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The Climate Change, Water Crisis and Forest Ecosystem Services in Beijing, China

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1. Introduction

Although the Earth's climate changes continually, as a result of natural processes, there is now a strong scientific consensus that global warming is occurring, that it is largely driven by greenhouse gas emissions due to human activity. The linear warming trend over the last 50 years is nearly twice that for the last 100 years, with average global surface temperature rising by 0.74 ^{0}C between 1906 and 2005 (IPCC, 2007). Climate change and its impact on human survival have been today's major challenge and key topics of discussion globally (Oli et al., 2008). The major observed evidence showed that, the trend of climate change in China was consistent with that of global climate change. As a developing country of responsibility, China attaches great importance to the issue of climate change, and has taken a series of policies and measures to mitigate and adapt climate change effects (NDRC, 2007). Beijing, the capital of China, is characterized by a warm temperate continental monsoon climate. In the context of global warming, the observed changes related to climate in Beijing include an increase in annual average temperatures, possible reductions in average rainfall and runoff, and more heat waves and less frost (Wang, 2008). Meanwhile, as a consequence of rapid population growth and economic development, Beijing is facing a water crisis, with rapid deterioration of water quality, serious water shortages, and reduced availability of groundwater. Therefore, it is noticeable that Beijing's actions should focus not on climate changes in isolation but on interactions between climate change and other stresses on the city growth and development. This chapter draws together evidences from a series of researches on climate change, water crisis and forest ecosystem services in Beijing, and provides a reference point for international research institutions, government agencies and other organizations to respond to these issues. The rest of the chapter is organized as follows. Firstly, the evidences for climate changes in Beijing, including temperature, precipitation, heat island effect and extreme weather events, are introduced. Secondly, the water resource situation and water scarcity risk in Beijing are analyzed. Finally, Beijing's forests and their services in the mitigation and adaptation to climate change are explored. I hope this chapter can provide some insights in the importance of urban forest under future climate change, and will help the global audience with similar issues.

2. Climate change in Beijing

2.1 Temperature

Based on the major observed evidence of climate change in China, the annual average air temperature has increased by 0.5-0.8 ^{0}C during the past 100 years, and the warming trend was more significant in western, eastern and northern China in the south of the Yangtze River (NDRC, 2007). Beijing is in the north of China and in the temperate climatic zone with a perennial mean temperature of 12 ^{0}C (Li et al., 2005). Under global warming background, the annual average air temperature in Beijing presented a fluctuating increasing tendency (Xie and Wang, 1994; Wang et al., 2009a). During the past 32 years, the annual average temperature in Beijing has increased by 1.7 ^{0}C, from 11.6 ^{0}C in 1978 to 13.3 ^{0}C in 2009 (see Fig.1). Moreover, the trend of climate warming in China will further intensify in the future. The nationwide annual mean air temperature would increase by 1.3-2.1 ^{0}C in 2020 and 2.3-3.3 ^{0}C in 2050 as compared with that in 2000 (NDRC, 2007).

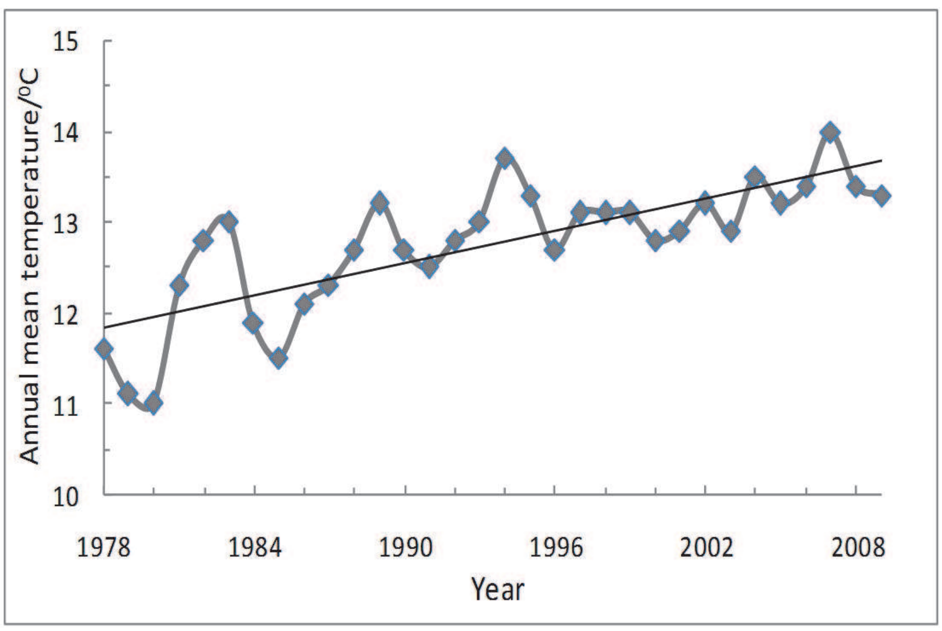

Fig. 1. Annual average temperature in Beijing from 1978 to 2009

2.2 Precipitation

Although there was no obvious trend of change in annual precipitation in China in the past 100 years, the decrease in annual precipitation was significant in most of northern China, eastern part of the northwest, and northeastern China, averaging 2-4 mm/a, with decrease in northern China being most severe (NDRC, 2007). Beijing is located in the northern tip of the North China Plain and in arid region with an annual average precipitation of 640 mm (Li et al., 2005). The annual precipitation in Beijing decreased gradually since 1950s with an average rate of 41.9 mm/10a (Yue, 2007). Figure 2 also shows the decrease tendency in average precipitation in Beijing from 1978 to 2009. In addition, the precipitation on urban stations decreased faster and fluctuated greatly than that in rural ones, and the fluctuation intensity of rainfall increased the risk of flood and drought in Beijing area (Zheng and Liu, 2008).

