layer, and the output layer comprises of temporal transitions to be modelled. Hidden layer contains neurons which can vary from one to ten in number. A back propagation (BP) algorithm, which operates in two steps, forward and backward, is used to establish the relationship between input and output layer. Network is initially trained by supplying it with a random set of pixels along with the value of their driving variables during time period *t*-1 as input layer. Output layer contains the transitions such as forest to crop land or barren land to urban area that took place between time period *t*-1and *t*, and need to be modelled for future. Output layer during training can be considered as a set of binary numbers, where 1 is allocated to transition that has actually taken place while rest of the transitions are assigned with value 0. These can also be considered as observed probabilities of occurrence of the transition. Neurons in the hidden layer sums the weighted signals from all the input variables or nodes and perform sigmoidal transformation (to restrict the value within the range of 0 to 1) on the obtained values to generate output signal. After the BP algorithm completes one forward pass, output signal is compared with its observed value to determine error in the network. The algorithm then propagates backwards and adjust weights in the hidden layer neurons to reduce error in the network. This process is repeated until the error is reduced to the acceptable level. After training is over, the model is then executed for the LU map of time period *t* and the obtained output layer is converted to transition potentials or probabilities by dividing the value obtained for each modelled transition with the summation across all the transitions. Obtained transition potentials are used to create transition potential maps for the region. Projections of change are usually based on applying a threshold value to these transition probabilities (Verburg et al., 2002) which, in the current work, is determined from transition probabilities obtained from Markov transition matrix between LU maps of time *t*-1 and *t*.

A Markov process, given by Eq. [1], can be described as the probability of a phenomenon X_n being in state x_n at any time (say, t) given its state during previous time step (say, $t-1$):

$$P(X_n = x_n \mid X_{n-1} = x_{n-1}, X_{n-2} = x_{n-2}, \ldots, X_0 = x_0) = P(X_n = x_n \mid X_{n-1} = x_{n-1}) \qquad [1]$$

In LU modelling, Markov transition probability corresponding to each direction of change is obtained which creates Markov transition probability matrix. Based on the comparison between Markov transition probabilities and transition potential maps, a multi-objective land allocation is carried out which looks for all the plausible transitions along with identification of losing classes (LU categories which lose the area) and gaining classes (LU categories which gain the area). Finally, the results from land allocation are overlaid to produce a prediction map. Further details related to LU modelling using neural network can be obtained Eastman (2009).

In the present paper, validation of the LU change model is carried out by simulating LU for the year 2011 using the historic LU maps of the years 1980 and 2000. The simulated map of 2011 is then compared with the observed map to determine the projection errors. Errors between the simulated and observed LU maps are quantified using kappa index of agreement (KIA) developed by Pontius (2000). Value of KIA may lie between 0 to 1, where 1 indicates perfect agreement between simulated and observed images and 0 indicates that the agreement is as good as expected by chance. Overall KIA value in the present case is observed to be 0.67 indicating that the model is able to replicate the historic LU map with reasonable accuracy and can be considered suitable for obtaining future projections. LU of UGB is projected for the years 2020, 2030 and 2040 for four different scenarios in order to account for uncertainty pertaining to the LU change that may occur in the future. These four scenarios are as follows: (a) Scenario 1: Change in scrub forest and crop land; (b) Change in only crop land; (c) Change in urban area alone; and (d) Change in both crop land and urban area.

2.3 Climate projections

Climate projections from six GCMs for two Representation Concentration Pathways (RCPs), RCP 4.5 and RCP 8.5 are considered in the present work to drive the hydrologic model in order to understand the future implications of LU and climate change on streamflow simulations. Details pertaining to the selected GCMs could be obtained from Chawla and Mujumdar (2015). REA of future climate projections across six GCMs has been computed for the three climate variables rainfall (*R)*, maximum temperature (T_{max}) and minimum temperature (T_{min}) and the corresponding boxplots, along with boxplot of observed values (1971-2005), are presented in Figure 2.

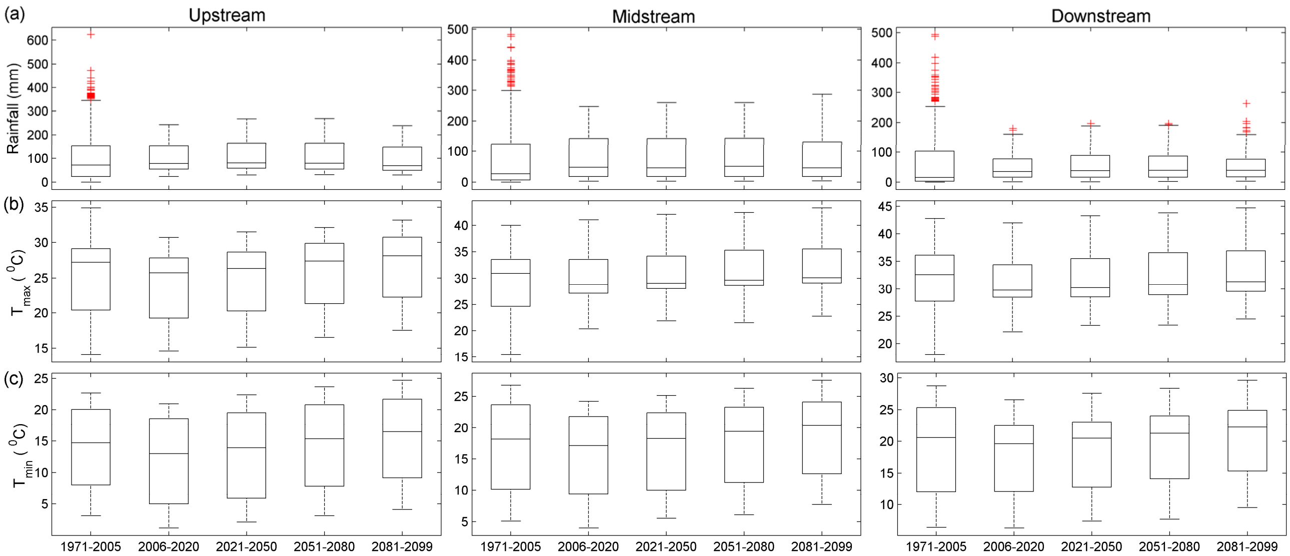

Figure 2. Comparison between (a) rainfall; (b) maximum temperature; and (c) minimum temperature during historic and future time periods for upstream; midstream; and downstream regions of the UGB.

It is observed from the figure that rainfall exhibited comparable variability with respect to historic data in case of midstream region while the ranges have considerably reduced for the upstream and downstream regions. The T_{max} in the upstream region is observed to be left skewed consistently across all the time periods (which could result in more number of high T_{max} values) while this phenomenon is not depicted in the other two regions. There is a reversal of skewness in T_{max} (from being left skewed in past to right skewed in future time period) for midstream and downstream regions. Furthermore, an upward trend of T_{max} is observed in midstream and downstream regions owing to occasional occurrence of few extreme events in the projected data. No significant change in T_{min} during future time periods could be observed for the three regions of the UGB. The climate projections (six GCMs for two climate scenarios) along with four LU scenarios thus obtained are used to generate 48 plausible LU-climate scenarios which are fed into the hydrologic model for three regions of the UGB.

2.4 Hydrologic model setup

LU and climate change impact assessment in the present work is carried out by employing a semi-distributed Variable Infiltration Capacity (VIC) hydrologic model (Liang et al., 1994). Consideration of a region in the form of grids with spatial resolution ranging between 1/8° and 2° is key feature of the VIC model. Due to this, the VIC model has been employed widely over basins of varying sizes across different parts of the world.

Executing a hydrologic model usually requires parameters that cannot be obtained directly from any data and need to be fixed on an ad hoc basis. In order to minimize errors between simulated and observed streamflow, calibration of these parameters is required. Traditionally, calibration process involves manual adjustment of parameters which is time intensive and depends on the judgment and experience of the modeler. Further, due to subjectivity involved in the manual calibration, it is likely that several combinations of model parameter values may exist resulting in similar model outputs – commonly referred to as equifinality problem (Beven and Binley, 1992). To address the aforesaid issues associated with manual calibration and owing to the advancement in the computational facilities, automatic methods of model calibration have gained popularity in recent years. Although, several algorithms exist in the literature to calibrate a hydrology model, Parameter ESTimation (PEST) has been used in the current work due to its simplicity and wide applicability (Doherty and Johnston, 2003; Goegebeur and Pauwels, 2007; Wang and Brubaker, 2015).

Executing of the VIC hydrology model requires specification of several parameters, most of which can be derived directly or indirectly from input data except the three parameters namely – *B*; *Ds* and *Ws*. Therefore, these three parameters are considered for calibration in the present work. *B* parameter regulates infiltration of water into the soil; *Ds* controls the nonlinear baseflow from the soil and *Ws* determines the maximum soil moisture level at which nonlinear baseflow is initiated. To attain the optimum value for these parameters, a PEST-VIC interface is established with an objective function of minimizing the squared sum of errors (*SSE*) between model simulated streamflow (Q_{sim}) values and Q_{obs} a. A brief summary regarding the concept of PEST-VIC interface is presented below. Further information can be obtained from Doherty (2001).

The process of streamflow simulations by hydrologic model can be represented by the following equation:

$$\xi = \Psi\left(\eta \middle| \Theta\right) \quad [2]$$

where,

η is a n size vector containing model parameters (3 in the present case – *B*, *Ds*, *Ws* which are provided as input to the VIC model); ξ is the output vector of size α (which in the current case contains streamflow simulations obtained from the VIC model); Θ is the set of input data required to drive the hydrologic model (climate, LU, and topography information) and Ψ is a function that represents the hydrologic (VIC) model. The Eq. [2] is linearized as:

$$\hat{\xi} = \xi + J\left(\hat{\eta} - \eta\right) \quad [3]$$

where,

$\hat{\eta}$ and $\hat{\xi}$ are respectively the input and output vector estimates; *J* is a Jacobian matrix (of *a* rows and *b* columns).

Based on the outputs generated from hydrologic model, PEST updates the input vector using following set of equations.

$$\begin{aligned} \hat{\eta}_{\delta+1} &= \hat{\eta}_{\delta} + \phi_{\delta} \\ \phi_{\delta} &= \left(J_{\delta}^{T} J_{\delta}\right)^{-1} J_{\delta}^{T}\left(\xi - \hat{\xi}_{\delta}\right) \end{aligned} \quad [4]$$

where,

the subscript δ indicates the iteration number; ϕ is the update vector; superscripts -1 and *T* indicate matrix inverse and transpose respectively. The above equation is derived from objective function which computes SSE between simulated (Q_{sim}) and observed (Q_{obs}) streamflow. The algorithm is kick started at iteration $\delta = 1$ by providing initial estimates of parameters set along with other requisite input data to drive the VIC model so as to obtain initial streamflow simulations. In the current work, η_1 for the optimization algorithm is considered from the manual calibration carried out by Chawla and Mujumdar (2015). The estimates of streamflow ($\hat{\xi}_1$) thus obtained are used in updating input parameters through Eq. [4]. The newly updated parameter vector ($\hat{\eta}_2$) is then provided as input to the VIC model after which the process is iteratively carried out until convergence in the parameters is achieved.

2.5 Uncertainty in model output

In order to obtain a reasonable estimate of streamflow for future time period, it is necessary to address cumulative uncertainty at the model output stage. In the present paper, Reliability Ensemble Approach (REA) technique, original proposed by Giorgi and Mearns (2002; 2003), is used to quantify uncertainties in the model output. REA method is commonly used to quantify GCM model and scenario based uncertainty in projected climate variables (Murphy et al., 2004; Tebaldi and Knutti, 2007). The algorithm evaluates two criteria: (a) model performance – ability of the model to reproduce observed conditions, and (b) model convergence – degree of deviation in one model simulation with respect to other model simulations. Weights are assigned to models based on their performance and convergence with respect to observed data. Therefore, REA ensures higher weights being assigned to model predictions that are more reliable either in terms of representation of observed hydro-climatology or have provision of less outlier simulations for future compared to other models. Consequently, reliable models or better performing models contribute more towards the ensemble average.

The REA procedure, which was originally intended to quantify uncertainties in mean precipitation and temperature changes, was modified by Ghosh and Mujumdar (2009) to make the method applicable over the

Cumulative Distribution Functions (CDFs) of the monsoon rainfall. Through this paper, we extended the applicability of this approach to future streamflow simulations obtained from hydrologic models (driven using several LU – climate change combinations). The following procedure is implemented in the current work to carry out REA:

1) Let $S_{obs} = \left\{S^{i}_{obs}, i = 1,2,\ldots,n\right\}$ be historic records of streamflow of size *n* and $\hat{S}^{k}_{hist} = \left\{\hat{S}^{k,i}_{hist}, i = 1,2,\ldots,n\right\}$, where $k = \left\{1,2,\ldots,\upsilon\right\}$ be time coherent streamflow simulations each of size *n* obtained from υ GCMs. Using these records, ensemble streamflow simulations is obtained using Eq. [6]:

$$\bar{S}_{hist} = \sum_{k=1}^{\upsilon} w^{k}_{hist} \times \hat{S}^{k}_{hist} \qquad [5]$$

where:

$$w^{k}_{hist} = \frac{\left(RMSE\left(S_{obs}, \hat{S}^{k}_{hist}\right)\right)^{-1}}{\sum_{j=1}^{\upsilon}\left(RMSE\left(S_{obs}, \hat{S}^{j}_{hist}\right)\right)^{-1}} \qquad [6]$$

where:

$$RMSE\left(l,m\right) = \sqrt{n^{-1} \cdot \sum_{j=1}^{n}\left(l_j - m_j\right)^2} \qquad [7]$$

$\bar{S}_{hist} = \left\{\bar{S}^{i}_{hist}, i = 1,2,\ldots,n\right\}$ is the REA vector obtained for historic time period. It has to be noted that $RMSE\left(l,m\right)$ indicates root mean square error computed between vectors l and m.

2) The weights thus obtained during historic time period shall be used as initial weights for future streamflow simulations. Let $\hat{S}^{k}_{fut} = \left\{\hat{S}^{k,i}_{fut}, i = 1,2,\ldots,n'\right\} \forall k = \left\{1,2,\ldots,\upsilon\right\}$ be υ time coherent future streamflow simulations each of size n'. The initial ensemble average ($\tilde{S}_{fut}$) was obtained for future time period using following equation:

$$\tilde{S}_{fut} = \sum_{k=1}^{\upsilon} w^{k}_{hist} \cdot \hat{S}^{k}_{fut} \qquad [8]$$

3) The weights obtained for past time period are now updated iteratively using $\tilde{S}_{fut}$ through following set of equations:

$$\theta_j = \left(\left(RMSE\left(S_{obs}, \hat{S}^{j}_{hist}\right)\right)^{-1} + \left(RMSE\left(\Upsilon, \hat{S}^{j}_{fut}\right)\right)^{-1}\right) \Big/ 2$$

$$w^{k,ite}_{fut} = \frac{\theta_k}{\sum_{j=1}^{\upsilon}\theta_j} \qquad [9]$$

where, $\Upsilon = \begin{cases} \tilde{S}_{fut}, ite = 1 \\ \tilde{S}'_{fut}, ite > 1 \end{cases}$

and,

$$\tilde{S}'_{fut} = \sum_{k=1}^{\upsilon} w_{fut}^{k,ite} \cdot \hat{S}_{fut}^{k}$$

ite is the iteration count. This step is repeated until the weights converge ($w_{fut}^{k,ite\text{-}1} \approx w_{fut}^{k,ite} \forall k = 1,2,\ldots,\upsilon$). $\tilde{S}'_{fut}$, computed using the converged weights, is the ensemble average of streamflow simulations in the future time period.

3 RESULTS AND DISCUSSIONS

3.1 Land use analysis

Detailed investigation pertaining to the temporal LU analysis of the UGB from 1970/80's to 2011 was carried out by Tsarouchi et al. (2014) and Chawla and Mujumdar (2015) using Landsat imageries. Results from their analyses suggest significant changes in LU of the region that include increase in crop land and urban areas accompanied by decrease in barren lands over the past four decades. For future projections under scenario 1, where changes in scrub forest and crop land areas are modelled, slight increase in both the categories can be observed from 2020 through 2040 at the expense of dense forest. In case of scenario 2, an increase in crop land category was noticed for 2020 and 2030 along with decrease in areas of barren land and scrub forest. Scenario 3, which models changes in urban area, witnessed urban area expansion from 2020 to 2040 at the cost of scrub forest and crop land areas. Increase in urban areas could be attributed to population growth in the region. In scenario 4 (where changes in crop land and urban areas were modelled through time), increase in crop land area are observed to have replaced scrub forests from 2020 to 2040 while urban area remained constant (after an initial increase in 2020). Figure 3 presents the percentage of area under different LU categories for future projections along with the observed areas.

