Impacts of climate change on water resources and water environment in the Three Gorges Reservoir

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Abstract Climate change is one of the major global issues commonly concerned by international communities. Taking the Three Gorges Reservoir which is the largest water conservancy project in China as the object, this study attempts to clarify the current conditions of water resources and water environment especially the spatial distribution characteristics of water resources amount and main non-point source pollution loads in recent years, and further predict the evolution trends of hydrological elements and evaluate the impacts of climate change on water resources and water environment through coupling the global climate models with the hydrological model employing a statistical downscaling method. The results indicate that, 1) currently, except the precipitation in Wanzhou, Shizhu and Xingshan is larger while less in Zhong, Fengdu and Zigui, and the runoff in Wuxi, Kai and Xingshan is larger while less in Fengdu and Zhong, the spatial distribution of annual precipitation and runoff in the region is relatively even and do not vary greatly in the other counties; the spatial distributions of total nitrogen load and total phosphorus load are similar with the characteristics that six counties including Yichang, Kai, Yunyang, Zhong, Wanzhou and Badong contribute more and four counties including Yubei, Nanan, Jiangbei and Wulong contribute less; 2) in the future, comparing with the historical average, the temperature in the region will increase by 1.3℃ and the evapotranspiration will increase by 2.8%, while the precipitation, runoff and non-point source pollution load will decrease by 0.8% , 8.2% and 8% respectively. Although the precipitation will not change greatly, the reduction extent of runoff is larger than that of precipitation, bringing forward higher requirements for integrated water resources management in the Three Gorges Reservoir.

Key words Three Gorges Reservoir; distributed hydrological model; climate change

▪ INTRODUCTION

Climate change induced by greenhouse gas emissions is one of the major global issues commonly concerned by international communities. Global warming may affect hydrological processes through driving the change of climatic elements including precipitation and temperature, enhance the probability of hydrological extreme events, resulting in the temporal and spatial redistribution of water resources. Simultaneously, water environment including physical, chemical and biological characteristics of water body may also be influenced, for example, temperature change will affect the hydrological and ecological conditions, precipitation and runoff as well as the occurrence probability of flood and drought will affect the transfer and conversion processes of pollutants and nutrients in water bodies (Hao, 2010). Therefore, it is of great significance to evaluate the impacts of climate change on water resources and water environment for regional water safety and environment protection.

The Three Gorges Reservoir (58,000 km^2) is a world famous project and the largest water conservancy project in China with great comprehensive benefits including flood control, power generation, navigation and environmental protection and water supply, as well as the strategic reserve base of freshwater resources for the country. Water resources and water environment in the reservoir not only affect the sustainable development in the region but also the economical development and ecological conditions in the middle and lower Yangtze River Basin. However, the regional and surface hydrological conditions have changed significantly in the reservoir since beginning storing water in 2003, the harms of agricultural non-point source pollution have been increasingly obvious due to the increasing use intensity of chemical fertilizer and pesticide. With the social and economic development and climate change, the impacts of climate change on water resources and water environment will be exacerbating.

Studying the impacts of climate change on water resources has not been regarded by international hydrological communities until the middle of 1980s, many researchers carried out related work using different climate and hydrological models in different basins (Arnell, 1999; Mimikou, 2000; Matondo, 2004), and the general method is to evaluate the impacts of climate change through hydrological model simulations using the precipitation and temperature output of climate models. Related studies have been rapidly carried out in China since 1980s. Many related projects have been set up in the 7th, 8th and 9th national scientific research programs selecting the Northwest and North China, the Huai River Basin and the Tibetan Plateau as study areas. The general methods are assuming climate scenarios (Wang et al., 2000) and simply coupling climate models with hydrological models (Liu, 1997; Cao et al., 2004; Yuan et al., 2005).

Studies about the impacts of climate change on water environment at home and abroad have just been starting, and the methods can be summarized as two categories: statistical method which refers to evaluate the impacts of climate change on water quality by establishing the statistical relations among climatic elements and water quality indexes (Gao et al., 2006; Zhao et al., 2007; Tibby et al., 2007) and model simulation method which refers to evaluate the impacts of climate change on water environment by simulating the temporal and spatial variations of water quality based on climate model estimations and principles of quality, energy and momentum conservation described by mathematical equations (Mimikou et al., 1999; Ekaterini et al., 2002; Whitehead et al.,2006; Komatsu, 2007).

Many researchers focused on the climate change in the Three Gorges Reservoir in recent years (Liu, 2003; Wang et al., 2005; Zou et al., 2005; Zhang et al., 2005), most of these studies use the method by comparing the data at single meteorological site which actually can not represent the climate characteristics for the entire reservoir region. In addition, there are few quantitative researches about the impacts of climate change on water resources and water environment. This study attempts to clarify the current conditions of water resources and water environment and evaluate the impacts of climate change on water resources and water environment in the region, and the research results may provide decision support for integrated water resources management and environmental protection.