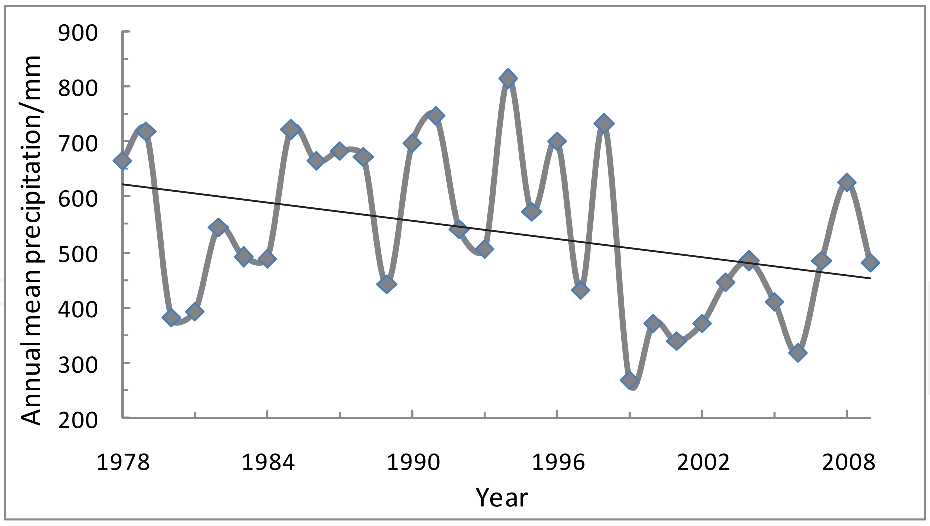

Fig. 2. Annual average precipitation in Beijing from 1978 to 2009

2.3 Heat island effect

The rapid development of urbanization causes the urban heat island to become a more and more serious problem. Urban heat island effect is due to the temperature difference between urban and its' surrounding suburban rural areas (Du et al., 2008). In recent years, the urban heat island in Beijing region has been constantly observed (Zhang et al., 2002; Song et al., 2003; Lin and Yu, 2005; Zhang et al., 2006). Based on the climate observation data collected from 11 weather stations, Wang et al. (2009a) reported that the temperature difference between urban and rural area in Beijing was increasing fluctuately from 1961 to 2008 (see Fig.3).

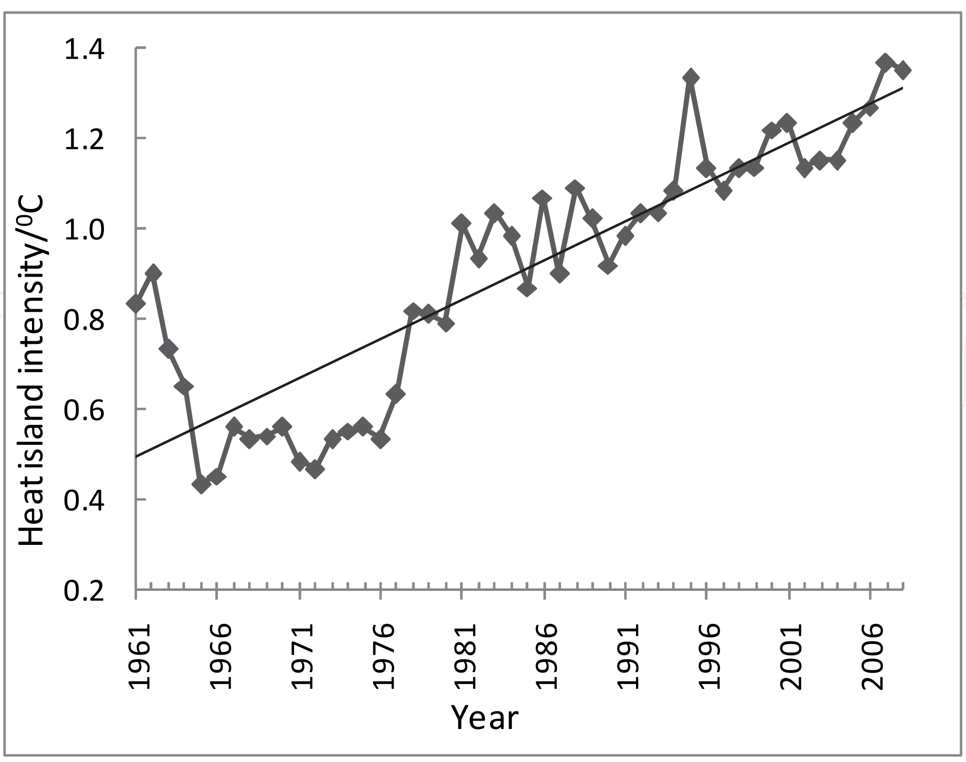

Fig. 3. Temperature difference between urban and rural area in Beijing from 1961 to 2008

Furthermore, there was a closer relationship between land-use and the surface urban heat island of Beijing, and the spatial pattern of urban heat island was turned to be more separate and a lot of cool spots appeared in the center city from 1987 to 2005 (Peng et al., 2007). In addition, urban heat island effect arose in summer and autumn and was the most intensive in summer (0.6-1.5 ^{0}C) (Yan et al., 2008).

