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Articles

Impacts of climate change *versus* land use change on recent Lijiang River flood regime, South China

Impactos del cambio climático frente al cambio del uso del suelo en el reciente régimen de inundaciones del río Lijiang, Sur de China

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Abstract

Rapid development synchronized with human-caused climate change, have induced several critical environmental challenges in south China. The current work compares the drivers of hydrological flux changes and flood reoccurrences in the Lijiang River basin. Using satellite images, SWAT and HEC-HMS models, Mann-Kendall and Minitab trend tests, analysis on climatic as well as land use/land cover changes (LULCC) were carried out statistically. Daily hydrometeorological data were quantitatively analyzed during 1967-2016 for fluctuation regime and pattern recognition. A more uneven rainfall pattern in recent decades was found aligned with the excessive runoff. The average temperature and relative humidity have continuously increased by 0.96 °C and decreased by 3 %, respectively during the last 50 years. Land use maps were used to observe the watershed land conversion during pre/post-development via GIS. Although up to 76 % increase in urbanized areas was detected; however, only 0.6 % of LULCC was noticed which had a 0.1 % change in the curve number (CN) in the entire watershed. HEC-HMS model results revealed negligible changes of hydrographs with and without LULCC. Our study suggests that the main cause of the recent flood upward trends is ascribed to the precipitation pattern changes as a response to global warming, rather than LULCC. The result is underpinned by a rise in the extreme intensity rainfall event’s frequency. The need for sustainable development to adapt to the new situation was supported by the outcomes.

Keywords: Land use change, Climate change, Lijiang basin, HEC-HMS, SWAT, Mann Kendall, Minitab.

Resumen

El cambio climático causado por el hombre, sincronizado con el rápido desarrollo en el sur de China, ha inducido varios desafíos ambientales críticos en dicha región. Este trabajo compara los impulsores de los cambios del flujo hidrológico y la recurrencia de inundaciones en la cuenca del río Lijiang. Se llevaron a cabo análisis estadísticos de los cambios climáticos y de uso/cobertura de la tierra (LULCC) utilizando imágenes satelitales, los modelos SWAT y HEC-HMS, pruebas de tendencia de Mann-Kendall y Minitab. Los mapas de uso del suelo se utilizaron para observar la conversión del suelo de la cuenca hidrográfica durante el desarrollo previo/posterior a través de GIS. Aunque se detectó un aumento de hasta el 76 % en las áreas urbanizadas, sólo el 0.6 % de LULCC se notó en toda la cuenca y había causado un cambio de 0.1 % en el número de curva (CN) en toda la cuenca. Los resultados del modelo HEC-HMS revelaron cambios insignificantes de hidrogramas con y sin LULCC. Los datos hidrometeorológicos diarios se analizaron cuantitativamente durante 1967-2016, para determinar el régimen de fluctuaciones y el reconocimiento de patrones. Se encontró un patrón de lluvia más desigual en las últimas décadas vinculado con una escorrentía excesiva. La temperatura media y la humedad relativa han aumentado continuamente en 0.96 °C y disminuido en un 3 %, respectivamente, durante los últimos 50 años. Nuestro estudio sugiere que la causa principal de las recientes tendencias al alza del volumen de escorrentía se atribuye a los cambios en el patrón de precipitación como respuesta al calentamiento global en lugar de LULCC. El resultado está respaldado por un aumento en la frecuencia del evento de lluvia de intensidad extrema. Los resultados respaldaron la necesidad de un desarrollo sostenible para adaptarse a la nueva situación.

Palabras clave: cambio de uso de la tierra, cambio climático, cuenca del río Lijiang, HEC-HMS, SWAT, Mann Kendall, Minitab.

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Introduction

Human impacts on the environment and landscape have drastically increased to a much larger scale since the industrial revolution. This rapid development by the growing population (UN, 2017) has imbalanced the ecosystem in some regions. Massive land use changes, ongoing production of greenhouse gasses, deforestation, vegetation deterioration, conversion of the natural lands to cultivated or/and irrigated farms, and additive expansion of cities have caused a number of changes including shifts in basins flood regimes. Accelerated human-caused global warming in the northern hemisphere, driven by the “greenhouse effect” is exemplified by numerous studies. According to the intergovernmental panel of climate change (2007), the near-surface temperature has increased by 0.74 ± 0.18 °C since the mid 20th century. This has caused irregular rainfall patterns, flood, and drought in different regions (Parry *et al*., 2007), besides the changes in water supply and demand (Petra, 2002).

Aligned with the temperature rise in the globe, China has experienced warmer periods in the past decades. A 0.55 °C incremental temperature in a decade was reported in south China (He *et al*., 2010). More precipitations that vary in space and time, as feedback to global warming, is the result of more water vapor in the atmosphere (IPCC Report, 2007). Combined with urbanization, excessive rainfall can cause more runoff and floods, especially in a monsoon dominated climate in south China which has an uneven distribution characteristic of rainfalls during the year.

To understand the nature of the variables in every phenomenon is a prerequisite for a sensible attempt to predict future requirements. As per literature, various parameters can impact the quantity of runoff in a watershed. A study on the climate changes effects on the Yanggong river basin concluded that the recent streamflow intensifications are due to variations of groundwater, snowmelt, and rainfalls in response to climate change and specifically raise in average temperature between 1979 and 2006 (He *et al*., 2010). Likewise, Shao, Guan, Zhang, Yu and Zhu (2018) observed that the upward trends in the streamflow in Erdos plateau (northwest China) are more affected by the additive temperature than land use changes in the past few decades. However, another study (Li, Liu, Wen-Zhao, Xun-Chang, & Fen-Li, 2009a) revealed that climate and land use changes in the Loess plateau have caused a drop in the amount

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of runoff. Cao *et al*. (2018) using the SWAT model studied the recent 10 years meteorological data and showed that the amount of evapotranspiration in Lijiang watershed is mainly controlled by land use type, while surface and groundwater are strongly depended on precipitation. Applying the same model in northwest china, the land use type was shown to be the influencing factor for the raise of runoff quantity (Wang, Kang, Zhang, & Li, 2008).

The interactions between land use / land cover and climate change, human activities, and their impacts on runoff are known to some extent. However, considering the current trends in developing countries, yet there is a need to research in this area to inform future possible sustainable development. Based on reports, more than 30 % of the tropical forests in Southeast Asia were changed by the human at the beginning of the 20th century (Lambin & Geist, 2003). Arable lands have intensively expanded in the last century as per FAO (2016) especially that new irrigation systems are developing yet (Rad *et al*., 2018; Lei *et al*., 2018). New technologies like satellite imagery or analytical tools have equipped researchers to analyze data on a larger scale. Analytical methods such as the Mann Kendall trend test as well as Minitab were used for big data analysis of climatic variables in different studies (Gomes-de-Souza-Mendes, Cecilio, Zaneti, & Dos-Santos, 2019; Jiang *et al*. 2019). A four years landscape composition analysis for Lijiang catchment was done in 2016 to show the mutual interactions between human and landscape using GPS data as well as remote sensing images and it was concluded that the human activity impacts on the environment overall causes scarce of the natural resources (Li *et al*., 2016). Hydraulic/ hydrological models

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such as the well-known HEC-HMS are applied widely to determine the current and forecast the future changes in watersheds (Dong & Li, 2004).

