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Climate Change and Its Impact on Water Resources in North China

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ABSTRACT

In the context of climate, water resources and areas of farmland suffered from drought and flood data, features and changes of climate and water resources as well as correlation between them are analyzed for the past 50 years in North China. Assessment models of water resources are developed. Impacts of extreme climate events on water resources and impacts of drought and flood on agriculture are further studied. In the end, possible impacts of climate change in coming years are discussed on the basis of climate model simulation. Countermeasures and suggestions are put forward for realizing water resources sustainable utilization.

Key words: Climate change, Impact, Water resources, North China

1. Introduction

With the social economic development, population increase and living standard improvement as well as natural eco–environment deterioration, people gradually realize water would become one of the most important factors which hamper social sustainable development in future. It is reported that about 3 billions of people would face the condition of water shortage by the middle of the 21st century. More than 40 countries and regions would be affected. Huge investments would be used to solve the problem of water supply.

Water resources are becoming more sensitive to changes of their impacting factors along with the water environmental deterioration and usable water resources decrease. Any adverse trend of each impacting factor would lead to serious water resources lack and make a deep impact on society. Climate changes in precipitation and temperature have a great impact on water resources. Particularly during the last 20 years, global warming is obvious. In 1998, annual mean temperature climbed up to the climax of the latest one hundred years. According to simulations of many climate models, temperature would still increase gradually in the 21st century. With climate change in mind, it is worthy to study the climate change and its impact on water resources for sustainable utility on regional scale.

North China lies in semi–arid and semi–humid zone with great sensitivity to climate change, where water resources have limited economic development seriously. The volume of gross water resources is severely deficient for population and farmland. In recent years, existing water resources have not met people's need. Meanwhile, a serial of mal–sequences have been produced in water using and exploring process. For example, level of ground water is descending, areas of many ground water funnels are expanding, water sources are polluted, surfaces of some lakes are shrinking, etc. All of these problems make the contradiction between water demand and water supply more intense than before. In 1997 and 1999, serious droughts occurred, which have leaded to huge losses of industrial and agricultural production and have touched the region of people living. The vulnerability of water resources to climate change is exposed thoroughly.

2. Climate change in recent 50 years in North China

Considering geographic and climatic conditions, as well as the provincial characteristics of water resources data and most impacting data, we choose the study area including Beijing and Tianjin, the two municipalities, Hebei, Shanxi, Shandong and Henan Provinces. The total area is about 0.69×10^6 square kilometers. This area is not only a politic, economic and cultural center but also a staple food and economic crop produced area in China.

Using monthly precipitation, temperature, and relative humidity of 43 stations (Fig. 1) data from 1951 to 1999 in North China, we analyzed distributions and changes of precipitation, potential evaporative power and water balance.

2.1 *Precipitation*

Precipitation is a direct source to surface, ground and soil water resources. The normal annual precipitation is about 624 mm averaged from 1951 to 1999 in North China. The spatial and temporal distributions of precipitation are quite uneven.

2.1.1 *Distributions of annual and seasonal precipitation*

Annual precipitation (Fig.2) decreases from 1000 mm in south to less than 400 mm in northwest. In spring, autumn and winter, the zonal distribution of each seasonal precipitation is obvious. In summer, the distribution is similar to annual. (Figures not shown).

Precipitation mainly concentrates in summer, accounting for 61% of annual precipitation. The maximal reaches 74% in these stations. In summer, the precipitation is often in form of heavy rain and usually leads to flood. In autumn, spring and winter, precipitation account for 19%, 16% and 4% of annual precipitations, respectively.

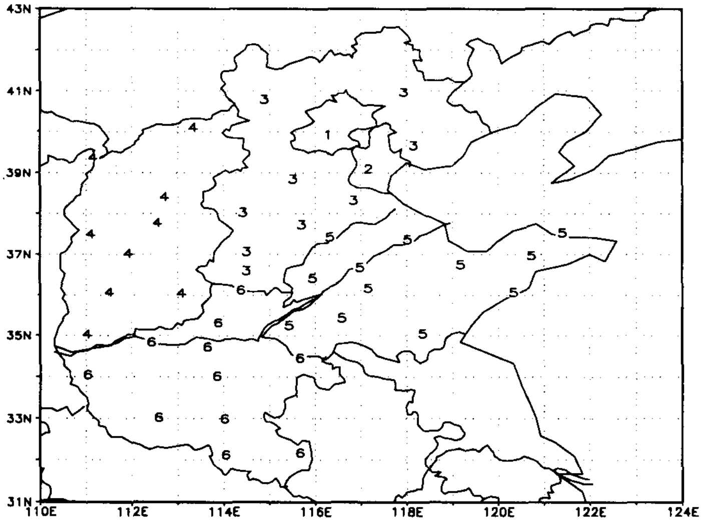

Fig. 1. Distribution of 43 stations in North China. 1. Beijing; 2. Tianjin; 3. Hebei; 4. Shanxi; 5. Shandong; 6. Henan.

