Assessing Drought Risk of Laohahe River Basin Using SWAT

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Abstract

Drought risk to climate change in Laohahe River Basin located in semi-arid of northeast China assessed by applying Soil Moisture Index (*SMI*) in sub-basins scale were simulated by defining scenarios for changes in climatic inputs to SWAT. The results indicate that in most sub-basins, *SMI* is very sensitive to climate change. Precipitation shifts would have a greater impact on *SMI*, as compared with temperature. Dry and warm climate increased drought risk obviously. The northern sub-basins were more sensitive and in relative stronger risk. Drought risk was smaller in forestland than in agricultural areas.

Keywords

Risk; Soil water; Climate change; Drought months; small watershed

基于 SWAT 的老哈河流域干旱风险评价

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设定气候变化情景驱动 SWAT 水文模型，以土壤湿度指数 *SMI* 为指标，在子流域尺度上评价了老哈河流域干旱风险：*SMI* 对气候变化响应敏感；降水对 *SMI* 的影响较气温更明显；暖干化天气组合使得干旱风险明显增强，位于流域北部的子流域，其 *SMI* 对气候变化敏感性更强，干旱风险也更大；林地面积比例大的子流域干旱风险要小于农用地比例大的子流域。

关键词

风险；土壤水；气候变化；干旱发生月；小流域

1. Introduction

Drought is one of the major natural hazards that bring about billions of dollars in loss to the farming community around the world each year. As stated by the IPCC (2000) there is evidence that extreme events will be more frequent and intense due to global warming. A series of extreme drought in the semi-arid area of Northern China occurring in the last two decades have stimulated discussions about the possible effects of climate change and human interventions in river basins. Agriculture in Laohahe River Basin (LRB) is mainly practiced under rainfed conditions. Irrigation practice in the basin was on a very small scale. However, with increase in population and the need to meet food security under the basin's poverty alleviation strategy, more lands are envisaged to be put under irrigation. With these demands, water supplies will be severely stretched and pollution problems and environmental degradation are likely to increase. In addition, with increased evaporation results from temperature rise, the distribution of monthly and annual flow would more uneven. These changes could stimulate increased periods of flooding or drought. In a word, assessment of the drought risk of LRB is essential in order to respond adequately to climate change in water management practices and optimize the river function in relation to each other.

Numerous efforts have been made to develop various methods for drought risk assessment (Zhang et al., 2005; Ma and Gao, 2004.), comparatively few studies in quantificationally evaluating drought risk to global warming, especially using GIS, GIS-based distributed parameter hydrologic models, and remote sensing at a high spatial and temporal resolution, which actually presents a new information diffusion method for risk assessment from another point of view.

This study aims at evaluating the effects of global warming on drought, and attempted to quantify drought risk predicted on account of the climate change scenarios in LRB. These objectives will be achieved by defining scenarios for changes in climatic inputs to SWAT (Soil and Water Assessment Tool), and then assessed the drought risk using soil water outputs simulated by SWAT.

2. Materials and methods

2.1. Study site

Laohahe River originates in Qilaotu Mountain, Hebei Province, China, and flows into Xiliaohe River before entering Liaohe River. The main channel is 182.5 km and it drains 27 977 km^2 of the semi-arid area (Fig.1).

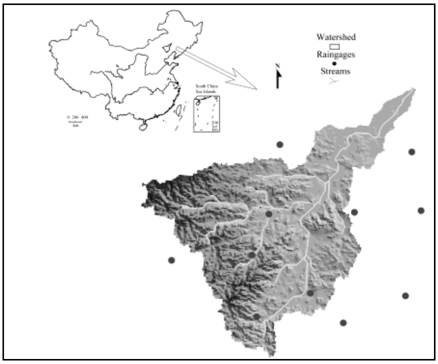

Fig. 1: Location and 3D Scene of LRB

The basin lies within latitudes 41°03′N and 43°30′N and longitudes 117°18′E and 120°51′E, elevation 405m –1935m. The average annual precipitation is approximately 424 mm and the average temperature is about 6.9℃. A total annual precipitation of 77.9% occurs during the flood season (Jun.-Sep.). Potential evapotranspiration exceeds precipitation through the summer months.

Runoff in LRB comes mainly from natural precipitation. The spatial distribution of runoff is similar to precipitation. The primary land cover types in LRB are cultivated land, forestland and grassland.

2.2. Hydrologic modeling

SWAT model (Arnold *et al*., 1998; Neitsch, 2002) was used in the present study to carry out the hydrologic modeling of LRB. SWAT is a distributed, continuous, hydrological model with an ArcView GIS interface. It can predicts the impact of land management practices on water, sediment, and agricultural chemical yields in large and complex watersheds with varying soils and land use and management conditions over long periods of time. The SCS curve number procedure (SCS, 1972) was adopted for estimating surface runoff in this research. The Penman-Monteith method (Monteith, 1965;Allen,1986;Allen et al.,1989), was used to estimate PET in this study.