Land-use change causes (Cao *et al*., 2017) and impacts (Liu & Liu, 2018) have been studied in many areas of the country recently; however, less research has been conducted in the Lijiang river basin (Guilin). Most Lijiang River researches have focused on runoff quantity (Jiangxuan & Junfeng, 2018), quality (Jianhui, Jian, Rui, & Yuan-Yuan, 2018), ecological and habitats (Li *et al*., 2015), as well as meteorological measurements (Junfeng, Huan, Xin, Rong-Jie, & Xin-Jian, 2011) while the interplay of human activity and flood regimes in this area are poorly understood. A 30-year analysis of the Li river runoff quantity indicated a relatively stable runoff quantity during the study period (Cheng, Chunqing, & Junchun, 2005). Peili, Jun-Feng, Xin-Jian, Chun-Qing and Rong-Jie (2011) analyzed the influencing factors on pan evaporation changes between 1980 and 2003 in Lijiang watershed and observed no additive trend on the temperature change. One of the land-use change impacts researches in the Lijiang watershed was done by Xiang *et al*. (2009) who reported a significant land use transformation in the upper reaches of Li River during 1991-2006 which results in a decline in various ecosystem service values. New research shows the different impacts of locals and tourist populations on the LULCC in some parts of the Lijiang basin using satellite imagery (Li *et al*., 2017).

The objective of this study is to correlate the changes in climatic indexes as well as the human impacts (LULCC) on flood frequency and quantity fluctuations during the last 50 years in the Lijiang basin as a case study. The karst green landscape of the Lijiang River (Figure 1) attracts

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millions of tourists every year to visit the scenic areas around the Li River (Guilin Chorography Office, 2011).

Figure 1. The study area of Lijiang River basin.

These tourist areas are mainly developed after the year 1990 (Le-Treut *et al*., 2017), as before that the urbanization progress in China was slow and only from 1990 ~ 2000 started to increase. Impacted by economic growth after the year 2000, the urbanization rate grew at an average annual rate of 1.3 % (Chuanglin, 2018). A report claimed that in the year of 2014 around 30 million visitors visited the Lijiang (Li *et al*., 2016) and it increased to 40 million in 2015 (Li *et al*., 2017), while the local population is five million people. This has provided rapid economic development for the region; however, environmentally it has caused several issues as well since the infrastructures have not been developed parallel to environmentally handle this crowd. This work aims to analyze and uncover the reason behind the recent more frequent floods in the three main zones (Guilin, Yangshuo, Pingle) of the Lijiang watershed.

Materials and methods

Site description

Lijiang is located in Guangxi province, south China. The main river resources are originated from Maoer Mountain, at the northern border of the state. The river flows 213 km from north to south where it merges the famous Pearl River (the 3rd largest river of China), as one of the 8 tributaries of Pearl River and it finally releases into the South China Sea. The watershed area in total is 11 378 km^2 which is divided into three subbasins. First, the northern part, as the smallest, is Guilin subbasin with a total area of 2 590 km^2 (23 % of the watershed). This fan-shaped subbasin in the upstream has a subtropical monsoon and a high amount

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of annual rainfall (Guo, Fang, & Jun-Feng, 2011) for around 1 900 mm on average (Figure 2). Geomorphologically, a major portion of it is steep or mountains with a complex forest and woodland coverage (Jin *et al*., 2016). The middle part of the watershed is Yangshuo with a 2 998 km^2 area (26 % of the watershed), less gradient, and average annual precipitation of 1 540 mm. Lastly, the southern part of the watershed is Pingle which is the biggest subbasin too. The total area in this zone is 5 790 km^2 as 51 % of the watershed with the lowest urbanized rate and an average annual rain of 1 375 mm.

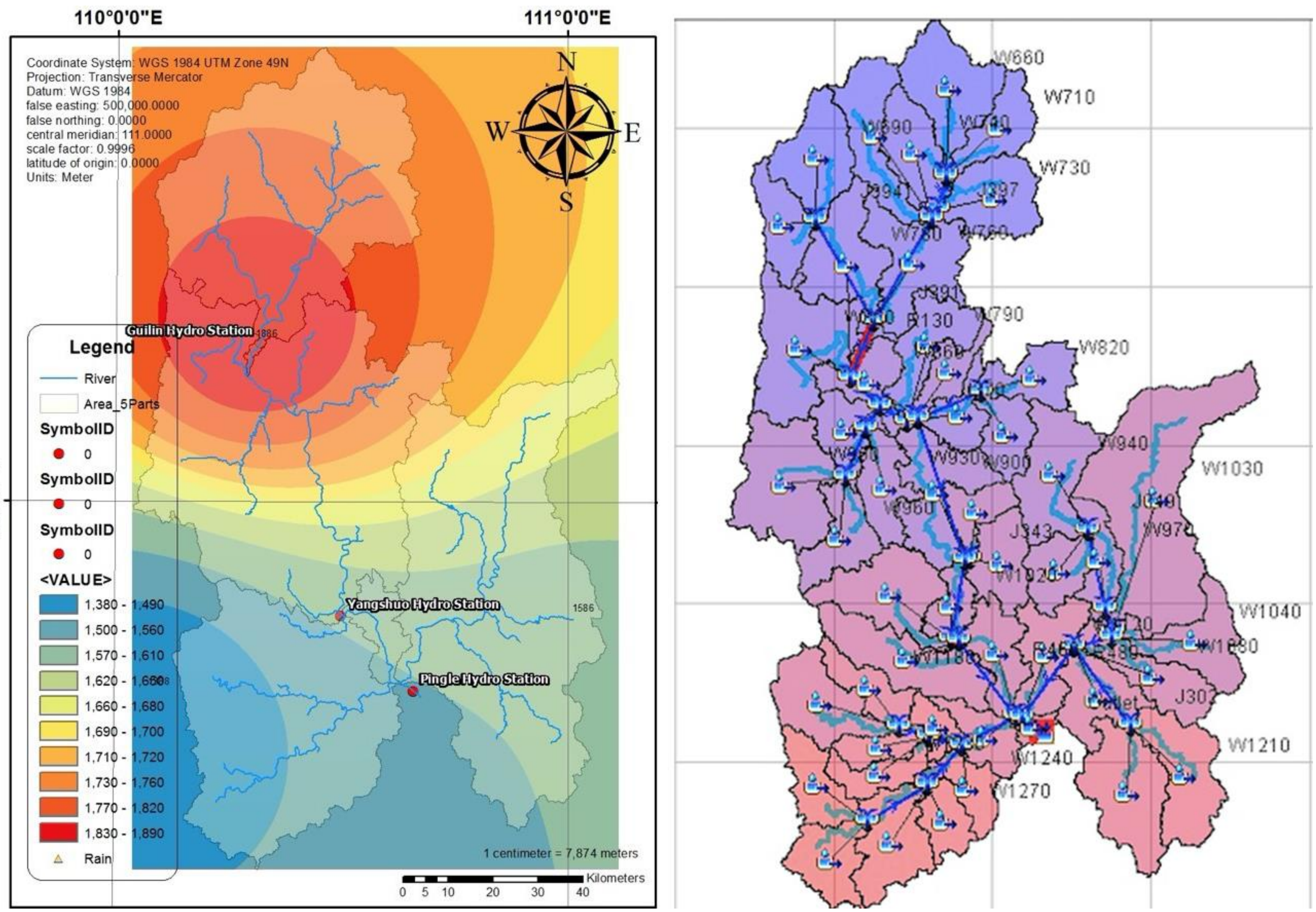

Figure 2. Zonal distribution of rain in the study area of Lijiang basin.

Since most of the scenic spots are around the Lijiang River, hence the majority of the related developments, such as tourism service providers, are located close to the river. Therefore during the raining season, if there is an excessive runoff, these would be the first flooded areas. Moreover, these cities all are located at their respective subbasin's outlets and so

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the hydrological stations. With shorter intervals lately, the latest Yangshuo flood is recorded in June 2020 (abcnews, 2020).

Applied methods

Half-century hydrological data (rainfall, runoff, relative humidity, and temperature 1967-2016) were acquired from local hydrometeorological stations of three respective sites (Guilin, Yangshuo, and Pingle), while temperature and relative humidity were collected from additional three weather stations too (Lingui, Xingan, Lingchuan). Land use maps from the earliest (1980), to the latest available image (2013) were obtained from China Geographical Information Monitoring Cloud Platform (GIM Cloud) to observe the pre and post-development urbanization rates. Although analyzing hydrological and land use data should be mutually done for the same period of time, however, it was not possible due to the fact that the first available land use image of the watershed is from 1980. Moreover, this image (1980) could sufficiently present the latest predevelopment condition of the basin's land use situation in order to compare with the post-development changes.