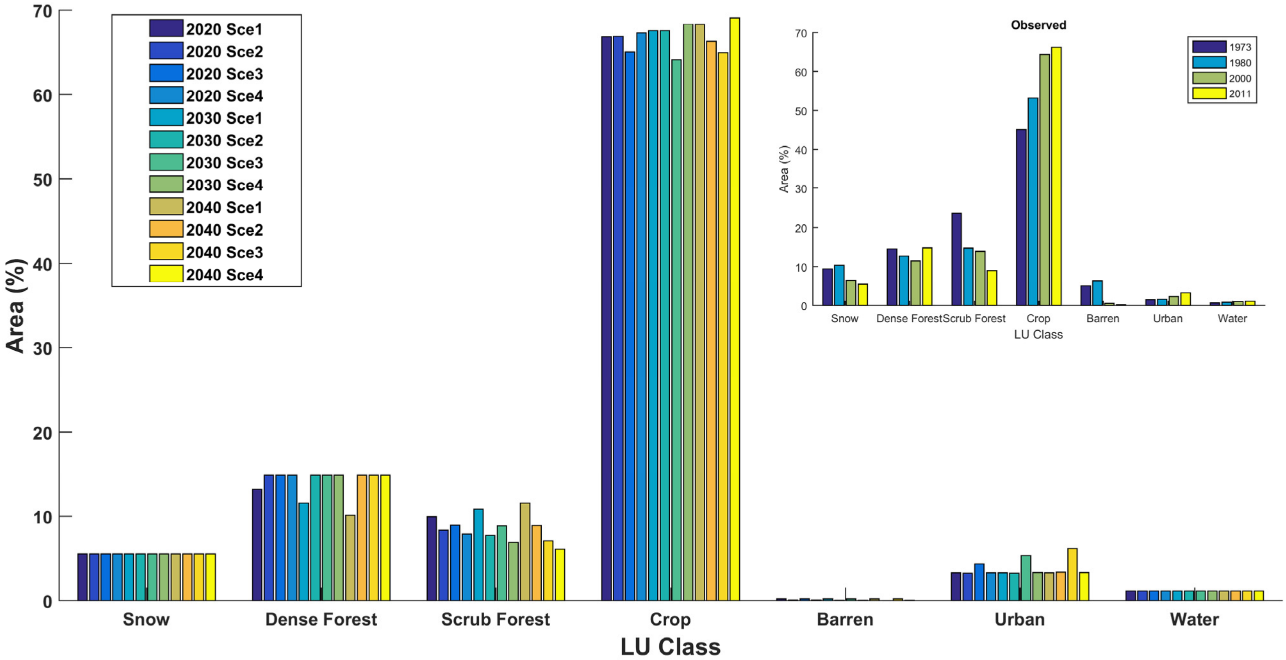

Figure 3. Observed and projected areas under different LU categories of the Upper Ganga Basin for future time periods corresponding to four scenarios.

3.2 Calibration and validation of the hydrologic model

The VIC model was calibrated and validated through single split sample procedure for the upstream and midstream regions of the UGB through using PEST optimization algorithm. 13 years (1987-99) and 6 years (2000-05) of Q_{obs} data were used for calibrating and validating (respectively) the VIC model for the upstream region. Model for the midstream region was calibrated and validated using 19 years (1977-95) and 10 years (1996-05) of Q_{obs} (respectively). The model performance was evaluated using normalized root mean squared error (*NRMSE*), coefficient of determination (R^2), Nash-Sutcliffe efficiency (*NSE*) and bias (β-where positive sign indicates overestimates of streamflow by the VIC model and vice versa); results of the same are presented in Figure 4 and Table 1.

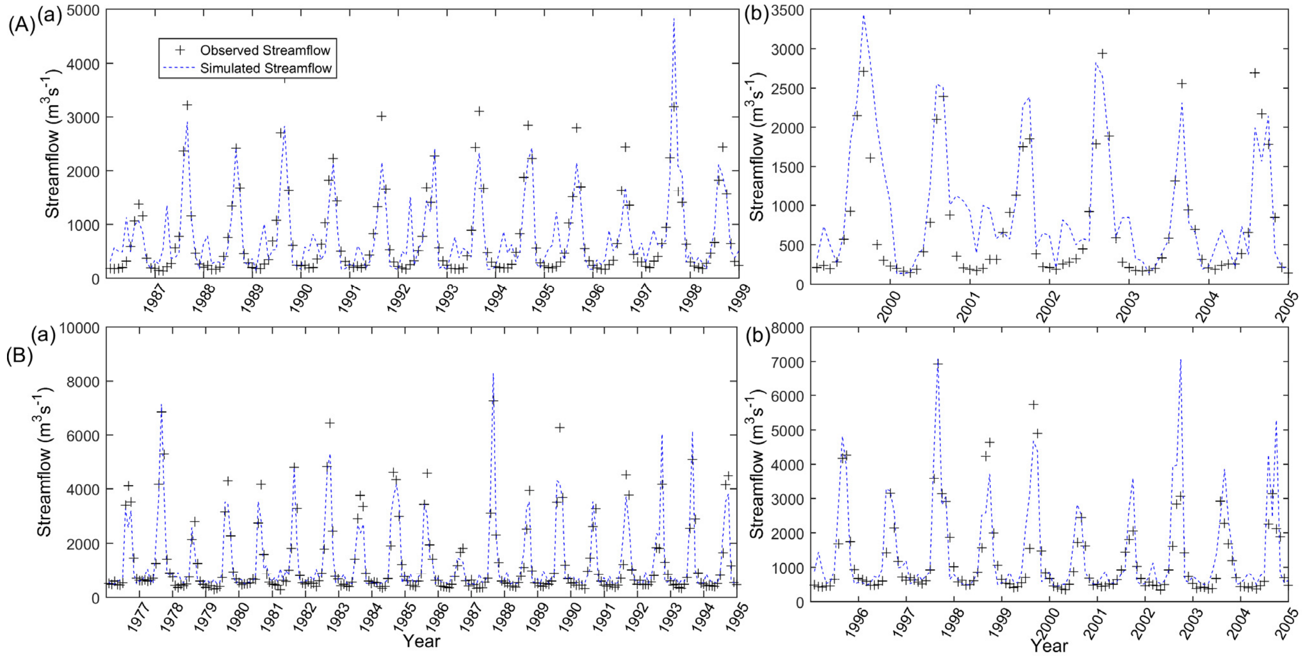

Figure 4. (a) Calibration and (b) validation results for the (A) Upstream and (B) Midstream regions of the Upper Ganga Basin.

Table 1. Calibration and Validation results for the Upstream and Midstream regions of the Upper Ganga Basin.

Region	**Value of optimum set of parameters**	**Calibration**				**Validation**			
		R^2	***NRMSE***	***NSE***	β (%)	R^2	***NRMSE***	***NSE***	β (%)
Upstream	*B*=0.137; *Ds*=0.00032; *Ws*=0.63	0.77	0.23	0.77	0.6	0.74	0.38	0.61	31
Midstream	*B*=0.0399; *Ds*=0.00086; *Ws*=0.633	0.88	0.12	0.88	0.5	0.71	0.41	0.59	16

Bias is observed to be significantly less during calibration phase in comparison to the validation phase. This might be due to overfitting of the hydrologic model during the earlier phase. Overall, calibration and validation results indicate satisfactory performance of the VIC hydrologic model for the two regions of the UGB. Based on this performance, model was considered for simulating future projections of streamflow under LU and climate change scenario.

3.2 Quantification of uncertainties in simulated streamflow

A total of 48 streamflow trajectories corresponding to plausible future LU-climate scenarios were obtained corresponding to the three regions of the UGB. For simulating streamflow from the downstream region, in the absence of any observed data, an independent model could not be established. Instead, due to topographical and climatological similarity between the midstream and downstream regions, the model obtained for the midstream region was used for the downstream. An ensemble representation of the annual streamflow simulations (obtained using REA approach) along with the uncertainty bounds for the three regions of the UGB are presented in Figure 5. Upper and lower bounds were obtained by considering 95th and 5th quantile (respectively) for each time period across the 48 simulations.

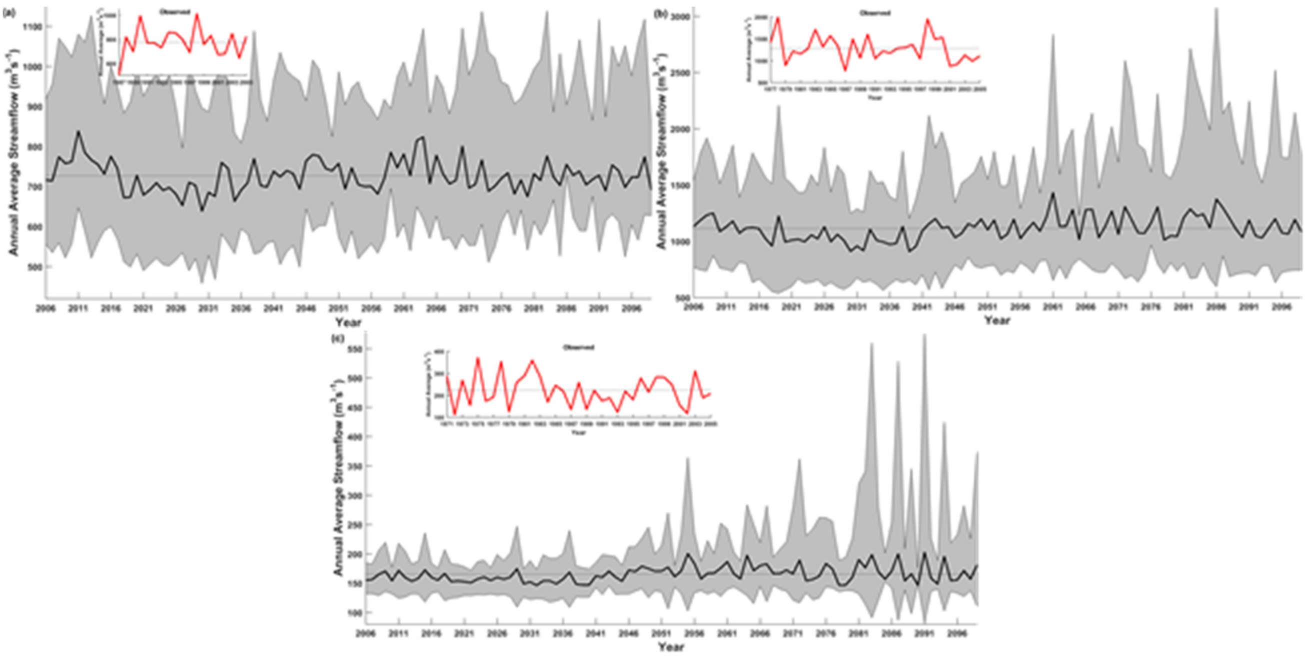

Figure 5. Annual future streamflow simulations within the uncertainty bounds for the (a) Upstream; (b) Midstream; and (c) Downstream regions of the Upper Ganga Basin along with their observed or historic values.

In general, streamflow is observed to reduce in future for the three regions in the UGB. Upstream is observed to show the decrease in average streamflow (at annual scale) by 51 cumecs (from 777 cumecs for the observed period to 726 cumecs during future scenarios). Midstream is observed to show this decrease by 202 cumecs whereas for the downstream region, difference of 57 cumecs is obtained between historic and future periods. However, the results may not be completely reliable for the downstream region as it doesn't have its independent VIC hydrologic model. This decrease in the future streamflow projections can be attributed to reduction in rainfall variability and increase in T_{max} in future for the three regions of the UGB. Upper bound obtained using the 95th quantile values are observed to have significantly high values in comparison to the mean indicating overestimation of streamflow by some of the models. Further bounds are quite variable for the later part of the century.

4 SUMMARY AND CONCLUSIONS

This paper attempted to investigate into the future implications of LU and climate change on the streamflow simulations. A semi-distributed VIC hydrologic model was used to carry out the analysis. A PEST optimization algorithm was combined with the VIC model to create a PEST-VIC interface in order to obtain best set of the hydrologic model parameters. Uncertainty in the streamflow projections was addressed by considering several combinations of future LU and climate and obtaining their ensemble through reliability ensemble approach. The results indicated that streamflow from the three regions of the UGB may decrease in the future with maximum decrease in the midstream region. This could be highly detrimental for this part of the UGB as it was dominated by crop lands. Furthermore, some of the GCMs were observed to significantly overestimate the streamflow projections for higher quantiles causing upper bound values to be considerably high. In addition to this, higher uncertainty in the streamflow projections observed for the latter half of the century.

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INSTITUTIONAL ANALYSIS OF WATER GOVERNANCE FOR ADAPTATION TO CLIMATE CHANGE

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ABSTRACT

There are many challenges for water governance and management under climate change. Institutional adaptations are one of those challenges, which have to consider uncertainties, participatory processes and monitoring. Elinor Ostrom, a Nobel winner, produced many relevant contributions to understanding institutional governance. Her work pointed to requirements of adaptive governance, institutional design principles for local common pool resources systems and social-ecological framework analysis. Recently, Ostrom´s institutional principles have been extended and refined for the governance of adaptation to climate change in the water sector. However, adaptation in water sector is a continuous process of learning. Drought management in the present and past is also a way of learning considering experiences on institutions leading with this problem. This paper demonstrates how some of Ostrom´s principles associated with drought management experiences might provide a continuous way for learning to adapt water governance to climate variability and change. An institutional analysis of the Brazilian water policy from a drought management perspective is presented to show the application of the principles.

Keywords: Climate variability; drought; water management.

1 INTRODUCTION

Adaptation is a customary practice in society, where individuals and communities adjust their activities and ways of life in order to take advantage of new opportunities. However, adaptation can also often be imposed by undesirable external changes. Being prepared to adapt, whether in order to take advantage of certain situations or the need to overcome external adversities, is a great and continuous challenge.

The presence of uncertainties is part of natural processes in ecological systems, in social processes, such as population growth and economic growth, and in the interdependencies of ecological and social systems, such as climate change. The integrated management of water resources deals with socio-ecological systems and, therefore, very uncertain.

Adaptation to uncertainty, within the integrated water resources management process, was introduced through the concept of adaptive management of water resources (Van der Keur et al., 2010). Although adaptive management is not a recent concept, there is still much debate about how integrated water resources management can incorporate adaptive water resources management (Huntjens et al., 2012).

While uncertainties and changes are part of socio-ecological systems, the ability to cope with and adapt to these characteristics are critical factors for the management of such systems. However, interventions in socio-ecological systems, with the aim of changing their adaptive capacity, depend on governance issues. Many resource management problems arise from governance failures and, therefore, a better understanding of governance is essential for the management of natural resources.

The concept of adaptive governance was introduced by Dietz et al. (2003) to expand the focus of adaptive management of socio-ecological systems and to address broader social contexts in the management of natural resources such as water resources management. Elinor Ostrom conducted a number of studies to better understand institutional aspects of governance of common pool resources (Ostrom, 1990; 2005; Anderies et al., 2004). Currently, several studies try to understand water governance in an adaptive perspective in complex systems such as large river basins in the context of uncertainties, such as globalization and climate change (Graham et al., 2003; Ostrom, 2010).

Climate variability is a natural part of the planet's climate. However, it is not possible to predict exactly its occurrence, anticipating, for example, when and for how long rainy or dry periods will occur. The temporal and spatial variability of precipitation is a characteristic feature of many regions of the world, where it represents a relevant factor for the availability of water resources.

Climate change may lead to more severe droughts, degradation and reduction of ecosystem services, and water supply problems, thus generating impacts on water resources and their users (Huntjens et al., 2012). Such challenges are so significant that they may require substantial adaptations and even transformations in social organizations and the use of their resources (Nelson et al., 2007). In the context of climate change, uncertainties associated with climate variability in the future are even more striking and complex for our understanding. In addition, climate change could intensify existing impacts on water users.

From the perspective of the integrated and adaptive management of water resources, it is important to understand aspects relevant to water governance, considering the adaptation to climate variability and climate change. Despite already existing systems for the management of water resources, many undesirable impacts continue to affect the water users. In this sense, this paper questions the following: in what aspects will water governance, through its policies, plans and management systems, need to adapt to better cope with climate variability and change? How to generate strategies to meet the requirements of this adaptive governance?

In order to address these questions, this paper is based on the following assumption: adaptation research on climate variability is a way to better understand challenges associated with adaptation to climate change, as well as the knowledge generated in climate change research can aid in the adaptation process to climate variability.

2 CONCEPTS

The main concepts discussed in this paper are presented below:

- Water governance: encompasses political, economic, social and administrative processes, by which governments, civil society and the private sector make decisions about how to use, develop and manage water resources (UNDP, 2004);
- Integrated water resources management (IWRM): is an ecosystem-based approach that considers the links between natural resource systems, biophysical processes and socio-economic systems and objectives in order to integrate them in the management of water resources (UNDP, 2004);
- Socio-Ecological Systems (SES): refer to a subset of social systems, where some of the interrelationships between human beings are mediated through interactions with biophysical and biological nonhuman units (Anderies et al., 2004);
- Adaptive water management: is a systematic process of continuous improvement of management policies and practices by learning from the results of implemented management strategies. One of its objectives is to increase the adaptability of the water system (Van der Keur et al., 2010);
- Institutions: are means of organizing activities that can affect the resilience of the environment (Dietz et al., 2003). Institutions are sets of rules, decision-making procedures and programs that define social practices and assign roles to participants in such practices, governing the interactions between the agents of such roles (Young, 2002).

3 INSTITUTIONAL ANALYSIS

This methodology has the following theoretical bases:

(a) The resilience of the socio-ecological system under study is constructed based on the institutional diagnosis of water governance, using Ostrom's (1990; 2005; 2007; 2009) and Huntjens et al. (2012) institutional principles, considering adaptation to climate variability and change;

(b) Adaptation strategies are proposed after that diagnosis, considering the investigation of vulnerabilities of the socio-ecological system, in the face of the uncertainties posed by scenarios of climatic variability and change;

(c) The consideration of temporal dynamics (Williams, 2011) contributes to the adaptive water governance of the socio-ecological system;

(d) The adaptive capacity of the socio-ecological system under study is strengthened through structures of resilience and vulnerability, as proposed by Engle (2011), observing the adaptation cycle proposed by Wheaton and Maciver (1999).

