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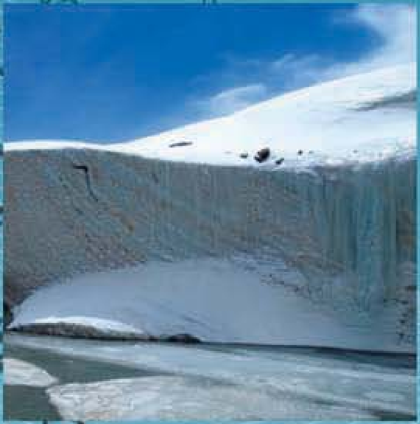
Climate Change and Adaptation for Water Resources in Yellow River Basin, China



IHP VII Technical Document in Hydrology
UNESCO Office in Beijing, 2010

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Note from the Editors

This publication is compilation of research papers on impact of climate change and adaptation for water resources in Yellow River Basin under the **MDG Achievement Fund supported UN China initiative of Climate Change Partnership Framework (CCPF)**. Some of the research papers were presented during the inception workshop and 4th Yellow River Forum. The editors changed the format of the papers for the sake of uniformity, from which we hope readers to feel comfortable, and rearranged the order of papers in order to reflect better where their contents are categorized into. However, only a minimum modification was made to the papers.

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Directory

River Ethics and Sustainable Water Resources Management

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Abstract

Rive ethics extends moral considerations among human beings into the relations between men and river. From a philosophical perspective, the concept confirms a new set of value scale and basic rights by proposing the rights of continuous survival of rivers, along with principles that need to be followed in river development taken by human beings. Sustainable water resources management explores a virtuous cycle between water resources development and good governance. Constituting of river ethics theories would improve the development of sustainable water resources management, pushing forward for the harmonious relations between men and rivers

Key words River ethics, lives, sustainable water resources management

1 Implications of river ethics

Based on deep reflections on river related crisis, the concept of river ethics is to input the "lives" of rivers into river management, investigating the rights, value and principles for river protection through both social and natural sciences perspectives. To mission of this concept is to set a threshold for excessive utilization of human beings on river, and further to realize harmonized relations between men and river.

1.1 Proposal of river ethics

In earlier times, the principles of ethnics are largely set to tackle moral relations within in human beings. Constrained by socio-economic development conditions at that time, conflicts between men and nature had not become an key issue, and thus the issue of ecological ethics would not draw much attention

Starting from the industrial revolution, prominent breakthroughs have been made in the relations between men and nature. In the late 300 years, rate of natural resources exploitation of human beings have surpassed those appeared in the past thousands years. The exploitation of coal, oil, natural gas, water resources and river, along with changes of land use, have fueled accelerated development of global economy. However, the overwhelming rate of exploitation also damaged natural environment, bringing problems such as desertification, depletion of natural resources, pollution of lakes and rivers, and extinct of a broad spectrum of plant and animal species. Further, the development itself is threatening, unprecedentedly, survival and sustainable development of human beings.

The serious situation forced people to re-think the relations between men and river, questions brought in mind include, what are the correct relations between men and rivers? How to utilize water resources, in a sustainable manner, to support continuous development of human society? At these times of reflection, the lives of rivers came into the vision of human beings, which has been a necessary part of human development. As a result, gradually, maintaining harmonious relations between men and rivers, and sustaining the health of river has been an innovative theme for river management and governance.

At the same time, the concept of river ethics reached its full-fledged development. It has been an innovative push of traditional ethnics by extending into the relations between men and rivers. The concept breaks the constraints of traditional ethnics theories in human beings only, extending a separate subject focusing on rivers, enriching the contents and implications of river ethnics.

The concept of river ethnics also completes hostile relations between men and river, opening a new door to re-investigation relations between men and river.

1.2 Implications of river ethics

River ethnics extends the field of moral studies to the relations between men and rivers, confirming a new scale for value recognition, and emphasizing the rights of river survival and sustainability. In addition, the concept has also proposed a spectrum of principles in relation to the exploitation of human beings for rivers. The concept has been a concrete support for harmonious relations between men and rivers.

Major implications of river ethics:

1.2.1 River is alive. The concept of river ethics is based on the respect and recognition of the lives of rivers, with the goal to sustain the health of rivers. Each and every life in this planet enjoys their own rhythm in the process of birth, evolution, development and perish. The core of lives of rivers is water, and its life rhythm is inherent in the flow of waters. The birth, development and evolution of rivers is a natural process, with its own external formalities and counter-effects. Rivers are composed of headwaters, mainstreams, tributaries at various levels, and a well connected channel. They are integrated life forms, consisting of animal and plant species, micro-organism and environmental factors connected by water. They are also open and complex ecosystems, including land-based river bank systems, aquatic systems, wetland systems, and swamp systems. The systems are endowed with their own functions such as habitat, filtration, channeling and confluence. The amount and status of river flows, along with existence of floods, wetlands and water quality couples into a grand but inter-connected picture.

1.2.2 Rivers are of value consisting of its natural and inherent values. River ethics is based on the recognition of river values with a perception to treat river not separately but as a whole articulated by the recognized river value. As an integrated life form with its own aims, rivers could not only exist by itself, but also, with its broad extension in space and temporal wises, they have nurtured the reproduction, growth and development of other lives. These effects have led to colorful biospheres surrounding various rivers. In addition to providing habitat for the land-based species, with its continuity, comprehensiveness and ecological functions (such as filtration, screening, channeling and confluence), rivers has become an integral part in the global scaled material cycling, energy transformation, and information transference. They have been the key for the balance and sustainable development of the global water cycle. As a result of geological movement, the birth of rivers by itself revealed the aims and rules of nature. Ever since rivers are created by the nature, they have been existent for billions of years independently. Within this long period of time, rivers have successfully adapted themselves to external changes, matching with changes and development of the nature. Fact as such reveals the inherent value and rights of the rivers, improving recognition of human beings to the aims, creativity of rivers.

1.2.3 Rivers are with the rights of their own. Such rights are based on the inherent values of rivers, among which the most basic is the right of survival. First of all, rivers are with the right of maintaining their integrity. Rivers are organic integrity with broad spectrum of special temporal and special allocations. Its basic features are its status and amount of flows. In this connection, the first item of river rights is to maintain its integrity. Based on its broad spectrum, the second item of right is to keep continuity of rivers. Connected by rivers, river basins are an integrated and continuous ecosystem. Continuity of river basins is represented by continuity of rivers, that of groundwater and surface water, along with that of land-based and aquatic ecosystems. Thirdly, rivers remain its right for cleanness. River cleanness is a must for the survival of ecosystems dependent upon rivers. Water pollutants could be automatically dissolved by rivers through physical, chemical and biological means. Such self-cleanness capacity reflected the rights of rivers to maintain its cleanness. Fourth, rivers are with their own right to keep sufficient amount of flows. Livers of rivers are largely supported by sufficient amount of flows, and the rivers are the rights to get the amount of flow necessary for its survival from waters confluence. Maintaining this amount of flow is to maintain the rights of survival and ecological viability of rivers. Fifth, rivers are with the rights of creation. With the function to ensure survival of living species in the river basins, rivers are with the rights to create and breed the birth and development of species.

2 Sustainable water resources management

Sustainable Water Resources Management is derived from the concept of sustainable development. Its aim is to investigate water resources problems under the general aims for sustainable development. In 1992, the UN held Convention on Environment and Development in Rio de Janeiro, Brazil. The convention led to the Rio De Janeiro Convention, also named as the 21st Century Agenda, which announced that sustainable development has been a common challenge faced by all human beings. While accessing to the rights of rich and healthy lives, human beings need to maintain harmonious relations with the nature and meet the needs the current generation, which would not jeopardize the justifiable needs of next generations for environment and development . The core question of sustainable development is how to well tackle the relations between population, environment, resources, and development, and reaching balance between the issues. In 1996, the working team of UNESCO-IHP defined “sustainable water resources management” as the management and utilization modes of water supporting current and future social development and benefits without damaging hydrological cycles on which it depends upon, and the integrity of ecosystem.” This concept seeks the best connection and coordination between economic development, environmental protection, and benefits of human beings in the process of water resources planning, development and management. The proposal of Sustainable Water Resources Management not only emphasizes importance of water resources management, but also broadens and deepens the content and principles of water resources management. Compared with other mode of water resources management, sustainable water resources management particularly emphasizes future changes, social benefits, hydrological cycle and the protection of ecosystem and its integrity.

Sustainable water resources management is to require the reasonable development, efficient utilization and integrated management of water resources. Specifically, the concept emphasizes the best utilization and allocation of water resources, along with the saving and protection of water resources. At the same time of avoiding damages of water on humans, the concept pays particular attention on negative impacts of human beings on water. The most direct goal of this concept is to improve efficiency and effects of water utilization results. It is a necessary for solving water resources problems from the root cause, and is also required by sustained water consumption and socio-economic development.

3 The theory of river ethnics is an important tool for the strengthening of sustainable water resources management

Sustainable water resources management satisfies demands for water resources of the current generation, while considering as well water-related benefits of the next generations. Striving for the sustained water resources utilization is one of the keys to harmonious relations between men and nature. People are expecting the result of improved water management and environment through the research and implementation of sustainable water management policies. From this perspective, it could be seen that sustainable water resources management implicates at economic, environment and resources aspects, promoting coordination between the aspects while enhancing international and regional cooperation and public participation. The concept has been a vehicle requesting policy innovations from the government and water management authorities, moreover, it paves the way for enhanced public participation. It is through this course that the theory of river ethics has been produced and strengthened.

River ethics gives out the scientific and moral frameworks for human activities in their relations with rivers. It advocates actions of all stakeholders to protect and save water resources, realizing sustained water resources management and utilization. In general, the theory of river ethnics has been an important handle tackling, and pushing forward sustainable water resources management.

3.1 River ethics helps improve recognition on water resources --- the essence of lives for rivers

River ethnics help improve level of public recognition on the lives of rivers. Through observation, analysis, reflection and prediction, the theory harmonizes relations between men and rivers, along with people and water. River ethics reveals position of water resources as essence of river lives, and major theme of the essence as flow of water. The theory investigates the inherent mechanism and operational rules of river-supporting life systems. It also explains concepts and principles constituting this theory, improving recognition of people on the importance of water, as the essence of lives of rivers. Moreover, the theory helps growth of the knowledge on water resources with other logic components of the river ethics theory.

The theory of river ethics treats river as an integral living organism, extending moral considerations from human societies to natural rivers. Recognition of this theory on the lives of rivers themselves provides a chance to re-evaluate the value of rivers and water resources, readjusting moral dimensions of economic, social and environmental elements. In addition, it provides theoretical sources for the harmonization of basin-scaled relations between stakeholders

River ethics provides knowledge and conditions for the selection of theories on framing the relations between men and river, between humans of different areas and different times. It consolidates moral awareness, standards, visions and judgment of various kinds, helping humans identify their role and effects in the river ethnics framework. By this means, humans would be able to clarify their rights and responsibilities, and thus building up their one guidance of behaviors. For instance, throughout the Yellow River, where scarcity based water conflicts are getting manifest, irrigation areas has been increasing continuously, and plants consuming water excessively are still grown in large areas. Water used to sustain the survival of the Yellow River has been significantly deprived damaging the health of the Yellow River. The essential reasons for this part are the deficiency of knowledge on rivers as living organism with its own rights and needs. Often, the river is simply treated as a tool, which has been the dominant perception to the relations between men and rivers. If the theory of river ethics can be set up, people would understand damage the health of river is similar to damage the fresh of lives, which is a guilty behavior. Such mentality would lead to a unsurpassable threshold for the sustained survival of rivers.

3.2 River ethics supports the righteous perception about water resources

Guided by traditional perceptions, human beings excessively get and damage water resources, with the most direct and convenient means, to satisfy their demands for economic development. This has led to the overdraft of water resources. However, the crisis of water resources on the contrary would bring negative impacts upon the “crisis makers”. Problems such as river interruption and water pollution not only restrict socio-economic development, but also threaten the existence of human beings. In the new temporal and cultural backgrounds, river ethics constitutes the new judgment criteria telling the value of rivers and water resources.

Based on the points of river ethnics, rivers need to be treated as an integrated life system. They won't be dependent on the evaluations of human beings, and are immune from the subjective perceptions of human beings. They are with the aims of their own, and their values are diverse and inter-connected, following the ecological rule of "self-initiated development". The over pursuance human beings for economic values from rivers would only be reached at the costs of damaging other values of the rivers. Through the judging criteria of values reflected in the process, research of river ethnics is based on an important goal, which is to inspire and arouse the attention and respect of human beings for rivers, leading their care for harmonious development between men and rivers, and facilitating their knowledge on the righteousness for protection and development of values for the lives of rivers, while avoiding the negative actions that damage or even destroy values and lives of rivers. In the past, humans used to set the rate of river exploitation and success of floods prevention as criteria measuring the success of river management. Based on the theories of river ethics, a new mentality needs to be applied, re-evaluating and re-considering the perceptions to rivers as tools. Instead, the perceptions for restoring ecological functions of rivers, maintain and protect ecological balance of river basins need to be re-installed in works for river management. Such thought needs to become an important Atlas guiding cultural and natural protection works for river basins.

3.3 River ethics help improve water resources management

Constituting the river ethics would help improve water resources management, tuning the perceptions of men to water from a subject of being used and owned into the relations of harmonization and co-existence.

When humans recognized the independent role, and inherent value and rights of rivers, the responsibilities and obligations of humans to rivers would become a basic necessity for the implementation of river ethics. Under the framework of river ethics, humans need to reasonably balance water resources, and explore innovative mode of river exploitation and governance. The theory also requires strengthening of compulsory good governance, ensuring the fairness, righteousness, orderliness in the process of water resources development. By this means, harmonization can be realized between men and men, men and river, and men and water. For instance, to tackle rivers of different situations, various target based measures need to be taken. For rivers heavily affected by floods, dams and other engineering works need to be built up, improving floods control capacity and preventing the damages of floods on human beings. Such works would also help change floods from disasters into resources. In the meantime, rivers and their operational rules need to be respected by leaving room for floods. For rivers haunted by water scarcity, basin-scalded integrated water resources management need to be planned and strengthened, improving best utilization and management of water resources. This would help stop rocketing increase of water demands, and promote water use efficiency. For rivers with heavy sedimentation loads, a series of measures such as "increasing the speed and amount of flow, reducing sedimentation while increasing water use efficiency" need to be applied. These measures would help balance the coordination between water and sediments in the river, and harmonize the two sides. For rivers in the ecological sensitive arid and semi-arid areas, the carrying capacity of rivers needs to be fully considered so as to rightly handle relations between socio-economic development and requests for ecological water. In these areas, efforts need to be taken to protect natural oasis, curbing the extension of desertification. In addition, pollution prevention needs to be applied to rivers of all types, strictly curbing pollutants release, and avoiding the heavy damages on rivers made by humans generated pollution.

3.4 River ethics create a good external environment for the implementation of sustainable water resources management

River ethics sets the template for rewarding, advising and modeling for mobilizing the thoughts and awareness among the public for self-discipline. Further, such thoughts and awareness, when combined with social lives, would be transcended into the psychological base of strong stability. Cite the management of Yellow River for example, due to changes of the Yellow River basin, it would be hard to promote sustainable water resources management if simply relying upon the forces of government and the market. For instance, at the peak times of irrigation, it is impossible to stop farmers on the coastal side from privately withdrawing water of the Yellow River. Even if such private withdrawal is prohibited by the law, it is quite hard to monitor. In addition, traditional thoughts on the ownership of water based on its household proximity provide another support for such phenomenon. To break such thoughts, righteous perceptions about the rights and value of river need to be instilled into the blood of people by formulating innovative and water saving trends in society. In this way, reasonable use and strict protection of the Yellow River would gain enhanced supports from the public, and the respect for lives of rivers would not only stay as a form and only attitude, but would become the heart-felt expectations to be grown, ultimately, into moral rule inherent in human consciences that guide the water protection behavior of human beings.

4 Concluding remarks

River ethics is quite an inclusive concept with strong feature of inter-disciplinary on the cutting edge. It extends the traditional moral dimensions into the relations between men and river, and men and water. It also sets an innovative perspective for sustainable water resources management that calls for the joint efforts and participation of the general public. Construction of river ethnics undoubtedly provides a strong support and push for the development of sustainable water resources management. In addition, sustainable water resources management also provides a strategic chance for the development of river ethics theories.

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Changes of the Yellow River Water Resources and Countermeasures

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Abstract

The Yellow River (YR) is short of water resources, with the decrease of rainfall and changing of underlayer condition, the runoff is trending down. Also due to the increasing of economic development, the industry development scale is enlarged and the water demand is also increased largely. All these would absolutely aggravate the contradiction between water demand and water supply in the Yellow Rive Basin. Therefore, besides the implementation of integrated catchment management and integrated water regulation in the Yellow River, the following measures will also be adopted to cope with the Yellow River water resources changes, strengthen water right system establishment, water saving society construction, improving water and sediment regulation system, promoting south to north water transfer project construction, strengthen the law measures, and establish perfect water resources monitoring system etc..

Keywords The Yellow River Water Resources Changes Countermeasures

1 Yellow River water resources overview and trends

1.1 Yellow River water resources overview and characteristics

1.1.1 Yellow River water resources amount

According to 1956 to 2000 series statistics, the total annual Yellow River water resources amount is 64.71 billion m3, of which the natural surface runoff is 53.48 billion m3, the ground water amount un-overlapped with surface water is 11.23 billion m3.

1.1.2 Characteristics of the Yellow River water resources

(1) Less water and more sand, water and sediment source differences, water does not cohere with sediment

Yellow River basin area accounts for 8% of land area of China, however natural runoff only account for 2% of the country, and YR ranking fifth in China's seven major rivers. In 2006, per capita runoff of YR basin is 473m3, account for 23% of the national average runoff; Per Mu of cultivated land occupied runoff 220m3, only account for 15% of the national average level. Take out of more than 100 million m3 of water transfer to other regions out of basin, the water quantity of per mu of cultivated land and per capita in the basin is less.

Yellow River is a world famous sediment-laden river. According to 1956 to 2000 series statistics, the average years of measured sediment runoff in Sanmenxia Station is 1.14 billion t, and the average sediment concentration over 31.6kg/m3, YR is in the top of the list of major rivers at domestic and abroad.

Yellow River runoff and sediment source areas in space and time distribution are extremely uneven. The runoff above Lanzhou accounts for 62% of the whole runoff of YR, sediment yield only share 9% of the whole river. The runoff from the middle reaches accounts for 38% of the whole river; however the sediment discharge is accounted for 91% of the whole river. The runoff from Hekouzhen to Longmen accounts for 9% of the whole river, sediment transport accounts for 54% of the whole river. Distribution during the year, the sediment is more concentrated than runoff of YR, runoff in flood season usually accounts for 60% of annual runoff, however the annual sediment load and sediment transport accounted for more than 80%. The unbalance water and sediment of the YR mainly represent high sediment coefficient and silt content from the main stream and tributary.

(2) Large annual variation of runoff, high concentrated distribution within a year, and continuous dry period of time long

The annual variation of YR runoff is large, generally the maximum annul runoff in the main stream hydrological station is 3.1~3.5 times bigger than the minimum runoff, and in the tributary the difference can be 5~12 times. The distribution of the runoff of the YR is concentrated. The runoff of the main stream and major tributary in the flood season from July to October accounted for more than 60% of the whole runoff the year, and flood forms most of the runoff.

Since there have field data in the YR basin, there have been three consecutive dry period and YR have the longest dry period of the duration in the north China. And from 1922 to 1932, 1969 to 1974, and 1990 to 2002 were of three consecutive dry periods, continued for 11 years, 6 years and 13 years respectively. The average natural river runoff was equal to 74%, 84% and 83% of the mean years.

(3) Inconsistent distribution of water resources and land sources

The runoff of YR is mainly from the upper reaches over Lanzhou, especially from the source areas. However, most of the arable land concentrated in the areas of Ningxia and Mongolia along the YR, middle reaches of Fen River, Wei River Basin, and irrigated areas in the downstream where local runoff is less. According to statistics, the source areas of cultivated land area is less than 1% of the whole basin, water accounts for 29% of the whole basin; Lanzhou - HekouTown area of the entire watershed land interval accounts for 20% of the whole basin, and water resources is only 6% of the whole basin, and consider the loss of the confluence and in the main channel, the natural runoff in Hekou Town section is only 200 million m3 more than that in Lanzhou section of. Down stream of YR is a hanging river, confluence area is small, the natural runoff of Lijin section only 200 million m3 more than that of Huayuankou section, but the area of the Yellow River Irrigation Area in this section is accounts for 32% of the whole YR effective irrigation areas.

(4) Serious issues on water for ecological environment and sediment transport

YR has high sediment transport capacity, high sediment, which causing the rivers serious. To reduce intensity of the lower Yellow River silting, it is needed to maintain necessary water sediment transport and ecological base flow. According to the average years of 21 billion m3 of water to transport sediment to the sea and sustain the ecosystem, the runoff utilization rate of the YR should not exceed 60%.

In the Yellow River Basin, the area of arid and semi-arid regions account for 32%, 210,000 km2 of sandy areas erosion intensity is greater than 5000t per year per square kilometer. Fragile ecological environment in these areas, ecological and environmental protection, especially sandy soil erosion need water.

1.2 Changes and trends of the YR water resources

1.2.1 Factors related to changes in the YR water resources

(1) Temperature changes

The temperature in the YR Basin is rise in the normal annual and interannual (see Figure 1), consistent with global warming, since 1990's this trend is particularly significant. Temperature increased by 0.77 ℃ (relative from 1956 to 1989 average).

(2) Precipitation

According to data analysis, the Yellow River Basin in general was decreasing trend in precipitation (Figure 2). From 1956 to 2005, the annual precipitation of the YR over Huangkou is about 450.5mm, which reduced rainfall since 1986 nearly 7%.

(3) Runoff

According to the calculations of the natural runoff (Huayuankou hydrological station) from 1956 to 2000, is 53.28 billion m3. In recent years, the natural runoff of the YR Basin greatly reduced (see Figure 3), natural runoff since 1986 has a decrease of nearly 20% (compared to before 1986). Runoff and precipitation trends broadly consistent with the trend, showing that climate influence the runoff.

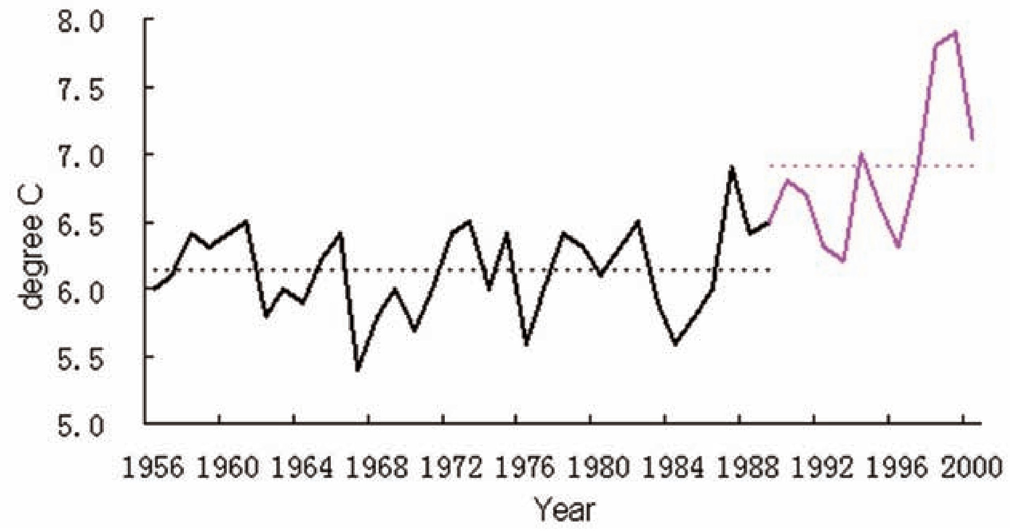

Figure 1 Annual average temperature changes in the Yellow River basin

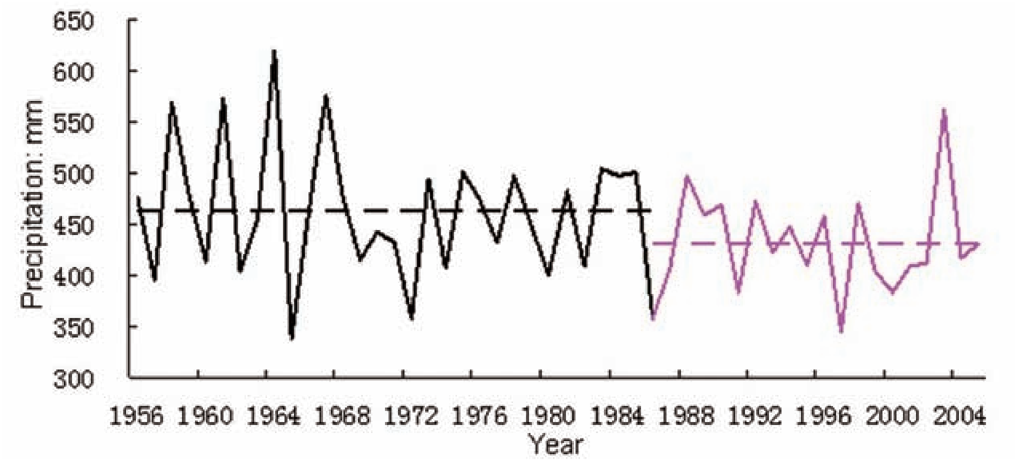

Figure 2 Annual precipitation changes in the Yellow River Basin upstream of Huayunkou station

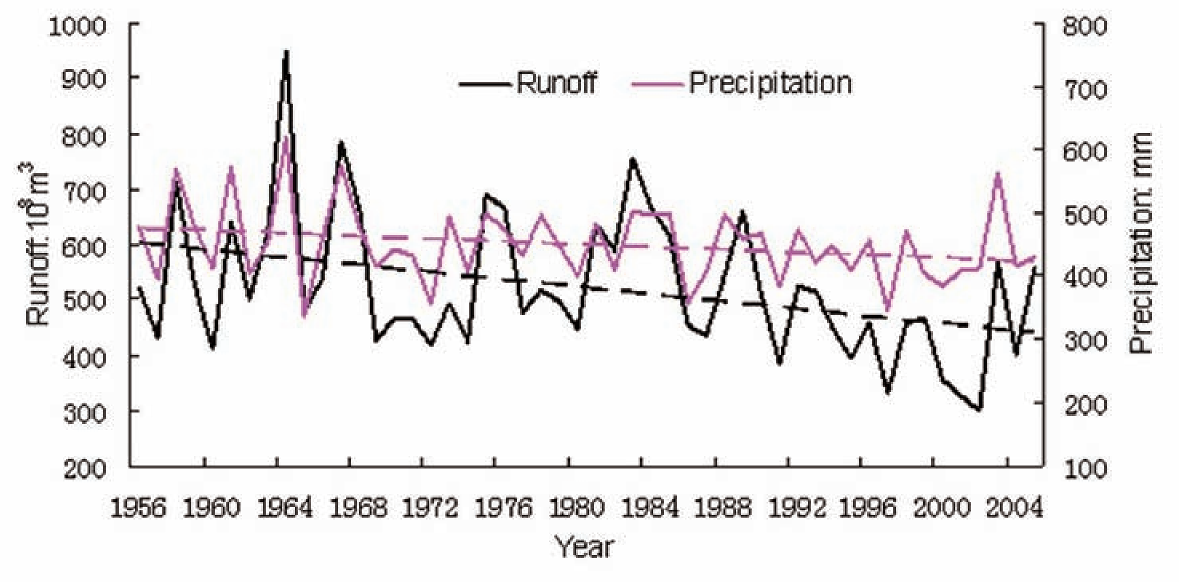

Figure 3 Natural runoff changes of the Yellow River at Huayunkou Station

(4) Change in water and sediment relation

Due to the increase of industrial and agricultural water consumption, increasing human activity and decrease of precipitation, etc, the runoff has dramatically reduced since 1980s,which has further deteriorated the uneven water and sediment relation of the Yellow River, and the main indication is the increase of the coming sediment coefficients of the main sediment source regions . For example, the average coming sediment coefficient of the region from Hekouzhen to Longmen, which is the main sediment source region was 0.76 kg/s of year 1956 to 1979, but the number increased to 0.89 kg/s of years for1980 to 2000. The increase of coming sediment coefficient of flood events was more obviously. The coming sediment coefficients of floods at Tongguan Station before year 1960, were normally smaller than 0.05 kg/s, but the coefficients were mostly bigger than 0.10 kg/s, and even higher than 0.30 kg/s.

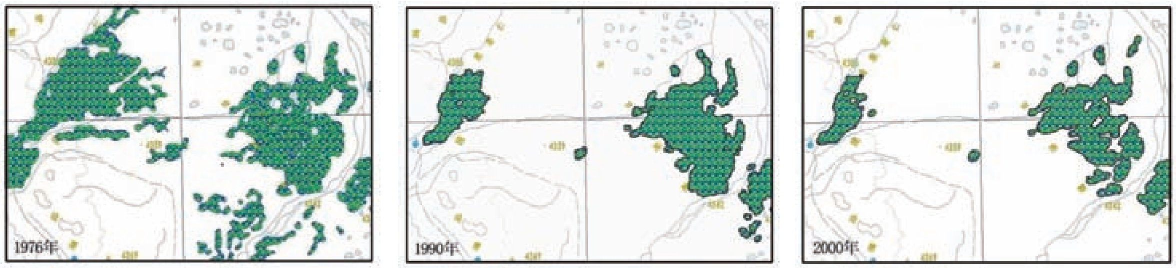

Figure 4 The changes in swamp and lakes in headwater region of the Yellow River upstream of Jishixia

The occurrence frequency of middle size floods also decreased. The characteristics of floods in the middle and lower reaches has changed a lot after 1986, the average number of flood events whose peak discharge at Huayunkou Station bigger that 3000 m3/s and 6000 m3/s in a year was 5 and 1.4 respectively before 1986, it decreased to 2.2 and 0.3 after 1986, and the peak discharge, duration and water volume of a flood event have also drastically decreased at the same time.

(5) Ecosystem and environment changes in the headwater region of the Yellow River

Due to warmer resulted from climate change, the glacier area of Animaqing Mountain in Headwater region of the Yellow River decreased 17% in recent 35 years from 1966 to 2000, the glacier line rose nearly 30m, many lakes shrank and even disappeared, the ecosystem and environment deteriorated. The area of swamp and lake decreased 3000 km2 from 1976 to 2000. The increase in temperature has probably led to the melt of permafrost, increase in evaporation, and runoff reduction.

At mean time, the climate change and over-grazing has resulted in degradation of grassland and serious rat hazard.

The headwater region is the main water sources region of the Yellow River , its runoff amount accounts 40% of that of the total basin. Thus, it is regarded as the water tower of the basin, the deterioration of the eco-environment in the headwater region has adversely effected the runoff volume of the whole basin.

(6) Land use changes in the basin

Since 1980s, the river runoffs in some regions has decreased even in the same rainfall condition due to the jointly impacts of less precipitation, water and soil conservation, groundwater development and rainwater collection and development. According to the result of the second round national water resources assessment of china, the annual average natural runoff the Yellow River Basin has decreased 3.6 km3 or 6% compared to last assessment. The runoff reduction trend is inevitable due to the land use changes.

As shown in Figure 5, the rainfall runoff relation of the middle reach changed apparently and can be identified in two different cluster , one is from year1956 to 1969 which was before the large scale water and soil conservation project, one was from year 1980 to 2000 when the water and soil conservation project took effect.

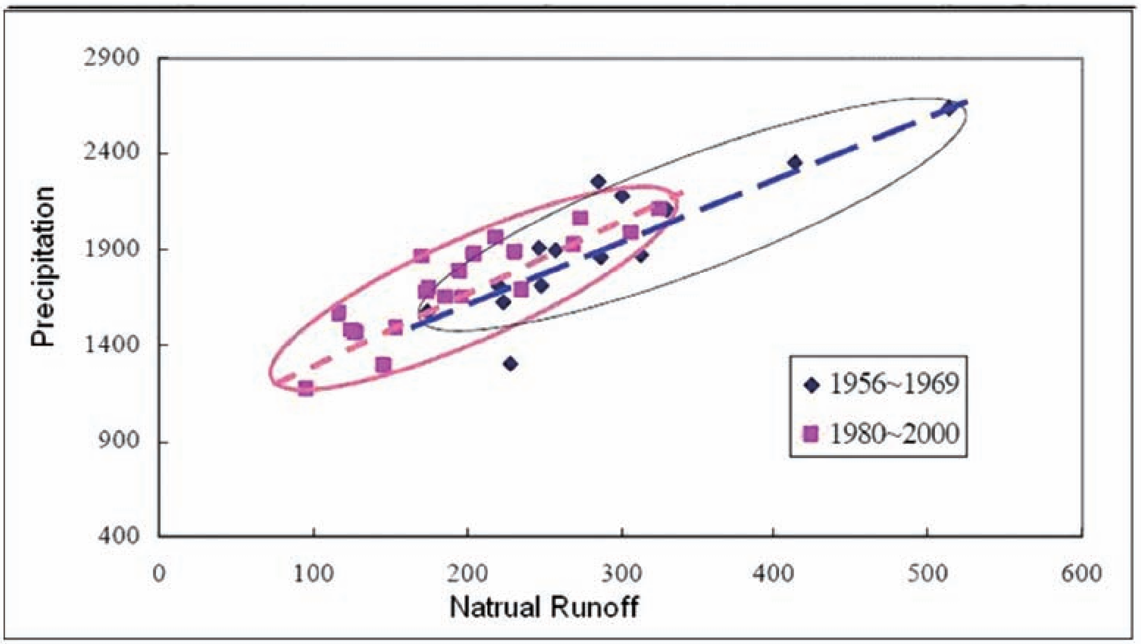

Figure 5 Rainfall runoff relation changes in the middle reach of the Yellow River

1.2.2 Analysis of the changing trend of Yellow River water resources

Based on the present knowledge, the precipitation change is mainly effected by the synchroneity and fluctuation of climate, which is difficult to predict its changing trend in short and middle term. However, the temperature of the Yellow River basin will be a constantly rise up trend, the land use change will also continuously decrease the runoff coefficient , thus the water resources of the Yellow River will be in decrease trend for a long term .

2 Water demand of economic and social development and supply—demand situation analysis

Economy development of Yellow River water supply area, on the whole, is relatively backward. Agriculture is the major water user, at the same time among industrial water users the high water using projects such as power, heavy chemical industry accounts for more than major. With the implementation of the west regions development, west-east power transmission and the rise of the central region development strategies, the Yellow River water supply area economy will have a great-leap-forward development and Yellow River water consumption especially industrial water demand will have a big increase. While Yellow River itself also need basic water to maintain the healthy life, the contradiction between supply and demand will be worsen.

2.1 Strategy position and overall layout of the economic and social development

Yellow River links east, central and west regions. land, mineral, energy resources of basin and related areas are rich. All these show that the basin is of important strategic position in ensuring the national food security, energy security and the ecological security.

The area along the Yellow River which anciently is agricultural economy development area has a long Yellow

River irrigation history. The status irrigation area reaches 11465 million mu (including the downstream out-watershed Yellow River irrigation area) which is the major grain-producing areas and agricultural production base. about 30 million mu wasteland in the Yellow River upper and middle region, which accounts for 30% of the total of wasteland of china, is an important reserve cultivated land resources. To ensure achieving steady-yield of Yellow River irrigation area is very important to realize the target of 100 billion jin grain yield increase and more than 95% grain self-sufficiency.

The Yellow River basin is of significant advantages in coal, electricity, petroleum and natural gas energy industry and is an important energy, heavy chemical industries base. Coal reserves 449.2 billion t, accounts for 46.5% of china. the total prognostic reserve reaches 1.5 trillion t. According to the relevant state planning, energy bases which need be supported by the Yellow River water resources are: ningxia east-ningxia energy base, Inner Mongolia energy base called the Hohhot- Baotou- Erdos "golden triangle", Wusitai and wuhai industrial energy base, shaanxi is northwest shaanxi yulin energy industrial base, lishi-liulin coal energy base. At the same time, the middle and lower Yellow River area is distributed changqing oilfield, zhongyuan oilfield and shengli oilfield. Mineral resources and energy resources development and utilization will play a leading role in boosting the development of national economy, with a strategic position of resources support and east-west region coordination in the whole process of national economy development.

The world's largest loess plateau is located at the upper and middle region of Yellow River. Weak ecological environment and serious soil erosion of loess plateau is not only the root of Yellow River hard to be harnessed and but also the important cause of local economic development behind. Therefore, further strengthen the soil erosion control, developing ecological agriculture is of great significance to ensure flood safety, to improve ecological environment, to ensure sustainable economic and social development.

Along with the national development strategy, investment will adjust to the Midwest, relying on the asian-european land bridge and Beijing-Guangzhou, Beijing-Jiulong, Beijing-Shanghai railway, the area along the Yellow River has become China's important communication link, transition zone of China's reform, opening up from south to north, east to west. In accordance with China's economic development strategy of the beginning of the 21st century, the area along the Yellow River will gradually formed Yellow River upstream hydropower and non-ferrous metal base of which the center is Lanzhou, including the zone from Longyangxia gorge to Qingtongxia gorge, accelerating hydropower resources and nonferrous metal mineral resources development , properly developing processing industry. In xian center for comprehensive economic hi-tech development zone, processing industries will be concentrated on the areas, built with hi-tech level of economic development zone, it will be northwestern region of technical equipment industrialization base. The middle Yellow River energy base will be formed in southern shanxi, northern shaanxi, west Inner Mongolia, west henan, etc, and it will be one of ten mineral resources areas. speeding coal resources development and electric power construction, combining the upstream hydropower development, increase the scale of west-east gas transmission, power transmission, key comprehensive industrial zone focused on coal, electricity, aluminum, chemical industry etc will be formed. In the lower Yellow River in huanghuaihai plain area, the important oil and Marine development, petroleum chemical industry base, and foreign-oriented economy development zone will be build.

2.2 Water demand analysis

2.2.1 River channel water demand

River water demand includes sediment transmission water in flood season and ecological water requirement in non-flood season.

(1) Sediment transmission water in flood season

Consider sand reduction of water and soil conservation and sustainable main channel, based on large amount of comprehensive analysis, the sediment transmission water in flood season averagely should be 15 ~ 17 billion m3 at LiJin section, 12 billion m3 at HeKouZhen section in the upstream of Yellow River.

(2) The ecological water requirement in non-flood season

Based on the comprehensive analysis of the Yellow River water resources, and considering the current situation and future water supply and demand situation, the ecological water requirement at LiJin section is 5 billion m3. Meeting the ice-flood control requirement and ecological environment requirements, the ecological water requirement at HeKouZhen section is 7.7 billion m3.

In conclusion, lower Yellow River LiJin section lower water demand is about 20 ~ 22 billion m3, the upstream of Yellow River channel HeKouZhen section lower water demand is about 19.7 billion m3.

2.2.2 Outside-channel water demand forecast

It is forecasted that in 2030 the Yellow River basin will be of 130 million population, urbanization rate reaching 59%, farmland effective irrigation area reaching 86.47 million mu which is 8.82 million mu more than that in 2006. industrial added value reaching 3.2 trillion yuan which is 2.5 trillion yuan more than that in 2006.

According to the requirements of water-saving society construction, strengthening water saving mode, industrial water reuse rate will reach 80% in the Yellow River water supply area in 2030, irrigation water use coefficient will increase to 0.59. Based on the forecast, off-channel water demand will increase to 65.1 trillion m3 in 2030 from current 58.7 trillion m3. Net increment is 6.4 trillion m3. Among those the basin water demand will increase to 54.7 trillion m3 in 2030 from current 48 trillion m3, and net increment is 6.7 trillion m3. industrial water demand increases 6.3 trillion m3 and agricultural water demand decreases 2.4 trillion m3.

2.3 Water Shortage Situation

The contradiction between supply and demand of water will become more acute. According to the analysis, under the current situation, the available water supply of Yellow River basin is 40.6 billion m3, and however national economy water demand is 48 billion m3, the gap is 7.4 billion m3.

In consideration of the water saving by 2030, national economy water demand will reach 54.7 billion m3, and the gap will reach 10.4 billion m3. At the same time, the water into the sea is only 18.3 billion m3 which can not meet the need of river ecological water demand. Therefore, the shortage of water resources will become the main restraining factor of future economic and social sustainable development and ecological environment benign maintenance.

3 Strategy to cope with the change of the Yellow River water resources

3.1 The measures being and to be adopted for the Yellow River water resources management

(1) Pioneer in implementing water right allocation at the basin level and the local level

In 1987, the State Council has approved the Yellow River water availability allocation scheme, which is valid until south-to-north water transfer project takes effect. The natural annual runoff of the Yellow River is about 58 billion m3, among which 37 billion m3 is allocated among 9 provinces within the basin, and Henbei province and Tianjin city outside the basin, and 21 billion m3 is allocated to be used for sediment transporting and ecological environment. The Yellow River is the first one to implement water allocation among all the major rivers in China.