2.4 Extreme climate/weather events

Apart from the meteorological debates, there is evidence that economic damage as a result of extreme weather events has dramatically increased over the last decades (Vellinga and van Verseveld, 2000). Many cities in the world are suffering from the increasing frequency and intensity of extreme weather events such as heavy rainstorms, floods, droughts, fires, and hurricanes due to climate change. The daily weather observation data from 1951 to 2003 showed that, the high temperature and frowzy events in Beijing had an increasing trend in the last 30 years, but low temperature, strong wind, thunderstorm and thick fog represented a decreasing trend (Zheng and Zhang, 2007). In addition, the events of high temperature, frowzy weather, low temperature, strong wind and thunderstorm have a remarkable annual change but faint periodicity, the rainstorm and sand storm's variation are periodical, their main period are 10 years and 8-10 years.

3. Water crisis in Beijing

Climate change is expected to produce higher temperatures and direr summers and wetter winters (Charlton and Arnell, 2011). Reductions in water availability are also expected as a consequence of climate change (Arnell, 2004), with implications for a reliable supply of water to customers. China is a country in water shortage and its average water resource capacity per person is only 1/4 of the world. Due to the economic and social development as well as the global warming effect, the problems of water shortage and water pollution have become important factors in hindering the future economic and social development in China. As the capital of China, Beijing has also been suffering from such water issues as water resources scarcity, water quality deterioration and over-extraction of groundwater. Even worse, the critical situation regarding water crisis in Beijing will still exist in the future (Zhang et al., 2010a; Tong, 2010).

3.1 Water resource shortage

Beijing is, an international metropolis, and has a residential population of 17.55 million in 2009 (Beijing Municipal Statistical Bureau, 2010). During the past several decades, the demand for water in Beijing has increased dramatically due to the rapid urban population growth and economic development (Wu and Zhang, 2005). At present, the total amount of water resources in Beijing is 2.18 billion cubic meters (Beijing Municipal Water Conservancy Bureau, 2009), the average water resource per person is only 125 cubic meters, which is far lower than the severe water shortage standard of 1000 m^3/person (Wang et al., 2009b). Figure 4 shows the amount of water resource, surface water and ground water from 1988 to 2008, which all representing a decreasing tendency. The scarcity of water resources has significantly compromised the social economic sustainable development in Beijing (Zhang, 2004).

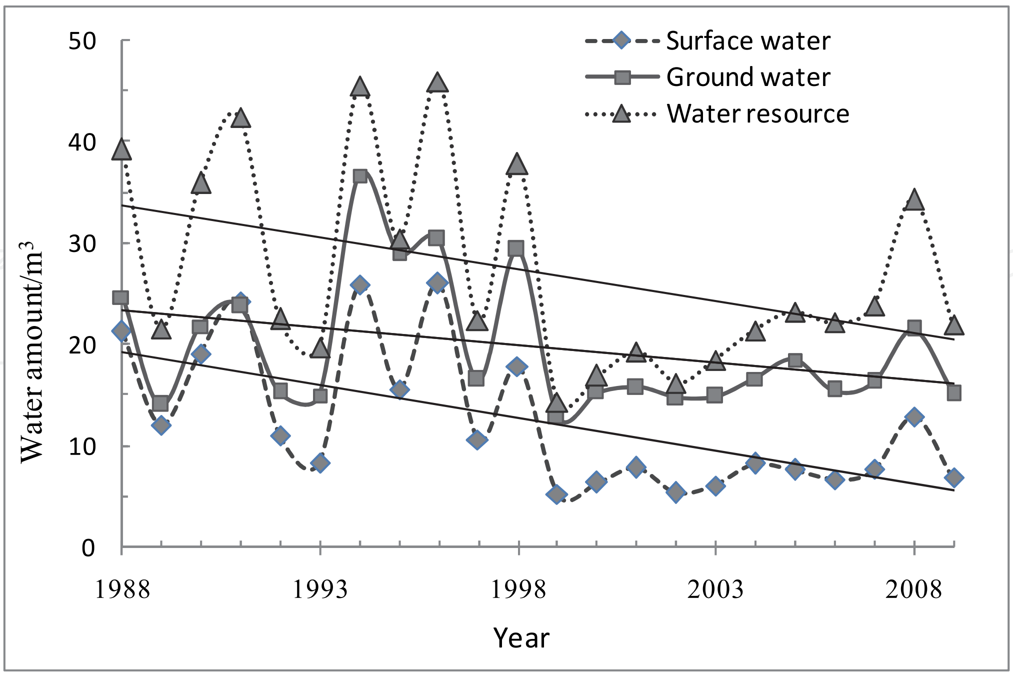

Fig. 4. Water resource amount in Beijing from 1961 to 2008

According to the projections of the water supply plan of Beijing, water use will increase by 3.42% while the population increases by only 1% (Zhang et al., 2007). During the 11th five-year plan period (2005-2010), the residential population in Beijing increased by an annual average of 520 thousand persons. And it is expected that the population will continue to increase to 21-26 million persons by 2020. With system dynamics method, Tong (2010) found that the carrying capacity of Beijing would decline if current water supply and use standard and structure were unchangeable (see Table 1). Consequently, both growing demand and declining supply are contributing to the serious water shortage that Beijing has faced. During the past several years, however, the situation has steadily deteriorated, with little evidence that scarcities will be alleviated in the future.