To start, the runoff data was analyzed to find out the trends and significant changes in the amount of precipitation and storm water during the time via two trend testing methods including Minitab as well as the

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Mann Kendall trend tests. Mann Kendall trend test is a formulated non-parametric statistical test applicable to detect any monotonic trend in sequential order data for a prolonged time series (Yue & Wang, 2004) and has widely been used in hydrology (Halefom *et al*., 2018). In Minitab, the P values for 4 tests (clustering, mixtures, trends, and oscillation) were obtained to examine the existence of possible trends in the amounts of rainfall and runoff.

After the runoff pattern recognition, its two possible drivers (land use change and climate change) were studied via the Soil and Water Assessment Tool (SWAT) model, and Hydrologic Modeling System (HEC-HMS) to detect the probable correlations. The well-known HEC-HMS model with its extensions has been widely used to analyze and forecast the hydrological situation of watersheds in China (Li *et al*., 2009b). Pre and post-development scenarios were examined via HEC-HMS to compare the situations in these two time periods.

For the land use/land cover change (the first driver), to evaluate the hypothesis and the likelihood of correlating the flood with the LULCC, high grid resolution satellite images (spatial resolution of 30 m) were obtained. The catchment area boundary map was delineated based on the Digital Elevation Model (DEM) as well as the existing vector data of the Li river network. Later, the land use and watershed boundaries were embedded in ArcGIS (10.2 version). To identify the land use map in the watershed, based on ArcMap, the DEM data as well as the actual river network data were loaded to generate the watershed and its three subbasins boundaries. Remote sensing data was loaded by the Hydrologic Response Unit (HRU) module of the model. The land use types classified into five

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groups for simplification (include farm, woodland, grassland, water, and urbanized land). The raster data were quantified according to identified color codes for different land use types. The remote sensing data were automatically tailored according to watershed boundaries, and the area ratios of different land use types were obtained according to pixels counting to calculate the proportion of land use transformation in each sub-basin through the HRU analysis report. Using GIS via raster calculator (according to land use and soil maps), the curve numbers (CN) of the watershed, averagely (which can impact the produced peak flood), from 1980 to 2013 were compared to identify the changes. Lastly, the produced flood hydrographs of pre and post-development for a 50-years return period were analyzed.

Having 50 years of rainfall-runoff data, HEC-HMS was used to produce the basin and its subbasins unit hydrographs in order to analyze and forecast different scenarios aligned with the objectives. Snyder’s synthetic unit hydrograph (SUH) (Bhunia, Panda, & Goel, 2011) of 24-hrs rainfall for 50 years return period; which is for basins with more than 250 km^2 area; was applied in HEC-HMS and then calibrated via SCS method. Hyfran Plus program (*hydrological frequency analysis PLUS)* was used to calculate the maximum discharge rate per second (the expected hydrograph peak) for different return periods in the three subbasins. It can also check the homogeneity as well as the independency of the given data. Then the calculated unit hydrograph (SUH) produced by HEC-HMS later was calibrated in terms of hydrograph peak discharge and or base time for the same volume of the flood. Lastly, the produced hydrographs of each subbasin as well as the watershed outlet (Pingle) were obtained

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for certain return periods by multiplying its obtained effective rain in SUH and taking into consideration the lagtime at each hydro station. Moreover, the Linear *Muskingum* method (Geem, 2011) was used in the HEC-HMS model to take into account the prism and wedge storage, which is dependent on topography and geomorphological characteristics of the watershed.

Climatic indexes, as the second probable causes of the runoff, were analyzed statistically. For this purpose, daily rainfall data were investigated to monitor the fluctuations in each subbasin comparatively. Using non-parametric analysis, the Mann Kendall trend test applied to identify the significant monthly and yearly increasing/decreasing trends, regardless of the randomness nature of individual rainfall events. This could demonstrate if the fluctuation of runoff during the study period is a response to the variations in precipitation. Temperature and relative humidity records also were examined to find the trends and potential links, since precipitation is thought to mainly result from the nature of these two, in general.

Results

Runoff and Rainfall Trends

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Looking into the data in time series of five decades (Figure 3), runoff volumes show a continued upward trend of June across the watershed unlike for May. Figure 3a shows the average monthly amounts of streamflow in m^3/s measured in the three subbasins of the watershed during five decades comparatively. It also presents a shift of peak month from May to June. Moreover, the gaps between the recorded maximum-minimum values of the streamflow were found to be increased during the time.

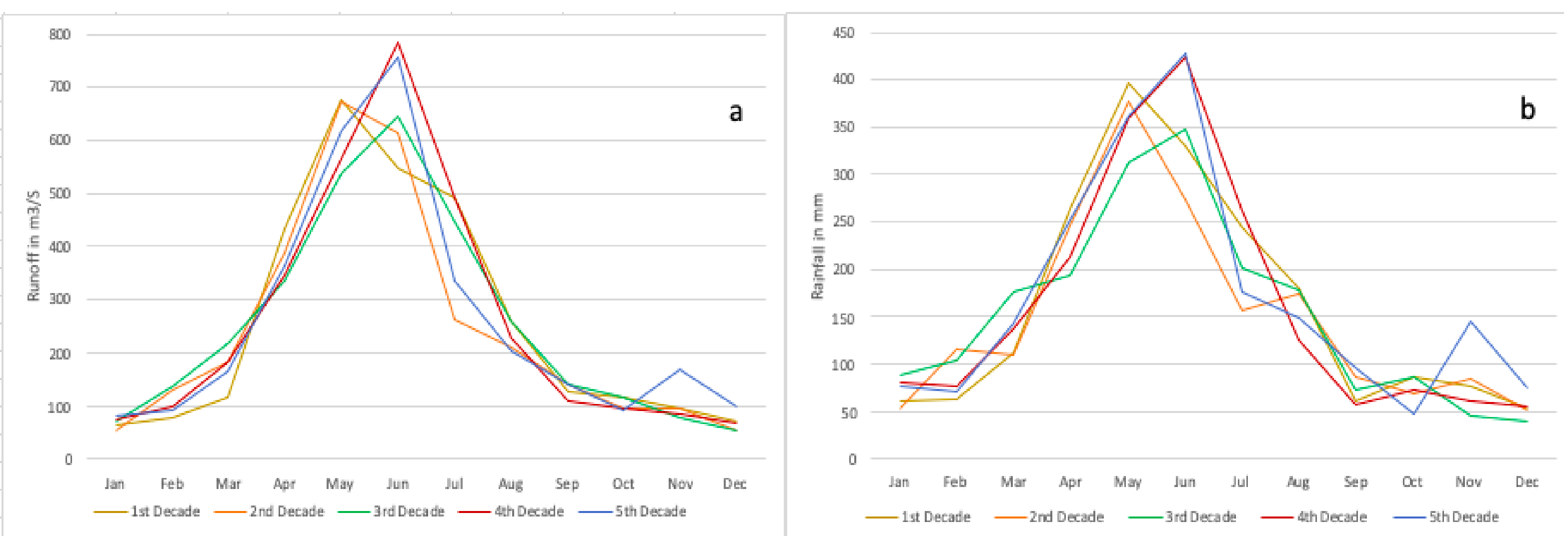

Figure 3. Average monthly runoff in m^3/s (a) and precipitation in mm (b) during five decades (1967-2016) in Lijiang watershed.

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Figure 3b shows the fluctuation of the average monthly precipitation (in mm) in each 10 years period in the entire catchment area (an average for all of the three subbasins). Likewise, the monthly rainfall upward trends were significant for March and June. However, since the magnitude of the precipitation in March in the region is very low compared to June, therefore, it could not cause any flood. A decreasing trend in April and May and a shift of peak month from May to June can be seen in which June instead has a constant upward trend that is significant in 2 stations. These upward trends of June in the past three decades and the shift of the peak month from May to June with a more uneven annual distribution pattern, all match with the runoff diagram (Figure 3a).

