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The impact of land use change on water balance in Zhangye city, China

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ABSTRACT

Land use change has a significant effect on water balance, especially in arid region, such as Northwest China. In this paper, we analyze the effect of land use change on water balance in terms of the amount of water supply and demand from economic perspective. It's the first time to extend the basic 48 sectors input-output table to include water and land accounts that involved into multiple production processes for Zhangye city. We then perform the improved ORANI-G model, a single region Computable General Equilibrium (CGE) model, to analyze the effect of land use change on water balance under three scenarios. Subsequently, scenario-based simulation results are interpreted through selected sectors from agricultural, industrial, and service sectors respectively. Finally, the effect of land use change on water balance is analyzed through the difference between business-as-usual and land use unchanged scenarios. The results show that the extent of effect on water balance is different among sectors. Specifically, from the perspective of absolute value, service sectors are the largest, followed by industrial sectors, and the agricultural sectors are the least. Conversely, in terms of percentage change of land use, the largest extent of effect occurs in agricultural sectors. Additionally, with the rapid urbanization and the development of social economy, water balance in industrial sectors and service sectors will be stricken and reconstructed to a new high level. Simulation results also show that agricultural land shrinking will mitigate water scarcity distinctly, which indicates that balance the relationship among different stakeholders is imperative to guarantee water transformation from agricultural sectors to industrial and service sectors.

1. Introduction

With socioeconomic development, land use pattern changed significantly for direct human demand (Foley et al., 2005; Wada et al., 2011). However, Land use change (LUC) will disturb water balance (Foley et al., 2005; Schilling et al., 2008). In recent years, a multitude of studies have investigated the effect of LUCC on water balance (Awotwi et al., 2015; Bellot et al., 2007; Bhaskar and Welty, 2012; Branger et al., 2012; Haase and Nuissl, 2007; Tong et al., 2012; Twine et al., 2004; Wissmar et al., 2004), including the effect on surface water (Awotwi et al., 2015), runoff (Ellison et al., 2012; Kumar et al., 2013; Shi et al., 2007; Twine et al., 2004), evapotranspiration (Awotwi et al., 2015; Twine et al., 2004), rainfall (Ellison et al., 2012; Haase and Nuissl, 2007; Pielke et al., 2007), and groundwater recharge (He et al., 2009). In particular, LUC will distribute water balance seriously in arid regions. Deng et al. analyzed the impacts of LUC on water balance in Heihe River, which located in arid region of Northwest China (Deng et al., 2015). Besides, some scholars are trying to examine water balance in terms of the balance between water supply and water demand (Deng et al., 2014a,b; Rico-Amoros et al., 2009; Wada et al., 2011). Shen et al. found that serious water shortage will happen during April and May, and the situation will be worse in the future (Shen et al., 2013). In arid regions, it is difficult to increase the amount of water supply, however, the amount of water demand will continue to increase accompanied with dramatic LUC. Therefore, it is imperative to investigate the impact of LUC on water balance in detail for improving water management.

Serious water pollution and excessive water exploitation has exacerbated water scarcity, and value of water came to the awareness of scholars and public (Gibbons, 2013; Young and Loomis, 2014). Computable General Equilibrium (CGE) model is a reliable economic system model for supply and demand analysis. Previous studies integrate water into CGE model as a production

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factor to investigate water balance (Diao et al., 2008; Kim and Konan, 2004; McKinney, 1999). Kim et al. projected sector-based water demand for 2010, 2020, 2030 according to the data in basic year 1997, and found that water demand continued to increase. However, the increasing amplitudes are different under different scenarios (Kim and Konan, 2004). Glyn et al. thought that more available water for non-household users was obtained from households in 2013 compared with 2001 in Australia (Wittwer, 2006). Diao et al. analyzed the reciprocal influence between surface water and ground water use in Morocco (Diao et al., 2008). Maria et al. investigated water balance in Catalonia under different water management policies, and the result showed that the most important contradiction is to trade off water usage between economic development and eco-environment protection (Llop and Ponce Alifonso, 2012). To date, studies about the impact of LUC on water balance are underexplored. Moreover, there is few studies attempt to integrate LUC data into sectors of input-output table, which is the basic data of CGE model. In particular, land use data is not included in investigation for compiling input-output table in China, and there are no consistent land use categories that link and match input-output table. In this study, we integrate data of land using for production, which was visualized interpreted by remote sensing images and field investigation, into sectors of input-output table to examine the impact of LUC on water balance.

The per capita amount of freshwater in China only approximate 1/4 of world average, moreover, water shortage is increasingly serious, especially in arid Northwest China (Jiao, 2010). A serious water crisis has forced China's government to develop a specific plan for integrated water management, though the plan may be improper to a certain extent (Liu and Yang, 2012). The Tarim River, the largest inland river, has been suffering more and more intense water crisis (Stone, 2008). The Heihe River, the second largest inland river, seems to follow the pattern of development of the Tarim River. Therefore, it is necessary to enhance level of management to prevent water crisis. The objective in this study is to provide a quantitative reference for making a specific water management plan for the Heihe river basin.

2. Study area

Heihe River is the second largest inland river in China (Geng et al., 2014), and it plays an important role in economic development and ecological maintenance for Northwest China. Zhangye city is located in the midstream of the Heihe River and is also a critical node in “the Silk Road Economic Belt and the 21st-Century Maritime Silk Road” (B&R) (Fig. 1). The total GDP is 29192.80 million Chinese Yuan (approximate 4624.60 million US dollars) in Zhangye in 2012, which accounted for more than 80% of GDP in the Heihe River Basin. Zhangye city is the main region of economic activities and attracts 95% population in Heihe River Basin (Wu et al., 2014), and consequently Zhangye city is the major region of consuming water of productive use. Zhangye city is one of Chinese commodity grain bases, and main agricultural products are wheat, corn, oilseed, cotton, fruits and vegetables. Zhangye city provides a majority of grain and vegetables for Northwest China. From the perspective of value added in 2012, the dominant industries are Mining of Metal Ores, Manufacture of Foods and Tobacco, Construction, Traffic, Transport and Storage, Wholesale and Retail Trades, Public Management and Social Organization (Fig. 2).