▪ METHODS

The general outline of the methodology is: firstly, the distributed hydrological model for the Three Gorges Reservoir is established based on different kinds of data including Digital Elevation Model (DEM), soil, land use, hydrology, meteorology, population, Gross Domestic

Product (GDP), pesticide and fertilizer use, sown area, grain yield, livestock breeding and other related statistical materials; secondly, the distributed hydrological model is calibrated and validated using the observed daily runoff data at main hydrological stations; thirdly, current conditions of water resources and water environment especially the spatial distribution characteristics of water resources amount and main non-point source pollution loads in recent years are evaluated through the hydrological model simulation; finally, future climate scenario is established based on the ensemble average dataset of 20 General Circulation Models (GCMs), and the evolution trends of hydrological elements as well as the impacts of climate change on water resources and water environment are evaluated through coupling the GCMs with the hydrological model using a statistical downscaling model. The data and methods mentioned above are each described in the following sections.

- **Distributed hydrological model**

The distributed hydrological model used to simulate the hydrological processes in this study is EasyDHM (Easy Distributed Hydrological Model) (Lei et al., 2010). The EasyDHM, which is actually a software including several models and an operation interface, consists of hydrological processes simulation model, soil erosion model, one and two dimensional hydrodynamic and water quality simulation model, automatic parameter identification model, pre-processing module and results analysis tool. The calculation units can be grids or sub-basins.

Specially, hydrological processes in the EasyDHM model system are treated as modules and each process could be simulated using different algorithms. For example, runoff yield can be generated by two mechanisms, infiltration excess (Horton) runoff and saturation excess (Dunne) runoff, flow concentration can be calculated using several methods including diffusion wave, kinematic wave and Muskingum method. Soil erosion processes are simulated using the Modified Universal Soil Loss Equation (MUSLE). For the simulation of water quality, produced loads of point source and non-point source pollutants as well as the soil erosion in different types of area are firstly calculated, then point source pollution is simulated through the transfer and conversion processes within river channels in sub-basins and non-point source pollution is simulated through transfer and conversion processes both within soil and river channels in sub-basins respectively.

The EasyDHM model system can meet the demanding for water resources assessment, flood forecasting, non-point source pollution and water environment management, and has been successfully applied to the Yangtze River, the Yellow River, the Hai River and the Songliao River in China.

Details of the model system and its application are given by Lei et al. (2010).

- **Future climate scenario**

GCMs perform differently in different regions in the climate change study. Many researches show that ensemble average of climate models performs better than a single model. The GCM data used in this study are from the World Climate Research Programme’s (WCRP’s) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset including estimation results of more than 20 climate models provided by the Program for Climate Model Diagnosis and Intercomparison (PCMDI). Based on the dataset, the multi-model average dataset under three emission scenarios A1B, A2 and B1 which were provided by the Intergovernmental Panel on Climate Change (IPCC) in 2000 can be obtained using Reliability Ensemble Average (REA) method. We select the temperature and precipitation data during 2021-2050 in the Three Gorges Reservoir in this study.

Details of the dataset and scenarios are given by National Climate Centre (2009).

■ Statistical downscaling model

Generally, the spatial resolution of GCMs is inconsistent with that of hydrological models, and there are two kinds of methods for downscaling the GCM outputs, dynamical downscaling method and statistical downscaling method. Statistical downscaling methodologies have several practical advantages over dynamical downscaling approaches. In situations where low-cost, rapid assessments of localized climate change impacts are required, statistical downscaling represents the more promising option currently. Therefore, in this study, we select the statistical downscaling methodology, concretely the Statistical Down-Scaling Model (SDSM), to downscale the GCMs output. The SDSM is a widely used statistical downscaling model in the world. In recent years, many studies have shown that SDSM model is of superior performance and easy to use and its application becomes more widely (Fowler et al., 2007).

The Statistical Downscaling Model (SDSM) allows the construction of climate change scenarios for individual sites at daily time scales using the grided output of the GCM, and is the first tool of its type offered to the broader community investigating the affects of climate change. The statistical relationship between large scale climatic factors (predictors) and local variables (predictands) is firstly established, and then local climate information is simulated and future climate change scenarios can be obtained.

Details of the model and application are given by Wilby et al. (2002).

■ Data

The DEM data used in this study are from the United States Geological Survey (USGS) and can be obtained from the website: http://edcdaac.usgs.gov/gtopo30/hydro/. In order to ensure the simulated river network is consist with the observed, the original DEM data is firstly modified based on the observed river network, and then used to generate simulated river network.

