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Integrated agriculture water management optimization model for water saving potential analysis

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ABSTRACT

This paper studied on the quantification of agriculture water savings under water integrated optimal management and analyze the economic increment of agriculture water savings. First, an integrated agriculture water management optimization model composed of a planting structure optimization model and water resources allocation under conjunctive use of surface water and groundwater optimizing model is built in this paper and applied to Fendong District of Fenhe Region in Shanxi Province, China. Resilience of water utilization and saving inside agriculture have been fully developed through detailed expressions of demand process of multi crops and the interaction and transformation between surface water and groundwater. Optimal solutions of planting structure and corresponding water resources allocation scheme indicate that water demand and supply are more reasonable after assembling crop water demand to flood seasons. Water saving could be realized in the premise of maximum economic benefit after integrated optimization management. Next, active water saving and passive water saving scenario have been set to analyze the correlativity between water saving quantity and maximum economic benefit through adopting integrated agriculture water management optimization model. The results show that water saving potential and agriculture benefit demonstrate a negative correlation. The interval linear function of water saving-effect comprised of two scenarios is used to represent this negative correlation. Consequently, approximately 10% of surface water could be saved in Fenhe Region under current planting scale. Finally, an optimization model for agricultural water transfer are formulated to the further study on agriculture water savings reallocation by maximizing incremental benefit of water resources. The interval linear function of agriculture water saving-effect and water production function of the second industry and tertiary industry have been introduced to obtain agriculture water transfer trend under various circumstances. For Fenhe Region, agriculture water transferring to the second industry (533×10^4 m^3) and tertiary industry (235×10^4 m^3) could bring an incremental benefit about 8.66–8.94 billion RMB, and 90.2–93.1 RMB for 1 m^3 of irrigation water, which exhibits a huge potential of economic benefit of agriculture water savings. The results indicate that optimization model for agricultural water transfer is an efficient way to analyze economic value of irrigation water and provide agriculture water transfer strategies.

1. Introduction

As water resources become scarce relative to accelerating process of industrialization and urbanization, effective management of limited available water resources becomes critical (Jiang, 2009). This is particularly true in regions where irrigated agriculture coexists with sectors like tourism and industry (Costa et al., 2007). The North China Plain is one of the most important agricultural regions in China because its food production accounts for about one-fifth of national food production (Zhang et al., 1999). Agriculture, industry, ecology in north China accounted for 65.8, 14.6, 6.2% respectively of the total water consumption in 2013. However, it is estimated that water use efficiency of agriculture irrigation in the North China Plain merely approach to 0.58. Hence agriculture have enormous potential to conserve water resources. Furthermore, water consumption of 10,000 RMB output value in agriculture and industry respectively approximated 531.53 and 70 m^3 (China Irrigation and Drainage Development Center, 2012; The Ministry of Water Resources of the People's Republic of China, 2014). There would be a huge increment by reallocation of saved water from

