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SPECIAL TOPIC ON REGIONAL CLIMATE CHANGE IMPACTS AND ADAPTATION

Climate Change Impacts on Central China and Adaptation Measures

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Abstract

In Central China, the obvious climate change has happened along with global warming. Based on the observational analysis, the climate change has significant effects, both positive and negative, in every field within the study area, and with the harmful effects far more prevalent. Under the scenario A1B, it is reported that temperature, precipitation, days of heat waves and extreme precipitation intensity will increase at respective rates of 0.38°C per decade, 12.6 mm per decade, 6.4 d and 47 mm per decade in the 21st century. It is widely believed that these climate changes in the future will result in some apparent impacts on agro-ecosystems, water resources, wetland ecosystem, forest ecosystem, human health, energy sectors and other sensitive fields in Central China. Due to the limited scientific knowledge and researches, there are still some shortages in the climate change assessment methodologies and many uncertainties in the climate prediction results. Therefore, it is urgent and essential to increase the studies of the regional climate change adaptation, extend the research fields, and enhance the studies in the extreme weather and climate events to reduce the uncertainties of the climate change assessments.

Keywords: climate change; impact assessment; adaptation measures; uncertainty; Central China

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1 Introduction

Report from Working Group II[*IPCC*, 2007] within the IPCC AR4 evaluated the historical climate changes and the possible impacts in the future, and then proposed some suggestions on the adaptation measures. It also said the global warming had induced some distinguishable influences in the nature and the biological systems, but some undistinguishable impacts also existed. Therefore, adoptions of the adaptation policies combined with the mitigation measures can reduce the risk of climate change. In China, climate change impacts had appeared in various fields [*ECSCNARCC*, 2011]. For the agriculture in China,

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the beneficial and harmful impacts coexisted with the harmful ones especially noticeable. Generally, the measured river streamflow in northern China decreased significantly, and the ecosystems in the source regions of the Yangtze River and the Yellow River and the inland rivers have degraded. In China, there exhibited some regional differences in climate change impacts, of which the more fragile the ecol-environment in some regions, the more significant the effects induced by climate change.

Central China mainly covers Hubei, Henan and Hunan provinces with an area of 600×10^3 km^2. It is an important national grain production base, of which both the yields and the areas of oil-seed rape in Hubei, wheat in Henan and rice in Henan rank first in China. In addition, Central China abounds in water resources because of the Yangtze River, the Yellow River and the Huaihe River running through. Furthermore, the Three Gorges Project and the Middle Route of the South-to-North Water Diversion Project are located here. On the other hand, Central China, one of the more sensitive regions to climate change, can be impacted by climate change in many aspects. In the present study, two major issues in Central China will be analyzed using the results from published literatures and model simulations: 1) to assess and project the effects of climate change on agriculture, water resources, wetland ecosystem, forest ecosystem, the key engineering facilities, human health and energy consumption; and 2) to propose suggestions about the climate change adaptations as the basis to support policy making in each province.

2 Methodology of climate change impact assessment

First, changes in agro-climate resources and meteorological disasters and northern boundary of double-cropping paddy are analyzed with statistical methods. Second, the growth period and the yield of crops are projected based on the future meteorological projection during 2011–2050 by the crop model (e.g., PRECIS). Third, the responses of water resources to climate change are explored by utilizing the hydrological model and statistical measures, and quantitatively estimations of the influences of the future climate change in water resources are performed. Fourth, climate change impacts on regional energy consumption for heating and cooling are analyzed based on degree-days. The observational data are daily average temperatures in Central China from 1961 to 2005. The projection data are from the global model BCC_CSM_1.1 during 2011–2100. Lastly, through surveys in typical regions and the results from the published literatures, the climate change impacts on other fields are synthesized.