Nevertheless, since flood occurrence is more dependent on individual rainfall events than average values, Figure 4 is being plotted to provide a better understanding of the individual precipitation values and their reoccurrence frequency, besides the average analysis. The calculated values for 10-years return period precipitation in Guilin, Yangshuo, and Pingle (calculated via Bell method) were equal to 107.65, 86.04, and 80.03 mm, respectively. This graph shows the number of events per decade where the amount of rainfall in mm was 50% higher than the highest average monthly precipitation for each respective subbasin.

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Figure 4. Number of rainfall events per decade in a single and/or multiple subbasins where by values recorded are more than 50% higher than the highest obtained average values in each subbasin.

Mann Kendall test results (Table 1) show that for the runoff trend, almost in all the three stations, the highest positive values (monthly) are obtained for June which for Yangshuo and Pingle are significant. Also in May and April, it decreased but not significantly. For the annual data, although the values for the runoff are positive; however, a low gradient

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shows that the total magnitude of the streamflow had just slightly increased. The annual trend increasing (though not significant) in Guilin and Yangshuo and decreasing in Pingle. As for the Minitab trend test (Figure 5), the "P" values for clustering, mixtures, trends, and oscillation tests trend tests were obtained. The P values for clustering and trends show zero means there were no significant changes (no trend) in the data observed during the time, while the P-value of 1.00 for mixtures, and oscillation presents the normal seasonal changes as the loaded data was 24-hours rainfall data.

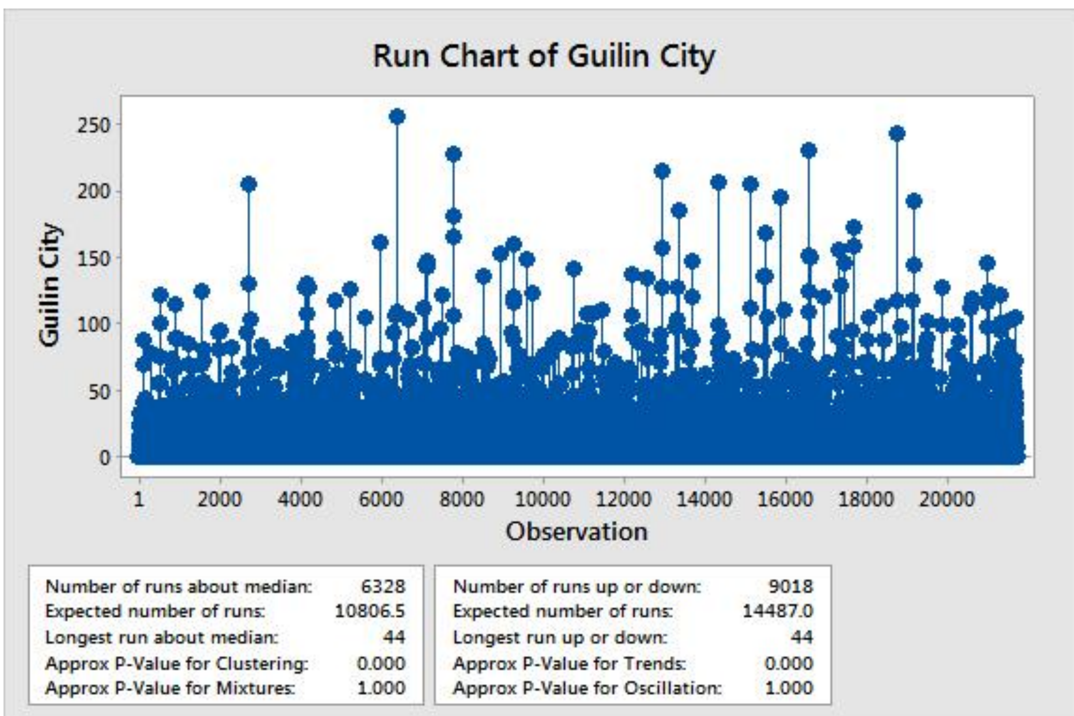

Figure 5. Minitab trend test (clustering, mixtures, trends, & oscillation) on 24-hours data (1957-2016). The X and Y-axis are the amounts of rainfall in mm and the number of time-series data points as observation.

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Table 1. Results of Mann Kendall test statistic (Z-score) for annual and monthly runoff, precipitation, temperature and humidity during 1967-2016. *, **, & *** **bold** characters show statistical significance trend at 5 %, 1 % & 0.1 % or 95 %, 99 % and 99.9 % confidence level. - and + values indicate the decreasing/increasing trends.

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Runoff	Guilin	1.67	0.44	0.43	-1.57	-0.73	1.59	0.03	-0.93	0.47	-1.08	-0.23	0.72	0.01
	Yangshuo	1.78	0.28	1.77	-1.41	-1.26	1.91*	0.65	0	0.88	-0.85	-0.1	1.37	0.75
	Pingle	0.89	-0.08	1.86	-1.26	-1.58	1.97*	0.83	0.16	0.48	-0.99	-0.13	1.05	0.65
Rainfall	Guilin	0.87	0.53	2.16*	-1.48	-1.53	2.2*	0.1	-0.79	1.2	-1.74	1.24	0.77	0.68
	Yangshuo	0.7	-0.39	2.39*	-1.36	-1.51	2.11*	0.07	-0.55	0.41	-1.88	0.81	0.79	0.97
	Pingle	0.56	-1.54	2.17*	-1.32	-2.58**	1.56	-1.12	-2.36*	-1.1	-1.64	0.64	0.62	-0.47
Temperature	Guilin	1.08	2.53*	1.63	3.29***	1.28	2.28*	1.03	2.13*	2.08*	3.35***	2.94**	0.43	5.68***
	Yangshuo	1.59	2.55*	1.85	2.75**	1.25	1.04	0.06	1.56	1.82	3.02**	3.11**	0.59	5.15***
	Pingle	1.08	2.16*	1.28	2.72**	1.8	1.59	1.08	2.46*	1.41	1.95	2.66**	0.25	4.5***
	Lingchuan	1.22	2.62**	1.83	3.61***	1.52	2.53*	1.47	1.99*	1.63	3.15**	2.53*	0.2	5.85***
	Ling Gui	0.84	2.40*	1.39	3.01**	1.18	1.49	0.58	1.52	0.96	2.56*	2.15*	0.01	4.82***
	Xing An	0.96	2.54*	1.92	3.30***	1.26	2.42*	1.31	0.67	1.01	2.42*	2.39*	0.21	5.15***
Humidity	Guilin	-1.69	-0.79	-2.33*	-3.42***	-3.14**	-1.59	-2.00*	-3.66***	-2.48*	-2.26*	-1.26	-2.12*	-4.51***

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	Yangshuo	-1.66	-1.1	-1.3	**-2.27***	-1.8	0.48	-0.37	**-2.17***	-**2.03***	-1.45	-1.59	**-2.0***	**-3.30*****
	Pingle	-0.96	-0.91	-1.3	**-2.29***	-3.64***	0.26	-0.72	**-2.46***	-1.39	-0.55	-0.76	-1.89	**-2.80****
	Lingchuan	-0.81	0.35	-1.04	-1.74	-1.01	1.05	-0.72	**-2.73****	-1.26	-1.51	-0.34	-1.4	**-2.06***
	Ling Gui	-1.03	0.44	-0.07	-1.68	-1.47	0.42	-1.34	**-2.31***	-0.8	-0.94	0.43	-1.42	-1.72
	Xing An	-1.1	-0.39	-1.84	**-3.00****	-1.84	0.28	-1.89	-2.41	-1.53	-1.22	-0.53	-1.4	**-2.28***

Climate change (temperature and humidity)

Average daily temperature (°C) and relative humidity (%) during the study period were used to provide monthly amounts (in five decades) compared in 6 meteorological stations of the watershed. It was aimed to see if there is any correlation between the changes of these two climatic indexes and flood regime changes. The changes are summarized as Mann-Kendall results in Table 1, as well as shown graphically in Figure 6 (a, b).