The land use data used in this study are from the Chinese Academy of Sciences. The original land use data is reclassified according to the land use categories in the EasyDHM model.

The soil data used in this study are from the soil database of Institute of Soil Science, Chinese Academy of Sciences, which can be obtained from the website: http://www.csdb.cn/viewdb.jsp?uri=cn.csdb.soil, and the resolution of the data is 2km×2km.

The hydro-meteorological stations used in this study include 13 hydrological stations, 56 rainfall stations and 17 meteorological stations. The observed runoff data at hydrological stations are from 2006 to 2007, while the data at rainfall stations and meteorological stations are from 1961 to 2009.

The statistical data needed for non-point source pollution simulation in this study are from the Statistical Yearbook of the counties, including the population, GDP, pesticides and chemical fertilizer, plant structure, crop yield, livestock and other related statistical data from 2003 to 2007.

■ FINDINGS AND DISCUSSION

- **Description of study area**

The Three Gorges Reservoir is located at 105°44"-111°39"E and 28°32"-31°44"N, and the dam site is located at the middle of the Yangtze River, Sandouping in Yichang City. The scope of the reservoir involves 21 counties in Hubei Province and Chongqing Municipality with a total area of 58,000 km^2 (Fig.1). The length of the Yangtze River within the reservoir from Jiangjin to Sandouping is about 660 km. The normal water level of the reservoir is 175 m, with a total capacity of 39.3 billion m^3 and a flood control capacity of 22.1 billion m^3.

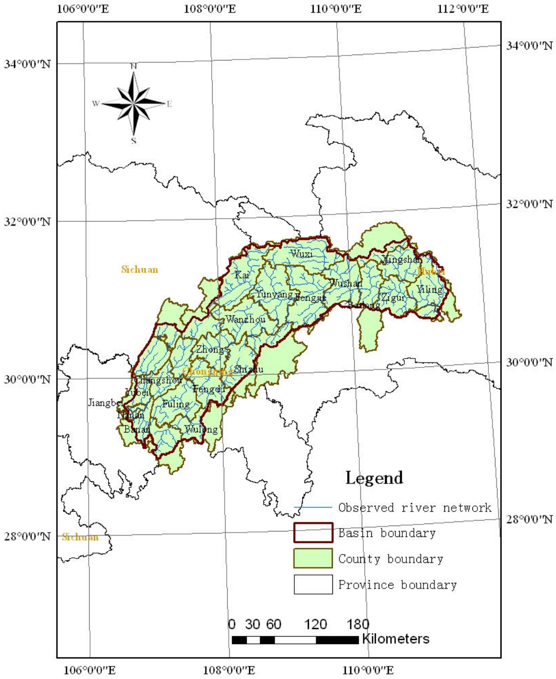

Fig.1 Description of the Three Gorges Reservoir

The topography in this region is mainly hilly and mountainous, and the north and south is higher than the middle. The climate is humid subtropical monsoon, annual average temperature is 17.3℃, annual average precipitation is 1229mm, annual average relative humidity is 80% and annual average evapotranspiration is 1705mm. The spatial distribution of precipitation is relatively even while temporal distribution is uneven, and the precipitation during the period of April to October accounts for 80% of the total annual amount, and rainstorm occurs frequently during the period of May to September.

- **EasyDHM for the Three Gorges Reservoir**

Subdivision of calculation units

The study area is firstly divided into 13 parameter partitions (Fig.2) using the pre-processing module according to the location of hydrological stations, and each parameter partition adopts an individual set of calibrated parameters to calculate. Each parameter partition is then divided into sub-basins based on the simulated river network, and each sub-basin in hilly areas is further divided into 1-10 contour bands according to the elevation of the grids. The contour bands are the calculation units of EasyDHM as shown in Fig.3.