The institutional diagnosis of water governance for the SES, considering adaptation to variability and climate change, is carried out through two phases: 1. Analysis of water resources policies, plans and management system; 2. Analysis of past experiences in the context of climate variability and its impacts on users of water resources. Then, it was possible to identify gaps and institutional arrangements for water governance and corresponding strategies were proposed. Ostrom identified a set of sustainable and robust institutional principles for good governance of Common Pool Resource (CPR) systems by individuals and communities (Ostrom, 1990; 2005), while Huntjens et al. (2012) extended Ostrom's principles for the governance of adaptation to climate change for the water sector. The combination of these principles is used in this paper, as shown in Table 1 (Silva et al., 2017). This diagnosis was made considering the dynamics of SES over time, according to Williams (2011).

Table 1. Institutional principles for governance of adaptation to climate change in the water sector (Silva et al., 2017, based on Ostrom, 1990; Ostrom, 2005; Huntjens, et al., 2012).

Institutional Principle	Description
1. Clearly defined boundaries	Ostrom (1990) defined this principle as: “Individuals who have rights to withdraw resource units from CPR must be clearly defined, as must boundaries of the CPR itself”. The principle was extended by Huntjens et al. (2012) as: “Completeness of water-user stakeholders in the adaptation process and clarity about who has rights to use water resources in the case of droughts.”
2 Congruence between appropriation and provision rules and local conditions	Ostrom (1990) defined this principle as: “Appropriation rules restricting time, place, technology, and/or quantity of resource units are related to local conditions and to provision rules requiring labor, material, and/or money”. Ostrom (2005) also presented the principle as: “Proportional equivalence between benefits and costs: rules specifying the amount of resource products that a user is allocated are related to local conditions and to rules requiring labor, materials, and/or money inputs.” “The second design principle is that the rules-in-use allocate benefits proportional to inputs that are required. If a group of users is going to harvest from a resource over the long run, they must devise rules related to how much, when, and how different products are to be harvested. They also need to assess the costs of operating a system on users. When the rules related to the distribution of benefits are made broadly consistent with the distribution of costs, participants are more willing to pitch in to keep a resource well-maintained and sustainable…” (Ostrom, 2005). Huntjens et al. (2012) specified the principle for adapting to climate change in large river basins as: “Equal and fair (re-)distribution of risks, benefits and costs, requiring engagement with, and strong representation of, groups likely to be highly affected or especially vulnerable”.
3 Collective-choice arrangements	Ostrom (1990) defined this principle as: “Most individuals affected by the operational rules can participate in modifying the operational rules”. Huntjens et al. (2012) extended this principle as follows: “To enhance the participation of those involved in making key decisions about the system, in particular on how to adapt.”
4 Monitoring	According to Ostrom (1990), “Monitors, who actively audit CPR conditions and appropriator behavior, are accountable to the appropriators or are appropriators”. Huntjens et al. (2012) defined this principle as: “Monitoring and evaluation of the process: providing a basis for reflexive social learning and supporting accountability”. “Appropriator can be used to refer to anyone who appropriates resource units from some type of resource system. In many instances appropriators use or consume the resource units they withdraw. Appropriators also use resource units as inputs into production processes.” Ostrom (1990).
5 Graduated sanctions	Ostrom (1990) considers that “appropriators who violate operational rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other appropriators, by officials accountable to these appropriators, or by both”.
6 Conflict-resolution mechanism	This principle is presented by Ostrom (1990) as follows: “Appropriators and their officials have rapid access to low-cost arenas to resolve conflicts among appropriators or between appropriators and officials”. Huntjens et al. (2012) added: “Including timing and careful sequencing, transparency, trust-building, and sharing of (or clarifying) responsibilities”.
7 Minimal recognition of rights to organize	Ostrom (1990) described this principle as “the rights of appropriators to devise their own institutions are not challenged by external governmental authorities”.
8 Nested enterprises	For resources that are parts of larger systems, Ostrom (1990) established another principle: “Nested enterprises: appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises”. Huntjens et al. (2012) presented this principle as “Nested enterprises/polycentric governance in a multi-level context, as functional units to overcome the weakness of relying on either just large-scale or only small-scale units to govern complex resources systems.”
9 Robust and flexible process	Huntjens et al. (2012) defined this principle as: “institutions and policy processes that continue to work satisfactorily when confronted with social and physical challenges but which at the same time are capable of changing”. Based on other studies, they indicate five characteristics that might build robust and flexible processes: organizational redundancy, flexibility to include new initiatives, confidence-building, integration of intersectoral policies or ‘integrating adaptation’ ("climate adaptation does challenge integration"), and sequential and time dilemmas.
10 Policy learning	According to Huntjens et al. (2012), policy learning is related to “policy and institutional adjustments based on commitment to dealing with uncertainties, deliberating alternatives and reframing problems and solutions.”

4 APPLICATION

This methodology was applied to a real world management problem in the drought-prone semi-arid region of Brazil. The National Water Resources Policy, Water Plans and Management System were analysed, considering the socio-ecological system of Epitácio Pessoa reservoir (Figure 1).

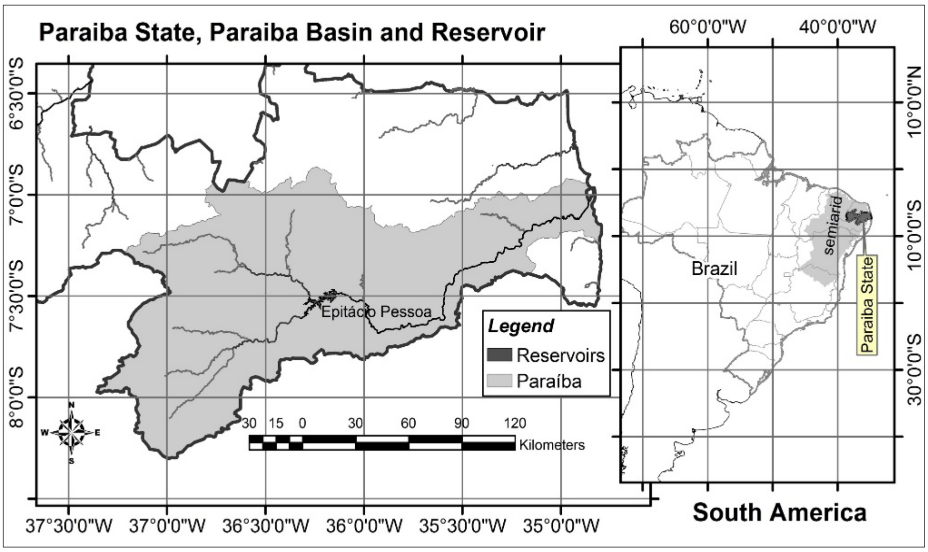

Figure 1. Brazilian semi-arid, Paraiba River Basin and Epitácio Pessoa Reservoir.

Historically, several adaptation strategies have already been implemented in this basin, among them the construction of large and small reservoirs, and residential rainwater cisterns. However, due to the very high climatic variability and the mismanagement of their water resources, periodic severe scarcity has happened, with serious social and economic consequences (Galvao et al., 2001; Ribeiro et al., 2012; Grande et al., 2014).

The reservoir Epitácio Pessoa basin (12,411 km^2) was built between 1951 and 1957, with maximum storage capacity of 535 million m^3. Its storage capacity has decreased over time and currently is estimated in 411 million m^3. It is located in the driest region of Brazil, where rainfall is concentrated in four months of the year and have a high inter-annual variability (annual average 500 mm), and high evaporation rates. Information on seasonal precipitation forecasts for this region is quite reliable for a season in advance. However, reliable forecasts for periods of more than one year still do not exist. The Reservoir supplies the city of Campina Grande, which is the largest urban centre located in the semi-arid region of Brazil and the second largest city in the state of Paraíba.

The years 1993 and 1998 were extremely dry in the region. At the end of 1999, the Reservoir presented the lowest level and the worst water quality index since its construction. The water available in the reservoir was insufficient to meet all of its demands. The use of its waters for irrigation was suspended and severe water rationing occurred for urban consumption. This has caused diverse social and economic impacts on users. This fact was a national example of inadequate management of water resources (Galvao et al., 2001).

With the beginning of new rainy years, between 2004 and 2011, with the exception of 2007 and 2010, the reservoir recovered high storages (Grande et al., 2014). With the onset of a new dry period (2012-2017), the reservoir has again lost its storage significantly, irrigation has been suspended or reduced and new rationing of water for urban supply occurred. Currently, there are several uncertainties associated with the management of the Epitácio Pessoa reservoir. Among them, differences between estimates of regularized discharge.

Considering the analysis of this socio-ecological system, the methodology used allowed, through the documental analysis, a deep appreciation of the water resources policy, from the perspective of Ostrom principles. It was observed that the institutional principles were identified in the water resources policies and plans. However, failure to effectively implement these policies and plans indicates that there are several governance issues that need to be overcome.

These governance problems have had several impacts on the socio-ecological system, making water users vulnerable to climate variability. More specifically, the analysis of experiences related to climatic variability has allowed the perception of how governance conditions have affected the socio-ecological system, such as users, water availability and quality.

Specific problems related to the management of the Epitácio Pessoa reservoir were identified in the analysis of the socio-ecological system, as well as broader issues associated with water resources policy and the national water resources management system.

We identified in the analysis of the water crises of the Epitácio Pessoa reservoir that the water resources management instruments have not been properly implemented and monitored, including the Water Resources

Plans (National, State and basin scales). In the analysis of the principles, we identified that decentralized and participatory management revolves around water resources plans, which are key factors for collective choice arrangements, polycentric governance and, consequently, mechanisms for conflict prevention and resolution for the equal and fair (re)distribution of risks and benefits.

A robust and flexible governance process is related to the monitoring and evaluation of the whole process by collective choice arrangements. Water resources committees and councils need to be strengthened and effectively play a role in monitoring and reviewing water resources plans. The transfer of financial resources, related to the implementation of the plans and their revisions through collective choices, is a means for these plans to return to the agenda, not only in their elaboration, but also in their effectiveness and monitoring.

Likewise, water resources plans integrate the instruments and the system of water resources management. Therefore, more forms of redundancies in the system related to the implementation of water resources plans are necessary for transparency and for social learning.

A worrying factor identified is the lack of transparency, demonstrated through the representation, by the managers, of the drought as the only reason for the recurrent water crisis in the reservoir. This transfer of responsibility brings with it the illusion that the problem is a climatic one, not a lack of management. As discussed earlier, with climate change, extreme events may intensify, including drought events. Accountability for new crises could also be transferred to the effects associated with these changes. In this way, non-compliance with management can be covered up by climate change.

Gaps related to the dominance of waters were also identified, as it is the case of state basins that have waters stored in federal reservoirs. The means to manage those resources in an integrated way are not clear in the national and state policies of water resources. This lack of integration was identified in the case study analysis:

- Approximately half of the water storage capacity in reservoirs in the Paraíba River Basin is in federal reservoirs and there is no compulsory system of connection between the federal water resources management body and the collective choice arrangements;
- Relations of the federal water agency with the Hydrographic Basin Plan, the State Water Resources Plan, the Paraíba River Basin Committee, and the State Water Resources Council are non-existent.

It was perceived that the treatment of climatic variability often focuses only on extreme events, such as dry periods. However, analysis of the climate variability context has identified that learning to manage water resources in the rainy years to overcome the drought years is still a challenge to be learned. This change of paradigm is necessary for the treatment of climatic variability and guarantee advances in the management of multiple uses of water.

In Brazil, water resources plans have contemplated climate change, which is a positive factor. However, for adequate adaptation to climate change, it is important that the problems identified for water governance in conditions of climate variability are overcome. Even a high level of knowledge about scenarios of variability and/or climate change may lead to non-robust adaptation strategies. Governance failures may turn into centralization of the implementation of water resources management instruments, as well as their non-effectiveness.

Since 2013, several reservoirs in Brazil had their storage volumes quite reduced, regardless of whether their waters are under federal or state domains. Therefore, it is relevant to evaluate whether the governance rules, through the implementation of the water resources management instruments, take place properly in the socio-ecological systems that involve these reservoirs.

Both the adaptation of the Ostrom's institutional design principles to the case study and its application depended on a great deal of research and analysis. As the research was deepened, the complexity of the socio-ecological system studied was perceived. The more knowledge the researcher presents about the object of study, the richer the analysis may be. For this reason, one of the limitations of this study is that adapting institutional principles and applying the analysis of these principles could be further explored through questionnaires with stakeholders in the adaptation process.

5 CONCLUSIONS

The application of Elinor Ostrom's extended institutional principles in a temporal perspective, considering the structure of analysis of socio-ecological systems was very useful for analysing water governance, considering adaptation to climate variability and change. The whole process of adaptation could be investigated, through documental analysis, and consolidated with experiences related to the socio-ecological system. It was possible to devise strategies to meet the requirements for adaptive governance.

This study reinforced Huntjens et al. (2012) conclusions: governance structure is an important element in adapting to climate change, especially in how institutional principles support the adaptation process at different levels. In addition, it has been identified that understanding challenges related to water governance can contribute to proactive adaptation to climate variability and, as a learning process, overcoming such challenges can contribute to proactive adaptation to climate change.

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IS "GREENING OF ECONOMY" THE ANSWER TO SUSTAINABLE WATER RESOURCES MANAGEMENT UNDER CLIMATE CHANGE?

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ABSTRACT

The global financial crisis as well as the environmental crisis that the planet is currently facing, are mainly caused by the dominant economic development model and the policies that have been developed over the past decades. The current foremost development model, based on the uncontrolled use of resources to meet demands, has directly resulted in over-exploitation and overconsumption. Both, the problem of poverty (social sustainability) and the one of healthy ecosystem services (ecological sustainability) had not been successfully resolved. It is clear that there should be a shift to a "new type" of economy. The transition to this new "green economy" requires new thinking about water and its management. Climate change, as major environmental threat of our century which definitely affects water, calls for immediate action. Two types of response to climate change, mitigation and adaptation play an equally important role in the transformation towards sustainability. Sustainable water management should revolve around maintenance of ecosystem services, reallocation among sectors, true cost price and public engagement in all stages of decision-making. This paper explains the "new development model" and its characteristics and provides a set of structural and non-structural measures for adaptation to climate change impacts on water resources. A debate is presented on whether the "greening of economy" is the answer to sustainable water resources management under climate change. Various examples, using different applied methodologies on water adaptation policies, on how to improve water resources planning and management and on how to proceed with effective water policy actions considering climate variability and change are presented and discussed. Concluding, green development provides the necessary framework for sustainable water management, however specific parameters should be carefully considered and examined in order to be successful.

Keywords: Green development; water resources management; climate change; EU adaptation policies; rebound effect.

1 INTRODUCTION-THE WATER RESOURCE CHALLENGE

Water is the most vital resource significantly affected by climate changes. Natural climate variability and human-induced climate change have posed severe threats to natural resources. Research results provide clear evidence that climate changes affect the water cycle and the water demand (Huntington, 2006; Arnell et al., 2001) as well as the water supply (Bates et al., 2008). For each degree of global warming, approximately 7% of the global population will be confronted with a decrease of renewable water resources of at least 20% (Jiménez Cisneros et al., 2014). In contrast, AR5 projects that the increased intensity of rainfall events associated with increased temperatures will increase renewable water resources in higher-latitude regions not directly affected by the Hadley circulation (IPCC, 2014). Climate change is expected to affect groundwater withdrawals, and aquifer recharge, reducing groundwater availability in many areas of the world. Increasing air and water temperatures, floods and droughts will decrease river and lake water quality in many ways. Increasing flooding risk will affect human safety and health, property, infrastructure and the environment in many basins. Tourism, food and energy production, infrastructure, agriculture, and ecosystems are among the sectors that are harshly affected. Continued population growth and urbanization are factors that are likely to act as drivers for land-use changes that in turn are going to impact the hydrological cycle and water availability. In addition to impacts of climate change, the future of freshwater systems will be impacted strongly by demographic, socioeconomic, and technological changes, including lifestyle patterns (IPCC, 2014).

Water resources managers and planners will face new risks and vulnerabilities that may not be properly get along with existing practices since the whole system seems to not have linear behavior anymore (Milly et al., 2010; Kundzewicz et al., 2007).

Sustainable water management should be seen as a trajectory of decisions which may challenge previous decisions as water managers should embrace engineering and ecological perspectives of non-stationarity. As water is crucial to development and as the global scientific community agrees that the current development model needs to change there is an imperative need to provide solutions on sustainable water management and planning.According to WWAP (2015), "Unless the balance between demand and finite supplies is restored, the world will face an increasingly severe global water deficit".

This paper explains the concept of green economy and its application on water management and opens a debate on the effectiveness of green economy adaptation policies to face climate change impacts on water resources.

2 THE CONCEPT OF GREEN ECONOMY-GREEN GROWTH

The green economy concept was promoted as a means of reforming current economics to better reflect natural and social capital.

UNEP (2011) defines Green Economy as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities". In fact, the concept itself takes up the three pillars of sustainability – economy, society and environment and provides a paradigm in which core concepts are resource efficiency, ecosystem resilience, and social equity.

Green Economy recognizes the need for comprehensive and coherent policy reforms and has as main objective to enable policy-makers to implement effective policies and regulations for the reduction of poverty, by providing jobs and expanding social welfare, supporting a secure and sustainable way of life for the world's population. Both economy-wide and sector-targeted policies are needed to achieve structural and behavioral change among consumers and producers.

Green growth is economic growth that is environmentally sustainable, as it fosters economic development "while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies" (OECD, 2011).