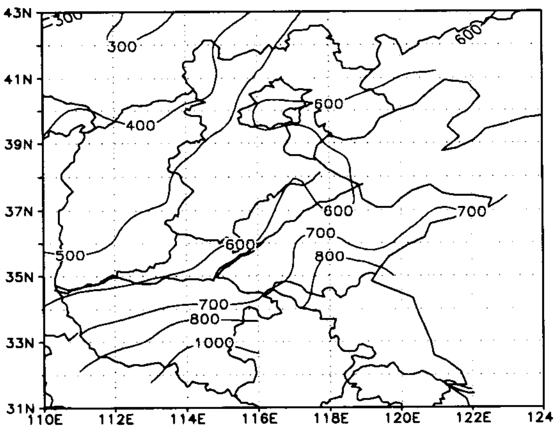

Fig. 2. Distribution of normal annual precipitation (mm) in North China averaged from 1951 to 1999.

2.1.2 *Stability of precipitation*

The normal relative variability of annual precipitation (namely precipitation anomalous percentage) in North China is about 0.22 (refer to Fig. 3). The values of most part range from 0.15 to 0.25 or so. Especially in Hebei Province, the values are high between 0.25 and 0.35. Such an unstable feature of precipitation in North China enhances the difficulty of water utility and exploitation greatly.

2.1.3 *Changes in recent 50 years*

Ten years mean anomalous values of annual precipitation have reduced since the 1950s. In the 1990s, it decreased to the bottom, which is 70 mm (approximately 48.3 billions cubic meters) less than that in the 1960s (Table 1). In summer, ten years mean anomalous value in the 1990s is also the minimum. The reasons leading to less precipitation in the 1990s is entirely different from that in the 1980s (Fig. 4b). In the 1980s, rainfall is often less than normal in

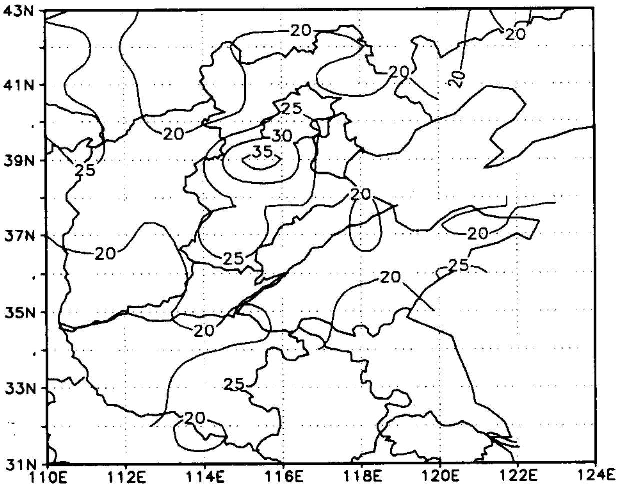

Fig. 3. As in Fig. 2 but for relative variability of annual precipitation (Unit: %).

successive years, for example the period 1985–1989. However, in the 1990s, it is because extreme less precipitation occurred frequently, like in 1997 and in 1999. Precipitation in 1997 and in 1999 are the first and the second lest in recent 50 years, respectively. In spring, precipitation in the 1970s is the smallest. Even though there are a few increases in the 1980s and in the 1990s, the frequency of less than normal rainfall is still high, that had done harm to winter wheat growth during its extensive water–consuming period (Fig. 4a) and had increased the agricultural irrigating volume. In both autumn and winter, precipitations decrease either. Especially in autumn, the precipitation has been less since the late 1980s (Figs. 4c and 4d).

Table 1. Changes in ten years mean anomalous values of annual and seasonal precipitation (mm) in North China from 1951 to 1999. The normal is on the basis from 1951 to 1999

	1950s	1960s	1970s	1980s	1990s
Annual	39.7	25.7	3.3	−28.3	−44.8
Spring	−3.7	9.3	−8.0	−2.2	5.0
Summer	44.1	−0.3	6.7	−23.5	−30.1
Autumn	−6.4	20.2	1.7	−2.2	−14.8
Winter	5.9	−3.5	2.9	−0.6	−4.5