(2) Carrying out water right transfer demonstration sites in a positive and stable way

In the Yellow River, the agricultural water use amount consists of 79% of the total water use amount, especially in Ningxia and Inner Mongolia autonomous regions, the ratio is 97%, and the irrigation water use coefficient is only 0.3~0.4, so the water saving potential is big in the agricultural water use. In order to explore the approach of optimizing the Yellow River water resources allocation by market means, support the local economic development sustainable, promote water saving society construction, and lead the limited water resources transferring to high efficiency industries, in 2003, the Yellow River water right tranfer demonstration sites have been carried out in both Inner Mongolia and Ningxia Hui autonomous region. The owner of newly built industrial projects invested in water saving projects construction of the irrigation districts. The amount of lost water during the transport can be saved and transferred to the newly built industrial projects in a paid way.

Up to now, 14 projects, approved by the national development and reform commission, have finished water saving projects construction task, the accumulated invest is 0.798 billion RMB, the lined channel is 1716.7 km, the amount of water transfer is 0.164 billion m3.The north Yellow River district, Inner Mongolia has completed the construction goal of 2010 which has been set in water transfer planning. The accumulated investment is 0.69 billion RMB, the amount of water transfer is 0.13 billion m3.

Currently the approved second phase of Erdos city water transfer focus on further promoting high efficient agricultural water saving facilities, adjusting the planting structure in a rational way, 0.1 billion m3 of water can be further transferred through implementing the water saving task set in the planning.

(3) Implemented the Yellow River water regulation

In order to alleviate the conflict on water supply and demand of the Yellow River, after being approved by the State Council, the unified water regulation has been implemented since March, 1999. Following the principles such as water allocation approved by the state council, the unified regulation by YRCC, the water use and water distribution by the Provinces, double control on the total water use and flows of the inter-province section, the unified regulation on major water diversion projects and reservoirs, the unified water regulation has been carried out in a way combining annual plan, monthly and ten-day regulation scheme and real time regulation orders. The Yellow River water Regulation System has been developed, the Yellow River water management and regulation capability has been enhanced, and the water regulation modernization level is promoted. And with the issue of the Yellow River Water Regulation Ordinance on first August 2006 by the State Council, the Yellow River water regulation range is extend from the part mainstream to the whole mainstream and main tributaries, and regulation period is spread from no-flood season to the whole year.

Since the Yellow River water regulation has been implemented, Yellow River Conservancy Commission adopted administrative, jural, constructive, technical and economic means synthetically, consecutive ten years no river drying has been realized, and enormous social, economic and ecological benefit has been achieved. First is implementing the big river integrated water regulation and management has been originated in the world, the management mechanism and mode of basin management combing with Regional management according with the national situation have been established, the established coordination and negotiation mechanism, institution system, work procedure and technical demand have been extracted as the national law. Second is through the regulation, the increasing speed of water use is led down, water use distribution at every department is nearing reasonable, fair water use system has been formed, the safety of water supply is ensured. The water consumption amount of the main users is reduced significantly, water utilization efficiency is improved notability. According to calculating, the water utilization amount of every 10000 yuan GDP reduced from 1672 m3/s in 1990 to 354 m3/s in 2006, the irrigation quota reduced from 514 m3 in 1990 to 420 m3 in 2006. Third is the deteriorating trend of the basin ecology has been held back, and being improved gradually. In the condition of the natural annual runoff is less than that of before implementing water regulation, the annual runoff flowing into the sea in Lijin Station is increased 0.6 billion m3, and during no-flood season, 1.9 billion m3 is increased. The river base flow is increased, addition with enhancing pollution controlling measures, the Yellow River water quality is better observably, the river ecological system is restored. According to remote metering, in 2009, the wetland area increased 253 km2 than that in 1997, and the bird kinds in the Yellow River delta national natural protection area increased 109 than that in 1990, the bird number increased 400 than that in 1990. Fourthly is the economic benefit is very significant. According to the preliminary calculate and analysis of China Institute of Water Resources and Hydropower Research and Tsinghua University, during the 10 years of implementing water regulation, the GDP increased 350.4 billion yuan and the food production increased 3.719 x107 t totally.

(4) Implementing the Lower Reach ecological water regulation successfully

The development of the Yellow River water resources management and the demand of construction ecological civilization demand that the Yellow River water resources utilization should increased for ecology, and to improve the Yellow River basin ecological environment further. So two times of the lower reach ecological water regulation were implemented in 2008 and 2009 respectively. Recent period, the priority of the lower reach ecological water regulation is to content the delta wetland ecological system water use, and consider the lower reach channel and offing ecological water use. The objective of ecological water regulation is to increase the delta wetland area stably, improve the wetland ecological system, and protection biodiversity.

3.2 Countermeasures to the future Yellow River water management

(1) Establishing perfect water right systems

The system construction has to be enhanced, and the management behavior has to be put in order so as to construct perfect Yellow River water management system. Water use monitoring and measuring as well as information summation systems have to be established. Water licensing information system has to be established to strength water permitting and wastewater discharge permitting. Water justification system has to be established to perfect water justification system. Groundwater management system needs s to be established to enhance supervisions on groundwater development and utilization. The strict water regulation and management system in the tributary needs to be established to perfect low flow regulation and emergent flow regulation system. The compensation mechanism on over allocation water use or use ecological water has to be established to curb over allocation water use. The drought control information collecting and sharing needs to be established. Water transfer system has to be constructed. The bulletin of the current status of water quality of key water function zone also needs to be established, and the governors’ responsibility system has to be established for inter-provincial relief zone.

(2) Set up scientific constraint index system

Firstly the red line system has to be set up for Yellow River water development and utilization control. According to the allocation scheme on available Yellow River water supply approved by the state council, the total amount of water permitting within one province have to be allocated to each region. Water regulation scheme in the Interprovincial tributary has to be carried out as soon as possible. Taking the scheme on the amount of permitted water within one region, flow control index at each cross section as well as some national policies into consideration, the red line the red line system has to be set up for Yellow River water development and utilization control.

The regulation on the Yellow River water regulation needs to be implemented, and water regulation scheme on annual, monthly and 10-days basis is scientifically compiled and strictly implemented in order to guarantee the minimum flow at the inter provincial section and confluence section. Some research on no functional drying out in the Yellow River has to be explored in order to promote the good maintenance of ecosystem in the river channel/wetland and estuary delta.

Secondly the red line has to be set up for water efficiency control. According to some national law/policies and the requirements for establishing resources saving, environmental friendly society, the construction project water justification report, which center around water efficiency, has to be reviewed. It puts strict constraints on high water consumption and heavy polluted construction project, and turns water use into high efficiency and pollution reduction, and promotes water saving society construction.

Water right transfer and exchange are carried out. On the basis of water right transfer demonstration sites in Ningxia and Inner Mongolia, the water right transfer scope has to be widen. For some provinces withdrawing more water than permitted, no more new water right transfer projects can be approved. For some provinces with no extra amount of permitted water and some new construction projects still need more water, the amount of water required by the new construction project has to be meet by water right transfer. The study on Han river to Wei river water right exchange has to carried out, and the demonstration site has to be carried out at the right time. Some research on water and sediment exchange and inter city water right transfer has to be carried out. The Yellow River water right transaction market needs to set up in order to the optimum water allocation and efficient water utilization.

Based on research on water requirements by various river functions, no drying out index system at key sections along the mainstream is put forward, which is used to guiding the regulation practice on no functional drying out in the Yellow River. The healthy life of the Yellow River evaluation indices needs to be put forward, and the healthy status of the Yellow River is evaluated every some time.

Thirdly the red line on wastewater discharge has to be set up. In line with the water quality goal required by water functional zone, focusing on administrative region, taking water quality monitoring in the relief zone along the inter province as nodes, specifying the red line for waste water discharge in water functional zone, the allocation scheme on the total amount of permitted wastewater discharge at the provincial level will be put forward.

(3) Set up strict supervision and implementation system

The responsibility system on water regulation has to be implemented so as to specify the duties and sectors of the tributary regulation at local level. The implementing situations of the Yellow River water regulation have to be main components of achievements examination of officials the local governments and head of some concerning enterprise. In line with the implementation of most strict water management at national level, the provinces has to make the total amount of water use, water efficiency and the total amount of wastewater discharge as constraint indices under supervision. These indices have to be included into the integrated evaluation system on local socio-economical development. The mechanisms on the total amount of water use and water efficiency review need to be explored.

The double control of both the total amount of water use and flow need to be enhanced during water regulation in order to guarantee that some provinces don not withdraw more water than permitted and flow at the key section meet the requirements. The punishment and compensation system on over allocation water use and use water for ecology has to be implemented. For some provinces whose flow release at certain section not meeting the requirement or taking more water than permitted, some bulletins will be issued at the first time, finally some cap has been put on new construction projects approval.

The system on keeping the public informed has to be implemented. Some regulations such as the Yellow River water regulation and water license and water resources fee collection and management regulation have to be implemented. The information on the current status of water regulation and water functional zone has to be issued every some time in order to promote the public, fairness, justification of the Yellow River water management.

The supervision on wastewater discharge in water functional zone has to be enhanced. The double control of both water functional zone passing rate and limitation on the total wastewater discharge has to be realized gradually. Water protection supervision and management system, which take water functional zone as the basic unit, has to be perfect. The management scope and jurisdiction on water functional zone and wastewater discharge has to be specified. The outline planning of wastewater discharge is compiled. The remediation and standardization of key wastewater discharge projects has to be carried out. The license management on the newly built, converted and extended wastewater discharge projects has to be enhanced, and the supervision on interprovincial relief zone also has to be enhanced.

(4)Set up science and technology supporting system

Firstly the Yellow River water monitoring capacity needs to be further improved. Based on the second phase of the Yellow River water regulation management system, the remote monitoring and control on the downstream water diverting gates should be set up. The online monitoring of 90% of the mainstream water use can be realized by constructing remote monitoring system covering 70 major water diverting projects in the upper and middle reaches as well as 16 water returning projects in Ningxia and Inner Mogolia. The measurements at the key hydrological stations will be updated in order to increase measurement accuracy. Water quality monitoring system needs to be further improved in order to improve water monitoring capacity. The water quality information sharing between water conservancy sectors within the basin as well as between water conservancy and environmental protection sectors should be set up. The information sharing platform of groundwater monitoring and control management should be set up so that the information sharing between the basin level and local level monitoring stations.

Secondly the Yellow River water and sediment regulation system needs to be further improved. The water conservancy works such as Longyangxia, Liujiaxia, Daliushu, Jikou, Guxian, Sanmenxia and Xiaolangdi play important role in regulating water and sediment, improving unbalanced water and sediment as well as rational optimum of water resources. Among these water works Longyangxia, Liujiaxia, Sanmenxia and Xiaolangdi have been constructed, and produced huge integrated benefits. In order to reduce sediment silt in the river channel and sustain middle flow river channel, Guxian and Daliushu water conservancy works should be constructed as soon as possible in order to regulate and allocate runoff and sediment in the upper and middle reaches. With the implementation of western china development strategy, the water requirements by socio-economic development and ecological environmental protection will increase. In the long term, the west route of North to South water transfer has to be constructed.

Thirdly decision making supporting capacity on water management and regulation has to be improved. The study on unified optimum reservoir regulation modeling, low flow routing modeling, pollutant transport and diffusion modeling, the downstream water requirement and runoff forecasting system on the basis of soil moisture and irrigation plants and plant structure have to be carried out in order to improve the capacity on optimum water regulation and emergency response. The decision making supporting system needs to be further improved. On the basis of the existing information, some information such as soil moisture, drought, wetland, animal and plants indices as well as ecological observation should be collected. The emergency response subsystem should be built in order to deal with the minimum flow, emergent pollution event and warning on regional drought and put forward response measures. The management system on the total amount of the permitted water along the mainstream and tributary as well as the cities should be set up based on GIS.

Climate Change and Hydrologic Response: Recent Studies on China’s River Basins

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Abstract

This paper reviews recent studies that have addressed how climate change may impact runoff, evaporation and sea level in China. These studies give out a panoramic view of the runoff response of nine river basins/basin groups in China: an increase in the Inland Basin Group, Southwest River Basin Group, Southeast River Basin Group and the Songhua River Basin in the northern Northeast China; a slight increase in the Yangtze River Basin; a decrease in the Hai-Luan River Basin Group, Yellow River Basin and Huai River Basin, but the Liao River Basin remains uncertain. The studies also reveal that the annual mean surface temperature in China has significantly increased during the past 100 years, with slightly greater magnitude of temperature increase than the globe. As projected, the surface temperature will continue to increase, and the relative seal level along Chinese coastline will rise by 4~16 cm until 2030. The studies are discussed in light of model uncertainty and monitoring ability. Further studies on the impacts at shorter time duration and on water quality and extreme hydrological events are recommended.

Key word: Review, Impact, Runoff, Evaporation, Sea Level

Over the past 150 years, global average surface temperature has increased 0.76°C (IPCC 2007). Global warming has caused greater climatic volatility such as changes in precipitation patterns and increased frequency and intensity of extreme weather events, and has led to a rise in mean global sea levels. These changes have affected many regions of the world, including China.

The National Assessment Report of Climate Change (I) (Ding et al. 2006) stated that ‘The Climate change in China shows a considerable similarity to the global change, however there still exist significant differences between them’. This paper reviews evidence of how climate change is affecting runoff in China’s river basins. The review is based on an extensive literature survey and other studies carried out by concerned governments, research institutions, international organizations and academics.

1. China’s river basins

China has extensive natural water systems, its rivers and tributaries playing a vital role in economic development, particularly in supporting industrial and agricultural production. China’s territory is composed by 4 river basins and 5 basin groups as shown in Figure 1, of which the water resources, arable land, gross domestic product and people living in these basins/basin groups are shown in Table 1.

Table 1 Water Resource Indicators of Chinese River Basins/Basin Groups in 1993

Basin (B)/ Basin Group (BG)	Population	Urban. Rate	GDP per capita	Arable Land	Available Water Resources[1]	Unit Water Availability	
	106	%	Index	106 ha	109 m3	m3 per capita	m 3/ha [2]
Songhua-Liao BG	113.2	41	107	19.5	193	1,705	9,900
Hai-Luan BG	117.6	24	113	10.8	42	355	3,900
Yellow B	99.2	22	84	12.4	74	746	5,970
Huai B	190.5	17	85	14.7	96	504	6,800
Yangtze B	402.5	22	93	22.9	961	2,390	41,950
Pearl B	141.5	28	130	6.5	471	3,330	72,450
Southeast BG	65.1	24	135	2.4	259	3,980	107,900
Southwest BG	18.3	11	32	1.7	585	31,970	344,100
Inland BG	24.7	37	91	5.4	130	5,265	24,050
Total China	1,172.6	24	100	96.4	2,812	2,400	29,150

Notes:[1] Excluding groundwater recharge estimated to be transformed under natural conditions into river discharge.

[2] Equivalent of available water distributed uniformly over arable land.

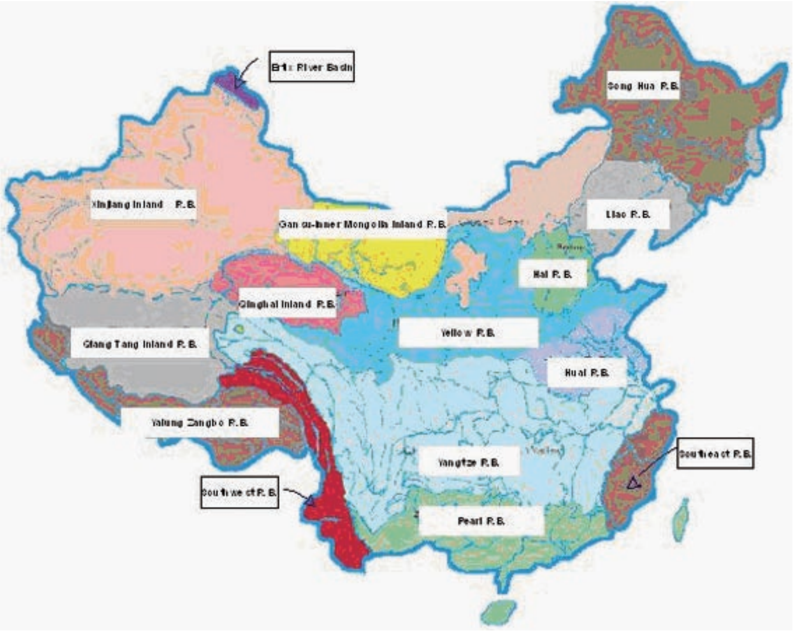

Figure 1 China's River Basin/Basin Group and Water Resources

2. Observed and projected runoff response

Yellow River Basin

In the upper Yellow River, the runoff has been substantially reduced since the 1990s (Zhang et al. 2004; Liu & Chang 2005; Li et al. 2004; Liu & Zheng 2003; Liu 2004). In the middle Yellow River, the relationship between runoff and sediment has been greatly changed since the 1990s (Xu 2004; Rao et al. 2001; Gao et al. 2002; Yin 1998) and more droughts occurred since the 1980s (Yu & Lin 1996; Wang & Zhang et al. 2004; Wang & Wang et al. 2004). Under the dual impact of climate change and land-used cover change, the runoff coefficient in the lower Yellow River decreased by around 9%, resulting in annual runoff reduction of around 5.6 billion m3 (Liu 2004). The runoff of the whole Yellow River has a significant decline since the 1980s and this decline is more significant in the upper Yellow River than the lower (Ma 2005).

Using various models in the Yellow River (Liu et al. 2003; Xia et al. 2005; Ye et al. 2006; Wang et al. 2002; Hao et al. 2006; Zheng & Liu 2001; Zhang 2006), the runoff is projected to follow a downward trend in the next few decades.

Among these studies, Hao et al. (2006) coupled climate models with a large scale distributed hydrological model to assess water resources in the source area of the Yellow River. The results based on the 13 series of GCMs of IPCC DDC show that the hydrological trend during next 100 years in this area will be coherent to global warming, saying that temperature will continue to increase; evaporation will significantly increase; in spite of an increase of precipitation, water resources will be reduced; the inter-annual distribution of hydrological factors will be more and more uneven; and the area will be threatened by severe droughts and floods.

Zhang (2006) applied HadCM3 climate model to analyze the average natural runoff changes of the Yellow River. The results under various climate scenarios show that under the A2 scenario, the average natural runoff will see changes of 5.0% during 2006 and 2035, of 11.7% during 2036-2065 and of 8.1% during 2066-2095; under B2 scenarios, the changes will be 7.2%, -3.1% and 2.6%, respectively.

Liu (2004) pointed out that under dual impacts of climate change and land-use cover change, the runoff coefficient in the lower Yellow River decreased by around 9%, resulting in annual runoff reduction of around 5.6 billion m3. Huang (2002), based on annual runoff data, adopted wavelet approach to study runoff evolution since the 1920s, and found that overall runoff change of the Yellow River presents three stages: increase, slow decrease and rapid decrease.

Shi et al. (2003) indicated that both precipitation and runoff have increased significantly and that the climate has been in a transition from warm dryness to warm wetness in the western and middle part of Northwest China since 1987.

Yangtze River Basin

The annual mean runoff of the Yangtze River increased since the 1960s, but not significantly (Ren et al. 2004; Qin et al. 2005). The future water resource in the Yangtze River remains the current level, but spatially uneven (Liu et al. 2008). However, a simulation showed that the decrease of runoff may be -7.7% in the Han River, a major tributary of the Yangtze River (Chen and Liu 1996).

With the runoff reproduced with ECHAM5/MPI-OM model and the GHG emission scenarios (SRES-A2, A1B, B1) in 2001-2050, Liu et al. (2008) analyzed the temporal and spatial patterns of future surface runoff in the Yangtze River basin. The results show that the long-term average annual surface water resources of the Yangtze River under three scenarios are similar, while inter-annual fluctuations are complicated with different trends. The surface water resources decline gradually in fluctuation under the A2 scenario, show no obvious trend under the A1B scenario, and present a relatively significant increasing trend under the B1 scenario. Decadal variations of the surface water resources are notable, showing an overall decline trend under all the three scenarios in 2001-2030, while an increase trend to varying extent after the 2030s, especially in summer and winter.

Shi et al. (2004) selected 32 heavy flood records in the Yangtze River catchment between 1840 to 2000 to analyze the relation between flood evolution and climate change. This study come to a conclusion that during the cold period before the1910s, there occurred 13 heavy floods and the corresponding frequency is 1.9 times/10a; during the warm period from 1921 to 2000, there happened 19 heavy floods and the corresponding frequency is 2.4 times/10a. The observed heaviest flood occurred during the warm period (year 1954). The1990s is the warmest decade. Mainly influenced by south-east monsoon, the middle and lower reaches of the Yangtze River basin have experienced their top precipitation during recent 100 years. It is estimated that the higher frequency of heavy floods during the 1990s (5 times/10a) is caused by global warming.

Jiang et al. (2003) indicated that the heavy floods occurred in 1998, 1954 and 1870 would reappear due to climatic warming and rapid urbanization in the Yangtze River Basin. The study estimated that increase of greenhouse gases like CO2 will lead to an increase of about 2.7℃of annual mean temperature in the Yangtze River Basin and an increase of 10% precipitation will increase runoff by 37%.

Zhang et al. (2003) applied radiocarbon method (14C) to buried paleotrees, peat and shell ridges to study the relationship between flood occurrences and climate changes in the Yangtze River Delta. The frequent flood periods are consistent the climatic transition periods. The study also shows that the Delta area has been more and more seriously influenced by sea level rise, causing frequent disastrous inundation. A Comparison between the Yangtze River Delta and the America show similarity in paleoflood occurrences corresponding to climate change. The study also shows a close relationship between flood occurrences and El Nino events.

Other River Basins/Basin Groups

On the assumption that temperature increases by 4℃ and precipitation remains unchanged, the glacier in the source area of the Urumqi River in the Inland River Basin Group will disappear, and the runoff will be reduced by about 16% (Lai 1995). Runoff of the rivers in Northwest China will be decreased if the temperature increases by 2℃ and precipitation increases by several percentages (Liu 2002).

Obvious runoff changes during 1956-2000 were observed: an increase in the Pearl River Basin and a decrease in the Songhua River; Compared to the 1960's, the annual runoff in the lower reaches of the Pearl River increased by 12%, while in the lower reaches of the Songhua River reduced by 6.5% during 1990's (Ren 2007).

In comparison with the measured runoff series during 1980’s, a decrease trend can be detected in the basins of the Yellow River, Hai River and Pearl River, among which the most significant reduction occurred in Hai River Basin (Zhang 2007). The runoff of the Hai-Luan River Basin Group is projected to experience a reduction ranging from -7.2% to -26% (Zhang et al. 1996). The impact of rainfall on the runoff in the Hai-Luan Basin Group is greater than that of evaporation and continuous climate warming may increase the minimum river flow (Shi 1995).

Under GCM scenarios (WRIC-MWR 1996), most river basins in China are projected to experience change in water stress by 2030. In the five major river basins in China, namely the Yellow, Huai, Hai, Song-Liao and Yangtze, the projection is that Yangtze river basin will experience an increase in flooding risk; while other basins will have tighter water shortage stress. The study shows in particular more water stress in upper and middle reaches of the river basins of Yellow and Hai-Luan and a weakened stress in the Songhua River basin. The study estimated that the annual runoff in Qinglong River, Tanghe River and Shahe River in North China will reduce by 10% to 20%, while that in the Baihe river basin by 40%, if the temperature rises by 2 ℃.

Wang (2002) and Qu (2007) indicated that climate change will pose significant impact on water resources in the river basins of Yellow, Huai and Hai based on the estimation with GCM, hydrologic balance model and water resources model. Based on HD and MPI models, it is projected that by 2030, natural runoff in most of river basins in China will experience increase, of which the Liaohe River, the section from Hekou Town to Sanmenxia of the Yellow River, the Dongting Lake, all coastal rivers in the west of Guangdong Province, all rivers in the east and south of Fujian Province and the Minjiang River will see an increase by 11.64%～14.64%, implying higher flood risk. In particular, runoffs in the Liao River and Minjiang River during the flood season from June to August will rise by 9.3% and 18.9% respectively, the maximum runoff of the latter may rise by 23%.

Yuan et al. (2005) combined VIC (Variable Infiltration Capacity) Model with PRECIS (Providing Regional Climate for Impact Studies) Model to make a trend analysis on the water resources under various climate scenarios in the Hai River Basin. The results show that in spite of rainfall increase the mean annual runoff under climate scenarios tend to decrease, implying more serious water shortage. Higher flood risk under climate scenarios is also found.

Yang et al. (1996) analyzed the rivers in the Hexi area in Northwest China. The analysis shows that the runoff decreased in the eastern and middle Qilian Mountains during the periods from the 1950s to the 1990s and from the 1970s to the 1990s, the runoff changes are in the opposite in the western Qillan Mountains. Using a statistical analysis method, Yang et al. (1996) projected that the runoff relying on rainfall will decrease by 30% and 50% if the precipitation decreases by 25%～50% due to climate warming, and the runoff of the rivers fed by ice-snow melt water will increase by 40%~70% if temperature rises by 2.5℃～3.5℃.

Wang et al. (2006) indicated that climatic warming has become more and more significant in the Tarim River Basin in recent 10 years. The study found the facts that the precipitation has been significantly increased recently and the 1990s is the warmest period during recent 40 years. The study also observed that the precipitation was significantly increased in the southern piedmont of the west Tianshan Mountains and the Pamirs during the 1990s. The annual runoff of the four main tributaries of the Tarim River increased by 6.6% during the 1990s due to climate warming.

Li (1999) analyzed a 50-year recorded hydrological series and revealed that the Southwest River Basin Group has experienced a decline of temperature and precipitation. Liu and Yang (2002) estimated that an increase of 1℃will increase evaporation by 5% and reduce runoff by 4% in the Southwest River Basin Group. In condition that temperature increases by 1.6 ℃ and precipitation increases by 10% the runoff change may range between -8%～5% in 2010 and between -2%～15% in 2050 in Southwest China (Liu 2002).

Chen and Liu (1996) applied Xinanjiang Model to the upper Huai River. The study reproduced annual runoff processes corresponding to GCM scenarios and estimated that the reduction of runoff due to climate change can reach up to 15%.

Deng & Tang (1998) applied monthly balance model and Penman-Monteith equations to identify the hydrological response to the climate change scenarios of NCAR CCM, OSU, GISS, GFDL and UKMO

GCMS in the Tuojiang River in Southwest China. The analysis reveals that the runoff is not sensitive to temperature but sensitive to precipitation. If temperature increases by 2~4℃, the runoff will decrease by 5%~10%; and if precipitation increases by 20%, the runoff will increase by 35%~40%. Under NCAR CCM Scenario, the seasonal distribution of hydrological factors will significantly change.

Fei et al. (2007) focused on the groundwater issue regarding climate change in North China. The study revealed that climate change has reduced underground water due to decreasing precipitation and ascending temperature in recent years and therefore worsened water resources shortage.

Shi (1995) pointed out that Northwest China will experience seasonal snow decrease, glacier retreat, lake shrinkage, and the North China will experience an increase of runoff by 15% ~ 20% if temperature increases by 1～1.5℃ and precipitation by 10%. Shi et al. (2003) believe that the climate have been in a transition from warm dryness to warm wetness in the western and middle Northwest China since 1987.

Ren (2007) indicated that the climate change will increase the runoff of the Songhua River and Pearl River by 5% ~ 10%, while that of the Yangtze River and Yellow River by less than 5%.

With the monthly runoff series since 1950 observed from 19 key hydrological control stations in the six larger basins in China, Wang et al. (2008) employed Mann-Kendall test method to analyze seasonal distribution, concentration rate, concentration period and variation. The results reveal significant change of the runoff since the 1980s. The study also reveals uneven coefficient of runoff distribution and longer concentration rate in Song- Liao River Basin Group, monthly runoff increase in winter and spring in Southern China, and obvious runoff decrease in the Yellow River Basin, Huai River Basin and Hai-Luan River Basin Group.

Wang & Liu (2007) took karstic areas in the Southwest River Basin Group as study case to analyze climate change impact on karstic ecosystem with special focus on hydrological regime and water resources. The study reveals that precipitation change posed great influence on runoff and runoff decrease followed precipitation decrease; precipitation change resulted in droughts and floods and prolonged the duration of these disasters; and potential evaporation experienced significant seasonal and annual change.

3. Observed and projected evaporation response

Ding et al. (2006) indicated that the annual mean surface temperature in China has significantly increased during the past 100 years, with slightly greater magnitude of temperature increase than the globe. The precipitation trends during the last 50-100 years are not obvious, but since 1956 it has assumed a weak increasing trend. The frequency and intensity of main extreme weather and climate events have also assumed significant change. As projected by Ding et al. (2006), the surface temperature will continue to increase in China in the 21st century.

Jiang et al. (2003) revealed that the mean temperature during the 1990s increased by 0.2~0.8℃ and the annual precipitation increased by more than 5%~20% during the 1990s compared to the averages between 1951 and 1980 in the Yangtze Delta.

Ren and Guo (2004) made a trend analysis on pan evaporation regarding climate change to whole China using recorded data from 600 stations. The study reveals that pan evaporation significantly decreased during the period from 1956 to 2000 for the whole country, in which the Yangtze River Basin, Hai-Luan River Basin Group, Huai River Basin, Pearl River Basin Song-Liao River Basin Group experienced significant evaporation decline, but the Songhua River Basin and Southwest River Basin Group had no significant change. It also reveals that the most significant evaporation decline occurred during summertime for the Yangtze River Basin and Huai River Basin, during springtime for the Pearl River Basin and Liao River Basin, and during both summertime and springtime for the Hai-Luan River Basin and Inland River Basin Group.

Liu et al. (2008) analyzed climate change during 50 years in the source area of the Yellow River and deemed that the temperature increase resulted in evapotranspiration increase and runoff reduction.

Based on the monthly precipitation from 80 observation stations and monthly temperature mean during the period from 1961 to 2000, Sun et al. (2003) calculated maximum potential evaporation, aridity index and water budget for the rivers in Northeast China and examined spatial and temporal distribution of temperature. The results show significant changes in temperature, its spatial and temporal distribution and inter-annual and decadal surface aridity index. Since the mid of the 1990s, Northeast China has presented an obvious aridity trend which strongly correlated with temperature.

Zheng et al. (2006) analyzed 40 years of recorded temperature, precipitation and evaporation in Ningxia Hui Autonomous Region. The results show that the mean temperature has a significant decadal change and there was an obvious climate jump around 1986 which is followed by a warm winter. The analysis reveals an evaporation decline since 1978. The study indicated that the average temperature of Ningxia corresponds to climate warming which made the local average temperature increased by 1.1℃in spring and 1.3℃in other seasons.

Using the instrument-conversion method and climate model to hydrological and meteorological data from 5 observation stations around the Poyang Lake in South China, Min et al. (2007) analyzed the yearly and monthly water surface evaporation of the Poyang Lake during 1955～2004 in terms of temperature, humidity and wind speed. The results show that the water surface evaporations decreased in recent 50 years corresponding to the increases of air temperature and humidity which are closely related to greenhouse gas emission.

Guo et al. (2006) made a trend analysis on pan evaporation using a data series from 1961 to 2003 observed in 14 meteorological stations and 6 hydrological stations around the Poyang Lake. The results indicate that there was a temperature jump in 1990 and an upward trend since then. The study revealed that a significant decreasing trend of pan evaporation existed in summer and the reference evapotranspiration sharply decreased since 1992; the areas sensitive to climate change are the Inland River Basin Group and the upper reaches of the Yellow River Basin; and the Poyang lake has been significantly impacted by climate change.

Wang et al. (2005) analyzed pan evaporation, reference evapotransporation and actual evapotranporation using measured data during 1961 and 2000 from 115 meteorological stations in the Yangtze River Basin. The results revealed that significant decreasing trends of pan evaporation, reference evapotransporation and actual evapotranporation exist in all Yangtze River Basin in summer, but it does not exist in spring and autumn.

Gao et al. (2006) used the Penman-Monteith Method to the climatic data series during 1956 and 2000 from 580 stations throughout China to provide a climatological reference for potential evapotranspiration. The study analyzed the spatial and temporal distributions of the potential evapotranspiration over China and the temporal trends of the regional averages for 10 major river basins and whole country, and made a partial correlation analysis to the major climate factors affecting the temporal variation of potential evapotranspiration. The results show that 1) China as a whole and most of the river basins have experienced a decline of seasonal and annual potential evapotranspiration during the past 45 years; 2) the annual potential evapotranspirations averaged over 1980-2000 are lower than those for the period 1956～1979 in most parts of China and exceptions are some parts in the Shandong Peninsula, the river basins in central and western parts of Southwest China, Ningxia Hui Autonomous Region and the source areas of the Yangtze River and

Yellow River, implying disadvantages to the exploitation and utilization of water resources in these areas; 3) sunshine duration, wind speed and relative humidity posed greater impact on potential evapotranspiration than temperature; and 4) sunshine duration and wind speed are estimated to be the major factors driving potential evapotranspiration in most areas.

Qu (2007) predicted that the summer evaporation in Northeast China between 2020 and 2049 will increase by 4.3%～5.4% and that between 2071 and 2100 by 12.3%～14.4%. With HD model and MPI model, Wang (2003) projected that the Yellow river basin will experience an increase of average temperature during next 30 years, saying 2.0 ℃～2.38 ℃ in the northern basin and 1.8 ℃～1.5 ℃ in the southern, and by 2030, China's average annual evaporation will increase by 3% to 15.1%, as shown in Table 2 in which that in the Yellow River Basin and the Inland River Basin Group will witness an increase of about 15%.

Table 2 Projected Evaporation Response in Some Chinese River Basins by 2030

Method	Pear River Basin	Yangtze River Basin		Huai River Basin	Yellow River Basin	Hai-Luan River Basin Group		Inland River Basin Group	Song-Liao River Basin Group	
		Han	Gan			Hai	Luan		Liao	Heilong
HD	4.0	3.0	3.8	3.5	5.6	13.0	12.5	6.0	6.6	8.6
MPI	3.1	3.0	3.1	3.3	4.8	14.8	5.1	15.1	6.0	11.5

4 Observed and projected sea level response

Zheng et al. (2001) focused on the coastal area in recognizing its sensitivity and fragileness of eco-environment and high risk of natural calamity. The study indicated that the relative sea level rise, resulted from the piling of absolute sea-level rise and ground subsidence, has become the vital strategic issue for the coastal areas in China.

Based on the outputs from seven climate models under SRES A2 greenhouse gas and aerosol scenario, Jiang et al. (2004) analyzed the decadal trend of climate change in China during 2001 to 2030. The results show that the surface temperature, the maximum temperature and the minimum temperature in China will increase by 0.3～2.3℃, 0.1～2.0℃ and 0.5～2.7℃, respectively; the sea level pressure anomalies over East Asia

Table 3 Projected Sea Level Rises (Unit: cm) (Tian 1999)

Region	Year		
	2030	2050	2100
Costal areas in Liaoning and Tianjin	13.1	22.5	69.0
Costal areas the Shandong Peninsula	1.1	5.7	40.2
Costal areas in Jiangsu and the east of Guangdong	15.5	25.4	73.9
Costal areas in the Pearl River Estuary	7.6	14.8	1.8
Costal areas in the west of Guangxi	15.3	25.5	74.2

in winter will be in between -1.0hPa and 0.4hPa and present a zonal band-shape distribution; and the zero contour line will gradually move southward and The results also show that summer precipitation will increase by 0.1~0.8 mm/d over most parts of the Qinghai-Tibet Plateau, Southeast China, and the Hetao region during 2001 to 2030.

Tian (1999) and Wang (2002) projected the seal level rise duo to climate change for the five coastal areas in China, saying that the relative sea level along Chinese coastline will rise by 4~16 cm until 2030 and that until 2050 by 9 ~ 26cm by 12 ~ 23 cm as shown in Table 3 and Table 4.

Table 4 Projected Seal Level Rises under Three Scenarios (Unit: cm) (Wang 2002)

Coastal areas in Liaoning and Tianjing	2030			2050		
	Lower Scenario	Appropriate Scenario	Higher Scenario	Lower Scenario	Appropriate Scenario	Higher Scenario
	9.5	11.4	13.1	16.2	19.6	22.5
Costal areas in Shandong Peninsula	-2.5	–0.6	1.1	-0.6	2.8	5.7
Costal areas in Jiangsu and the east of Guangdong	5.5	11.5	13.5	19	22.5	25.4
Costal areas in the Pearl River Delta	4	5.9	7.6	8.5	11.9	14.8
Costal areas in the west of Guangdong and in Guangxi	11.6	13.6	15.3	19.2	22.7	25.5

5. Concluding remarks

The above studies picturize climate change impact on the runoff in China's river basins/basin groups: an increase in the Inland Basin Group, Southwest River Basin Group, Southeast River Basin Group and the Songhua River Basin in the northern Northeast China; a slight increase in the Yangtze River Basin; a decrease in the Hai-Luan River Basin Group, Yellow River Basin and Huai River Basin, but the Liao River Basin remains uncertain.

The annual mean surface temperature in China has significantly increased during the past 100 years, with slightly greater magnitude of temperature increase than the globe. It is projected that the surface temperature will continue to increase in China in the 21st century.

The relative sea level along Chinese coastline will rise by 4~16 cm until 2030 and that until 2050 by 9 ~ 26cm by 12 ~ 23 cm.

There is growing confidence about model predictions of changing temperatures and rainfall, but the impact of climate change on water resources from specific rivers, lakes and underground sources remains poorly understood. As an example, one effect of temperature increases is to increase evaporation rates. Since the balance between evaporation and rainfall determines whether a climate is humid or arid, aridity will tend to increase where rising temperatures are not matched by rising rainfalls. Changes in aridity will have a substantial impact on both surface runoff and groundwater recharge as will have changes in the timing and intensity of rainfall.

Actually climate change impact on water quality is not paid enough attention. Reductions in river flows will reduce their capacity to dilute wastes and require additional investments to achieve the same standards of environmental protection. Changing runoff patterns and temperatures may result in water quality effects.

The ability to monitor and predict climate change impacts at a scale that is helpful to users is still extremely limited, leading the technical team of the IPCC working on water and climate (IPCC, 2008) to conclude that:"There is a need to improve understanding and modelling of changes in climate related to the hydrological cycle at scales relevant to decision making." Most of actual studies focused on decadal and multi-decadal climate change and hydrological response, however the changes at annual, seasonal, monthly, even daily level are needed if noticing the vital importance of these time steps for taking adaptive actions. Although the importance of hydrological monitoring has been highlighted at all United Nations conferences on water and sustainable development since the 1977 Mar del Plata conference, the quality of the hydrological data, which is needed to monitor the impact of climate change and to guide future planning, is generally unsatisfactory in China.

China has notable hydrological vulnerability and sensitivity to climate change. But, there exist great uncertainties in projecting climate change and simulating hydrological response. Studies on water cycle and the impacts due to both climate change and human activity are needed to cope with the adverse consequences of climate change. There are great needs to improve the knowledge on hydrological response to climate change impact in the upper reaches of the Yangtze River Basin and the source area of the Yellow River Basin.

The impact of climate change on extreme hydrological events, such as droughts and floods need to be further strengthened. In this sense, cross cutting study between hydrology and climatology on the hydrological response to climate natural variability and climate forced change impacts need to be encouraged.

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Climate Changes and Changes of Runoff and Sediment Loads from Chinese Rivers

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Abstract

The temporal and spatial variations in water and sediment loads of rivers in China were analyzed by using data of long-term annual runoff and sediment loads from the furthest downstream hydrological stations of 10 large rivers. The data series at most gauging stations were over 50 years. Long-term precipitation data from representative stations across China was also presented in the paper for comparing the effect of climate changes. Effects of the influence factors for the variations in water and sediment loads were shown by using examples of the upper Yangtze River, middle Yellow River, Three Gorges Project, Xiaolangdi Reservoir and Guanting Reservoir. It shows that there was no obvious effect of change in precipitation on annual runoff and sediment load of major rivers in China. Human activities such as soil and water conservation and dam construction are main causes for the reduced sediment load in rivers.

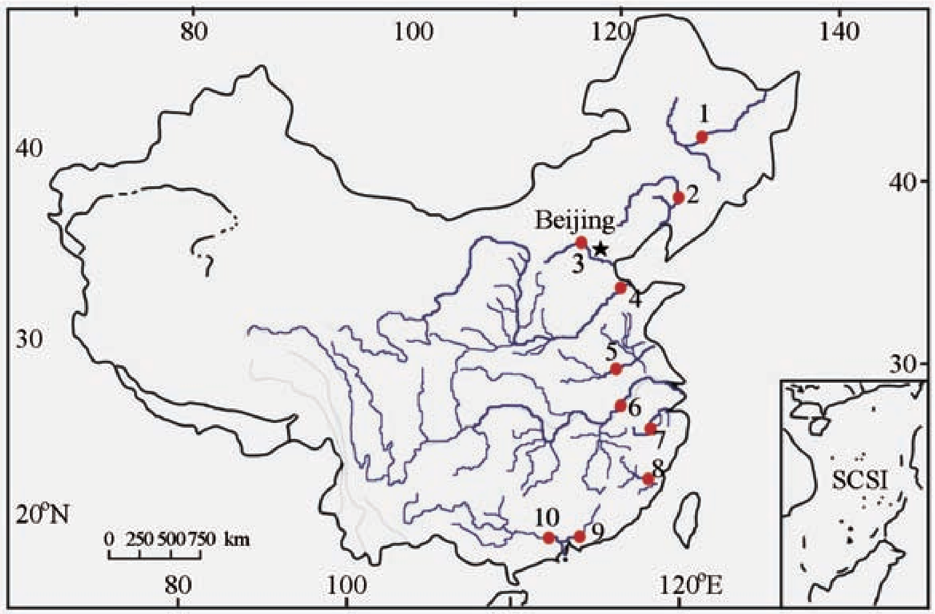
Key words Sediment load, runoff, Yangtze River, Yellow River.