3 Observed climate change impacts

3.1 *Agriculture*

With the changing agro-climate, the volatility of agricultural yields and crop diseases and insect pests have increased. The causes of this phenomenon can be traced to: 1) Climate conditions and meteorological disasters during the growth seasons have changed. For example, the beginning date of daily mean temperature $\geqslant$10°C in Central China has advanced 2–5 d earlier, followed by an increase of 2–9 d in the duration and 300–550°C d in active accumulated temperature [*Liu et al.*, 2010]. Although the low temperature disasters for rice growth decreased, the high temperature hazards increased [*Li et al.*, 2007]. For the wheat, the dry-hot winds and the frosts have become worse with accurance of 50.6% (approximating to 2-year return period), and frosts have decreased at a rate of 6.3% per decade [*Liu et al.*, 2009]. 2) The species and the spatial distribution of crops have changed. Due to the growth of heat resources, the northern boundaries for sowing the double cropping rices have moved about 0.3°–0.5° latitudinal northward [*Liu et al.*, 2011]. The cultivated areas of the semi-prostrate winter or the feeble-spring wheat varieties have expanded, but the winter wheat areas have decreased. For fruit planting, the growing areas (e.g., citrus and kiwi) have moved northward and to higher altitudes. 3) The period suitable for sowing winter wheat were delayed, the crop development stages have shifted to be earlier [*Chen et al.*, 2010], and the yields of the grains fluctuated with large variabilities and their quality has changed [*Wang et al.*, 2010]. In autumn, the temperature declined, followed by the delaying period of daily mean temperature higher than 17°C [*Hao et al.*, 2002]. For example, in northwest of Henan province, the central and northern Hubei province, the period suitable for sowing winter wheat delayed 2–6 d [*Chen*, 2006]. The temperatures in winter and spring increased, which make the development stages in spring of the winter crops and the citrus earlier [*Wan*, 2003]. As the night temperature increased 1°C, the rice yields reduced about 1%. More proteins were easily assimilated into rice with the declining diurnal temperature range (DTR), at rates of 1.10% per °C in the corresponding period and of 0.55% per °C in later stages for the early and mid-season rices. 4) The crops diseases and insect pests have worsened. The occurrences of the rice plant hoppers tended to increase in Hubei. Moreover, it is reported that the areas with the rice plant hoppers have increased by about five times during the period of 1991–2007 [*Li et al.*, 2010; *Ye et al.*, 2005].

3.2 *Water resources*

Climate change and human activities have caused significant change in the water resources of the land surface, and increase in droughts and floods. The impacts of climate change on water resources are very complicated, which include quality, quantity and distribution of water resources and their explorations and utilizations. It is no surprise that some uncertainties exist. At present, it is difficult to isolate the contribution of climate change from the analysis of streamflow and runoff. Under the combined influences of climate change and human activities, the annual streamflow in the middle reaches of the Yellow River has decreased by 9.2% per decade from 1951 to 2004. Moreover, the mean streamflow was lower than 33% after 1980s, and decreased sharply since 1990 [*Zhang and Wang*, 2009]. Within the Dongting Lake Basin, annual maximum streamflow in Xiangjiang River and Yuanshui River did not exhibit obvious changes, while both the subbasins of Zishui River and Lishui River Basin decreased [*Zhou*, 2007]. Around 1991, the annual streamflow in the middle and lower reaches of Hanjiang River had abruptly decreased. For the mainstream of the Yangtze River in Hubei, the annual runoff in the 1990s increased slightly but with great spatial and seasonal differences [*Chen et al.*, 2008]. The observed annual streamflow during 1950–2004 in Yichang and Hankou, for instance, decreased at rates of 0.70% and 0.21% per decade, respectively [*Zhang et al.*, 2008]. Seasonal streamflow changes were manifested as decreases in spring and autumn, and increases in summer and winter. Simultaneously, the increased streamflows in summer exert stress of the summer floods control, and in winter lessen the tension of water shortage to some extent.