The structure of water consumption among sectors in Zhangye follows the global pattern, because the agricultural sectors consumed almost all water of productive use (Figs. 3 and 4). Especially the rapid development of corn for seed has caused the rapid growth of amount of water demand in recent years. However, the downstream in the Heihe River required a large amount of water from the midstream to recover their ecology. Various influence factors have disequilibrated water balance in Zhangye city (Wissmar et al., 2004). Zhangye city began to attempt to develop eco-tourism, and the industrial transportation accompanied with LUCC will affect water balance. Therefore, it is necessary to analyze the effect of LUC on water balance, and the result will provide reference for water management in Zhangye city, even in Heihe River basin.

3. Data and methodology

3.1. Data

The basic data of CGE model is input output table. However, as there is no published prefecture-level city or county-level input-output table from statistical departments, we complied Zhangye city input-output table nested with land and water in 2012 (Deng et al., 2014a,b). The input output table is 48 sectors according to the 42 sectors national input output table, and disaggregating agriculture sector into 7 sectors which are main agricultural sectors introduced in introduction.

The most difficult work is to calculating the value of water and land during compiling input output table. As for land of agricultural data, we use area of sowing area from Zhangye Statistical Yearbook (2012) as land use data (Fig. 5), and use average land use rent 7500 yuan/ha (approximate 1181.12 dollars/ha) as price of land of agricultural sectors. As for land of non-agricultural sectors, we use the 0.6-meter spatial resolution remote sensing image from Google Earth, and interpreting these remote sensing images according to 41 non-agricultural sectors in input output table into vector format data. Furthermore, we calibrated the data through measuring each polygon on-site inspection, and adjust our result of interpretation slightly (Fig. 6). Since land is owned by government in China, therefore, using price of land remising divided land usage term as the price of each sector in input output table. Then, using area of land use in non-agricultural sectors calculating the corresponding area as the value of land in input output table.

As for water data, the main consuming sectors are agricultural sectors, the amount of water use of agricultural sectors are using water consumption coefficient which means quantity of water consumption that products per unit crop in each crop calculate the corresponding sowing area. As for the amount of water of non-agricultural sectors, we use information of water resources survey 2011 including 639 enterprises in Zhangye city, and mapping these enterprises into 41 non-agricultural sectors. What is more, the water includes surface water, underground water and other water (Fig. 4). Finally, using data in Gansu Water Resources Bulletin (2011), 2012 to calibrate the data in 48 sectors to guarantee the total amount of water use is accord with the amount of water use in Gansu Water Resources Bulletin (2012). As for water price, surface water is 0.01 yuan/m^3, underground water is 0.15 yuan/m^3, and other water price is referenced to tap water price. Using the amount of water use in 48 sectors calculating the corresponding price as the value of water in input output table.

3.2. Methodology

CGE model is a system economic model, and a powerful tool in analyzing the evolution of balance of economic system through changing exogenous influence factors. Therefore, it is applicable for us to analyze the evolution of water balance, and we regard LUC as the exogenous influence factor to analyze the effect of LUC on water balance. In this paper, the study area is a single region which is Zhangye city for long time sequence. Hence, we adopt a dynamic single country model, ORANI-G (A Generic Single-Country

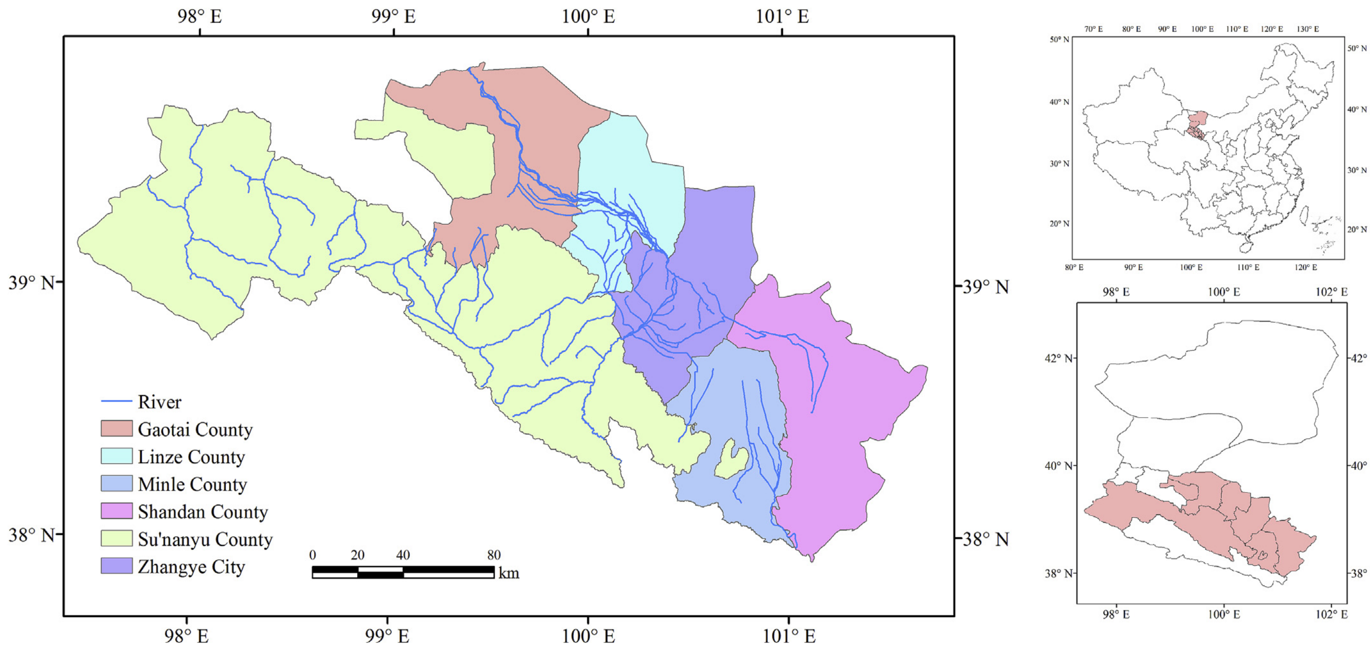

Fig. 1. The location of Zhangye city in midstream of Heihe River.