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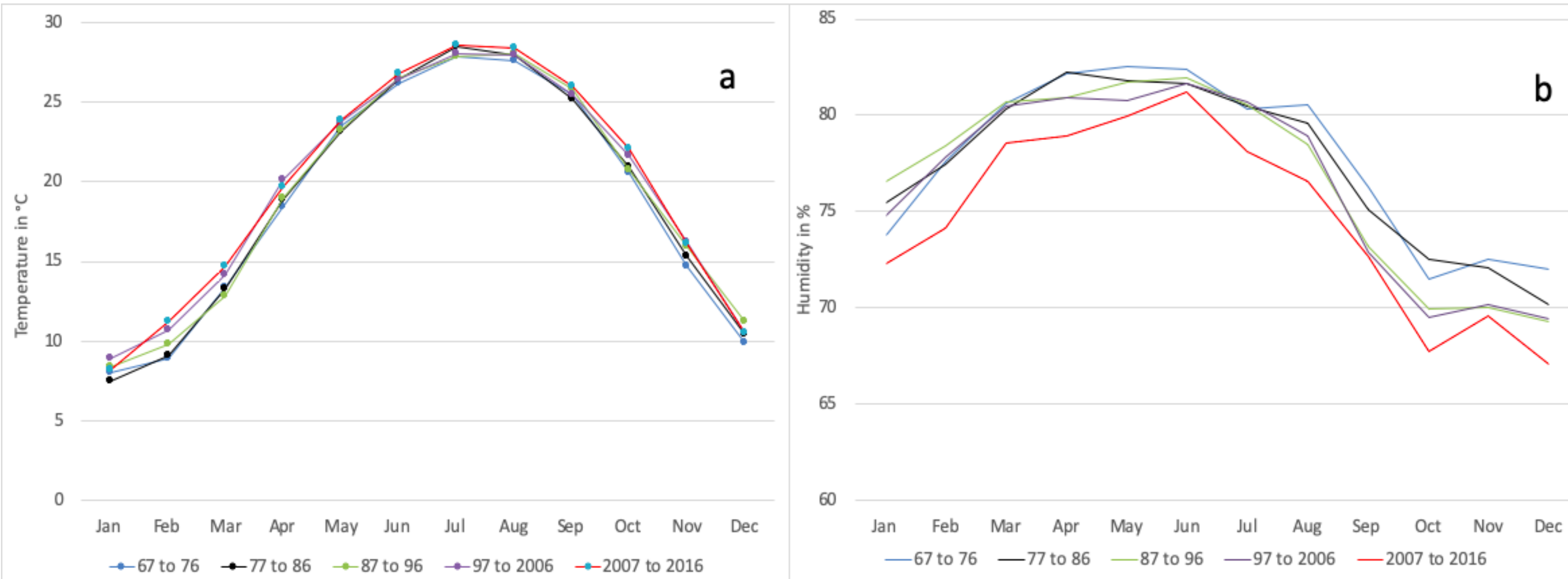

Figure 6. Average monthly temperature in mm (a) and relative humidity in % (b) comparison of five decades (1967 to 2016) in six Lijiang watershed meteorological stations.

Land use change trends

According to the land use maps, the form and structure of the landscapes in these three subbasins have just slightly changed during pre to post-development periods. The informative "a" and comparative "b" land use maps in Figure 7 show the situation as well as changes in the areas covered by each land use group. As can be seen in Figure 7b, the red color areas had a higher CN number in 2013 compared to 1980 and CN

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has decreased for blue color spots while no changes for the rest of the yellow part. The following pie chart (Figure 8) presents the covered areas by each land use group in Lijiang watershed in km^2 as well as %, with the changes during time. The latest land use map of Guilin subbasin shows that out of total 2 590 km^2, lash woodlands (1 750 km^2) and paddy fields (266 km^2) with 68 % and 10 %, respectively are the major components of this zone while ponds and wetlands contribute the minimum coverage of the zone for 21 km^2. The subbasin mainly consisted of woodlands for more than 72 %, less than 17 % farms and orchards, more than 4 % grasslands, around 5 % construction (including rural areas), and 2 % covered by river, wetlands, and ponds (water), approximately.

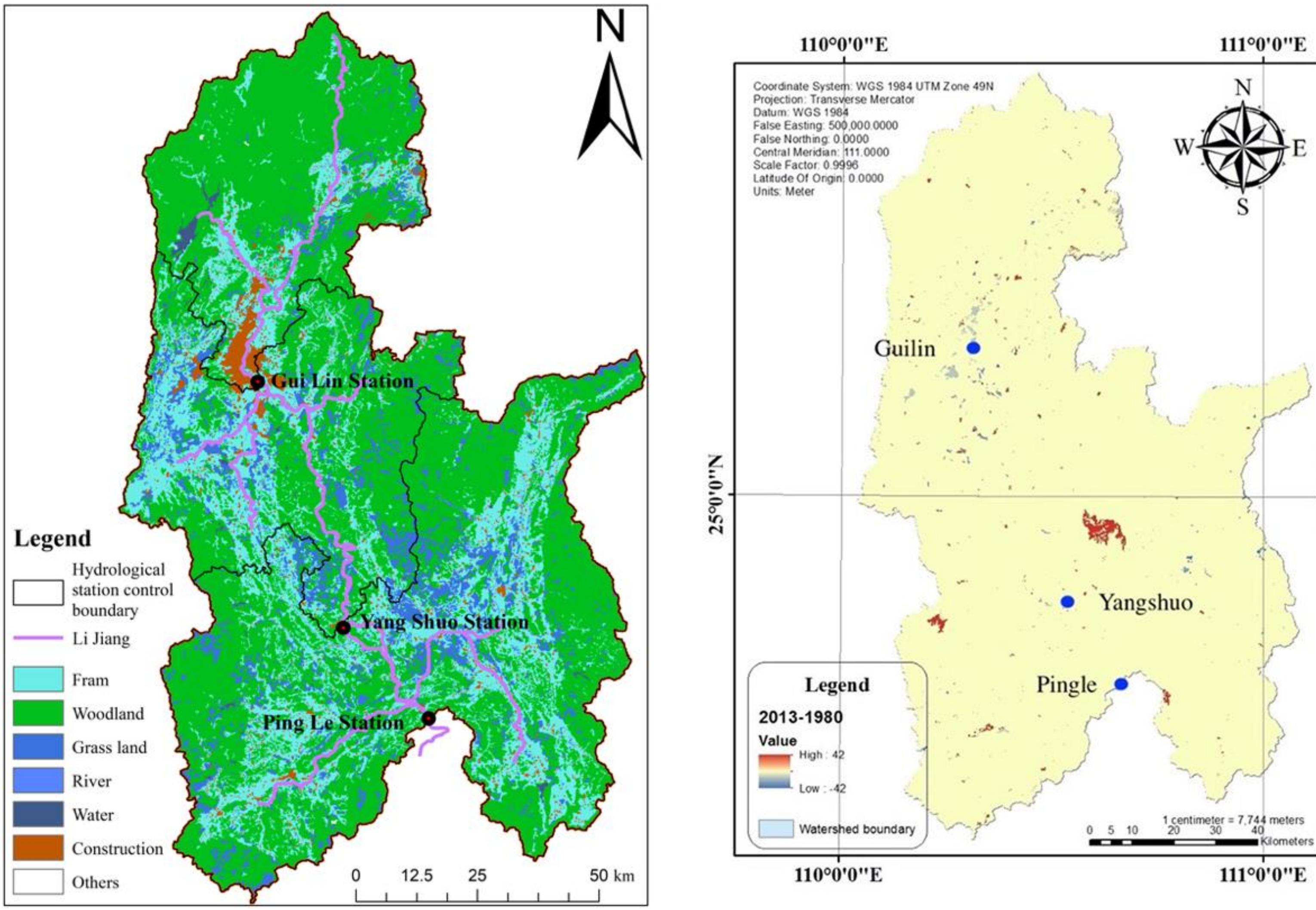

Figure 7. Lijiang basin land use maps for 2013 (a), and CN number changes comparison between 1980 to 2013 (b).