1 General situation of major Chinese rivers

China is a vast country of 9.60 million km2 territory. The topography is high in the west and low in the east. Most of the major rivers flow from west to east, emptying into the Pacific Ocean (Figure 1).

China mainly lies in two climate zones, i.e., the temperate zone and the tropical zone. Most of the territory is in the northern temperate zone and subtropical zone. East-Asian monsoon is the principal factor affecting the climate. However, the complexity of topography makes the meteorological and hydrological conditions of rivers differ significantly. The mean annual precipitation is as high as over 1500 mm in the regions along the southeastern coast and decreases gradually toward inland, reaching less than 50 mm in northwest (Figure 2).

Under such complex conditions of climate and topography, the variability of characteristics of Chinese rivers is distinct. Ten large rivers in 4 typical regions in China are selected for the study. (1) Pearl River (Zhujiang River) in the subtropical zone: The Pearl River is the largest river in South China. It has 3 main tributaries: the Xijiang, Dongjiang and Beijiang Rivers. (2) Yangtze River (Changjiang River), Huaihe River, Qiantang River and Minjiang River in the temperate zone of wet climate: The Yangtze River is the largest river in China with a catchment of 1.80 million km2. The Huaihe River is in Central China, situated between the Yangtze and Yellow Rivers. The Qiantang and Minjiang Rivers are in the southeastern region of China. (3) Yellow River (Huanghe River), Yongding River and Liaohe River in the temperate zone of dry climate: The Yellow River is the second largest river in China and is to the north of the Huaihe River. The Yonding River is one of the 5 main tributaries of the Haihe River in North China. The Liaohe River is in the southern part of Northeast China. (4) Songhua River in the frigid zone: The Songhua River is a main tributary of the Heilong River



(Amur River). It mainly flows northward to join the Heilong River, which is a border river between China and Russia.

Gauging stations on studied rivers:

1. Harbin station on Songhua River
2. Tieling station on Liaohe River
3. Yanchi station on Yongding River
4. Lijin station on Yellow River
5. Bengbu station on Huaihe River
6. Datong station on Yangtze River
7. Lanxi station on Qiantang River
8. Zhuqi station on Minjiang River
9. Boluo station on Dongjiang River
10. Gaoyao station on Xijiang River

Figure 1. Major rivers in China

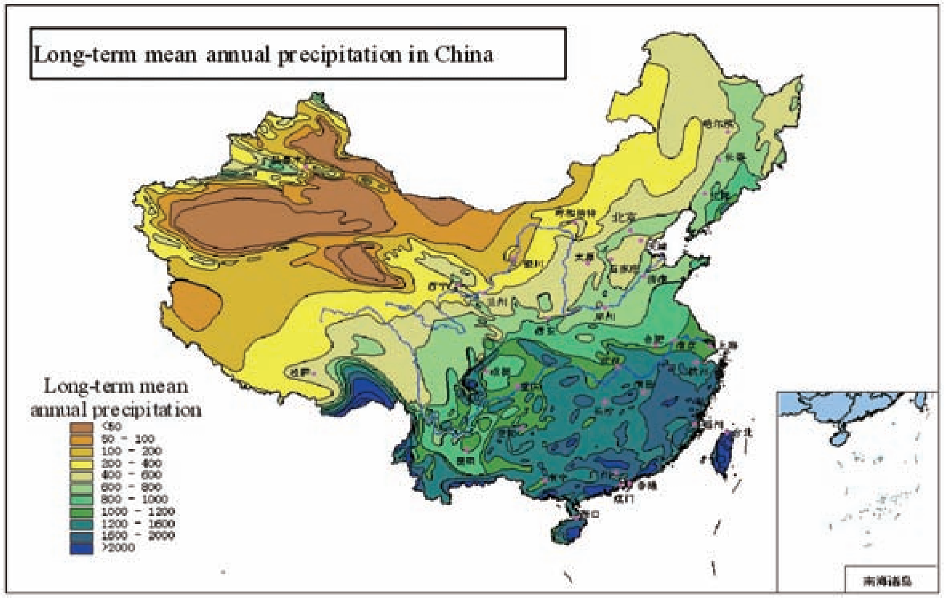


Figure 2. Long-term mean annual precipitation in China (SDINFO, 2008)

2 Long-term hydrological characteristics of 10 large rivers

2.1 Long-term precipitation data from representative stations across China

Precipitation is one of the important factors affecting the runoff and sediment load of rivers. Table 1 lists the long-term mean annual precipitation depths and short-term (in the past 10 years) mean annual precipitation depths at some meteorological stations in the relevant catchments of the studied rivers (Liu, et al., 2008). Most data series of the stations were more than 50 years. The ratios of the short-term mean annual precipitation depth to the corresponding long-term mean annual precipitation depth are also presented in Table 1. The range of the ratios is (0.89-1.11) with an average of 1.00. The figures show that the variation trend of the short-term precipitation depths were almost in a normal state compared with the long-term precipitation depths.

Table 1. Mean annual precipitation depths at meteorological stations

River	Meteorological station	Data period	Long-term mean P_L (mm)	Short-term mean P_{10} (mm)	P_{10}/P_L
Songhua	Nenjiang	1951-2006	482.5	427.7	0.89
Songhua	Mudanjiang	1951-2006	545.9	515.2	0.94
Liaohe	Chifeng	1951-2006	367.0	357.8	0.97
Liaohe	Siping	1951-2006	635.6	582.8	0.92
Yongding	Huailai	1954-2006	390.6	352.6	0.90
Yellow	Dari	1956-2006	542.81	543.16	1.00
Yellow	Lanzhou	1951-2005	313.83	289.46	0.92
Yellow	Yulin	1951-2006	396.93	373.13	0.94
Yellow	Zhenzhou	1951-2006	639.88	656.02	1.03
Huaihe	Zhumadian	1958-2006	975.2	1018.9	1.04
Huaihe	Bozhou	1953-2006	808.4	886.6	1.10
Yangtze	Tuotuohe	1957-2006	279.4	309.7	1.11
Yangtze	Qumalai	1957-2006	402.5	401.0	1.00
Yangtze	Yushu	1953-2006	480.6	476.3	0.99
Yangtze	Ganzi	1951-2006	645.3	657.3	1.02
Yangtze	Xichang	1951-2006	1020.0	1085.4	1.06
Yangtze	Chengdu	1951-2003	904.4	815.1	0.90
Yangtze	Shapingba	1951-2006	1087.3	1103.5	1.01
Yangtze	Youyang	1951-2006	1350.6	1355.7	1.00
Yangtze	Changde	1951-2006	1350.0	1453.3	1.08
Yangtze	Zijiang	1951-2006	1264.5	1272.0	1.01
Yangtze	Lingling	1952-2006	1431.1	1502.7	1.05
Yangtze	Ji’an	1952-2006	1506.4	1603.6	1.06
Yangtze	Nanchang	1951-2006	1612.6	1744.8	1.08
Yangtze	Yichang	1952-2006	1154.4	1121.1	0.97
Yangtze	Wuhan	1951-2006	1263.6	1277.4	1.01
Yangtze	Nanjing	1951-2006	1051.7	1093.0	1.04
Qiantang	Quzhou	1951-2006	1669.4	1653.8	0.99
Minjiang	Yong’an	1951-2006	1565.0	1600.1	1.02
Dongjiang	Heyuan	1953-2006	1939.6	1920.6	0.99
Xijiang	Wuzhou	1951-2006	1481.0	1457.4	0.98
Mean					1.00

2.2 Long-term and recent 10-year mean annual runoffs and annual sediment loads of 10 large rivers

Specific discharges and rates of erosion were used to study the changes in annual runoff and annual sediment load of each river. Table 2 lists the relevant data from the furthest downstream hydrological station of each river released in the China Gazette of River Sedimentation (MWR, 2000-2007, Liu, et al. 2008). The data series at most gauging stations were over 50 years. The catchment areas range from 18,233 km2 (the Qiantang River at Lanxi) to 1,705,383 km2 (the Yangtze River at Datong).

Table 2. Long-term and recent 10-year specific discharges and rates of erosion of 10 large rivers in China

River	Station	Catchment area (km^2)	Data period	Specific discharges $l.s^{-1}.km^{-2}$			Rate of erosion $t.km^{-2}.yr^{-1}$			Sediment concentration $kg.m^{-3}$		
				Long-term mean Q	10-yr mean Q_{10}	Q_{10}/Q	Long-term mean E	10-yr mean E_{10}	E_{10}/E	Long-term mean S	10-yr mean S_{10}	S_{10}/S
Songhua	Harbin	389769	1955-2005	3.45	2.96	0.86	16.7	12.3	0.74	0.153	0.132	0.863
Liaohe	Tieling	120764	1954-2005	0.80	0.45	0.56	103.5	23.4	0.23	4.10	1.65	0.402
Yongding	Yanchi	43674	1963-2005	0.48	0.24	0.50	3.1	0	0	0.205	0	0
Yellow	Lijin	752032	1952-2005	1.32	0.46	0.35	1034.5	256.1	0.25	24.8	17.6	0.710
Huaihe	Bengbu	121330	1950-2005	6.99	6.47	0.93	75.5	42.8	0.57	0.342	0.210	0.614
Yangtze	Datong	1705383	1950-2005	16.80	17.56	1.05	242.7	164.7	0.68	0.458	0.297	0.648
Qiantang	Lanxi	18233	1977-2005	28.75	28.16	0.98	108.7	87.9	0.81	0.120	0.0989	0.824
Mingjiang	Zhuqi	54500	1950-2005	31.13	32.09	1.03	110.1	42.9	0.39	0.112	0.0424	0.379
Dongjiang	Boluo	25325	1954-2005	28.89	27.64	0.96	97.0	57.6	0.59	0.106	0.0661	0.624
Xijiang	Gaoyao	351535	1957-2005	19.86	20.40	1.03	193.4	134.1	0.69	0.309	0.208	0.673

From Table 2 some facts can be founded: (1) Except the Songhua River, which is in the far north of China, and the Yongding River, which is an almost totally human-controlled river, the long-term specific discharges of the remaining 8 rivers increase from north to south. (2) As for the long-term rate of erosion, the Yellow River is the largest, the Yangtze River is the second, and the Songhua River is the smallest (the Yongding River is not included). This fact indicates that the rate of erosion of a river depends not only on water flow, but also the topography, erodibility of soil, vegetative cover, land use, etc. of the catchment. Such a situation makes the change in rate of erosion in different catchments differ greatly. (3) As for the long-term sediment concentration, the Yellow River still stands on the top, the Liaohe River becomes the second, and the Yangtze River stands third. The smallest values occur in the Qiantang, Minjiang, Dongjiang, and Songhua Rivers. This manifests the complexity of relationship between runoff and sediment load. (4) As for the short-term (the recent 10 years) variation of specific discharges, two groups of rivers can be divided. The rivers with ratios of Q10/Q larger than 0.85 (7 rivers) belong to the first group. They are rivers with stable annual runoff both in a long-term period and a short-term period (Q10 is the average of specific discharges in the past 10 years and Q is the long-term mean specific discharge). The second group includes the Yellow, Yongding, and Liaohe Rivers with ratios of Q10/Q between 0.35 and 0.56. This indicates these rivers had a declining annual runoff in the past 10 years. (5) As for the short-term variation of rate of erosion, the variation trend is more complex than that of the specific discharge, but is almost similar as that of the specific discharge. Rivers in the first group had the value of E10/E larger than 0.5 (6 rivers, not including the Minjiang). The second group of 3 rivers had the value of E10/E smaller than 0.5. There are two exceptions. One is the Minjiang River in Southeast China with clear water (its long-term mean annual sediment concentration is 0.112 kg/m3), its E10/E is only 0.39, while its Q10/Q is as large as 1.03. The small figure of E10/E was not resulted by the reduction in annual runoff, but by the trapping of sediment in reservoirs. At present there are 7 large reservoirs and 36 medium-sized reservoirs and several small reservoirs on the Minjiang River. Those reservoirs trapped much sediment and reduced the sediment load released to the downstream (China Gazette of River Sedimentation, 2002). The other is the Yongding River. Almost all the incoming sediment load to the Guanting Reservoir (which controls about 97% of the total catchment) is trapped in the reservoir. The released water is almost clear. (6) The Yongding River may be served as a representative of the 5 major tributaries of the Haihe River. In the 1950s a large reservoir was built at the end of the mountainous section of each river. Thus, the runoff and sediment load were almost controlled by the reservoir and the released runoff and sediment load were quite few. The river channels below the reservoirs were almost dried up. Meanwhile, Yanchi hydrological station on the Yongding River started in 1963, its long-term data only represented post-dam situation. (7) As for the variation of S10/S, it is more complex than that of the change in S and S10. The value of S10/S of the Yellow River stands third, showing the intricate relationship of them. (8) Based upon the above-mentioned, the variation of annual runoff and annual sediment load in the past 10 years of the 10 large rivers in China may be summarized in Table 3.

Table 3 Variation of annual runoff and sediment load in the past 10 years of the 10 large rivers in

Group	Rivers	Average Q_{10}/Q	Average E_{10}/E	Average S_{10}/S
1	Songhua, Huaihe and rivers to the south	0.977	0.68 (not including Minjiang)	0.708 (not including Minjiang)
2-a	Yellow and Liaohe	0.45	0.24	0.556
2-b	Yongding	0.50	0	0

3 Yearly variation of specific discharges and rates of erosion of 10 large rivers from 2001 to 2005

From the data of yearly variation of specific discharges and rates of erosion of 10 large rivers from 2001 to 2005, it is natural to deduce that the yearly variation of specific discharges and rates of erosion of a river in a short period of time depend mainly on climate conditions. As for different rivers, it will differ greater than that of a river. Table 4 lists the variation of Qr/Q and Er/E of the two groups (Qr is the yearly specific discharge in a year and Er is the rate of erosion in a year, Q and E are the same as before).

Table 4. Variation of Qr/Q and Er/E of rivers

Group	Q_r/Q		E_r/E	
	Minimum	Maximum	Minimum	Maximum
1	0.293 (Huaihe, 2001)	2.43 (Huaihe, 2003)	0.00746 (Minjiang, 2004)	1.10 (Qiantang, 2002)
2-a	0.222 (Liaohe, 2003)	1.06 (Liaohe, 2005)	0.00477 (Liaohe, 2002)	0.431 (Yellow, 2003)
2-b	0.118 (2002)	0.321 (2003)	0	0

Table 4 shows: (1) Any river in any year may appear the maximum or minimum figure, indicating the occurrence of such a figure being stochastic. (2) The difference between the maximum Qr/Q and minimum Qr/Q is quite large, indicating great yearly variability of annual runoff. It is almost the same for the difference between the maximum Er/E and minimum Er/E. (3) For a river in the study, the appearance of a maximum (or a minimum) Qr/Q in a year dose not mean the concurrence of a maximum (or a minimum) Er/E in the same year.

4 Effects of Influence Factors

4.1 Effect of change in precipitation

From section 2.1, precipitation across China had no clear trend of variation in the past half century. One can conclude, therefore, that there is no obvious effect of precipitation on the variability of annual runoff and annual sediment load.

4.2 Effect of soil and water conservation

The practices of soil and water conservation are generally effective in decreasing the amount of soil loss and in influencing the average annual water yield. A large amount of soil and water conservation works has been implemented in the eroded areas across China, particularly in the Upper Yangtze River and the Middle Yellow River.

4.2.1 Upper Yangtze River

Reduction in sediment load in the Upper Yangtze River during the past 10 years may be caused by climate change (variation of precipitation and its spatial distribution, in particular), trapping of sediment by upstream reservoirs, widespread soil conservation and afforestation projects, as well as sand-gravel mining from the river channel.

Since 1988, soil and water conservation works have been implemented in the Upper Yangtze River catchment. Until 2000, soil and water conservation works were implemented in 63 thousand km2 of eroded land. The 5th stage of soil and conservation works (1999-2003) expanded to the Upper and Middle Yangtze River, covering 116 counties in 8 provinces with a total land area of 28.9 thousand km2, among which 15.6 thousand km2 were eroded area. In this period of time, soil and water conservation works were implemented in 13.1 thousand km2 eroded area. Those works included a large amount of check dams, ponds and terracing, afforestation, grassing of land, etc. At the 6th stage (2004-2008), the works expanded to 185 counties in 10 provinces. In 2005 soil and water conservation works were implemented in 3.6 thousand km2 area. As a result, the ratio of vegetative coverage has been increased, the ecological environment has been improved, soil loss has been reduced and the capacity of water conservancy has been increased (MWR, 2000-2005).

4.2.2 Middle Yellow River

The main sediment source area of the Yellow River is the loess plateau. It has a total area of 640 thousand km2, among which 434 thousand km2 is eroded area. The area of severe soil loss (212 thousand km2) supplies 90% of the total sediment load to the Yellow River. The soil conservation work in the Yellow River has a long history. Due to political, economic, social and natural reasons, the soil conservation work underwent ups and downs before the 1970s. In the 1980s an unprecedented state of sustaining and stable development of soil conservation took place in the Yellow River basin thanks to the new policy adopted in 1978. Small watershed management has been extensively developed. Meanwhile, planting of trees, shrubs and grass in severe natural conditions has been successfully implemented. These have resulted in the reduction in sediment load. In Figure 3 the areas of soil conservation work above Sanmenxia dam are shown. The rapid development of soil conservation work is obvious (Zhou and Yang, 1995; MWR, 2000-2005).

Meantime, more than 3 million small water conservancy works have been built, including about 100 thousand

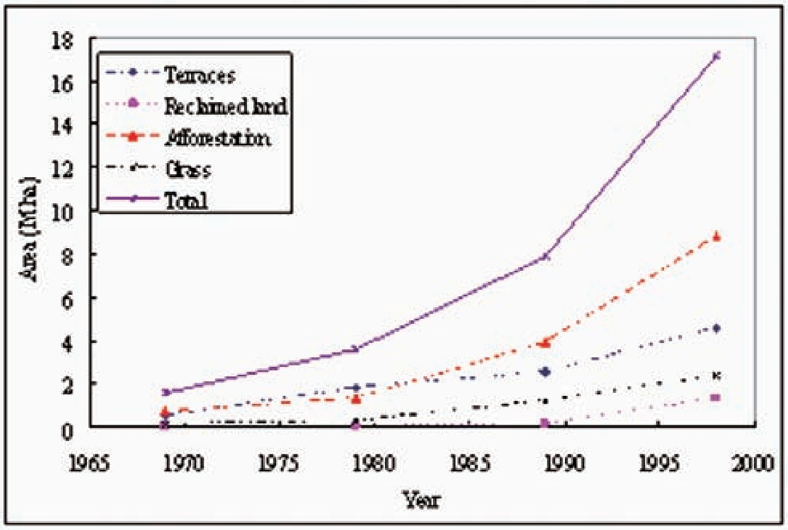


Figure 3. Areas of soil conservation work above Sanmenxia, Yellow River

warping dams and 1077 key check dams in main gullies. Those engineering and soil conservation works have resulted in the reduction in annual sediment yield. The hydrologic data from the Yellow River showed an obvious reduction in annual runoff and sediment load in the 1970s and an even more remarkable reduction in annual sediment load in the 1980s, as shown in Figure 4 (Gu, 1994; Zhou and Yang, 1995). The relevant analysis ascertains that besides the climate variations, man's activity has played an important role in this aspect. The effects of man's activity may be classified into two categories: water resources development and soil conservation. It is estimated that since 1970s the sediment yield of the Yellow River has been reduced about 0.3 billion tons annually by water conservancy and soil conservation measures. From Fig 4 it can be concluded that the reduction of annual runoff and annual sediment load increased in each decade (Gu, 1994).

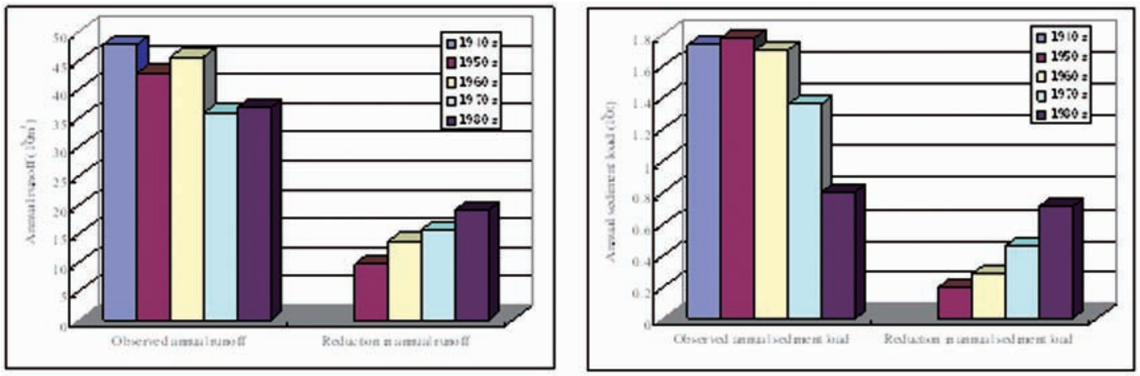


Figure 4. Annual runoff and annual sediment load at Sanmenxia Station

4.3 Reservoir sedimentation

Reservoirs have significant effect on the rivers where they are built, both in the reservoir proper and in the channels below the dams. Reservoir sedimentation is one of the great impacts on the rivers.

4.3.1 Three Gorges Project (TGP)

The TGP is built on the main stream of the Yangtze River, which controls 55.9% of the total catchment. The TGP reservoir was partly impounded on June 1, 2003 at the pool level of 135 m (the normal pool level is 175 m, which is the objective in 2009). For the next 3 years since then, the pool level was maintained at 135m during flood seasons and at 139m during dry seasons, and reservoir capacities varied between (12.4-14.2) billion m3. In the same period, 441.6 million tons of sediment deposited in the reservoir (147 million tons per year on average). The trap efficiency from 2003 to 2005 was 60%. Table 5 lists the inflow, outflow and sediment deposition of the Three Gorges reservoir, from which the impact of the TGP reservoir on the sediment load at downstream stations can be learned (TGHB, 2006).

Table 5. Inflow, outflow and sediment deposition of the TGP reservoir

Period	Inflow		Outflow		Deposition (109 t)	Trap efficiency (%)
	Water (109m3)	Sediment (109 t)	Water (109m3)	Sediment (109 t)		
June-Dec. 2003	325.4	0.208	338.6	0.084	0.124	59.6
2004	389.8	0.166	412.6	0.064	0.102	61.6
2005	429.7	0.254	459.0	0.103	0.151	59.4
Total	1144.9	0.628	1210.2	0.251	0.377	60.0

When the TGP reservoir is under NPL started in 2009, the trap efficiency at the initial stage will be larger than 60%, according to the result of sediment mathematical models. It means that the impact of the reservoir will be larger than it is now.

4.3.2 Xiaolangdi reservoir

The Xiaolangdi Project is built on the main stream of the Yellow River, controlling 694 thousand km2, i.e., 92.3% of the total catchment. The annual runoff and annual sediment load at the dam site account for 91.2% and almost 100% of the total, respectively. Its initial storage capacity is 12.65 billion m3. It is the most downstream project for controlling water and sediment inflows into the lower Yellow River. It was commissioned in May 2000.

Reservoir sedimentation developed soon. Until October 2006, 2.16 billion m3 sediment deposited in the reservoir, accounting for 17.1% of the initial storage capacity (MWR, 2000-2005). As large amount of sediment deposited in the reservoir, the released sediment load from the reservoir dropped significantly, resulted in the reduction in sediment load in the downstream hydrological stations, such as Lijin Station.

4.3.3 Guanting reservoir

Guanting Reservoir on the Yongding River controls a catchment area of 43400 km2, about 97 % of the total catchment area. The mean annual runoff at the dam site is 1.4 billion m3 and the mean annual sediment load is 81 million tons. The initial reservoir capacity is 2.27 billion m3. The project was commissioned in 1955. The Yongding River is heavily sediment-laden with a mean annual sediment concentration of 34.6 kg/m3. Reservoir sedimentation was so serious that up to 1985 612 million m3 of storage capacity was silted up, accounting for 27.0% of the initial storage capacity. However, the rates of deposition in various periods

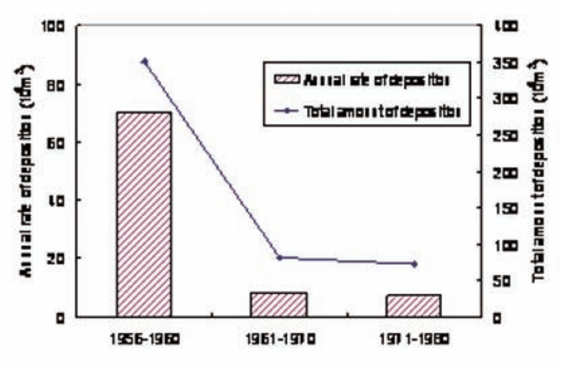


Figure 5. Reduction in sedimentation rate in Guanting Reservoir

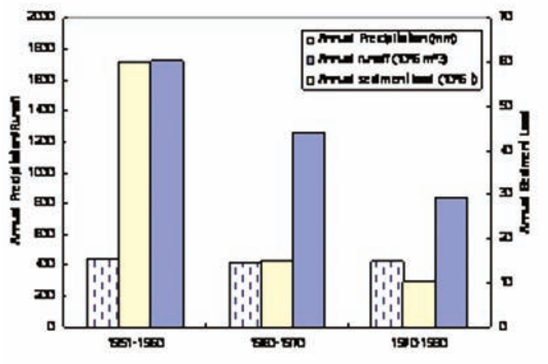


Figure 6. Reduction in annual runoff and annual sediment load

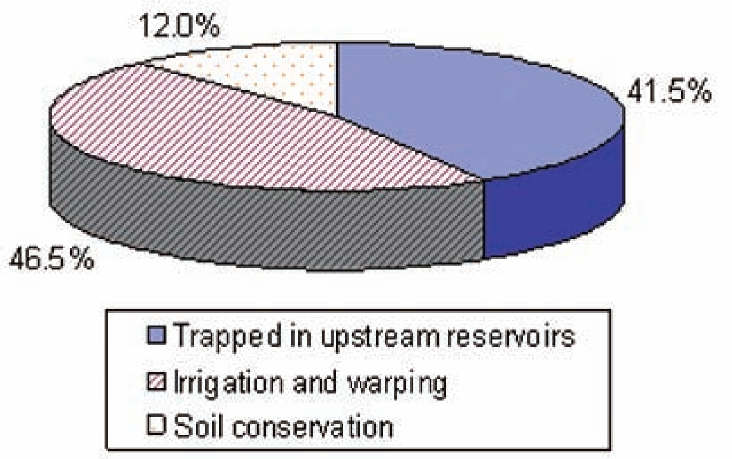


Figure 7. Annual reduction in sediment load in Guanting Reservoir by various measures

were quite different (Figure 5). Although the average annual precipitation and precipitation in flood seasons of the 1950s, 1960s, and 1970s were almost the same, the incoming runoff and sediment load have reduced significantly since 1960 under the influence of man's activity, as shown in Figure 6 (Zhou and Yang, 1995).

Annual reduction in sediment load in Guanting Reservoir by various measures is about 41 million t. Among them, sediment trapped in the upstream reservoirs accounted for 41.5% of the total amount of reduction (Figure 7). Since 1958, 275 small and medium-sized reservoirs with a total storage capacity of 1.4 billion m3 have been commissioned. The largest reduction of sediment to the Guanting Reservoir was resulted from irrigation and warping. There are 267 thousand ha irrigated farmland upstream of the Guanting Reservoir. Warping has been applied to half of the land irrigated. From 1950 to 1980, 6200 km2 of eroded area in the upper Yongding River have been under control, accounting for one fourth of the total area. It was estimated that the overall reduction in annual sediment yield amounted to 10 million tons. However, the planting of astragalus membranceous, a Chinese medicine herb, road and urban construction and mining led to an annual increase in soil erosion by 5 million tons. The net reduction by soil conservation measures dropped to 5 millions tons annually.

As the Guanting Reservoir trapped almost the total incoming sediment load and sediment releasing from the reservoir only carried out occasionally, therefore, the sediment load at Yanchi Station approached zero all the year round.

5. Concluding remarks

(1) The short-term (recent 10 years) precipitation depths at most meteorological stations across China were almost in a normal state compared with the long-term (50 years) precipitation depths. This shows that there was no obvious effect of change in precipitation on annual runoff and sediment load of major rivers in China.

(2) The long-term specific discharges of most rivers increase from north to south, except the Songhua River in the far north of China. As for the long-term rate of erosion, the Yellow River is the largest and the Songhua River is the smallest.

(3) The major rivers can be divided into two groups. Rivers of group 1 have a stable annual runoff and a decreasing annual sediment load. Rivers of group 2 have both decreasing annual runoff and annual sediment load. Group 2 can be further divided into sub-group 2-a and sub-group 2-b (Yongding River is a representative). Rivers in group 2-b are impounded rivers, their water flow and sediment load are almost totally controlled by large reservoirs. The Songhua River is the only river to be included in group 1. Although the Songhua River is located in the far north, its catchment occupies the largest national forest region in China with little impact of human activities. Consequently, its specific discharge and rate of erosion are almost stable.

(4) Any river in any year may appear the maximum or minimum figures of Qr/Q and Er/E, indicating the occurrence of such a figure being stochastic. The difference between the maximum Qr/Q and minimum Qr/Q is quite large, indicating great yearly variability of annual runoff. It is almost the same for the difference between the maximum Er/E and minimum Er/E. For a river in the study, the appearance of a maximum (or a minimum) Qr/Q in a year dose not mean the concurrence of a maximum (or a minimum) Er/E in the same year.

(5) A large amount of soil and water conservation works has been implemented in eroded areas across China, particularly in the Upper Yangtze River and the Middle Yellow River. The effect of those works is great. For example, it is estimated that since 1970s the sediment yield of the Yellow River has been reduced about 0.3 billion tons annually by water conservancy and soil conservation measures.

(6) A large amount of dams has been built in China. Reservoir sedimentation is serious in many reservoirs, which has induced many effects. Guanting Reservoir on the Yongding River may serve as an example. On the one hand, it trapped almost all the incoming sediment load into the reservoir, depleting the effective storage capacity. On the other hand, almost no water and sediment were released to the downstream channel, which has become a dried-up channel. Meantime, many measures have been adopted in the upstream basin of the Guanting Reservoir, including irrigation and warping with muddy water, building small and medium-sized reservoirs and soil conservation works. Those measures have reduced the sediment load into the Guanting Reservoir and helped to increase the lifespan of the reservoir. Most rivers below dams experience channel degradation in different extents.

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Feasibility of Dendro-hydrologic Analysis Utilizing in the Yellow River Basin

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Abstract

Based on tree-ring dating, Dendro-hydrologic Analysis (DHA) focus on analyzing impact of hydrological variables (precipitation, runoff, etc.) and tree-ring on hydrological variables and their biological response relationship. Domestic and international researches show that the DHA has become an important method for reconstructing hydrological events, which is being more and more widely used. Since the 50s, the DHA has been used to analyzing water quantity in the Yellow River Basin (YRB), and which was used to study a long sequence of drought and flood events of midstream and runoff process in upper reaches of the Yellow River. Though the DHA has some limitation in application, the associated scientific research shows that the method is feasible to be applied in the YRB.

Keywords DHA; tree-ring; climate change; hydrological reconstruction;

1 Introduction

Because of its accuracy in tree-ring dating (Tree-Ring Dating, TRD), good continuity, high resolution and precision in reconstructing climatic and hydrological process, tree-ring becomes one of the important methods to obtain data on past climatic and environmental evolution in the global climate change research. Then, the DHA is used to studying dendrochronology series, and focused on analyzing impact of hydrological variables (precipitation, runoff, etc.) and tree-ring on hydrological variables and their biological response relationship based on tree-ring dating.

At the early 20th century, the TRD was established by Dr. Douglas (Douglass), an American astronomical scholar, that is, study a sequence of dendrochronology, and the TRD was used to determine age of the Indians site with tree-ring of residual trees, and cleared era of the site. Then, this method has been accepted in research prehistoric era of the United States. In the 70s, Stockton et al. Started to focus on tree-ring hydrology study in the western United States, based on tree ring, he had applied the DHA to prolong hydrological records and annual runoff in the southwestern United States in 1971. In 1975, the relationship between a long-term surface water supply and flow or water level has established in the Colorado River. In 1978, the first study of tree-ring hydrology monograph "using tree-ring series to extend the runoff to record ara" is published, which accelerated development and application of the DHA (Jiangfeng Li, 2000). Since the 80s, global water shortage has became increasingly prominent, the uncertainty of global climate change makes water resources shortage serious, which is grimmer than ever before in arid and semi-arid areas. Then, research of reconstructing hydrological on climatic factors with tree ring has been attracted people's attention even more. And the DHA could be more widely used. D'Arrigo RD et al (1993) had sampled in the northern high latitudes (Canada central, eastern, western, Scandinavia and Russia), and regionalized temperature reconstructed with tree ring, and rebuilt temperature in 1682~1968 (that is, until the end of the post-Little Ice Age). Villalba et al (1997) had collected 15 nothofaguspumilio samples at 1200m~1750m above sea level of north the Andean

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*The author: Xinfeng FU (1977-), male, Born in Zhoukou city, He'nan province, Ph.D. Major study fields are hydrology and water resource and ecology. Email:fxf77@163.com region in Patagonia (41°S), and relationship between the tree ring width changes and the spring and summer temperature and precipitation were analyzed. Overpeck J et al (1997) had established last 400 years average temperature records in the Arctic with paleoclimate data (lake sediments, trees, glaciers, marine sediment), and considered that the warming of the early 20th century put an end to the Little Ice Age of the North Pole region and result in the glaciers retreat, permafrost and sea ice melt, and land and lake ecosystem change. So far, International DHA is mainly used for reconstruction of runoff, and extreme hydrological events (droughts and floods), and other hydro-climatic factors (such as historic water level of lakes and swamps, lake's salinity, and large-scale hydro-climatic factors), and precipitation and the possibility of precipitation. Applied research with the DHA includes reconstruction of drought, floods and other extreme events, and analyzing the possibility of history, distribution, frequency, period, severity of major hydro-climatic variables (such as runoff, precipitation), and interaction of regional surface water and so on. At present, the DHA has been applied to hydrological and hydro-climate research in more than 20 countries, which indicates that the method has a more broad application prospect in reconstructing of hydrological events in the global research.

2 DHA

The DHA is a method that reconstructing the past long-term important hydrological variables (such as runoff and precipitation) with tree species that is sensitive to hydro-climatic factors. So far, major hydro-climatic factors reconstruction research is carried out with tree-ring width. The growth of trees is affected by seasons, sunshine, precipitation, temperature and other climatic factors, and the tree-ring width reflects climatic conditions. And the past temperature change could be researched with a longer period high-resolution record provided by tree-ring data, and precipitation and runoff processes at the corresponding temperature could be analyzed based on correlation between temperature and precipitation or runoff. In particular, the program of the DHA is starting from field sampling, cross-dating, chronology establishment, calibration and validation, to hydrological process reconstruction, of which chronology establishment and hydrological process reconstruction are the key.

The chronology is established. Tree-ring samples were taken back to drying and fixing, then polishing the samples' surface bright, and then dating with conventional process. The tree-ring ordinal number is demarcated from pith to bark, and the relative width of the corresponding ring is marked with different vertical length line on 1mm × 1mm grid paper, longer vertical line represents relatively more narrow width of the corresponding ring, then schematic plan that the relative width changes with time is obtained, which is also known as skeleton diagram. Then, skeleton diagram of different samples from the same tree are put together to compare with each other, if the type of the ring width is consistent in shown, and they were put together with that of other trees, then the demarcated error of single tree-ring ordinal number is confirmed, and then the lack or pseudo ring at ordinal number values of individual sample are cleared, therefore, the accuracy of dating is improved. Accuracy of dating of the sample is obtained after such repeated comparisons. The tree-ring width is measured with measurement instrument based on the skeleton diagram dating, and the width sequence of at each corresponding sample ring is obtained. Then, the sample sequence is re-dating tested based on the sample width sequence. Finally, accurate dating purposes is achieved with correlation analysis as well as many other test methods after relation of every sample sequences is found out in detail. In order to remove growth trend in conjunction with tree age, and stabilize sequence of impact of the tree age on mean and variance, the width sequences were detrended revised and converted into dimensionless index series. The growth trend is fitted with spline function. The revised approach is take quotient of the width sequence and growth trend line, and conventional standardized chronology be constructed after double average trend line sequence.

Hydrological reconstruction analyzes of a series of relationship between the tree-ring and hydro-climatic factors based on tree-ring chronology, which highlights the hydrological limiting factor, obtains the best relevant period, and then the reconstruction equation is established. And credibility of hydrological reconstruction can be measured with multiple correlation coefficients, and then hydrological reconstruction can be continued after calibration and verification. In hydrological reconstruction, the range of the value of the instrumental record be interpreted is about 40% ~ 70% > 60%, and the change be interpreted is considered good (Woodhouse CA., 2000). Hydrological reconstruction includes reconstruction of runoff, extreme hydrological events, lake water level, water swamps, lakes and salinity, advance and retreat of glaciers, dry or wet, relationship of snow-covered field and the atmospheric circulation.

Runoff reconstruction is one of the most important content of the DHA, since 1936, Hardman and Reil had reconstructed hydrological process and extended hydrological records at the Truckeer river in Nevada, the United States for the first time, then study field of runoff reconstruction is being expanded. In the United States, the tree-ring chronology has been widely used to prolong the hydrological records and rebuild annual or seasonal runoff.

Reconstruction of extreme hydrological events is an important research field that the DHA is applied, which includes reconstructing annual or seasonal or monthly hydrological events, and prolonging drought and flood records, analysis of drought cycle, reconstructing drought frequency, severity, duration and spatial distribution. Drought and flood are two of nature's most destructive disasters. Reconstruction of drought and flood events with tree-ring, and their appearing frequency, period, intensity, duration and severity were understood, which have always been important application of the DHA.

But the DHA has certain limitations in application: ①There be old trees in the area; ② uncertainty in hydrological events reconstruction. Then, the reason of error is that the measurement error is from instrumental data and tree-ring data measurement and that the standard model error results from unsatisfied correlation between tree-ring and hydro-climatic factors.

3 Feasibility of DHA Utilizing in the YRB

Since the 70s, the tree-ring has been applied to reconstructing temperature in the northwest China. Pan Yating et al (2007) had established sequence of tree-ring chronology according to the tree-ring samples collected from the Boertala River basin at western part of the Tianshan Mountains, and successfully reconstructed 461-year monthly average temperature of the basin. YU Shulong, et al (2007) had reconstructed May-August average temperature in years 1,468 - 2,001 based on significant correlation between three tree-ring chronologies on upstream and the May-August average temperature of the Jinghe river. Based on tree-ring chronology established with fir tree ring on olecranon Cliff at Zhenan, Shaanxi province at the southern slope of the Qinling Mountains, Liu Hongbin et al (2000) had analyzed response relationship between tree’s radial growth to regional climate factors change and reconstructed early spring temperature changes from 1755 in Zhen'an region and analyzed cycle and mutation of the reconstruction sequences.

Based on the temperature reconstruction, the DHA has been applied in past precipitation sequence reconstruction in the places such as the central Tianshan Mountains in Xinjiang (Urumqi River Basin), northern Xinjiang, eastern Tianshan Mountains, Qilian Mountains, Dulan region of Qinghai province and Helan Mountains. And hundreds of years humidity sequence of these areas is obtained. Ma Limin, et al (2003) had reconstructed May-July precipitation of the past 270 years in the North Temple of the Helan Mountains (Figure 1). Based on the tree-ring samples collected from upper reaches and runoff of hydrological stations on upstream of the Heihe river basin, Kang Xingcheng, et al (2002) had established correlation between tree-ring chronology and runoff with the DHA, and reconstructed runoff sequence of the upper Heihe River. Then, the result is gained, that is, since 1319, the largest runoff of Yingluoxia hydrological station is 2.674 billion m3/a, and the smallest one is 0.644 billion m3/a, and the annual variability Cv is equal to 4.17, and the average annual runoff is 1.528 billion m3/a.