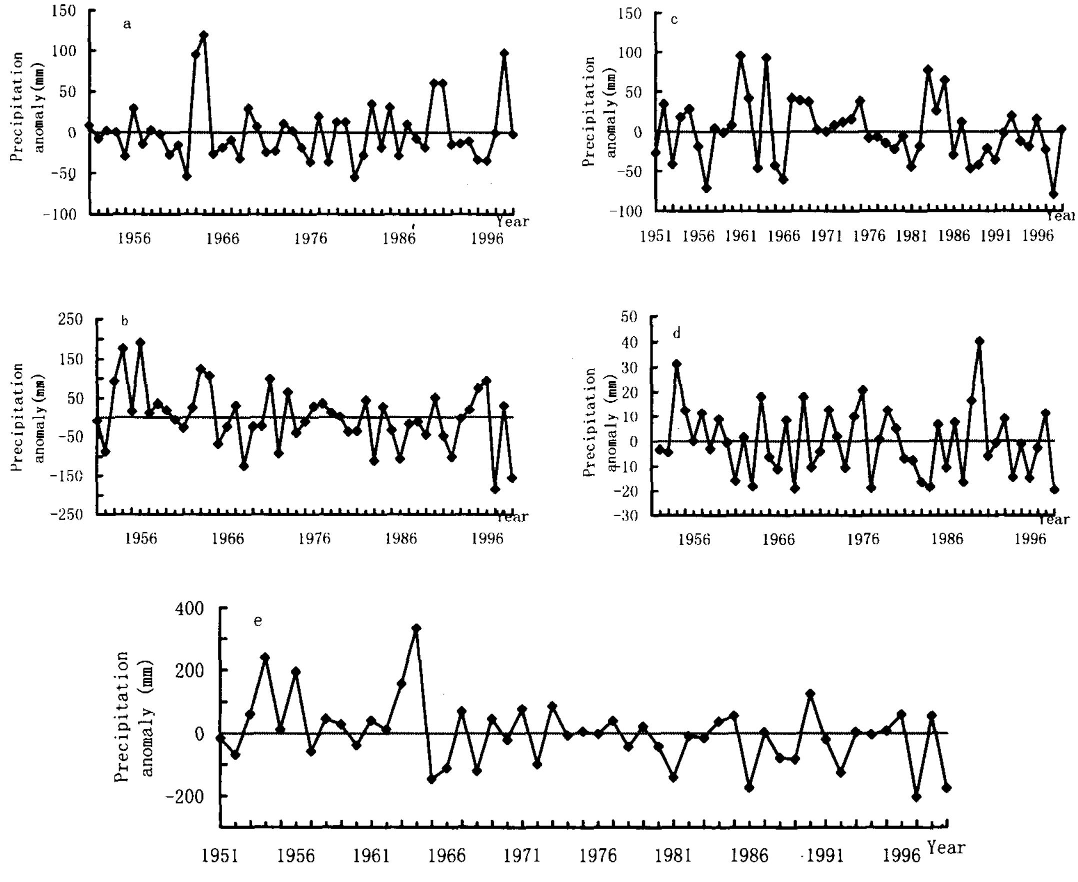

Fig. 4. Curves of seasonal and annual precipitation anomaly (mm) from 1951 to 1999. (a) spring, (b) summer, (c) autumn, (d) winter; (e) annual.

2.2 *Potential evaporative power and temperature*

As a segment in the water cycle, evaporation is equally important, as compared to rainfall. We adopt empirical formula of monthly evaporative power (Cheng, and Cheng, 1980) to estimate the annual and seasonal evaporative power in North China. The method had been compared with other formulas, proved to be applicable, and of a small error for evaporative power calculation in North China. The expression is given by

$$E_0 = 0.19(20+t)^2(1-f), \qquad (1)$$

where t denotes monthly mean temperature (°C), f stands for monthly mean relative humid (%), E_0 is monthly evaporative power (mm).

2.2.1 *Distributions of annual and seasonal evaporative power*

The normal annual evaporative power in North China is 879 mm. In summer, seasonal evaporative power reaches maximum, at 37% of annual value. There is a secondly maximum in spring, and E_0 is further decreased in autumn and in winter.

The values of annual evaporative power range generally from 700 to 1000 mm (Fig.5). In spring (MAM), the seasonal evaporative power in north is higher than that in south. In summer (JJA), the 300 mm isoline moves toward south compared to spring. In autumn (SON), the values decrease but are less than those in spring. In winter (DJF), the values are all down to their bottom of a year. In most areas, they are less than 100 mm (seasonal figures not shown).

The normal relative variability of annual evaporative power, only 9%, is small compared to precipitation.

2.2.2 *Changes in recent 50 years*

Impact of temperature on water resources is achieved through evaporation indirectly. From Table 2, annual, autumn and winter evaporative powers have been increasing clearly in recent 30 years. Especially in the 1990s, not only the annual but also each seasonal evaporative power is far more than normal value, the increments of them in the 1990s are also far greater than those in previous decades. Meanwhile, not only annual but also seasonal

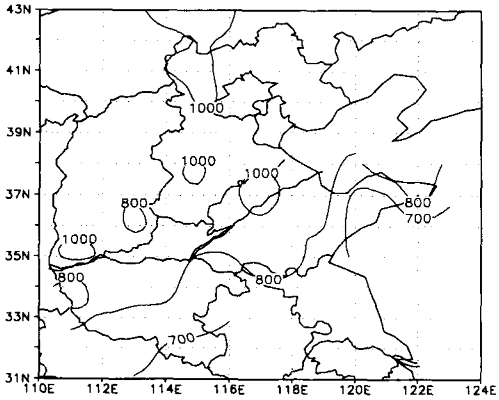

Fig. 5. As in Fig. 2 but for annual evaporative power.