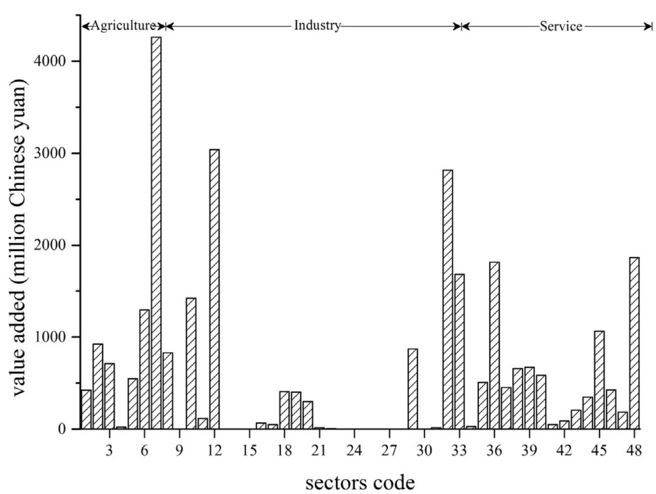

Fig. 2. Value added of 48 sectors in CGE model.

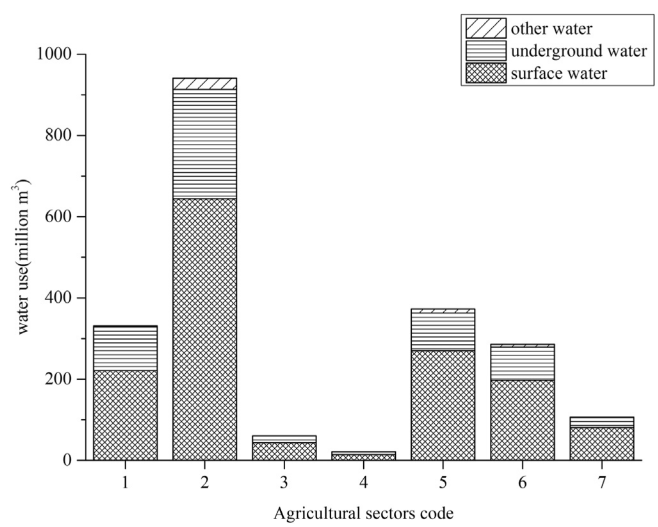

Fig. 3. Amount of water use in agricultural sectors.

Computable General Equilibrium Model). And then, we improve the model nested land and water to analyze the effect of LUC on water balance.

The ORANI-G is developed by CoPS (Centre of Policy Studies) in Australia (http://www.copsmodels.com/oranig.htm). And the model has been widely used by Australia and other countries (Zhan et al., 2015). The theory of the model is similar to that of other CGE model, and the main modules are production module, income distribution module, final demand module, trade module, commodity market equilibrium module, factor market equilibrium module, and the macro closure module. The main improvement is putting land and water into the model as primary factors in production module (Fig. 7). Surface water, underground water and other water are aggregated into water through CES (constant elasticity of substitution) function (Equations (1)–(4)). And then, water and land are aggregated into land and water through CES function as well. The main equations in the aggregation of land and water in production module (Equations (5)–(7)) are as followed.

$$SWT_i = sswt_i \cdot \left[\frac{PRWT_i}{PSWT_i}\right]^{\sigma rwt_i} \tag{1}$$

$$UWT_i = suwt_i \cdot \left[\frac{PRWT_i}{PUWT_i}\right]^{\sigma rwt_i} \tag{2}$$

$$OWT_i = sowt_i \cdot \left[\frac{PRWT_i}{POWT_i}\right]^{\sigma rwt_i} \tag{3}$$

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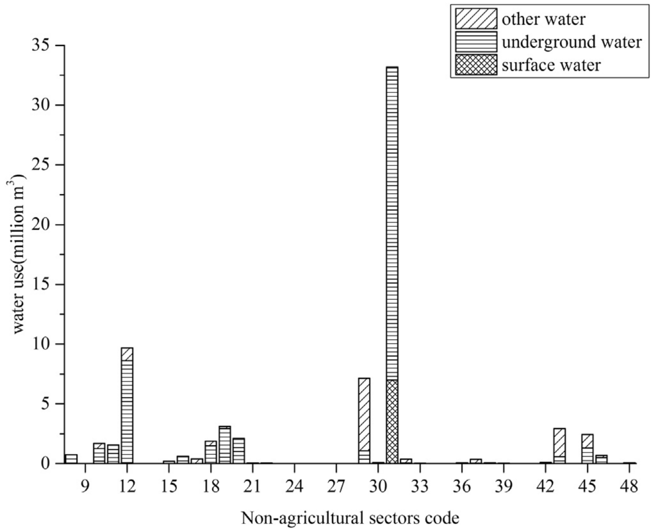

Fig. 4. Amount of water use in non-agricultural sectors.

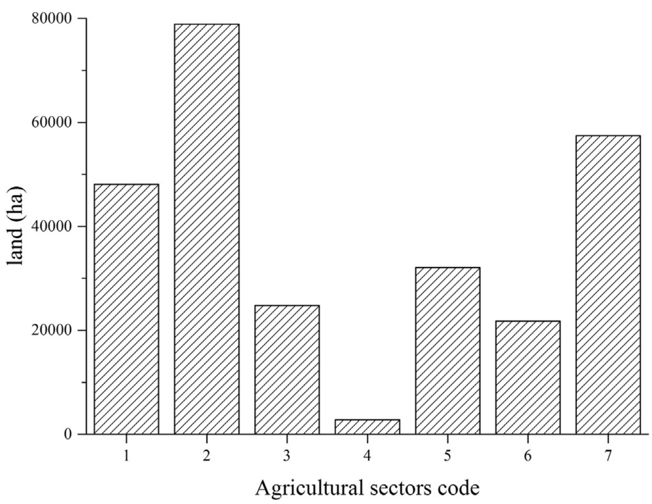

Fig. 5. Area of land of agricultural sectors.

