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Spatio-temporal variations of the flood mitigation service of ecosystem under different climate scenarios in the Upper Reaches of Hanjiang River Basin, China

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Abstract: Extreme rainstorm and the subsequent flood increasingly threaten the security of human society and ecological environment with aggravation of global climate change and anthropogenic activity in recent years. Therefore, the research on flood mitigation service (FMS) of ecosystem should be paid more attention to mitigate the risk. In this paper, we assessed FMS in the Upper Reaches of Hanjiang River (URHR), China from 2000 to 2014 using the Soil Conservation Service Curve Number (SCS-CN) model, and further simulated the future FMS under two climate scenarios (in 2020 and 2030). The results reveal that the FMS presented a fluctuating rising trend in the URHR from 2000 to 2014. The FMS in southern URHR was higher than that of northern URHR, and the change rate of FMS in the upstream of URHR (western URHR) was higher than the downstream of URHR (eastern URHR). The future FMS under scenarios of Medium-High Emissions (A2) and Medium-Low Emissions (B2) will decrease consistently. As land use/land cover changes in the URHR are negligible, we concluded that the change in FMS was mainly driven by climate change, such as storm and runoff. Our study highlights that climate scenarios analysis should be incorporated into the assessment of hydrologic-related services to facilitate regional water resources management.

Keywords: ecosystem services; scenario analysis; climate change; SCS-CN model; Hanjiang River

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1 Introduction

Hydrological services are critical for sustaining ecosystem structure, ecosystem process and region ecological environment security (Castello and Macedo, 2016; Sun *et al*., 2016). These services can be divided into four categories: diverted and in situ water supply, flood mitigation service, water-related cultural services, and water-associated supporting services (Brauman *et al*., 2007), among which the flood mitigation service (FMS) has drawn much attention because of the increasingly intensification of global climate change and extreme storm event in recent years (Barbedo *et al*., 2014; Watson *et al*., 2016; Sonter *et al*., 2017). FMS is one of the key flood regulation services (Bagstad *et al*., 2011, 2014; Sturck *et al*., 2014), which denotes the capability of ecosystem to reduce and retain floodwater to avoid flood damages to downstream populations by vegetation, soil and other components of ecosystem (Carvalho-Santos *et al*., 2016; Watson *et al*., 2016; Sonter *et al*., 2017). Compared with human-dominated water conservancy project, the natural ecosystem plays a more positive and effective role in flood mitigation (Sturck *et al*., 2014; Barth and Döll, 2016), and has less negative impacts on biodiversity protection and ecological environment (Zhang *et al*., 2010; Sturck *et al*., 2014; Keesstra *et al*., 2018).

In fact, flood mitigation is a comprehensive hydrological process, which is composed of flood interception by canopy, litter, flood storage in soil, and storm runoff, etc. (Zhang *et al*., 2010; Barth and Döll, 2016; Kim *et al*., 2016). Thus, vegetation and soil, even artificial land in terrestrial ecosystem, all have the potential to mitigate the flood (Nedkov and Burkhard, 2012). However, most of the previous studies focused on the FMS of wetland and soil (Marsooli *et al*., 2016; Ouyang *et al*., 2016; Pappalardo *et al*., 2016; Watson *et al*., 2016; Liu *et al*., 2017), but few assessed the whole natural ecosystem. For instance, Ouyang *et al*. (2016) adopted the empirical method between the available water storage capacity and area to assess the flood mitigation capacity of wetland. Jiang *et al*. (2007) estimated the water subtraction quantity of wetland soils within the Momoge Reserve. As far as we know, Nelson *et al*. (2009) adopted the InVEST model to assess FMS in the terrestrial ecosystem at a fine spatial resolution, however, data availability of single storm event limits the application of this model to large-scale areas. Zhang *et al*. (2010) and Kim *et al*. (2016) grouped these hydrological process as interception, stem flow, litter interception and water storage, whereas, it is very complicated to calculate these ES and is difficult to establish precise mathematical model. Promisingly, Fu *et al*. (2013) developed a method to assess FMS based on watershed runoff model, i.e., the SCS-CN model (Li *et al*., 2015; Lin *et al*., 2017). This SCS-CN model takes account of multiple watershed characteristics, such as soil, land use, hydrologic condition and antecedent moisture condition (AMC), and it has great potential to evaluate FMS at a broad scale (Mishra *et al*., 2012; Chen *et al*., 2017; Lal *et al*., 2017). In addition, current research seldom analyzed the temporal dynamics of FMS, let alone the variations under different climate changing scenarios (Fu *et al*., 2015). The lacking of systematical understanding of FMS variations may weaken the decision-making for regional flood management.