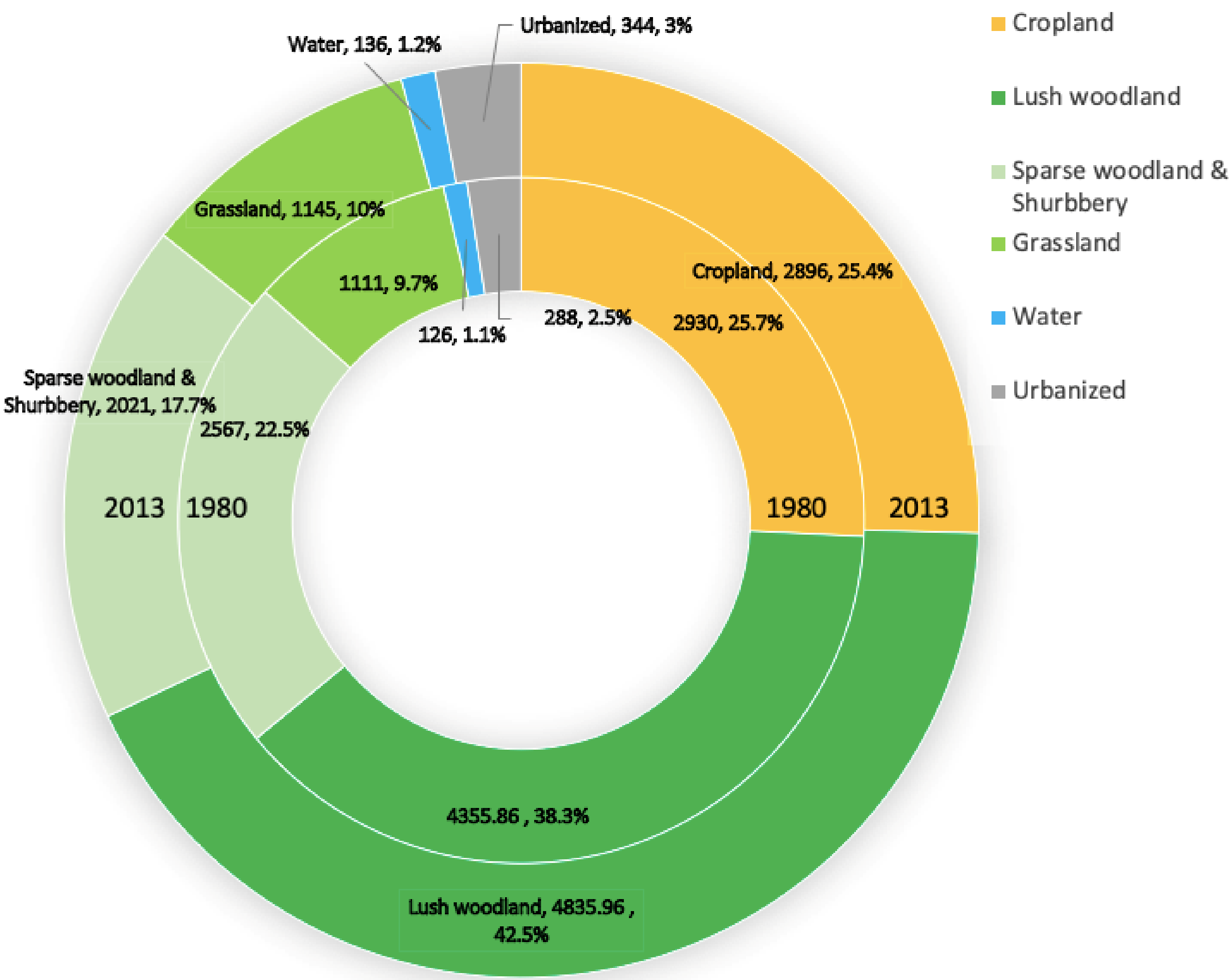

Figure 8. Land use groups area comparison (1980-2013) at Lijiang watershed in km^2 and %.

For the Yangshuo subbasin, the composition of the landscape, especially the green area is different than the upstream. The jungle surface (52 %), as well as its density, is remarkably lower than Guilin. In contrast, this 2 998 km^2 subbasin has considerable areas utilized for

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agriculture (30 %), which are mainly rice cultivations. Here around 13 % of grasslands beside a 3 to 4 % urbanized lands and around 1 % water, make this subbasin different.

For Pingle; the last and the largest subbasin; woodlands are 59 %, farms are 27 %, and grasslands less than 11 %. It has the highest percentage of the green areas (farm + woodland + grassland) compared to Yangshuo and Guilin (97.12 % > 95.60 % > 92.97 %, respectively). A 480 km^2 sparse to lush woodland landscape transformations have occurred in Pingle. At the same time, it has the lowest percentage of urbanized areas in the watershed for 0.2 %; however, the highest rural area for 105 km^2. Agriculture is the main business in this area in which the area used for, is much bigger than in Yangshuo and Guilin (1 569 km^2, 892 km^2, 435 km^2, respectively). In general, the changes orientation in Guilin and Yangshuo were to reduce the natural resources and green areas and expand the manmade areas rapidly which might cause quicker concentration-time, in contrast with Pingle.

HEC-HMS model was used to estimate two hydrographs (98 % confidence level) for a 50-year return period precipitation (134 mm during six hours) in the three identified hydro stations of Guilin, Yangshuo, and Pingle (Figure 9). The applied changes in the CN number of the subbasins had a negligible impact on the produced hydrographs. The Nash–Sutcliffe efficiency of the Lijiang model was 0.972 which is highly reliable (Nash-Sutcliffe value ranges between $-\infty$ to 1 and defined to evaluate the predictive power of a hydrological model.

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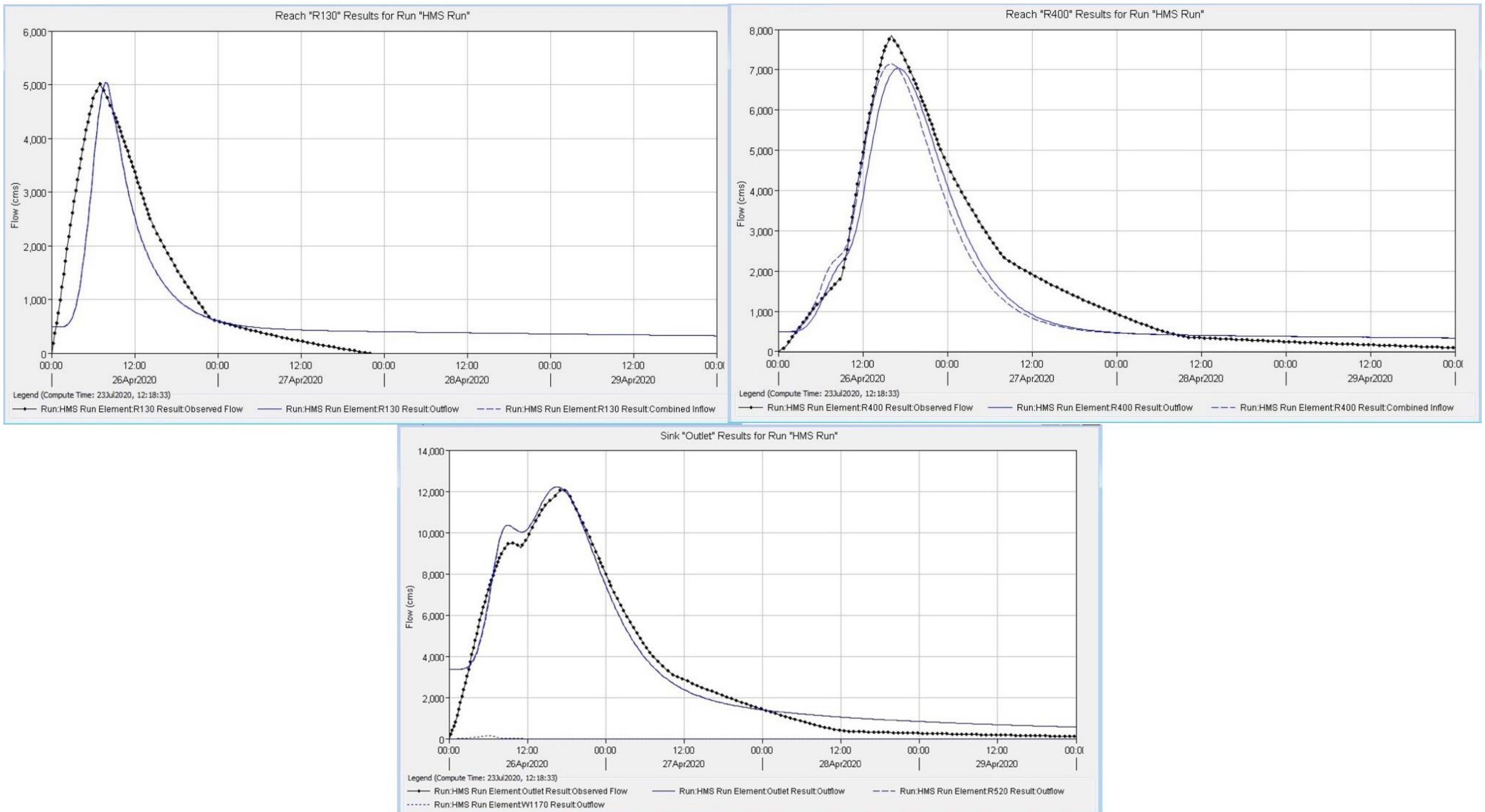