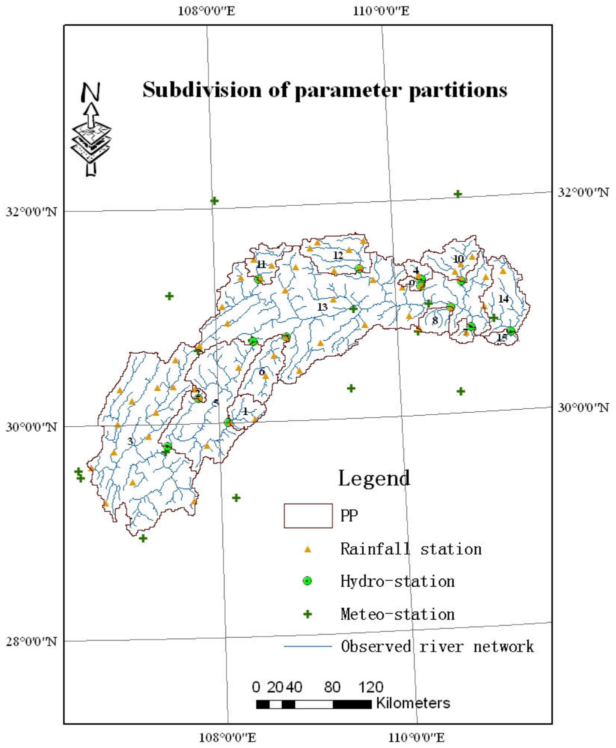

Fig.2 Subdivision of parameter partitions（PP）in the Three Gorges Reservoir

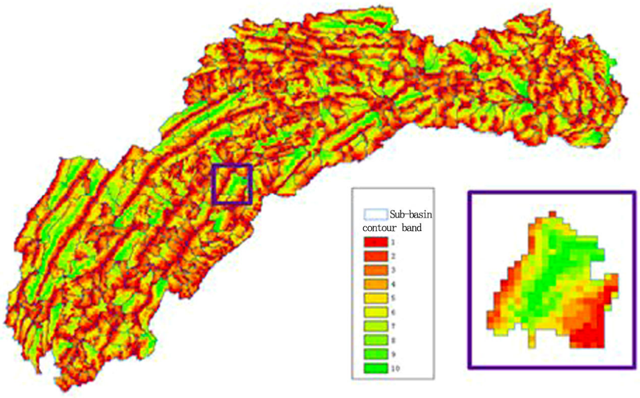

Fig.3 Subdivision of calculation units-contour bands in the Three Gorges Reservoir

Model validation

The parameters for each parameter partition are calibrated using the observed daily runoff data from 2006 to 2007 at 9 hydrological stations according to the three calibration rules: minimizing the average monthly discharge error during the simulation period, maximizing the Nash-Sutcliffe efficiency coefficient and maximizing the correlation coefficient between simulated discharge and observed values.

Model validation results as shown in Table1 indicate that the average error of monthly runoff is 5.4%, the average Nash-Sutcliffe efficiency coefficient of monthly runoff at 9 hydrological stations is 0.76, and the average correlation coefficient between simulated and observed monthly runoff is 0.88. A validation example for 3 stations is shown in Fig. 4.

Table 1 Validation results of EasyDHM for the Three Gorges Reservoir

Hydro-station Name	Lat	Lon	Indexes of model performance		
			Relative error（%）	Nash-Sutcliffe coefficient	correlation coefficient
Shizhu	30.0	108.1	-5.49	0.45	0.75
Lianghe	30.2	107.8	15.44	0.72	0.85
Qingxichang	29.8	107.4	1.36	0.99	0.99
Shibanping	31.3	110.3	8.78	0.45	0.68
Wanxian	30.8	108.4	0.80	0.99	0.99
Changtan	30.8	108.8	1.51	0.53	0.81
Xingshan	31.2	110.8	-10.2	0.84	0.93
Wuxi	31.4	109.6	-4.25	0.87	0.95
Gezhouba	30.7	111.3	0.63	0.99	0.99