In this study, the Upper Reaches of Hanjiang River basin (URHR) is taken as study area. URHR is the water source of the middle route of South-to-North Water Transfer Project (SNWTP) in China. The study of hydrologic ecosystem services and water resources in URHR, not only concerns the local ecological water use safety and the socio-economic development, but also provides benefits for the sustainability of lower reaches of Hanjiang River and national water recipient areas of SNWTP (Chen *et al*., 2007; Li *et al*., 2016). Besides, rapid changes in land use and climate have increasingly influenced the ecosystem services (ES), therefore, it is necessary to look into the plausible future change of ES. In recent environment research, the scenarios analysis is widely adopted as a vital and effective approach providing possible descriptions of future change in climate or land use based on reasonable assumption (Feng *et al*., 2016; Runting *et al*., 2017; Wang *et al*., 2017). The integration of these plausible and reasonable descriptions to ES research will help stakeholders better understand the processes and response mechanisms of ecosystem to environmental change and anthropogenic activity (Scholes 2016; Thom *et al*., 2017; Yuan *et al*., 2017), as well as provide scientific reference for targeted preventive measures in face of the future flood risk in URHR.

Based on the FMS model and climate change scenarios analysis, this paper aims to: (1) analyze the historical spatio-temporal variations of FMS from 2000 to 2014 and the future variations in the years of 2020 and 2030 under two climate scenarios in URHR; (2) discuss the major driving factors of FMS variations; and (3) discuss the implication of climate scenarios analysis on FMS management. This research may contribute to a better understanding of the relationship between climate change and ecosystem services (ES), and help facilitate watershed water resources management.

2 Materials and methodology

2.1 Study area

Hanjiang River is the largest branch of Yangtze River in China, and it is also the water source of the middle route of South-to-North Water Diversion Project in China (Chen *et al*., 2007; Li *et al*., 2016). The Upper Reaches of Hanjiang River basin is located between 105.85°–111.60°E and 31.02°–34.48°N, with a basin area of 62384 km^2, and extends 652 km from the west to the east in Shaanxi province (Figure 1). This basin is characterized by sub-tropical monsoon climate, and precipitation concentrates in summer and autumn, with frequent storms and continuous rain (Chen *et al*., 2007). The average annual temperature ranges from 12°C to 18°C, and the average annual precipitation ranges from 653 to 1183 mm (Li *et al*., 2017; Wang *et al*., 2017). Topographically, the northern border of URHR is formed by the Qinling Mountains, and southern border is formed by the Daba Mountain and Micang Mountain. Hanjiang River flows through these mountains. The URHR is known as a key natural ecological zone in central China, and flood disasters frequently occur in this region, due to the natural condition (i.e., steep slopes and large river bed gradient) and subtropical humid monsoon climate. This poses great threats to the human well-being in the middle and lower reaches of Hanjiang.

2.2 Datasets and methodology

2.2.1 Flood mitigation service model

Soil Conservation Service curve number (SCS-CN) model, is one of the most popular methods for evaluating the surface runoff volume in a single rain event (Mishra *et al*., 2012).

It accounts for watershed characteristics of runoff yield and has been adopted by engineers and practitioners in various regions under different climatic conditions (Yang *et al*., 2015; Hooshyar and Wang, 2016; Liu and Li, 2017). Integrating SCS-CN model into FMS assessment can be helpful for the spatially-explicit evaluation of storm runoff and flood mitigation magnitude in large watershed.

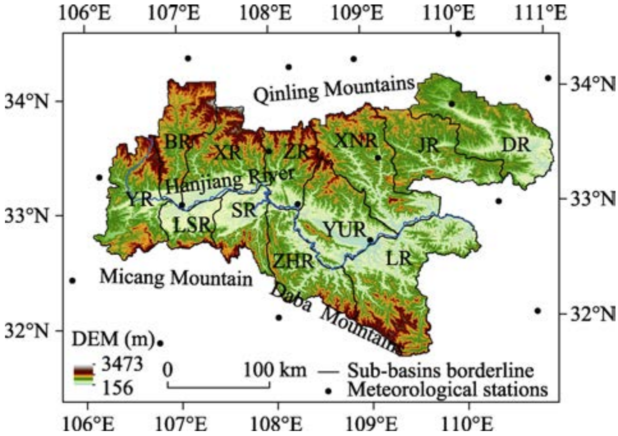

Figure 1 Location and 12 sub-basins of the Upper Reaches of Hanjiang River (URHR), China. These sub-basins are Yanghe River (YR), Baohe River (BR), Xuhe River (XR), Ziwuhe River (ZR), Xunhe River (XNR), Jinqian River (JR), Danjiang River (DR), Lengshuihe River (LSR), Shuangmahe River (SR), Zhuhe River (ZHR), Yuehe River (YR), Lanhe River (LR), respectively.

