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EVALUATION OF THE IMPACT OF PLANTING STRUCTURE ON WATER RESOURCES

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Abstract

Many regions are facing formidable freshwater management challenges. In this research, the Water Evaluation and Planning System (WEAP) was used to simulate water demand and supply under planting structure adjustment scenario in Laohahe River Basin (LRB), China. The effects of planting structure adjustment on alleviating the water resources vulnerability were simulated by defining scenario for changes in crops sown area inputs to WEAP model. The results show that compared with the Reference, planting structure adjustment can decrease unmet demand of all demand sites obviously, can slow the depletion of groundwater which can increase water shortage 70-350×$10^6$$m^3$, as well as can increase all demand sites' coverage effectively. There is substantial reduction in water resources vulnerability when the strategy was used. The planting structure adjustment strategy is effective overall in improving water resources vulnerability, especially during dry flow conditions. In brief, the evaluation approach based on the WEAP model can help decision makers assess alternative policy and management options in mitigating water resources vulnerability.

Key words: agriculture, irrigation, modeling planting structure, unmet demand

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1. Introduction

Water resources not only depends on the river runoff and groundwater recharge volume, changes in the allocation of time, but also depends on the characteristics of the water system, the pressure changes of water system, and what kind of system management and measures taken to adapt to water shortage. Many regions are facing formidable freshwater management challenges. Allocation of limited water resources, environmental quality, and policies for sustainable water use are issues of increasing concern (SEI, 2008). How to assess the impacts of water resources management on alleviating the water shortage is the key to take measures further. The benefits of water management, however, can be difficult to quantify (Benchea et al., 2011; Iliadis et al., 2010; Miller, 2006). As a water evaluation and planning tool, Water Evaluation and Planning System (WEAP) (SEI, 2008) is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP model has been used in many countries (Lancaster, 2004; Levite et al., 2003).

Laohahe River is a main branch of upper Xiliaohe River. LRB lies mainly in Inner Mongolia Autonomous Region and with minor parts in Hebei Province and Liaoning Province. LRB is dominated by the monsoon climate cycle, and shows strong seasonality. The mean annual precipitation is 412.6 mm. Runoff in LRB comes mainly from natural precipitation. The primary land cover types in LRB

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are cultivated land, forestland and grassland (Hao et al., 2008; 2009; 2010). LRB is an agricultural-based economy which more than half of the population is in agricultural sector. Water resources have played a significant role in the expansion of agriculture and industry in the LRB. However, intensive irrigation has resulted in almost full cessation of the water inflow, as well as the drastic drop in underground water level. Water resources are severely stressed and water requirements continue to grow. On the other hand, water management is still lagging in this area, water deficit has been one of the major constraints hampering development in the LRB.

The main objective of this research is (1) to analyze present planting structure situation in the LRB, and (2) to quantify the effect of water management such as changing planting structure on regional hydrology by using WEAP.

2. Materials and methods

2.1. The WEAP model

WEAP is distinguished by its integrated appr oach to simulating water systems and by its policy ori entation. As a database, it provides a system for maintaining water demand and supply information. As a forecasting tool, it simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, it evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (SEI, 2008). WEAP calculates a water and pollution mass balance for every node and link in the system on a monthly time step. Water is dispatched to meet instream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints.

Point loads of pollution into receiving bodies of water are computed, and instream water quality concentrations are calculated (Yates et al., 2009). WEAP operates on a monthly time step, from the first month of the Current Accounts year through the last month of the last scenario year (SEI, 2001). Each month is independent of the previous month, except for reservoir and aquifer storage. Thus, all of the water entering the system in a month (e.g., head flow, groundwater recharge, or runoff into reaches) is either stored in an aquifer or reservoir, or leaves the system by the end of the month (e.g., outflow from end of river, demand site consumption, reservoir or river reach evaporation, transmission and return flow link losses). Since the time scale is relatively long (monthly), all flows are assumed to occur instantaneously. Thus, a demand site can withdraw water from the river, consume some, return the rest to a wastewater treatment plant that treats it and returns it to the river. This return flow is available for use in the same month to downstream demands (Yates et al., 2005).

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The Current Accounts provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. Alternative sets of future assumptions are based on policies, costs, technological development and other factors that affect demand, pollution, supply and hydrology. Scenarios are constructed consisting of alternative sets of assumptions or policies. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (SEI, 2008).