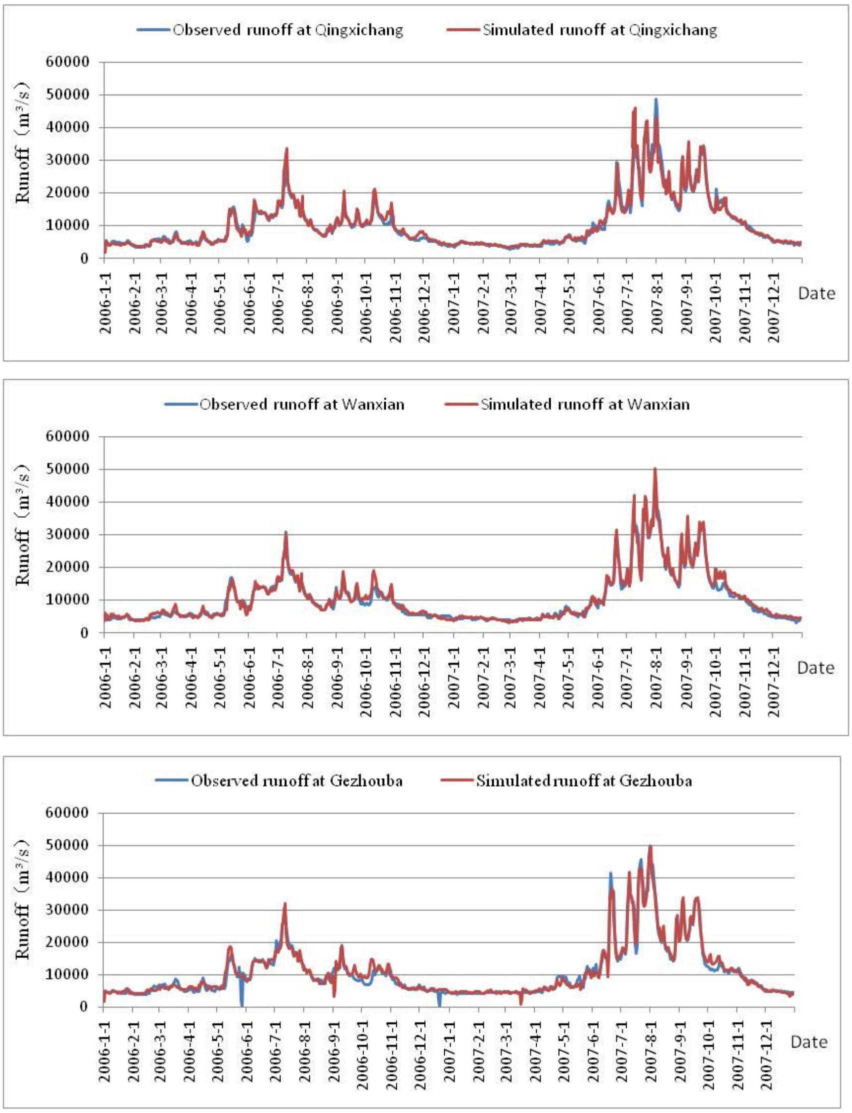

Fig.4 Comparison of simulated daily runoff with observation at Qingxichang, Wanxian and Gezhouba station

■ Current conditions of water resources and water environment

The estimated current conditions of water resources and water environment in the Three Gorges Reservoir in 2006 and 2007 based on the validated EasyDHM, which include the average annual precipitation, temperature, evapotranspiration, runoff and loads of main non-point source pollutants such as Biochemical Oxygen Demand (BOD$_5$), Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP), are shown in Table 2, and the spatial distributions of the elements above are also analysed. The spatial distributions of precipitation and runoff for the parameter partitions as well as the spatial distributions of TN load and TP load for the counties are shown in Fig.5 as an example.

Table 2 Estimated current conditions of water resource and water environment in the Three Gorges Reservoir (2006-2007)

PP	P	T	E	R	BOD$_5$	COD	TN	TP
1	1197.6	18.8	1122.4	341.9	3637.4	7057.7	823.1	152.6
2	1067.4	17.6	1082.2	347.9	619.2	1042.5	194.1	53.9
3	1140.9	18.7	1106.1	355.7	31996.3	51907.1	10459.9	2024.4
4	1523.7	18.0	1070.1	783.1	886.4	3218.2	204.0	62.6
5	1081.5	18.5	1121.9	109.3	30434.2	51844.9	7811.1	1794.6
6	1352.7	19.1	1153.2	455.2	3884.7	7288.9	1244.6	273.7
7	1102.4	17.7	1070.7	314.0	2059.6	8472.6	491.6	161.6
8	1162.6	18.0	736.6	412.2	3174.9	12632.1	750.2	242.1
9	1346.7	18.0	1379.3	232.3	1123.8	3674.8	263.9	74.8
10	1342.6	18.0	1151.4	494.6	2194.0	11055.6	767.0	199.8
11	1213.7	19.1	1028.5	556.3	6856.91	13047.5	1819.4	380.8
12	1175.0	19.1	989.0	655.2	5360.0	10195.1	1577.0	506.5
13	1164.9	18.7	1116.7	415.2	69414.3	163513	19739.4	4614.7
Total	1165.1	18.4	1104.1	375.0	161641.6	344950	46145.4	10542.1

Note: PP represents Parameter Partition, P represents Precipitation, T represents Temperature, E represents Evapotranspiration, R represents Runoff. The unit for P, E and R is mm, the unit for T is □, and the unit for BOD$_5$,COD,TN and TP is ton/year.

From Fig.5 we can see that, currently, except the precipitation in Wanzhou, Shizhu and Xingshan is larger while less in Zhongxian, Fengdu and Zigui, and the runoff in Wuxi, Kaixian and Xingshan is larger while less in Fengdu and Zhongxian, the spatial distribution of annual precipitation and runoff in the region is relatively even and do not vary greatly in the other counties; the spatial distribution of TN load and TP load is similar with the characteristic that six counties including Yichang, Kaixian, Yunyang, Zhongxian, Wanzhou and Badong contribute more and four counties including Yubei, Nanan, Jiangbei and Wulong contribute less.