In the study, we apply SCS-CN model to estimate FMS in two steps:

(1) Evaluating storm runoff: the theoretical base of SCS-CN is water balance and the two basic assumptions in SCS-CN model are as follows:

$$P = I_a + F + Q \tag{1}$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \tag{2}$$

$$I_a = \lambda S \tag{3}$$

where P represents the rainfall (mm), I_a represents the initial abstraction (mm), F represents cumulative infiltration (mm), Q represents the direct surface runoff (mm), S represents the potential maximum retention (mm) and λ represents the initial abstraction coefficient (generally, λ is set as 0.2 in this work).

Surface runoff can be calculated as follows:

$$Q = \begin{cases} \dfrac{(P - I_a)^2}{(P - I_a + S)}, & P \geqslant I_a \\ 0, & P < I_a \end{cases} \tag{4}$$

$$S = \frac{25400}{CN} - 254 \tag{5}$$

Particularly, substituting P_s (representing storm rain) into formulas SCS-CN model, Q_s (representing storm runoff) can be calculated.

$$\begin{cases} Q_s = \dfrac{(P_s - I_a)^2}{(P_s - I_a + S)}, & P_s \geqslant I_a \\ Q_s = 0, & P_s < I_a \end{cases} \tag{6}$$

In the model, *CN* is a comprehensive variable that accounts for hydrologic soil group (HSG), land use and antecedent moisture condition (AMC), and the parameters can be looked up from the table in the National Engineering Handbook (USDA, 1985). The table of *CN* value was built up in ArcGIS 10.2. The land use data of the URHR in 2000, 2005 and 2010 were selected to represent the land use condition in each period: 2000–2004, 2005–2009 and 2010–2014 respectively.

(2) The flood mitigation service can be evaluated by using water balance equation (Fu *et al*., 2013):

$$F_M = P_s - Q_s \tag{7}$$

where F_M represents flood mitigation (mm). Substituting P_s and Q_s in Eq. (6) into Eq. (7), the F_M can be put as follows:

$$F_M = \left(S_{ev} - \frac{(S_{ev} - 0.25)^2}{S_{ev} + 0.85} \right) \times storm\_days \tag{8}$$

where S_{ev} represents single rainstorm event (mm), *storm_days* represents the storm days per year.

2.2.2 Climate change scenarios setting

Scenarios are stories that describe possible futures about socio-economic, technological and environmental conditions, etc. (Moss *et al*., 2010). Applied in climate change research, this approach can promote understanding of complex interactions of climate conditions, human activities and ecosystems (Moss *et al*., 2010; Liang *et al*., 2017), and has great value in better providing references for targeted options for the regional decision-making and ecosystem management (Fu *et al*., 2015). General Circulation Models (GCMs) are the most popular methods in climate change research, studying the future scenarios and dynamic mechanism of climate change through mathematical equations. However, the GCM outputs are too coarse for the regional climate study, so we downscaled the model to better fit for our study (Yang *et al*., 2017). In this study, the automated regression-based statistical downscaling tool (ASD) was chosen to set the climate change scenarios in URHR (Hessami *et al*., 2008). The model is widely used because of its preferable simulation effect and simple operation (Guo *et al*., 2012; Lu *et al*., 2016). In the simulation process of ASD, three forms of data were used:

(1) Daily precipitation data (from 2000 to 2014) of meteorological stations in the URHR. This dataset was derived from National Meteorological Information Center of China Meteorological Administration (http://data.cma.cn/). The storm events were selected from the meteorological data.

(2) NCEP/NCAR reanalysis data at the spatial scale of 1°×1° from 1991 to 2001. The data were derived from National Centers for Environmental Prediction and National Center for Atmospheric Research.

(3) Climate change scenarios (from 1961 to 2099) of the Hadley Centre Coupled Model Version 3 (HadCM3) output data under Special Report on Emissions Scenarios (SRES) A2 and B2 scenarios at the spatial scale of 3.75°×2.5° (Johns *et al*., 2003). This dataset was derived from Hadley Centre for Climate Prediction and Research. The A2 scenario represents a Medium-High Emissions world with more rapid population growth but less rapid economic growth, and B2 scenario represents a Medium-Low Emissions world with slower population growth, economic and social sustainable development (Nakicenovic *et al*., 2000; Walz *et al*., 2014). ASD method was applied to obtain the future storm runoff and FMS in 2020 and 2030, representing relatively near future, in which the FMS can be comparable with the current situation and targeted preventive measures can be carried out timely.