2.2. Input data

Daily historical data of precipitation, temperature and solar radiation were obtained from the China Meteorological Administration (CMA). Monthly stream flow was obtained from Chifeng hydrology bureau and Data-Sharing Center of China Water Resources. Agricultural management practices were obtained from Chifeng agricultural statistical yearbook, Inner Mongolia statistic yearbook, field investigation, Inner Mongolia Agricultural Investigation Group and etc.

Based on the historical data of hydro, water resources, water utilization, economy, agricultural management, industry and etc, elements such as river, water demand sites (agriculture, industry, animal husbandry and life) were created and entered into the schematic. Return flow links were created too. The schematic of water resources utilization in LRB was shown in Fig. 1.

2.3. Setting up scenario

The Current Accounts represent the basic definition of the water system as it currently exists. The Current Accounts are assumed to be the starting year for all scenarios. The Current Accounts include the specification of supply and demand data (including definitions of reservoirs, pipelines, treatment plants, pollution generation, etc.) for the first year of the study on a monthly basis. 2003 was selected as the Current Accounts Year, i.e. the first year of the analysis period.

Reference, which was assumed to develop in present tendency (2004-2030), was initially executed prior to performing the scenario simulations. The scenario was then run for the same simulation period to provide a consistent basis for comparison of the scenario impacts. Water unmet demand was selected as vulnerability index to assess the effects of planting structure adjustment on alleviating water vulnerability. The effects were estimated by defining scenario for changes in sown area of different inputs to WEAP model.

In Reference, the water supply and demand situation during 2004-2030 was estimated based on the present condition of LRB.

The annual growth rate of urban population was 1%, rural population was 1.2%. The annual growth rate of livestock population was 1.5%, industrial output was 7%. The annual growth rate of irrigable field area and paddy field area was 2.5%, rainfed field area was -2.5%.

In Planting Structure Scenario, the sown area of maize and millet will not change since 2004 in all agricultural catchments. Rice will be substituted with maize in those catchments with more rice sown areas.

2.4. Calibration

The WEAP model was calibrated using stream flow monthly data during the period of 2003-2005. The coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) were used to evaluate the model predictions for both time periods. R^2=0.8553, E_{NS}=0.7893. These calibration results indicate that WEAP accurately replicated LRB water resources situation for the simulated time period.

3. Results and discussion

3.1. Impact of planting structure on unmet demand

Unmet demand is the amount of each demand site's requirement that is not met. When some demand sites are not getting full coverage, it is useful in understanding the magnitude of the shortage. Fig. 2 is annual unmet demand difference of Planting Structure Scenario and Reference in LRB from 2004 to 2030.

Compared with the Reference, unmet demand of all demand sites can be found decreased obviously in Planting Structure Scenario. During the water shortage period, the unmet demand decreased much more.

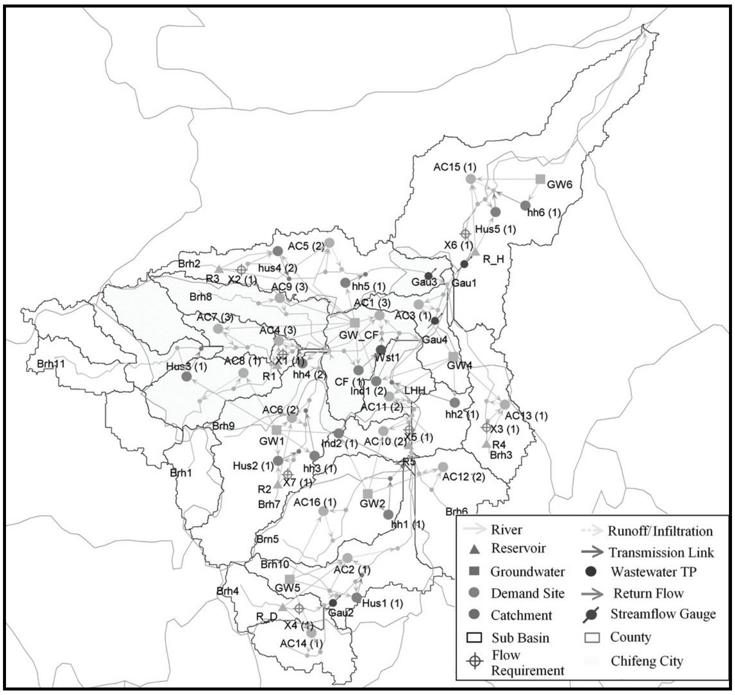

Fig. 1. Schematic of water resources utilization in LRB (Hao et al., 2010)