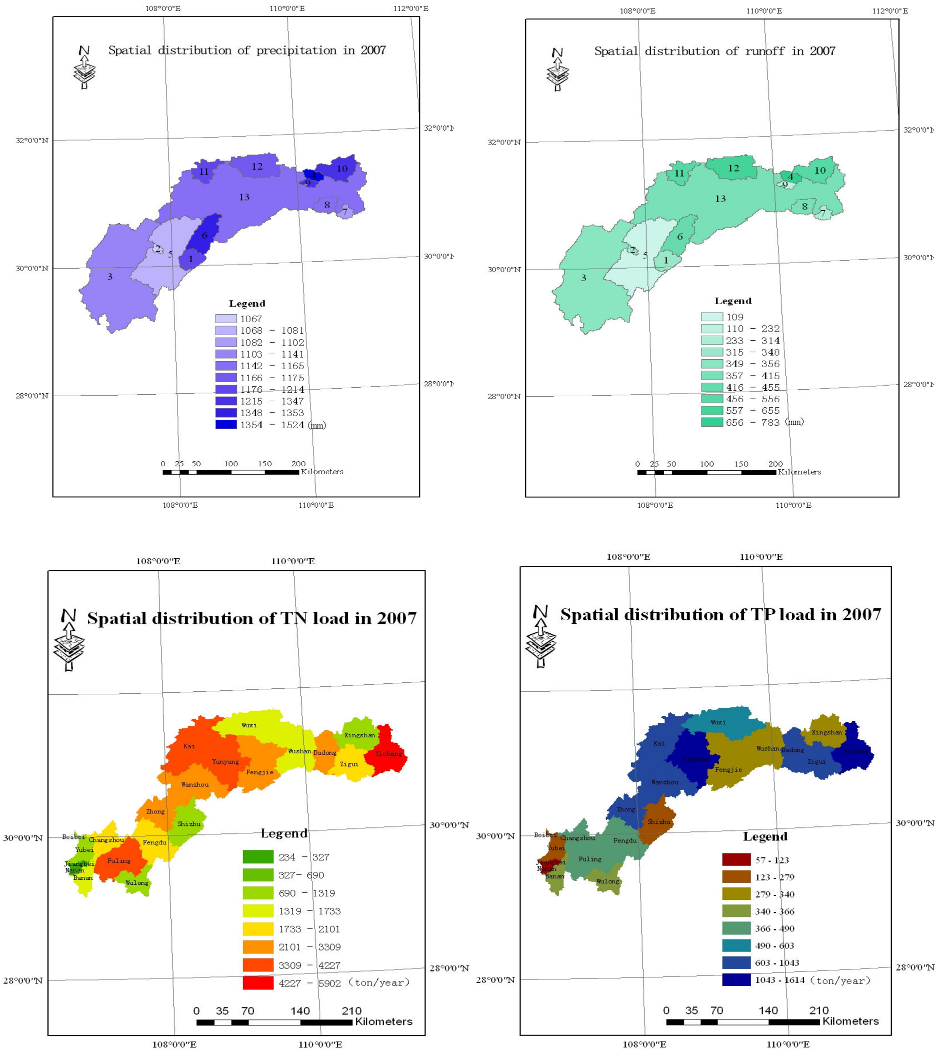

Fig.5 The spatial distribution of precipitation, runoff, TN load and TP load in the Three Gorges Reservoir in 2007

■ Application of SDSM

The precipitation and temperature data both under historical conditions (1961-2009) and three scenarios in the future (2021-2050) at 17 meteorological stations in the Three Gorges Reservoir estimated by GCMs can be obtained through downscaling the GCMs output using SDSM. The performance of GCMs dataset can be verified through the comparison of monthly average precipitation and temperature during 1961-2009 between downscaled results of three scenarios and observations at 17 meteorological stations. The comparison at Yichang station is shown as an example in Fig.6.

As can be seen from Fig.6, the GCMs dataset performances well and the downscaled results could reflect the actual change trends of monthly precipitation and temperature. Thus, we conclude that the GCMs dataset could characterize the climate features in the Three Gorges Reservoir, and can be used to provide the climate scenarios in the future for studying the impacts of climate change on water resources and water environment in the region.