Topographic parameters and stream channel parameters were estimated from the digital elevation model. A dominant soil and land use type within each sub-basin was used to develop soil and plant inputs to the model. Based on the DEM, the catchment was subdivided into twenty-seven sub-basins (Fig.2). Within these sub-basins, 127 hydrological response units (HRUs) were defined. (Hao et al., 2008).

The SWAT model was calibrated and validated using stream flow data. The total available historical weather data (1959-2000) were divided into two sets: 20 years (1961-1980) for calibration (1959-1960 was assumed to be an initialization year) and 20 years for validation (1981-2000). The coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) (Nash and Sutcliffe, 1970) were used to evaluate the model predictions for both time periods. The R^2 and E_{NS} values was 0.72 and 0.70 for the calibration period, and the validation period was 0.82 and 0.77 (Hao et al., 2008). These validation results indicate that SWAT accurately replicated LRB hydrologic characteristics for the simulated time period.

Fig. 2: Sub-basins from 1 to 27 for LRB

In the current study, soil moisture is the hydrologic component of interest. For annual soil water simulation, Climate change scenarios constitute 4 sets of combinations of different temperature and precipitation change: unchanged temperature and precipitation (baseline); 3℃ rise in temperature and 30% increase in precipitation; 3℃ rise in temperature and baseline precipitation; 3℃ rise in temperature and 10% decrease in precipitation.

2.3. Drought evaluate methodology

Drought indices are widely used for the assessment of drought severity by indicating relative dryness or wetness effecting water sensitive economies (Gosain et al., 2006). The Palmer Drought Severity Index (*PDSI*) is one such widely used index that incorporates information on rainfall, land use, and soil properties in a lumped manner (Palmer, 1965). The Palmer index categorizes drought into different classes. *PDSI* value below 0.0 indicates the beginning of drought situation and *PDSI* value below –3.0 indicates severe drought condition.

Recently, due to advancements in Geographical Information Systems (GIS), GIS-based distributed parameter hydrologic models, and remote–sensing, Soil Moisture Index (*SMI*) has been developed (Narasimhan and Srinivasan, 2002) to assess drought severity using SWAT output. *SMI* is a more effective drought assessment index developed at a higher spatial and temporal resolution. *SMI* has been employed in the present study to focus on the agricultural drought where severity implies cumulative water deficiency. Monthly information has been derived using daily SWAT outputs which in turn have been used for analysis of drought severity.

Using historical weather data from 1959-2003, long-term monthly normal soil moisture was estimated. This long-term monthly normal soil moisture data was used to calculate *SMDI* at sub-basins.

The soil moisture deficit ratio and the Soil Moisture Index (*SMI*) during a given month are calculated respectively as formulas given by Narasimhan and Srinivasan, 2002.

3. Results

The *SMI* for climate change scenario of all the sub-basins of LRB has been computed using the soil moisture deficit ratio parameters of baseline.

Take March as example, number of drought months of sub-basins in LRB (consisting of months with *SMI* of less than 0, -1 and -2.), for both baseline and climate change scenarios are shown that the numbers of drought months have considerably increased during climate change scenarios of 3℃ rise in temperature and 10% precipitation decrease, and scenarios of 3℃ rise in temperature and precipitation unchanged barring about scenarios of 3℃ rise in temperature and 30% increase in precipitation. Analyses have also been performed with respect to drought conditions over other months separately but could not be presented here due to lack of space.

4. Discussion and conclusions

The drought risk to climate change assessed by applying Soil Moisture Index in sub-basins scale were simulated and calculated by defining scenarios for changes in climatic inputs to SWAT model, and then analyzed, relative to a scenario baseline.

The results indicate that in most sub basins in LRB, *SMI* is very sensitive to climatic variations, both on a seasonal basis and over longer time periods. The scenario outcomes indicate that the *SMI* decreased with increased precipitation, while increased with increased temperature in sub basins in LRB.

Drought months shift apparently with climatic variations both on *SMI*<0, *SMI*<-1, and *SMI*<-2. Precipitation shifts would have a greater impact on *SMI*, as compared with temperature. Compared with b_2, the sub basins influenced by drought in b_1 was obviously less than in b_2. The reason is due to with the same degree rise in temperature both in b_1 and b_2, 30% precipitation increase in $b_{1.}$ The similar situation was also found in a_1 and a_2, c_1 and $c_{2.}$

The spatial distribution of drought events (months) in sub-basins of LRB for baseline and 3 scenarios shown that sub basins located in the northern LRB which were apt to suffer drought during 1959 to 2003 were more sensitive and vulnerable to climate change and in relative stronger risk than the sub basins located in the southern LRB . For example, with 3℃ rise in temperature and 10% precipitation decrease, drought events in northern LRB were more than sub basins in southern LRB obviously, especially on the condition of *SMI*<-1 and *SMI*<-2. In addition, the spatial distribution of drought events (months) in sub-basins presented gathered distributing.