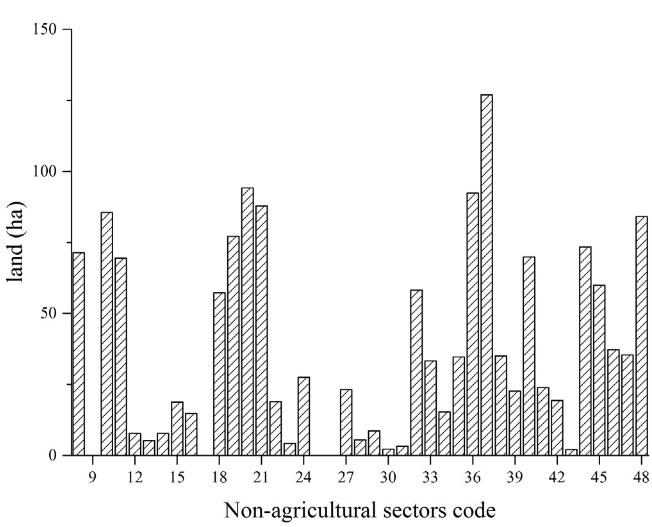

Fig. 6. Area of land of non-agricultural sectors.

$$PRWT_i = \left[srwt_i \cdot PSWT_i^{1-\sigma rwt_i} + suwt_i \cdot PUWT_i^{1-\sigma rwt_i} + sowt_i \cdot POWT^{1-\sigma rwt_i}\right]^{\frac{1}{1-\sigma rwt_i}} \quad (4)$$

$$RWT_i = srwt_i \cdot \left[\frac{PLWT_i}{PRWT_i}\right]^{\sigma lwt_i} \quad (5)$$

$$LND_i = slnd_i \cdot \left[\frac{PLWT_i}{PLND_i}\right]^{\sigma lwt_i} \quad (6)$$

$$PLWT_i = \left[srwt_i \cdot PRWT_i^{1-\sigma lwt_i} + slnd_i \cdot PLND_i^{1-\sigma lwt_i}\right]^{\frac{1}{1-\sigma lwt_i}} \quad (7)$$

There are three assumptions in this dynamic model. First, we assume that one-year gestation lag between investment and capital stock. Second, the relation between investment and the rate of profit is positive. Third, the relationship between wage growth and employment is negative. For capital accumulation, we adopt perpetual stock system method. The capital stock is equal to the investment plus the previous capital stock that has been deducted for depreciation (Equation (8)). For investment and the rate of profit, there are two parts. One is that the relationship between ratios of investment and capital and expected rates of return are positive (Equation (9)). The other is that expected rates of return converge to actual rates of return via a partial adjustment (Equation (10)). For the wage growth and employment, the real wage will rise by x% during the period when the employment exceeds some trend level by x% in the end of period (Equation (11)).

$$K_{i,t+1} = K_{i,t}(1 - D_i) + I_{i,t} \quad (8)$$

$$G_{i,t+1} = \frac{Q_i \cdot G_{i,trend} \cdot M_i^{\alpha}}{Q_i - 1 + M_i^{\alpha}} \quad (9)$$

$$G_{i,t+1} = \frac{Q_i \cdot G_{i,trend} \cdot M_i^{\alpha}}{Q_i - 1 + M_i^{\alpha}} \quad (10)$$

$$\frac{W_{i,t+1} - W_{i,t}}{W_{i,t}} = \gamma_i \left[\frac{L_{i,t}}{T_{i,t}} - 1\right] + \gamma_i \left[\frac{L_{i,t+1}}{T_{i,t+1}} - \frac{L_{i,t}}{T_{i,t}}\right] \quad (11)$$

3.3. Scenarios design

In this paper, LUC is referred to the land change for productive use in 48 sectors, and water balance is also the balance between supply and demand for productive use. In order to analyze the effect of LUC on water balance, we design three scenarios, including business as usual (BAU), land use unchanged scenario (LUU) namely land use keep the land use same with the condition in 2012, land use planning scenario (LUP). As for the BAU, LUC follows the trend of LUC from 1985 to 2008, which is 25 categories land use data from Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. However, these data are not one-to-to corresponding relation with 48 sectors in CGE model. Therefore, we create mapping relation between these LUC data and 48 sectors (Table 1). From the trend of LUC, we found that they basically correspond with linear fitting relationship. Therefore, we use the average percentage change from 1985 to 2008 as the percentage change of LUC in each sector referred to the mapping relationship. As for LUU, we keep the land use same