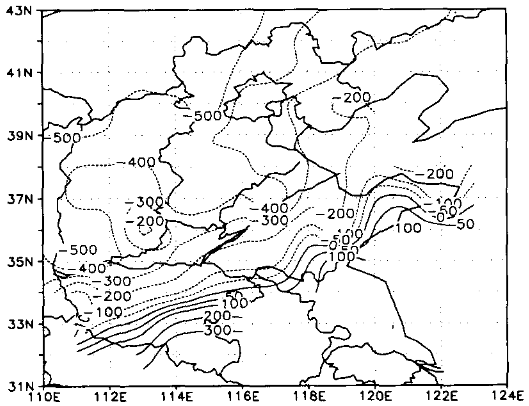

Fig. 6. As in Fig. 2 but for annual water balance.

mean temperature anomaly has been increasing since the 1960s too (except in summer). Particularly in the 1990s, both the annual and each seasonal mean temperature anomalies turn to be positive and far higher than their normal. For example, in winter, about 1.2°C higher than normal.

Table 2. Changes of ten years mean anomalous values of annual and seasonal evaporative power (E: mm) and mean temperature (T: °C). The normal is on the basis from 1951 to 1999

		1950s	1960s	1970s	1980s	1990s
Annual	E	−11.9	−11.2	−22.0	−20.1	72.3
	T	−0.15	−0.18	−0.11	−0.03	0.52
Spring	E	−3.0	−7.7	1.8	−0.3	10.3
	T	−0.34	−0.14	−0.04	0.20	0.35
Summer	E	−0.8	12.8	−11.8	−13.1	14.36
	T	0.01	0.22	−0.18	−0.23	0.21
Autumn	E	5.5	−12.8	−6.5	−4.8	20.8
	T	0.09	−0.21	−0.09	−0.04	0.28
Winter	E	−7.3	−1.3	−4.1	−1.3	14.8
	T	−0.22	−0.66	−0.09	−0.12	1.2

2.3 *Water balance*

Water balance is calculated by subtracting evaporative power from precipitation. Its positive (negative) value denotes the water surplus (deficiency).

2.3.1 *Distributions of annual and seasonal water balance*

Annual water balance is surplus in the south of Henan and Shandong Provinces (Fig.6). Most of the rest areas show deficiency in the water balance. North of the Yellow River have values between −300 mm and −500 mm. In spring (figures not shown), values in most part are negative. In summer, water deficit only occurs in northwest area. In the other areas, the values are positive. It is because this time is humid season, precipitation is more than evaporative power. In fall, the distribution is similar to spring's but the deficit is less than that in spring. In winter the deficit diminishes obviously, only about −50 to 0 mm in most part.

As for the whole area, water deficit in spring is the most among four seasons. Adding to strong wind and fast warming at the same time, soil loses water quickly. Drought is rather serious and frequent.

2.3.2 *Changes in recent 50 years*

Except summer, the normal of annual and the rest seasonal water balance is negative in North China. Annual water deficits become more and more since the 1950s (Table 3). Particularly in the 1990s, annual and each seasonal deficits increase obviously. The surplus in summer also decreases obviously. In spring, though slightly increase in precipitation occurs in the 1990s compared to the 1980s, the deficit is more than that in the 1980s. It may be offset by increase of evaporation due to temperature rising.

Table 3. Changes of ten years mean anomalous values of annual and seasonal water balance (mm). The normal is on the basis from 1951 to 1999

	1950s	1960s	1970s	1980s	1990s	Normal
Annual	51.5	36.9	25.2	−8.21	−117.6	−255.0
Spring	−0.7	17.0	−9.7	−1.9	−5.2	−169.7
Summer	44.9	−13.0	18.4	−10.3	−44.4	55.1
Autumn	−11.9	33.0	8.2	2.7	−35.6	−81.1
Winter	13.1	−2.2	7.0	0.7	−19.2	−30.6

In summary, climate in North China have a clear trend of warm and dry in recent 50 years. Water deficiency is enhancing, and water resources become more precious.

3. Water resources characteristics and model assessment

Taking Beijing, Tianjin, Hebei and Shanxi Provinces as examples, we analyze the characteristics of water resources and its relationship with the climate condition by use of some data in North China. The data include annual surface water volume (about 35 years) and gross water resources volume (33 years) data as well as annual precipitation and annual mean temperature data averaged in each province in recent 50 years. In the end, we set up water resources assessing models.

3.1 *Water resources change in recent 50 years*

For Hebei Province, we show that surface water resources (or gross water resources) and annual precipitation nearly have the same variations and unanimous decreasing trends (Fig.7), This feature is true for the other provinces and municipalities.

Following Table 4, we demonstrate that the relative variabilities of surface water volume or of gross water volume are greater than those of annual precipitation. This means that water resources has larger instability compared to precipitation and the water resources are very sensitive to precipitation change. That is, the water resources volume will have much larger changes with a little anomalous in precipitation and further amplify the negative influence of adverse climate condition.