Before setting future climate scenarios of precipitation and FMS, the model performance had been evaluated with the calibration process in the period of 1961–1975 and validation process in the period of 1976–1990. Specifically, in evaluation process, the Nash-Sutcliffe efficiency coefficient (NS) and the coefficient of determination (R^2) had been used to evaluate the residual between measured precipitation data and the simulation results, with the value 0.76 (NS) and 0.78 (R^2) in calibration period, 0.83 (NS) and 0.84 (R^2) in validation period, which indicated the model is considered acceptable and accurate in local area (Lu *et al*., 2016). Thus, with the output from ASD model, the future storm, storm runoff and FMS can be obtained.

3 Results

3.1 Temporal and spatial variations of flood mitigation service

During the period of 2000–2014, the annual mean FMS in the URHR was 101.93 mm. The annual FMS ranged from 34.42 mm in 2001 to 203.98 mm in 2011, with a fluctuating rising trend of 1.97 mm/yr. This change trend was consistent with the results of China's first national ecosystem assessment (2000–2010) (Ouyang *et al*., 2016). Besides, during the 15-year period, there were evident fluctuating inter-annual variations of FMS, and the FMS reversed abruptly in 2011. Thus, the change of FMS could be divided into two phases: in the first phase, FMS continuously increased at a rate of 6.20 mm/yr from 2000 to 2010, while subsequently, FMS dramatically decreased at a rate of –48.99 mm/yr from 2011 to 2014.

Spatial pattern of FMS revealed an apparent gradation from southwest to northeast (Figure 2a). In the southern URHR, the values of FMS were high, especially in the LSR, SR and ZHR region, where the FMS values were above 130 mm. By contrast, the values of FMS in the north were far less, and the values in the DR, BR, XNR and JR were less than 80 mm (Figure 2c). In most regions of the URHR, FMS had increased since 2000, while in the northwestern, DR was the only area where FMS decreased. Meanwhile, the change rates of FMS in the west and the east of the URHR were significantly different (Figure 2b). Specifically, the change rates of FMS in the eastern URHR (downstream of URHR) were relatively

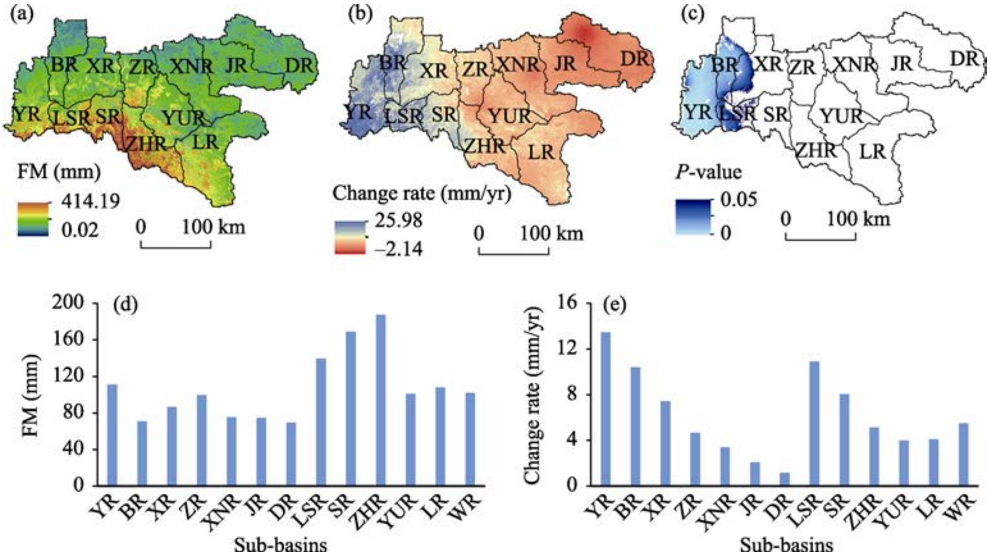

Figure 2 Spatial patterns of annual FMS (a), change rate (b), the significant level (c) and sub-basins distribution of annual average (d) and change rate (e) of flood mitigation service in the URHR. In (d) and (e), WR represents the whole region (URHR).

low, for example, the change rates in DR, JR and XNR were under 4 mm/yr, while in the western URHR (upstream of URHR) the change rates were relatively high, the values in YR, BR and LSR were all above 10mm/yr ($P < 0.05$).

3.2 Flood mitigation service in different climate scenarios

In the climate scenarios of A2 and B2 in 2020 and 2030, the mean FMS ($FMS_{A2\text{-}2020}$, $FMS_{A2\text{-}2030}$, $FMS_{B2\text{-}2020}$ and $FMS_{B2\text{-}2030}$) will be 82.15, 63.43, 64.37 and 60.97 mm, respectively. In comparison with historical annual mean FMS (101.93 mm), the FMS in the four scenarios will all decrease. Besides, the future FMS ($FMS_{A2\text{-}2020}$, $FMS_{A2\text{-}2030}$, $FMS_{B2\text{-}2020}$ and $FMS_{B2\text{-}2030}$) in each sub-basin will all be lower than the historical mean value.