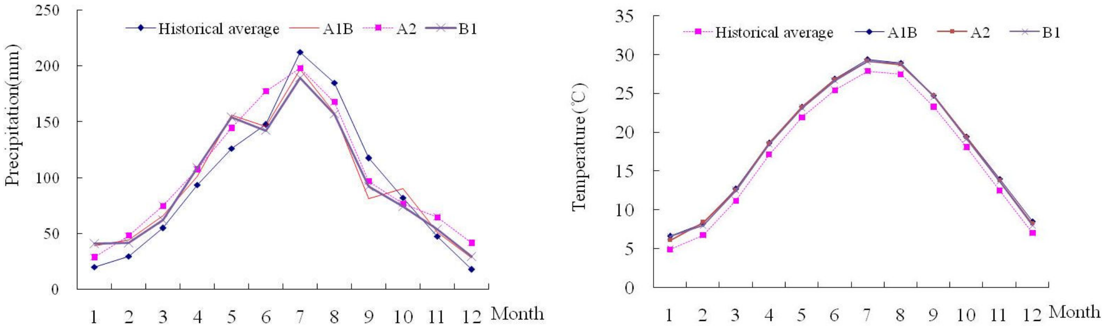

Fig. 6 Comparison of downscaled monthly results with observations at Yichang station

■ Impacts of climate change on water resources and water environment

The precipitation and temperature under three scenarios A1B, A2 and B1 in the future in the region can be obtained based on the GCMs dataset and SDSM. The results indicate that although the prediction results of three scenarios are different from the values, the evolution trends of precipitation and temperature characterized by three scenarios are consistent: precipitation in the future will slightly decrease while temperature will increase. Specially, comparing with the historical average (1961-2009), under the scenarios of A1B,A2 and B1 in the future, the annual precipitation in the region will decrease by 0.4%, 1.4% and 0.5% respectively, and the annual temperature will increase by 1.5℃,1.3℃and 1.2℃. In this study, we select the average condition of three scenarios as the future climate scenario for convenience to evaluate the impacts of climate change on water resources and water environment in the Three Gorges Reservoir through the hydrological model simulations. The results are shown in Table 3.

Table 3 Water resources and water environment in the Three Gorges Reservoir in the future

PP	P	T	E	R	BOD_5	COD	TN	TP
1	1188.0	20.1	1156.4	295.3	3141.4	6095.3	710.8	131.8
2	1058.9	18.9	1107.8	315.2	561.0	944.5	175.9	48.9
3	1131.7	20.1	1137.7	320.3	28808.7	46735.9	9417.8	1822.8
4	1511.5	19.3	1097.1	750.0	848.9	3082.1	195.3	59.9
5	1072.8	19.8	1154.8	100.0	27849.2	47441.3	7147.6	1642.2
6	1341.9	20.5	1194.1	414.0	3532.3	6627.9	1131.7	248.9
7	1093.6	19.1	1106.9	287.1	1883.5	7748.2	449.6	147.8
8	1153.3	19.3	757.8	403.3	3106.1	12358.5	734.0	236.9
9	1335.9	19.3	1414.3	205.2	992.8	3246.5	233.1	66.1
10	1331.9	19.3	1180.1	463.8	2056.9	10365.1	719.1	187.3
11	1204.0	20.5	1060.9	524.3	6462.1	12296.4	1714.7	358.8
12	1165.6	20.4	1018.6	626.6	5125.6	9749.4	1508.1	484.4
13	1155.5	20.0	1145.3	381.2	63724.3	150110	18121.5	4236.4
Total	1155.8	19.7	1134.8	344.4	148093.1	316801	42259.2	9672.1

Note: The meanings of the abbreviations are the same as described in Table 2.

As can be seen from Table 3, in the future, comparing with the historical average, the temperature in the region will increase by 1.3℃ and the evapotranspiration will increase by 2.8%, while the precipitation, runoff and the non-point source pollution load will decrease by 0.8%, 8.2% and 8% respectively. Although the precipitation will not change greatly, the reduction extent of runoff is larger than that of precipitation, bringing forward higher requirements for integrated water resources management in the Three Gorges Reservoir.

■ CONCLUSION

This paper demonstrates a multidisciplinary study by coupling the GCMs output with a distributed hydrological model employing a statistical downscaling model to help evaluate the impacts of climate change on water resources and water environment in an important region and some preliminary results are obtained. This endeavour has led to expand the application of the distributed hydrological model and GCMs from basin scales to super reservoir scales and can be regarded as a reference for evaluating the impacts of climate change on water resources and water environment.

It should be noted that many uncertainties may arise during this study. For example, the prediction results are based on the GCM estimation data which have great uncertainties especially for precipitation, and the application of SDSM when downscaling the GCM data may also bring out uncertainties. In addition, we do not consider the social and economical development in the region when predicting the non-point source pollution load in the future, actually, the prediction of water environment should be reasonably made based on planning materials for the social and economical development, resulting that the prediction results in this study can just be regarded as a reference. Limited to the data available, the hydrological model is just validated using the observed runoff data of 2 years, although the validation results is good, more observed data including long series of runoff, evapotranspiration and groundwater table should be collected for more reasonable and comprehensive validation.