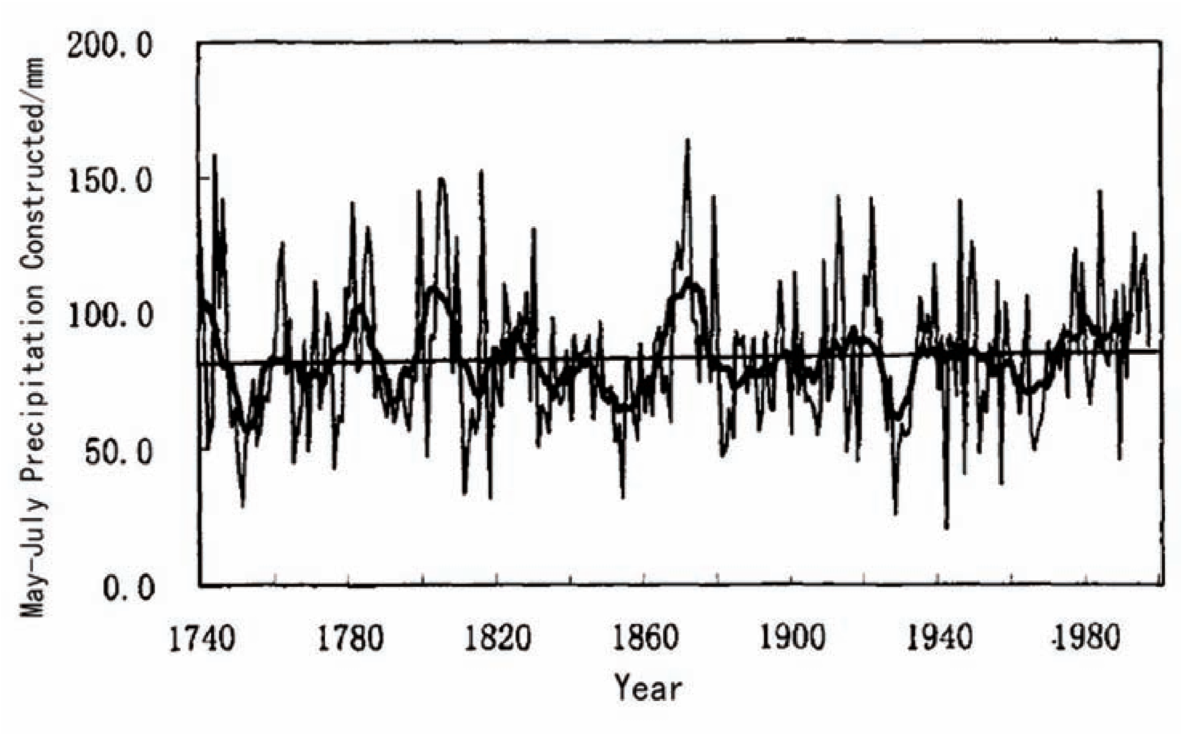

Figure 1 reconstructed May-July precipitation of the past 270 years in the North Temple of Helan Mountains

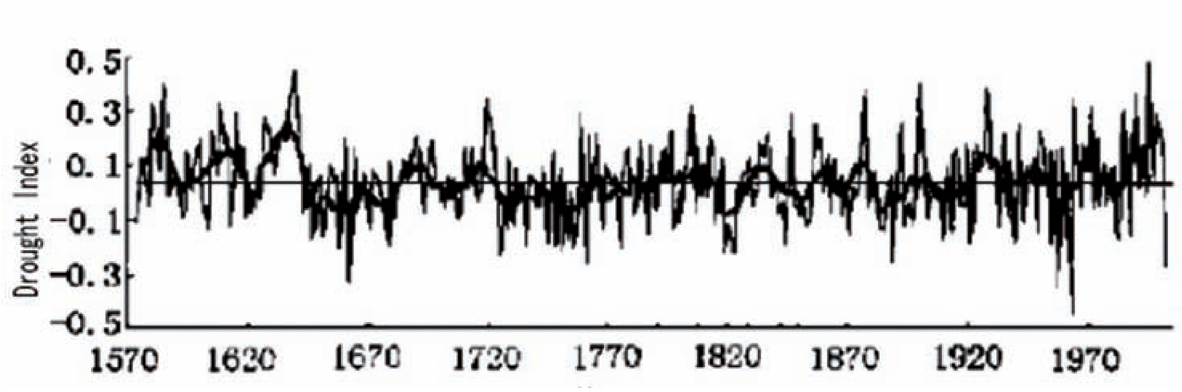

Figure 2 Drought index and 10 year move average value at midstream of the Yellow River

In the YRB, the application research with the DHA has been ongoing. Wang Yunzhang et al (2004) considered that some of the old tree ring information on upper reaches of the Yellow River was used to analyze annual runoff changes as early as 1956. Wang Yunzhang, et al (2004) had reconstructed drought index sequence of the midstream Yellow River since 1575 (Figure 2) with droughts and floods level and some tree-ring data in the basin, and analyzed historical pattern and trend of the drought. Based on seasonal drought index series in summer half year of the Yellow River, Wang Changgao et al (2004) had analyzed frequency and characteristics of droughts. And considered that there is a higher probability of occurrence of drought lies in the YRB, and the ratio of the drought occurs or not is about 7:3 at early summer and autumn and that is 6:4 in summer. Moreover, the probability of the special and severe drought occurs in summer half year in1986-2002 is 3 times of that before, and the autumn drought index is still high, which means no autumn floods basically. Yu Shuqiu (1996) had analyzed summer (May ~ September) drought and flood levels sequence in 1470 ~ 1991 of the middle Yellow River in China with T-test method. Kang Lingling, et al (2007) had analyzed drought and flood levels in 1934 ~ 1977 of six stations such as Lanzhou, Linxia, Dawu, Maqu, Jiuzhi and Dari, and tree-ring data of Qilian Mountain, and runoff anomaly of Yingluoxia hydrological station, and annual flow of Zhimenda station in the Tongtianhe river and their relationship with natural runoff at Lanzhou station, and studied the relationship with regression analysis. And then the formula of natural runoff at Lanzhou station in flood season (May ~ October) was established, and the natural runoff sequence in 1485-2004 was rebuilt, then its periodic and cyclical analysis had been done.

If the old trees are sensitive to climate factors in the YRB, and the credibility of complex correlation of the old tree ring chronology and the hydro-climatic factors is verified, and measurement error of the tree-ring data is in permitted range, considered limitations of the DHA in application and its scientific research, it is feasible for the DHA to apply in the YRB.

4 Conclusions

(1) Based on temperature reconstruction with tree ring, the DHA is an analytical method for prolonging hydrological sequences and reconstructing extreme hydrological events after related formula was fitted with complex correlation coefficients of climate elements and hydrological elements.

(2) The DHA plays an important role in hydrological events research on base of climate change. However, the method is more widely used in hydrological events reconstruction in the United States, while the method is still used relatively few in China, which is difficult to meet people's objective cognitive demand on long-term runoff changes and extreme hydrological events.

(3)Long sequence runoff and extreme hydrological events could provide data for water resources management in the YRB under climate change, based on its applied research, the DHA has a very good application prospect in hydrologic studies in the basin under climate change.

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Research on the Forecasting Method of Flood Maximum Sediment of Jiahetan Station in Lower Yellow River

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Abstract

In the section from Jiahetan to Huayuankou in lower Yellow River (YR), the water and sand entering YR is few. The flood maximum sediment in Jiahetan station affected by upper reach flood sediment, upstream peak discharge and peak flow of forecasting station. It is used the method of correlation analysis and Artificial Neural Networks to design the scheme and model of flood maximum sediment of Jiahetan station in this paper. We attempted to forecast the maximum sediment of flood in August 2004 in Jiahetan applying the scheme. The forecasting value is 250kg/m3, which is 7.4% less than the observation value of 270kg/m3. This is the 1st forecasting of flood maximum sediment in Lower YR, lifting the curtain of the forecasting.

Key Words Maximum sediment, tentative forecast, flood in August 2004, correlation analysis
Artificial Neural Networks model, Jiahetan

The Yellow River is a river of the largest sediment transportation and the highest sediment concentration in the world. The lower Yellow River is the world-famous supended river. Along with the deepening of the management and development of the YR, in order to satisfy with the demand of measures of YR harnessing, such as flood prevention in lower YR, water and sediment regulation, the sediment drainage from Longmen to Tongguan and so on, the request of the highest sediment forecasting in flood of major mainstreams in the middle and lower YR has been brought forward by the Yellow River Conservancy Commission (YRCC) in 2003. The sediment volume in the river is related to not only the sediment entering the river, but also to hydraulic elements and sediment characteristics in the reach. Moreover, indirect interaction and adjustment existed between the two conditions. Therefore, the process of sediment transporting from upstream to downstream is imbalance. Compared with the current evolution, the evolution of sediment displays more randomicity. As an attempt, we firstly study the forecasting scheme of the maximum sediment, the method we used is the relevant analysis and artifiical neural network method, and the section we selected is from Huayuankou to Jiahetan station.

1 Data

The forecasting standard of flood in Huayuankou station is 5000m3/s before the year 1997, and now is 4000m3/s. Due to the control of reservoir in upper and middle YR and the reducing of carrying capacity in lower mainstream, the flood of peak discharge from 3000m3/s to 4000m3/s should be pay attention to. Thus, the flood standard we selected is the peak discharge of Huayuankou station is over than 5000m3/s and 3000m3/s during the period from 1960 to 1986 and from 1987 to 2003 respectively. In addition, 3 floods that occurred in August 1954, July 1957 and July 1958 were taken into account. So the total number of the flood selected is 89.

2 Precision Control

The accuracy evaluation index of sediment forecasting is established, according to the accuracy evaluation idea of forecasting flood peak. When the observed value is larger than the boundary, the permitting error is assessed by relative error, when the relative error is less than or equal to 20%, this predicting figure is eligible, otherwise it is ineligible. When the observed value is smaller than the boundary, the allowing error is estimated by absolute error, when the absolute error is less than or equal to 20% of the boundary, this predicting figure is desirable, otherwise it is undesirable.

The average amount of the 89 sediment peak is 95.5kg/m3, thus 100kg/m3 is regarded as the boundary number in this thesis.

3 Scheme Establish

3.1 Correlation Analytical Method

Scheme 1. Take the sediment peak in Huayuankou station as independent variable

The reach from Huayuankou to Jiahetan is 96km, during the section there is hardly water and sand entering. Because of the sediment peak is mostly lag the flood peak and the discharge is not small when the sediment peak occurred, the balanced process of sediment transportation is presumed. The correlativity of Jiahetan sediment peak and Huayuankou sediment peak is displayed in Figure 1, the correlative coefficient is 0.910 and the eligible ratio of computing result is 82%.

Scheme 2. Take the sand inflow coefficient in Huayuankou station as independent variable

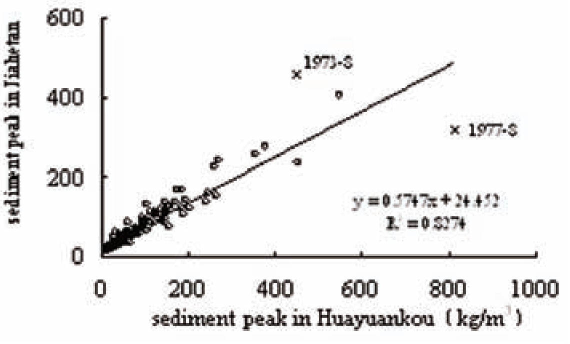

Figure 1 the correlation between ρ and ρ

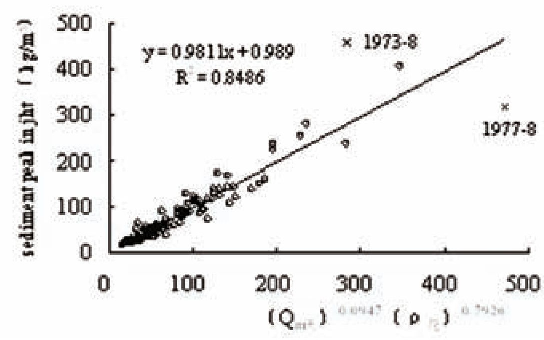

Figure 2 the correlation between ρ and ψ

Taking the coefficient of coming sediment in Huayuankou station as independent variable, the reason is the sand inflow coefficient reflects the matching correlation between water and sand in one side. Generally speaking, if the sand inflow coefficient is large, the river channel may be filted up, otherwise it is scouring. The scour or deposition of the river channel can influence the sediment quantity. The correlativity is indicated as Figure 2, the correlative coefficient is 0.807 and the eligible ratio of computing result is 57.3%, which is lower than that of scheme 1.

Scheme 3. Take Qmαρβ as independent variable

Water is the carrier of sand. The discharge impact directly to the carrying capacity of sand in a stream segment, considering the character of more water coming and more sediment drainage in lower YR, therefore we should take into account not only the sediment of upper station, but also the flood peak in predicting station. The correlativity that taking Qmαρβ as independent variable is illustrated as Figure 3, the correlative coefficient is 0.921 and the eligible ratio of computing result is 84.3%, which is higher than that of scheme 1 and scheme 2.

From what has been discussed above, because scheme 3 meets the rule of more water coming and more sediment drainage, so we may safely conclude that its correlation coefficient and eligibility ratio are both higher, followed by is the scheme 1. The difference of the 2 schemes is not distinct, which illustrate the presumption of scheme 1 is feasible and receivable. Thus when carrying out the concrete predicting, firstly scheme 3 should be take into consideration. This scheme need the forecasting flood peak, which includes error when predicting this number, so scheme 1 should be think over simultaneously.

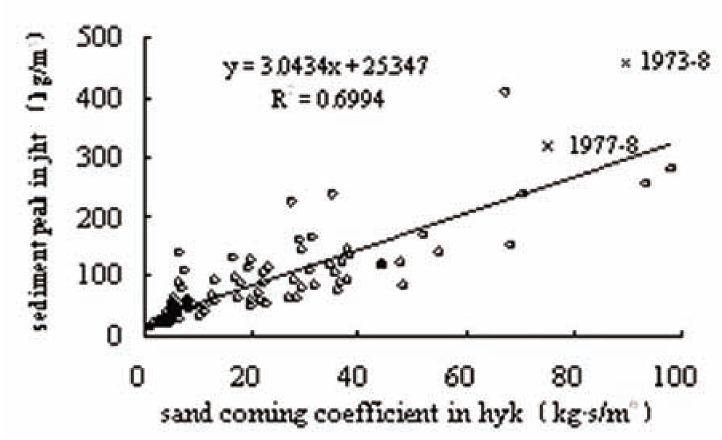

Figure 3 the correlativity between ρ and Qmαρβ

3.2 Artificial neural network model

Concerning the primary principle and operating process of artificial neural network method, the systematic introduction is seen in reference 2 and reference 3. The reason that combining this model with the predicting of sediment peak in flood includes the following, on the ond hand, this method has the superiority in dealing with random effect, on the other hand, the result of this method can be compared with the result of correlation analytical method.

(1) Variable selection. The maximal sediment in Jiahetan is mainly affected by the sediment peak in upper station and flood peak in Jiahetan. Considering the change of scour and silting of river channel, sediment peak in Huayuankou and flood peak in Jiahetan are selected as inputting variable.

(2) Model establishment. In order to confirm the correlation between maximum sediment in Jiahetan and affecting factors, Back Propogation neural of 3 layers are constructed. Among them, inputing layer has 2 nodes, concealed layer has 2 nodes and outputting layer has 1 node.

（3）Data pretreatment

For the sake of eliminating the effect of dimension, the original data is dealed with the follwing procedure. Presuming the affecting factor is xij, i=1,2; j=1,2,…n, then the dealing formula is as follw.

$$X_{ij} = \frac{X_{ij} - X_{i\min}}{X_{i\max} - X_{i\min}}$$

Among them, i and j is the number of affecting factor and sample respectively.

（4）Establishment, training and evaluation of the model

Above all, model is established with 10 samples. Secondly, training is carried by other 69 samples. When after 50000 times learning, the change of network error is considerably small, the 4th number after the decimal has not changed any longer, then the training will be end. Finally, the remainder 10 samples are inputted into model and carrying out the computing. The emulational result is revealed as Table 1.

In term of the estimating index, we can see clearly that there are 3 samples are undesirable in the 10 evaluating samples, i.e. the eligibility ratio is 70%, which show the applicability of the model is comparatively high.

Table 1 emulational result

No.	Jiahetan flood peak（m3/s）	Huayuankou sand peak（kg/m3）	Jiahetan observed sand peak（kg/m3）	Jiahetan computed sand peak（kg/m3）	Absolute error（kg/m3）	Relative error（%）	Eligible?
1	2330	136	119	95.2		-20.0	
2	2440	121	107	84.1		-21.4	no
3	2890	78.1	74	51.7	-22.3		no
4	7150	155	129	131.4		1.9	
5	2700	124	89.2	88.1	-1.1		
6	3090	378	279	248.0		-11.1	
7	4020	161	117	123.2		5.3	
8	2650	145	84.8	103.9	19.1		
9	1860	81.1	65.3	47.6	-17.7		
10	3320	174	171	128.9		-24.6	no

4 Tentative Prediction of the Maximum Sediment in Jiahetan in August 2004

4.1 Flood Origin

The flood occurred in August 2004 is a high sediment flood, which was rooted mostly in Jinghe, Weihe and the section from Xiaolandi to Huayuankou. The sand was mainly origined from Jinghe.

Due to the effect of rainfall, the 1st flood peak of Zhangjiashan station in Jinghe is 1210m3/s occurred at 6:48 on 20 August, the 2nd flood peak occurred at 2:18 on 21st, which is 1380m3/s. The 1st sediment peak is 801kg/m3 occurred at 8:00 on 20 August, the 2nd maximum sediment is 623kg/m3 occurred at 2:00 on 21st. The flood peak in Xianyang station in Weihe is 362m3/s occurred at 14:48 on 22nd, the maximum sediment is

131kg/m3 occurred at 14:00 on 23rd. After the flood in Jinghe entering the Weihe, the flood peak in Huaxian station, which is the control station in Weihe, is 1050m3/s occurred at 6:48 on 22nd, the sediment peak is 695kg/m3 occurred at 9:00 on 21st.

Meantime, there is one flood process of low sediment from Longmen to Togguan. The peak discharge in Longmen station is 1560m3/s, which occurred at 4:42 on 21st, the relative sediment is 59kg/m3. When the flood from Jingweihe and YR converged and evolutioned to Tongguan station, owing to the diluted by the flood from YR, the flood peak in Tongguan station is 2140m3/s occurred at 12:48 on 22nd, the sediment peak is 442kg/m3 occurred at 14:00 on 22nd.

In order to avoid the deposition of this high sediment flood in Sanmenxia reservoir area, the water release and sediment flush from Sanmenxia reservoir before the flood of Jinghe and weihe coming. The flood peak in Sanmenxia station is 2960m3/s occurred at 3:00 on 22nd, the sediment peak is 524kg/m3 occurred at 6:00 on 22nd. The 2nd flood peak is 2460m3/s occurred at 8:00 on 23rd, the sediment peak is 478kg/m3 occurred at 8:00 on 23rd.

The high sediment flood entering Xiaolangdi reservoir area, the muddy reservoir is formed. The water and sand regulation is carried out at 20:00 on 22nd in Xiaolangdi reservoir. During the period from 2:00 on 23rd to 12:00 on 24th, the discharge is retained between 2080m3/s and 2590m3/s, and 3 times sediment peak happened, which is 292 kg/m3 occurred at 8:00 on 23rd, 352kg/m3 emergenced at 0:00 on 24th, and 338kg/m3 appeared at 10:00 on 24th.

The flood peak in Huayuankou station is 3550m3/s occurred at 0:00 on 24th, the sediment peak is 394kg/m3 occurred at 22:00 on 24th, which was showed in Figure 4. Owing to this flood is abnormal, according to the demand of regulation of reservoir and flood prevention in lower YR, the flood forecasting was issued by Hydrological Bureau, although the peak discharge is not up to predicting standard. Thus, the project group of sediment forecasting performed the trial prediction in Jiahetan station.

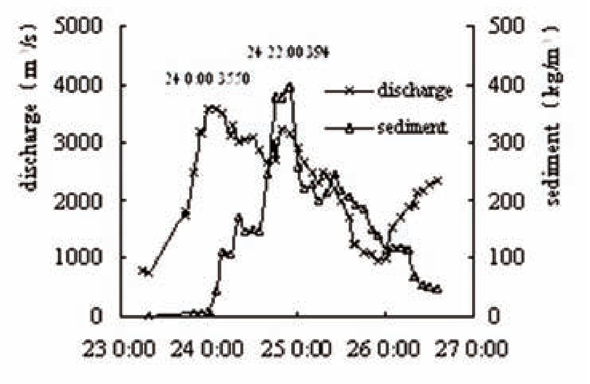

Figure 4 the observed discharge and sediment process in August 2004 in Huayuankou station

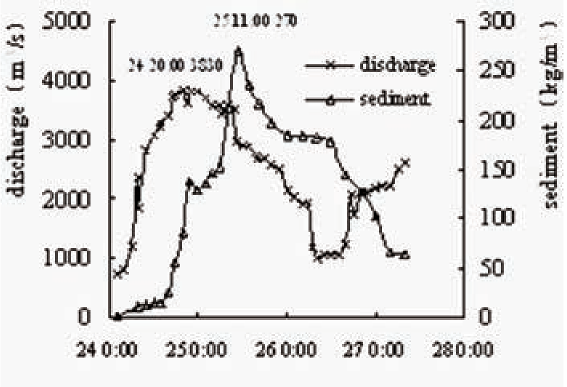

Figure 5 the observed discharge and sediment process in August 2004 in Jiahetan station

4.2 Tentative prediction process

The maximum sediment in Huayuankou is 384kg/m3 occurred on 22:00 24th. The observed flood peak in Jiahetan is 3830m3/s (seen in Figure 5), the result in Jiahetan of scheme 1 and scheme 3 in the correlation analysis methodis is 250.9kg/m3 and 245.5kg/m3 respectively, the mean is 248.2kg/m3; the result of the 2nd method is 258.6kg/m3; the average of the 2 method is 253.4kg/m3. So the predicting result is 250kg/m3 which issued by Hydrology Bureau.

4.3 Actual condition

The flood peak in Jiahetan is 3830m3/s occurred at 20:00 on 24th. The maximum sediment is 270kg/m3 occurred at 11:00 on 25th. The forecast value 250kg/m3 is 7.4% lesser than the observed value, which is in the range of the precision demand.

5 Conclusion

(1) According to the characteristic of sediment in middle YR, taking the sediment, sand inflow coefficient and Qmαρβ as independent variable, the predicting scheme of the highest sediment in Jiahetan station has been established. Among them, when the independent variable is Qmαρβ, the correlation coefficient and eligible ratio of the scheme is the highest.

(2) The mean sediment peak of the scheme 1 and scheme 3 in the correlation analysis method in Jiahetan station in August 2004 is 248.2kg/m3, which is 8.1% lesser than the observed value.

(3) The maximum sediment in August 2004 in Jiahetan station is 258.6kg/m3 computed by artificial neural network model. The absolute error is -11.4kg/m3, and the relative error is -4.2%. The precision is higher than that of correlation analytical method.

(4) The tentative forecasting value of Jiahetan maximum sediment in August 2004 is 250kg/m3, which is 7.4% lesser than the observed value.

(5) This is the 1st forecasting of flood maximum sediment in lower YR, lifting the curtain of the forecasting.

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Impact of Climate Change and Human Activities on Water Resources of the Qinhe River

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Abstract

Climate warming is an indisputable fact. Response of different regions in the Yellow River Basin to global warming varies in circumstance. As one of the most important tributaries of the middle Yellow River, the Qinhe river is chosen to study impacts of climate change on the Yellow River water resources. Based on the Qinhe river runoff and precipitation data, the runoff from 1953 to 2006 decreases gradually on the trend, and the precipitation shows the same trend. In order to find out impacts of climate change on the Qinhe river water resources, the Yellow River Water Balance Model (YRWBM) is used for simulating and identifying runoff sequences based on analyzing human activities occurred in the Qinhe river. And the results show that the percentage of impacts of climate change on the Qinhe river runoff is 46.1%, and that of human activities is 53.9%. Impact of human activities on runoff is more significant than that of climate change.

Key words climate change, the Qinhe river, runoff, YRWBM model, impact

1 Introduction

China's climate is warming, and its trend is consistent with global climate change. In the past 100 years, China mainland's average temperature increased significantly, and annual average temperature increased about 0.6~0.8℃ (Qin Dahe, etc., 2005). Since 1960, weather stations' mean temperatures rose 0.63℃ in the Yellow River Basin (YRB), and mean rate is 0.14℃/a. The temperature in different regions of the YRB varies with geographical location in response to global warming. According to climate change researches (Lan Yongchao, 2005, 2006) and actual observation of the YRB, climate warming is indisputable. As one of the most important tributaries of the Yellow River, the Qinhe river is chosen to find out impacts of climate change on the Yellow River water resources. Based on runoff, precipitation and other basic data, the YRWBM model is used to identify impacts of climate change and human activities on the Yellow River water resources. The result can be used for decision-making of the Yellow River water resource management.

The Qinhe river is one of the two major tributaries in range of Sanmenxia and Huayuankou of the Yellow River. The Qinhe river originated from Erlangshen ditch southern of Huo mountain in QinYuan county of Changzhi City, Shanxi Province, and its length is 485km, flows from north to south through cities such as Qinyuan, Anze, Jincheng, Yangcheng in Shanxi province and Qinyang, Wuzhi in Henan province, to the Yellow River at Nanjia village of Wuzhi city. The drainage area of the Qinhe river is 13532km2, of which the area of 12304km2 lies in Shanxi province, accounting for 90.9%. And the Danhe river is the biggest tributary of the Qinhe river, its last intersection is Shanluping hydrological station, and its area is 3152km2, which is about 23% of the Qinhe river's area, of which the area of 2962km2 lies in Shanxi Province (see in Figure 1).

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2 Runoff

The runoff sequences data of the Wulongkou and Shanluping hydrologic station in the Qinhe river basin in 1953-2006 is analyzed, and sum of the two hydrologic stations' annual runoff can reflect actual annual runoff of the Qinhe River. From Figure 2, Multi-year average runoff of the Qinhe river in 1953-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999 and 2000-2006 is 2.187 billion m3, 1.891 billion m3, 1.354 billion m3, 1.134 billion m3, 0.787 billion m3 and 0.656 billion m3 in order. Since 1953, the multi-year average runoff of Qinhe River decreases generally. Compared with runoff in 1953-1959, the multi-year average runoff reduction is 0.296 billion m3, 0.833 billion m3, 1.053 billion m3, 1.4 billion m3 and 1.531 billion m3 in order. And the multi-year average runoff rate in reduction followed by 13.5%, 38.1%, 48.1%, 64.0% and 70.0%. Thus, the Qinhe river multi-year average runoff reduction is more than 30% since 1970s, and the multi-year average runoff decreases greatly from 1990s, and the multi-year average runoff in 2000-2006 is less than 1/3 of that in 1953-1959.

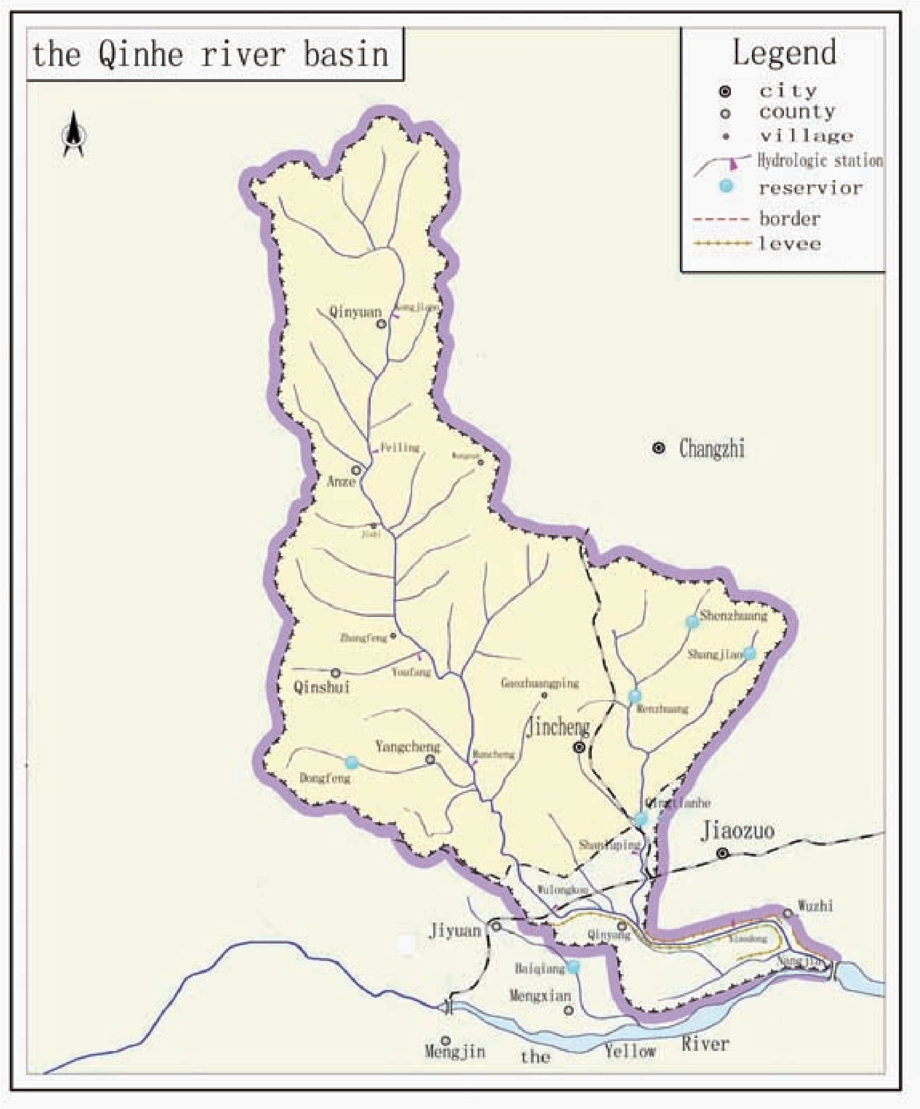

Figure 1 Sketch map of the Qinhe river basin

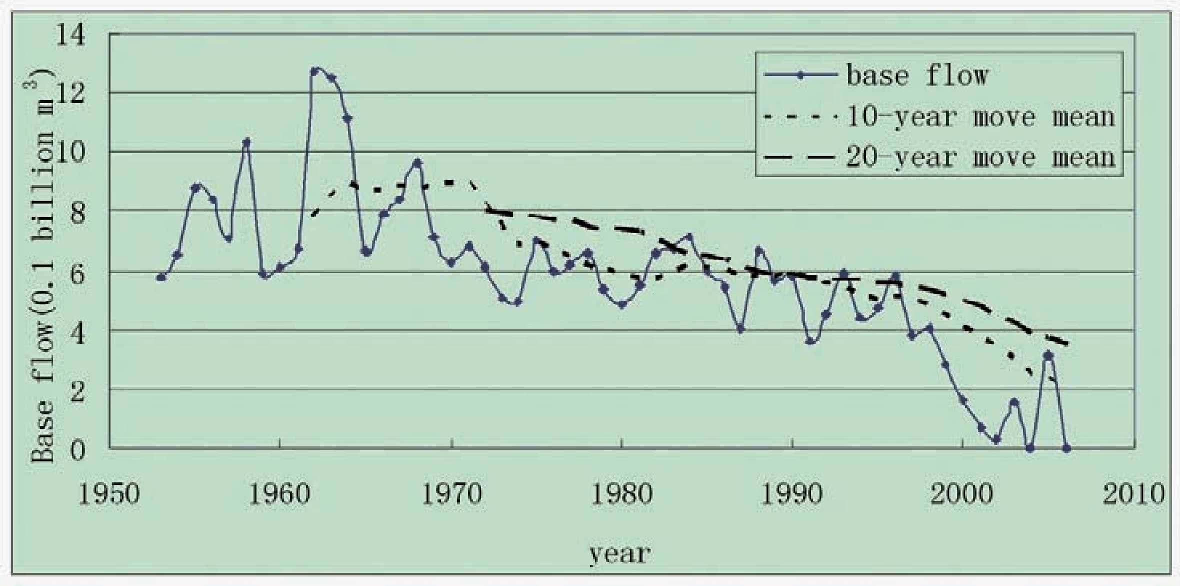

Figure 2 Natural annual runoff of the Qinhe river

Impact of climate change and human activities on water resources is analyzed based on impact of precipitation on runoff is being identified in the Qinhe river. That is, the base flow of the Qinhe river need to be analyzed. The cut method of stream flow hydrograph is used to analyze the Qinhe river's base flow in 1953-2006 (see in Figure 3).

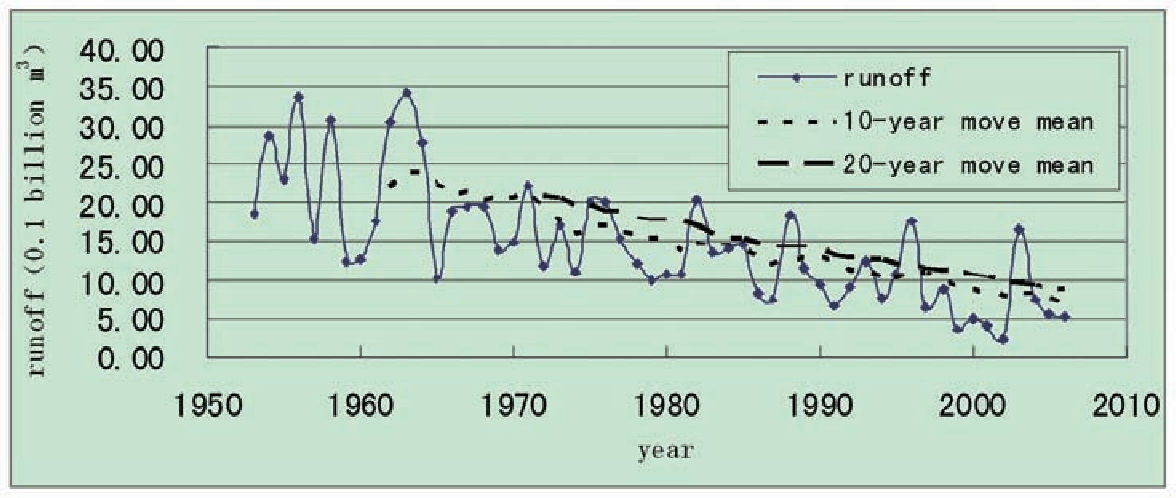

Figure 3 Annual base flow of the Qinhe river

The multi-year average base flow of the Qinhe river in 1953-1959, 1960-1969, 1970-1979, 1980-1989, 1990-1999 and 2000-2006 is 0.753 billion m3, 0.874 billion m3, 0.601 billion m3, 0.585 billion m3, 0.456 billion m3 and 0.107 billion m3 respectively. Since the 1960s, the multi-year average base flow decreases generally. Compared with that of the 1960s, the multi-year average base flow reduction from the1970s is 0.273 billion m3, 0.289 billion m3, 0.418 billion m3 and 0.767 billion m3 in order. And the base flow reduction rate is 31.2%, 33.1%, 47.8% and 87.8%. Thus, the base flow reduction rate is more than 30% from the 1970s, and the rate decreases greatly since the 1990s, and the multi-year average base flow in 2000-2006 is less than

1/8 of that of the 1960s. Compared with that of the multi-year average runoff, the base flow reduction rate is larger, and the base flow is zero particularly in 2006.

The meteorological and hydrological change trend analysis method is used for trend diagnosis based on the Qinhe river runoff and base flow trend being analyzed. And the Mann-Kendall Rank correlation test Analysis method is used to analyze runoff and base flow sequence data in 1953-2006. Thus, the MK trends process in 1954-2005 of runoff and base flow is obtained (see in Figure 4).

From the MK value of annual runoff and base flow sequences of the Qinhe river in 1953-2006, the annual average MK value is -2.45 and -1.86. And the MK value of the runoff exceeds -1.96, which is the threshold at significant level of 0.05, while that of the base flow is lower than -1.96.

From temporal distribution, the MK value of the mean annual runoff in 1954-1977 is -0.63, while the value in 1978-2005 is -4.00, which indicates that the annual runoff in 1978-2005 decreases more obviously than ever before. And the mean MK value of the base flow in 1954-1978 is 0.38, while the value becomes -3.93 from 1979 to 2005, which indicates that the base flow decreases greatly since 1979.

3 Climatic factors

The climatic factors mainly include precipitation, temperature, evaporation. The precipitation of the Qinhe river is analyzed specifically in the paper, and temperature and evaporation is analyzed with domestic related researches.

The multi-year mean precipitation of the Qinhe river is 636 mm with the data of 34 rainfall stations in 1953-1998. And the mean precipitation from 1950s to 1990s is shown in Table 1. Compared with the mean precipitation in 1950's, the precipitation reduction rate since 1960s is 0.1%, 8.4%, 11.4% and 21.1% respectively. The precipitation decreasing trend is the same as that of runoff in the Qinhe river Basin, while reduction rate is less than that of the runoff significantly. The results show that precipitation is an important factor of runoff reduction in the Qinhe river.

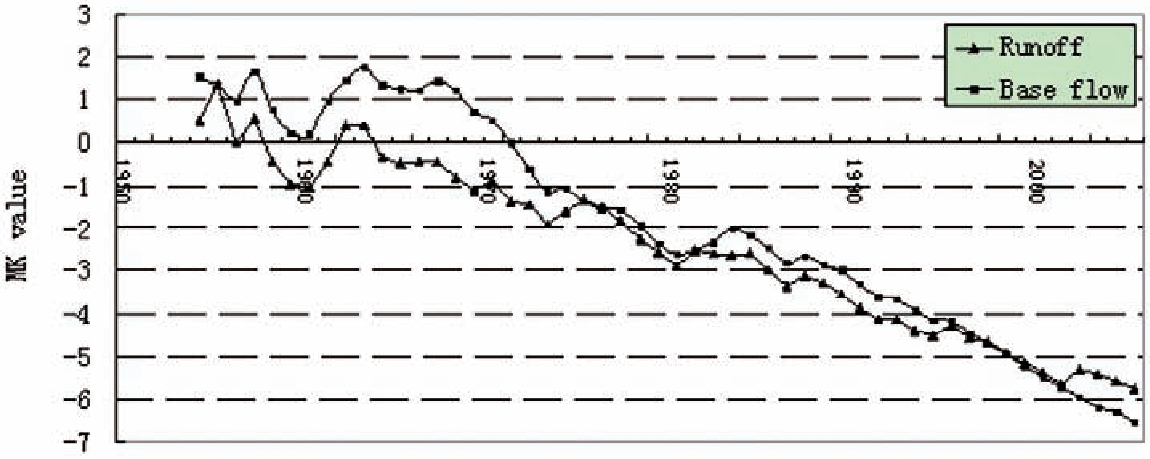

Figure 4 Annual runoff and base flow MK trend process of the Qinhe river

According to HUANG Ronghui et al (2006), the precipitation in range of Sanmenxia - Huayuankou section of the Yellow River Basin was gradually decreasing on the trend since 1950s, the mean annual precipitation

Table. 1 The mean precipitation in the Qinhe river Basin at different stage

Basin	Precipitation（mm）				
	1950s	1960s	1970s	1980s	1990s
the Qinhe river Basin	665.0	664.4	608.9	589.5	524.6

reduction rate in 1990-2000 is about 17.9%. Wang Daoxi, et al (2006) considered that the reduction trend of precipitation and runoff coefficient is basically the same with their process line. The situation shows that natural runoff and precipitation in the basin has a direct relation. The results proved that precipitation decreases greatly in the basin is in certain rationality.

Lan Yongchao (2006) considered that the temperature in range of Sanmenxia - Huayuankou of the Yellow River increases to a certain extent. After studying the climatic factors in the middle Yellow River, Jianyun Zhang, et al (2007) considered that 10-year mean temperature in Xi'an, Yan'an decreases 0.275℃and 0.208℃ respectively, and the temperature increasing trend is very significant. While the temperature incremental rate is about 0.047℃/10a in Zhengzhou, and the overall ascending trend is not significant. The evaporation capacity in some places such as Zhaoshiyao, Zhangshan etc. decreases on the trend generally in the middle Yellow River. However, annual evaporation capacity in 1998-2002 increases in Zhengzhou area. According to domestic researches, the mean temperature increases gradually since 1950s and the incremental rate is not high, while the overall evaporation capacity is on downward trend before 1998.

4 Human activities

The main human activities in the Qinhe river basin mainly is coal mining, artificial rainwater harvesting, industrial and agricultural water consumption, groundwater extraction and water and soil conservation etc. (Yan Heye, 2003). According to actual survey, the Qinhe river runoff in 1997-2006 decreases about 0.286 billion m3/a because of coal mining. According to statistics in 1999, a total 15466 artificial rainwater harvesting projects has been built in the Qinhe river basin, developed irrigated area 8850 mu with water consumption of 33 million m3. So far, there is nearly 100,000 rainwater harvesting projects and annual water use 5.32 million m3 in the Qinhe river basin. Here, industrial and agricultural water consumption incremental rate is about 91 million m3/a in 1997-2006. From Qiao Yongjie etc. (2006) study, the mean groundwater extraction amount is only 0.1 billion m3/a, which is very small before 1990s in the Qinhe river basin. While, the groundwater extraction increases rapidly, and the main groundwater extraction amount is 0.474 billion m3/a. The cumulative soil erosion management area is 9350 ha, and rate of soil erosion management reached 55% at the end of 2000 in the Qinhe river basin. In recent years, the overall vegetation is in good condition, and soil and water conservation investment is limited, and governance progress is not very clear, which shows that impact of soil and water conservation on runoff is little.