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Variable declaration

α	is rainfall utilization coefficient, 0.85
α^a	is the coefficients of rainfall infiltration, 0.15
α^i	is the coefficients of irrigation infiltration, 0.15
μ_k	specific yield of region k, 0.55
λ_{ji}	is water sensitivity index of crop j within growth stage i
η^c	is the water use efficiency of canal system from canal entrance to the billing gate.0.65
η_h	is conveying efficiency of water type h, h = 1,0.8, h = 2,0.85
A_k	is cultivated area of region k, ha
$A^a{}_k$	is area of the aquifer in region k, ha
$A^R{}_k$	is area of artificial recharge of region k, ha
A_{kj}	is cultivated area of crop j in region k, ha
$A_{\max k}$	is the upper limit of cultivated area in region k, ha
$A_{\min k}$	is the lower limit of cultivated area in region k, ha
AC_j	is the lower limit of cultivated area of crop j, ha
AW	is the total groundwater allowable withdrawal, 10^4 m^3
B_j	is market price of crop j, RMB/kg
BA	is output value of agriculture after agriculture transfer, billion RMB
BA′	is output value of agriculture before agriculture transfer, billion RMB
BS	is output value of secondary industry after agriculture transfer, billion RMB
BS′	is output value of secondary industry before agriculture transfer, billion RMB
BT	is output value of tertiary industry after agriculture transfer, billion RMB
BT′	is output value of tertiary industry before agriculture transfer, billion RMB
C_h	is price of water type h, RMB/m^3, h = 1,0.15, h = 2,0.3
E_{kt}	is soil evaporation within time period t in region k, mm, 0
EG_{kt}	is groundwater evaporation within time period t in region k, m^3
ET_{kji}	is the actual water consumption of crop j within growth stage i in region k, mm
ET_{kjt}	is actual water consumption of crop j within time period t in region k, mm
$ET_{\max ji}$	is maximum water consumption of crop j within growth stage i, mm
$ET_{\min ji}$	is minimum water consumption of crop j within growth stage i, mm
F_j	is investment of crop j, RMB/ha
$f(X)$	is agriculture water-saving quantity-output function
f(SW + SX)	is the water production function of second industry
f(TW + TX)	is the water production function of tertiary industry
h	is the index of water resource types
$H_{\max kt}$	is the lower limit of groundwater depth within time period t in region k, m
$H_{\min kt}$	is the upper limit of groundwater depth within time period t in region k, m
HE_{kt}	is groundwater depth of region k at the end of time period t, m
HS_{kt}	is groundwater depth of region k at the beginning of time period t, m
i	is the index of crop growth stages
I_{kjth}	is field water of type h from irrigation to crop j within time period t in region k, mm
j	is the index of crop
k	is the index of region
K_{kt}	is groundwater supplement for soil within time period t in region k, mm
mu	is the upper limit of multiple cropping index
P_{kt}	is precipitation within time period t in region k, mm
q_{jit}	is proportion of growth stage i of crop j in time period t
Q_{kjth}	is total water supply of type h from irrigation to crop j within time period t in region k, m^3
Q_{kjih}	is charging water of type h to crop j within stage i in region k, m^3
R_{kt}	is artificial recharge water within time period t in region k, mm, 0
SW	is water allocated to second industry under the current condition, 10^4 m^3
SX	is agricultural water transfer quantity for second industry, 10^4 m^3
T	is the index of time periods
TW	is water allocated to tertiary industry under the current condition, 10^4 m^3
TX	is agricultural water transfer quantity for tertiary industry, 10^4 m^3
V_{kt}	is groundwater extraction volume within time period t in region k, m^3
W	is annual surface water supply for Fendong District, m^3
W_{kt}	is total surface water supply within time period t in region k, m^3
$W^C{}_{kt}$	is canal leakage water within time period t in region k, m^3
$W^L{}_{kt}$	is groundwater recharge through weak permeable layer within time period t in region k, m^3
$W_{\max jt}$	is the upper bound of soil water content of crop j in time period t, mm
$W_{\min jt}$	is the lower bound of soil water content of crop j in time period t, mm
WE_{kjt}	is soil water content in cultivated area of crop j at the end of time period t in region k, mm
WS_{kjt}	is soil water content in cultivated area of crop j at the beginning of time period t in region k, mm
WSA	is the limit of agricultural water transfer quantity, 10^4 m^3
ΔWS_{kjt}	is variation of soil water content in cultivated area of crop j within time period t in region k caused by variation of root-zone, mm
X	is agricultural water-saving quantity, 10 m^3
$Y_{\max j}$	is maximum yield of crop j, kg/ha

agriculture to industry or service sectors in most developing countries (Gohari et al., 2013). Accordingly, it is quite significant to carry on the accurate assess of irrigation water saving potential and decide reasonable solutions of agriculture saving water reallocation in the premise of maximum appreciation.

Agricultural water-saving potential mainly consist of water savings generated by techniques, engineering project and water-saving management (planting structure adjustment, water resource rational allocation, optimal irrigation schedule and water right policy). Blanke et al. (2007) indicated that adoption of water-saving engineering methods and technology could bring