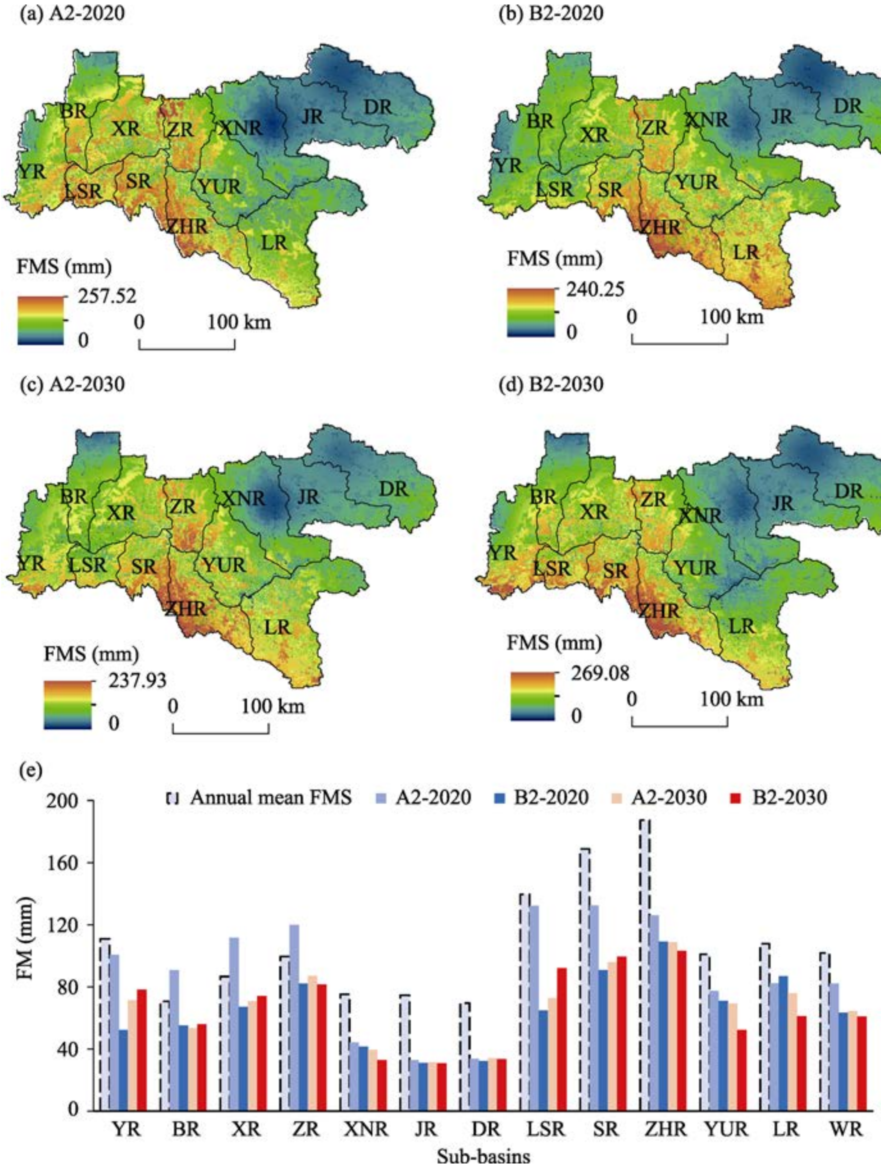

Figure 3 The flood mitigation map under climate change scenarios in the URHR: A2-2020 (a), B2-2020 (b), A2-2030 (c), B2-2030 (d) and sub-basins distribution in scenarios (e). In (e), WR represents the whole region (URHR).

The FMS in the same SRES scenario varies by year: in SRES A2, the FMS in 2030 will be lower than value in 2020 in each sub-basin; in SRES B2, in upstream of URHR (YR, BR, XR, LSR and SR), FMS in 2030 ($\mathrm{FMS}_{\mathrm{B2\text{-}2030}}$) will be higher than value in 2020 ($\mathrm{FMS}_{\mathrm{B2\text{-}2020}}$), and in downstream of URHR, the FMS in 2030 ($\mathrm{FMS}_{\mathrm{B2\text{-}2030}}$) will be lower than value in 2020 ($\mathrm{FMS}_{\mathrm{B2\text{-}2020}}$). In addition, the FMS in the future years varies by SRES scenarios: in 2020, the scenario value for A2 ($\mathrm{FMS}_{\mathrm{A2\text{-}2020}}$) will be nearly higher than value for B2 ($\mathrm{FMS}_{\mathrm{B2\text{-}2020}}$) in each sub-basin; in 2030, the scenario value for A2 ($\mathrm{FMS}_{\mathrm{A2\text{-}2030}}$) will be lower than value for B2 ($\mathrm{FMS}_{\mathrm{B2\text{-}2030}}$) in upstream of URHR (YR, BR, XR, LSR and SR), and in downstream of URHR, the scenario value for A2 ($\mathrm{FMS}_{\mathrm{A2\text{-}2030}}$) will be higher than value for B2 ($\mathrm{FMS}_{\mathrm{B2\text{-}2030}}$).