It is important to say that economic growth is not synonymous to economic development. The first is about increasing GDP **(**national income / national output) whereas the second additionally entails social aspects such as improvement in quality of life and living standards.

The main characteristics of green economy are:

(a) Decoupling natural resource use and environmental impacts from economic growth;
(b) Conservation through resource efficiency technologies that can enable users in different sectors to reduce water use and/or promote sustainable water use;
(c) Creation of employment, directly or indirectly (green jobs) through projects and environmentally friendly activities;
(d) Interference of the state to secure economic development, environmental protection, and social equity. (Kolokytha et al., 2017).

3 IWRM - DEVELOPMENT & THE TRANSITION TO GREEN ECONOMY

The transition to green economy requires prioritization, classification of actions in a time manner (short-term, mid-term, long-term) and enhancing integrated water resources management (IWRM).

Altering water ecosystems by abstracting, diverting, polluting or degrading water resources contradict other important economic benefits whose provision derive from the conservation of water resources and their associated ecosystems. Development in terms of economic development entails water security. The nature of water as both being a catastrophic as well as productive power is key to understanding how investments in water security can support economic development. Reducing the negative economic costs associated with scarcity, flooding, and pollution, and profit from the economic benefits of using water productively can provide the means for long-term economic development. (Quick and Winpenny, 2014). Natural disasters (floods, fires etc.) should be imported into national capital accounts as loss, while the protection and restoration from natural disasters, as well as investments in the natural environment, should be introduced as gains in financial government accounting.

Securing the balance between water use and pressures on the one hand, and conserving water on the other is crucial. This is basically a political challenge and a precondition for successful water planning. In the transition to the green economy, water resources planning needs to be improved into a cross-cutting policy, in order to guarantee that all respected sectors (urban, industry, energy and agricultural) have comprehensive policies that in total serve IWRM. To achieve this goal several different policy instruments are used:

Institutional and regulatory arrangements that function within increasing complexity;

New and evolving set of skills to support the emerging green sectors in the economy.

Innovation planning towards a "water smart" society where water demand will be delivered by alternative water sources (brackish, virtual water, reused etc.), exploring new materials/ techniques that can possibly address water scarcity, groundwater contamination, water quality degradation.

Novel DSS and governance systems that support our "digital world". People, things and processes are connected through the internet, mobilizing sources for data acquisition and dissemination.

Important for the transition to green economy is education and awareness to make sure that green measures are well designed, implemented, and understood, without causing unintended impacts or being averted by practical or political challenges (UNEP, 2011).

4 WATER AND ADAPTATION OPTIONS

Adaptation aims at increasing the resilience of natural and human systems to current and future impacts of climate change (Bates et al., 2008). Limit to adaptation is a big discussion which apart from technical and economic constrains entail issues of ethics, culture, perception of risk and values and of course the diversity of goals of adaptation which complicates attempts to define limits. How people perceive issues of “risk”, “need”, “habit” heavily depends on personal values which are different for different stakeholders of a society. Considering that information is critical for adaptation, even if society is provided with information about how to adapt, people who do not believe adaptation is a priority, are highly unlikely to retain or act on this information (Kolokytha et al., 2017).

While there is no single formula to enable a successful climate adaptation policy, a combination of important elements would provide a viable solution:

Operational and infrastructure changes as well as adoption of demand management. In order to manage the problem of conflicting water uses better use of existing water resources is important. Operating plans should incorporate climate forecasts, conjunctive use of water and be more flexible to the new circumstances. It seems that infrastructures should comply with the needs and sometimes an existing project may be operated more efficiently as part of an integrated system rather than an independent project per se.

Demand management is the best possible solution since water conservation and efficient allocation of water limit the need for more infrastructures which cost a lot and harm the environment. Pricing mechanisms and other economic instruments such as green taxes, green accounts, water markets, and pollution rights promote water conservation. Innovative technology such as drip irrigation in agriculture, waste reuse in water treatment, and conservation technologies for urban use and tourism such as low- water-pressure devices serve the same goal.

Most measures to reduce water demand function better at the local level where cooperation and coordination of actions can guarantee a win-win adaptive policy.

New metrics may be used, such as ecological, carbon and water footprint, which are easy to communicate and hand over the urgency of global problem, raising public awareness. In the case of water problem, the water footprint can successfully calculate the direct and indirect water use. The overall context, boundary conditions, and different complexities need to be taken into account in order to avoid poor policy decisions (Kolokytha et al., 2017).

5 WATER AND GREEN DEVELOPMENT

The globalization of the economy and the strong international competition induced, has obliged national and local economies, to incorporate international production models which do not necessarily comply with the local climate and environmental conditions. This has resulted to severe environmental degradation of both water and natural resources and consequently the collapse of local economies. In Greece for example, the development of golf courses to attract tourists in small islands with severe water scarcity problems and the cultivation of cotton in agricultural basins with limited water resources ended up to overexploitation, depletion and degradation of local water resources. The basic challenge in water management in applying the characteristics of green development is the prospect to change the current productive model in order to generate “development”. This development should respect the carrying capacity of the ecosystem and should be based on the relative advantages of each basin. Green development suggests the shift towards traditional economic activities, which are fully compatible with the climate and the environment. This is a break though, since economic development is in line with the environment without exhausting the already limited water reserves.

6 EU AND ‘GREEN WATER MANAGEMENT

Sectors like agriculture, water supply/treatment infrastructure, tourism, energy, and industry are interrelated to water efficiency practices, demand management policies for water conservation and protection.

EU has adopted several sectoral policies in order to make real progress towards sustainable water management and water security. Lack of integration of those policies though, hinders impressive results. The interconnection of the water policy objectives of the Common Agriculture Policy, the renewable energy, transport and disaster management come at first priority. Five thematic priority areas: (1) water re-use and recycling; (2) water and wastewater treatment, including recovery of resources; (3) the water-energy nexus; (4) flood and drought risk management; and (5) ecosystem services provide opportunities to implement green economy potential. Cross-cutting priority areas include: water governance; decision support systems and monitoring and financing Science for Environment Policy (2015). Lately, innovation and water –smart society are gaining a lot of attention.

6.1 Sector-targeted adaptation strategies

Table 1 2 and 3 illustrate some sector-targeted adaptation strategies. Table 4 provides a list of EU water related projects which investigate green economy perspectives and adaptation strategies.

Table 1. Sector-targeted adaptation strategies-Agriculture.

Sector	**Policy approach Structural measures**	**Policy approach non-structural measures**	**Benefits**
Agriculture		Institutional reform	
		Legislation-legal framework	
	Drip irrigation networks	Eco-taxation	Avert rebound effects
	Organic farming		Improved water quality
		Green skills training	Use of environmentally friendly methods in farming
		Educational programs / water conservation fees	New cropping / planting
	Separate networks/use of grey water		Increase of water availability

Table 2. Sector-targeted adaptation strategies-Urban.

Sector	**Policy approach Structural measures**	**Policy approach non-structural measures**	**Benefits**
Urban		Institutional reform	Water pollution
		Tariffs	Water conservation
	Water metering		Water conservation
	Efficient household appliances		Water conservation
		Changes in public priorities- environment vs economy	Environmental protection
	Green roofs		Reducing water consumption, flood risk, improving urban environment

Table 3. Sector-targeted adaptation strategies-Industry.

Sector	**Policy approach Structural measures**	**Policy approach non-structural measures**	**Benefits**
Industry	Use of membranes		Alternative water sources
	Greywater / municipal wastewater / recycling		Energy generation
		Sanitary safety plans	Integrated risk assessment
	Use of effluents	Strict regulations	Protect public health
		Educational programs	Reduce water pollution
	IT tools in Production process	Smaller water footprint /	Water conservation/environmental protection / less waste

6.2 Economy-wide perspective

In Europe, effective planning and efficient implementation of adaptation measures can significantly reduce the potential regional impacts from climate change on flood risk and agriculture. In Europe impacts are moderate compared to other regions is the world, such as Sub-Saharan Africa, and this explains why significant benefits can be achieved through adaptation, if optimally implemented. Yet, mitigation remains an important complementary strategy because it directly reduces the adaptation expenditure needed in Europe. Moreover, by reducing impacts in high vulnerable regions, where climate impacts can reduce GDP by up to 30% in 2100, it mitigates indirect climate risks that could affect Europe as well through migration and international trade (Jeuken et al., 2016).

Table 4. Selected EU projects related to green development (adopted by the Knossos project (2012)).

EU PROJECTS	**Digital address**	Title	**Policy approach**
The ACQWA project	www.acqwa.ch/	Investigating the vulnerability of water resources to climatic change in mountain regions	Model results are used to quantify the environmental, economic and social impacts of changing water resources in order to assess how robust current water governance strategies are and what adaptations may be needed in order to alleviate the most negative impacts of climate change on water resources and water use
AQUASTRESS	www.aquastress.net/	Mitigation of water Stress through new approaches to integrating management, Technical, Economic and Institutional Instruments	Proposal of effective integrated tools, namely water pricing and local taxes in order to effectively implement the WFD
NEWATER	www.newwater.uni-osnabrueck.de/	New approaches to Adaptive Water Management under uncertainty	NeWater stimulated capacity building and learning among water managers directly involved in participatory management processes. It provided information on the socio-ecological water system. Water managers were engaged in research processes to enrich the practical relevance of research and provide a ”safe space“ allowing for (experimental) changes in the approach to governing and managing the water system.
SOILSERVICE	www.lu.se/soil-ecology-group/research/soilservice	Investigating the conflicting demands of land-use, soil biodiversity and the sustainable delivery of ecosystem goods and services	Interdisciplinary approach by integrating economical models in order to value soil biodiversity in relation to ecosystem services. Aim to design effective management policies and enhance sustainability of soil-based goods and services.
Climate Water	www.climatewater.org/	Bridging the Gap between Adaptation Strategies of Climate Change Impacts and European Water Policies	Adaptation strategies that were developed in Europe and also globally for handling (preventing, eliminating, combating, mitigating) the impacts of global climate changes on water resources and aquatic ecosystems, including all other water related issues of the society and nature.

Most of the EU recent projects deal with resource efficiency, through innovative technologies and new techniques which lie in the heart of green development.

7 THE REBOUND EFFECT

Rebound effect refers to efficiency improvement in the technical process of the use of a resource that ultimately defeats the original purpose through a higher overall use by society (Dumont et al., 2013). Efficiency gains in resource use may lead to more use of other resources (indirect rebound) or more use of the same resource (direct rebound). This is so because efficiency improvements might bring about outputs cheaper. Economy wide rebound effect also exists where more efficiency drives economic productivity overall resulting in more economic growth and consumption at a macroeconomic level. Some illustrative examples of "rebound effect" are the use of energy-saving devices (for heating) which can be left open several hours because they consume small amounts of energy. In the case of water, the spread of drip irrigation and the consequent saving in water /unit may end-up to the expansion of irrigated land putting in danger the groundwater reserves. (Kolokytha et al., 2017). Farmers may also switch to more profitable and water-consuming crops as a result of this higher reliability of new technology efficient sprinklers. A more efficient use of water in agriculture in general, has extended the land dedicated to crop in many countries, using more water than estimated.

Indeed there is clear evidence that even in the theoretical case of an economy growing by "green means" there would still be rebound effects. An example explained by Santarius (2012) supports the previous claim. Consider the very different quantities of resources, labour, and capital needed to build on the one hand the first cars with internal combustion engines and on the other the hybrid cars of today. First-generation engine technology required few parts – parts that were in the main made of iron and steel – and involved relatively simple design plans that were devised by a manageable number of researchers and engineers. By contrast, the technology of a hybrid car is complex, incorporates countless different raw materials from all over the world, the mining and transport of which involves numerous companies, and is developed by armies of scientists and engineers, all of whom draw salaries and are themselves, consumers. In short: while hybrid cars use less energy per ton-km, their manufacture involves multiple macroeconomic and worldwide rebound effects.

The traditional view of rebound effect is based on the change in efficiency. In a detailed accounting framework (Perry et al., 2009; Molden and Sakthivadivel, 1999), the reusability of the return flows must be assessed.

A very useful tool to handle the rebound effect is ecological taxation. This is a tax levied on activities which are considered to be harmful to the environment and is intended to promote environmentally friendly activities via economic incentives. Such a policy can complement or avert the need for regulatory (command and control) approaches and can halter or minimize rebound effects.

According to the German Advisory Council on the Environment (SRU) it seems that although there exist some measures that could minimize or event reverse these effects, if the economy keeps growing, the rebound effects, can counterbalance half or even all resource saving achieved (SRU, 2011).

8 DEBATE ON GREEN ECONOMY

The debate on the effectiveness of green economy starts with the following arguments**:** i. the production-consumption model seem to have a never-ending goal: to produce more, to satisfy current needs to consume more. ii. pursuit of continuing economic growth, usually measuring by GDP is synonymous to development. iii. Also the green economy concept "producing more with less" referred to energy and resource efficiency accepts the on-going production-consumption model, whereas, in reality, planet earth can no longer sustain these patterns of consumption. This new economic model seems to be a new "green" capitalism since there is a clear targeted increase in specific innovative markets. Global market for environmental services and products is expected to triple from 1.37 trillion $/year to 2.47 trillion $ until 2020. Basic sectors involved are, energy, water, transport and wastewater. (Allianz Global Investors, 2013). The global water supply, treatment and distribution sector is a critical enabler of our society: it guarantees our food, sanitation, health and wellbeing. Without it everything else in the 69.8 Trillion Euro global economy would fail (adopted by GWI, 2016). Too much emphasis is being placed on the role of the private sector and too little on the responsibilities of the state as organizer of the sustainable use of natural resources (Die, 2012).

Finally, the concept of green economy, although struggling for the achievement of the SDGs does not say how increased production and efficiency will change the poverty in the world, or will ensure a more equitable distribution of wealth and power, or education and equity.

Relevant to this discussion is the notion of de-growth widespread by Latouche. He claimed that "a society of infinite growth is impossible in a finite world" Latouche (2004). In fact, this "unlimited growth" on a finite planet has almost led us to ecological and social collapse.

De-growth is an ethical concept of how the world needs to change. The de-growth concept relates the social and ecological questions of distribution, with the reduction of consumption and production to secure social rights for everyone. The de-growth movement refers mainly to the reduction of overconsumption of energy and materials and advocates that economic de-growth is a necessary step in the transition to a more sustainable society (Kolokytha et al., 2017).

9 DISCUSSIONS AND CONCLUSIONS

Green growth and green economy lie on the idea of a "resource efficiency revolution" that uses green innovative climate friendly technologies, to restructure specifically those sectors that are affected by climate change impacts, water being a significant one of them.

Green economy, through resource efficiency, social coherence and protection of the environment provides the framework for sustainable water management and planning which should be carefully examined.

The new development model should rely on economic activities based on the comparative advantages of each country. On the quest for sustainability, the only way to balance economic, environmental, and social aspects of the development would be to base the economy upon activities that are fully compatible with the carrying capacity of the ecosystem. Enhance ecosystem services by providing development opportunities which should rely on products and activities fully compatible with the local conditions, such as the climate, the environment, the tradition, and the human resources.

Moreover, the environmental objectives can no longer be a barrier but an incentive for development. The new development model needs to incorporate the reduction of consumption regarding demands, especially in the developed West, redirecting consumption toward more efficient paths and redistributing resources to the "poor" nations. Limiting thus, the rebound effects from increasing demand because of resource efficiency. Withdrawal rights is an effective measure to explicitly specify that the water savings should not satisfy new demands. Price usually restrains additional withdrawals, when referring to groundwater, because the costs of pumping have a direct impact on profitability. But this is not the case for urban use where the elasticity of demand is very low. Generally, the rebound effect is considered differently in the case of energy and that of water (Dumont et al., 2013). In the case of water, the main issue is to insist on an accurate evaluation of local hydrological and hydrogeological settings and conditions of use beforehand, to identify losses and target savings from water efficiency methods. Solution may be found when a balance in the world economy may occur on some mutually agreed sustainable level of consumption by de-growing economies in the north, while allowing some more growth in the south.

The transition to sustainability is not an easy path but it is better to be approximately right than precisely wrong.

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ASSESSMENT OF THE IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN THE NANLIUJIANG RIVER BASIN OF CHINA

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ABSTRACT

Variable Infiltration Capacity or VIC model is a distributed land surface hydrological model based on cell-grids. Because of its ability to be coupled with climate models, VIC model is widely applied to reveal the impact of climate change on water cycle. As a result, it can provide powerful decision support for dealing with climate change issues on a regional or watershed scale. In this paper, a VIC model is built in the Nanliujiang River basin of China and the sensitivities of the model parameters are analyzed. Then, the water resources under different future climate scenarios are predicted by coupling five climate models with the VIC model. The research results show that the VIC model is applicable to modelling the runoff in the Nanliujiang River basin, the fraction of maximum soil moisture where non-linear baseflow occurs, the variable infiltration curve parameter and the thickness of the second soil moisture layer in the VIC model are sensitive, and water resources in the Nanliujiang River basin present an increasing trend under different future climate scenarios. However, the variation trends are different under climate models.

Keywords: Climate change; VIC model; climate model; sensitivity analysis; Nanliujiang River basin.

1 INTRODUCTION

Climate change is one of the global concerns in the international community today. According to the IPCC AR 5, the average temperature of the earth surface has increased by 0.89°C over the past century (IPCC, 2013), and global warming is the main feature of the climate change. Global warming leads to sea levels rising (Willis et al., 2012), causes glacier area to decrease (Ren et al., 2006), intensifies the variation of the temporal and spatial distribution of water resources (Vorosmarty et al., 2000) and increases the frequency of extreme weather events (Meehl et al., 2000) et al. As a result, the natural ecological system and human survival environment are influenced (Piao et al., 2010). The research on water cycle under changing climate, especially the evolution mechanism and law of extreme hydrological events, is considered to be able to provide powerful decision support for dealing with climate change issues on a national, regional or watershed scale.