5 YRWBM model

The YRWBM model is a simplified large-scale hydrological model that estimates monthly stream flow from monthly rainfall, temperature and potential evaporation data (Wang, et al, 2000). The model has four parameters, and has two output variables of runoff and soil moisture. The calculated discharge of the model consists of surface flow, ground flow and snowmelt flow. Flow concentration was not considered as monthly calculation interval is long enough and all runoff components can flow out the study basin. The model has been successfully applied in some semiarid or humid catchments which are located in China (Guoqing Wang, 2006). Compared with other hydrological models, such as SIMHYD model, Tank model, SMAR model, etc., the model not only has advantages of simpler structure, fewer parameters, more flexibility, but good performance as well. Model structure is shown in Figure 5, and calculation principle was introduced below.

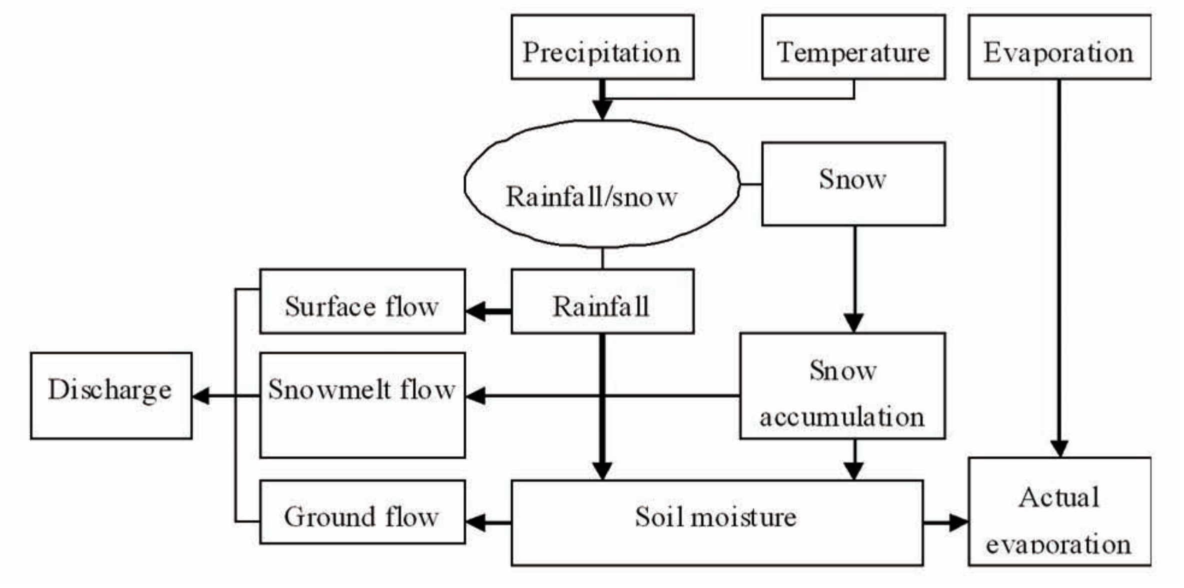

Figure 5 Sketch of monthly water balance model structure

In YRWBM model, precipitation is firstly divided into rainfall and snowfall according to the corresponding temperature. The former is to form surface flow and recharge soil moisture which diverts water to ground flow and is depleted by evaporation. The later is accumulated into snow cover, and finally becomes snowmelt flow and recharges soil moisture as well.

According to water equilibrium principle, soil moisture can be calculated with the following equation.

$$S_i = S_{i-1} + P_i - Q_{ci} - E_i$$

(1)

Where, S_i , P_i , Q_{ci} and are soil moisture, precipitation, calculated discharge and actual evaporation in the calculation interval i respectively. And is soil moisture in the calculation interval i-1.

Calculated discharge can be constructed by liner-recombining surface flow, ground flow and snow melting flow.

(2)

Where, Q_{Si} , Q_{gi} and Q_{SM} are surface flow, ground flow and snowmelt flow in the calculation interval i respectively.

$$Q_{ci} = Q_{Si} + Q_{gi} + Q_{SM}$$

Actual basin evaporation is calculated by one layer soil evaporation model, the calculation formula is given as follow.

$$E_i = \frac{S_{i-1}}{S_{max}} \cdot E_{601i}$$

(3)

Where, E_{601i} is potential evaporation measured by evaporator E601.

Separation of Rainfall and snowfall is prerequisite for surface flow and snow melting flow calculation. Critical temperature T_H and T_L (4℃ and -4℃ respectively) that is related to precipitation form are chosen firstly by analysis on recorded data of precipitation and air temperature. And snowfall can be estimated by the following linear interpolation function when temperature occurred between and .

$$P_{SMi} = \frac{T_H - T_i}{T_H - T_L} \cdot P_i \tag{4}$$

$$P_{Ri} = P_i - P_{SMi} \tag{5}$$

Where, P_{Ri} , P_{SMi} and T_i are rainfall, snowfall and air temperature in the calculation interval i respectively.

The surface flow is directly proportional to soil moisture and precipitation. And surface flow calculation formula is:

$$Q_{si} = k_s \cdot \frac{S_{i-1}}{S_{max}} \cdot P_{Ri} \tag{6}$$

The ground flow is calculated by a linear reservoir theory. The equation is given as follow.

$$Q_{gi} = k_g \cdot S_{i-1} \tag{7}$$

Snow melting rate is not only an exponential function with air temperature, but also proportional to snow accumulation. And snowmelt flow formula is mathematically expressed as follow.

$$Q_{SMi} = k_{sn} \cdot e^{\frac{T_i - T_L}{T_H - T_L}} \cdot SN_i \tag{8}$$

$$SN_i = SN_{i-1} + P_{SMi} \tag{9}$$

Where SN_i and SN_{i-1} are snow accumulation in the calculation interval i and i-1.

6 Results and discussion

The YRWBM model is used to analyze impacts of climate change and human activities on the Qinhe river runoff. And the Nash and Sutcliffe efficency criterion was employed to evaluate model performance using observed data and model estimates (Nash & Sutcliffe, 1970). It is proved that the YRWBM model can be applied to simulate the Qinhe river runoff with better precision (see in Figure 6). Simulating results show that maximum relative error of simulated and recorded runoff is less than 15%, and the Nash-Sutcliffe model efficiency coefficients were 73.2% and 70.8% on validation period (1955-1965) and calibration period (1966-1969). And the mean relative error is less than 5%. This shows that the YRWBM model has a high credibility in analyzing impact of climate change and human activities on the Qinhe river runoff (Guoqing Wang, 2006; Jianyun Zhang, 2007).

Based on the YRWBM model, specific simulating results of the Qinhe river runoff are shown in Table 2. From Table 2, the recorded runoff and simulated runoff generally match well. And the recorded runoff decreases gradually on the trend from 1970s, while the simulated runoff decreasing trend is relatively obvious. Impact level of climate change on the Qinhe river runoff is about 45% since 1970s. However, the absolute and relative impact amount of human activities on runoff keeps an increasing trend generally in 1980-2006. Since

2000, impact amount of human activities on the Qinhe river runoff reaches 54.7% compared with impacts of climate change on the Qinhe river runoff. And the degree of influence of human activities on runoff markedly enhanced. In average, impact of climate change and human activities on the runoff is 46.1% and 53.9% respectively. Impact of human activities on the runoff is more significant than that of climate change. According to impact of human activities on runoff conditions, combined with the results of climatic factors such as precipitation, temperature and evaporation, the simulation result is in certain rationality.

Table 2 Impact of climate change and human activities on the Qinhe river runoff

Year	Recorded value (mm)	Simulated value (mm)	Total reduction (mm)	impact of climate change on the Qinhe river runoff		impact of human activities on the Qinhe river runoff	
				(mm)	(%)	(mm)	(%)
Background value	117.6	120.1					
1970-1979	47.7	87	69.9	30.6	43.8	39.3	56.2
1980-1989	42.5	80.6	75.1	37	49.3	38.1	50.7
1990-1999	20.8	66.4	96.8	47.2	48.8	49.6	51.2
2000-2006	18.6	55.6	99.0	44.8	45.3	54.2	54.7
1970-2006	33.5	74.7	84.1	38.8	46.1	45.3	53.9

7 Conclusions

Based on the Qinhe river runoff decreasing trend gradually since 1953s, The YRWBM model is used to simulate impact of climate change and human activities on runoff. The results show that the YRWBM model is well applied to the Qinhe river. And impact of climate change and human activities on the Qinhe river runoff is 46.1% and 53.9% respectively. Impact of human activities on runoff is more significant than that of climate change.

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Analysis of Climate Change Impact on Hydrology and Water Resources in the Yellow River Basin

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Abstract

The hydrological cycle has been highly influenced by climate change and human activities and it is significant for analyzing the trends of hydrology and water resources that occurred in past decades in order to understand past changes and predict future trends. By incorporating historical meteorological data and available geographic information related to the conditions of the landscape, a distributed hydrological model has been employed to simulate the natural runoff without consideration of artificial water intake. Based on the data observed and the results simulated by the model, the hydrological trends have been analyzed quantitatively for evaluating the impact from climate change and human activity. Together with the statistic data, it was found that artificial water consumption showed a significant increasing trend during the past 50 years and was the main cause of the drying-up of the Yellow River. However, in contrast to the common perception that the serious drying-up of the downstream in Yellow River during the 1990s was caused by the rapid increase of artificial water consumption during the same period, it had been found that the main cause of this aggravation is the drier climate that has existed since the 1990s. The main reason for drying-up situation became better in the 21 century is due to the enhanced water resources management since 2000. Based on the concept of water use flexibility to climate fluctuation and actual water use data from 1988-2006, a set of flexible limits to water shortage due to climate fluctuation has been proposed for the Yellow River basin. This includes total water use flexible limit to water shortage for each province in the basin, which is approximately 70%; and the different water use flexible limits to water shortage for each social sector, which are approximately 90% for agriculture, 85% for domestic use, and 50% for other industries. The concept of water use flexible limit offers a simple, yet effective, methodology for future water resources allocation in the Yellow River basin to achieve the optimal use of water resources considering climate change.

1. Introduction

The hydrological cycle traces the largest movement of any substance on Earth (Chahine, 1992), and at the same time, has been greatly influenced by climate change and human activities in the past five to ten decades. The components of the regional hydrological cycle include precipitation, evapotranspiration, runoff, and change of water storage including soil water, groundwater, ice water, snow water, canopy water and reservoir water. Runoff is given more attention for its close relation to the water resources (McCabe et al., 1997; Bronstert et al., 2002). Overall, global land precipitation has increased since the beginning of the 20th century but the increase is neither spatially nor temporally uniform (IPCC, 2007). Over the last 50 years, there has been a slight decrease in annual precipitation in China (Zhai et al., 1999) including the Yellow River basin (Yang et al., 2004). As a result, it was found that the runoff was reduced in some major river basins in China, such as the Yangzte River basin (Yang et al., 2005; Xu et al., 2008) and the Yellow River basin (Fu et al., 2004; Yang et al., 2004). Regarding the evapotranspiration, many observations show that pan evaporation has been steadily decreasing around the world for over the past 50 years (Peterson et al., 1995; Chattopadhyay et al., 1997; Thomas, 2000; Liu et al, 2004; Moonen et al., 2002; Michael et al, 2004). It has been disputed that the decreasing of the pan or reference evaporation predicates the decrease of the actual evaporation

(Peterson et al., 1995; Brutsaert et al., 1998). Based on the Budyko hypothesis, Yang et al. (2006) suggested that a complementary relationship exists in non-humid areas where the precipitation is the controlling factor of the actual evapotranspiration and that a proportional relationship exists in humid areas where energy is the controlling factor.

The population in China has been tripled during last 50 years, it reached around 1.3 billion at present time. At the same time, water crisis is increasing in many regions, especially in northern China. Near one-third of the population, about 381 million, live under conditions of water scarcity. The Yellow River basin, which is the second longest river basin in China, is one of the regions facing to serious water shortage due to dry climate and heavy water uses. In recent 20 years, the Yellow River has become a seasonal river. The duration of no-water in the river along the lower reaches rapidly increased in 1980s and 1990s. In the most serious situation in 1997, the main river close to the sea was dry-up for more than 226 days, and the longest dry distance was 704 km from the river mouth. Several recent researches have been addressed for understanding the water resources problem and improving the river management in the Yellow River basin. Most of the research focused on discussion of the river dry-up along the lower reach (Cheng and Wang et al., 1998; Cheng and Li et al., 1999). He et al. (2000) analyzed the status of water resources, especially on the changes in recent 20 years. Ren et al. (2002) discussed variation of the river discharge at three gauges in the past 50 years and the possible impacts by human activity. Management of the Yellow River basin was emphasized on the flood control and soil-water conservation. Due to the increase of water shortage especially in 1997, problem on water resources became the same important issue (Wang and Fong, 2001).

Water resources planning and allocation in the river basin scale is among the most widely discussed issues in water resources management. Various programming methods were developed in the recent years, and some of them have been utilized by the Yellow River water resources management (Feng et al., 2007; Xu et al., 2003). However, most of these are either aimed at developing a water resources allocation plan based on water availability at the average level or optimizing the water resources allocation according to variations of the water storage volumes. Therefore, what they determined was the water resources allocation for the average climate level. However, climate change has significant consequences on water resources in a watershed scale (Wood et al., 1997; Giacomelli et al., 2008). The planning and allocation decisions in watershed management require strict review, especially in the arid or semi-arid regions with different dryness levels, because water resources are becoming scarcer and increasingly susceptible to variation. A water allocation policy should integrate equity, efficiency, and environmental consciousness (Jouravlev, 2005). A stable water rights system should be strengthened in multiple dimensions, focusing on security and flexibility, to be an effective incentive for the development and conservation of water resources (Solanes and Jouravlev, 2006). Under scarce water conditions, the difficulty level of allocation increases due to the conflict of interests among users. Therefore, an effective method of water resources allocation should consider different water resources reliability to seek harmony with the resources base under the climate change (Garrote et al., 2007).

In the present study, 50 years of daily meteorological data are used together with the available geographic information related to the land cover and vegetation, and an assessment of the natural river discharge is carried out by applying GBHM for simulating the hydrological cycle over the last 50 years in the Yellow River basin without consideration of the artificial water intake. Based on long-term observation and hydrological simulation, the hydrological trends in this basin are analyzed for understanding the influences of climate change and human activity. On the other hand, this paper aims to analyze the water shortage experiences of the provinces and social sectors along the Yellow River, and design a water resources reallocation plan that can serve as a model for the water deficient regions of China.

2 Study area

Yellow River, the second largest river in China, originates from the Tibetan plateau, wanders through the northern semi-arid region, crosses the loess plateau, passes through the eastern plain, and finally discharges into the Bohai Gulf (Fig. 1). The river mainly flows through nine provinces (municipalities), namely Qinghai, Sichuan, Gansu, Ningxia, Shaanxi, Shanxi, Henan, Shandong province, and Inner-Mongolia municipality. The main course of the river flows about 5,500 km in distance and accumulates 753,000 km2 of drainage area. Approximately 100 million people live within the basin, which consists of 1200 million ha of farmland, nearly half of which is irrigated by the Yellow River.

From the origins to the river mouth, the Yellow River experiences three typical landforms, the Tibet plateau with elevation from 2,000 to 5,000 meter, the loess plateau and middle reach tributaries with elevation from 500 to 2,000 meter, and the alluvial plain. The climate conditions vary from cold to temperate zones, and change from arid, semiarid to semi-humid regions. The long-term basin-average annual precipitation is reported to be 476 mm, and varies from 200 to 650 for the most regions (Cheng, 1996).

The long-term mean annual natural runoff of the Yellow river is about 58,000 million cubic meters, accounting for 2.0% of the total river runoff in China. However, an evident inter-annual variation of the natural runoff exists for Yellow River. The annual natural runoff frequently changes at different years due to climate fluctuations (Table 1). In the 1990s, the Yellow River basin experienced a continuous dry spell (Yang et al., 2004). This led to the dry-up of the lower reach, thereby causing numerous eco-environmental problems. For this reason, an effective and flexible water resources allocation policy must consider the annual and inter-annual variability of water resources, aside from the long-term mean of the water availability. It is only logical to set up a water allocation policy considering various situations of water shortage for the water resources management in the Yellow River basin.

3 Hydrological trends

The trend analyses focus on precipitation, evapotranspiration and runoff ignoring the water storage change. The precipitation and potential evaporation changes are the two most important indicators of climate change from the hydrological perspective. The observed runoff incorporates the influence of climate change and human activities. These direct activities include land use change, water intake and reservoir regulation. In the present study, the runoffs simulated by GBHM from 1951 to 1981 reflect the impact of climate change only since the same land use data has been used in simulation, and the runoffs simulated from 1982 to 2000 reflect the impact of climate and land use changes. Since there is no consideration of water intake, irrigation and reservoir operation, the simulated runoff is called natural runoff in this paper.

3.1 Long-term hydrological characteristics

3.1.1 Spatial hydrological characteristics

The general hydrological characteristics can be found from the annual water balance (see Table 2), which shows high spatial variability in this basin. Based on the available data, the annual precipitation ranges from less than 200 mm to more than 700 mm, which increases from north to south and from west to east. The annual actual evapotranspiration ranges from 137 mm to 589 mm (see Fig. 2a). The annual runoff ranges from 0~345 mm (Fig. 2b) which consists of only about 20% of the annual precipitation.

From the annual runoff simulated under natural conditions, it can be seen that the major source areas are upstream of the Lanzhou gauge. This region generates about 50% of the basin's total annual runoff, with only 30% of the basin total area. At the same time, the annual runoff generated from the main tributaries in the midstream between the Longmen and Sanmenxia gauge shares about 25% of the basin total, the same proportion of the drainage area. The area downstream of the Sanmenxia dam generates about 10% of the basin's total annual runoff with only 6% of the basin's total area. The semi-arid region and the loess plateau between the Lanzhou and Longmen gauges generate less runoff compared to their shared drainage areas.

3.1.2 Seasonal hydrological characteristics

Considering the seasonal precipitation and water consumption, the year may be divided into a dry season from November to June and a wet season from July to October. Table 2 shows the seasonal characteristics of the water balance in the study basin. The highly uneven distribution of the seasonal precipitation can be seen from Table 2, in which about 64% of the annual precipitation is concentrated within the wet season from July to October. This seasonally-uneven distribution of precipitation is more serious in the semi-arid region and the loess plateau (between the Lanzhou and Longmen gauges) where precipitation in the wet season accounts for about 70% of the annual total precipitation. After the land surface hydrological processes, this seasonally-uneven distribution of precipitation produces similar uneven seasonal river discharge and the uneven distribution of the river discharge is amplified in the semi-arid region. For the entire simulated area, about 60% of the annual runoff occurs within the wet season from July to October.

3.1.3 Inter-annual variability of runoff

For the annual runoff, the ratio of the maximum value to the minimum value during the last 50-years is 3.0 at the Lanzhou gauge and is 4.5 at the Huayuankou gauge. Fig. 3 shows the monthly river discharges at the Lanzhou and Huayuankou gauges from 1951 to 2000. The inter-annual variability of the base flow is much smaller than the peak flow. The variability in the monthly peak discharge is about a factor of five between a dry year and a wet year at the Lanzhou gauge. This variability is enlarged at the Huayuankou gauge, reaching more than a factor of ten. The high inter-annual variability of the river discharge determines the likelihood floods and droughts, and makes it difficult to manage the water resources in this basin.

3.2 Hydrological trends in the past 50 years

The hydrological trend and Mann-Kendall test results during the past 50 years are summarized in Table 3. It can be seen that trends of the annual precipitation, pan evaporation, actual evapotranspiration and natural runoff are not consistent temporally and spatially. During the period of 1951-2000, precipitation shows a slight decreasing trend (non-significant) of 4.7 mm/10yr2 from 1951 to 2000 for the whole study area, and this non-significant decreasing trend is found primarily downstream of the Lanzhou gauge mainly; however, the precipitation in upstream of the Lanzhou gauge has an increasing trend (non-significant). The pan evaporation has a significant decreasing trend of 31.1 mm/10yr2 for the whole study area, and this decreasing trend is found in both upper and lower parts of the Lanzhou gauge. The actual evaporation has similar trends as precipitation. The simulated natural runoff has significant decreasing trends for both upper and lower reaches of the Lanzhou gauge and the whole study area.

The difference between the simulated runoff and the observed Runoff can be viewed as the direct human effect on the river runoff such as water storage, water extraction from the rivers and water transfer to other basin, with respect to the reduction of river flow. Figure 3 shows the comparison between the simulated and observed discharges at the Lanzhou and Huayuankou gauges. From Fig. 3(a) it can be seen that the difference between the simulated and observed hydrographs is very small during 1950s and 1960s, but this difference has been enlarged since 1970s. The reason for this change is the impact of reservoir operation, because there is relatively less artificial water consumption in this region. Similarly, it can also be found that difference between the simulated natural discharge and observed discharge was small in 1950s for other hydrological stations and this difference gradually increased (e.g. the Huayuankou gauge in Fig. 3(b)) due to the reservoir regulation and artificial water consumption. The artificial water use is mainly the agricultural irrigation in the Yellow River basin, and the irrigation projects had been constructed since the end of 1950s. Therefore, we can attribute the difference between simulated and measured annual runoff to the direct human effect on the river runoff, which consists mainly of the artificial water consumption and reservoir storage. Figure 6 shows the difference between the simulated and observed monthly discharges in different decades.

Taking the river discharge at the Huayuankou gauge as the naturally available runoff for the whole of Yellow River basin because of the suspended river along the lower reaches, the direct artificial effect on the river runoff for the whole Yellow River basin can be estimated as the difference between the simulated river discharge at the Huayuankou gauge subtracted from the observed river discharge at the Lijin gauge (see Fig. 4). The degree of direct artificial effect on river runoff continually increased from the 1950s to the present. However, the statistic data of artificial water consumption in the Yellow River basin shows that the artificial water consumption does not increase since the 1990s. The river drying up along the lower reaches has been continuously aggravated since the 1970s and was at its worst in the 1990s. It improved during the 21st century. However, the annual discharge into the sea has continuously decreased since the 1970s (see Fig. 4), which is closely related to the natural runoff. Therefore, it can be concluded that the main reason for the river dry-up is the increase of artificial water consumption, dry climate is the main cause for the desiccation of the lower reaches in the 1990s, and this situation improved during the 21st century as a result of the enhanced water resources management mainly in addition to the climate.

4 Analysis of the water shortage experience in the Yellow River basin

Based on the data provided by “Bulletin of Yellow River Water Resources” (Yellow River Conservancy Commission, 1988-2006) and “China Water Resources Bulletin” (The Ministry of Water Resources of China, 1998-2006), the actual water consumptions from 1988 to 2006 of the provinces or municipalities along the Yellow River were analyzed. A set of empirical flexible limits to the water shortage adapted to the Yellow River basin was proposed (Shao et al., 2008).

4.1 Analysis on the flexible limit of water consumption to water shortage for the provinces (municipalities)

Table 4 shows the variations of actual annual water consumptions in different provinces/municipalities from 1988-2006 since the “Water Resources Allocation Plan” was issued in 1987. The actual mean annual surface water consumptions of Shaanxi and Shanxi provinces have been lower than the 1987 quota. This is because their surface runoff in the Fenhe and Weihe Rivers (two main tributaries of the Yellow River) was deficient and they could not take water from the Yellow River easily. In the meantime, groundwater was pumped extensively in these areas. Table 4 also indicates that the actual mean annual water consumptions of Qinghai, Gansu, Ningxia, and Henan were a little less than the 1987 quotas, while the actual mean annual water consumptions of Inner-Mongolia and Shandong were much higher than the 1987 quotas. With the exception of Shaanxi and Shanxi, the variance of the actual mean annual water consumptions of other provinces and municipalities ranged from 47%~193%. According to the definition of water use flexible limit to water shortage, and considering the 1987 quotas are the normal annual water requirements for the provinces, the flexible limit of water consumption for Henan province is about 50%, about 60% for Gansun province, about 70% for Qinghai and Shandong provinces, about 80% for Ningxia province, and about 90% for Inner-Mongolia municipality. This preliminary result indicates that the mean flexile limit to the water shortage is approximately 70% of the normal year for all provinces (municipalities) along the Yellow River. The implication of which is that water supply for the provinces must guarantee 70% of the normal year level;

otherwise, disasters may happen.

4.2 Analysis on the water consumptions and flexible limits to water shortage for different sectors

Based on the data from “China Water Resources Bulletin,” an analysis has been carried out on the agricultural, industrial, and domestic water consumptions in the Yellow River basin from 1998 to 2006. Tables 5–8 indicate the actual maximum, minimum, and mean amount of water consumption, and variation ranges from the minimum to the mean are identified as the flexible ranges of water use to water shortage.

These four tables indicate that from 1999-2006, the variations of the agricultural, industrial, urban domestic and rural domestic water use for all provinces were about 77.6～123.8％, 32.6～190.9％, 61.5～129.4％, and 37.9～164.0％, respectively. The mean flexible limits to water shortage of agricultural, industrial, urban domestic and rural domestic users were approximately 90%, 50%, 85% and 75% respectively. It can be observed that the industrial water user had the largest flexible range to water shortage, while the agricultural and urban domestic water users had the least flexible range to water shortage. This may be because the industry can enhance water recycling techniques and improve production technologies to largely reduce the proportion of water use when a water shortage happens. When droughts occur, the agricultural water supply should be guaranteed at least 90% of the normal level, especially during the critical growing period for the crops. However, during the non-critical growing period, irrigation water for the plants can be reduced accordingly. Here, rural domestic water consumption in the Yellow River basin has a larger extent than urban domestic water consumption, primarily because in rural areas some crude projects are effective, such as ponds for collecting precipitation and wells for pumping groundwater, whereas these water resources are not included in the statistics. In fact, domestic water use can not be reduced too much due to social security; 85% of the normal level may be the limit.

5. Discussion on water resources allocation considering the climate change

Giacomelli et al. (2008) pointed out that “the significance of water rights is to establish a maximum limit of water consumption allowed for each user; in fact, it cannot exceed the respective water rights limit and it can be far lower,” which implicitly reflects the concept of the water use flexible range to water shortage we proposed. The disciplinary perspective of drought was discussed and the competition among water users along the Adda River was analyzed in their paper. They focused on the inner-annual (monthly) water resources demand and supply analysis and produced a preliminary picture of the water right volumes. Wheida et al. (2007) argued an alternative solution for the water shortage problem in Libya, including water supply management, water demand management, and water allocation management. In water demand management, they mentioned that the reduction of agricultural water consumption could be achieved by several means, such as a national policy on water resources, agricultural planning, irrigation technique, and production efficiency. For the water allocation management aspect, they mentioned how Libya needs legislation for actual water consumption. Their paper presented a similar idea through controlling the water supply when droughts happen, but they focused on water-saving techniques and legislation improvement. The “Urban Water Management Plan” for the City of Santa Cruz (City of Santa Cruz Water Department, 2005) analyzed the city’s water shortage contingency plan. It divided the water shortage condition into four stages and decided water consumption reduction methods for social activities based on these four stages (minimal, moderate, serious, and severe). For example, there are voluntary restrictions of water consumptions for the minimal stage and mandatory restrictions of water consumptions for the moderate shortage. This plan provided a detailed description of water supply reliability and water shortage countermeasures, which would be a good reference for our further study.

In contrast with the operational plan issued in 1998 for the Yellow River, which stipulated the same reduction proportion of water supply to all provinces or municipalities in a dry year due to climate change or fluctuation, the method proposed in our research appears to be more reasonable because it considered the varying water shortage-bearing capacities of the provinces. Furthermore, it can also instruct water reallocation among different social sectors. However, as a preliminary design of water entitlements, this research calls for further study, such as more detailed water shortage classifications, impact of populations increment on water reallocation policy, and a more operable program for water reallocation especially at the inner-annual scale.

6. Conclusion

Taking the Yellow River basin as a case study, this paper first analyzed the hydrological trend in the Yellow River basin during the past 50 years to explore the changes of water resources and the reason for the drying-up of the Yellow River, and then discussed a method for designing a future water resources allocation plan especially during the dry years and dry seasons. It indicates that if the Yellow River basin once again experiences a dry year in the future, based on the water use flexible limits to water shortage of the provinces along the river, water supplies for the provinces must guarantee 70% of the normal year level; otherwise, disasters maybe happen. Meanwhile, for the social sectors of all the provinces, agricultural water supply for the critical growing period must guarantee 90% of the normal year level, industrial water use about 50% of the normal year level, and domestic water use about 85% of the normal year level. This would be a simple and pragmatic method for prior allocation and would be utilized in determining future allocation based on the water resources assessment and the flexible limits analysis. This method is expected to provide a useful reference for water resources management under the condition of climate change or fluctuation.

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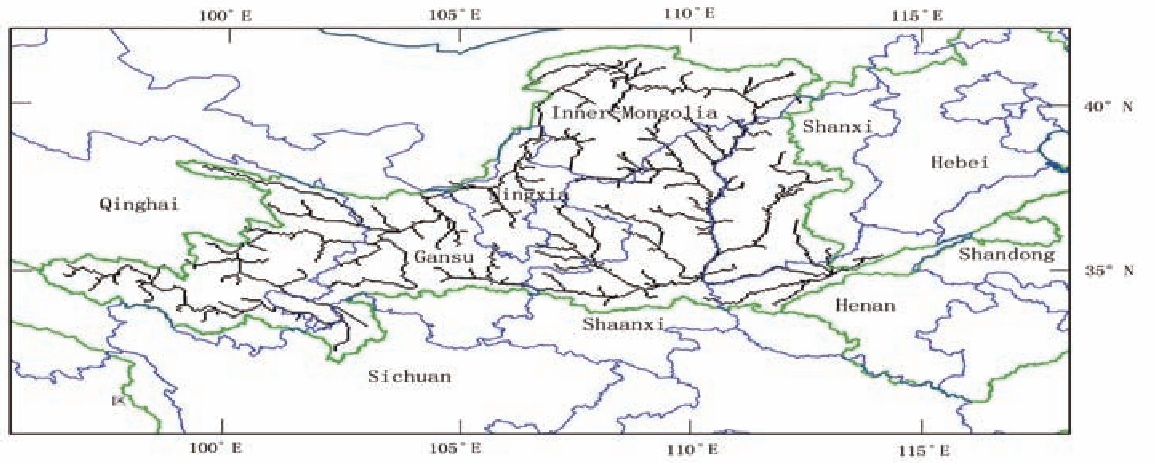
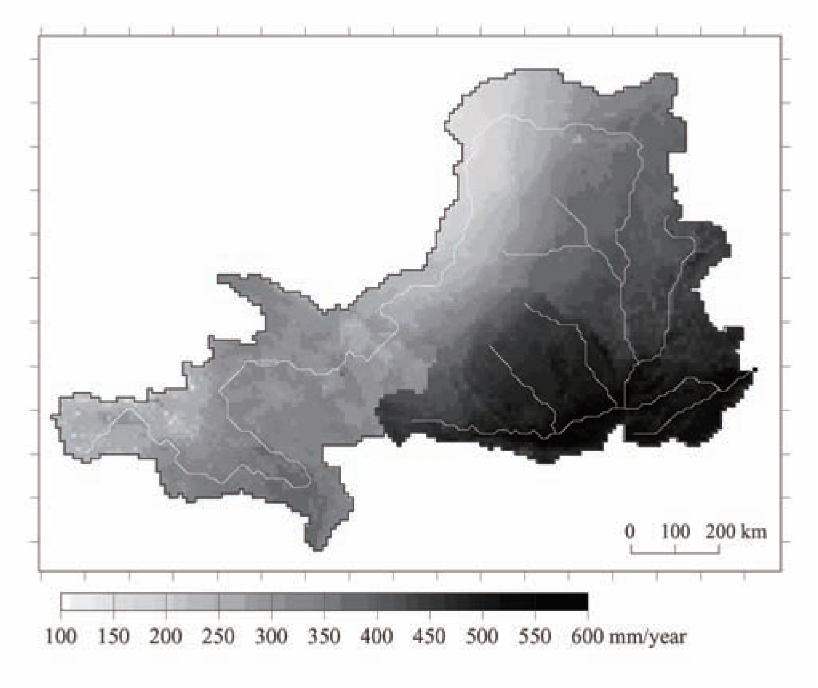
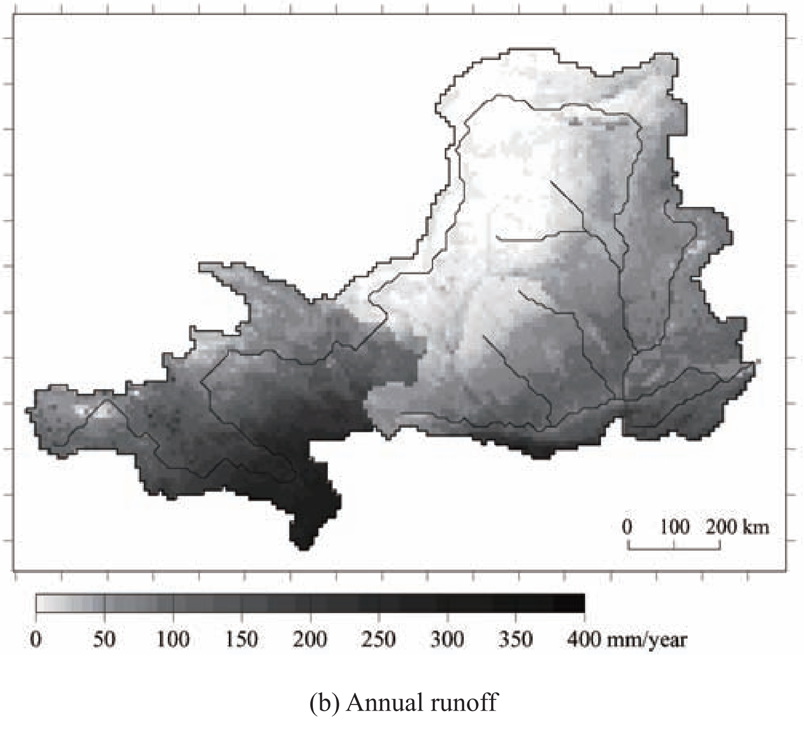


Figure 1. The Yellow River basin, its river networks and the provinces (municipalities) along the Yellow River

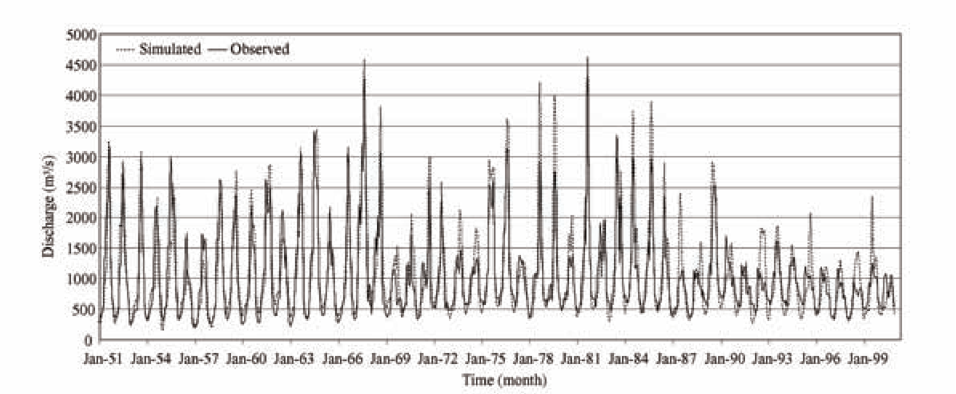


(a) Annual evapotranspiration

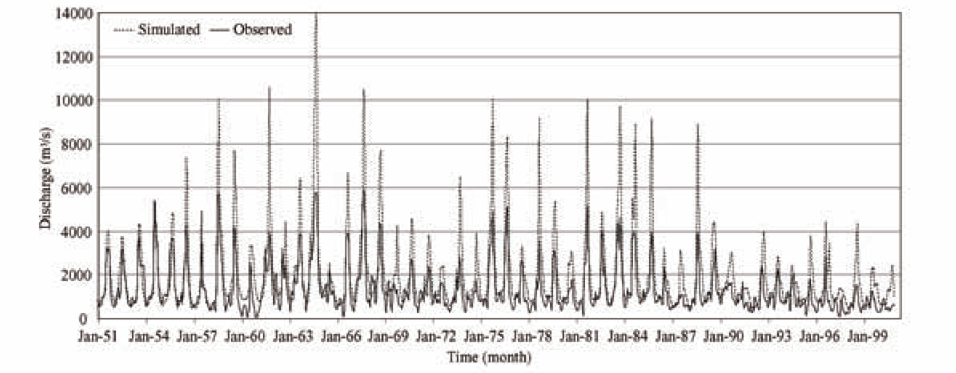


(b) Annual runoff

Figure 2. Spatial distributions of the 50-year mean: (a) Annual evapotranspiration and (b) Annual runoff



(a) Lanzhou



(b) Huayuankou

Figure 3. Monthly river discharge at the Lanzhou and Huayuankou gauges

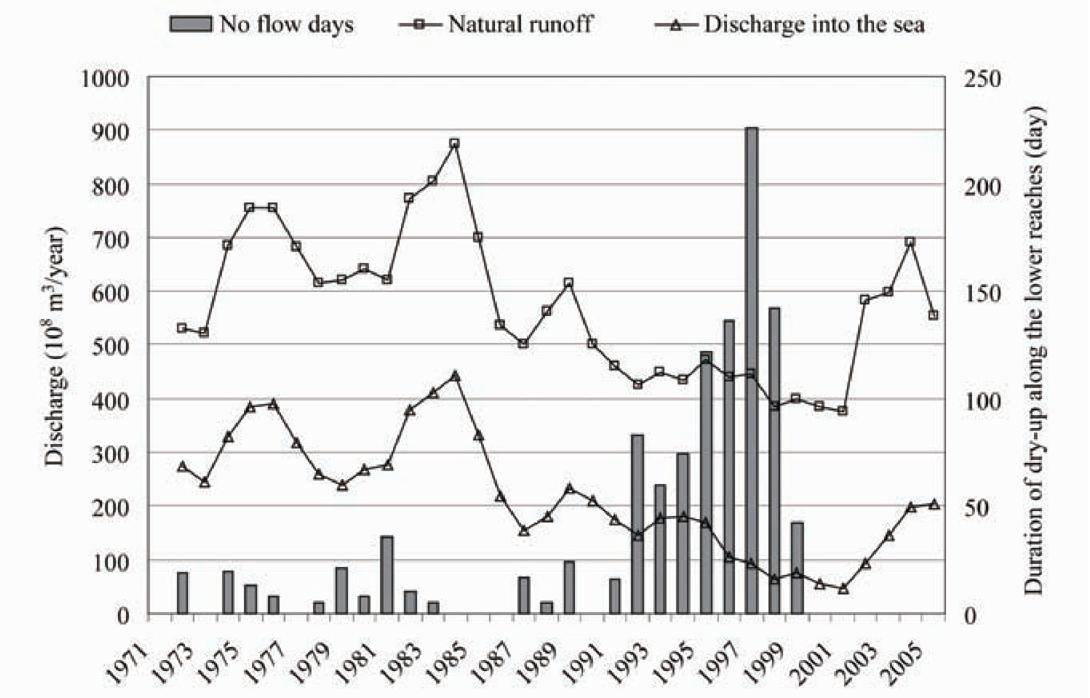


Figure 4 Relationship between the natural runoff, discharge into the sea and the duration of the dry-up (the natural runoff and discharge into the sea are 3-years average values)

Table 1. The natural runoff of the Yellow River in recent years (unit: 10^8 m^3)

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Annual runoff	378.17	447.97	452.18	349.87	323.33	300.30	575.42	396.70	555.47	400.41

Table 2. Long-term average water balances from 1951 to 2000

Region	Precipitation (mm/yr)			Actual Evaporation (mm/yr)			Runoff (mm/yr)		
	Annual	Dry	Rain	Annual	Dry	Rain	Annual	Dry	Rain
Upstream of Lanzhou (I)	447	173	274	309	121	189	137	57	79
Lanzhou - Toudaoguai (II)	264	83	180	251	113	139	12.4	6.6	5.6
Toudaoguai - Longmen (III)	420	135	285	382	184	198	42	14.8	23.6
Longmen - Sanmenxia (IV)	548	204	344	468	238	230	84	27	53.7
Sanmenxia - Huayuankou (V)	631	247	384	510	258	253	126	43.3	77
Whole study area	440	159	280	362	168	194	77	30	47

Table 3. Hydrological trend in the Yellow River Basin

Period	Region	Trend (mm/10yr2)				Is Kendall test accepted?			
		P	ETp	ETa	Rsim	P	ETp	ETa	Rsim
1951-2000	Upper	7.7	-44.8	14.1	-5.2	N	Y	Y	Y
	Lower	-9.9	-21.3	-2.5	-6.3	N	N	N	Y
	Whole	-4.7	-31.1	2.4	-5.9	N	N	N	Y
1951-1981	Upper	28.3	-46.3	20.2	10.2	Y	Y	Y	N
	Lower	-1.7	56.5	1.0	-0.9	N	N	N	N
	Whole	7.2	11.0	6.7	2.4	N	N	N	N
1982-2000	Upper	-27.0	75.6	10.8	-35.7	N	N	N	Y
	Lower	-33.2	65.7	-6.2	-24.5	N	N	N	Y
	Whole	-32.4	68.6	-1.2	-1.2 -28.1	Y	Y	N	Y

Table 4. Actual water consumption of provinces/municipalities along the Yellow River (10^8 $m^{3)}$

Province/ municipality	Qinghai	Gansu	Ningxia	Inner-Mongolia
Allocation quota in 1987	14.1	30.4	40.0	58.6
Maximum water consumption from 1988-2006	15.90	30.05	42.5	71.55
Minimum water consumption from 1988-2006	9.83	17.56	30.37	50.46
Mean of actual water consumptions from 1988-2006	12.01	25.90	36.88	62.22
Variation of the actual water consumption from 1988-2006 compared to the quota in 1987	69.7%~112.8%	57.8%~98.8%	75.9%~106.3%	86.1%~122.1%

Province/ municipality	Shaanxi	Shanxi	Henan	Shandong
Allocation quota in 1987	38.0	43.1	55.4	70.0
Maximum water consumption from 1988-2006	26.84	14.4	50.82	134.8
Minimum water consumption from 1988-2006	17.30	9.04	26.07	49.57
Mean of actual water consumptions from 1988-2006	21.84	11.24	33.98	77.45
Variation of the actual water consumption from 1988-2006 compared to the quota in 1987	45.5%~70.6%	21.0%~33.4%	47.1%~91.7%	70.8%~192.6%

Table 5. Statistics of annual agricultural water use for the eight provinces (municipalities) along the Yellow River from 1998~2006 (unit: m3 per year per mu)

Province/ Municipality	Annual Maximum	Annual Minimum	Annual Mean	Variation (%)
Qinghai	647	616	628.0	98.1～103.0
Gansu	628	542	589.3	92.0～106.6
Ningxia	1352	848	1092.3	77.6～123.8
Inner-Mongolia	455	353	408.6	86.4～111.4
Shaanxi	318	280	298.1	93.9～106.7
Shanxi	217	201	209.3	96.0～103.7
Henna	234	170	203.1	83.7～115.2
Shandong	275	232	251.8	92.1～109.2

Table 6. Statistics of annual industrial water use for the eight provinces (municipalities) along the Yellow River from 1998~2006 (unit: m3 per 10 thousand RMB value added of industry)

Province/ Municipality	Annual Maximum	Annual Minimum	Annual Mean	Variation (%)
Qinghai	476	264	365.3	72.3～130.3
Gansu	540	182	355.9	51.1～151.7
Ningxia	514	120	278.9	43.0～184.3
Inner-Mongolia	185	84	136.4	61.6～135.6
Shaanxi	230	63	148.1	42.5～155.3
Shanxi	187	62	120.4	51.5～155.3
Henna	201	80	135.3	59.1～148.6
Shandong	117	20	61.3	32.6～190.9

Table 7. Statistics of the annual urban domestic water use for the eight provinces (municipalities) along the Yellow River from 1998~2006 (unit: liter per day per capital)

Province/ Municipality	Annual Maximum	Annual Minimum	Annual Mean	Variation (%)
Qinghai	217	195	201.8	96.6～107.5
Gansu	194	190	191.6	99.2～101.3
Ningxia	192	115	157.6	73.0～121.8
Inner-Mongolia	134	71	115.4	61.5～116.1
Shaanxi	192	147	171.0	86.0～112.3
Shanxi	148	99	114.4	86.5～129.4
Henna	186	159	171.4	92.8～108.5
Shandong	145	119	132.6	89.7～109.4

Table 8. Statistics of the annual rural domestic water use for the eight provinces (municipalities) along the Yellow River from 1998~2006 (unit: per capital L/d)

Province/ Municipality	Annual Maximum	Annual Minimum	Annual Mean	Variation (%)
Qinghai	124	39	79.6	96.6～107.5
Gansu	57	41	49.5	99.2～101.3
Ningxia	44	25	34.0	73.0～121.8
Inner-Mongolia	121	28	73.8	61.5～116.1
Shaanxi	57	42	50.1	86.0～112.3
Shanxi	48	35	40.1	86.5～129.4
Henna	70	44	55.5	79.3～126.1
Shandong	67	49	56.3	87.0～119.0

Impact of Climate Change on Streamflow in Headwater Catchment of the Yellow River Basin

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Abstract

To investigate how streamflow in headwater catchment of the Yellow River basin will be affected by climate change in the future, four Global Climate Models (GCMs), the Canadian Global Coupled Model CGCM2, CCSR developed by Japanese Research Center of Climate Systems, the Australian developed CSIRO, and the HadCM3 model developed at the Hadley Centre in the United Kingdom, were used to generate low emission scenarios (B2) in this study. Then, two types of downscaling techniques (delta and statistical methods) were used to generate the future possible local meteorological variables including air temperature and precipitation in the study area. The downscaled data was then used as input to the Soil and Water Assessment Tool (SWAT) hydrological model to simulate the corresponding future streamflow regime in headwater catchment of the Yellow River basin. Three benchmark periods simulated were 2010–2039 (2020s), 2040–2069 (2050s) and 2070–2099 (2080s). Although four GCMs and two downscaling techniques do not provide identical results, the time series generated by four GCMs and both downscaling methods indicate a significant increasing trend in both maximum and minimum air temperature, and a slight increasing trend in precipitation. The hydrological impact analysis made with the downscaled air temperature and precipitation time series as input to the SWAT model suggested an overall decreasing trend in mean annual streamflow in headwater catchment of the Yellow River basin in three benchmark periods in the future.