In sum, in downstream of URHR, the future FMS will continuously decrease from 2020 to 2030 ($\mathrm{FMS}_{2020} > \mathrm{FMS}_{2030}$) under the same scenarios and the future FMS will also be lower under a Medium-Low Emissions scenario ($\mathrm{FMS}_{\mathrm{B2}}$) than a Medium-High Emissions ($\mathrm{FMS}_{\mathrm{A2}}$) in the same year. However, the variations of scenarios value in upstream of URHR will be unstable between years or between SRES scenarios.

4 Discussion

4.1 Driving factors of the FMS variations

Land use/land cover (LULC) change and climate change are key factors that impact the runoff, consequently, influence the FMS (Piao *et al*., 2007; Fu *et al*., 2015). The LULC change has a major impact on runoff and flood mitigation processes, such as canopy interception, depression detention, infiltration, and so on. However, the LULC in the URHR showed limited change during 2000–2014 because of the mountainous environment and backward economic development. According to the LULC transfer matrix (Table 1), the land use in URHR presented little change. In terms of land use types, the woodland, artificial land (e.g., land for construction) and wetland rose gradually, while the cropland, bare land and grassland declined slowly. In general, LULC change will affect major runoff and flood mitigation processes, such as canopy interception, depression detention, infiltration, etc. However, the change in artificial land, wetland, bare land and grassland was feeble (all less than 50 km^2), which limited their effect on the local FMS variations. With the implementation in ecological projects, such as “Grain for Green Project” in Qinling-Daba Mountains (Liu *et al*., 2016), the vegetation coverage in URHR increase gradually, thus the increasing of woodland might

Table 1 The transfer matrix of land use/land cover in URHR from 2000 to 2014 (km^2)

Land cover	Grassland	Wetland	Cropland	Artificial land	Bare land	Woodland	Decrease
Grassland	367.25	1.25	0	0	0	0	1.25
Wetland	0	328	1.25	0	6.25	0	7.5
Cropland	0	11.06	12629.19	41.81	2.44	351.38	406.69
Artificial land	0	0	0	401.69	0	0	0
Bare land	0	24.56	0	0	245.69	0	24.57
Woodland	0	0	0	0	2.5	48412.57	2.5
Increase	0	36.88	1.25	41.81	11.19	351.38	–
Net change	–1.25	29.38	–405.44	41.81	–13.38	348.88	–
Relative change (%)	–0.34	8.56	–3.02	10.41	–4.54	0.72	–

facilitate the increase in FMS (Fu *et al*., 2013). However, the relative change in woodland only occurred in the limited areas (e.g., some river basins and low hills area in URHR), being less than 1% of the whole area. As a result, during 2000–2014, the land use in URHR showed little change, and thus has little effect on local FMS variations.

In addition, we compared the temporal change and spatial patterns of the storm, runoff and FMS in the URHR to assess their similarities and differences. During 2000–2014, the storm, runoff and FMS increased at rates of 0.52, 1.97 and 2.49 mm/yr, with the similar fluctuant change trends and characteristics. The FMS was highly correlated with the storm and runoff: the correlation coefficient between FMS and storm was 0.96 ($P<0.01$), and the correlation coefficient between FMS and runoff was 0.97 ($P<0.01$). Additionally, the FMS shared a similar distribution pattern with storm and runoff in change trend (see Figure 2(b), Figure 4(b) and Figure 4(c)). The change rates of FMS, storm and runoff in upstream of URHR were all higher than that in downstream of URHR. Besides, similar spatial distribution patterns of these three factors' change rates also could be found in sub-basins distribution. As for FMS change in different SRES scenarios, we found that the FMS all showed apparent decreasing trend, which were similar to the decreasing trend of storm and runoff. The A2 and B2 scenarios are different perspectives of socio-economic situation which are set based on the deduced global greenhouse gas emission, therefore, the different scenarios lead to different variations of FMS in 2020 and 2030. However, the future FMS under scenarios of A2 and B2 in 2020 and 2030 all show decreasing trend, though they differ in the magnitude of variations.