3.3 *Wetland ecosystem*

Because of climate change and human activities, the wetland area decreased with the changed structures and functions, the water quality degraded, and even the ecological vulnerability increased in Central China. Central China, as a typical wetland ecosystems with lakes and rivers, can be impacted by climate change, farmland reclamation, aquatic farming, unban and town developments, hydraulic engineering, and other human activities. With the existing datasets, it is hard to determine the influences induced by climate change in wetland ecosystems. Compared to the lake areas in the 1950s, the Dongting Lake, the Honghu Lake, the Futou Lake, the Liangzi Lake, and the Longgan Lake had reduced by 36%, 47%, 28%, 27% and 45% respectively in the early 21st century under the combined effects of climate change and human activities [*Deng et al.*, 2006; *Yang et al.*, 2001; *Huang*, 1999]. Over the almost 50 years, the average air temperature and the precipitation increased by 1.5°C and 5.7%, and 0.81°C and 2.0% respectively in the wetlands of Honghu Lake and Dongting Lake. Just as the changing precipitation was insufficient to offset the impacts caused by the increasing temperature on wetland ecosystems in Honghu and Dongtinghu Lake, the wetlands types have also changed, for example some parts of the Honghu Lake wetlands have transformed to herbaceous swamps, the aquaculture farms or other artificial wetlands induced by the variations of water level. In addition, the drop in river and lake water levels was favorable to the concentration of the algae species, resulting in water quality degradation and even promoting water blooms [*Dou and*

Hou, 2002]. In the middle and lower reaches of Hanjiang River, the first blooms happened in 1992, and subsequently occurred in 1998 and 2000 again, which presented the characteristics of the shortened bloom cycle and the lengthened duration within larger areas. The regional and seasonal differences in rainfall caused some changes, such as the advance of wetlands dry season onset, the extended duration, and the increased water level volatility. The changes also include the reduction of the capacity of flood control and carbon sink, the threatened biodiversity, the changed habits, and the increased vulnerability of the wetlands. The phytoplankton species decreased; bird breeding season advanced and their migration patterns changed; alien species invaded and bloomed.

3.4 *Forest ecosystem*

Forest tree phenophase moved earlier. Cool-oriented species migrated to higher altitudes, and risk of forest pests and fire increased. Temperature rising made the spring phenophase of forest arbor come in advance by about 10 d and green period extended by about 15 d [*Liu et al.*, 2007]. Affected by climate warming and policy implications, the regional forest area and growing stock volume tend to increase. The amount of carbon sequestration increased, and the carbon sink function had also been enhanced. The Fir trees such as *Abies fargesii* migrated to higher altitudes [*Dang*, 2007]. Because of the rising temperatures and longer period of the drought, the forest fire season came earlier and lasted longer, which resulted in increased intensity, frequency and burned area of forest fires [*Zhao et al.*, 2009]. Due to climate warming, species, intensity and frequency of forest pest increased significantly. Forest pest outbreak cycle shortened, for instance, caterpillar broke out occurs once every 10 years in the past, but over the past 20 years its outbreak reduced to about once every 5 years. The population base of caterpillar over winter became larger because of warm winter in 2001 and 2002, which led to widespread forest plant diseases and insect pest [*Ding et al.*, 2010].

3.5 *Major projects*

The precipitation and runoff in the Three Gorges reservoir area and the Danjiangkou area decreased slowly and their variability increased, which makes the engineering and operations management more difficult. The annual precipitation and runoff reduced slowly in the Yangtze River basin from 1960 to 2007. The rainfall in the flood season had apparent increase [*Jiang et al.*, 2005]. The frequency of extreme heavy precipitations was 86% from May to September. The occurrence of precipitations in flood season and the droughts in dry season became more frequent, which made the reservoir operations management harder [*Su et al.*, 2006]. The precipitation and runoff tended to decrease in Danjiangkou area, and significantly less than normal in the 1990s [*Cai et al.*, 2008]. The spatial distribution of annual precipitation showed inverse relationship at the two ends of the central route of the South-North Water Transfer Project, with wet (dry) years of catchment areas in the south corresponding to dry (wet) years of accepted watershed in the north. From 1951 to 2010, the probability favoring the South-North Water Transfer Project (rich precipitation in the south and poor precipitation in the north) was 62%, and the probability of unfavorable spatial precipitation distribution (withered in both the north and the south) was just 8%.