Year	Scenarios 1		Scenarios 2		Scenarios 3	
	Carrying capacity of water use for life activity	Carrying capacity of total water use	Carrying capacity of water use for life activity	Carrying capacity of total water use	Carrying capacity of water use for life activity	Carrying capacity of total water use
2015	913.21	991.68	719.63	1506.51	1690.98	1506.51
2016	905.77	973.98	589.09	1485.85	1676.72	1485.85
2017	898.44	956.89	453.17	1465.88	1655.69	1465.88
2018	891.24	940.39	311.36	1446.53	1658.29	1446.53
2019	884.14	924.45	163.09	1427.73	1654.96	1427.73
2020	877.16	909.04	296.17	1520.53	1800.64	1520.53

Table 1. Population carrying capacity of Beijing under various scenarios (Tong, 2010)
Unit:10^4 persons

3.2 Over exploration of underground water

Groundwater in urban environments is an important and valuable resource for portable water supply and industrial use (Yang, et al., 1999), but is at risk from over-exploitation and polluting land use (Lerner, 1990). In Beijing, two-thirds of the municipality's total water supply comes from groundwater. The Beijing Water Bureau estimates that its available groundwater ranges from 2 to 2.45 billion cubic meters per year. As recently as 30 years ago, Beijing residents regarded groundwater as an inexhaustible resource (Probe International, 2008). Now hydroeologists warn it too is running out (He, et al., 2005; Yue, 2007; Tian, 2010). The over-exploration of underground water caused serious ecological and environmental problems, such as land subsidence, sea water intrusion, waste water seeping into groundwater, and ecosystem deterioration, of which the declining of water table was the most serious. Figure 5 shows that the groundwater tables decreased greatly from -16.42 m to -24.07 m during the period of 2002-2009, due to the over exploration of underground water in Beijing city.

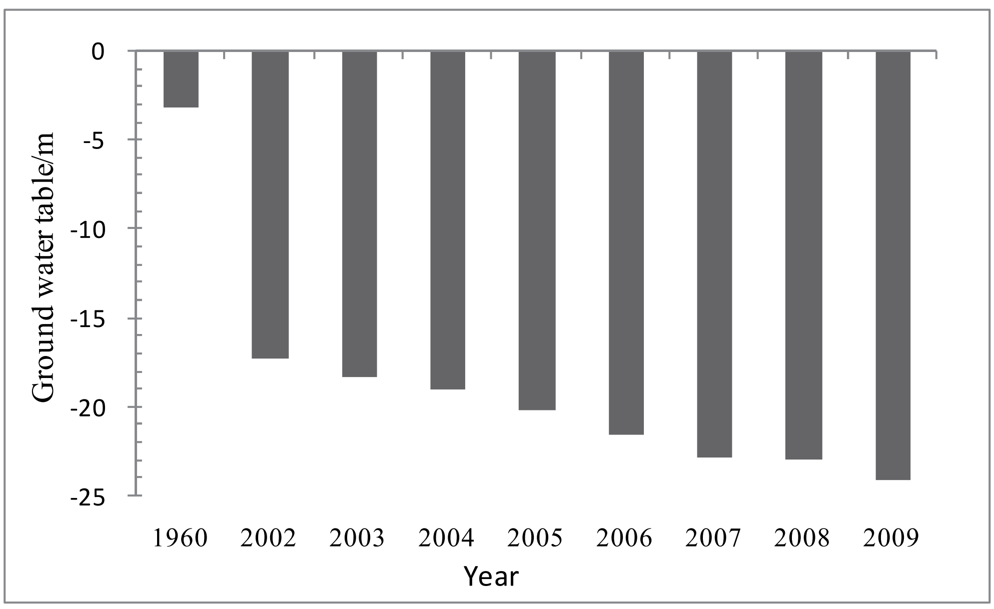

Fig. 5. Ground water level in Beijing from 1961 to 2009

3.3 Water quality deterioration

Although Beijing has made great efforts in recent years to improve water quality, there is serious pollution of surface water. According to the Quality Standards of Surface Water Environment (GB 3838-2002), only 46% of rivers in Beijing could reach the water quality requirement in 2009, the water quality in 1245.1 km of 2545 km of rivers being monitored were in the fourth and fifth grade or worse than fifth, which accounts for 53% of the total length of the rivers being monitored (Beijing Municipal Water Conservancy Bureau, 2009). There was 1.2 billion cubic meters waste water discharged annually in Beijing, about 0.9 million cubic meters of which from urban area, only 12% of which was treated through waste water treatment plants (Beijing Environment Protection Bureau, 1999). Figure 6 indicates that the amount of wastewater has being discharged and treated, and the treatment rate of wastewater in Beijing from 2003 to 2009. Untreated waste water discharged to the seeping wells, rivers and waste water ponds, is getting into ground water through seepage, which causes ground water pollution.