At present, the assessment of the impact of climate change on hydrologic process are mainly carried out by coupling climate models with hydrological models (Wang et al., 2011; Xu et al., 2009; Yang et al., 2012; Zeng et al., 2012). More specifically, at first the meteorological data predicted by climate models is downscaled, and then the processed data is used to drive the hydrological models so as to find out how the future water resources will change under changing climate. Xu et al. assess the future water resources in the Jinhuajiang River basin (Xu et al., 2015), and their results show that the change of annual average runoff is not significant, but the change in seasonal runoff is obvious. Liu et al. (2010) couple regional climate model PRECIS with land surface hydrological model VIC and predict the variation trend of the runoff in the Taihu basin under changing climate (Liu et al., 2010). Their results indicate that the runoff depth has prominent differences between the south and north of the basin. The commonly used hydrological models at present are SWAT (Arnold et al., 1998), SWIM (Krysanova et al., 2005), SWMM (Huber et al., 1988), DHSVM (Wigmosta et al., 1994) and VIC (Liang et al., 1994). VIC model can simultaneously consider water and energy balance between land surface and atmosphere, and take into account the impact of heterogeneous soil in sub-grids on runoff generation and the spatial unevenness of precipitation. Because of the above-mentioned characteristics, VIC model is commonly used to analyze and reveal the impact of climate change on water cycle.

In this paper, a VIC model is built in the Nanliujiang River basin of China and the sensitivities of the model parameters are analyzed. Then, the water resources under different future climate scenarios are predicted by coupling five climate models with the VIC model. The results can provide powerful decision support for dealing with climate change issues of the basin.

2 STUDY AREA

Located in the southeast of Guangxi Zhuang Autonomous Region of China, the Nanliujiang River basin ranges from 109°00'03"E to 110°23'12"E and 21°35'54"N to 22°52'32"N. It has a length of 287km and an area of 9,704km^2, which makes it the longest and vastest river with the most abundant water among the rivers that flow from south Guangxi into the sea. Topographically, the basin is high in elevation in the north and becomes lower and lower towards the southwest, and the main stem flows longitudinally between Liuwan Mountains and hilly area, both sides of which are mostly hilly and platform. Downstream of Hepu County, the river forms an alluvial plain, where the terrain is flat and low-lying and the land is fertile. The geographical position of the Nanliujiang River basin and the distribution of hydrological and meteorological stations are shown in Figure 1. Climatically, the basin is characterized by South Asian tropical monsoon climate, where rainfall is plentiful and concentrated mainly in summer and autumn. The annual average precipitation is 1,693mm, and the rainfall from April to September accounts for 80% of the precipitation of an entire year. The climate is temperate and the sunshine is plenty with an annual average temperature of 21.9°C.

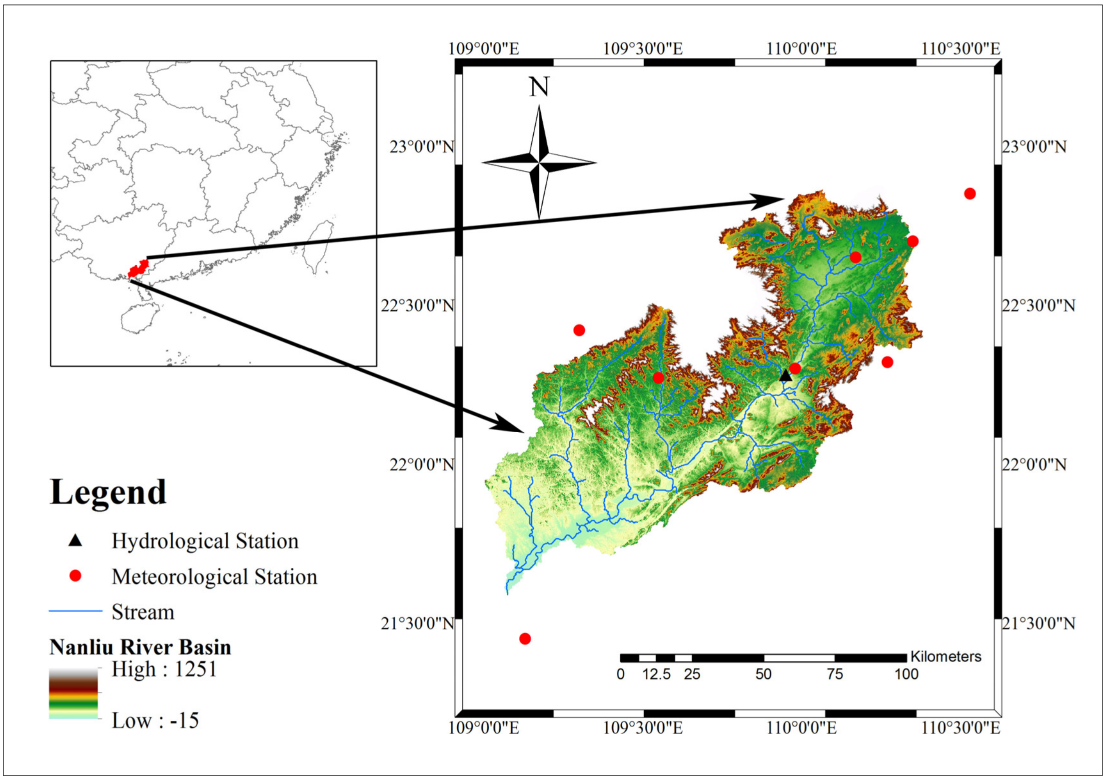

Figure1. Location of the Nanliujiang River basin and distribution of hydrological and meteorological stations.

3 METHODOLOGIES

3.1 Introduction to VIC model

Variable Infiltration Capacity or VIC model is a macroscale distributed land surface hydrological model based on cell-grids. Because of its grid feature, it can easily be coupled with climate models to assess the impact of climate change on water resources. It can simultaneously simulate water and energy balance between land surface and atmosphere, calculate runoff depth and evaporation of each grid, and then transform the runoff depth of each grid into streamflow process at the basin outlet. VIC model makes up for the deficiency of traditional hydrological models in its description of the energy process.

VIC model was originally a two-layer model, considering mainly the physical exchange processes among atmosphere, vegetation and soil. The model reflects the state change and transfer of water and heat among atmosphere, vegetation and soil. In order to strengthen the description of dynamic variation of soil moisture in surface layer and diffusion process of soil moisture in soil layers, the model was improved in such a way that a 0.1m soil layer is separated from the upper soil layer. So, the model now has three layers of soil (Liang et al., 1998). VIC model can consider different vegetation types including bare soil, and simultaneously take water and energy balance into account. Then, the model was optimized by Liang and Xie, and a new runoff mechanism which can simultaneously consider Dunne and Horton runoff and sub-grids heterogeneity was developed (Liang et al., 2001; Liang, 2003). Currently, VIC model is successfully applied to simulating the runoff in China, America and Germany et al. (Abdulla et al., 1996; Lohmann et al., 1998; Nijssen et al., 1997; Su et al., 2003).

3.2 Building of VIC model

Since a VIC model is calculated independently based on cell-grids, the grids which cover the whole basin should be build first. The Nanliujing River basin was separated into 156 grids and the resolution was

0.083°×0.083°. In each grid, several sets of input data including vegetation library files, vegetation parameter files, soil parameter files, meteorological forcing files and global parameter files were prepared to run the model.

Vegetation parameters used in the VIC model were described by the vegetation library files and vegetation parameter files. Vegetation library files provided parameters of different vegetation types, and vegetation parameter files provided the information about the number of vegetation types per grid cell, and their fractional coverage, leaf area index (LAI) et al. In this paper, Land Data Assimilation System (LDAS) is used to determine the parameters in vegetation library file, and the 1km×1km AVHRR Global Land Cover Classification developed by University of Maryland is used for land cover.

Soil parameter files described the heterogeneity in sub-grids, including such data as the main soil type parameters, mean elevation and annual average precipitation et al in each grid. The soil is classified by 5' FAO soil map of the world provided by the National Oceanic and Atmospheric Administration (NOAA). The soil parameters were mainly obtained by means of Cosby’s results (Cosby et al., 1984).

Meteorological forcing files consisted of daily precipitation, daily maximum temperature and daily minimum temperature data. In this paper, eight meteorological stations inside or around the basin were chosen. The observed data of daily precipitation from 1961 to 2010 were obtained from China Meteorological Administration (http://data.cma.cn), and they were interpolated by Kriging method to obtain the daily precipitation of the whole basin.

Global parameter files functioned as connectors, which describe the locations of the input/output files and set parameters such as start and end dates, time step that govern the simulation.

3.3 Sensitivity analysis of parameters

Due to the complexity of runoff production, six parameters closely related to hydrologic process were difficult to obtain. Therefore, the observed runoff data were used to calibrate the model. The six parameters are *B*, *Dsmax*, *Ds*, *Ws*, D_2 and D_3, respectively. *B* ranges from 0 to 0.6, which refers to variable infiltration curve parameter and means the inhomogeneity of spatial distribution of water content in each grid. The greater the value of *B* is, the more uneven the distribution is. *Dsmax* ranges from 0 to 30, which is the maximum velocity of baseflow in the lower soil. *Dsmax* is influenced by the hydraulic conductivity of soil and means the gradient of grids. *Ds* ranges from 0 to 1, which is the ratio of the baseflow to *Dsmax* where non-linear baseflow begins. *Ws* ranges from 0 to 1, which means the ratio of the soil moisture to the maximum soil moisture where non-linear baseflow occurs. D_2 and D_3 mean the thickness of the second and third soil layer, respectively.

Nash-Sutcliffe efficiency coefficient *NSE* and relative error of runoff *Er* are used as assessment indicators for sensitivity analysis. *NSE* and *Er* reflect the fitting degree of streamflow process at the basin outlet and the precision of the total runoff. The sensitivities of the parameters can be expressed by the following functions:

$$P_{NSE} = (\Delta NSE/NSE)/(\Delta x/x) \quad [1]$$

$$P_{E_r} = (\Delta E_r/E_r)/(\Delta x/x) \quad [2]$$

where x refers to the parameters and Δx means the variation of x.

The greater $|P_{NSE}|$ and $|P_{Er}|$ are, the more sensitive x is. Therefore, a scheme was designed to analyze the sensitivities. Specifically, one of the six parameters was increased or decreased by 10%, 20% and 30% respectively, while keeping the remaining 5 parameters unchanged, and the VIC model was run again. At last, the sensitivities can be analyzed by the value of functions [1] and [2].

3.4 Water resources prediction

General Circulation Models (GCMs) are the main tools to assess the impact of climate change. A series of international model intercomparison projects such as AMIP (Gates et al., 1992) and CMIP (Meehl et al., 1997; 2000) are organized by World Climate Research Programme (WCRP), and dozens of GCMs are assessed by the programme. All the results show that GCMs are reliable for global climate simulation. However, a mismatching exists between GCMs and hydrological models. The scale of the GCMs is larger, generally with hundreds of kilometers, while the assessment of the impact of climate change on water resources often is conducted on a regional or watershed scale. To solve this problem, downscaling method (Fowler et al., 2007) is usually used to more accurately simulate the climate on a regional or watershed scale.

Five GCMs data are used to predict the water resources under changing climate, which are GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M, respectively. The data provided by ISI-MIP (http://www.isi-mip.org) contains daily maximum temperature, daily minimum temperature and daily precipitation under the three climate scenarios of Rcp2.6, Rcp4.5 and Rcp8.5. The data are interpolated and corrected by bilinear interpolation and statistical bias correction based on the probability distribution methods, respectively. The resolution of the corrected data is 0.5°×0.5°, and the data can be used as meteorological forcing input data. In this paper, 1981-2010 and 2021-2050 are set for baseline period and future period, respectively, and water resources in the Nanliujiang River basin are predicted under three climate scenarios.

4 RESULTS AND DISCUSSIONS

4.1 Calibration and validation

Monthly runoff data of the Bobai hydrologic station from 1961 to 2010 are used for the calibration and validation of the model. In order to guarantee the number of high flow years equals to the number of low flow years during the calibration and validation period, the periods of 1961 to 1970, 1971 to 2000 and 2001 to 2010 are selected as warm-up, calibration and validation period, respectively. Nash-Sutcliffe efficiency coefficient *NSE* and relative error of runoff *Er* are selected as assessment indices. Runoff simulation and assessment results are shown in Figure 2 and Table 1, respectively.

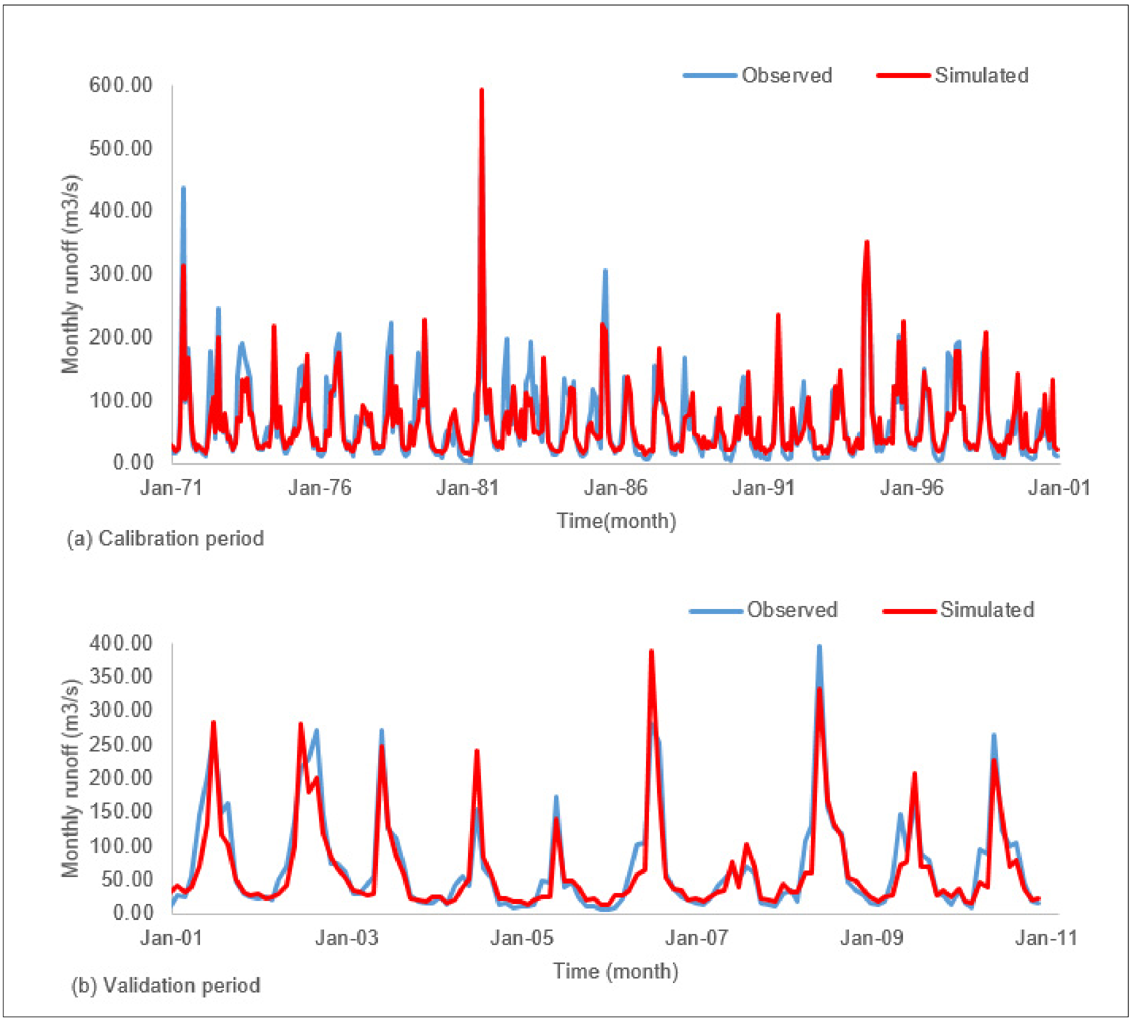

Figure 2. Calibration and validation results in the Nanliujiang River basin.

Table 1. Performance indices during calibration and validation period at Bobai hydrologic station.

Period	*NSE*	*Er* (%)
Calibration	0.78	5.39
Validation	0.85	7.79

From Table 1, *NSE* are 0.78 and 0.85 in calibration and validation period, respectively, and they are both greater than 0.7. *Er* are 5.39% and 7.79% in calibration and validation period, respectively, and they are both less than 10%. Figure 2 illustrates that simulated monthly runoff is in agreement with the data observed at the Bobai hydrologic station. However, the model underestimates the flood peak discharges. Overall, the VIC model can have a relatively good performance in simulating the runoff in the Nanliujiang River basin.