Table 4. Comparisons of relative variability of water resources with annual precipitation

Name	Precipitation	Surface water resources	Gross water resources
Beijing	0.274	0.451	0.392
Tianjin	0.224	0.482	0.424
Hebei	0.192	0.403	0.367
Shanxi	0.216	0.591	0.781

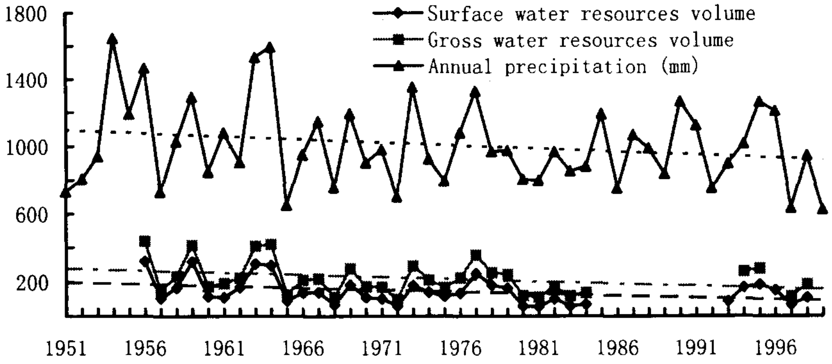

Fig. 7. Curves and trends (dashed line) of annual precipitation (mm), surface water volume and gross water volume (10^8 cubic meters) in Hebei Province from 1951 to 1999.

3.2 *Foundation of water resources assessment models*

From above analyses, we have seen precipitation is a major factor to water resources in North China. There are clear positive correlations between them. Table 5 shows these correlation coefficients for each province. All correlation values exceed 0.8 and pass the F significance test at 0.01 confidence level.

Table 5. Linear correlation coefficients between climate factors and water resources

	R and P	W and P	R and t	W and t
Beijing	0.884	0.919	−0.326 *	−0.273 *
Tianjin	0.805	0.837	−0.091 *	−0.156 *
Hebei	0.874	0.928	−0.316 *	−0.294 *
Shanxi	0.805	0.837	−0.425 * *	−0.444 * *

* The coefficient does not pass the F significance test at 0.05 confidence level

* * The coefficient passes the F significance test at 0.05 confidence level

The others are the same as signal (* *) but for 0.01 confidence level

R is surface water resource, P is precipitation, W is gross water resource, t is temperature.

Anti–correlation between water resources and temperature is not clear. Except that correlation coefficient of Shanxi Province passes the F significance test at 0.05 confidence level, the others are failed the test. However, temperature change may influence evaporation in water balance, especially, when global warming. Even if no change takes place in precipitation, higher temperature than normal can still cause water resources to decrease as a result of evaporation increase. Therefore, it is very necessary to consider temperature when we build a water resource assessment model and the fitting accuracy of assessment model will be improved in theory.

By statistic analysis, the multiple linear regression assessment model is expressed as follows

$$Y = a_1 + a_2 P + a_3 t + a_4 (P/t), \tag{2}$$

where Y denotes the surface water resource (or gross water resource), a_1, a_2, a_3, a_4 are the fitting parameters (see Table 6), P and t are the same as in Table 5.

Table 6. The fitting parameters and effect of water resources assessment models

	R and P, t					
	a_1	a_2	a_3	a_4	r	s
Beijing	−59.133	−0.095	4.139	1.728	0.930	5.148
Tianjin	−39.545	−0.020	2.586	0.630	0.807	3.544
Hebei	−352.802	−0.124	20.008	7.102	0.881	35.146
Shanxi	−270.346	−0.551	24.236	8.091	0.851	17.918
	W and P, t					
	a_1	a_2	a_3	a_4	r	s
Beijing	−73.382	−0.106	5.752	2.048	0.949	5.589
Tianji	−28.974	−0.011	1.817	0.591	0.839	3.869
Hebei	−460.138	−0.023	27.643	7.960	0.932	34.608
Shanxi	−311.749	−0.673	30.647	9.438	0.887	16.343

r denotes the correlation coefficient

s denotes the residual mean square deviation

The other signals are the same as in Table 5.

The fitting result is shown in Fig. 8 (taking Beiing as an example). By the model, we calculated the values in 1999. The predicted value is very close to the observed one.

4. Impacts of climate change on water resources

4.1 *Impacts of anomaly climate events on water resources*

Many evidences have shown that climatic factors play important roles in water resources′ variations, which further exert a profound impact on society. Interannual change in precipitation can also affect surface water volume, ground water, gross water resources volume, and water storage of reservoir, etc.. Higher temperature will lead to more evaporation, and in summer it will also enhance the consumption of water in city and agricultural irrigation in country.

Beijing is one of the cities in which water shortage is most severe. The per capita of water is less than 300 cubic meters. Though there are 613 mm area–averaged normal annual precipitation in Beijing, which are far more than that in Tianjin (554 mm), Shanxi (482 mm) and Hebei (540 mm), relative variability of precipitation in Beijing is the largest among these places. Beijing had experienced three severe water crises since 1949. Each time is caused by climate factors. During the periods of 1965–1968, 1971–1975, and 1980–1984, annual precipitations are successively less than normal (Fig.9), which cause very serious influences on society. The Beijing′s water shortage crises in different decades were solved by taking different mitigation measures, including digging the Jing Mi Aqueduct in the 1960s, exploiting excessively ground water in the 1970s, and restricting other user of Miyun Reservoir in the 1980s.