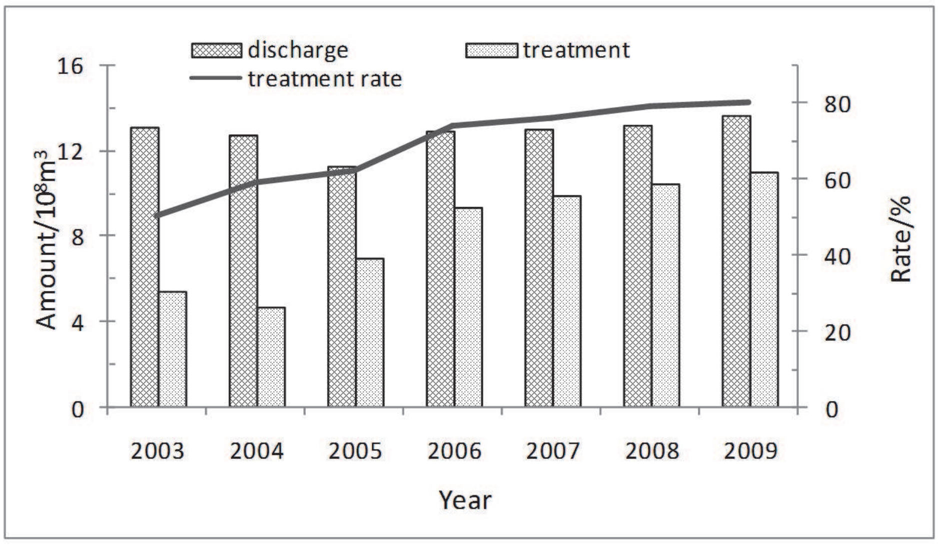

Fig. 6. Amount of waste water and treatment rate in Beijing from 2003 to 2009

3.4 Loss of stormwater runoff

Rapid urban expansion leads to the replacement of native vegetation areas, which provide rainwater interception, storage, and infiltration functions, with impervious surfaces, which often results in an increase in the rate and volume of surface runoff of rainwater (Whitford et al., 2001; Mansell, 2003). Climate change may further increase these fluctuations and the flood risk (Villarreal et al., 2004). Since the Reforms and Opening-up policies were implemented in the 1980s, Beijing has undergone rapid urbanization. The urban area was 183.84 km^2 in 1973, and it increased to 1209.97 km^2 in 2005; the built-up area has increased by 1026.13 km^2 during the past 32 years, having expanded at a rate of 32.07 km^2 per year (Mu et al., 2007). Owing to the fast urbanization, natural ecosystems are being increasingly replaced by an impervious urban surface (Xiao et al., 2007). Impervious surfaces increase the speed and volume of water running off a site, while decreasing the quality of that water and highly modifying the hydrology of urban areas (Shepherd, 2006). A higher proportion of rainfall becomes surface-water runoff which results in increased peak flood. There was a significant rise (0.04–0.08) in the runoff coefficient before and after the 1970s in Beijing (see Fig.7). To reduce the high runoff during rainfall, a great deal of stormwater drainage system

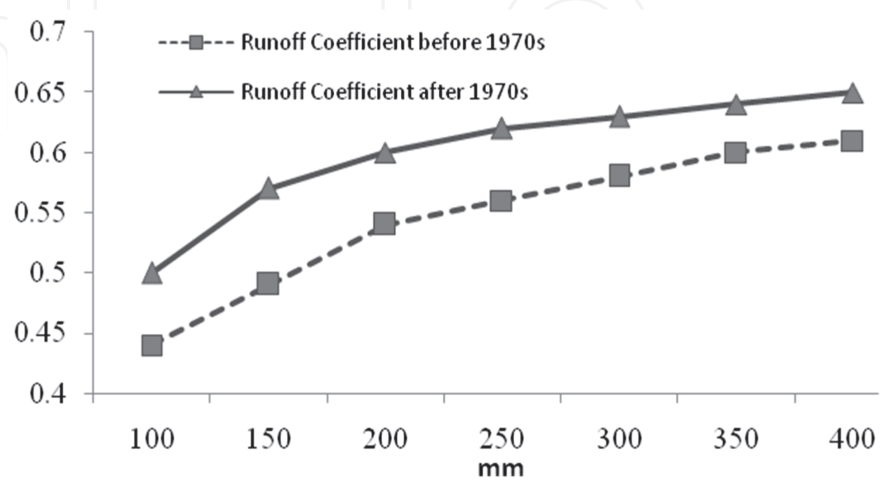

Fig. 7. Stormwater runoff coefficient in Beijing before and after 1970s

were constructed in Beijing. There was a constant increase in the total length of rainwater drainage pipes from 2999 km in 2001 to 4849 km in 2009 (see Fig.8).