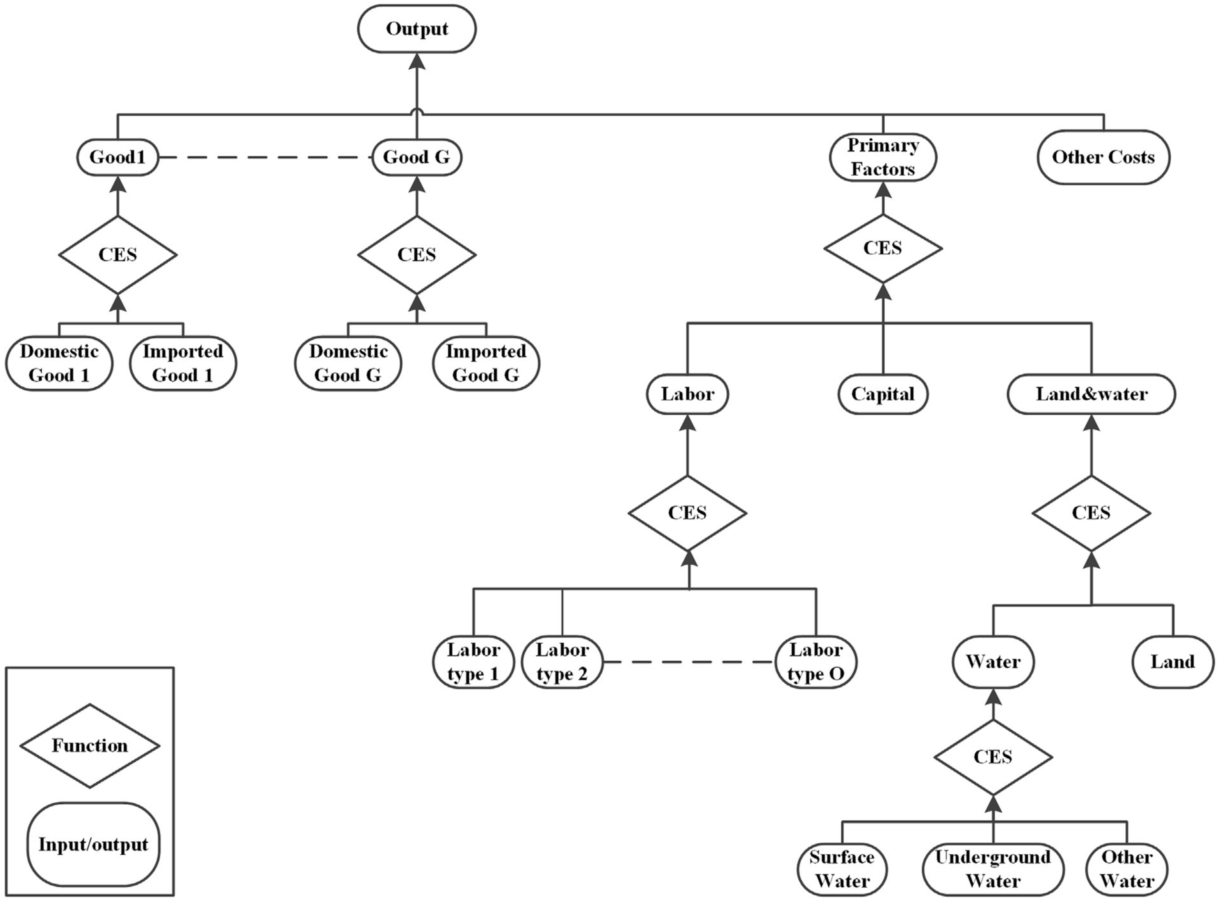

Fig. 7. Production module of improved ORANI-G model.

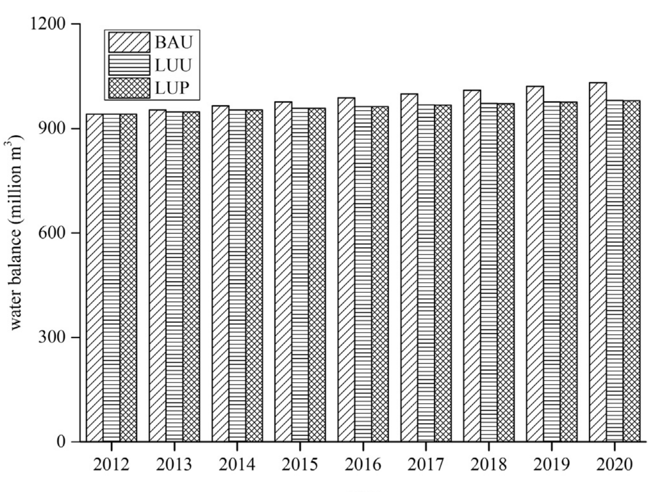

Fig. 8. Water balance of Corn from 2012 to 2020 under different scenarios.

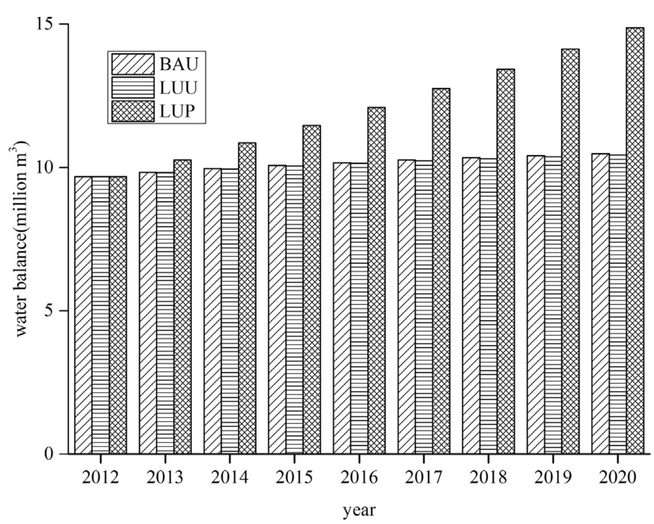

Fig. 9. Water balance of Manufacture of Foods and Tobacco from 2012 to 2020 under different scenarios.

with the condition in 2012. As for the LUP, we refer to Zhangye land use general planning 2006–2020 (http://gtj.zhangye.gov.cn/Item/15635.aspx). We assume that the growth of LUP is also correspond linear relationship from 2005 to 2020. Regarding the change of least cultivated areas as the change of agricultural sectors (1–7), the average change ratio of the least cultivated areas is −0.014% from 2005 to 2020. The average change ratio of other built-up land which stands for industrial sectors (8–32) is 5.16% from 2005 to 2020. The average change ratio of urban built-up land which stands for service sectors (33–48) is 25.59% from 2005 to 2020 (Table 2).

The only difference is LUC among different scenarios. Therefore, we can analyze the effect of LUC on water balance by comparing these three scenarios.