According to both the historical and future scenario analysis of FMS and its potential driving factors' change, it can be concluded that the FMS in URHR was mainly determined by climate change, such as storm and runoff.

4.2 Implications of scenario analysis for mapping FMS

Ecosystem supply FMS by reducing and retaining floodwater in forest canopy, leaf litter and soil to avoid flood damages to downstream populations, and the FMS is one of the key hydrological services. However, the increasingly intensification of climate change and human activities can lead to degradation of the FMS, increasingly threatening the local water resources security and ecological stability. In FMS research, flood risk zonation can be executed according to relative risk grade of different areas, Priority Areas for protecting FMS can be designated in local area (Zhang *et al*., 2017), and some potential problems in regional water crisis could be prevented or mitigated in the future.

The provision of ES depends on biophysical conditions of ecosystem (Sturck *et al*., 2015). The ecosystem has been and will continue be increasingly influenced by anthropogenic land use change and climate change (Burkhard *et al*., 2012). Given this, a long-term study on the ecosystem change can help better understand the mechanism and future trend of the ES change (Li *et al*., 2017). For example, in this study, the FMS increased with fluctuations from 2000 to 2010, while FMS decreased dramatically from 2010 to 2013, which revealed the internal instability of ecosystem under the changing environment. Our study also found that storm rain had a significant perturbation on FMS. Thus, the analysis of historical change can help identify driving factors of FMS, and further provide theoretical basis for scenario analysis. For instance, the climate change is the main factor that influences on FMS, so the