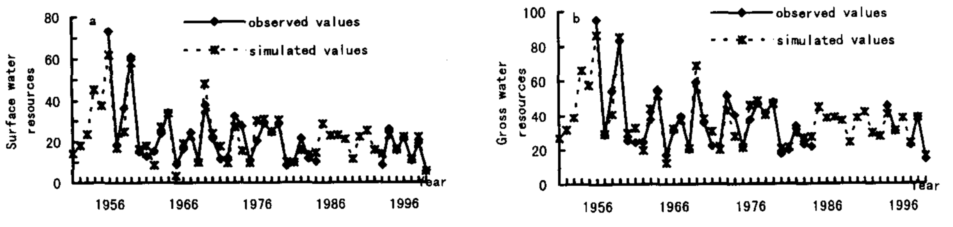

Fig. 8. Curves of observed (solid line) and simulated (dashed line) annual surface water volume (a) and gross water volume (b) in Beijing from 1951 to 1999. (Units: 10^8 cubic meters)

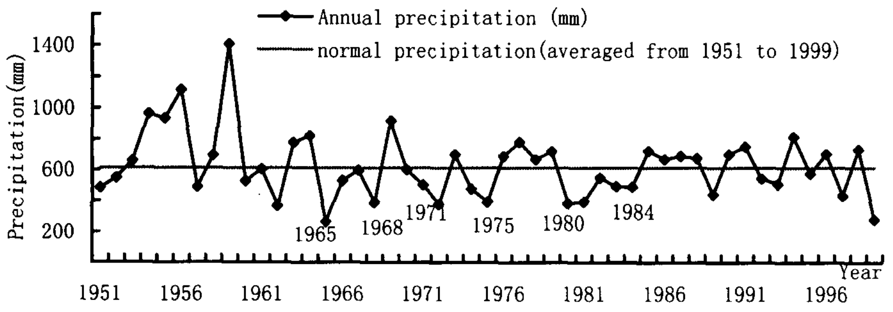

Fig. 9. Curve of annual precipitation in Beijing from 1951 to 1999.

Under the warming and drying climatic background in North China, anomaly climate events, which are not benefit to water exploitation and utility, are occurring much more frequently than before, especially in the 1990s. For example, the annual precipitation of the whole area in 1997 is the minimum in recent 50 years, which corresponds to the highest mean temperature in the summer. Only after one year, annual precipitation / annual mean temperature reaches the secondary minimum / maximum in 1999.

It is worth noting that during 1997, most areas in North China have had anomalous and continuous drought and hot weather in summer, which may be related to the strongest El Niño events in recent 100 years. In most provinces and municipalities, annual precipitation is about 25 percent less than normal, with 40 percent in Shanxi Province. During summer, the precipitation deficiency is even larger. In Hebei, Tianjin, Shanxi and Henan, precipitations are 50 percent less than normal. Mean temperature in summer is also the highest in the past 50 years.

Under the double adverse climate conditions, water resources appeared very deficient (Table 7, also refer to China Water Resources Bulletin 1997). Surface water resources of all provinces and municipalities are 50 percent less than normal, Tianjin's is up to 73.5 percent less. Ground water resources and gross water resources are all less compared with 1996. The ground water resources are 30–56 percent less. Ground water level at plain area generally descended. The annual ground water storage diminished. The gross water resources are 40 – 77 percent less. In 1997, water storage of many large and middle size reservoirs in Henan and Hebei reduced by 2.95 and 2.46 billion cubic meters relative to 1996. Drying condition in the middle and lower reaches of the Yellow River was the most severe in recent several years. The beginning time, duration and river length of drying up all renewed the history records in 1997. It strained water utility in irrigation area. Meanwhile, it also devastated the eco–environment. It was evaluated that the losses caused by water shortage is up to 200 billion Yuan (about 24 billion American dollars) only in cities at plain in North China, which was equivalent to 3 percent of gross domestic product.

Table 7. Comparison of water resources in 1997 with normal or 1996(* represents comparison with 1996)

	Annual precipitation	Precipitation in summer	Surface water resources	Ground water resources	Gross water resources
Beijing	−25.3	−39.6	−51.3	~−45−30 *	~−50 *
Tianjin	−32.4	−56.6	−73.5	−56.3 *	−77.4 *
Hebei	−37.1	−55.6	−56.3	~−45−30 *	−62.6 *
Shanxi	−41.4	−51.9	−48.6	~−45−30 *	~−50 *
Shandong	−24.1	−38.4	−51.6	~−45−30 *	~−40 *
Henan	−34.3	−51.4	−55.8	~−45−30 *	−55.9 *

In 1999, climate condition similar to 1997 appeared. The situation and range of drought are more than those in 1997. The degree of water shortage in Beijing overran 1997. For example, water storage of Miyun Reservoir decreased by 0.65 billion cubic meters, which was minimal storage since it was built. Both Guanting and Miyun Reservoirs' water outputting was greater than their importing since they were built. Level of ground water descended to a large extent. By the end of 1999, the mean depth of ground water was 14.49 meters in the plain area of Beijing, descending by 2.3 meters relative to the same period in 1998. This was a year that level of ground water descended to the lowest in the 1990s.The fourth water crisis occurred in Beijing. Drought was also serious in other provinces and cities.