4.2 Sensitivity analysis of parameters

The results of sensitivity analysis are shown in Figure 3. From Figure 3 (a), it can be observed that *B* and *Ws* are the most sensitive parameters to $|P_{NSE}|$. D_2 is less sensitive. The least sensitive are *Ds* and *Dsmax*, which are sensitive when Δx ranges from -30% to 0, but are insensitive when Δx ranges from 0 to 30%. From Figure 3 (b), it can be observed that *Ws* and *Ds* are the most sensitive parameters to $|P_{Er}|$. *B* and D_2 are less sensitive. D_3 and *Dsmax* are the least sensitive. In general, *Ws*, *B* and D_2 are more sensitive than other parameters. *B* reflects the inhomogeneity of spatial distribution of soil moisture in grids, which influences directly rainfall infiltration allocation and runoff production. As a result, *B* is sensitive to the fitting degree of streamflow process at the basin outlet. D_2 means the thickness of the second soil layer, and it can dynamically reflect the impact of soil on precipitation process. The soil of the third layer will not have response to rainfall until the soil of the second layer is fully saturated. Moreover, the distribution of the vegetation root system is determined by the soil of the second layer and it also can affect the evaporation process. Therefore, D_2 can directly affect the soil infiltration capacity, soil moisture and runoff production. Although *Ws* is sensitive, all of the parameters, *Ws*, *Ds* and *Dsmax*, influence the soil moisture, and these three parameters are related to and interact with each other. Therefore, further research on the sensitivity of *Ws* should be carried out.

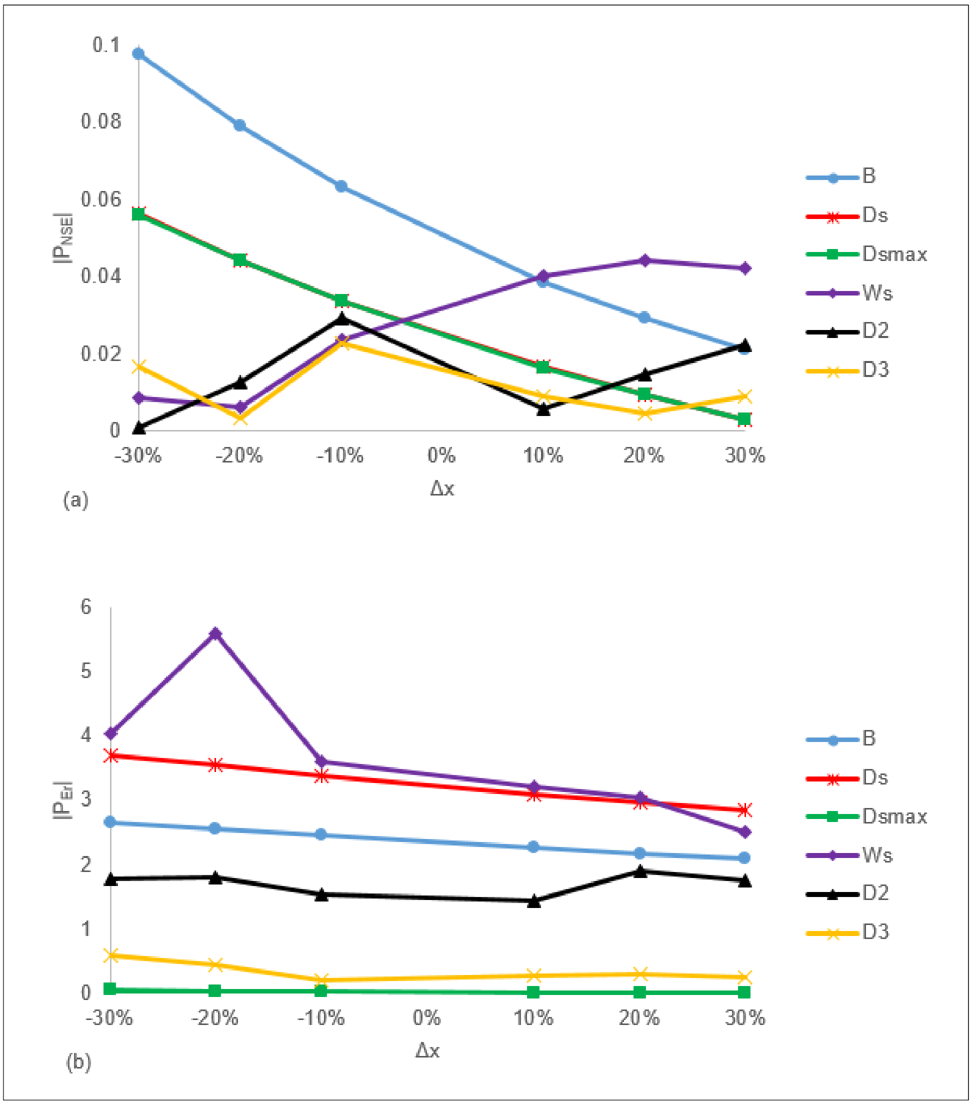

Figure 3. Sensitiveness of parameters.

4.3 Water resources prediction

4.3.1 Spatial change in water resources

Figures 4 to 6 illustrate the spatial distribution of relative changes in mean annual runoff depth under the scenarios of Rcp2.6, Rcp4.5 and Rcp8.5, and the results simulated by the VIC model coupled with five climate models under the three climate scenarios are similar. Water resources in the Nanliujiang River basin show an increasing trend. The runoff depth increases significantly in northern mountainous area, while it increases modestly in the middle and lower plain of the basin.

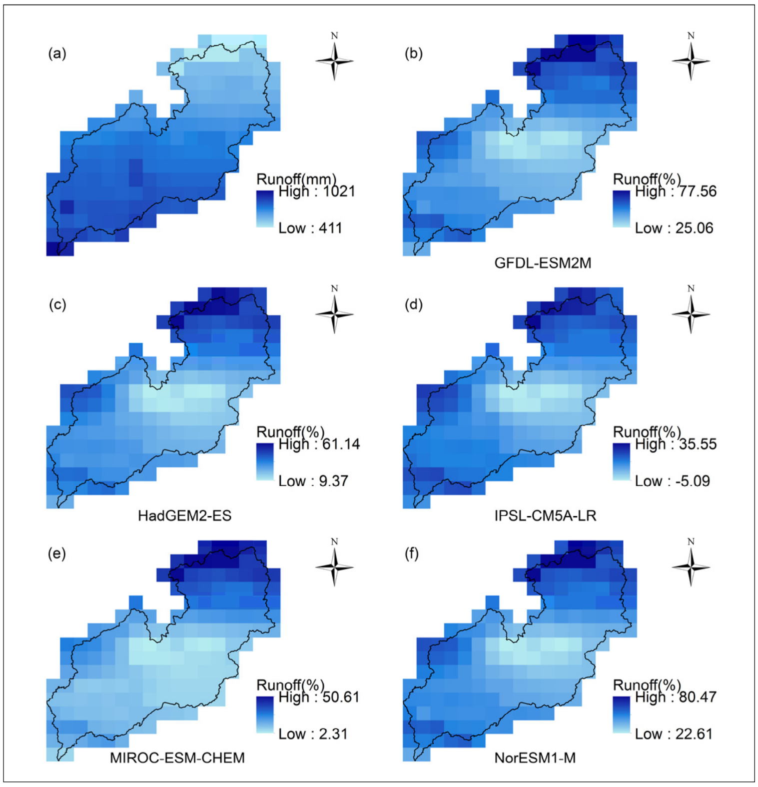

Figure 4. Spatial distribution of relative changes in mean annual runoff depth under Rcp2.6 scenario.

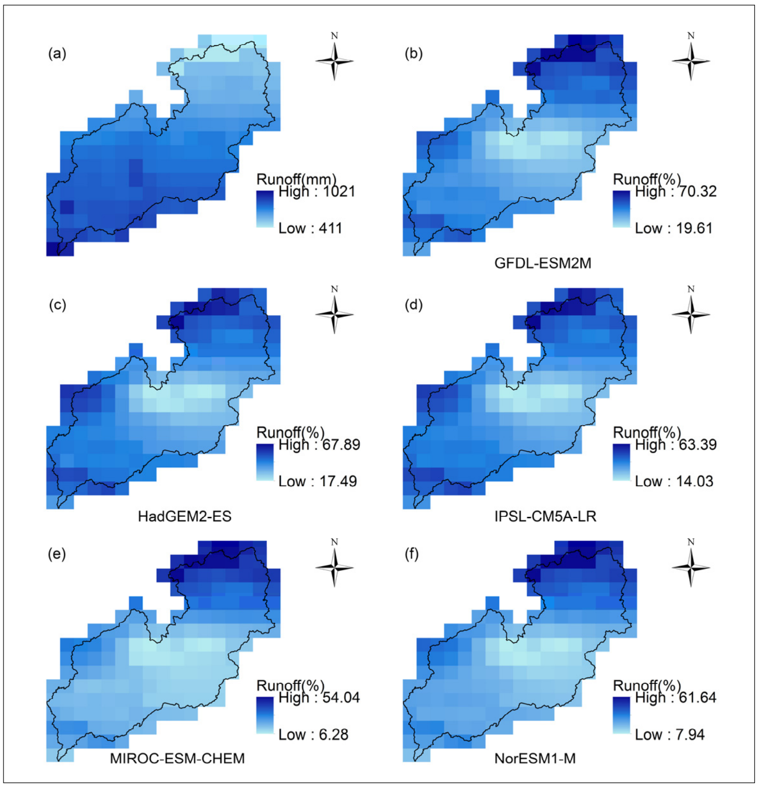

Figure 5. Spatial distribution of relative changes in mean annual runoff depth under Rcp4.5 scenario.

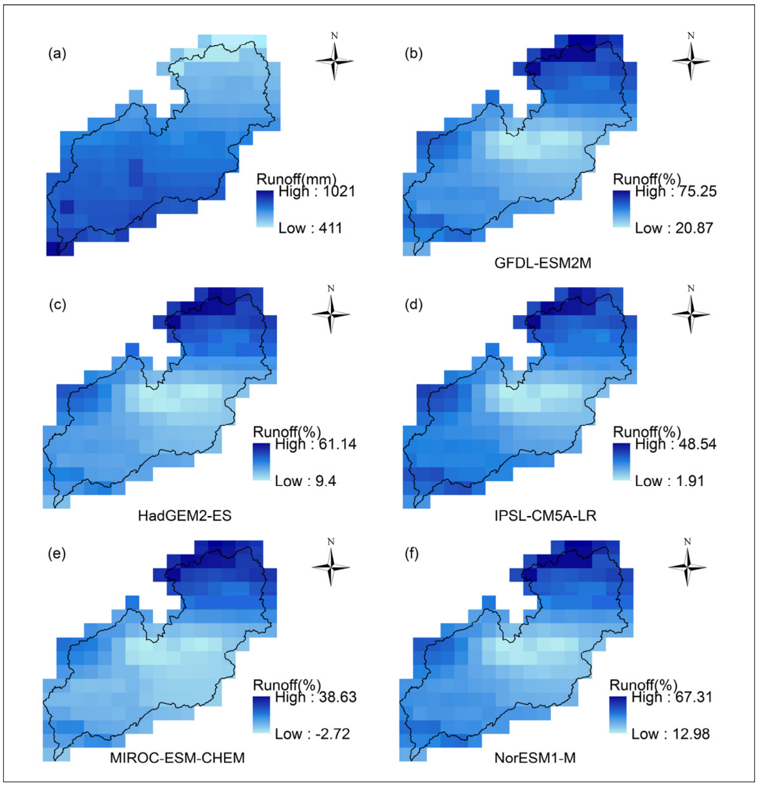

Figure 6. Spatial distribution of relative changes in mean annual runoff depth under Rcp8.5 scenario.

4.3.2 Temporal change in water resources

The mean annual runoff observed at the Bobai hydrologic station during the baseline period was about 2.1 billion m^3. Under the Rcp2.6 climate scenario, the mean annual runoff in the future period are 3.1, 2.7, 2.4, 2.6 and 3.0 billion m^3, respectively. Compared with the baseline period, they increased by 42.8%, 28.1%, 10.1%, 21.0% and 41.9%, respectively.

Under the Rcp4.5 climate scenario, the mean annual runoff in the future period are 2.9, 2.9, 2.8, 2.7 and 2.7 billion m^3, respectively. Compared with the baseline period, they increased by 37.5%, 34.4%, 30.2%, 24.8% and 27.0%, respectively.

Under the Rcp8.5 climate scenario, the mean annual runoff in the future period are 3.0, 2.8, 2.5, 2.4 and 2.8 billion m^3, respectively. Compared with the baseline period, they increased by 39.3%, 28.7%, 18.4%, 14.7% and 31.5%, respectively.

The relative changes in mean monthly runoff under the climate scenarios of Rcp2.6, Rcp4.5 and Rcp8.5 are shown in Figure 7. In general, the runoff in the future period has an increasing trend, while the relative changes are different among the five climate models under the three climate scenarios. Compared with the baseline period, a small variation has been predicted in June during the future period, while a dramatic reduction has been predicted in July, especially by the MIROC-ESM-CHEM model. The mean monthly runoff decreases by 56.6%, 44.4% and 53.3% under the three climate scenarios, respectively. Runoff shows an increasing trend in other months.

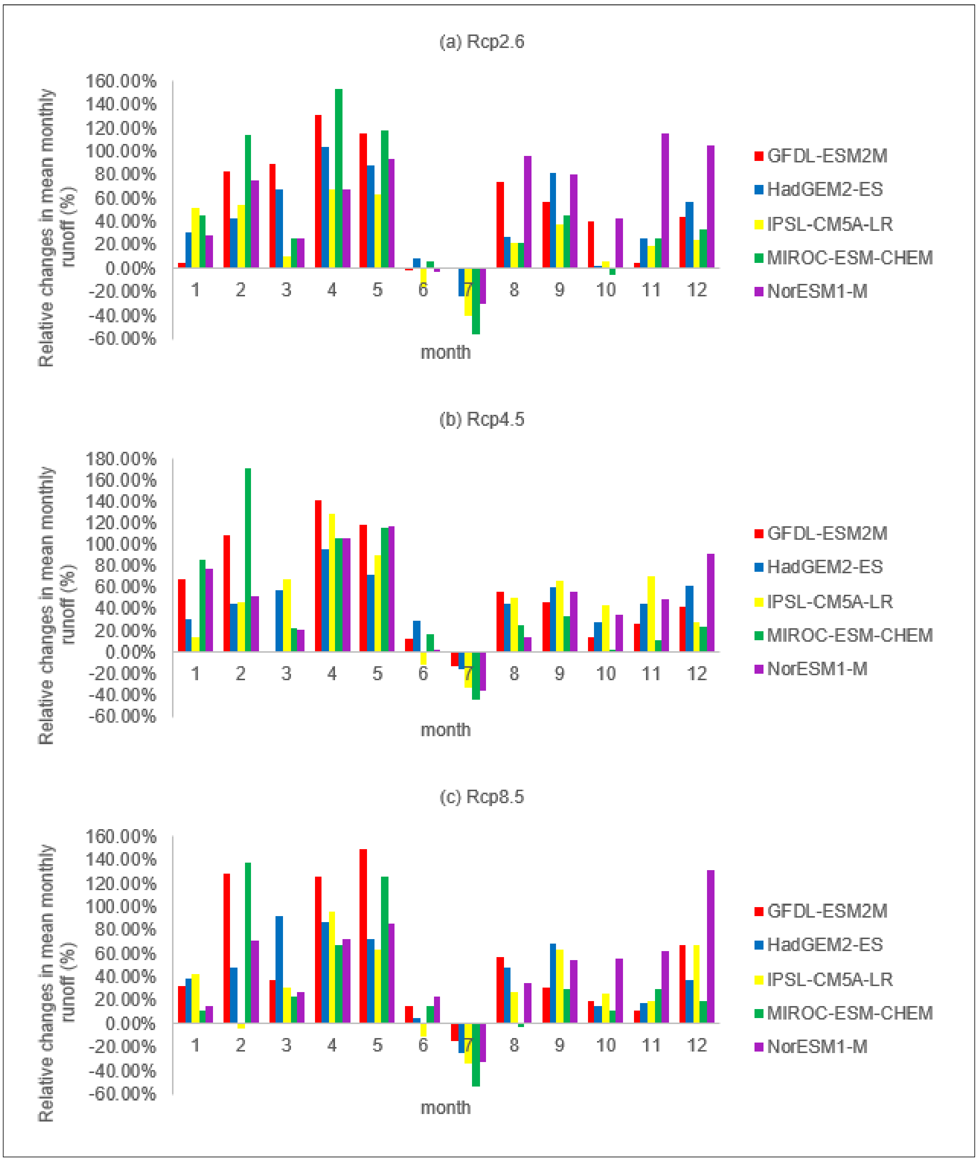

Figure 7. Relative changes in mean monthly runoff under three climate scenarios.

4.3.3 Flood frequency analysis

The annual maximum design flood peak discharge at the Bobai hydrologic station under the three climate scenarios is shown in Table 2 to 4. Under the three climate scenarios, different frequencies of flood peak discharges predicted by GFDL-ESM2M and MIROC-ESM-CHEM models in the future period are both larger than those in the baseline period, while different frequencies of flood peak discharges predicted by HadGEM2-ES model in the future period are smaller than those in the baseline period. Different frequencies of flood peak discharges predicted by IPSL-CM5A-LR in the future period are larger than those in the baseline period under the climate scenarios of Rcp2.6 and Rcp4.5, while the situation under the Rcp8.5 climate scenario is opposite. Compared with IPSL-CM5A-LR model, an opposite result is predicted by NorESM1-M model. As whole, different frequencies of design flood peak discharge are increased under changing climate. Namely, the return period of a flood under changing climate is shorter than that of a flood with the same magnitude without considering climate change shortened with the same magnitude, which poses a serious threat to the flood control in the future.

Table 2. Annual maximum design flood peak discharge under Rcp2.6 climate scenario.