Figure 9. HEC-HMS 50-year return period at 3 Lijiang subbasins (m^3/s).

Discussion

As presented in the results, runoff has shown a number of changes such as: upward trend in June which was significant in Yangshuo and Pingle, downward trends in Apr and May although not significant, a shift in the peak month that noticed from May to June, and slightly upward (but not significant) trend of annual values. Also, the increasing gap of extreme recorded values maximum-minimum reconfirmed the additive imbalanced runoff in the latest time series in which the graphs for the earlier decades are more bell-shaped, while sharper for the latest decade. Hence, here the impacts of land use, rainfall, and climatic indexes on runoff regime changes in the Lijiang basin have been discussed in detail.

Land use change impacts on flood in Lijiang

The urbanization of Lijiang watershed has started since 1993 (Liang & Liu, 1984) which is almost during the 4th and 5th decades of this study (where we had a higher flood reoccurrence), hence it was thought to analyze it as a possible driver behind the streamflow regime changes. In Guilin, the city population has raised rapidly over the past decades and the dense crowd has induced more land use changes consequently. The developments here are more on the conversion of woodlands and farms to industrial as well as residential areas to host the massive number of tourists. The industrial lands have multiplied around 13 times (from 1.45 to 18.76 km^2) and urban areas have expanded for an additional one third in the year 2013 compared to 1980 which reflects how quickly the area is developed. However, based on the land use maps in total, only 1.4 % (37 km^2) of the subbasin have been urbanized.

Although there was a reduction (2 km^2) in the ponds area during the city expansions, still around 21 km^2 of ponds and wetlands are functioning in this subbasin which means the more impervious pavements should not cause any shorter lag time or excessive runoff in latest decades. For Yangshuo, the LULCC was even half of Guilin in which 0.7 % (21 km^2) of the subbasin's green areas were urbanized (17 km^2 to urban lands and 4 km^2 to ponds). In Pingle at the downstream; however, less than 0.2 % of the catchment area (10 km^2) was impacted by the changes where the green areas were converted to urban lands and ponds partially (6 and 4 km^2, respectively). While 4.2 % of the entire Lijiang watershed area (480 km^2) was positively changed from sparse to lush woodlands. Recently some areas covered by timbers in the watershed are expanded due to the government "Green policy" which encourages farmers to convert the sloped farms to timberland (Mao, Meng, & Wang, 2014) and reduce deforestation. However, as commercialized timberland areas, these may not be much expected to efficiently control the runoff.

According to HEC-HMS results, the three subbasins had close CN values such as Guilin 75.64, Yangshuo 77.68, and Pingle 77.84. Overall, based on Figure 7b, the CN value changes (influenced by the land use type and impermeable areas) were negligible across the watershed (less than 0.1 % higher, from an average CN number of 75.999 in 1980 to 76.069 in 2013). The simulated flood hydrographs using HEC-HMS presented in Figure 9 for a 50-years return period rainfall in the watershed; after applying these changes in CN number; were almost

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identical with similar peak time and lagtime (lagtime was calculated via SCS method) for these two time periods (pre and post-development).

As hydrographs show, the peak value in Guilin (with 4900 m^3/s of peak flood for 50 years return period) was much higher than in Yangshuo (2300 m^3/s). Although less difference between the area and the amount of the calculated precipitation or CN for them, however, the slop difference (calculated via ArcHydro in GIS) in Guilin subbasin was 13.62 % compared to Yangshuo for 7.63 % slop (in Pingle was 12.74 % and 3910 m^3/s). This slop difference will cause prism and wedge storages based on *Muskingham* formula (Das, 2007), which is due to the topography and geomorphological characteristics of the basin and produces a higher peak and shorter base time. The additive results of Hyfron plus for 50 years return period peak hydrographs in Guilin 4930 m^3/s, Yangshuo 7590 m^3/s, Pingle 11500 m^3/s, were calibrated in Snyder SUH used in the modle.

Assuming that negative impact means increasing the runoff and positive means reducing, overall the land conversion rate of the study area were as bellow:

1- Woodlands: (+) 4.2 % of the watershed which was covered by sparse woodlands changed to lush woodlands. Also, (-) 0.6 % of the catchment's sparse woodlands were reduced.

2- Farms (mainly paddy field): decreased for (-) 0.3 % of the watershed.

3- Grasslands: increased for (+) 0.3 % of the watershed.

4- Water (ponds mainly): were expanded for (+) 0.1 % of the total catchment area.

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5- Urbanized lands: increased for (-) 0.5 % of the entire watershed area (negative or positive show the impact on runoff only not the value).

To assess the total impact of LULCC, the following can be discussed. By equalizing the impacts of farm removal (-0.3 %) and grassland expansion (+0.3 %), these two can be taken out of our equation. Therefore, besides the 4.2 % woodlands density enhancement (sparse to lush woodland), we can suppose that 0.6 % of the woodlands are converted to urban areas (0.5 %) and water (0.1 %). The major increased areas of water (0.08 % of the basin or 8 km^2) were due to the pond's expansion.

On the other hand, ponds are normally meant to detain a 10-years design storm, safely (Rad *et al*., 2016). If properly located, they can collect the runoff of rains with a 95 % reoccurrence from an area of 100 times bigger than their surface area as per USEPA (1999). It means, even for up to 8% of the watershed being urbanized in future (now is 3 %), the current ponds must be able to collect excessive surface water (caused by urbanization) in 95 % of the rainfall events and reduce the peak flood in the remaining 5 % of less frequent but larger magnitude rainfalls.

Hence to conclude the LULCC impacts on floods in this watershed, the negative impacts of recent extra 0.5 % urbanized areas, are balanced with the positive impacts of the ponds and woodlands and it practically should not be able to contribute much into the increased runoff. These results were underpinned via HEC-HMS hydrographs and CN numbers in both scenarios. In total, 53.4 km^2 ponds/wetlands for 344.4 km^2 urban areas, plus the 480 km^2 new lush woodlands positive impacts in the catchment, are seemingly good enough to control the impermeability effects of urbanization on the runoff; therefore, the LULCC impacts hypothesis is rejected.