4.2 *The relationships between climate change and agricultural areas damaged by drought and flood*

Areas damaged by flood and drought in North China account for large potion of entire country, which amount to 26.4 percent and 37.0 percent, respectively. Almost every year, both drought and flood damages take place one or another in North China. Areas covered and affected by drought are much more than by flood. The average area covered by drought is about 0.12 billion mu, severe affected area 0.05 billion mu. The average area covered by flood is less than one–third of the area by drought, about 0.038 billion mu, severe affected areas 0.024 billion mu.

Figure 10 shows anomalous percentage of covered and affected areas by drought (Fig. 10a) or flood (Fig. 10b) in recent 50 years in North China. Because of abundant precipitation in the 1950s and in the 1960s (refer to Fig.4e), the flood damages in these periods are heavier than normal. After the 1970s, flood damage is obviously lighter. Only in 1996 heavy flood damage occurred. From 1959 to 1961, droughts are quite heavy. In the early and mid 1970s, we can find an interesting thing that area covered by drought is successively more than normal, but the affected area is less than normal. This may be due to human mitigating measures by exploiting and utilizing excessively the ground water. In the early 1980s, precipitation is still less, but area covered and affected by drought is smaller. This is mainly offset by usage of ground water and other water sources. However, in the late 1980s, namely from 1986 to 1989, precipitation is successively less than normal. Ground water resources are not enough for irrigation demanding. The areas covered and affected by drought are greater than in the 1970s and early 1980s. During the 1990s, drought condition becomes even worse. In 1997 and 1999, areas covered and affected by drought are far above the normal value.

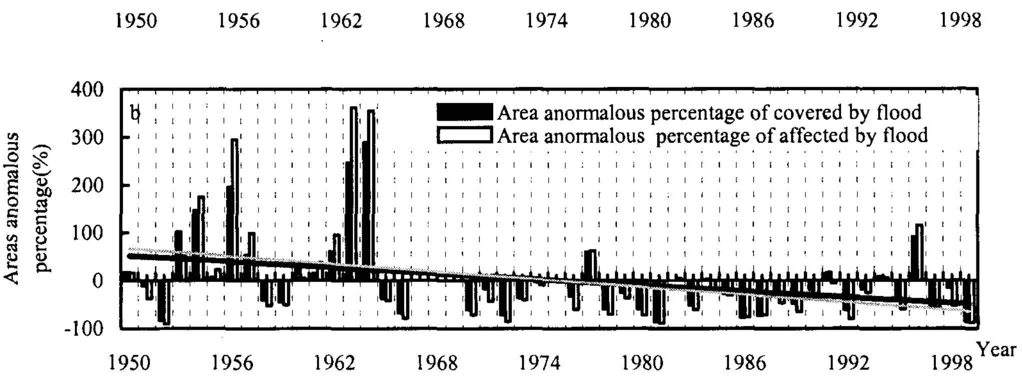

Fig. 10. Areas anomalous percentage of covered and affected by drought (a) and flood (b) from 1950 to 1999 (lacking data from 1967 to 1969) in North China respectively.

5. Possible impact of climate change on water resources in the coming years and countermeasures

We analyzed the possible climate change outlook in coming 100 years in North China by use of instantaneous simulating results of five global ocean and atmospheric coupled climate models, which were obtained from IPCC Data Distribution Center (DDC). Models include ECHAM4 (Germany), HadCM2(England), GFDL–R15(America), CGCM1(Canada) and CSIRO–Mk2b (Australia). Models consider greenhouse gas and aerosols as kinds of radiative forcing and IS92a and IS92d as two kinds emissions scenarios. Here, we show averages of area mean temperature and precipitation anomalies of 5 models in every 30–year segment (2010–2039, 2040–2069, 2070–2099) for IS92a emission (increase by 1% per annum) scenarios in North China (Table 8).

Only greenhouse gas considered in models, climate will be warming and wetting in the 21st century in North China. Temperature will increase in each 30–year period. By the end of the 21st century, temperature will increase by 5.7°C and the increasing rate will reach maximum. Precipitation will increase and level off in the middle of 21st century, amount to 38 mm more than present value.

Under the scenario considering both forcing of greenhouse gas and aerosols, the results are slightly different. Compared to previous scenario, temperature trend is still positive, but the magnitudes will be less. Precipitation will have a less increase in the early 21st century. In the mid 21st century, it is going to decrease. By the end of 21st century, it will be 15 mm less than the present value. In summary, climate will become warm and dry.

Table 8. Possible climate changes outlook of every 30 years in future in North China (relative to 1961–1990)

	Temperature anomaly (°C)		Precipitation anomaly (mm)	
	Affected by greenhouse gas	Affected by greenhouse gas and aerosol	Affected by greenhouse gas	Affected by greenhouse gas and aerosol
From 2010 to 2039	2.0	1.5	20.8	3.7
From 2040 to 2069	3.6	2.6	38.7	–3.3
From 2070 to 2099	5.7	4.3	31.4	–15.0

As it is well known, the warming and drying trends are very disadvantage to the future of water resources utility. Even if climate become more warming and wetting, higher increases in temperature may also lead to more evaporation. The increases in precipitation may not be enough to compensate the water resources loss due to evaporation. Many studies have shown that anomaly or extreme climate events will occur more frequently and extensively in future even if averages of precipitation and temperature have slight change (see IPCC 1995, Shi, et al., 1995). This situation may not be avoidable in North China. To some degree, it would enhance the vulnerability of water resources due to climate change.