Return period (year)	Baseline (m^3/s)	GFDL-ESM2M (m^3/s)	HadGEM2-ES (m^3/s)	IPSL-CM5A-LR (m^3/s)	MIROC-ESM-CHEM (m^3/s)	NorESM1-M (m^3/s)
100	4135	5577	2781	5045	5714	4115
50	3655	4662	2428	4145	4981	3617
20	3008	3481	1968	2996	4002	2951

Table 3. Annual maximum design flood peak discharge under Rcp4.5 climate scenario.

Return period (year)	Baseline (m^3/s)	GFDL-ESM2M (m^3/s)	HadGEM2-ES (m^3/s)	IPSL-CM5A-LR (m^3/s)	MIROC-ESM-CHEM (m^3/s)	NorESM1-M (m^3/s)
100	4135	7065	2680	4629	4672	3433
50	3655	5956	2368	3837	4295	3061
20	3008	4513	1951	2825	3754	2555

Table 4. Annual maximum design flood peak discharge under Rcp8.5 climate scenario.

Return period (year)	Baseline (m^3/s)	GFDL-ESM2M (m^3/s)	HadGEM2-ES (m^3/s)	IPSL-CM5A-LR (m^3/s)	MIROC-ESM-CHEM (m^3/s)	NorESM1-M (m^3/s)
100	4135	6956	2514	2586	7267	4881
50	3655	5793	2277	2298	6105	4134
20	3008	4300	1955	1909	4599	3166

5 CONCLUSIONS

A VIC model is built in the Nanliujiang River basin of China; the streamflow process is simulated and the sensitivities of the model parameters are analyzed. Then, the water resources under different future climate scenarios are predicted by coupling five climate models with the VIC model.

(1) Both *NSE* in the calibration period and that in the validation period are greater than 0.7. Both *Er* in the calibration period and that in the validation period are less than 10%. In general, the VIC model is applicable to modelling the runoff in the Nanliujiang River basin;

(2) *Ws*, *B* and D_2 are sensitive to the VIC model. The rainfall infiltration allocation and runoff production are directly influenced by *B*. The soil infiltration capacity, soil moisture and runoff production are largely affected by D_2. Soil moisture is influenced by *Ws*, *Ds* and *Dsmax*. The three parameters are related to and interact with each other, and have direct and indirect influence on the VIC model. Therefore, further research on the sensitivity of *Ws* should be carried out;

(3) Water resources in the Nanliujiang River basin show an increasing trend. Spatially, the runoff depth increases significantly in the northern mountainous area, while it increases modestly in the middle and lower plain of the basin. Temporally, a small variation has been predicted in June, while a dramatic reduction has been predicted in July, and runoff has an increasing trend in other months. As the increase of water resources in the future, the flood return period shortened due to climate change will pose a serious threat to the flood control.

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IMPACT OF CLIMATE AND LAND-USE CHANGE ON RUNOFF IN TYPICAL AREAS OF SANJIANG PLAIN

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ABSTRACT

In order to make a quantitative analysis of the impact of climate and land use change on annual runoff, the Naoli River basin, which is located in the Sanjiang Plain of northeast China, is selected as a case study area. The impact of climate change on runoff is separated by an analysis of the changing tendency and statistical regression of precipitation and runoff in the Naoli River basin. The relationship between land use change and runoff is analyzed using land use change data since 1986. A statistical simulation model of runoff process is established based on precipitation and the area of paddy field. Results show that, during the study period, both precipitation and runoff decrease significantly and runoff has a sudden change in the year 1967, and a good correlation exists between precipitation and runoff and the correlation coefficient is as much as 0.9938. Since 1986, due to land use change, especially the significant increase of paddy field, the area of paddy field has become a key factor affecting the runoff change and, thus the correlation coefficient between the area of paddy field and the runoff is 0.9098. From 1986 to 2010, the rate of runoff change caused by land use change increases from 34.55% to 70.83%, which indicates that land use change has an increasingly significant impact on runoff change.

Keywords: Climate change; Land Use/Cover Change (LUCC); runoff variation; Naoli River Basin.

1 INTRODUCTION

Against the background of climate change, human activities (Wang et al., 2016) have a great impact on runoff and one of the most important factors is Land Use/Cover Change (LUCC) (Nazir and Wan, 2015) such as arable land, forestland, grassland, etc. Since the 1980s, there have been a series of international water science programs such as IHP、WCRP、IGBP and GWSP, which aim at discussing water cycle and related resources under rapidly changing environment including hydrologic cycle (Jiang et al., 2015). LUCC plays an important role in controlling the hydrological response (Wagner and Waske, 2016; Siriwardena et al., 2006; Niehoff et al., 2002). In recent years, there have been a large number of studies(Bell et al., 2012; Legesse et al., 2003; Zhang et al., 2011) about the impact of LUCC on runoff, but studies on the impact of human factors, particularly land use/land cover (LUCC), on runoff at watershed scale are fewer(Tran and O Neill, 2013). Due to different regional features of different areas (Lørup et al., 1998), it is very necessary to establish a general theoretical relationship between LUCC and runoff by using some typical river basins as case study areas.

The Sanjiang Plain, which consists of the Songhua River, the Amur River and the Wusuli River, is the biggest grain base and concentration area of wetland in China. Over the past three decades, the runoff in the Sanjiang Plain has changed significantly due to dramatic change in land use. To formulate better policies for reasonable and sustainable utilization of water and soil resources, it is urgent to study the relationship between hydrological process and land use pattern at a watershed scale.

2 STUDY METHOD

2.1 Case study area

With a catchment area of roughly 20,577 km^2 in the mid-eastern Sanjiang Plain, the Naoli River basin (Figure 1) is situated in the sub-humid warm temperate continental monsoon climate zone with latitude between 32° and 42° N and longitude between 96° and119° E. The Naoli River, one of the biggest tributaries, has a length of 596km, which originates from the southwestern mountainous area and flows northeast into the Wusuli River. Annual mean precipitation in the Naoli River basin is about 580mm and annual mean evaporation is 760mm. Mean annual temperature ranges from 1 ºC to 3 ºC. The average wind speed is 4.25m/s with west and northwest wind in winter, southwest wind in spring and east and southeast wind in summer.

The Naoli River basin is an important national grain-producing base in China. At the same time, it is a national nature reserve for wetland. As a result, water resources play an important role in the regional economic development and environmental protection. In recent years, especially over the last three decades, due to climate change and LUCC, the runoff in the Naoli River has changed significantly. Hence, it is very necessary and significant to analyze the impact of LUCC on runoff in the typical area of the Sanjing Plain. This paper takes the Naoli River basin as a case study area.

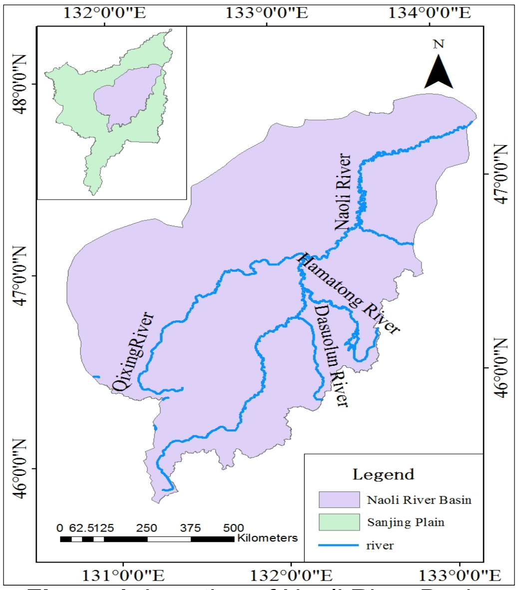


Figure 1. Location of Naoli River Basin.

2.2 Data source

The LUCC data (1986, 1996, 2000, 2005 and 2014) is from Landsat /TM, which is received by China remote sensing satellite ground station with a resolution of 30m. Since the data are collected from June to September on days with no or little cloud, it in general meets the application requirements. According to the geographical feature of the case study area, image quality and our research objective, LUCC is divided into 7 types including paddy field, dry land, forest land, grassland, waters, building land and unused land.

Meteorological data including precipitation and runoff from 1956 to 2010 is from the Baoqing hydrological station in the upper basin of the Naoli River and the Caizuizi hydrological station in its lower basin.

2.3 Research method

The method of analyzing effects of climate and land use change on runoff is composed of two parts(Bewket and Sterk, 2004; Potter, 1991): rational method based on hydrological data and the method of soil and hydrology coupling simulation model based on a large number of field soil and hydrological data and distributed hydrological model. This study chooses the former, namely, a variety of trend analysis methods and regression fitting methods are used to analyze effects of land use change on runoff (Huang and Zhang, 2004; Legesse et al., 2003; Loerup et al., 1998) based on long-term observation data and LUCC data of study area.

2.3.1 Analysis of climate change and its effect on runoff

To analyze the trend of runoff and precipitation and fix the location of the sudden change site, linear regression, Mann-Kendall test of ordered statistics, 5 point moving average and cumulative departure curve are applied in this paper. The specific method is introduced by related papers (Sheng and Paul, 2004).

In order to analyze the impact of climate change on runoff, at first the location of the sudden change site is fixed by analyzing the trend of hydrological processes, then the linear equation relationship between precipitation and runoff is established in the period which is before the sudden change point of precipitation and during which there is no significant land use change. Finally, the equation is used to calculate runoff in the period which is after the sudden change point of precipitation and during which there is no significant land use change. The difference value between the computed result and the observed value is the impact of climate change on runoff.

2.3.2 Analysis of LUCC and its effect on runoff

LUCC data (1986, 1996, 2000, 2005 and 2014) from Landsat /TM is used to analyze the land use change by means of ARC/INFO and ERDAS IMAGE. According to geographical feature of the study area, image quality and our research objective, LUCC is divided into 7 types: paddy field, dry land, forest land, grassland, waters, building land and unused land. Two indices, the rangeability and transfer rate of LUCC, are used to reveal the basic characteristics and spatial variation pattern of LUCC. Corresponding analysis methods are as follows:

The rangeability of single land type Pi is used to measure LUCC.

$$P_i = \left(LU_{it_1} - LU_{it_0}\right) / LU_{it_0} * 100 \qquad [1]$$

where LU_{it0} and LU_{it1} represent the area of LUCC of type *i* at the beginning of the study and at the end of the time t of the study area respectively.

A probability matrix among different land-use types in different periods is established to analyze the transfer rate from one land-use type to other types in a period of time. There are 5 series of LUCC data in the study area, and thus piecewise linear interpolation technology is used to acquire a continuous data series of land use change from 1986 to 2014. The specific equation is as follows:

$$LU_{\mathrm{ijt}} = LU_{\mathrm{ijt\text{-}1}} + \gamma_j (LU_{\mathrm{ij}} - LU_{\mathrm{ij0}}) \qquad [2]$$

where *j* is the number of segments (in this paper there are 4 segments that are 1986-1996, 1996-2000, 2000-2005 and 2005-2014 respectively), LU_{ij} and LU_{ij0} are the area of type i early and late in segment *j*; and γ is weight factor.

To analyze the impact of land use change on runoff, a linear equation between land use and runoff is established in the period during which there is dramatic land use change but no climate change. The difference value between the computed result and the observed value is the impact of land use change on runoff.

2.3.3 Quantitative analysis of impact of climate and land use change on runoff

$$R_1 = Q - Q_1 \qquad [3]$$

$$R_2 = Q - Q_2 \qquad [4]$$

$$\hat{Q} = \alpha Q_1 + \beta Q_2 \qquad [5]$$

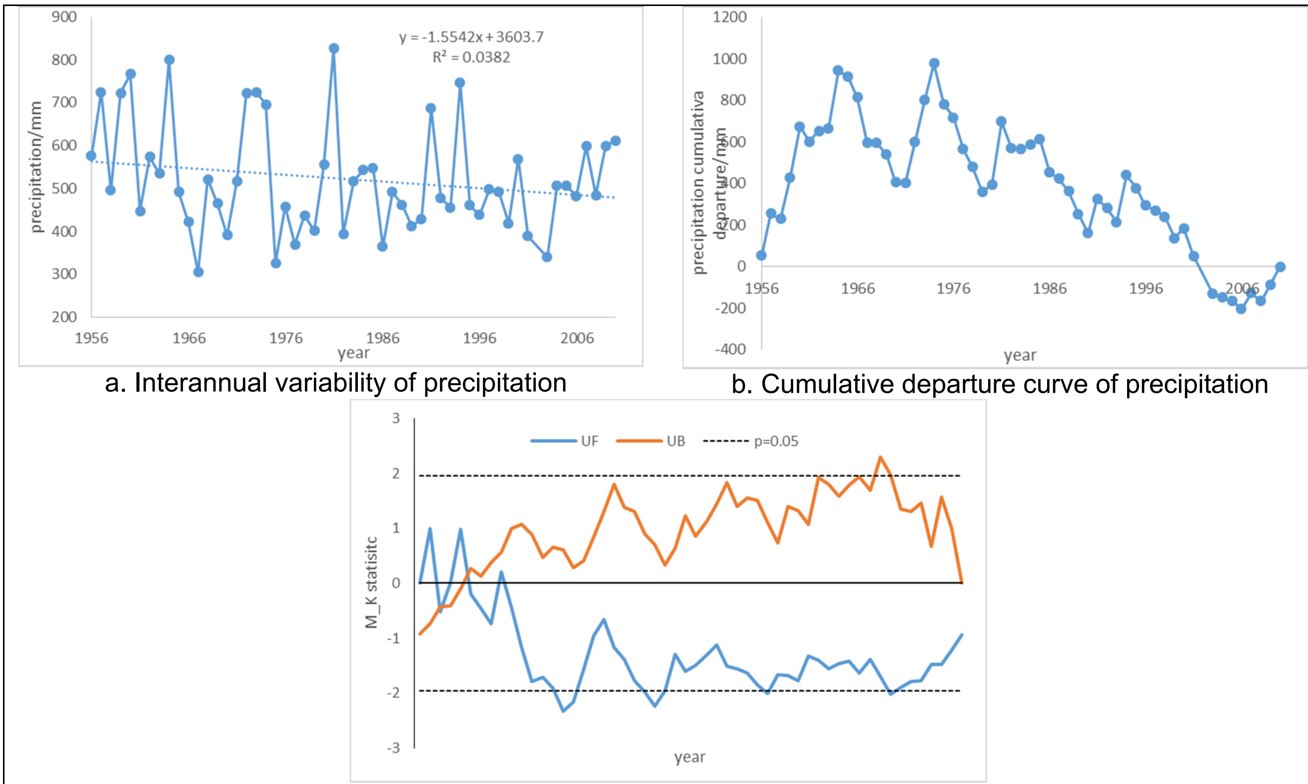
where, α and β are weight coefficients of land use change and climate change respectively; R_1 is the difference value between observed value and Q_1; Q_1 is the runoff against the background of climate change; R_2 is the difference value between observed value and Q_2; Q_2 is the runoff against the background of land use change; $\hat{Q}$ is the result of the model based on precipitation and land use.

3 RESULTS

3.1 Analysis of climate change and its effect on runoff

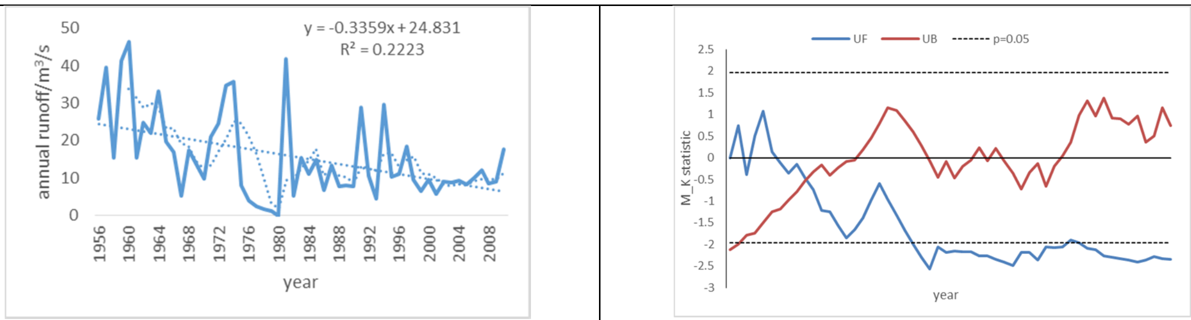
3.1.1 Trend analysis of runoff change

From Figure 2(a), it can be seen that the precipitation of the Baoqing station located in the upper basin of the Naoli river decreases significantly from the year 1956 to 2010, and the maximum precipitation is 826.5mm in 1981 and the minimum is 305.3mm in 1967. It can be seen that precipitation decreases clearly after the year 1965 and after 1975 by means of the cumulative analysis. Curve UF is less than zero after 1964, which indicates that precipitation has a decreasing trend. The precipitation decreases so significantly that its decreasing trend exceeds the significance level of 0.05 in more than one period. The annual precipitation has a sudden change in the year 1961 according to the location of the intersection.



a. Interannual variability of precipitation
b. Cumulative departure curve of precipitation
c. M-K statistical curve of precipitation

Figure 2. Trend analysis and change point of annual precipitation in Naoli river basin.



a. Interannual variability of runoff
b. M-K statistical curve of runoff

Figure 3. Trend analysis and change point of annual runoff in Naoli river basin.

The annual runoff in the Naoli River basin decreases significantly and the decreasing slope is -0.3359(Figure 3a), which indicates the decreasing range in the Naoli River basin is big. In addition, we can see from 5 point moving average that at the initial stage of the 1970s and 1980s, the annual average runoff of the Naoli River significantly increases, and it is related to the increase of precipitation. According to M-K test of annual average runoff in the Naoli River, it can be found that curve UF is less than zero after the year 1975 and decreases gradually, which indicates that annual average runoff drops significantly. The location of the intersection point of curves UF and UB indicates that the annual runoff has a sudden change in the year 1967 and declines clearly after the sudden change point.