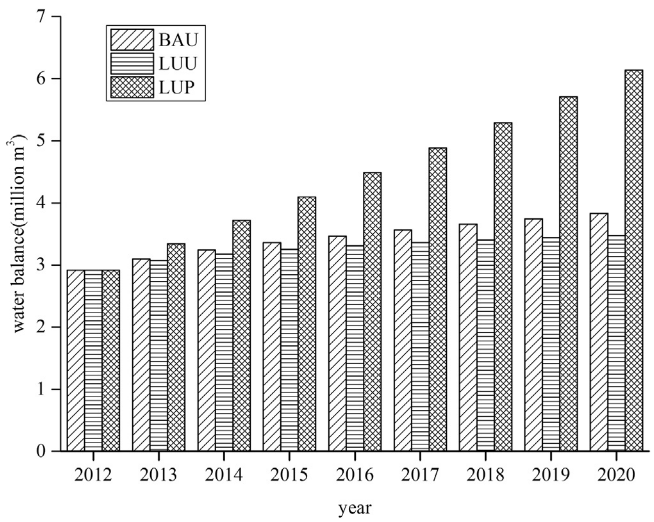

Fig. 10. Water balance of Management of Water Conservancy, Environment and Public Facilities from 2012 to 2020 under different scenarios.

4. Results and discussion

In order to guarantee the accuracy of the model, we first use real GDP to calibrate the model. The real GDP is 32608.36 million Chinese yuan (approximate 5165.68 million US dollars) at 2012 price from Gansu Statistical Yearbook (2014). The simulated value of 32609.34 million Chinese yuan (5165.84 US million dollars), the error is 0.003%. Therefore, we can use this model to analyze the effect of LUC on water balance.

Water balance data involves 48 sectors from 2012 to 2020 under three different scenarios, the information is detailed and complicated and it is difficult to show it in a lump. We choose one sector with most of water from agricultural sectors, industrial sectors, service sectors, separately.

In recent years, as shown in Fig. 8, corn especially corn for seed, has been developing rapidly, and water demand in corn has been increasing rapidly with the development of corn. As for BAU scenario, the land maintains the 0.67% growth rate each year from 2012 to 2020, namely grows from 78893.33 ha to 83222.52 ha, and water demand and water supply grows from 941.26 million m^3 to 1031.99 million m^3. As for LUU scenario, the land stays the same as the year 2012, however, the water demand and water supply grows slower than BAU. The water demand and water supply grows from 941.26 million m^3 to 980.26 million m^3 from 2012 to 2020. Compared with these two scenarios, the water demand and water supply reduces companied with land decreases. The land will reduce by 4329.19 ha and the water demand and water supply will reduce by 51.73 million m^3 under LUU compared with the BAU in 2020. This means that planting one less ha corn will consume 11949.12 m^3 less water in 2020. As for LUP, the land decrease 0.014% each year, and the water demand and water supply grows from 941.26 million m^3 to 979.58 million m^3. As for the trend of corn development, its planting began to decrease after reaching the peak, (http://www.zyny.gov.cn/zyny/zgxw/zyny/2015-02-02/19387.html), which will decrease water demand and water supply in the future, and this will mitigate water scarcity to a certain extent.

In Zhangye city, results in Fig. 9, the structure of manufacture is relatively simple. Manufacture of Foods and Tobacco sector is one of dominant industries, and it also uses the most water. Land use changed slightly in the past with the average growth rate of 0.06%. As for BAU, following the historical trend, land keeps annual 0.06% growth rate. The land grows from 7.77 ha to 7.81 ha from 2012 to 2020 accompanied with water demand and water supply from 9.68 million m^3 to 10.48 million m^3. As for LUU, it keeps the same as 7.77 ha, however, the water demand and water supply grows from 9.68 million m^3 to 10.44 million m^3. Compared with these two scenarios, the result is similar to the Corn sector. The land increases by 0.04 ha, however the water increases by 0.04 million m^3 under BAU scenario compared with LUU scenario in 2020. This means that increase by more one ha land in Manufacture of Foods and Tobacco will increase by 1 million m^3 in 2020. As for LUP, the land grows from 7.77 ha to 11.62 ha from 2012 to 2020, and the water demand and water supply grows from 9.68 million m^3 to 14.87 million m^3. If the development of Manufacture of Foods and Tobacco sector follows the planning scheme, the water demand and water supply will increase more 4.39 million m^3 than the BAU. With the socioeconomic development, manufacture will increase rapidly, especially

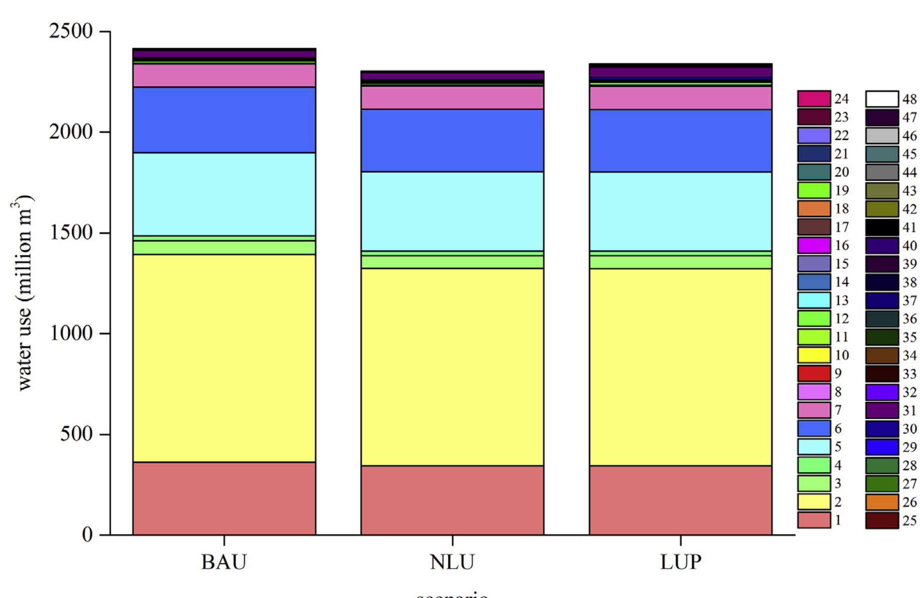

Fig. 11. Water balance of 48 sectors under different scenarios in 2020.

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Table 1
The mapping relationship between 25 categories and 48 sectors.