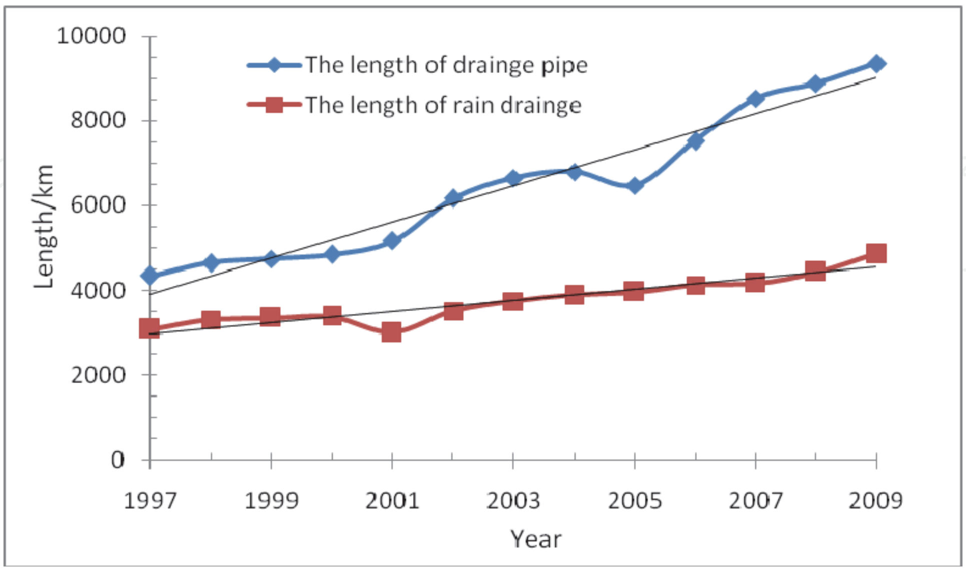

Fig. 8. Length of rain drainage pipes from 2001 to 2009 in Beijing

3.5 Beijing's policies of guaranteeing water supply

Nowadays, more and more people recognize that, water scarcity and conflict over supply has become a serious and common issue because of population growth, food needs and industrialization. Official responses to Beijing's drought and competing water demands attracts a lot of attention, and much effort is given (Probe International, 2008): (1) reallocate surface water from rural to urban consumers, (2) extract ever-deeper groundwater, (3) divert surface water to Beijing city from reservoirs and rivers outside Beijing municipality, (4) restrict water use in upstream Hebei, (5) Cut off river flow to downstream Tianjin, (6) shut down or relocate polluting and water-intensive industries. For example, the central government began arranging "emergency water transfers" from neighboring regions to Beijing city in 2003, of which is the massive South-North diversion project, which approved in 2001.

However, the construction of infrastructural projects to bring more and more water to the metropolitan area is neither sustainable, nor economically feasible, nor is it environmentally and socially desirable (Tortajada and Castelan, 2003). In a changing climate, the functionality provided by urban forest becomes increasing important. Especially the roles of forests in water supply (including quantity, quality, timing of release, flood reductions and low flow augmentation) should be given more attention. Maybe the creation and management of more urban forest is an answer to the recent calls for a more ecological and sustainable water management.

4. Beijing's forest and its roles in mitigating climate change and water crisis

In recent years, the forest area in Beijing has rapidly increased. According to the investigation data of Beijing Forestry Survey and Design Institute, the area of forest land grew by 20.2 % between 2000 and 2005, to a total of 105.4 million ha. The absolute annual expansion rates has increased to an average 20.8 thousand ha per year and relative rate grew somewhat to 4.04% over these five years (Zhang et al., 2010b). Based on the survey data of 2004, Beijing's forest ecosystem has a total area of 917 509 ha of which 14.95% is represented by coniferous forests, 42.59% by broadleaved forests and 7.42% by broadleaved-coniferous mixed forests, making a total forest area of 596 054 ha. The remaining 35.04% correspond to shrub forests. The dominant tree species include *Quercus dentasa*, *platycladus orientalis*, *pinus tabulaeformis*, *populus*, broadleaf tree, *robinia pseudoacacia, populus davidiana* , *betula platyphylla* and *Larix principis-rupprechtii*, which host a rich variety of other species of fauna and flora. The spatial distribution of forest resources in Beijing was showed in Figure 9.