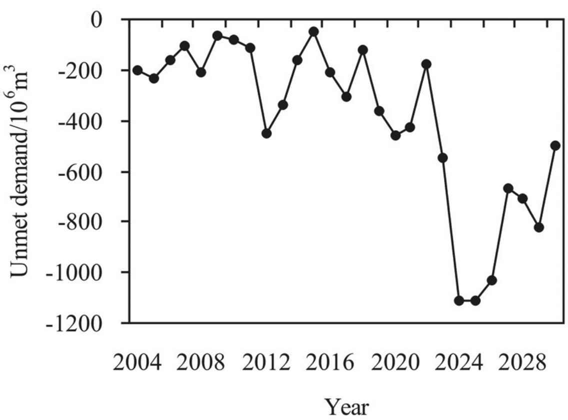

Fig. 2. Unmet demand difference of Reference and Planting Structure Scenario in LRB (2004-2030)

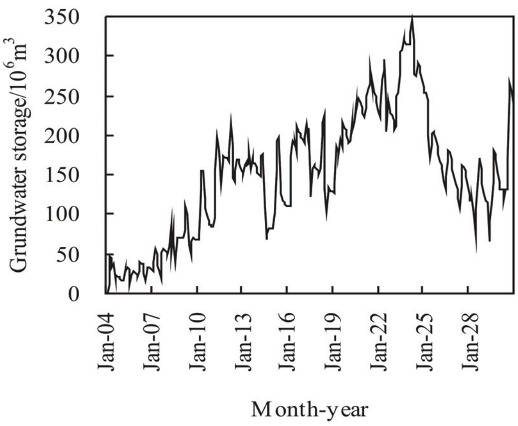

Fig. 3. Groundwater storage difference of Reference and Planting Structure Scenario in LRB (2004-2030)

3.2. Impact of planting structure on groundwater

The groundwater storage in this research represents the aquifer storage levels at the end of each month. Planting structure adjustment can alleviate water shortage effectively, as well as slow the depletion of groundwater. Fig. 3 is monthly groundwater storage difference of Reference and Planting Structure Scenario in LRB from 2004 to 2030. The results show that the Planting Structure Scenario slows the depletion of groundwater which can increase water shortage 70-350×10^{6}m^3 during the water shortage period compared with Reference.

3.3. Impact of planting structure on coverage

Coverage is the percent of each demand site's requirement (adjusting for demand site losses, reuse and demand-side management savings) that is met, from 0% (no water delivered) to 100% (delivery of full requirement). It gives a quick assessment of how well demands are being met. Fig. 4 is annual coverage change of Reference and Planting Scenario.

Fig. 4 is annual water demand coverage change of Reference and Planting Structure Scenario in LRB from 2004 to 2030. Fig.4 shows that, the Planting Structure Scenario can increase demand site's coverage obviously, especially during the water shortage period compared with Reference. As reduction of sown area of those crops with more water consumption, the water demand coverage increase subsequently.

The coverage will be increase of about 2%-7% during normal hydrological years, and about 7%-14% during dry years. Therefore, planting structure adjustment can increase all demand sites' coverage effectively.

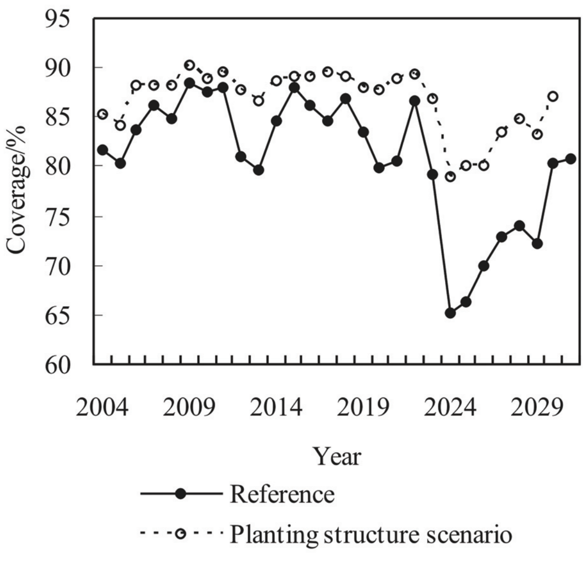

Fig. 4. Annual coverage of Reference and Planting Structure Scenario in LRB (2004-2030)

3.4. Present planting structure situation in LRB

Large changes in land-cover, land-use and water management practices have taken place in LRB during the last 40 years. Although the farmland areas in the 1970s, 1980s and 1990s changed not very obviously compared with the 1960s, effective irrigation areas increased evidently in Chifeng where LRB lies mainly. For a long time, because of reservoir regulation, the risk of farmland inundated by floods has been weakened. Both river banks, even drying channel were used largely for farmland. The riverbank farmland has become local main farmland due to sufficient light, fertile soil coupled with guaranteed water. Rice, corn and wheat are the main crops on the riverbank farmland. The increased effective irrigation area results in stream flow reduction.