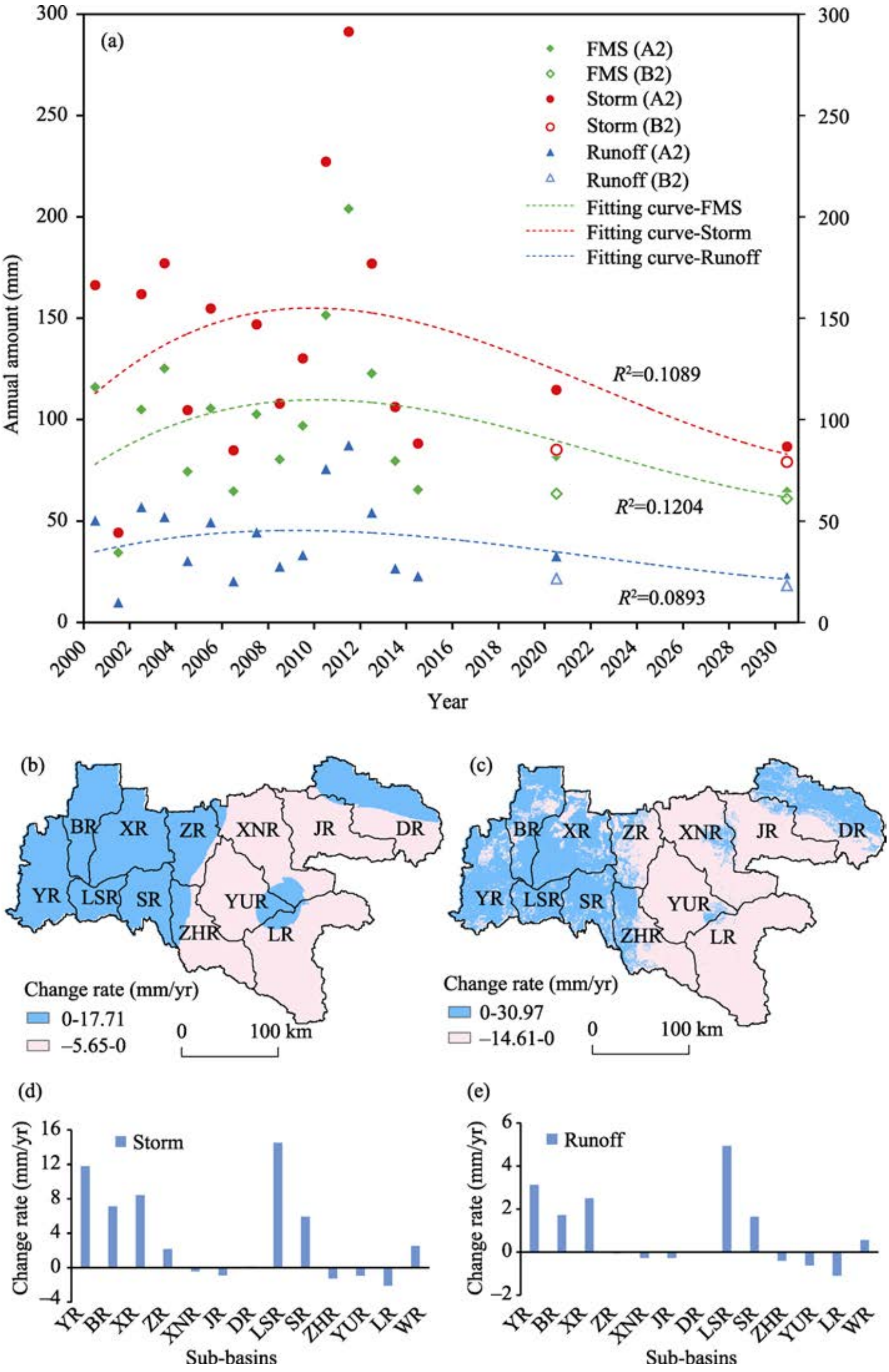

Figure 4 Temporal variations of storm and runoff (a), spatial variations of storm change slope (b), spatial variations of runoff change slope (c), storm change slope of sub-basins (d) and runoff change slope of sub-basins (e). In (d) and (e), WR represents the Whole Region (URHR).

climate scenario was chosen to simulate the future FMS. The driving forces chosen in this study are only a special example, and in general, ES is driven by multi-factor in complicated and non-linear process. To find out the dominant factors, more comprehensive methods are needed.

Scenario analysis helps stakeholders consider the possible futures change of ES. After knowing the potential impact of future environmental change, stakeholders could develop adapting strategies to prevent regional water resources risks (Leng *et al*., 2015; Gosling *et al*., 2016; Popp *et al*., 2017). For instance, in the URHR, our study showed that the FMS will decrease in 2020 and 2030 under climate scenarios of A2 and B2. With this knowledge, we can suggest that there would be less flood risk in the URHR, and the stakeholder may invest moderate funding to defense risk. Besides, by integrating historical change and scenario analysis into ES assessment, we provide a useful framework to understand the whole dynamic variations of ES. After controlling for some variables and contrast changes of variables, the dominant factor and possible magnitude of the effect of dominant factor on ESs can be identified (Popp *et al*., 2017).

There are also some uncertainties in the process of FMS evaluation, though we carefully deal with the models. First, future climate changes scenarios provide a possible but not completely accurately description of future climate change (Leng *et al*., 2015). In this study, the impacts of historical and future climate change on the ecosystem services is the main content of research, thus there is only one climate model (HadCM3) involved in. In further study about the construction of exhaustive ecosystem services assessment, more diverse climate change models and scenarios should be taken into consideration. It could be helpful for the stakeholders to find out more suitable measures and put forward a more targeted policy in protection of natural ecosystem. In addition, the key parameter CN in the SCS-CN model is sensitive to the local land use change, micro-topography and local climate change, and may affect the runoff calculation to some extent (Fu *et al*., 2013). On the small-scale regional studies, the local land use micro-change should be taken into account. Furthermore, the land use change scenario should be considered in the future studies, especially in regions where land use changes rapidly. As discussed above, the land use change has a remarkable hydrological effect on ecosystem (Carvalho-Santos *et al*., 2016; Zuo *et al*., 2016), and Fu *et al*. (2015) also emphasized that more attention should be paid to the link between ES and land use. In our study, the land use of URHR showed little change during 2000–2014, so we did not model the land use scenario. However, in a constantly and dramatically land use changing region, the role of land use change in the FMS should not be neglected.

5 Conclusions

Assessing and mapping of flood mitigation service (FMS) are critical for regional water resources and flood risk management. Based on the SCS-CN model and climate scenario analysis, we analyzed the historical spatio-temporal variations and future variations of FMS in the URHR, China. The main conclusions are as follows:

FMS showed a fluctuating rising trend during the period of 2000–2014, and FMS reversed abruptly in 2011, thus dividing the period into two phases with apparently different trends: FMS increased from 2000 to 2010, while decreased from 2011 to 2014. Spatially, the FMS in southern URHR was higher than that of northern URHR, and the change rate of FMS in the upstream of URHR was higher than downstream of URHR. The future FMS under scenarios of A2 and B2 in 2020 and 2030 will decrease in comparison with the historical annual mean FMS (2000–2014). For each sub-basin, compared with 2020, the FMS in 2030 will decrease further. Besides, the difference between A2 and B2 scenarios is quite small.

The slight land use changes in the URHR have feeble impacts on the FMS, while the runoff and storm change have a significant influence on the FMS. We concluded that the climate change played a key role in the flood mitigation in the URHR.

Our study suggests that both historical and scenario analysis are vital for better understanding the ecological process, and practically provides scientific reference for government and stakeholders to make targeted and purposeful measures in watershed water resources management.

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