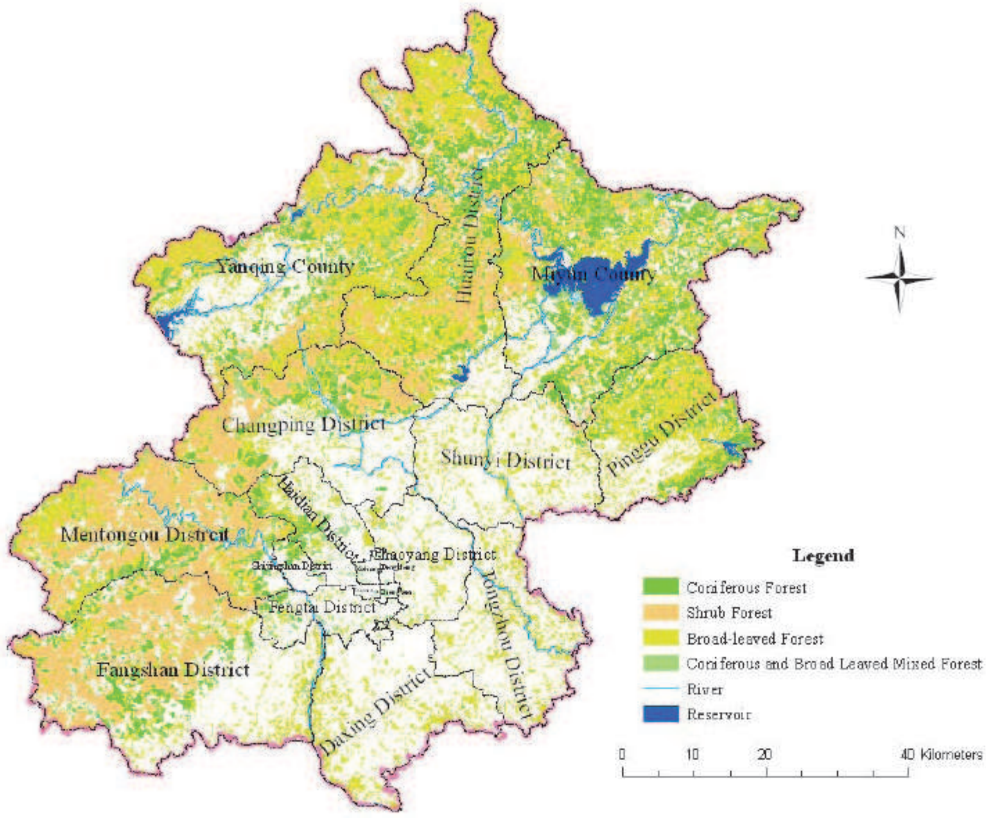

Fig. 9. Distribution of the forests in Beijing

Forest, one of the most important terrestrial ecosystems on the earth, provides fundamental services for human such as internal nutrient cycling, soil protection, biodiversity conservation, climatic regulation, and water supply (Nunez et al., 2006). Xie et al. (2010) estimated the magnitudes and economic values of the forest ecosystem services in Beijing at subplot level. The result showed that, the forests in Beijing supported a lot of ecosystem services to local and around communities, including primary products, water supply, gas regulation, hydrological regulation, environmental purification, soil formation and conservation, cropland protection, wind protection and sand fixation, biodiversity conservation, increasing employment, recreation, science and education. The economic value of forest ecosystem services in Beijing was estimated to be 19 billion RMB (Chinese Currency, 6.83 RMB=US$ 1) in 2004. In addition, the studies of Yu et al. (2002) and Wu et al. (2010) also reported that these ecosystem services to human welfare were much more important than what we had thought.

4.1 Water conservation

In the context of global climate change, the hydrological and meteorological role of forests has attracted much attention from the public (Bonell et al., 1993; Black et al., 1998; Vazken, 2004; Ian, 2007), and water supply provided an important argument for forest sustainable management and protection around the planet (Dudley and Stolton, 2003). In China, the term of water conservation often is described as a comprehensive regulation of forests on water resources through various hydrological processes, and grouped into three services, i.e., rainfall interception, soil water storage and fresh water provision.

Rainfall interception is the benefit provided by forests through reducing the risk of flood. In Beijing mountainous areas, the intensive rainfall events in rainy season often cause flood, debris flow and landslide. Forest ecosystem can intercept a proportion of rainfall by the plant canopy, forest floor and soil, to reduce the rainfall amount loaded on forest land in a short time, so that the occurrence possibilities of flood, debris flow, and storm related natural disasters can be reduced.

The results showed that, the maximum potential capacity of rainfall interception of the forest ecosystems in Beijing was approximately 1.43 billion cubic meters in 2004. And if all conditions were ideal, the forest canopies could intercept about 193.29 million cubic meters of rainfall, which accounting for 13.5% of total interception capacity; the forest litters could contain about 5.72 million cubic meters of water, only occupying 0.04% of total rainfall interception, and the forest soils could intercept rainfall nearly 1.23 billion cubic meters and constitute 86.1% of total interception capacity.

Soil water storage is one of the important regulating services provided by forests through maintaining constant soil moisture to reduce the impact of drought on agriculture and household livelihoods. Beijing has experienced a continuous low water period from 1999 to 2004 (Zhang, 2004), and suffered from enormous economic damage, which ultimately compromised its social and economic sustainable development. In forest ecosystems, the plant roots and microorganisms in the rizosphere increase soil porosity improving oxygen exchange and water retention capacity (Nunez et al, 2006). Consequently, forest soils can conserve a large amount of water in wet season, and slowly released them to maintain the proper soil moisture for the plants survival in dry season, and the service of soil water storage contributes to the effective utilization of water resource (Liu et al, 1996), and the drought risk reduction (Primack et al., 2001). It was estimated that nearly 278 million cubic meters of water could be stored in saturation state by the forest ecosystems of Beijing.

Fresh water provision is the benefit of freshwater resources, obtained from forests through ‘filtering, retention and storage of water in, mainly, streams, lakes and aquifers’ (de Groot et al., 2002). Forest ecosystems play an important role in helping to maintain water supply to major cities in the world, and a large amount of the water available for the world population as drinkable water comes from existing reserves in natural and artificial forests (Nunez et al., 2006). So the provision of fresh water contributes to the sustainable development of social economy and the relief of water crisis in Beijing. We estimated Beijing’s forests provided about 287 million cubic meters of fresh water in 2004, corresponding to 27.8% of Beijing residents’ water consumption (1.03 billion cubic meters) in the same year (Zhang et al., 2010b).

4.2 Water purification

Water quality would normally be expected to be good from forest. An exception may occur in high pollution climates where deposition rates of atmospheric pollutants may lead to catchment acidification and high nitrate concentrations in soil and groundwater (Calder, 2007). In urban environments, grassed areas are effective in removing sediment and nitrogen bound to the sediment (Deletic, 2005). Barrett et al. (1998) determined the reduction effect in suspended solid matter of two grassed strips alongside a highway to be 85%, and they found a 31–61% decrease in total phosphorus (P), total lead (Pb), and total nitrogen (N). Given continuous urban expansion and increased road use leading to more pollutants entering the stormwater system, this form of urban forest should be viewed as a valuable resource (Fam et al., 2008).