3.1.2 Impact of climate change on runoff

The results above demonstrates that the annual average runoff shows an obvious continuous declining trend and climate change plays an important role after the sudden change. According to the variation characteristics of precipitation and runoff from Figure 2 and 3, precipitation and runoff have a good linear correlation before the year 1961, and the statistical relationship can be obtained using the precipitation and runoff data from 1956 to 1961. It indicates that there is a significant linear correlation between precipitation and runoff and precipitation is a principal factor in the formation of runoff. The statistical equation to quantitatively analyze the relationship between precipitation and runoff by regression analysis is as follows:

$$Q_2 = 0.11P - 38.555 \qquad [6]$$

where Q_2 is the runoff against the background without land use change and P is precipitation.

The correlation coefficient of Eq. [6] is 0.9938, which indicates there is a very close relationship between precipitation and runoff in the case where there is not any climate change or significant land use change. The correlation can be used to well simulate the relationship between precipitation and runoff with a high reliability.

3.2 Analysis of land use change and its effect on runoff

3.2.1 Dynamic change characteristics of LUCC

There are 7 types of land use including paddy field, dry land, forest land, grassland, waters, building land and unused land in the Naoli River basin. Paddy field, dry land and forest land are the three types of land-use with the biggest, second biggest, and third biggest percentage of area among the 7 types of land use, and thus have the most significant impact on runoff. The change characteristics of the Naoli River basin from the year 1986 can be seen in Table 1.

Table 1. The change characteristics of Naoli River basin since 1986.

types of landuse		paddyfield	dryland	forest land	grassland	waters	building land	unused land
proportion of 2014		18.55	41.16	24.24	4.37	0.61	1.67	9.40
P_l	1986-1996	-72.29	22.89	0.19	-29.00	-23.82	4.89	-15.58
	1996-2000	442.82	-11.38	-10.20	-8.79	42.38	-3.72	-6.32
	2000-2005	-5.49	5.81	0.25	111.23	79.65	-6.34	-33.78
	2005-2014	64.55	-14.07	-0.73	-11.72	9.01	10.02	0.17

As shown in Table 1, dryland has the biggest percentage of area by 2014, followed by forest land and paddy field. Water bodies such as lakes and so on have the smallest percentage of area. So the emphasis of analyzing the relationship between land use and runoff is on paddy field, dry land and forest land, especially paddy field. Paddy field changes a lot from 1986 to 2014. It decreases by 72.29% from 1986 to 1996 and then increases by 442.82% from 1996 to 2000, which is a critical period for land use change due to rapid increase of paddy field. Dry land is the biggest part in the Naoli River basin, which presents fluctuating changes from the year 1986 to 2014 and in general shows a trend of decline. Forest land shows a trend of slight decrease, namely it changes a little and has no effect on runoff change from the year 1986 to 2014. In a word, paddy filed plays the most important role in runoff change in the Naoli River basin because of its rapid change, dry land and forest land change slowly, and the proportions of other types of land use are not big enough.

Table 2 is the transfer matrix of land use in the Naoli river basin since 1986. It can be seen that the area of paddy field that has become dry land is 1733.59 km^2 and unused land is 53.19 km^2 from the year 1986 to 1996. During the period, paddy field decreases rapidly. Meanwhile, the area transforming from dry land to paddy field is 328.21km^2 and to forest land is 144.66km^2 and unused land is 122.94 km^2. At the same time, there is an area of 309.98km^2 that has been transformed from forest land to dry land. The general tendency during the period is that paddy field decreases rapidly, dry land increases significantly and forest land increases slowly. From the year 1996 to 2000, there is an area of 80.48km^2 that is transformed from paddy field to dry land, 2375.48km^2 transformed from dry land to paddy field and 591.95km^2 from forest land to dry land. The overall situation during the period is that paddy field increases sharply and dry land and forest land decrease slowly. From 2000 to 2005 there are 1710.54km^2 and 270.58km^2 transformed from paddy field to dry land and forest land respectively. During the period, there are 1717.79km^2, 396.50km^2 and 374.49km^2 of areas have been transformed from dry land to paddy field, forest land and grassland respectively. To some extent, the general tendency during the period is that paddy field decreases slowly and dry land and forest land increases slightly. From the year 2005 to 2014, the area transformed from paddy field to dry land is 140.39km^2, from dry land to paddy field is 1816.45km^2 and from forest land to dry land is 146.17km^2. During the period, paddy field increases significantly, while dry land and forest land decrease slowly.

Table 2. The transfer matrix of land use since 1986.

		paddyfield	dryland	forest land	grassland	waters	building land	unused land
1986-1996	paddyfield	170.65	1733.59	0.75	27.26	1.59	1.39	53.19
	dryland	328.21	9750.14	144.66	57.80	0.79	18.55	122.94
	forest land	0.10	309.98	6437.14	35.15	0.00	1.96	4.61
	grassland	3.50	215.62	169.63	471.41	2.26	0.69	45.39
	waters	0.00	0.78	0.00	1.87	47.95	0.00	21.25
	building land	0.09	2.96	0.43	0.36	0.06	398.19	0.00
	unused land	48.42	795.37	49.46	51.20	2.09	0.96	3547.20
1996-2000	paddyfield	459.37	80.48	0.10	0.00	0.00	0.09	10.94
	dryland	2375.48	10330.55	12.18	43.94	0.25	2.96	43.07
	forest land	0.39	591.95	6089.49	80.18	0.00	0.43	39.64
	grassland	87.78	90.51	4.82	461.58	0.00	0.36	0.00
	waters	0.00	2.24	0.00	0.00	52.12	0.06	0.32
	building land	1.54	15.51	0.96	0.69	0.00	402.16	0.88
	unused land	66.32	239.90	0.82	1.95	25.56	0.00	3460.03
2000-2005	paddyfield	910.16	1710.54	22.96	57.55	3.99	15.09	270.58
	dryland	1717.79	8530.07	396.50	374.49	16.96	97.48	217.84
	forest land	32.65	489.36	5454.97	61.99	1.98	7.94	59.47
	grassland	37.23	140.82	182.66	34.63	29.79	1.33	161.89
	waters	2.97	5.62	2.15	0.64	39.80	0.17	26.59
	building land	14.28	120.72	6.94	3.54	0.37	257.70	2.50
	unused land	111.69	1013.04	57.20	709.91	47.12	0.60	1615.33
2005-2014	paddyfield	2637.39	140.89	7.29	1.66	3.15	7.08	29.30
	dryland	1816.45	9935.33	123.88	17.36	4.31	57.41	55.44
	forest land	6.52	146.17	5936.80	25.37	3.45	2.23	2.82
	grassland	140.32	39.77	6.97	1048.57	0.23	0.73	6.18
	waters	0.04	1.00	0.33	0.26	133.79	0.04	4.55
	building land	3.46	25.29	1.25	0.09	0.01	349.95	0.25
	unused land	47.24	32.39	2.45	3.77	7.69	0.99	2259.68

3.2.2 Impact of land use change on runoff

Through the analysis of land use change in the Naoli river basin, it can be seen that the prominent sign of its land use change is the rapid increase of paddy field and the slow decrease of dry land and forest land. Most of the decreased area of dry land and forest is changed into paddy field. The change of dry land and forest land is not significant, but there is a constant increase in paddy field. As a result, paddy field is selected to analyze the impact of land use change on runoff. The yearly data of paddy field is calculated by means of Eq. [2]. The runoff data of the Caizuizi station located in the lower reaches of the Naoli River from the year 1996 to 2000 and the area of paddy field are used to establish statistical regression relationship between land use change and runoff. The equation is as follows.

$$Q_1 = -3.9175S + 33.54 \quad [7]$$

where Q_1 is the runoff against the background of land use change and S is the area of paddy field.

The correlation coefficient of Eq. [7] is 0.9098, which indicates that there is a very close relationship between land use change and runoff from the year 1996 to 2000. The result calculated by Eq. [7] is of high reliability.

3.3 Extent of impact of climate and land use change on runoff

The coefficient in Eq. [5] during different study periods can be confirmed by Eq. [6] and [7] in the method of the least square. The runoff process simulation model can be established based on the coefficient in Eq. [5], and the simulation results of optimal parameters are shown in Table 3.

Table 3. Impact factor values of climate and land use change on runoff.

1986-1996		1996-2000		2000-2005		2005-2010	
α	β	α	β	α	β	α	β
0.7083	0.2917	0.3455	0.6545	0.5574	0.4426	0.5856	0.4144

Table 3 shows the simulated result of optimal parameter during different periods. From the year 1986 to 2010, average annual runoff is affected seriously by land use change and slightly by climate change, and the contribution rate of expansion of paddy field is above 50%. On the whole, land use change plays a dominant role in runoff change from 1986 to 1996 and results in 70.83% of the runoff change. From 1996 to 2000, the rate of the impact of land use change on runoff decreases to 34.55%, and during the period paddy field dwindles and climate change plays an important role in runoff change. During the period from 2000 to 2005, due to the rapid increase of paddy field, the impact of land use change on runoff reaches 55.74% and, during the period from 2005 to 2010, that is 58.56%. It indicates that land use change is a key factor in runoff change and the impact of paddy field on runoff is becoming obvious.

4 DISCUSSIONS

The main purpose of the paper is to analyze land use change in the Sanjiang Plain by taking the Naoli River basin, the typical area in the Sanjiang Plain, as an example. Dynamic change characteristics of LUCC and the transfer matrix of land use are analyzed. The results show that dry land, forest land and paddy field are the three types of land use with the biggest, second biggest, and third biggest percentage of area in the Naoli River basin. Overall, dry land has a decreasing trend from the year 1986 to 2014 and forest land slightly increases. On the contrary, paddy field increases rapidly. As a result, the paddy field from the year 1996 to 2000 is chosen to analyze the correlation between land use change and runoff.

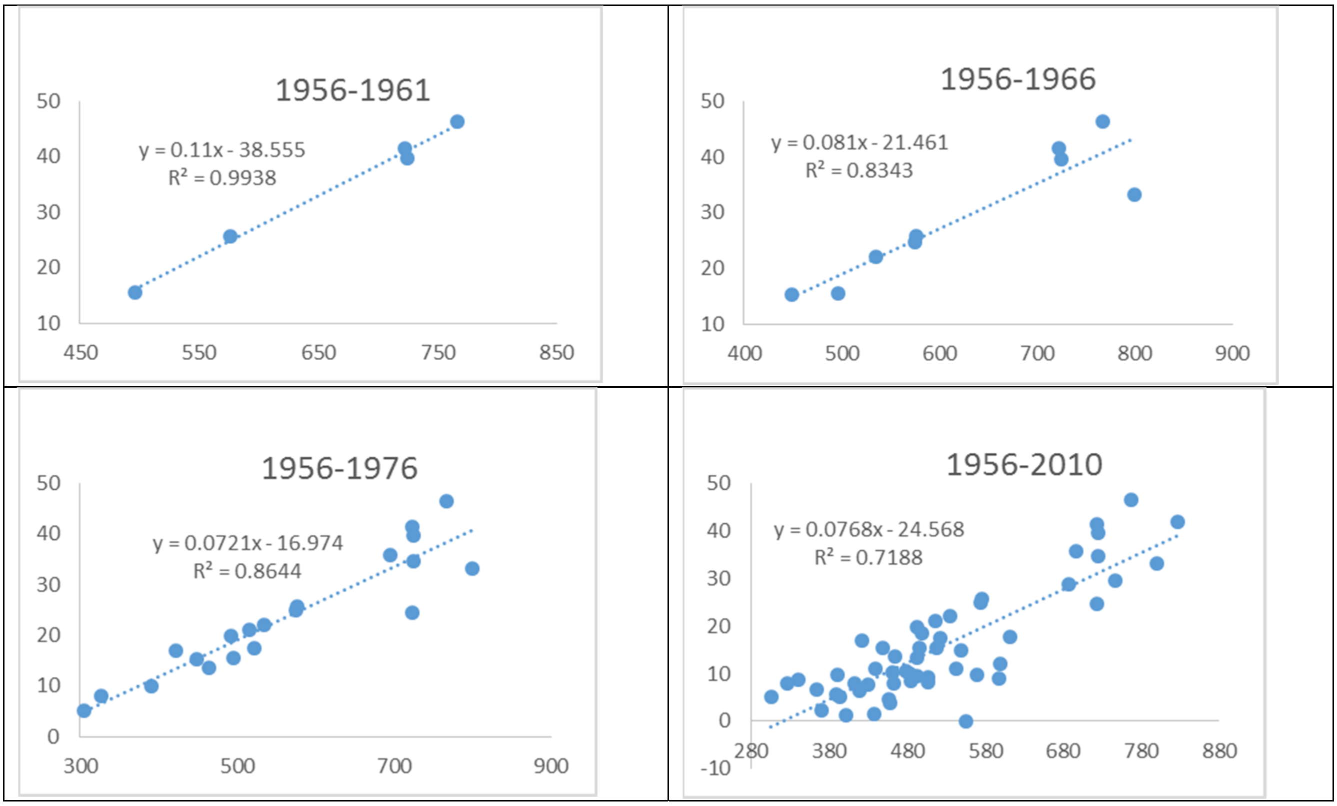


Figure 4. The correlational relationship between precipitation and runoff of Baoqing station.

To analyze the correlation between precipitation and runoff, the Baoqing station located in the upper basin of the Naoli River is chosen as a representative station. The methods of linear regression, Mann-Kendall statistic test, used 5 points moving average and accumulated anomaly to confirm the change point of precipitation and runoff. Precipitation has change point in 1961 and runoff in 1967. In the follow-up work of analyzing the correlation between precipitation and runoff, there is always a good correlation between precipitation and runoff in the Baoqing station during different periods (Figure 4). The reasons are: (1) the Baoqing station is located in the upper basin of the Naoli River that is a mountainous area and thus there is little land use change in that area and precipitation is the main factor leading to runoff change; and (2) although different methods such as linear regression, Mann-Kendall statistic test are used, every method has its weakness. As a result, both precipitation and runoff need to be further studied to find out whether there are change points in the Naoli River basin. The only thing that can be confirmed is that precipitation and runoff have a decreasing trend.

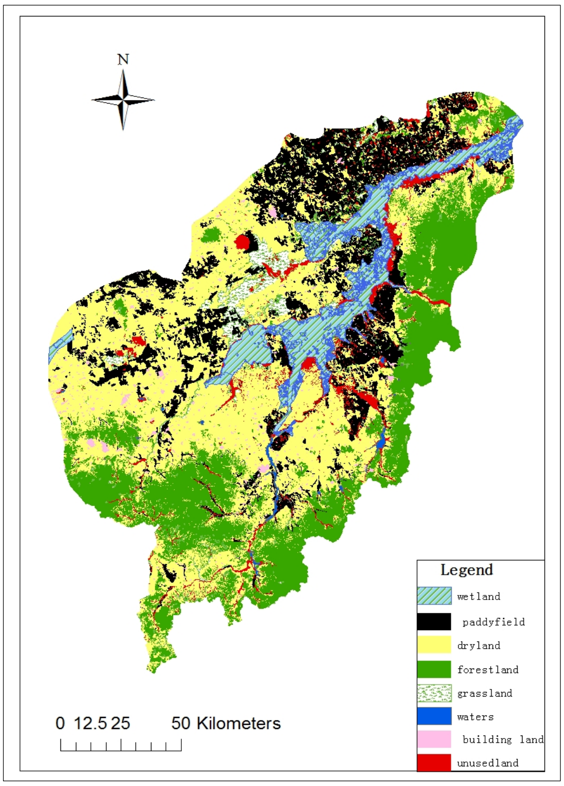


Figure 5. The land use situation of the Naoli River basin in 2014 and the distribution of wetland.

The correlation between land use change and runoff is very good from the year 1996 to 2000, but the time series is not so long, which needs to be further confirmed in long time series, because there is no linear relationship between land use change and runoff in the Caizuizi station throughout the study period. It indicates that there are other impact factors except for climate change and land use change. Preliminary analysis shows that wetland (Figure 5) has significant impact on runoff. The future work should analyze the impact of wetland on runoff and the contribution rate of different land use types.

5 CONCLUSIONS

The impact of land use change on runoff in the typical area of the Sanjiang Plain is analyzed. Firstly, the relationship between precipitation and runoff in the Baoqing station is analyzed by the methods of linear regression, Mann-Kendall statistic test, 5 points moving average and accumulated anomaly. Precipitation has a change point in 1961 and runoff in 1967. There is a good correlation between precipitation and runoff. The correlation coefficient is 0.9938. Then dynamic change characteristics of LUCC and the transfer matrix of land use are analyzed and results show that dry land, forest land and paddy field are the three types of land use with the biggest, second biggest, and third biggest percentage of area in the Naoli river basin. Overall, dry land has a decreasing trend from the year 1986 to 2014 and forest land slightly increases. On the contrary, paddy field increases rapidly. Thirdly, the relationship between land use change and runoff in the Caizuizi station from 1996 to 2000 is analyzed and result shows that runoff can be well simulated by paddy field and the correlation coefficient is 0.9098. Finally, the contribution rate of the impact of climate change and land use change on runoff is quantitatively analyzed, and results show that the impact of land use change increases from 34.55% to 70.83%, which indicates that land use change plays an important role in runoff change.

Due to the complex situation in the Sanjiang Plain, in addition to climate change and land use change, there are other factors affecting runoff. The next step work should analyze the impact of wetland on runoff and the contribution rate of different land use types.

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