3.6 *Human health*

Climate change produced many harmful effects on human health in Central China. The cardiovascular mortalities increased year by year in Wuhan from 1998 to 2008. And the morbidity was highest in winter and lowest in summer [*Chen*, 2000]. The increasing frequency and intensity of summer heat waves resulted in the increased risk of summer cardiovascular, respiratory system diseases and heat stroke. The regional precipitation became uneven in Central China, which caused more floods and increased risk of infectious diseases like malaria, Japanese encephalitis, and conjunctivitis. The incidence of intestinal infectious diseases increased from 66.04% to 80.97% in Hubei during 1991–1997. Climate warming helped snails survive the winter season, shorten hibernation period and expand from the south to the north in the Yangtze River Basin [*Peng et al.*, 2006].

3.7 *Heating and cooling*

The heating degree-days in winter decreased, and summer cooling degree-days increased since the 1980s, therefore, annual total energy consumption amount increased. The heating degree-days decreased 17.5°C d per 10 years from 1961 to 2007. The cooling degree-days had a declining tendency from the 1960s to the 1980s, and increased rapidly since the 1980s. The winter heating degree-days and summer cooling degree-days decreased from the 1960s to the mid-1980s, and the total annual energy demand decreased. Since the 1980s, the winter heating degree-days have decreased and the summer cooling degree-days have increased. However, the energy efficiency of 1°C in summer is two times of that in winter [*Chen and Hong*, 1998], and the demand of summer cooling is larger than the winter cooling demand. Therefore, the overall energy consumption demand increases for the year [*Ren et al.*, 2010].

4 Estimation of future climate change trends & possible impacts

4.1 *Estimation of future climate change trends*

In the future, the temperature and inhomogeneity of precipitation will increase, and extreme temperature and rainfall events will happen more frequently. The tendency of climate change in Central China is estimated by global and regional climate models. Under the A1B scenario, the temperature in Central China will increase 0.38°C per decade from 2011 to 2100. By the end of the 21st century, the regional average temperature will increase 3.2°C from the base year. The regional precipitation will increase 12.6 mm per decade. At the end of the 21st century, the regional average annual precipitation will increase 90 mm from the base year. At the end of the 21st century the extremely hot waves will increase 6.4 d per decade, and frost days will reduce 3.4 d per decade. Precipitation intensity will increase 47 mm per decade, and extreme precipitation contribution rate will increase 0.3% per decade.

4.2 *Possible impacts in the future*

Agriculture The area suitable for double-crop rice will expand further north from 2011 to 2050. The optimum area for early-maturity and middle-maturity match model will extend to Xiangyang in Hubei and Dabie Mountain foothill from 2011 to 2040, and further extend to the border of Hubei and Henan from 2021 to 2050. The whole growing period of winter wheat in Henan and the north of Hubei will shorten by 4–7 d on average from 2011 to 2050, and the growing period of double-crop rice will shorten by 1.5–4.5 d. The yield per unit area of rainfed rice will reduce by 0 to 30% from 2011 to 2050. The generation of *Thrporyza incerthlas* in Hubei rice area will increase from 4 generations now to 5 generations by 2080.

Water resources The runoff rates in the Yangtze River Basin will range from –10% to 10% during 2071–2079 under A2 scenario, in which the upstream belongs to water stress area (–10% to 0), and downstream is no lack of water. The runoff rates varies from –20% to 10% during 2071–2079 under B2 scenario, in which upstream rate variability will be –20% to –10%, and in the middle and lower reaches from –10% to 10%. The annual runoff of Huayuankou hydrological station in the Yellow River Basin will be 40 billion m^3 in 2050, and 10% more than average [*Kang et al.*, 2009]. The runoff of Chenglingji hydrological station in the Dongting Lake Basin will respectively increase by 6.1%, 8.6% and 1.7% under SRES A2, A1B and B1 scenarios in 2050. The change trend of runoff in Yichang station in upstream and Hankou station in midstream is not obvious, and variation will be no more than 10% [*Zeng et al.*, 2010].