In China, a summary of several studies also reported that forest possess considerable adjusting and controlling ability over the non-point pollution (Lei, et al., 2000). Hillside forest can reduce 60% of solid pollutant and avoid the loss of nutrient up to 30-50%. Water temperature in the drainage area where the forest has been logged increases 0.2-0.4 ^{0}C, and the loss of N ranges from 4 kg/hm^2·a to 142 kg/hm^2·a. Chen et al. (2002) found the buffering forest belts between farmlands and ditches can effectively stop and purify such elements as N and P in soil runoffs, thus controlling non-point source pollution of agricultural lands. Based on the investigation to water conservation forest and observation of surface water in Miyun county of Beijing, Li et al. (2004) reported that, the non-point source pollution caused by field fertilization had been reduced, which led muddy degree of surface water and the content of NH_4^+ to decline. The result showed the process of leaching, exchange, absorption, etc. between water conservation forest in valley of Miyun reservoir and precipitation can cleanse rainfall. In Beijing, the water quality in green areas also is superior to the runoff from roofs and roads (Hou et al., 2006), and it is often used as reclaimed water for green-land irrigation and vehicle washing. Since forests are key to clean water, the maintaining supplies of clean water and protecting watersheds are major reasons why public domain forests and rangelands should be reserved.

4.3 Microclimate regulation

The influence of urban forest on local microclimate is multidimensional and complex, including modification of solar radiation, wind speed, air temperature, relative humidity, and terrestrial re-radiation (Jim and Chen, 2009). In western countries, the public mainly focus on tree effects on cooling and heating energy saving at the local scale in low-density residential neighborhoods. In Chicago, an increase in tree cover by 10%, or planting about three trees per building lot, could reduce the total energy for heating and cooling by US$ 50-90 per dwelling unit per year (McPherson et al., 1997). Taha et al. (1997) found that urban trees could cool the city on the average by about 0.3-1.0 ^{0}C, and total annual energy savings could attain US$ 10-35/100 m^2 of roof area of residential and commercial buildings. The urban trees in Los Angeles could potentially save about US$ 93 million of energy use per year and could reduce peak power demand by 0.9 GW (Akbari, 2002).

However, Chinese cities usually focus on the evapotranspiration effect at the city level. Evapotranspiration process would significantly decrease the ambient air temperature, and raise the relative humidity in the vicinity of trees. Therefore, urban forests could produce an "oasis effect" to render the urban environment, specifically its bioclimatic conditions, more comfortable. Liu et al. (2008) testified the environmental effect of urban forest in Yuan-Da-Du Park in Beijing. They found that the tree-shrub-herbage mixture with higher coverage brought about a wider range of temperature and humidity effect, and had a greater effect on lowering temperature and increasing relative humidity, compared with lawn. Zhu et al. (2011) investigated six green belts with different width along the west fourth ring road of

Beijing and reported that, the temperature and relative humidity benefit increases as the width of green belts rise. The green belt of 6 m width has little effect on the decrease of temperature and unobvious effect on the increase of humidity. It has a comparatively obvious effect with the width of 16-27 m, and obvious effect with the width of 34 m; an extremely obvious and stable effect with the width of more than 40 m. Therefore, reasonable structure and composition of plant community could make the urban forest better exert their effects in decreasing temperature and increasing humidity in summer.

5. Conclusions

Based on the above analysis, the present situation of water resources in Beijing is severe. If nothing will be done, the sustainability of water resources in Beijing will face serious challenge, and more and more people will suffer water scarcity in the near future. However, climate change predictions that link reduced precipitation with increased storm intensity may have a smaller effect on water availability to forest ecosystems than reduced precipitation, which could help forests' survival and maintain productivity even under drier conditions (Yaseef et al., 2010).

Beijing's forests affect water quantity by intercepting precipitation, increasing water infiltration rates, and transpiring water, which can materially reduce the rate and volume of storm water runoff, flood damage, stormwater treatment costs, and other problems related to water quality. Therefore, the effectiveness of the forest ecosystem in Beijing with such roles on watershed management is definitely very essential. Nowadays, throughout the world there is increasing interest in land and water developments and policies in which forestry is a central focus. There is evidence that the forest in Beijing can help urban areas adapt to the impact of climate change, and policies should be used to encourage the optimal structure and composition of urban forest through ecosystem management strategies. Especially urban forest plans should be integrated with watershed assessments and with watershed recovery plans.

6. Acknowledgements

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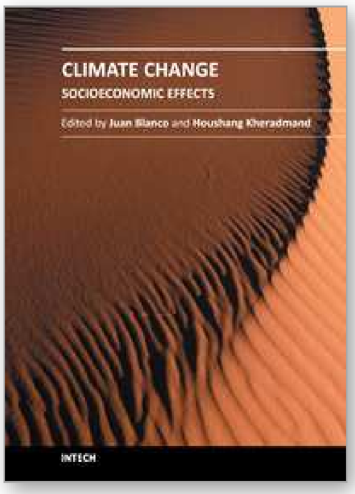

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