The planting structure also has undergone significant changes in LRB. During the last 20 years, a shift in agriculture practices towards more water consuming crops, such as rice, took place. On account of the advantage of riverbank farmland, the sown area of rice increased apparently. Fig. 5 is annual sown areas of rice and millet in Chifeng from 1949 to 2002.

As is shown in Fig. 5, since 1980, the sown area of rice increased obviously in Chifeng. During the last 20 years, the rice area has almost six times increased. The water consumption of rice is greater than millet, maize and other crops, thereby the unreasonable planting structure have had a negative impact on water resources. In addition, in the past 40 years, the precipitation in spring was observed to increase, while the spring runoff coefficient shows a significant negative trend. Spring is the peak irrigation season in LRB. This indicated the runoff significantly reduced in spring mainly attributes to the irrigation.

In addition, irrigation is the main water utilization in LRB. Before the 1980s, the main irrigation water was from the surface water and reservoir. After 1984, the Hongshan Reservoir mainly used for power generation, water for irrigation reduced, which makes groundwater utilization increased evidently.

With the widely use of pumping well, groundwater was overexploited. Survey and interviews also showed with the annually increased utilization of groundwater, the groundwater level seriously dropped ranging from 1m to 2m. The change of effective irrigation area (EIA) in Chifeng shows exploited groundwater increased obviously (Fig. 6).

As the sown area of crop increased with more water consumption, groundwater was over exploited, leading to a decline in runoff supply. In brief, unreasonable planting structure and over irrigation is a strong constraint to integrated water resources management in LRB.

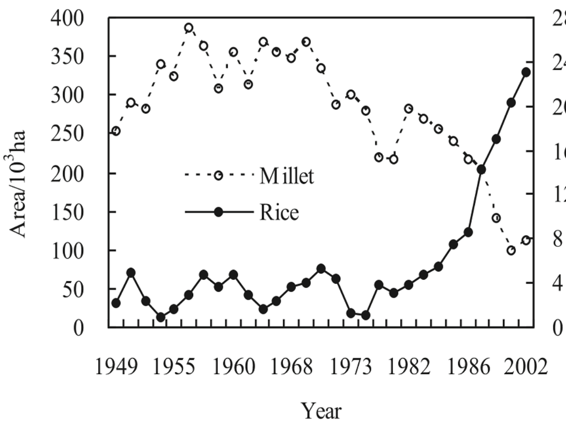

Fig. 5. Sown areas of rice and millet in Chifeng (1949-2002)

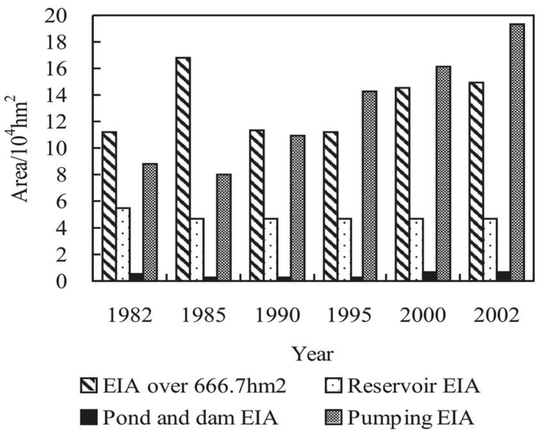

Fig. 6. The effective irrigation area (EIA) in Chifeng

4. Conclusions

WEAP can examine and quantify the benefits of water management, and can provide reference and guidance for the strategies making. In this research, the effects of planting structure adjustment on alleviating the water resources vulnerability were simulated by defining scenario for changes in crops sown area inputs to WEAP model.

The results show that compared with the Reference, planting structure adjustment can decrease unmet demand of all demand sites obviously, can slow the depletion of groundwater which can increase water shortage 70-350×10^{6}m^3, as well as can increase all demand sites' coverage effectively.

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