In a word, with the global climate continuously warming, the impacts of climate change on water resources and water environment will be exacerbating. Due to the technical difficulties and uncertainties in distributed hydrological modelling, climate estimation, coupling GCMs with hydrological models as well as social and economical development, more efforts should be made for studying the impacts of climate change on water resources and water environment in the strategic Three Gorges Reservoir.

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■ REFERENCES

[1] Arnell N. W. Climate change and global water resources. Global Environmental Change, 1999(9): 31-49.

[2] Cao L. Q., Yu J. H. ,Ge C. X. Variation of atmospheric water vapor with climate and its impact on water resources of North China. J. Hohai University (Natural Sciences) ,2004,32(5), 504-507.

[3] Chu J.T. Statistical downscaling methods and their application in Hai River Basin of China. PhD Dissertation, Graduate University of Chinese Academy of Sciences, 2009.

[4] Eiji Komatsu. A modeling approach to forecast the effect of long term climate change on lake water quality. Ecological Modeling, 2007: 351-366.

[5] Ekaterini, et al. Quantity and quality integrated catchment modeling under climate change with use of soil and water assessment tool model. Journal of Hydrologic Engineering. 2002, 7(3): 228-245.

[6] Fowler H. J., et al. Linking climate change modeling to impacts studies: recent advances in downscaling techniques for hydrological modeling. International Journal of Climatology, 2007(27): 1547-1578.

[7] Gao Y.X. Research on the effect of hydrological and meteorological factors on the eutrophication and algal growth in Taihu Lake. Yangzhou University, 2006.

[8] Hao X.P.,Xia J., Wang R. Influence of climate change on surface water environment. Hydrology, 2010, 30(1): 67-72.

[9] Jonathan I Matondo, Graciana Peter, et al. Evaluation of the impact of climate change on hydrology and water resources in Swaziland: Part I. Physics and Chemistry of the Earth, 2004(29): 1181-1191.

[10] Jonathan I Matondo, Graciana Peter, et al. Evaluation of the impact of climate change on hydrology and water resources in Swaziland: Part II. Physics and Chemistry of the Earth, 2004(29):1193-1202.

[11] Lei X.H., Jiang Y.Z.,Wang H., et al. Distributed hydrological model Easy DHM. China Water Resources and Hydropower Publishing, Beijing,2010.

[12] Liu C.Z. Potential Impact of climate change on hydrology and water resources in China. Adv. Water Sci.,1997,8(3), 220-225.

[13] Liu H.L. Variety in agro-climate of Three-Gorges Reservoir in Chongqing. Chinese Journal of Eco-Agriculture, 2003, 11 (4) : 139-142.

[14] Mimikou M.A., Kanellopoulou S. P. Human implication of changes in the hydrological regime due to climate change in Northern Greece. Global Environmental Change, 1999(9): 139-156.

[15] Mimikou M.A, E.Baltas, Varanou E., et al. Regional impacts of climate change on water resources quantity and quality indicators. Journal of Hydrology, 2000(234): 95-109.

[16] National Climate Centre. Climate change estimation dataset in China Version 2.0: Manual, 2009

[17] Tibby, Tiller. Climate-water quality relationships in three Western Victorian(Australia) lakes 1980-2000, Hydrobiologia, 2007(591): 219-234.

[18] Wang G. Q., Wang Y. Z. , Shang C. K. Impact of climate change on water resources in the Yellow River. Yellow River,2000,22(9), 40-41.

[19] Wang M.H., Liu L.H., Zhang Q. Climatic characteristics in Sanxia Area. Meteoeological Monthly, 2005, 31 (7) : 68-72.

[20] Whitehead P. G., et al. Impacts of climate change on in stream nitrogen in a low land chalk stream: An appraisal of adaptation strategies. Science of the Total Environment, 2006(365): 260-273.

[21] Wilby R. L., Dawson C. W., Barrow E M. SDSM-a decision support tool for the assessment of regional climate change impacts. Environmental Modeling & Software, 2002(17): 147-159.

[22] Yuan F., Xie Z.H., Ren L.L., Huang Q. Hydrological variation in Hai River Basin due to climate chang. Journal of Hydraulic Engineering, 2005,36(3): 274-278.

[23] Zhang Q.,Wan S.Q.,et al. Characteristics of temperature changes around the Three Gorges with complextopography. Advances in Climate Change Research, 2005, 1 (4) : 164-167.

[24] Zhao H.Y., Li C.C. The climate change and its effect on the water environment in the Hulun Lake Wetland. Journal of Glaciology and Geocryology, 2007,29(5): 795-801.

[25] Zou X.K., Zhang Q., Ye D.X. An analysis on the climatic characteristics of consecutive rainfall in the Three Gorges Area. Journal of Catastrophology, 2005, 20 (1) : 84-89.