Key words Yellow River; Headwater catchment; Climate change; SWAT model; Streamflow

1. Introduction

Global warming resulted from increased concentrations of atmospheric greenhouse gases is usually estimated with Global Circulation Models (GCMs), and there have been remarkable advances in the development of these models over the last 20 years (IPCC, 2001; Huntingford et al. 2006). However, raw output from GCMs is inadequate for assessing impacts of climate change on hydrological responses at regional scales. This is because the spatial resolution of GCM grids is too coarse to resolve many important sub-grid scale hydrological processes, and because GCM output is often unreliable at individual grid. GCMs were not developed for investigating climate change impact on hydrological cycle and do not provide a direct estimation of hydrological responses to climate change. Therefore, in climate change impact studies, hydrological models are required to simulate sub-grid scale phenomenon. However, such hydrological models require input data at similar sub-grid scale, which has to be provided by converting the GCM outputs into at least a reliable regional hydrological time series at the selected watershed scale. The methods used to convert GCM outputs into local meteorological variables required for reliable hydrological modeling are usually referred to as 'downscaling' techniques (Dibike and Coulibaly, 2005).

A variety of techniques are developed for downscaling during the past decades. The most conventional method is to perturb historical time series of high resolution meteorological variables by the difference or ratio of the means of GCM output between the altered and controlled climate runs. Another alternative methodology, statistical downscaling, involves bridging the two discordant scales by establishing empirical relationships between features reliably simulated by the GCM at grid-box scales and surface predictands at sub-grid scales. It has been shown that different GCMs and downscaling methods may yield different regional climate change outputs. It is, therefore, helpful that the relative merits of different GCM output and downscaling methods should be compared. With this issue in mind, the present study compares four GCMs and two scaling methods. These scenarios were constructed by using: (1) statistically downscaled GCM output; and (2) Delta output. Atmospheric circulation indices and humidity variables derived from the HadCM3 model developed at the Hadley Centre in UK, the Canadian Global Coupled Model CGCM2, CCSR developed by Japanese Research Center of Climate Systems, and the Australian developed CSIRO, were used to downscale daily precipitation and temperature series at headwater catchment of the Yellow River basin. The climate scenarios generated were then used to drive a distributed hydrological Soil and Water Assessment Tool (SWAT) model. Changes in the modeled daily flow regime between current and future climate scenarios were compared. Finally, the relative merits of the four GCMs and two downscaling techniques for regional scenario development and climate change impact assessment is discussed.

2. Study area descriptions

Yellow River, the second largest river in China, has experienced great changes in hydrological regime during the past several decades. According to hydrological characteristics, it is divided into three reaches, the upper reach, the middle reach, and the lower reach. Both middle and lower reaches are significantly affected by human activities, and the headwater catchment of the upper reach is much less affected by anthropogenic factors. Headwater catchment of the Yellow River basin from source of the river to Tangnaihai station with an area of 122,000 km2, known as the 'water tower' of the basin, contributes on average 35% of total runoff in the Yellow River basin, as shown in Fig. 1. In terms of climate, the catchments are described as a semi-humid region of the Tibetan Plateau. Annual average air temperature varies between -4oC and 2°C from southeast to northwest. August generally is the warmest month, and January is the coldest month. The annual evaporation ranges from 1200 mm in the northwest to 2300 mm in the southeast. The annual average precipitation is about 450 mm. More than 70% of the total annual precipitation falls in the flood season from July to October. Precipitation tends to decrease from southeast (800 mm) to northwest (300 mm).

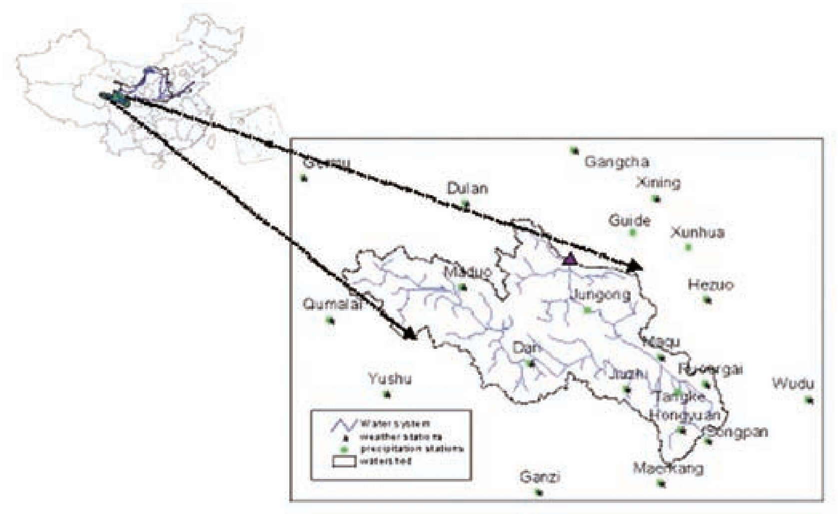


Figure. 1 Location of the study area and the meteorological stations selected

During the past several decades, the streamflow regime in headwater catchment of the Yellow River basin has changed greatly, which further resulted in degradation of the ecosystem in the study area. Changes in hydrological regime include decrease in streamflow and, more significantly, occurrence of drying-up, i.e. periods with zero flow. Understanding the relationships among the hydrological regime, climate factors, and anthropogenic effects is important for the sustainable management of water resources not only for the study area but also for the entire Yellow River basin. Attempts have been made to understand the causes of the changes in steamflow in the study area. It is recognized that other factors such as climate change or variability and land-use change, may have contributed to the changes in streamflow regime. But it has proven difficult to quantify their individual effects.

3. Data description

Spatial data used in this study include a digital elevation model (DEM), land use/cover, soil type, and climatic data. A digital elevation model with a scale of 1:250,000 was provided by the Data Center for Resources and Environmental Sciences (RESDC), Chinese Academy of Sciences. Land use data with a scale of 1:1,000,000 and soil data with a scale of 1:4,000,000 were also obtained from same organization. The baseline used in this study is 1961–1990, the standard World Meteorological Organization period. It has been selected because it incorporates some of the natural variability of the climate, including both dry (1970s) and wet (1980s) periods (Prudhomme et al., 2002).

A number of meteorological and hydrological datasets were used in this study. Daily streamflow data at the Tangnaihai station was available. Daily maximum and minimum air temperatures (TMAX and TMIN) from 7 stations in and around headwater catchment of the Yellow River basin were compiled and daily precipitation (PRCP) from 16 gauging stations are available in this study. Daily grid point data for mean sea level pressure (mslp), lagged one-day mean sea level pressure (lagm), 2m (near surface) temperature (temp), 500 hPa geopotential heights (p500), 850 hPa geopotential heights (p850), near surface specific humidity (shum), specific humidity at 500 hPa height (r500), surface vorticity (p_z), near surface wind velocity (p_u), and wind speed at 850 hPa height (p8_u) were obtained from the National Center for Environmental Prediction (NCEP) for the period from 1961 to 1990. All data were re-gridded from the NCEP grid (1.8758 latitude by 1.8758 longitude) to the GCM grid (2.58 latitude by 3.758 longitude).

4. Methodology descriptions

4.1 Downscaling methods

In this study, the delta method is firstly used. Then, the statistical relationships between GCM output climate variables and local surface weather station variables were developed by using the statistical downscaling model (SDSM), which is used to produce statistically significant relationships between GCM predictors and local climate variables. Then the projected changes in air temperature and precipitation from the GCM were applied to the historical daily time series (1961–1990) at gauging station. Spatial ‘downscaling’ approaches have recently been investigated as a mean to relate the large scale atmospheric predictor variables with local meteorological variables which could be used as input to hydrological models. A variety of empirical/statistical downscaling techniques have been developed over the past few years and each method generally lies in one of the three major categories, i.e., regression (transfer function) method, stochastic weather generator and weather typing scheme. The method used in this study is focused on the most widely used downscaling method which has been recently suggested by the Canadian Climate Impact Scenarios (CCIS) project for climate change impact studies (Dibike and Coulibaly, 2005). A well recognized statistical downscaling tool is made available to the broader climate change impact study community via the Canadian Climate Impacts and Scenarios project (http://www.cics.uvic.ca/scenarios/). It implements a regression based method and is referred to as Statistical DownScaling Model (SDSM) (Dibike and Coulibaly, 2005).

Daily precipitations as well as daily maximum and minimum air temperature data were chosen as predictand variables for the downscaling experiments. Seven meteorological stations and sixteen rain gauging stations that are inside or around the study area, and each with 41 years of precipitation and air temperature records representing the current climate, were identified for the downscaling experiments. Observed daily data of large-scale predictor variables representing the current climate condition is derived from the NCEP reanalysis data set. Climate variables corresponding to the future climate change scenario for the study area are extracted from Hadley CM3 output at four grid points which is closest to the study area. Data is extracted for three distinct periods, namely, the 2020s (covering a 30 years period between 2010 and 2039), the 2050s (2040–2069) and the 2080s (2070–2099).

4.2 SWAT model

SWAT model is a physically-based model being able to estimate the impact of land uses on water, sediment and agricultural chemicals on a subcatchment and land use unit scale over long periods of time (Arnold and Fohrer, 2005; Sun and Cornish, 2005). In which, the surface runoff is estimated using a modified SCS curve number method based on moisture content. Although such a modification can be more accurate in identifying the soil water moisture condition, it nevertheless made the runoff estimation mainly dependent on soil profile information such as the soil layer classification and in particular the soil profile depth. Compared with the original SCS method, which describes moisture condition as a function of antecedent rainfall, the modified curve number method may cause calibration problems relating to soil structure, profile depth and plants grown (Govender and Everson, 2005).

For runoff and recharge estimation, the rooting depths of plants and the growth season are the primary drivers governing the soil water processes (Sun and Cornish, 2005; Tripathi et al., 2005). Soils are divided into layers and water balance is performed in each soil layer according to saturated conductivity and soil water content of the soil layers. When rainfall occurs, surface runoff is estimated first, and the rest of the rainfall enters into the soil profile for redistribution. Subsurface runoff is estimated using a simplified slope storage concept where water flow through the soil is estimated by using the saturated conductivity of the soil layer and the slope length. Vertical water movement goes through the soil layers when the soil water content exceeds the field capacity of the layers. It enters into an unsaturated vadose zone when it passes through the lowest soil layer, which becomes recharge to shallow groundwater. Recharge to shallow groundwater may discharge to the catchment outlet as groundwater. SWAT model allows the recharge to ‘revap’ from the shallow groundwater through the unsaturated vadose zone by capillary activity to meet the needs of evapotranspiration when the soil profile is dry. This means that recharge to the shallow groundwater does not necessarily all become groundwater and discharge, rather it can be redrawn upwards by soil water potential during dry periods. This is a distinct feature of SWAT, as many other models regard recharge beyond the root zone as drainage lost permanently (Sun and Cornish, 2005).

4.3 Model performance assessment

The Nash and Sutcliffe (1970) coefficient of efficiency (ENS), the coefficient of determination (r2) and the percentage volume difference DV(%) are used to assess the model performance. Simulation are considered satisfactory when Dv is below 10% and excellent when Dv is less than 5%. The coefficient of efficiency describes how well the volume and timing of the calibrated hydrograph compares to the observed hydrograph and is estimated as

(1)

in which

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs}^{i} - Q_{sim}^{i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs}^{i} - \overline{Q}_{obs}\right)^2}$$

$$\overline{Q}_{obs} = \frac{1}{n}\sum_{i=1}^{n} Q_{obs}^{i} \qquad (2)$$

in which n is the number of time-steps, Q_{obs}^{i} is the observed stremflow at time step i, and is the simulated streamflow at time step i. The coefficient of determination, r^2, measures how well the shape of the model hydrograph reflects the observed hydrograph and depends solely on the timing of changes in the hydrograph. The closer the values of ENS and r^2 are to^1, the more successful the model calibration/validation. In every simulation for calibration, only one parameter was adjusted while others were kept unchanged. Reiterations of optimization were done until satisfactory results were met, which was based on graphical comparison and numeric evaluation of the simulated discharge against the measurements.

5. Results analysis and discussion

Firstly, the historical daily air temperature and precipitation time series were perturbed using the delta method to generate data sets for each climate change scenario. The SDSM was then used to downscale GCM outputs to generate scenarios in headwater catchment of the Yellow River basin. The spatially distributed hydrometeorological variables were used as input to SWAT model. Finally, modelled daily streamflow was used as measures to evaluate the scenarios and future climate change impact. The global atmospheric fields were selected using the US-National Centres for Environmental Prediction (NCEP) reanalyzed dataset and included daily fields for the base climate period 1961–1990 as defined by the World Meteorological Organization (Menzel and Bürger, 2002).

5.1 Climate scenarios

5.1.1 Delta method

Table 1 shows mean annual minimum and maximum air temperature for the study area during three benchmark periods projected by the HadCM3, CGCM2, CCSR, and CSIRO for 2030, 2050 and 2080. Maximum air temperature projected by HadCM3 increases more rapidly with time. Comparing with the baseline period, the increments of maximum air temperature for three benchmark periods are +1.41oC, +2.42oC, and +3.44oC, respectively. Similarly, the increments of minimum air temperature for three periods are +1.49oC, +2.68oC, and +3.76oC, respectively. The increment of air temperature in summer is greater than those in other seasons, these values reach +1.74oC, +2.83oC, and +3.98oC, respectively. The increments of maximum air temperature projected by CGM2 for three periods are +1.53oC, +2.50oC, and +3.28oC, respectively. The maximum air temperature in summer shows stronger increasing tendency. Three increments for minimum air temperature are +1.71oC, +2.97oC, and +3.89oC, respectively. The increments of both maximum and minimum air temperature projected by CCSR are relative smaller, as shown in Table 1. On contrary, the seasonal difference of increments for air temperature projected by CSIRO is great. Comparing with summer and autumn, the increments of air temperature in winter and spring is greater. For example, the increments of minimum air temperature in spring reach +4.78oC, +6.26oC, and +8.34oC, respectively, while those values in summer are only +1.78oC, +2.43oC, and +3.39oC, respectively.

Table 1 Maximum and minimum air temperature projected by using four GCMs for future three benchmark periods

Period	Maximum and minimum air temperature (0C)									
	HadCM3		CGCM2		CCSR		CSIRO		Average	
	TMAX	TMIN	TMAX	TMIN	TMAX	TMIN	TMAX	TMIN	TMAX	TMIN
2020s	1.41	1.49	1.53	1.71	1.76	2.01	1.83	2.96	1.63	2.04
2050s	2.42	2.68	2.50	2.97	3.40	3.74	2.81	4.27	2.78	3.42
2080s	3.44	3.76	3.28	3.89	5.28	5.44	3.69	5.74	3.92	4.71

Average increments of both maximum and minimum air temperature for four GCMs are given in Fig. 2. It is confident that a warming trend will occur in the study area for the future. By 2020, maximum and minimum air temperature will increase by +1.63oC and +2.04oC, respectively. By 2080, these increments will reach +3.92oC and +4.71oC, respectively. In other words, moderate warming (<2.5oC) is projected for both 2030 and 2050, and a much warmer climate is projected in headwater catchment of the Yellow River basin for 2080.

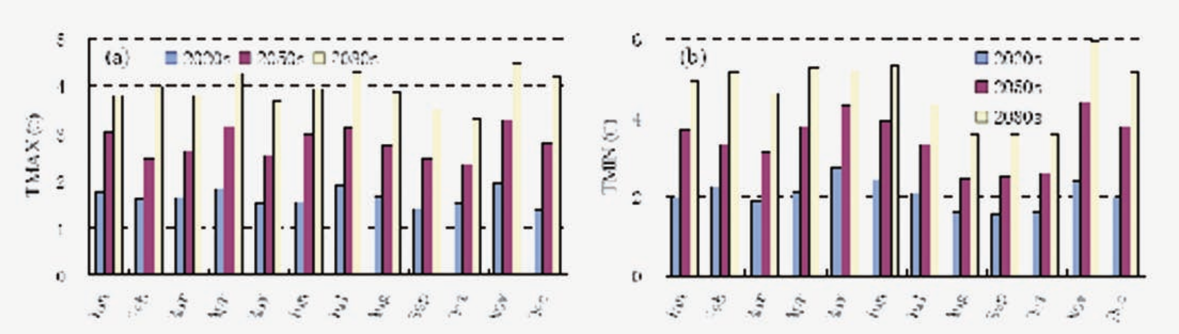


Figure. 2 Changes of maximum and minimum air temperature projected by different GCMs in future three benchmark periods

Four GCMs display considerable variability in precipitation projections in the study area. Precipitation projections in twelve months for each of four GCMs are shown in Fig. 3. These plots show that for the 2020s, changes in precipitation relative to the 1961-1990 baseline lie in the range of 8.5–12%. This percentage ranges from 19.5% to 25% for the 2050s. It further increases to 20% to 29% for the 2080. The seasonal difference of increments for precipitation show big difference for different GCMs. For HadCM3, the increments of monthly precipitation in January gives an increase of 26.1%, 51.7%, and 57.4% for three benchmark periods, but these values in March are -12.7%, -5.4%, and -1.4%, respectively. The greatest changes in winter precipitation are reflected by the Hadley Centre model (HadCM3), while the Canadian model (CGCM2) shows the greatest change in summer precipitation. Increments of seasonal precipitation in summer projected by CGCM2 for three benchmark periods are 36.3%, 54.6%, and 63.5%. The long-term trends for annual precipitation projected by CCSR and CSIRO are similar. The increment of seasonal precipitation in winter and spring is greater than that in summer and autumn. Three distinct patterns of change in monthly precipitation are easily seen from Fig. 3.

Average increments of annual precipitation for four GCMs are given in Table 2. Increase in precipitation for the 2020s ranges from 8.5% to 12% with an average of 9.4%. These percentages are 19.3% and 23.4% for the 2050s and 2080s. The HadCM3 projects a considerably wetter climate regime for the 2080s with precipitation increases of nearly 30% in the study area, while the CCSR gives a projection of wetter climate in the 2050s. A

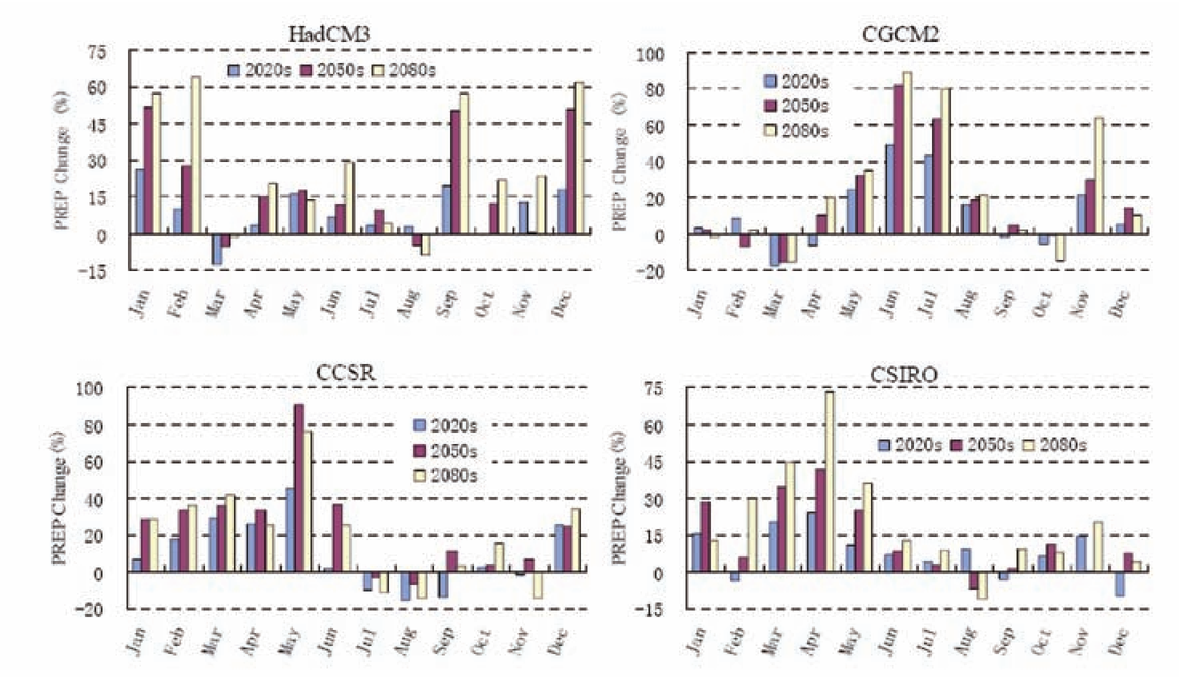


Figure. 3 Changes of precipitation projected by different GCMs in future three benchmark periods

considerable increase in precipitation is projected in the study area for all benchmark periods.

Table 2 Annual precipitation projected by using four GCMs for future three benchmark periods

Periods	Ratio of precipitation changes（%）				
	HadCM3	CGCM2	CCSR	CSIRO	Average
2020s	8.75	11.58	9.34	7.98	9.41
2050s	19.70	19.56	24.52	13.29	19.27
2080s	28.49	24.29	20.29	20.60	23.42

5.1.2 Statistical downscaling method

Daily predictor variables are generally needed to be normalized by using corresponding period means and standard deviations. Ten predictor variables were selected following a stepwise multiple linear regression analysis of the candidate variables. The selected predictors for daily precipitation, for example, include grid-box values of near surface specific humidity (shum), lagged one-day mean sea level pressure (lagm), relative humidity at 500 hPa geopotential height (r500), and surface vorticity (p_z). Then, it is possible to downscale all surface predictands with a physically plausible set of predictors. The downscaling model generally explained more than 70% of the variance (E%) in daily temperatures (TMAX and TMIN) and less than 40% in daily precipitation (PREP). Estimated explained variance and standard error for maximum and minimum air temperature, daily precipitation at three grid-box in the study area are given in Table 3. It shows that more than 50% and 23% of the variance in maximum and minimum air temperature can be explained by the downscaling model, while only 14.8 of the variance in daily precipitation can be explained. The relatively low explained variance for daily precipitation is consistent with previous studies and underlines the difficulty of downscaling local precipitation series from regional scale predictors. Presently the unexplained component in daily precipitation amounts is generally treated stochastically by the downscaling model.

Table 3 Explained variances and standard errors for maximum and minimum air temperature and daily precipitation during calibration period (1961-1975)

PREP		TMAX			TMIN	
E%	SE (mm)	E%	SE (℃)		E%	SE (℃)
HE	11.00	0.79	55.40	2.38	24.30	3.13
HW	25.30	0.61	49.15	2.64	31.10	3.54
SE	7.00	0.76	50.76	2.66	23.80	3.53
Catchment	14.78	0.72	50.45	2.62	27.51	3.49

After the statistical downscaling model was calibrated using air temperature and precipitation data from 7 meteorological stations and 16 rain gauging stations, the calibrated model is validated using same data for the period between 1976 and 1990. However, the statistic is not an appropriate measure of the model fitness for precipitation occurrence because this predictand is a discrete variable. A more useful metric is the percentage of correct wet and dry day classifications. On an average the downscaling model reproduces wet days better than dry days. These precipitation statistics were determined from a single realization of the stochastic downscaling. According to the results, wet-day occurrence is simulated in this study. Validation of the downscaling model is made using lengthy series of independent data (1976-1990). Table 4 compares the downscaling model estimates of daily PRCP, TMAX and TMIN for the year 1976–1990 with the observed series for the same period. From Table 4 it is evident that the downscaling model produces a little lower annual precipitation total, wet-day frequency, maximum wet-day period, and minimum air temperature than was recorded in the study area. Conversely, the downscaling model yielded higher estimates of daily mean TMAX than observed. It shows that the SDSM can give very good result for maximum and minimum air temperature. The bias for both variables are only +0.32oC and -0.47oC. The simulated daily precipitation is only 0.03 mm smaller than the measured value. Those bias are all within the acceptable ranges. In other words, the statistical relationship established by using SDSM is suitable to generate future climate change scenarios.

Table 4 Bias between simulated and measured daily precipitation, maximum and minimum air temperature during validation period (1976-1990)

Statistics	Monthly average precipitation (mm/day)	Probability of humid day (%)	Maximum dry periods (days)	Maximum humid periods (days)	Variance of monthly precipitation (mm2)	Maximum daily temperature (℃)	Minimum daily temperature (℃)
Observed	3.22	41.22	76.83	32.26	11.52	5.92	-7.97
Simulated	3.19	28.32	84.10	22.64	12.51	6.24	-8.44
Bias	-0.03	-12.90	7.27	-9.62	0.99	0.32	-0.47

Fig. 4 shows the comparison between the simulated and observed maximum and minimum air temperature during the validation period. The graph shows a very good agreement between the observed and simulated air temperature. However, the monthly average wet-spell lengths were underestimated. Although efforts have been made, it was difficult to improve this result since any attempt to increase the wet-spell length from the model output automatically affects other variables which were originally well calibrated. For the cases of TMAX and TMIN, means of these variables corresponding to each month were considered as performance criteria. Fig. 4 illustrates the validation performance of the downscaling model for each variable. The results show satisfactory agreement between the observed data and the simulation outputs of the downscaling model.

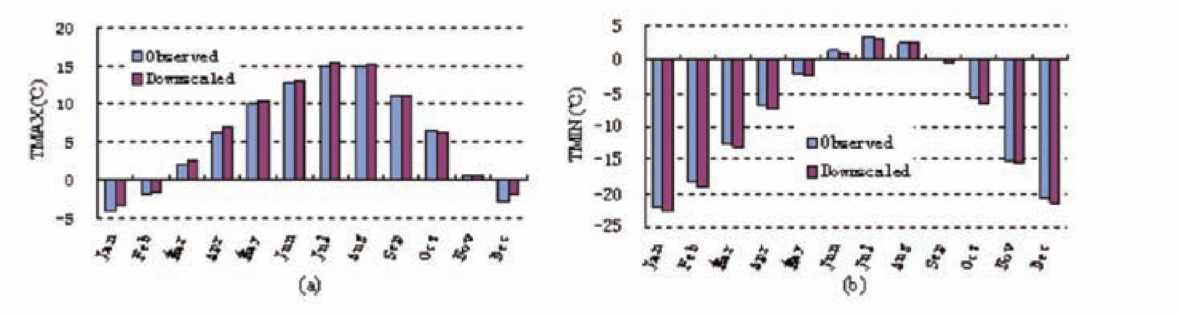


Figure. 4 Comparison between monthly maximum and minimum air temperature in the study area during validation (1976-1990)

After the downscaling model is validated, it can then be used to generate future climate scenarios. Fig. 5 shows the increments of maximum and minimum air temperature projected by SDSM model for future three benchmark periods. Maximum air temperature in spring and autumn shows stronger trend of increase than that in winter and summer. The maximum air temperatures in spring will increase by +1.49oC, +3.06oC, and +4.10oC, respectively, and maximum air temperature in autumn will increase +1.55oC, +2.31oC, and +4.05oC, respectively, for three benchmark periods. For the annual average, these increments will be +1.34oC, +2.60oC, and +3.90oC, respectively. Comparing with the maximum air temperature, the minimum air temperature shows smaller tendency of increasing with the increments of +0.87oC, +1.49oC, and +2.27oC, respectively. The minimum air temperature in summer and autumn shows stronger trend than that in winter and spring.

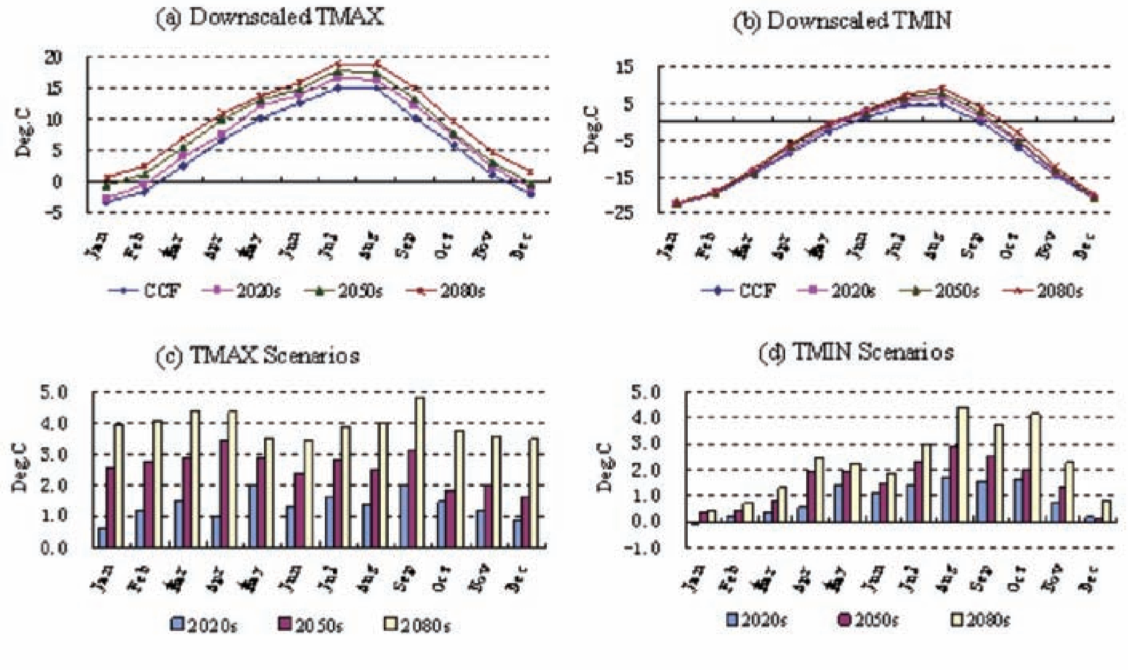


Figure. 5 Scenarios of daily maximum and minimum air temperature in the study area during the future three benchmark years

Fig. 6 shows the magnitude of increments for downscaled monthly precipitation during three benchmark periods. There are quite different characteristics for the changes of monthly precipitation in the future. For example, December and February show tendency of decreasing. The percentages of declination for three periods are -6.37%, -12.16%, and -14.56% in December, while these percentages are -4.20%, -12.41%, and -13.37% in February. June and September show the greatest tendency of increasing. Those percentages are 8.57%, 15.51%, and 19.90% for June, and 6.49%, 13.06%, and 19.19% for September. For annual precipitation, increasing tendency still dominates the long-term trend for future 100 years. The increments of annual precipitation for three benchmark periods are 3.47%, 6.42%, and 8.67%, respectively.

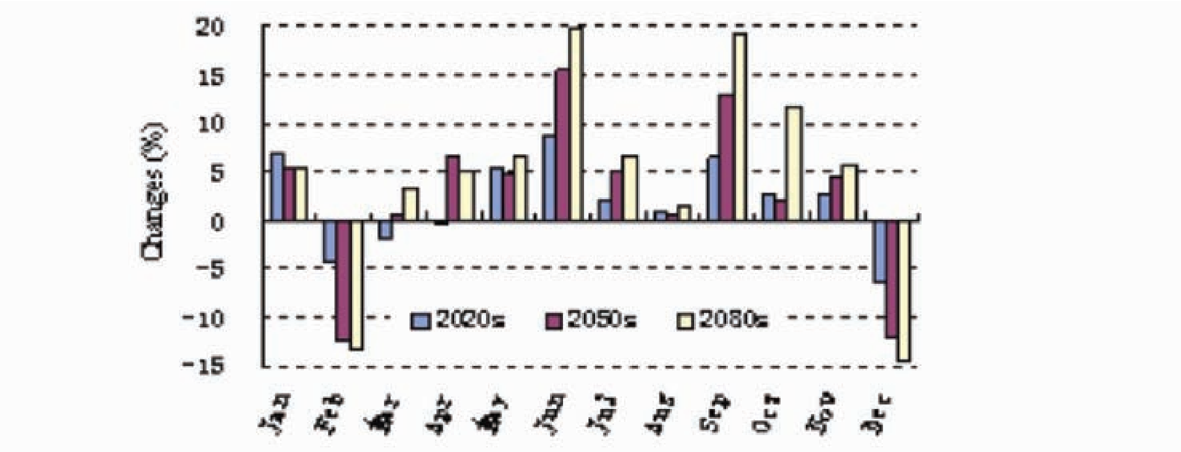


Figure. 6 Monthly average of daily precipitation in the study area during the future three benchmark years

It can be concluded that although the delta method and SDSM model gives different results, both results show significant tendency of increasing for both maximum and minimum air temperature. While the long-term trend for annual precipitation is insignificant, increasing tendency is obvious. Both delta method and SDSM model gives quite similar results.

5.2 Hydrological model calibration

Since SWAT model has a large number of parameters, a sensitivity analysis was first conducted to identify the set of parameters that have the most influence on simulated streamflow. The objective of sensitivity analysis is to determine which parameters are most highly correlated with the output. In this study, the sensitivity analysis was performed to examine the effect of different parameters on the simulated discharge. The base values used in the calculation of sensitivity statistics are optimized values, i.e., those that had the lowest mean absolute error. In order to perform sensitivity analysis of parameters in simulation, a single parameter perturbation approach was used, wherein a range of values between minimum and maximum ones for one parameter is used whereas values of other parameters remained unchanged during simulation. With the implementation of sensitivity analysis, sixteen parameters were identified as the key parameters with strong impact on the output of the SWAT model.

The historical records for Tangnaihai station over the period of 1986-2000 were split into two periods of ten and five years in length: 1986-1995 for calibration and 1996-2000 for validation. The SWAT model was first calibrated on the period of 1986-1995 and then validated on the other period of 1996-2000. Model calibration was conducted by comparing the SWAT simulated streamflow with the observed discharge on monthly basis. Fig. 7 compares simulated monthly streamflow with the observed streamflow values. Except several years during which simulated peaks are greater than observed ones (1986 and 1995) or peak flows are underestimated (e.g., 1989 and 1993), most of the years have a very good agreement between the simulated and observed streamflow. In particular, the low flow was simulated very well. The percent deviation for monthly average streamflow is 9.54%, and the r2 and ENS are 0.80 and 0.73. All are within the range of satisfactory accuracy.

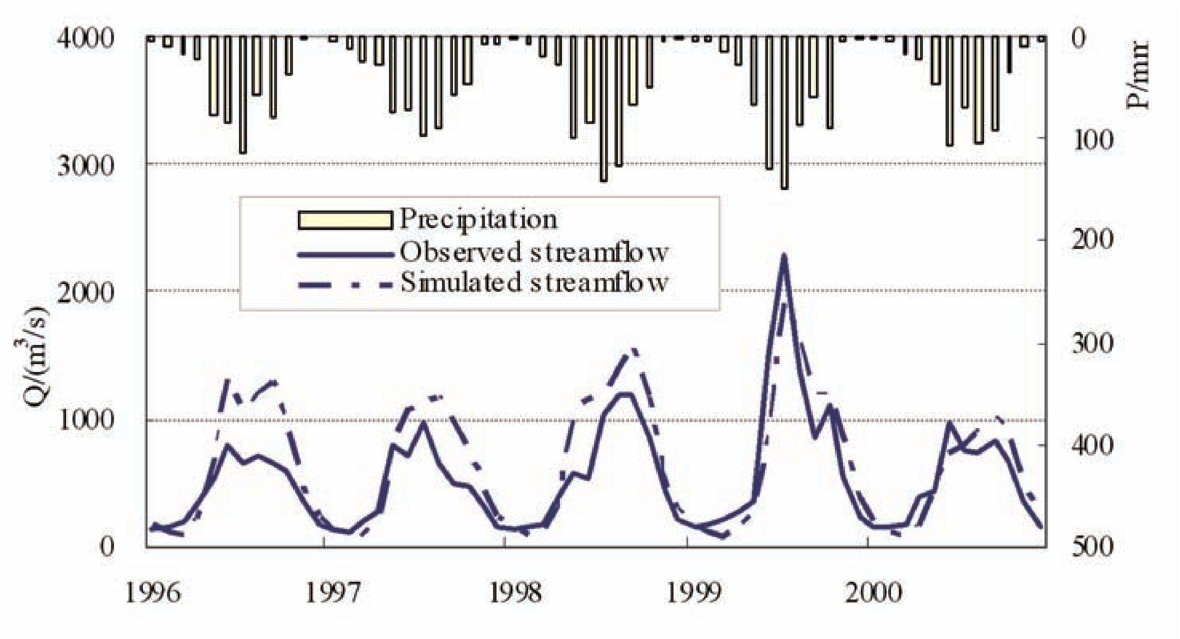


Figure. 7 Comparison between the simulated and observed monthly streamflow in the study area during calibration (1986-1995)

Performance of the calibrated model on the validation data set is presented in Fig. 8. The different performance measures including coefficient of determination (r2), Nash-Sutcliffe efficiency (ENS) and percent deviation (Dv) between the model outputs and the observed data are also summarized. Model validation result presented in Fig. 8 shows that the model gave satisfactory and comparable performance on the streamflow simulation. Model performance over the validation period was acceptable with 0.77 of r2, 0.59 of ENS and 20.1% of Dv values.