Drought risk to shifts in precipitation and temperature was predicted to be smaller in forestland than in agricultural areas. For *SMI*<-1, drought events (March) of sub basins 26 featured with 63.1% of forest land and 11.3% of agricultural areas was 26 in response to 3℃ rise in temperature and 10% precipitation decrease, however, sub basins 25 with 25.6% of forest land and 31.4% of agricultural areas was 42. Drought events (March) of sub basins 26 was 19 in response to 3℃ rise in temperature and precipitation unchanged, however, sub basins 25 was 36. Similar situations in other most sub basins and other scenarios were also found.

The impacts of combined drying and warming weather on increasing drought risk are greater obviously, both for light drought and severe drought. For *SMI*<0, average drought events (months) of all twenty seven sub basins was 38 in response to 3℃ rise in temperature and precipitation kept baseline, however, average drought events (months) of all sub basins was 43 in response to 3℃ rise in temperature and 10% precipitation decrease. For *SMI*<-1, average drought events (months) of all sub basins was 25 in response to 3℃ rise in temperature and precipitation kept baseline, however, drought events was 33 in response to 3℃ rise in temperature and 10% precipitation decrease. For *SMI*<-2, average drought events (months) of all sub basins was 11 in response to 3℃ rise in temperature and precipitation kept baseline, however, drought events was 21 in response to 3℃ rise in temperature and 10% precipitation decrease. This result indicates that with the combined drying and warming weather, drought risk ware predicted to increase obviously. In addition, with dry and warm climate, the severe drought risk (*SMI*<-2) was greater than middle drought risk (*SMI*<-1) which is also greater than light drought risk (*SMI*<0).

Drought risk to climate change in dry seasons was greater than that in wet seasons. For *SMI*<-1, drought events in March of sub basins 3 was 42 in response to 3℃ rise in temperature and 10% precipitation decrease, while July was 35. Drought events in March of sub basins 4 was 32 in response to 3℃ rise in temperature and precipitation unchanged, while July was 21. Similar characteristics in other sub basins and other scenarios were also found.

This study sets out to estimate drought risk to climate change for a small monsoon China watershed. These predicted climate change impacts may induce additional stresses and shall need various adaptation strategies to be taken up. The strategies and measures may range from change in land use, cropping pattern to water conservation, flood warning systems, etc. Other researches can be established that additional factors such as human activities may influence extreme hydrologic events. The results of this study also point to the need to perform a more extensive assessment of potential climate change impacts on LRB drought risk by simulating down scaled climate change scenarios. In addition, analysis risk of drought events is needed to provide a higher resolution both at spatial resolution of HRUs and at temporal resolution of weeks.

5. Acknowledgements

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2008 年中国南方低温雨雪冰冻灾害承灾体分类与脆弱性评价

——以湖南省郴州市交通承灾体为例

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摘要：基于灾害系统理论对承灾体进行分类，对于有效防灾减灾具有重要意义。依据北京师范大学民政部/教育部减灾与应急管理研究院的综合风险搜索引擎为灾情数据来源，从产业结构、灾害链和土地利用三个角度对中国南方低温雨雪冰冻灾害的承灾体进行分类，并以郴州市交通承灾体为例，进行了脆弱性评价。研究结果表明：第一产业承灾体种类最多、面积最大，第二产业承灾体集中在电力行业，第三产业承灾体集中在交通运输业;“结构破坏”、“断电”和“交通阻塞”在灾害链节点处的承灾体脆弱性强；土地利用中大面积的林地和园地，线网状的交通网、电网和通讯网用地的脆弱性强；郴州市交通承灾体脆弱性存在着明显的地域差异，京珠高速公路郴州段脆弱性为全市最高。本研究可为灾情评估和减灾工程布局提供科学依据。

关键词：雪灾；承灾体分类；产业结构；灾害链；土地利用；交通；脆弱性

中图分类号:X43 **文献标识码:**A

Classification of disaster-affected bodies and vulnerability assessment in low-temperature freezing and snow disaster occurred in South China, 2008: Case study of traffic disaster-affected bodies of Chenzhou City in Hunan, China

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Abstract: Classification of disaster-affected bodies based on the disaster system theory is of great significance to disaster preparedness and reduction. This paper proposes three classifications of disaster-affected bodies in low-temperature freezing and snow disaster occurred in South China respectively from the view of industrial structures, disaster chain and land-use types. And the datum of disaster effect is obtained from the search engine of integrated risk of Academic of Disaster Reduction and Emergency Management, developed by Ministry of Civil Affairs & Ministry of Education, Beijing Normal University. In addition, the paper sets up the vulnerability assessment index system which focuses on traffic system, and applies it into Chenzhou City.

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