In the past 50 years, we have realized that on one hand usable water become less and less, on the other hand consumption of water leaps upward year by year. For example in Beijing, the population has increased by a factor of 4 compared to 1949, total consumption of water has increased by a factor of 41; industrial consumption has increased by a factor of 32; farmland area requiring to be irrigated has increased by a factor of 24; sale of city water supply has increased by a factor of 86. In the coming years, the demanding of water will be far exceeding the present level with fast speed and high strength of social development. In order to achieve sustainable utility of water, we put forward the following advice on the basis of water characteristic, exploiting and utilizing status and present problems, and possible future climate influences in North China.

5.1 *Strengthen scientific management, reasonable exploit and usage*

It is necessary to carry out uniform management of water resources. A perfect managing network of supplying and transferring should be formed. The minimal waste of water system and the optimal disposition for whole benefit should be considered according to climatic conditions and projected usage of water supply. Many practices have demonstrated the scientific management and control on whole scale may reduce the lacking degree of water resource resulting from adverse climate. In 1999, serious drought could have leaded to river dry up condition as it had occurred in the middle and lower reaches of the Yellow River in 1997. However, the river dry up condition turned better in 1999 because the related department was responsible for water management took several effective measures, such as, dispatching water from the whole Valley; distributing and transferring water designatedly, etc. Meanwhile they also adapted the real weather condition and forecast result. It has been calculated that the river dry up days of Lijin hydrological station, located in Shandong Province at the lower reaches of the Yellow River, are only 42 days. The number is obviously less than those in 1997 (226 days) and 1998 (142 days).

5.2 *Looking for new water sources*

We may obtain more precipitation by the new technique–artificial precipitation (Huang, 1999) further utilizing the potential of water resource in sky. On the basis of climate features, i.e., more and hard summer rainstorm produced high intensity run–flow in short duration, we can make use of rain–torrent and open water sources up on the spot. In addition, we may make use of sea– water instead of fresh water as cooling water for industry and develop sea water desalted technique.

5.3 *Well realize the importance and necessary of water–saving*

Developing new water sources and the water–saving measures should be put on an equal position. Strict water–saving system should be set up. High effective water–saving technique should be developed and adapted. The water–saving potential of various industries should be effectively realized. The waste phenomena should be avoided.

5.4 *Strengthen the eco–environmental construction, protect water resources and control water pollution, promote water environment*

Various measures should be taken to improve the eco–enviroment, such as planting trees, forestation, and reducing blind reclamation and grazing, protecting water source, preventing water and soil erosion and desertification. Combination of recycling polluted water with management and control of polluting sources is another effective measure.

5.5 *Strengthen on irrigation project construction*

Function of irrigation project and water storing capacity should be enhanced. Water distribution spanning among the valleys should be carried out.

6. Conclusions

From above analyses, we have concluded as follows:

(1) Precipitation features in North China include less in gross amount, spatially and temporally inhomogeneous distributions and greater relative variability as well. Evaporative power is more concentrated in summer than in other seasons. The variability of evaporative power is smaller than that of annual precipitation. Considering water balance, evaporative power is greater than precipitation, and the water deficiency is very serious and often lead to severe droughts in spring in North China.

(2) In recent 50 years, the climate is warming and drying, which lead to severe water deficiency at present.

(3) Water resources have closer relations with precipitation than with temperature. However, water resources have more instability than precipitation and are quite sensitive to climate change. A small change in climate can lead to a large change in water resource. In terms of water balance, we have developed water resources assessment models in Beijng, Tianjin, Hebei, and Shanxi.

(4) Successive drought and extreme climate events have brought a huge influence on society in North China. The areas affected and covered by drought and flood clearly point to climate change impact on water resources and further impact on agricultural product.

(5) Warming tendency in future will bring further damaging influence on water resources. Meanwhile, water shortage is also going to increase. Hence, we will face more serious water supply problems in future. As long as taking effective measurements and making long–term projection about water resources from now on, we can achieve sustainable utilization of water in North China.

Resolution and settlement to water shortage in North China is one of the greatest strategies in the 21st century for the entire country. It is an important guarantee for keeping social economic development steadily.

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华北地区气候变化及其对水资源的影响

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摘 要

根据华北地区近 50 年的气候、水资源、旱涝灾害面积等资料，对该地区的气候特点及变化趋势、水资源的变化规律与气候变化的相互关系、极端气候事件对水资源的影响及气候变化对农业旱涝的影响进行了分析，并在气候模式预测结果的基础上，简要分析了华北地区未来气候变化对水资源的可能影响，提出了相应的对策建议，从而为实现水资源可持续利用提供科学依据。

关键词： 气候变化，影响，水资源，华北