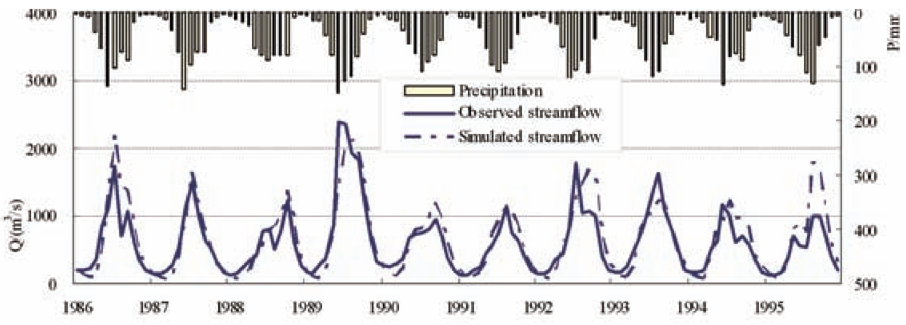


Figure. 8 Comparison between the observed and simulated streamflow in the study area during validation (1996-2000)

5.3 Effect of climate change scenarios on hydrological response

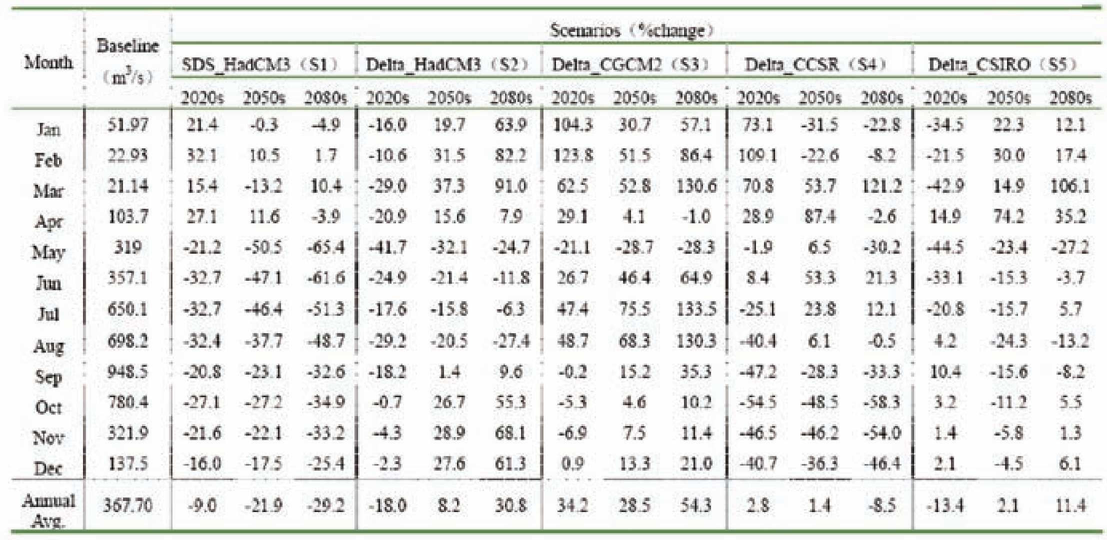
After validation of the hydrological models with the historical record, the next step in the investigation is to simulate streamflow corresponding to future climate conditions by using the downscaled precipitation data corresponding to different scenarios identified in this study. According to the analysis made in previous sections, fifteen scenarios are identified in this study, as shown in Table 5.

Table 5 Fifteen scenarios identified in this study

	2020s	2050s	2080s
SDS_HadCM3	S11	S12	S13
Delta_HadCM3	S21	S22	S23
Delta_CGCM2	S31	S32	S33
Delta_CCSR	S41	S42	S43
Delta_CSIRO	S51	S52	S53

Table 6 shows the results of simulated change in the average monthly streamflow for fifteen scenarios corresponding to the downscaled precipitation and temperature data of the current (1961–2000) and future (2010–2100) climate. Different scenarios produce a wide range of changes in the hydrological regime. Under three scenarios developed by using statistical downscaling, the simulated streamflow decreased for three benchmark periods with the declination of -9.0%, -21.9% and -29.2%. The magnitude of declination increased year by year for the future. However, under scenarios developed by using delta method, both tendency of increasing and decreasing will occur. Only the scenarios developed by CGCM2 showed increasing tendency for three periods, and gives the percentages of 34.2%, 28.5% and 54.3%. Other three scenarios showed quite different tendency. For the period of the 2020s, both HadCM3 and CSIRO showed decreasing tendency with the percentages of -18.0% and -13.4%, while CCSR scenario showed slight tendency of increasing, and the magnitude of increasing is 2.8%. For the period of the 2050s, three scenarios showed increasing tendency, that are +8.2%, 1.4%, and +2.1%, respectively. For the period of the 2080s, both HadCM3 and CSIRO gave increasing tendency with the magnitude of +30.8% and +11.4%, while CCSR showed decreasing tendency of -8.5%.

Table 6 Comparison between the baseline streamflow and projected values for different scenarios



Month	Baseline（m^3/s）	Scenarios（%change）														
		SDS_HadCM3（S1）			Delta_HadCM3（S2）			Delta_CGCM2（S3）			Delta_CCSR（S4）			Delta_CSIRO（S5）		
		2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
Jan	51.97	21.4	-0.3	-4.9	-16.0	19.7	63.9	104.3	30.7	57.1	73.1	-31.5	-22.8	-34.5	22.3	12.1
Feb	22.93	32.1	10.5	1.7	-10.6	31.5	82.2	123.8	51.5	86.4	109.1	-22.6	-8.2	-21.5	30.0	17.4
Mar	21.14	15.4	-13.2	10.4	-29.0	37.3	91.0	62.5	52.8	130.6	70.8	53.7	121.2	-42.9	14.9	106.1
Apr	103.7	27.1	11.6	-3.9	-20.9	15.6	7.9	29.1	4.1	-1.0	28.9	87.4	-2.6	14.9	74.2	35.2
May	319	-21.2	-50.5	-65.4	-41.7	-32.1	-24.7	-21.1	-28.7	-28.3	-1.9	6.5	-30.2	-44.5	-23.4	-27.2
Jun	357.1	-32.7	-47.1	-61.6	-24.9	-21.4	-11.8	26.7	46.4	64.9	8.4	53.3	21.3	-33.1	-15.3	-3.7
Jul	650.1	-32.7	-46.4	-51.3	-17.6	-15.8	-6.3	47.4	75.5	133.5	-25.1	23.8	12.1	-20.8	-15.7	5.7
Aug	698.2	-32.4	-37.7	-48.7	-29.2	-20.5	-27.4	48.7	68.3	130.3	-40.4	6.1	-0.5	4.2	-24.3	-13.2
Sep	948.5	-20.8	-23.1	-32.6	-18.2	1.4	9.6	-0.2	15.2	35.3	-47.2	-28.3	-33.3	10.4	-15.6	-8.2
Oct	780.4	-27.1	-27.2	-34.9	-0.7	26.7	55.3	-5.3	4.6	10.2	-54.5	-48.5	-58.3	3.2	-11.2	5.5
Nov	321.9	-21.6	-22.1	-33.2	-4.3	28.9	68.1	-6.9	7.5	11.4	-46.5	-46.2	-54.0	1.4	-5.8	1.3
Dec	137.5	-16.0	-17.5	-25.4	-2.3	27.6	61.3	0.9	13.3	21.0	-40.7	-36.3	-46.4	2.1	-4.5	6.1
Annual Avg.	367.70	-9.0	-21.9	-29.2	-18.0	8.2	30.8	34.2	28.5	54.3	2.8	1.4	-8.5	-13.4	2.1	11.4

The streamflow simulated under different scenarios for three periods are shown in Fig. 9. The SDS_HadCM3, Delta_HadCM3, Delta_CGCM2, Delta_CCSR and Delta_CSIRO scenarios provide quite different outlooks for future hydrological regimes in the study area. Most of these scenarios predicted a tendency towards a more rainfall dominated hydrograph and a reduction in the annual runoff, particularly for the periods of the 2050s and 2080s. Of the four climate models used in this study, the Canadian Global Coupled Model (CGCM2) provided the greatest estimate of the impacts of climate change on streamflow in headwater catchment of the Yellow River basin. The shape of the hydrograph was similar to the base scenario under different scenarios, and estimated runoff reduction in the 2080s was not as extreme as for other two periods.

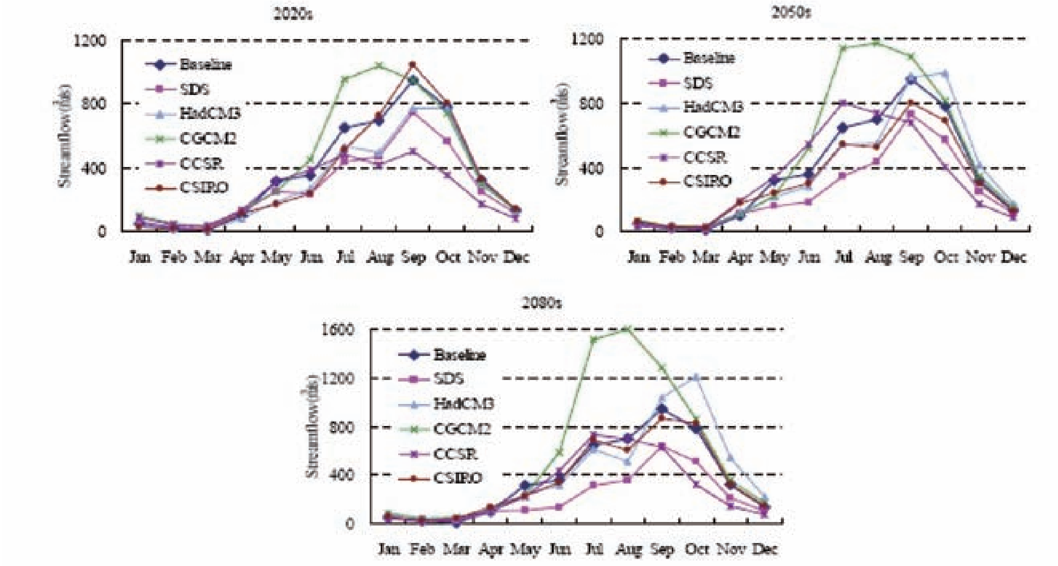


Figure. 9 Comparison between the observed runoff during basic period and simulated runoff during different benchmark periods under various scenarios

Fig. 10 gave the projection for different periods under five scenarios. The streamflow projected under the scenario developed from CGCM2 and downscaled with delta method showed greatest tendency of increasing. However, the streamflow projected using both CCSR and CSIRO showed a general tendency of increasing. The streamflow projected by using HadCM3 and downscaled with delta method showed complex tendency. During the periods of the 2020s and 2050s, streamflow showed decreasing tendency with the declination of -63.69 m3/s and -1.73 m3/s, while the streamflow showed an increasing tendency in the 2080s, which reached

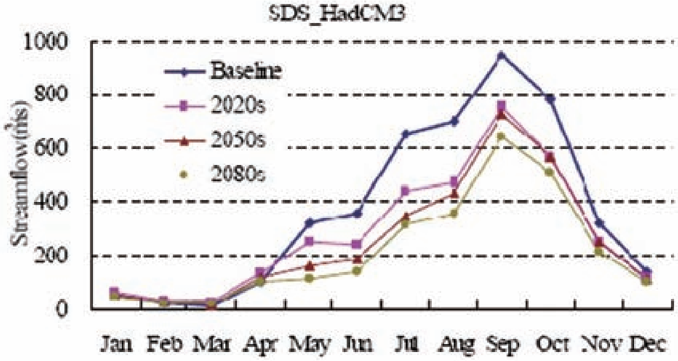


Figure. 10(a) Comparison among the projection of runoff during different periods by using statistical downscaling method

+46.93 m3/s. For the streamflow under HadCM3 scenario and downscaled with SDSM model, three periods all showed decreasing tendency, and the declination of annual streamflow are 88.61 m3/s, 116.64 m3/s, and 151.62 m3/s, respectively.

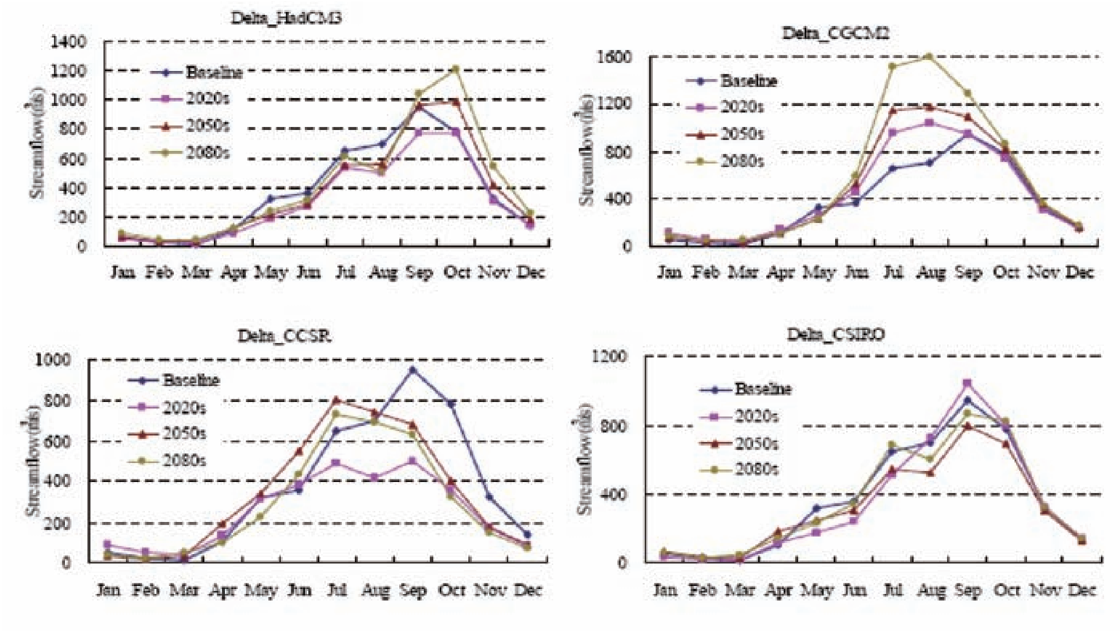


Figure. 10(b) Comparison among the projected runoff during different periods by using different delta method for four GCMs

From the plotting shown in Fig. 10, it can be concluded that there is a large degree of variation between predicted annual and seasonal runoff and the scale of the timing shift. All combinations of GCMs and emissions scenarios may give better results. Fig. 11 gives the average of streamflow generated by using four GCMs and downscaled by delta method. It can be seen that streamflow will increase in the three future periods, and the magnitude of increasing is 10.69 m3/s, 68.33 m3/s, and 58.94 m3/s, respectively. It may be resulted from the high estimation of the streamflow by using CGCM2, as shown in Fig. 11. If the results obtained under CGCM2 scenario is excluded, the streamflow projected should be declined for three periods.

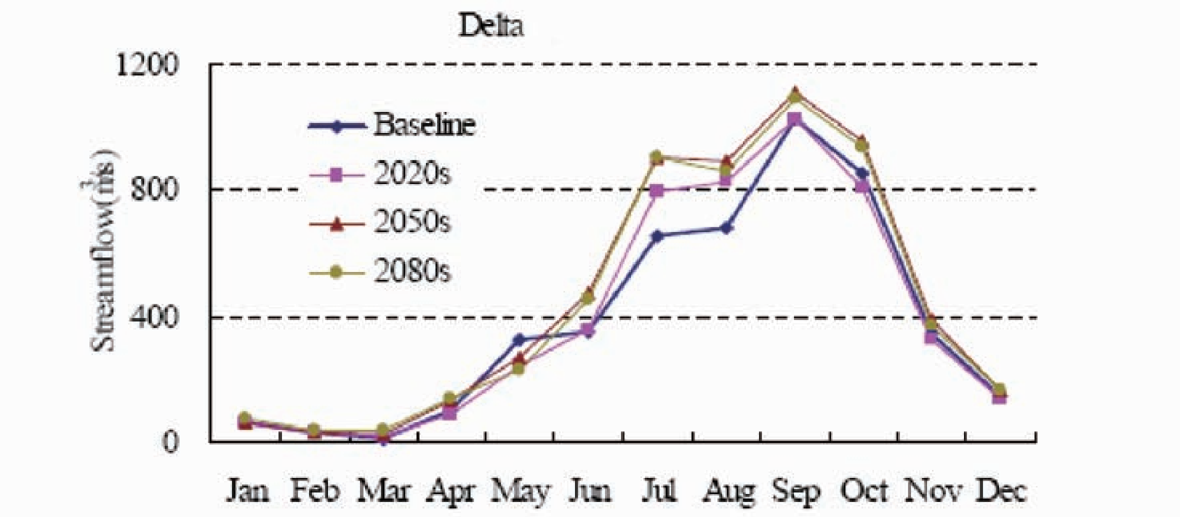


Figure. 11 Average of the simulated streamflow under four scenarios by using different GCMs during the future three benchmarks

6. Discussion and conclusions

The objective of this study is to downscale large scale atmospheric variables from GCM outputs to climate variables at regional scale in order to investigate the impact of future climate change on hydrological regime. Downscaling is necessary since the hydrological models normally used for impact studies require local meteorological time series, which are compatible with the size of the catchment. The dataset of precipitation and temperature time series from the study area is used in the downscaling experiments. Two downscaling techniques, namely the delta method and statistical downscaling technique are applied.

In general, both delta and SDSM methods approximate the observed climate data corresponding to the current state reasonably well, except that SDSM underestimated the mean wet-spell length for most of the months in the year. However, the analysis of the downscaled climate data from two models does not lead to identical conclusions. Even though both models indicate an increasing trend in mean daily temperature, SDSM resulted in a relatively higher increase than that of delta method. Moreover, SDSM output shows an increasing trend in the daily precipitation and their variability while delta method results do not show any obvious trend in both daily precipitation and their variability. It is not clear at this moment which of the two results should be considered more reliable. However, the well known fact that GCMs are not very reliable in simulating precipitation makes the reliability of delta method downscaling of precipitation more in doubt. The regression-based statistical downscaling model employed more than ten grid-box predictor variables to simulate subgrid scale daily precipitation and temperature series. A distributed hydrological model was used to simulate monthly runoff under competing GCM-derived and downscaled climate scenarios. It was demonstrated that downscaled daily precipitation and air temperature series for the observed climate can result in improved simulations of monthly runoff. The distributed hydrological model was used to compare fifteen future climate scenarios originating from delta and statistical downscaling model. Most of the scenario yielded greater reductions in projected streamflow over the study period.

Four GCMs and two downscaling methods used in this study project warming of 1.34–1.63oC by 2020, 2.6-2.78oC by 2050, and up to 3.9oC by 2080 for the maximum air temperature in the study area. These values are 0.87-2.04oC, 1.49-3.42oC, and 2.27-4.71oC for minimum air temperature. Weak changes in regional precipitation amounts are also projected. Annual precipitation will increase by 3.47–9.41% by 2020, 6.42-19.27% by 2050, and 8.67-23.42%. However, streamfow for most periods will decrease. Climate changes of this kind will affect regional water supply and security in the Yellow River basin. There is at least a qualitative consensus amongst the models that the future magnitude of streamflow will decline relative to current conditions for headwater catchment of the Yellow River basin. Research is ongoing to determine the generality of these water resource impacts for other regions, GCM outputs and downscaled scenarios. The scenarios presented in this paper, and the simulated impacts on the hydrological regime, raise questions over the availability of future water resources in the study area, particularly in terms of the magnitude of seasonal runoff.

Acknowledgement

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Water resources management and rehabilitation in China

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Abstract

A water resources management plan should be implemented throughout China, which is based on a unified watershed-scale. Water prices should be increased as well as investments in agricultural and industrial water conservation. Save water methods should be applied in the whole regions of water shortage. Increased water use efficiency will ensure that China's water resources will be used in a reasonable, effective and sustainable manner. New technologies and management methods will be required which are underpinned by science. Greater attention must be given to prevention of pollution and other forms of water quality degradation in large river basins.

Key words Water resources; problems; current usage; countermeasures

1. Introduction

Current water resource concerns include: (i) severe shortages, (ii) frequent flooding, (iii) uneven distribution of water resources in time and space, resulting in acute conflicts between supply and demand, (iv) poor water conservation implementation leading to serious wastage, and (v) water pollution and environmental degradation. Sustainable changes must be based on the use, source, quantity and quality of current resources together with projections of future demands, taking account of different hydrological regions, as well as environmental conditions.

Hydrological and environmental changes in China have seriously impeded sustainable development, for four centuries. Hydrological conditions of China's watersheds have long been monitored and studied. Overuse of some water resources has led to soil salinization and desertification. Only in the last few decades has this land degradation become a strikingly apparent, leading to a recognition that hydrological factors and environmental sustainability are inextricably linked. Both government agencies and non-governmental organizations (NGOs) have taken or are taking steps to address these issues (Kenneth, 1997). Reasonable countermeasures to protect ecosystems, land and water quality during intense water resource development are proposed, which nonetheless promote social development.

2. Current status

Provincial yearbooks have compiled hydrological data back to the 1950s. Some gauging stations have detailed measurements for over 40 years, while the remainder has at least 25 years data. Groundwater quantity and quality data were taken from China Water Research Bulletins published by Ministry of Water Resources (MWR). Agricultural, industrial, domestic and others water use data was obtained from the National Statistics Bureau (1998a,b, 1989). Data was not available for Macao, Hong Kong and Taiwan. China is divided into five regions, using hydrological, geological, geographical and climatological criteria. These are south east

China (SEC), south west China (SWC), north east China (NEC), north west China (NWC) and north central China (NCC) (Figure 1; Feng et al. 1999a). Regions exhibit different water use, development issues and trends, necessitating different rehabilitation measures.

The SEC Region includes Shanghai, as well as Jiangsu, Anhui, Hunan, Jiangxi, Hubei, Zhejiang, Hainan, Guangdong and Fujian Provinces (Figure 1), covering 1.23 million km2 or 12.8% of China's total landmass (Table 1). Middle reaches of the Yangtze River house extensive plains, while lower reaches are more hilly, with littoral plains and an estuary into the East China Sea (G). Several other large rivers traverse the region, including the Huaihe (D) and Zhujiang (F), which serve as the major water sources for the region. Under the influences of SE monsoons and tropical storms, precipitation varies from 800 mm yr-1 in the north to over 1600 mm yr-1 in the south, resulting in a climate that ranges from semi-humid to extremely humid (Table 2). Resources include 905 km3 in surface waters (97.4%) and 25 km3 (2.6%) in net groundwater (Table 1).

The SWC region contains Sichuan, Yunan and Guizhou Provinces, Guangxi and Tibetan Autonomous Regions and Chongqing City (Figure 1). Nine major rivers are located in or flow through the region. These are the Yangtze and Yellow (C), the Zhujiang, Honghe, Lanchangjiang, Nujian, Yiluowadi, and Yalunzangbu (H) as well as rivers close to the sea in Guangxi Autonomous Region. Numerous lakes dot the Tibetan and Yun-Gui plateaus, with a total area of 630,000 km2. Precipitation varies from 200 to 4490 mm yr-1, due to varied landforms and stratified climatic zones across a range of elevations (Table 2). The Tibetan glacial area accounts for 60% of China's glaciated area. Total net water resources in the region are 1280 km3, of which net groundwater is only 2 km3 (Table 1).

The NWC region is made up of Xinjiang and Ninxia Autonomous Regions, as well as the provinces of Qinhai, Gansu, and Shaanxi (Figure 1). It is located at least 600 km from the ocean and is surrounded by tall mountains. It has up to 400 mm yr-1 of rain in mountainous areas, but is arid to semi-arid in the plains, where precipitation can be as low as 50 mm yr-1 (Table 2). Several inland rivers are distributed across the region being the Tarim, Heihe, Shiying, and Urumqi. Regional water resources amount to 220 km3, with groundwater being less than 5% (Table 1).

The NEC region contains the provinces of Heilongjiang, Jilin and Liaoning (Figure 1). The region's watersheds include those of the Heilongjiang (J), Shuifen-Tumen and Liaohe-Yalujiang rivers (A). Under this semi-humid to humid climate, precipitation ranges from 500 to 1000 mm yr-1, under the influence of monsoons and different landforms (Table 2). Total net water resources are 150 km3, with 22 km3 of net groundwater (Table 1).

The NCC region includes Beijing and Tianjin, the provinces of Hebei, Shandong, Shanxi, and Henan, and the Inner Mongolia Autonomous Region (Fig. 1). Main watersheds in the region include the Haihe and Lunahe rivers (B) and middle and lower reaches of the Yellow River (Fig. 2). Climate is semi-arid to semi-humid, with precipitation ranging from 500-600 mm yr-1 under the influence of eastern monsoons (Table 2). Total net water resources in the region are 170 km3 with 43 km3 (25%) of net groundwater (Table 1).

Precipitation and thawing of alpine glaciers are the primary sources of runoff in China, but such waters are only exploitable when they flow in surface channels or emerge from springs (Yang 1981). The Yangtze and Zhujiang rivers carry the bulk (48%) of total runoff estimated at 2,700 km3. Based on measured seepage rates and volumes from farmland channel systems, particularly those in the piedmont plains, as well as a consideration of storm and flood event hydrographs, total net shallow groundwater in China represents about 100 km3 (Liu et al. 1996). Groundwater resources, excluding those feeding streams, occur mainly in the shallow aquifers of plains regions and total some 100 km3. While China ranks sixth amongst nations in total water resources, its per capita water resources (2344 m3 person-1) are roughly a quarter of the global mean

(Table 3).

Use of water in agriculture is the largest sector in terms of water withdrawal, rising four-fold in the last 50 years (Zhao 2000). Table 4 shows usage in relation to different regions. Different agricultural areas employ water in different ways. As agricultural water use includes irrigation, forestry and grassland use, fishery supplementation, so a wide range of problems has developed as a result of rapid agricultural development.

3. Water issues

3.1 Unequal distribution

China's water resources are unevenly distributed both in terms of area and population. China must feed 22% of the world's population with only 6.4% of the world's landmass, 7.2% of its farmlands and 5.8% of its runoff (Chen and Xia 1999). With very high population densities in SE China per capita farmland area is low, roughly 500 m2 person-1. Catchment areas of the Yangtze River and its southern tributaries account for 80% of China's total runoff, but house only 36% of China's farmlands (Chen and Xia 1999). Per capita water resources in northern China are one-quarter those in the south, while on an areal basis the north's water resources are a tenth of those in the south (Chen and Xia, 1999). The paucity of water resources in northern China results in more acute conflicts in supply and demand than in the south. Arid and semi-arid lands of the NWC region cover 47% of China, but only benefit from 7% of water resources (Table 1, 2). Humid and semi-humid regions of SE China account for the remainder and enjoy 93% of water resources (Table 2; Chen and Xia 1999).

The Liaohe, Haihe, Yellow, and Huaihe rivers supply 41% of China's farmlands, but only carry 6% of China's total runoff (Chen and Xia 1999). Per capita runoff volume in this region is only 431m3 person-1 yr-1, significantly below the 1000 m3 person-1 yr-1 generally agreed threshold criteria for water shortage. Available farmland water volume is low at 40.5 m3 km-2, being only 14% of the national average. In contrast, the Yangtze and Zhujian rivers serve only 29% of China's farmland, but carry 48% of China's total runoff (National Statistics Bureau 1998b). Water deficit predictions for the NW suggest deficits reaching 20% of available water by 2010, with significant impact on the region's agricultural production.

3.2 Serious water resource shortages

Water shortages have restricted China's agricultural, industrial and urban development. About 300 of 600 medium sized cities, of 0.1-1.0 million inhabitants, have experienced water shortages, while 108 of these cities suffer from a serious lack of water (Feng et al. 1999b). The area of drought-prone lands has risen by 50% since the 1950s, reaching 267,000 km2 in 1990. Only 500 of a potential 640,000 km2 of potential irrigated area has been developed, of which 100,000 km2 has poor irrigation facilities. So agricultural production and grain supply is restricted. Additionally, about 7.0 million people and 60.0 million head of livestock must drink highly saline water as no fresh water is available (Feng 1999).

Water shortages also adversely affect industrial production and living standards. In the late 1980s and 1990s, many electric power plants and factories in large, > 1.0 million inhabitants, and medium-sized cities of northern China had to suspend production due to water shortages. In Lanzhou mean power outages reached 600-1000 hr yr-1. Similar power outages have occurred in some cities of southern China. Excessive pumping of groundwater has led to a drop in water table, surface subsidence, and destruction of water-bearing aquifers. At the Minqin oasis, Gansu Province, salinity of ground water has now reached 17 g l-1, leaving roughly 76,000 people and 124,000 head of cattle with no potable freshwater and 37 million ha of farmland being abandoned (Feng 1999). From the mid-1970s to early 1990s some 3.63 km3 was pumped annually from underground aquifers in the arid inland Shiyang River watershed, leading to a 2-10 m drop in water table and formation of three water table depression cones. Across northern China, about 87% of water resources was drawn from groundwater stores, which was only replenished at a rate of 0.3 km3 yr-1 (Feng and Cheng 1998). The drop in water table extended over 23,000 km2.

3.3 Deterioration of aquatic ecosystems

Regions susceptible to soil erosion have reached 38% of China's landmass. On the Loess plateau, 430 and 276,000 km2, or 69% and 44% of total area, are subject to moderate and severe soil erosion, respectively (Feng et al. 1999a). Across half the Loess plateau, soil erosion is greater than 5 Gg km-2 yr-1, while in some areas it reaches 30.7 Gg km-2 yr-1. Despite annual investments of $2.4 million (U.S.), reclamation rates are below rates of soil erosion, leading to loss of land productivity. In the Loess plateau alone, losses of nitrogen, phosphorus and potassium are estimated to amount to 40 Tg yr-1, equivalent to the total annual chemical fertiliser output in China (Tang and Qu, 1992). Economic loss is roughly $50 billion.

Downstream sediment deposition not only decreases flood discharge capacity and shortens useful life of watercourses and storage facilities, but also encourages overflow under flood conditions, resulting in high evaporation of water as well as land salinization. Continued sediment deposition in river courses, reservoirs, and drainage networks will decrease their flood regulating capacity. Due to sediment deposition, lakes along the Yangtze have quickly shrunk dropping by 1500 km2 in area and 12 km3 in volume between 1949 and 1983 (Wang et al. 2000). Lake shrinkage has resulted in a 20% decrease in adjustment capacity, a rise in water level of 0.76 m, and a concomitant economic loss of $6.0 billion.

Water pollution is a very serious problem in China. In 1990, 56.0 km3 of sewage drained into lakes and rivers, of which 68% originated from industrial sources and 32% from domestic sources (Feng et al. 1999b). Discharge of largely (85%) untreated polluted water directly into rivers and lakes contributed 30-40 Tg yr-1 pollutants in the 1970's, and 45 Tg yr-1 by the 1980s, contaminating these water bodies of water and some farmlands. Use of polluted water to irrigation has resulted in contamination of 0.1 million km2 of croplands, and contributed to economic losses of $5.2 billion (Shen and Su 1998). A survey showed that more than 400 of 500 rivers were contaminated to different degrees, and 12 of 15 large cities situated near big rivers had seriously contaminated water supplies. At present, urban sewage water disposal and reuse rates average are 18% and 15%, respectively.

Polluted water can affect people's standard of living and health indirectly or directly through local diseases outbreaks. Localized endemic illness has increased due to bad water quality: in Bailedou, Qinghai Province with diarrhoeal symptoms have been attributed to water with a high sulphate content. In Yan'an, Shaanxi Province and Qinyang, Gansuu Province (NWC), respectively, keshan and kaschin-beck diseases have been attributed to drinking water high in humic acid and low in selenium (Feng and Cheng 1998).

In China, 334,000 km2 of desertified land accounts for roughly 15.5% of total land area (Zhu and Cheng 1995). From the late 1950s to mid-1970s, land desertification in north China expanded at a rate of 1,570 km2 yr-1. By the end of the 1980s, desertified land area had reached 176,000 km2 in north China, with a further 122,000 km2 of desert-prone farmlands and pastures (Wei and Tang 1987). Similarly, during the past forty years, mismanagement of water resources has led to salinized land in north China increasing at a rate of 12.8 km2 yr-1.

3.4 Flood and waterlogging damage

Seasonal and annual variations in precipitation and stream flow in China are comparatively large. Precipitation within the four months of the flood season may account for 60-80% of annual totals. Ratio of annual streamflow in a wet year to that in a dry year may approach five in southern regions, but may exceed ten in the north. As floods, water-logging and drought occur frequently, a keen awareness of hydrological extremes guides development and use of water resources in China. Despite building many conservation structures in the past forty years, their ability to prevent floods remains poor. In addition to inadequate control of soil erosion and serious silting of waterways, criteria for water conservation projects have been rather lax. Statistical analysis has shown that about 100 of 370 large reservoirs (0.1 km3) have potential dangers, 670 of 2,500 common reservoirs (0.01-0.10 km3) have potential dangers, and 32,000 of the 80,000 small reservoirs (0.001-0.010 km3) also have serious problems. Frequent flooding in recent years throughout China has clearly demonstrated the limited communication and forecasting systems. Poor condition of flood safety structures has seriously compromised flood control. In 1998 he most extensive flood of the 20th century on the Yangtze River damaged a quarter of the cities in southern China, affected 12 cities of 0.1-1.0 million inhabitants, and resulted in losses of $36 billion (Zhao 2000). In 1995, a large flood in Liaoning Province hit 9 cities, 39 counties and 500 villages, flooded large tracts of farmland, surrounded numerous homes, and resulted in significant economic losses. Some 146,000 km2 of farmland as well as homes over an area of 330 km2 were destroyed, resulting in economic losses of $0.96 billion. In 1994, flooded areas totalled 193,000 km2, affecting 223 million people, and resulting in direct economic losses of $2.17 billion (NIHWR 1997).

3.5 Acute gap between water demand and supply

Conflicts between water supply and demand are mainly the result of poor regulation of water resources, competition between users along rivers and uncoordinated structure and distribution of industrial development (Qu 1998). Conflicts between water users along rivers has become more apparent in recent years due to inadequate management legislation, uncoordinated water distribution, uncontrolled development and water resource wastage in river basin. Such conflicts have the potential to cause land desertification and environmental degradation in the lower reaches of rivers (Feng et al. 2001). In the landlocked watersheds of the NWC region, use of most of the streamflow in middle reaches has resulted in the area of terminal lakes being significantly reduced. The surface area of West Juyan Lake on lower reaches of the Heihe River in Inner Mongolia was 3,000 km2 in the 1960s, but by 1995 only 17 km2 remained. In recent years the lake has dried up in the summer. Some 4,565 km2 of the 38,000 km2 of desertified lands in the Tarim basin are directly attributable to unreasonable water resource exploitation (Zhu and Cheng 1995).

Natural poplar (Populus euphratica) and shrub forest (Tamarix spp.) are generally distributed along riverbanks in a corridor-like manner (Wu 1992). This has been seriously degraded due to increasing use of water and land resources, P. euphratica and Elæagnus angustifolia L. are the main tree species of NW China's arid plains and forest areas in lower reaches of the Tarim river declined by 3820 km2, from 1958 to 1990. At the same time shrub and meadow areas declined by 200 km2, at a rate of 6.25 km2 yr-1 (Feng et al. 2000).

Haphazard construction of industrial infrastructure is common in China, which has prevented location of industries being geared to more effective use of water resources. Different governmental departments have set up factories, each developing water resources for their own economic benefit in an excessive manner. In agricultural production, water consumption is closely related to crop species. Similarly, water requirements for growing cotton (Gossypium hirsutum L.) are 110-112% of precipitation, still 6-17% short of available precipitation in normal precipitation year, but much better than those for wheat (Qu and Ma 1995). An irrational distribution of crops adversely affects sound allocation of water resources.

3.6 Wastage of water resources

While China suffers from shortages, a large proportion of water resources in China are wasted. Much of the water in reservoirs built between 1960s and 1970s on the plains evaporates. Large irrigation quotas and heavy irrigation are common. Annual irrigation norms across China range from 150 to 530 mm (Table 5). Areas where water conservation techniques applied are few, as some farmers still use traditional but inefficient multi-channel water-diverting methods for irrigation, thus wasting a great deal of water. Poorly constructed channels for water conveyance suffer from severe seepage, mean conveyance efficiency in the NEC and SWC regions ranges from 0.03 to 0.45 (Table 5).

Under flood irrigation conditions with excessive amounts of water, water tables can rise and soils become salinised. Consequently fields must be irrigated in the spring in order to leach salts from the topsoil, thus significantly reducing water use efficiency. In Shandong Province, Hainan, Shiyang River area and over the entire Shiyang River basin water use efficiencies are 24 kg m-3, 25 kg m-3, 75 kg m-3, and 41 kg m-3, respectively. The latter case represents wastage of over half the water (Xia and Takeuchi 1999). In China water use efficiency is very low, and the output water demand index of 0.4-0.7 kg m-3 much lower than the worldwide mean of 2.0 kg m-3.

Legislation on urban water use is seldom enforced. Furthermore, low water prices result in a great waste of urban water resources. The range of rural domestic water quotas is 65 – 110 l person-1 yr-1 (Table 5). In some locations where well water is used, water consumption may rise as high as 200 l person-1 yr-1, resulting in a sizeable waste of water (Qu and Ma 1995).

Water wastage by industries is widespread. The comprehensive industrial index of water use per $1000 product output averaged 86, 158, 118, 95, 46 m3 in the SEC, SWC, NWC, NEC and NCC regions (Table 5), showing the high and extremely variable water consumption of China's industries. Industrial water reuse ratios are as low as 10-20%.

4. Rehabilitation measures

To ensure sustainable development and use of water resources, some new policies will have to be implemented. Detailed rehabilitation measures are proposed for the five geographical regions (Table 6). Efforts must be made to promote urban, industrial and agricultural water conservation. Sprinkler and drip irrigation are only used on 1.5% of irrigated areas, though water savings relative to traditional irrigation methods could be as high as 50% and 70%, respectively (Qu and Ma 1995). The water wasted under flood irrigation occurs mainly through channel seepage and saturated water evaporation, and results from the lack of coordinated canal systems and poor seepage control techniques. If increasing expenditures on channel upgrading could raise their water conveyance efficiency, 10-15% of the total water used in field irrigation could be saved. An enhancement of field water conservancy projects, including the levelling of fields and a change from flooding to sprinkler or drip irrigation could save 10-20%, even up to 40%, of total irrigation water use in arid regions and up to 30% of total irrigation water use in humid regions (Cheng 1996). A rise of water use efficiency from 0.4 to 0.7 would result in water savings of 120-160 km3 yr-1.

As the highest water consumption per $1000 of output for the SWC region is over six-times greater than the lowest value for the NCC region, it is clear that a great potential exists for water conservation in the industrial sector (Table 5). The water-reuse ratio is low in the SWC and NWC regions, being 40 and 60% in most cities, but somewhat higher in the NCC and SEC regions. Were all industries to operate at NCC industrial water use and reuse levels, 160 km3 yr-1 of water resources could be saved.

A great potential also exists for urban water conservation; however, given low water prices, pressure for water conservation and efficient use of existing water resources are low in most Chinese cities. Water consumption in these cities ranges from 130-260 L person-1 yr-1 (Table 5). Poor management and maintenance of water conveyance infrastructure can result in serious wastage of water resources. Water leaking from pipes, excessive water usage in some large hotels and gardens, and public fountains can waste large quantities of water. By reducing waste and with wastewater reuse, cities could save 33-50% compared to their current water usage.

The capacity to allocate water resources would be enhanced if new water sources could be tapped, and in turn could remedy China's economically inefficient use of water resources (Table 6). As precipitation is an important water resource for development in northern regions, development of new techniques for collection and storage should be a priority (Kang et al. 2000). Collection of rain in mountainous regions could provide inhabitants with drinking water requiring little treatment (Tang and Qu 1992). Retention of rain could also improve soil moisture conditions in forested alpine lands. Studies have shown that for a rain harvesting efficiency of 70%, rain-harvest irrigation can increase crop yield by 30%, and production rate to 1.5 kg m-3 or more. In rural areas, surface runoff water sources can be developed, and more efficiently used through construction of terraced fields supported by local government. In the future, for certain regions, de-salinization of seawater may provide a solution to water shortages (Agnew and Anderson 1992). The local environment can be improved by use of floodwaters to recharge wetlands or groundwater, prevention of changes in river courses, attempts to control sediment deposition, and regulation of some international rivers. Water shortages in specific regions can continue to be alleviated by water diversion projects.