Wetland ecosystem In the future, climate will get warmer, and precipitation variability will increase [*Shi et al.*, 2008], which will cause more wetland floods and droughts. It may further reduce the vegetation stability and biodiversity of wetland ecosystem, which may lead to more changes in the migratory routes and the composition of wetland migratory birds.

Forest ecosystem Forest species diversity will reduce. Regional forest productivity will increase by 3% to 6% [*Lin et al.*, 2006; *Liu et al.*, 1998]. The vertical distribution area of Masson pine will be reduced by 9% in 2030 due to climate change. The northern limit of Chinese fir will expand 2.8° northward and ascend 110 m under the condition of 2–3°C temperature increase and precipitation increase of 25%.

Major projects The runoff in the middle route of catchment areas for the South-to-North Water Transfer Project will change relatively little in the future climate change. The variability over multi-year average transferable water will range from –3.9% to 14.6%, which will be helpful to the South-to-North Water Transfer Project on the whole [*Zhang et al.*, 2010]. The floods in wet season and droughts in dry season in the Three Gorges Reservoir may occur more frequently, which will increase the difficulty in power generation and dispatching operation [*Zeng et al.*, 2007].

Human health The prevailing months of cardiovascular and cerebrovascular diseases are from October to April in Central China, and the peak is from December to February. As the climate change and implementation of the South-to-North Water Transfer Project, Hunan, Hubei and most of Henan excluding Sanmenxia city in western Henan will become the potential risk area of schistosomiasis in 2040. All of Hunan, Hubei and Henan will become the potential transmission area in 2050 [*Zhou et al.*, 2004].

Heating and cooling The decreasing rate of heating degree-days is 45.2°C d per decade and the increasing rate of cooling degree-days is 37.2°C d per decade in Central China from 2011 to 2050. So, the overall energy consumption will increase over the next 40 years.

4.3 *Measures of adaption to climate change*

The traditional agriculture should be transformed and the modern agriculture should be developed. The agricultural layout should be optimized, the cropping system should be reformed; the research and development of science and technology should be strengthened; stress-resistant varieties should be cultivated. The construction of irrigation and water conservancy should be enhanced and the agricultural ecological environment should be improved. At the same time, the water-saving agriculture should be developed to increase the efficiency of agricultural water usage.

In order to establish a water-saving society, a modern water management system should be built; the infrastructure of water conservancy should be reinforced and the conservation of regional water resources be strengthened.

The project of regional wetland restoration should be implemented. This project will be included in the development plan and the related survey and assessment should be conducted. Meanwhile, the research about impact of climate change on wetland should be strengthened.

The forest area should be increased and the protection of natural secondary forest and primary forest should be intensified; a rational forest management plan should be designed; the forestry infrastructure and national forest park construction should be strengthened.

The joint scheduling mechanism of the Yangtze River Basin should be improved; a risk contingency system for the South-to-North Water Transfer Project should be established; the project ability to cope with extreme weather events should be enhanced; the defense capabilities of reservoir against the geological disasters should be improved.

Great efforts to carry out the regional census of schistosomiasis disease should be devoted and the snail-control project in an organized way should be implemented. The research on the occurrence and spread of human diseases influenced by the climate change should be strengthened; the outreach and training of science and knowledge about the impact of climate change on human health should be conducted.

Clean energy should be vigorously developed, the impacts of climate change should be taken into consideration in the energy development plan and the services of energy security under the natural disasters should be consolidated.

5 Uncertainty about the impacts of climate change

Due to different assessment methods used in the literature, different data source and time frame, the assessment of the observed climate change effects can differ to some extent. The assessment is based on a limited literature in different fields, so the coverage and quality of the literature could be improved.

The estimates of future climate change are achieved by the weighted average of a few global climate models provided by National Climate Center, China Meteorological Administration. Due to the uncertainty of the climate models and the emission scenarios, and the difference of the estimates in different studies, uncertainties are inevitable in predicting the future changes in temperature, precipitation and extreme weather events.

The possible impact of future climate change is mainly based on the assessment results obtained from studying the trend of future climate changes. Impact assessment model has uncertainties and different estimates may lead to different conclusions in various studies.

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