25 categories LUC in CAS	LUC code	48 sectors in IO table	Code of 48 sectors in IO table
Paddy land	11	Other agriculture	7
Dry land	12	Agricultural sectors	1,2,3,4,5,6
Forest	21	Other agriculture	7
Shrub land	22	Other agriculture	7
Woods	23	Other agriculture	7
Other forest	24	Other agriculture	7
Dense grass	31	Other agriculture	7
Moderate grass	32	Other agriculture	7
Sparse grass	33	Other agriculture	7
Stream and river	41	Other agriculture	7
Lake	42	Other agriculture	7
Reservoir and pond	43	Other Agriculture	7
Permanent ice and snow	44	Other agriculture	7
Beach and shore	45	Other agriculture	7
Bottomland	46	Other agriculture	7
Urban built-up land	51	Service sectors	33,34,… 48
Rural settlement	52	Not	Not
Other built-up land	53	Industrial sectors	8,9,10,… 32
Sandy land	61	Not	Not
Gobi	62	Not	Not
Salina	63	Not	Not
Swampland	64	Not	Not
Bare soil	65	Not	Not
Bare rock	66	Not	Not
other	67	Not	Not

Table 2
The trend of LUC from 1985 to 2008.

	1985–1995	1995–2000	2000–2005	2005–2008	1985–2008	Linear fitting (R^2)
Dry land	0.55%	0.31%	1.54%	0.001%	0.67%	0.93
Other agricultural land	−0.10%	−0.02%	−0.09%	0.04%	−0.06%	0.93
Urban built-up land	1.19%	0.36%	3.05%	0.23%	1.40%	0.92
Other built-up land	0.002%	0.01%	0.27%	0.00%	0.06%	0.65

dominant industries, and water demand have to increase absolutely.

Since 2010, shown in Fig. 10, Zhangye government has begun to promote service industries, especially ecological tourism. They took advantage of natural Danxia landform and wetland to construct ecological tourism scenic spots. These measures have extremely contributed to the economic development. From the result of BAU scenario, the land grows from 2.14 ha to 2.40 ha from 2012 to 2020, and water demand and water supply grows from 2.92 million m^3 to 3.83 million m^3 from 2012 to 2020. As for LUU scenario, the land stays same as 2.14 ha from 2012 to 2020, however, water demand and water supply grows from 2.92 million m^3 to 3.48 million m^3. The result is similar to above two sectors, the water demand and water supply grows accompanied with land increase. Compared with these two scenarios, water demand and water supply increases more 0.35 million m^3, and land increases more 0.26 ha under BAU than LUU. This means increasing more one ha in Management of Water Conservancy, Environment and Public Facilities sector will consume 1.35 million m^3 of water. As for LUP, the land keeps rapid growth rate, and the land grows form 2.14 ha–13.27 ha from 2012 to 2020. At the same time, water demand and water supply grows from 2.92 million m^3 to 6.14 million m^3. Zhangye is a critical node in the “Road and Belt Initiative”, and the speed of development will be accelerated in the next few years. Service industries have to be the focal point of development. What is more, Management of Water Conservancy, Environment and Public Facilities sector is a public service sector, and it plays an important role in guarantee water supply and adjustment for other sectors. Therefore, the sector will increase water demand accompanied with the development of other sectors.

Water balance change is along with LUC via the above analysis. Therefore, LUC will affect water balance, and the extent of effect is different from sectors. Moreover, with the economic development, the land of industries and service industries will increase rapidly, which will cause water demand increase rapidly. However, the land of agricultural sectors may decrease in the future, which will mitigate water scarcity to a certain extent.

In order to observe the integral water balance in 48 sectors clearly in the future, provided by the Fig. 11, we analyze the condition of water balance under three different scenarios in 2020. Compared with LUU, the land of agricultural sectors (except Other Agriculture sectors), industrial sectors, service sectors in BAU increases slightly, however, water balance increases a lot. The total water demand and water supply grows from 2189.49 million m^3 to 2414.64 million m^3 from 2012 to 2020 under the BAU scenario, however, water demand and water supply is 2303.35 million m^3 under LUU scenario in 2020. As for the LUP scenario, the land of agricultural sectors decreases moderately. While the land of service sectors increases sharply. The water demand and water supply, less than the BAU scenario in 2020, is 2339.61 million m^3. The result confirms that the land of service sectors increase will increase water demand, and the land of agricultural sectors decrease will mitigate water scarcity.

From the above analysis, we can find that the increase more one ha land in service sector will affect water balance a lot, the next is industrial sectors, the least is agricultural sectors. However, the area of land in agricultural sectors is the most. The slight percentage change in agricultural sectors will cause huge effect in integral water balance. On the other hand, the water balance under LUP scenario increase less than that under BAU scenario, however, the change of GDP is adverse. The result shows that the rapid development of service sectors will bring economic development with less water demand.

CGE model is based on the theory of general equilibrium, and model has unique solution if and only if supply and demand reach the balance, not only in production factor but also in commodity market. Water is nested into the model as a kind of production factor, and the supply and demand of water for productive use is regarded as reaching balance each year in the model. However, the projected water balance in the model maybe regarded as water demand in the long run. Through the latest study, Zhangye city has suffered from severe water scarcity and stress in recent years (Zhang et al., 2015). Moreover, farmland has been increased so much that causing over-extracted surface water and underground water in the midstream of Heihe River Basin in the past decades (Geng et al., 2014; Hu et al., 2015). Some scholars simulate the precipitation and found it will increase slowly, nevertheless, the total amount of water resources will continue to decline in the next 10 years (Liu et al., 2008). With the rapid urbanization and economic development, water usages for industrial production and municipal use have to increase. Therefore, the condition of imbalance between supply and demand in Zhangye city is not easy to change in the short run. In the above we suggest that reducing the land of agricultural sectors maybe mitigate water scarcity, and some scholars approve the method (Wang et al., 2015). However, intensive conflict arises among stakeholder groups in the process of water transform from agriculture to manufacture, because of the conflict in economic interest (Wang et al., 2015).