Rainfall patterns change impacts on runoff regimes

Four important points were observed from rainfall data analysis which were *yearly*, *seasonally*, *monthly*, and *individual* rainfall data related. First, the annual upward trends of runoff were found to be not significant and this shows that although the rainfall patterns are more unequal during the year, but not much of extra precipitations (in total) were rained over the recent years. In other words, upward trends (excessive amounts) are balanced by downward trends across the year. This is shown in the rainfall trends (Table 1) in which no significant trend in annual data was detected and also in Pingle station the trend was downward. The same was underpinned by the Minitab rainfall trends test (Figure 5).

Second, for seasonal data more uneven patterns were noticed. Although the monsoon climate had heavily impacted the rainfall regimes of the Li river area, especially at the upstream which precipitation in this region is extremely uneven during the year, however, a more imbalanced rainfall pattern in the recent two decades was observed as per graph number 3b in which the amount of rainfall in summer was getting higher but spring and autumn lower in the latest two decades.

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Third, for the monthly data, a shift of peak rainfall/runoff records from the month of May (during the earlier decades) to June (during the latest decades) was observed. Table 1 shows an upward gradient in the magnitude of precipitation for the month of June (beginning of the tourist season) which in Guilin (upstream) and Yangshuo (midstream) were statistically significant. This was aligned with the runoff trend test in which significant upward trends were found in Yangshuo and Pingle (downstream) since the rainfall's main impacts in producing runoff would be at the respective downstream of each subbasin. Certainly, this has caused the imbalanced amount of storm water in the river in the month of June as it is replicated in the runoff trends.

Fourth, in the daily data, higher extreme values were noticed during recent decades. Flood events are dependent on individual rainfalls situationally but not on average monthly or yearly values, hence more specifically the main cause of the floods can be found in the 4th diagram. In this plot, as reflected the number of single rainfall events with extreme values (equal or higher than the highest average monthly rainfall) in a single or multiple subbasins has increased during the past years. In the latest two decades, these kinds of events have increased between 38 % (in the 5th decade) up to 60 % (in the 4th decade) compared to the earliest decades, and an upward trend can clearly be seen (Figure 4).

When this incidents (extreme rainfall event) occur in multiple subbasins concurrently, the upstream contributes to the down stream's already heightened runoff/base flow, and therefore, we can see the formation of a raise (in general) in the number of floods in these subbasins

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due to double peak hydrographs (Martínez-Carreras *et al*., 2016), beside the fact that the location of the cities is at the subbasins outlet.

Climate change (temperature and humidity) impacts

The two climatic indexes were analyzed as the probable causes of the rainfall pattern changes. Temperature comparison of five decades across the watershed (in six meteorological stations) shows that the average annual temperature, that was 18.7 ℃ during the earliest period (1967-1976), has constantly increased to 19.66 ℃ during the latest period (2007-2016) which is a raise of 0.96 ℃ in general. The results are underpinned by the Mann-Kendall trend test (Table 1) as an annual upward gradient in all the 6 stations with a 99.9 % confidence level. The upward trends are significant in Feb, Apr, Oct, and Nov and the same was confirmed observationally by graph 6a. The rise in temperature has orderly happened in early spring, winter and autumn compared to summer. In other words, we had slightly warmer weather in cold seasons (winter and autumns) but not so hotter weather in the warm seasons (spring and summer). The highest monthly average change in temperature happened in Feb (with the variance of 4.17) and the lowest in June (the variance of 0.68). This is similar to another report of a slower warming trend for summer than other seasons in south China (Li *et al*., 2017). The sign of global warming was clear in the region.

On the other hand, relative humidity comparison across the watershed (in 6 meteorological stations) shows 3.3 units lower (in % as the relative humidity is always expressed in) during the latest period averagely (from 77.7 % to 74.4 %). Annual downward trends of relative humidity in all the 6 stations (which was significant in five of them) are reflected in Figure 6b and Table 1. Monthly trends are downward mainly, except for the month of June with the minimum fluctuations (variance 1.6), while Oct had the largest (variance 7). In other words, we had slightly lower humidity in cold seasons (winter & autumn) but not so less humid weather in the warm seasons (spring & summer) compare to before. These downward trends of relative humidity are analogous with the temperature raise as per the definition of relative humidity (the ratio of the actual amount of water vapor in a volume of air to its maximum water vapor holding capacity at a certain temperature). Although precipitation can lower the air humidity temporary via condensation, still the air potential in holding the moist is greatly depending on the temperature (warm air can hold higher amounts of water vapor than the cold air) while other influencing factors like pressure or air displacement through wind will have lesser impacts. Although synchronizing climatic index results in the surplus of rain in small scales directly is not possible; however, this can be evidence of global warming and climate change consequently. The more imbalanced rainfall and runoff patterns, as a result, might be owing to climate change globally since temperature and humidity; not regionally

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but on a bigger picture in the planet; can impact the precipitation patterns.

Recommendations

Climate change is altering the hydrological situation in south China as the Lijiang case study has shown and actions need to be taken to adapt to the changes. Besides the well-known flood quantity control practices, our result suggests more research on the localized/situational solutions for the current impacts of the frequent floods, as well as long term alternates. Building dams, as well as the expansion of ponds and wetlands as the second priority to hinder the runoff developments are advisable for the devaluation of the runoff quantity, especially at up and midstream sub-watersheds. Other significant recommendations would be such as promoting timberlands and paddy fields more rapidly which also helps to reduce the peak flood considering the increasing demands of such products in China. Taking into consideration the rice-growing season and the peak time for irrigation in the region (May to Sept), also rice planting and importing statistics (Muthayya, Sugimoto, Montgomery, & Maberly, 2014) to supply the demand in the country, besides the reduction trend of farms and paddy fields, this can cause lower storm water along the river. Applying BMPs/LIDs parallel with certain optimizations on land use

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change policies can help to enhance the current situation and adjust with the global warming and climate change to reduce the catchment flood risks and damages, consequently. However, the ultimate solution might still be the reduction in greenhouse gasses production globally for sustainable development.

Conclusions

In this study, an investigation of climate changes and human impacts through LULCC on Li river floods quantity was conducted via the Mann-Kendall and Minitab trend tests as well as the HEC-HMS and SWAT models. Hydrological data analysis for 50 years (1967-2016) shows more frequent runoffs in the last few decades in Lijiang watershed. Results revealed that excessive runoff was mainly due to climate change than LULCC. Higher average temperature (0.96 ℃) and relative humidity (3.3 %) were observed in the latest periods. More uneven rainfall patterns, specifically for June was detected which have disturbed the water balance in the river's flood regime. More frequent rainfall events (with extreme values equal or higher than a 10-years return period) over multiple subbasins at the same time, or in a single subbasin, was found to be the main cause behind the floods in the watershed. In the first two

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subbasins in the up (Guilin) and midstream (Yangshuo), there was more rainfall abundance with higher urbanization rates (comparatively). In the 3rd subbasin (Pingle), although less precipitation increments accompanied by lower urbanization rates; however, more flood occurrences sourced from upstream. Satellite images show that over the last 33 years the total urbanized area in the basin was increased to 3 % from 2.5 % which is not causing a considerable change in the watershed CN number and the soil water holding capacity. Mitigation of green areas (forestlands and farms) for 0.6 % of the basin to urban areas (0.5 %) and water (ponds 0.1 %) had a minimum impact on the increased runoff. The conversion of sparse to lush woodlands was observed for 4.2 % of the total catchment. Although no definite quantitative model can accurately quantify the drivers' contribution rates; however, the basic ingredients found are uncontroversial. Irrespective of the details, for all of the three subbasins the flood quantity increase underpinned by imbalances rainfall. The LULCC results analysis suggests a minor contribution rate into excessive runoff and flood reoccurrences, we may, therefore, consider more frequent extreme precipitations as a response to climate change as the main cause behind the recent rise of the flood numbers.

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Conflicts of interest

The authors declare no conflict of interest.

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