Water resource management at the societal and environmental levels must be improved. Ecosystem variability is inevitable, but ecosystems can be modified to some extent to improve their ecological efficiency (Frederick 1994). Natural ecosystems inevitably vary with time; however, if one only considers economic benefits, ecosystems can be damaged (Jones 1999). Water pollution in China is serious and linked with economic development. According to interdepartmental investigations and analyses, 5.2 and 20% of the 95,000 km2 of river networks are either seriously polluted or polluted to a lesser degree, respectively. In recent years, the area affected by water pollution has been expanding, resulting in economic losses of roughly $400 billion. Consequently, China must strengthen its water resource management policies, establish water conservation regions, reduce water pollution and continue to raise water use efficiency.

Holistic resource management plans are needed. Inland rivers flowing through different regions require watershed-wide co-ordination. River management draws on expertise in conservation, forestry, industry, agriculture, water quality protection, and urban construction. Each department manages some aspects of the water supply-demand problem, but there is a lack of watershed-wide coordination. Water pollution, wastage and misuse occur when the right hand does not know what the left hand is doing. Co-ordinating water resource usage, requiring users to observe the water laws and unifying allocation of water resources at the watershed scale should be completed as soon as possible (Liu 1996).

Such improvements will require an investment in water conservation and water resources development based on state-of-the-art science and technology (Table 6). Between 1950 and 1990, government policy supported construction of water conservancy infrastructure, but in spite of social development and population growth such investments and such construction is now decreasing. However, in recent years, the government has increased investment in large-scale water development and conservation facilities, such as the Three Gorge and Three-Route Water Diversion projects. The Fifth Plenary Session of the Fourteenth Central Committee in 1998 adopted a proposal to put water conservation at the forefront in terms of infrastructure construction. This indicates that administrators' awareness of water conservation has been raised to a new level.

Susceptibility to flood damage, extent of floodwaters and their impact during and after the floods should feature in plans (Table 6). Areas where certain land uses are to be restricted or prohibited according to flooding risk must be delineated. Development of flood hazard control areas and appropriate building codes should assure that only low-value infrastructure such as flood-proofed homes with elevated foundations are built on flood plains. In dealing with actual flood conditions, it is necessary to address disaster contingency planning, community self-protection teams, flood forecasting and warning systems, improved information and education on floods and on actions to take in a flood emergency (Kundzewicz and Takeuchi 1999; Kundzewicz 1997). Once such legislation and networking are put in place, then dams and flood control reservoirs can be constructed. Diversions, flood ways, channels with improved capacities to convey a flood wave, embankment reinforcement, enhanced source control, must be implemented in a manner which considers the extent and location of the flood plain and wetlands. After and during flood damage, likelihood of recurrence, and the forecasting of river stage should be investigated. During post-flood environmental and economic recovery its is important to consider revision of existing flood management activities to improve the process and planning for future events (Kundzewicz , 1999).

5. Conclusions

Water scarcity seems to result from a region experiencing a series of droughts due to global climate changes and an outdated water resource management system. Sustainable use of available water resources requires the present system must be radically upgraded, then users might get a fair share of whatever is available. The two primary barriers to this are the water rights system and the pricing of water. The water resources management system is centralized and non-participatory. No forum exists for inputs from the population at large. Government authorities in China make water resources management decisions. Present infrastructure is a barrier to efficient water allocation, in particular during periods of drought. Consequently a more decentralized administration of water supply infrastructure should be promoted, and thereby enhanced willingness of users to pay. Low water prices have resulted in people ignoring unnecessary losses, and perceiving that water is an unlimited resource. The water allocation system must move towards a more realistic and localized pricing structure, a higher level of user payment and elimination of the unified nation-wide pricing system.

The level of scientific and technological expertise needs to be raised in monitoring, conservation, protection, management, and rehabilitation of water resources and associated habitats. Hydrologists, water quality and irrigation experts are often divided up between 3-4 government levels. They seldom share information and work independently, so that decisions are unilateral rather than products of consultation. Limitations on carrying capacity of a given watershed are seldom assessed. Endless papers, policy statements, NGO and consultants' reports exist about the terrible situation of this or that in China, frequently backed with extensive statistics and verbiage. Unfortunately very few publications exist which document implemented recommendations with an estimate of their effectiveness.

* Ministry of Water Research (MWR). Yearbook of China Water Resources (1997 and 1998).

Acknowledgements

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Table 1. Water resources distribution in China in 1990 (MWR, 1997, 1998)

Region of China	Extent of water resources [% relative to all China]				
	Total				
	Surface water (109 m3)	Groundwater (109 m3)	Volume (109 m3)	Per capita (103 m3 person-1)	Per area (103 m3 km-2)
	905 [34.2]	25 [24.5]	Volume (109 m3)	Per capita (103 m3 person-1)	Per area (103 m3 km-2)
Southeast (SEC)	905 [34.2]	25 [24.5]	930 [33.8]	2.0 [88.5]	756 [264]
Southwest (SWC)	1278 [48.3]	2 [1.9]	1280 [46.5]	5.3 [236.7]	492 [172]
Northwest (NWC)	210 [7.9]	10 [9.8]	220 [8.0]	2.5 [111.3]	71 [25]
Northcentral (NCC)	127 [4.8]	43 [42.2]	170 [6.2]	0.5 [23.5]	89 [31]
Northeast (NEC)	128 [4.8]	22 [21.6]	150 [5.5]	1.4 [63.4]	188 [66]
All	2648	102	2750	2.2	286

Table 2. Water resources in different climatic zones of China

Zones	Precipitation (mm yr-1)	Runoff (mm yr-1)	Area of China (%)	Proportion of Chinese Water Resources (%)
Arid	<200	<10	26.6	2
Semiarid	200-400	10-50	20.9	5
Total			47.5	7
Semihumid	400-800	50-200	18.6	12
Humid	800-1600	200-800	26.0	58
Extremely humid	>1600	>800	7.9	23
Total			52.5	93

Table 3. Total area, population, farmland, rain and water resources in China and the World

Region	Landmass area (106 km2)	Population (109)	Farmland (106 km2)	Rainfall (103 km3)	Water Resources		
					Volume (103 km3)	Per capita (m3 person-1)	Per area of farmland (m3 km2)
World	149.5	5.4	13.26	120	46.8	8690	353
China	9.60*	1.2	0.96	6.19	2.81	2344	293
Ratio (%)	(6.42)	22.2	1.0	5.2	6.0	27.0	83.2

Table 4. Current situation of water usage (km3) by different sectors in China in 1997 (MWR, 1997, 1998).

Region	*Irrigation*	*Forestry, pastures fisheries*	*Agriculture*	*Rural*	*Urban*	*Domestic*	*Industrial*	*Total*
Southeast	*150*	*7*	*158*	*14*	*11*	*25*	*63*	*245*
Southwest	*51*	*8*	*59*	*5*	*6*	*10*	*12*	*81*
Northwest	*46*	*20*	*66*	*1*	*2*	*3*	*5*	*73*
Northcentral	*71*	*5*	*77*	*6*	*5*	*10*	*15*	*102*
Northeast	*36*	*3*	*40*	*2*	*3*	*4*	*12*	*55*
Total	*354*	*43*	*400*	*28*	*27*	*52*	*107*	*557*

Table 5. Current water consumption of different users in China.

Region	*Irrigation quota (m3 m-2)*	*Irrigation rate (%)*	*Domestic water quota*		*Industrial water consumption (m3/1000 USD)*
			Urban (L)	*Rural (L)*	
Southeast	*0.20*	*76.5*	*260*	*110*	*86*
Southwest	*0.53*	*47.0*	*245*	*85*	*158*
Northwest	*0.25*	*50.4*	*130*	*65*	*118*
Northcentral	*0.50*	*57.0*	*185*	*71*	*46*
Northeast	*0.15*	*24.3*	*145*	*90*	*95*

Table 6. Water resources problem and countermeasures in China

Region	*Groundwater storage capacity*	*Problem*	*Countermeasures*
Southeast	*Poor*	*Seasonal drought; serious water pollution; frequent flood damage*	*Intensify construction of hydrological structures; intensify water pollution law enforcement*
Southwest	*Poor*	*Low water use efficiency; uneven land; poor water quality*	*Raise water use efficiency; intensify water management; control water pollution*
Northwest	*Abundant*	*Quite uneven lands; aquatic ecosystems seriously deteriorated; water wastage; increasing water deficits*	*Applying advance technique to save water; prevent environmental degradation and control water and soil loss; enhance management system on inland rivers*
Northcentral	*Abundant in plains*	*Scarcity; uneven water distribution; low water use efficiency; deterioration of aquatic ecosystems; frequent droughts and water-logging*	*Transport water from other drainage basin; increase the water use efficiency; support experimentation with new water conservation techniques; increase investment*
Northeast	*Poor*	*Uneven water distribution; serious flood damage*	*Improve water sharing agreements between upper and lower reaches; improve the ability of watersheds to adjust to floods by increasing their storage capacity*

Table 7. Predicted shortage of water resources in the year of 2010 (10^8 m^3)

Regions	*Items*	*Total*	*Industry*	*Irrigation*	*Forestry, pasture and fisheries*		*Rural*
Southeast	*Requirement*	*3264*	*832*	*2003*	*92*	*146*	*191*
	Supply	*2942*					
	Shortage	*-322*					
Southwest	*Requirement*	*996*	*211*	*582*	*77*	*66*	*60*
	Supply	*911*					
	Shortage	*-85*					
Northwest	*Requirement*	*980*	*68*	*674*	*206*	*8*	*24*
	Supply	*812*					
	Shortage	*-168*					
Northcentral	*Requirement*	*1421*	*234*	*957*	*72*	*70*	*88*
	Supply	*1148*					
	Shortage	*-273*					
Northeast	*Requirement*	*745*	*150*	*460*	*30*	*65*	*40*
	Supply	*646*					
	Shortage	*-99*					
The whole China	*Requirement* *Supply*	*7406*	*1459*	*4676*	*477*	*355*	*403*
	Shortage	*-947*					

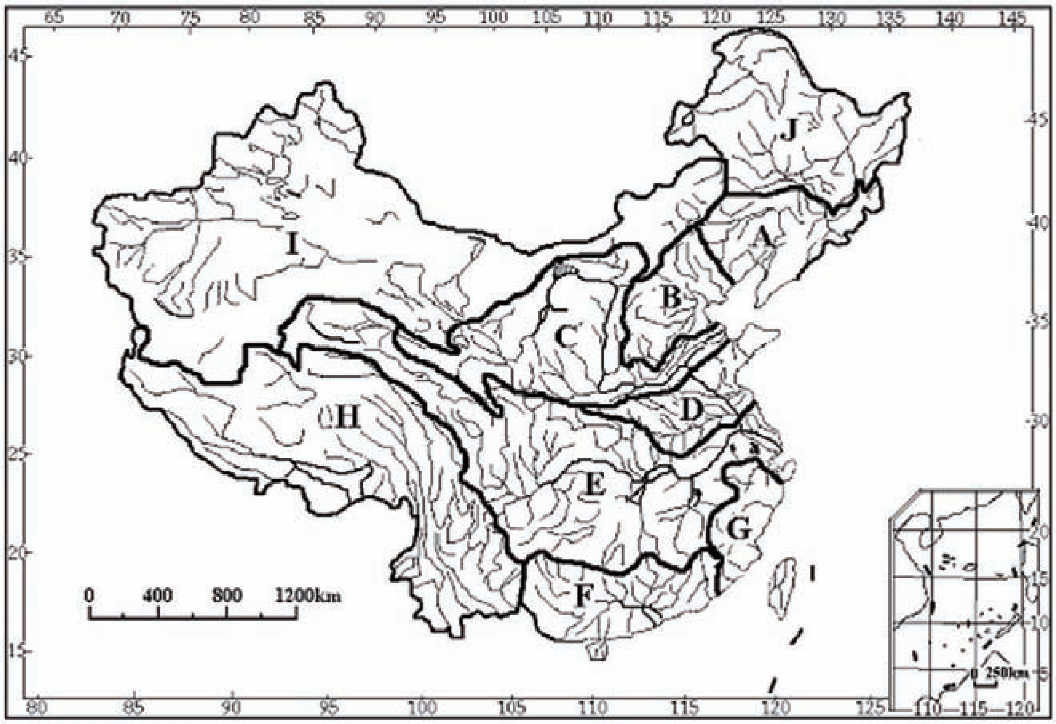

Figure 1. Sketch of water resources subdivision by provinces in China

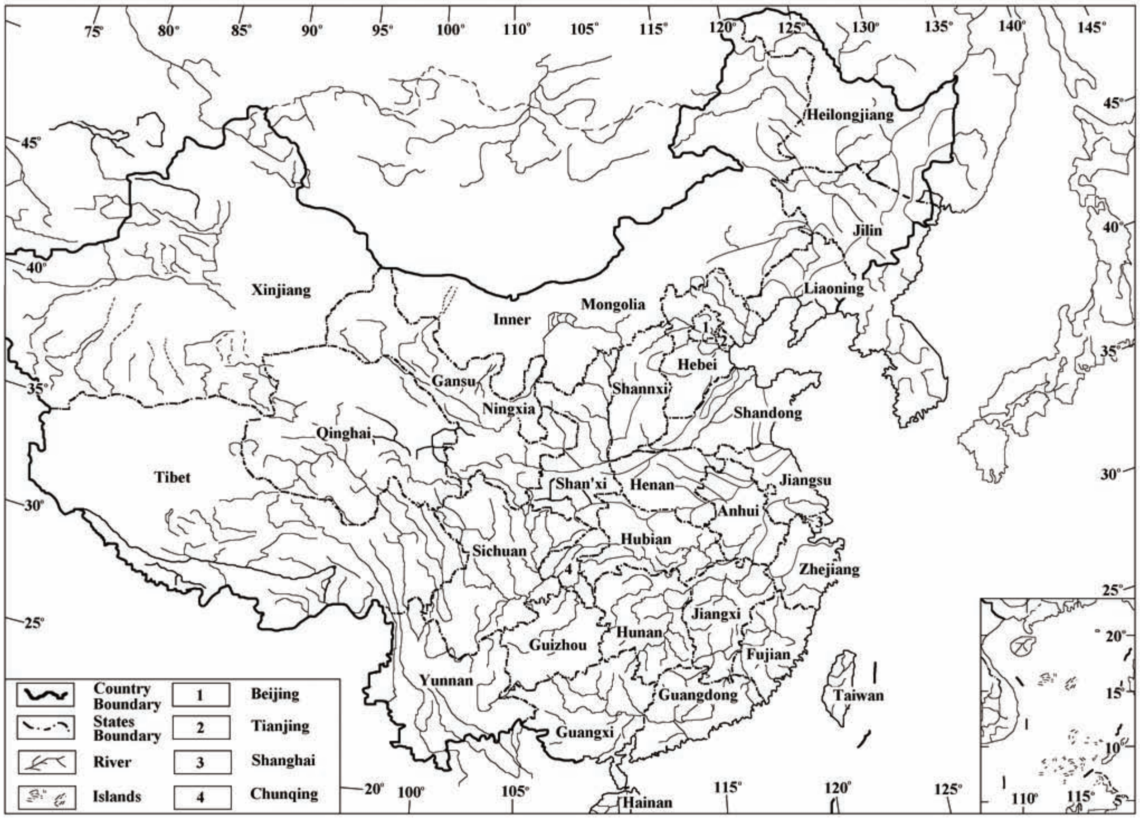

Figure 2. Water resources regions by watershed or river basin in China.

A: Liaohe; B: Haihe and Lunahe; C: Huanghe; D: Huaihe; E: Yangtze; F: Zhujiang river basins; G: rivers basins along the east China Sea in Guangxi Autonomous Region; H: Honghe, Lanchangjiang, Nujian, Yiluowadi, and Yalunzangbu rivers, excluding the rivers in G; I: Inland river basins including the Tarim and Heihe river basins, etc. J: Heilongjiang, Shuifen-Tumen and Liaohe-Yalujiang river systems.

Response of Water Resources in Yellow River Basin to Global Warming

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Abstract

Based on the observed hydrological and meteorological data, characters of water cycling factors, including precipitation, temperature and runoff in Yellow River Basin, are analyzed in this paper. The results show that temperature has been experience increasing and increasing amplitudes are different in each sub-zone; temperature increasing in source region of Yellow River Basin is not only the response to global warming but also one of reasons of climate change in the world. Evaporation and soil percolation also show rising trend because of climate warming. Precipitation changing has strongly regional characters with the variations of geographical position. Effected by the decreasing and temperature rising in the main water-yield zone, runoff in source region has been kept reducing. Runoff depletion has important impact on ecosystem in source region of Yellow River Basin.

Key words The source region of Yellow River Basin, temperature, precipitation, global warming

1 introduction of the source of Yellow River Basin

The source of Yellow River Basin was located on the Northeast of Tibet Plateau (95°50′E～103°30′E, 32°30′N～30°00′N) which includes the zone of upward of Tangnaihai hydrological stations[1] (Fig. 1). The catchment area is about 122 thousands km^2, which take 15% of the whole Yellow River Basin; annual average runoff is about 20 billions which takes nearly 40% of the whole basin. Sea level elevation in most area is above 3000 m, so its climate is very cold and there are massive, continuous permafrost and seasonal frozen soil. All the mountains are below the snow line except Animaqin Mountain with elevation of 6282m and glacier of 125.7km2. [7] So there is hardly any other modern glacier in the source region. Annual average precipitation is 525mm, amounts of precipitation in Jiuzhi and Ruoergai are up to 800～1000mm. The main water vapor origins the warm and wet air flow coming from the Bay of Bengal of Indian Ocean. The annual average depth of runoff is 168mm and the runoff coefficient is about 0.31. Precipitation in summer and autumn are the main discharge to runoff, and groundwater and ice-snow water are the second discharge[6].

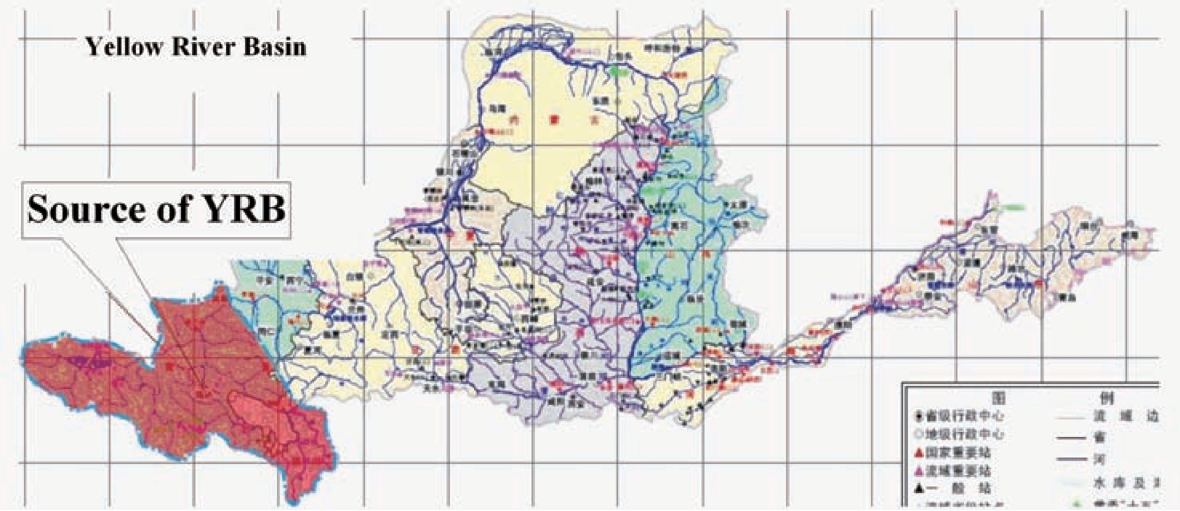

Figure. 1 the location of the source of Yellow River Basin

2 Data and methods

Considering the heterogeneity of meteorology station in the source region, 10 representative stations are selected from 18 stations in source region with long and continuous time series (Fig.1). The yearly and flood season series are calculated by using temperature and precipitation from 1960-2002. Area weighted method is used to obtain the precipitation on the basin level.
Some statistics methods are used to analyze the character of climate change and water resources, such as the linear tendency analysis, departure and accumulative departure, Mann-Kendall abrupt test.

3 Features of climate change in the source region

3.1 Variance of precipitation

Precipitation in source region is strongly effected by Asiatic monsoon. The warm and wet air flow from southeast is affected by the intensity and location of subtropical high pressure which decides the seasonal change of precipitation in source of Yellow River basin.

It can be seen from Fig.2, with the background of global warming, the precipitation in source region shows decreasing trend. Precipitation in 1990s decreased by 16.6% compared with 1960s. Because of the difference of monsoon and geography location, precipitation changing in source region has evidently regional characters. The area maximum decreasing amplitude is in the south of source region, where precipitation in 1990s decreased 212.6mm by 23.3% compared with 1960s, the speed is about 12mm/10a (Fig. 3), though precipitation in Maduo and Xinghai has not obviously changing.

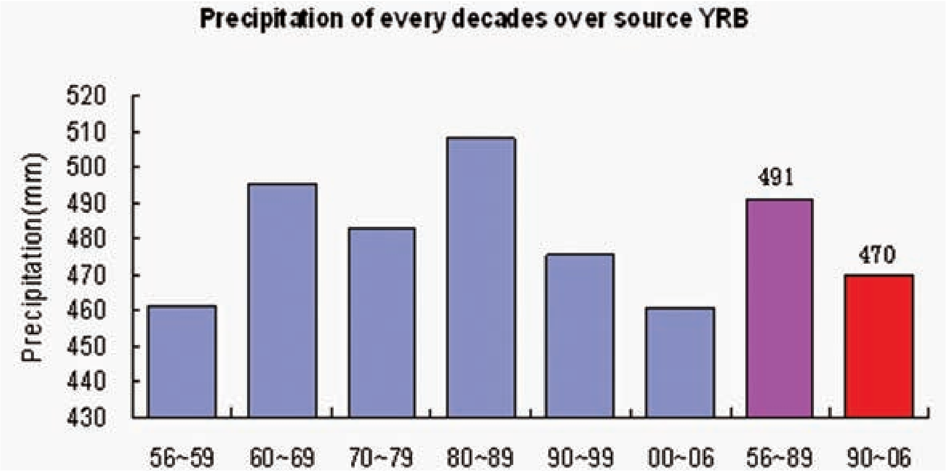

Figure.2 inter-annual change of precipitation in the source region of YRB

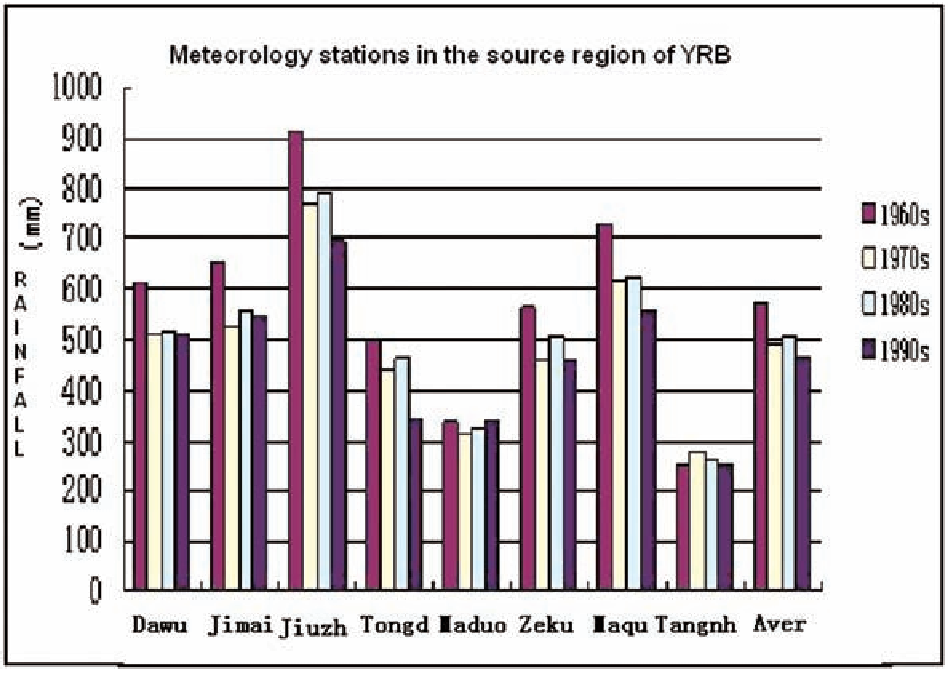

Figure.3 The regional change of Precipitation in source of YRB

3.2 Changing of temperature

Fig.4 shows the process of average temperature changing in source region. It can be seen that, the temperature has the fluctuating increasing trend by the speed of 0.3440C/10a and shows remarkable rising in recent 10 years. The maximum increasing area of temperature is around Zeku in the east of basin by the speed 0.3440C/10a, and the minimum area is around Jiuzhi in the south of catchment by the speed 0.030C/10a. Wang and Ding [3, 4] estimated the possible impact of temperature change on runoff in the source region, the result indicate that the runoff would reduce 3%～8% while the precipitation keeping unchanged and temperature rising 10C, and then it can be deduced that at least 4% ～10% runoff decreased because of the climate warming in recent 50 years.

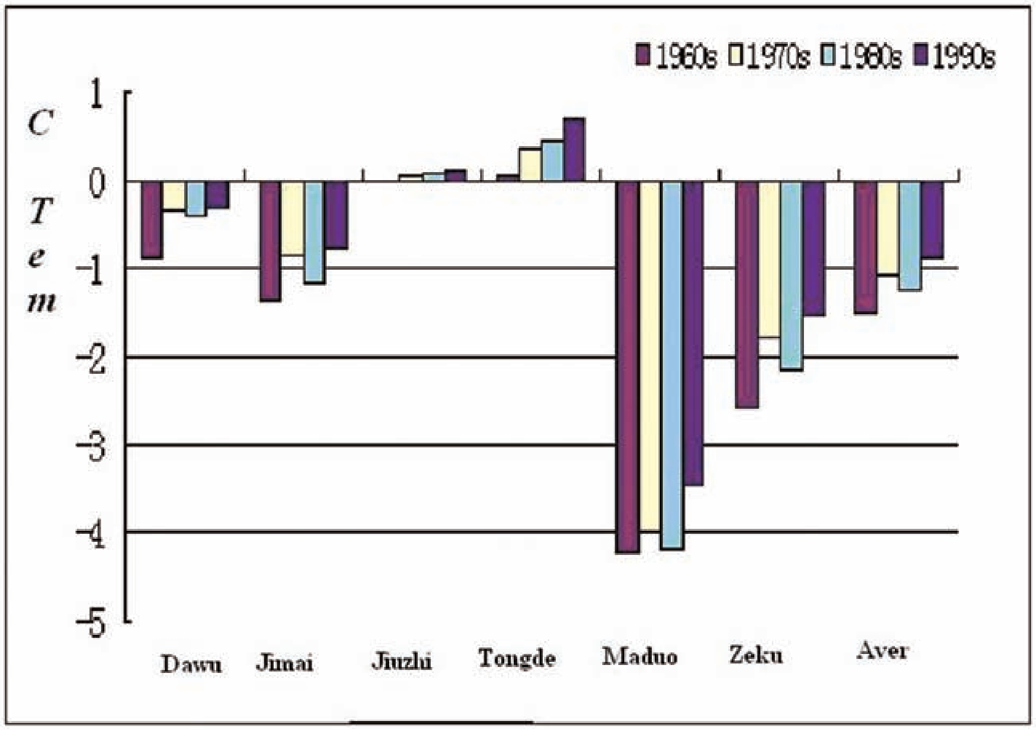

Figure.4 Average temperature changing in the source of YRB

3.3 Evapotranspiration and soil percolation

Evapotranspiration and soil percolation are the important parts in water recycling which consist of the sum of consumption in the processing of surface runoff yield. The land evaporation and soil percolation are restricted by hydrothermal and underlaying surface condition. Plant transpiration would be raised with the temperature increasing, in the other hand, vegetation degeneration and soil desertification led by climate warming could increase the land evaporation. Furthermore, climate warming would lead the frozen soil moving down or disappear, those helps the soil water percolation and decrease the surface runoff (Fig.5). Obviously, it is the response to temperature increasing and precipitation decreasing that the proportion of runoff from ice-snow and rainfall is yearly rising [5].

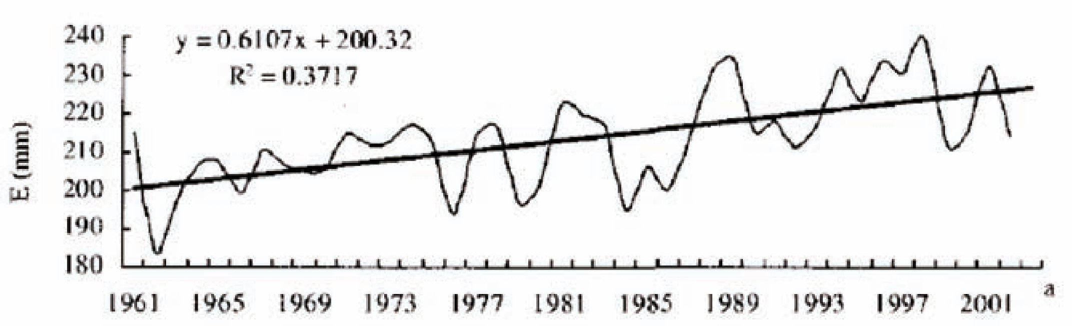

Figure.5 evaporation change in the source region of YRB

Climate warming and dry change the water recycling parts, such as the penetration of frozen soil layer, shrinking of lakes and marshes, expansion of soil desertification, consequently, the runoff yield condition of underlaying surface are changed. In the same precipitation condition, the runoff yields after 1990 are obviously less than that before 1990. especially recent years, the runoff coefficients show the decreasing trend (Fig. 6).

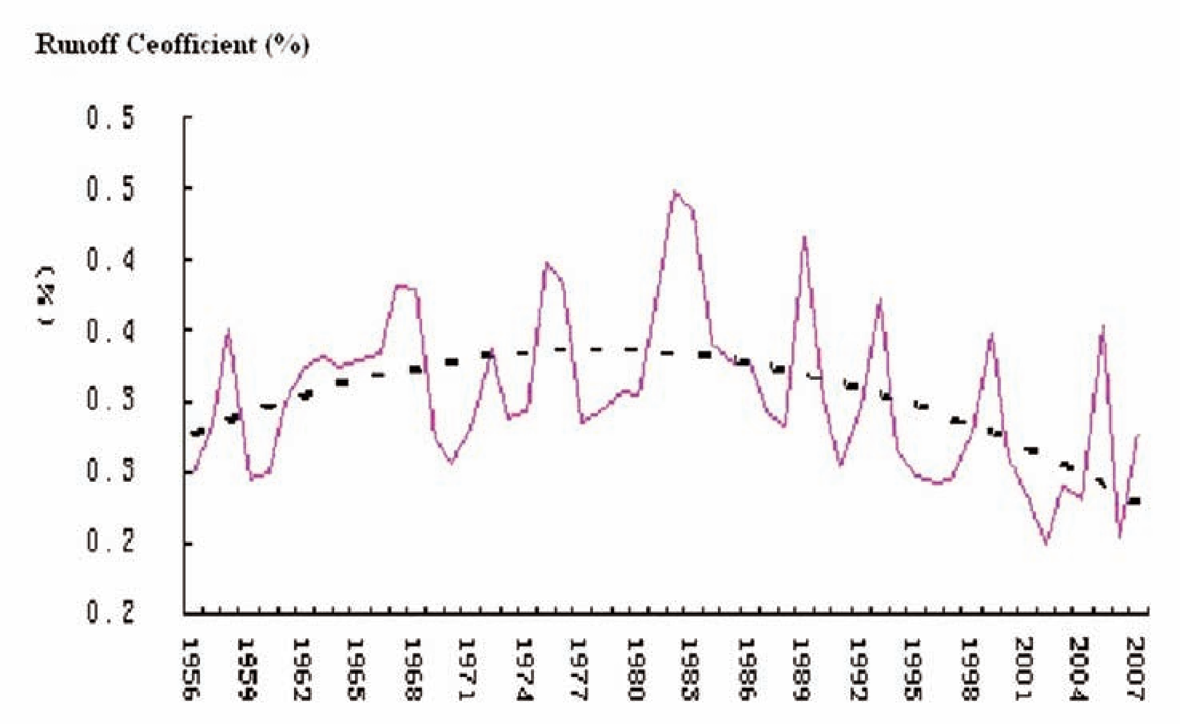

Figure. 6 the change of runoff coefficient in the source region

4 Runoff Change

4.1 The character and trend of runoff change

The runoff change is mainly decided by the amount of precipitation. So, the interannual variability of runoff basically consists with precipitation changing. The runoff shows decreasing trend in general in recent 50 years, and the descending amplitude of runoff is much more precipitation because of the increasing of evaporation, soil percolation, and land use degeneration. The runoff coefficient has been decreasing by year.

Since 1956 with the observed data, runoff change in source region has been experienced three stages. The fist stage is from 1956 to the middle of 1970s, there are fluctuating increments in runoff changing; the second, from the middle of 1970s to 2002, which is the weakening time, runoff has an basically oscillating decreasing; after 2003, runoff presents slightly and gradually rising.

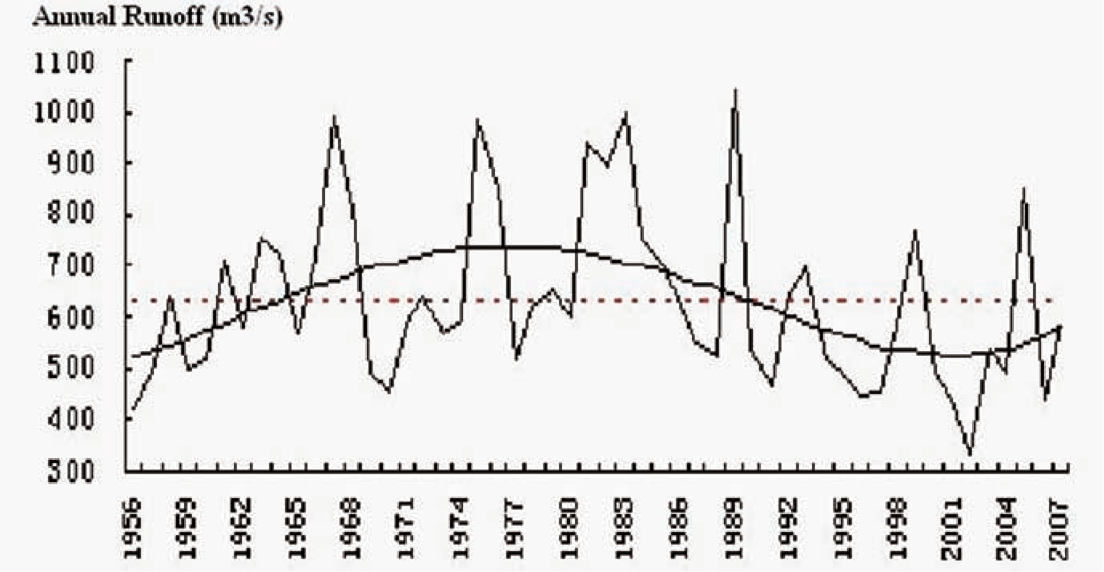

Figure. 7 the interannual change of runoff in the source region

4.2 Characteristic of flow variation

Viewed from the years variation of flow in the source region, the 1960s and 1980s are high flow years; 1970s are normal years; 1950s and 1990s are consistent with the rainfall of the corresponding period. However 2001-2007 are low flow years, which is obviously inconsistent with the historical plenty rainfall of the corresponding periods (refer to Table 1). In the recent decade, the temperature raising and environment degradation have led to the degeneration of the catchment underlayer. The runoff index has reduced yearly; therefore under the same condition of rainfall the runoff yield is obviously lower than ten years ago.

From the long term of view, the atmosphere precipitation assumes the periodic fluctuation. In accordance with the period analysis[6] on the annual rainfall of 1956-2003, the performance of extreme wavelet variance value of the year precipitation sequence of 128 year, 64 years and 32 years is most remarkable, which indicates that the precipitation of Yellow River Basin has the variation cycle of 128 years, 64 years and 32 years. These three periodic ondulation determines the variation of precipitation in the Basin. From the precipitation of the resources region in the recent decades we can find that, the rainfall increased since 2003, with the increase of rainfall the runoff in the sources region seem to be increased but the average value is still lower than the long-term value.

Table 1 Rainfall and runoff in the source region of deferent decades

Item	1950s	1960s	1970s	1980s	1990s	2000s	1956-2002	2003-2007	Long-term average
Rainfall (mm)	524.8	542.6	539.0	549.0	510.4	543.3	531.3	574.6	535.5
Runoff depth (mm)	133.5	176.8	161.9	196.9	145.1	136.9	165.2531.3	151.4	163.9

4.3 Regional Difference of Flow

In recent 50 years, though all the runoff is on the trend of decline, the flow in different sections of source region varies diversely due to different underlying condition. The runoff reduction trends increased with the catchments area, among which the sections above Maduo and Huanheyan station reduced least with the linear changing rate of -1.6 m3/s; while the flow under Tangnaihai station reduced largest with the linear changing rate of -16.5 m3/s.

According to studies, in the regions above Jimai are mostly covered by the glacier, snow and merzlota, thus the runoff reduction in this region are mainly due to the runoff consumption (increasing of evaporation and seepage) by permafrost melting, vegetation degradation caused by green-house effecting and human activity. While the rainfall reduction is mainly caused by the pathway variation of warm and wet air from south-east [7,8].

5 Analyses on the Rainfall-Runoff Regime in the Source Region

5.1 Effect of rainfall on the river runoff

The abnormal monsoon rainfall in China has close relationship with the density and position of subtropical high clone from western Pacific Ocean. The setion between Jimai and Maqu in the source region (including the sub-catchment of Black River and White River) has the largest rainfall because it located on the edge of south-east monsoon zone and strongly effected by the warm and wet air from the south-east. The area of this catchment is 41029 km^2, only occupies 34% of the areas above Tangnaihai, however, its long-term average runoff, about 11.1 m3 billion, occupies 52% of the runoff in Tangnaihai, where is also the area with highest runoff yield in the Yellow River source region (see table 4). Therefore, the water income in this area is significantly important to the water in the source region. In accordance with the researches of Zhang [7], the global warming has made the summer monsoon weaken in this region. In the August, the southern wind is weakened while the northern wind is strengthened with the trend of drying. Affected by this, the rainfall between Jimai and Maqu reduced constantly, this is also the main reason to result in the constant decrease of natural water inflow in the Yellow River source region for recent decade.

Table 2 Annual runoff modules in the main streams in the source region of YR

Station	Catchment area	Nature water inflow	Annual runoff modules	Area between Sections	Sectional runoff	Sectional runoff modules
Huangheyan	**20930**	**6.99**	**1.06**			
Jimai	**45015**	**40.0**	**2.82**	**24085**	**33.01**	**4.35**
Maqu	**86059**	**142.17**	**5.42**	**41044**	**111.18**	**8.28**
Tangnaihai	**121972**	**199.9**	**5.01**	**35913**	**45.74**	**4.04**

5.2 Global warming impact on the surface water

Climate warming and evaporation increasing led to runoff coefficients reduce, which is the another important reason of runoff reduction. It is analyzed by Li [18], the potential evaporation would increase 5～10% if temperature warming by 1℃. Fig. 8 shows the relative curve of evaporation and runoff change in source region. It can be seen that there is obviously negative relation between evaporation and runoff in flood season.

5.3 Human activities effect on runoff

Reservoir building can increase the evaporation of water surface for the augment of water area; and road constructions may destroy the vegetation of land surface, cut out the route way of surface runoff; field mouse disasters open up the passage of ground water, then accelerate the grass degeneration and shrinking speed [7].

6 Discussions and conclusions

(1) Temperature increasing in the source region is consist with the global warming. There are evidently increasing tendency in most area of the source region, especially in recent 10 years. Evaporation and soil percolation also show ascending trend with the climate warming. The precipitation has obviously regional character and change in space according with geographical locations and altitude.

(2) Runoff in source region shows remarkable descending trend. The sharply decreasing of precipitation in Jimai-Tangnaihai zone and increasing of evaporation and soil percolation in upstream of Jimai station are the couple reasons of surface decreasing in recent 10 year in source region. The underlaying surface condition and environment are gradually deteriorated by the strong human activities, which effect on runoff can not be neglected.

(3) the source region was located in higher altitude with very cold climate. There are sparse hydrological stations fro the stern natural environment, which can not meet the need to carry out the mechanism research on water resource changing. More attention must be paid to hydrological and meteorological station constructions in the source region.

(4) Both climate warming and ecological environment degeneration have strongly changed the water-yield and confluence conditions. It should be further research on the changing of water-yield and confluence character because of climate change and human activities.

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