From the perspective of whole Heihe River Basin, the upstream is the source of water supply, and consuming water for producing and domestic consumption in the midstream, and supplying water for maintain ecological balance in the downstream which is desert. Zhangye city is the dominated part of the midstream, and is also the main region of consuming water of productive use in the Heihe River Basin. The more water is used for producing and domestic consumption, the less water is used for ecology, and the more water is used for the midstream the less water is used for the downstream. Based on Lu's study, increasing each 1000 tons of cereal in the midstream will reduce 0.052 million US dollars' ecosystem service values in the downstream (Lu et al., 2015). Furthermore, the water supply is not stable because of LUC and climate change (Geng et al., 2014). So it is difficult of maintain water balance is the whole basin as well.

In this paper, we used the detailed IO table nested water and land in Zhangye city to study the impact of land use change on water balance. Especially water and land data match with the sectors very precisely. Besides, we analyzed the water balance from the economic perspective. Nevertheless, there are some deficiencies in the paper. For example, there are no accurate matching between land use change and sectors in CGE model in designing scenarios because of insufficient data.

5. Conclusions

In this paper, we integrate accounts of water and land for productive use into the 48 sectors input-output table in Zhangye city. We improve ORANI-G model to analyze the effect of land use change on water balance under three scenarios. Compared with land use unchanged scenario, we analyze the effect of land use change on water balance following the historical trend under business-as-usual scenario.

The results show that the extent of effect on water balance is different among sectors, and from the perspective of absolute value, service sectors are the largest, seconded by industrial sectors, and the agricultural sectors are the least. Conversely, in terms of percentage change of land use dynamics, the largest extent of effect is in agricultural sectors. Because land and water for productive use in agricultural sectors accounts for the most, slight percentage of land in agricultural sectors will affect total water demand in Zhangye city distinctively. Comparing to agricultural sectors, each unit of land will consume more water in industrial sectors and service sectors. From the Zhangye land use general planning 2006–2020, land in industrial sectors and service sectors will continue to increase rapidly in the future. With the rapid urbanization and the socio-economic development, water demand in industrial sectors and service sectors will continue to increase, which will exacerbate water scarcity in Zhangye city. However, from the land use planning scenario, total water demand will decrease from 2012 to 2020, and GDP will increase compared with the business-as-usual scenario. Consequently, land conversion from agricultural to non-agricultural uses will mitigate water scarcity to some extent, which indicates that balance the relationship among different stakeholders is imperative to guarantee water transformation from agricultural sectors to industrial sectors and service sectors.

Author contributions

Zhongxiao Sun did modelling works and wrote the paper, Feng Wu did land use change data and designed scenarios, Chenchen Shi contributed to translation and revised the paper, Jinyan Zhan designed the structure of this paper and went through all sectional works.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A

Table A1
The mapping relationship between code and sectors in CGE model.

Code	Sector
1	Wheat
2	Corn
3	Oilseed
4	Cotton
5	Fruit
6	Vegetable

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Table A1 (*continued*)

Code	Sector
7	Other agriculture
8	Mining and washing of coal
9	Extraction of petroleum and natural gas
10	Mining of metal ores
11	Mining and processing of nonmetal ores and other ores
12	Manufacture of foods and tobacco
13	Manufacture of textiles
14	Manufacture of textile wearing apparel, footwear, caps, leather, fur, feather (Down) and its products
15	Processing of timbers and manufacture of furniture
16	Papermaking, printing and manufacture of articles for culture, education and sports activities
17	Processing of petroleum, coking, processing of nuclear fuel
18	Chemical industry
19	Manufacture of nonmetallic mineral products
20	Smelting and rolling of metals
21	Manufacture of metal products
22	Manufacture of general purpose and special purpose machinery
23	Manufacture of transport equipment
24	Manufacture of electrical machinery and equipment
25	Manufacture of communication equipment, computer and other electronic equipment
26	Manufacture of measuring instrument and machinery for cultural activity &office work
27	Manufacture of artwork, other manufacture
28	Scrap and waste
29	Production and supply of electric power and heat power
30	Production and distribution of gas
31	Production and distribution of water
32	Construction
33	Traffic, transport and storage
34	Post
35	Information transmission, computer services and software
36	Wholesale and retail trades
37	Hotels and catering services
38	Financial intermediation
39	Real estate
40	Leasing and business services
41	Research and experimental development
42	Comprehensive technical services
43	Management of water conservancy, environment and public facilities
44	Services to households and other services
45	Education
46	Health, social security and social welfare
47	Culture, sports and entertainment
48	Public management and social organization

Appendix B

Table B1
Description of parameters and variables in equations.

Variable name	Description
$SWTi$	Demand quantity of surface water
$UWTi$	Demand quantity of underground water
$OWTi$	Demand quantity of other water
$RWTi$	Demand quantity of aggregated water
$LWTi$	Demand quantity of aggregated water and land
$PSWTi$	Price of surface water
$PUWTi$	Price of underground water
$POWTi$	Price of other water
$PRWTi$	Price of aggregated water
$PLWTi$	Price of aggregated water and land
LND_i	Demand quantity of land
$PLND_i$	Price of land
$K_{i,t}$	Amount of capital
D_i	Rates of depreciation
$I_{i,t}$	Investment
$G_{i,t}$	Investment/capital ratio
$G_{i,trend}$	Trend investment/capital ratio
Q_i	(max/trend) investment/capital ratio
M_i^{α}	E/R_{normal}
$W_{i,t}$	Real wage

Table B1 (*continued*)

Variable name	Description
$L_{i,t}$	Actual employment
$T_{i,t}$	Trend employment
Parameter name	Description
σrwt_i	*Elasticity of substitution among different sources of water*
σlwt_i	*Elasticity of substitution between aggregated water and land*
$sswt_i$	*Share* of demand quantity of surface water
$suwt_i$	*Share* of demand quantity of underground water
$sowt_i$	*Share* of demand quantity of other water
$slnd_i$	*Share* of demand quantity of other water
γ_i	Adjustment coefficient
α	Investment elasticity

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