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Spatio-temporal analysis of driving factors of water resources consumption in China☆

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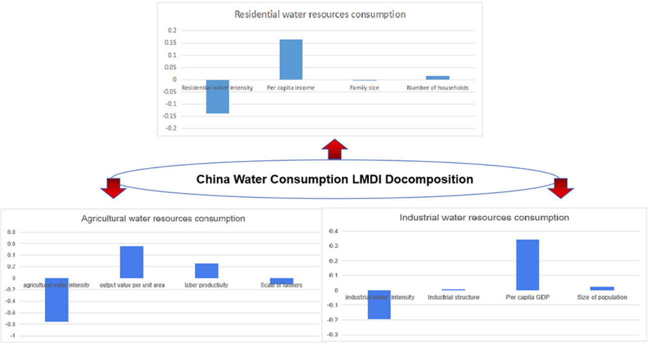
HIGHLIGHTS

- The driving factors and regional differences of water consumption are discussed.
- The LMDI addition decomposition is selected to expand the water theoretical method.
- The paper studies the differences of water use between provinces and cities.
- Different water-saving measures in different departments are proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

China is the largest consumer of water resources in the world, the total consumption of water resources is still increasing year by year. What are the main reasons for rising water resource consumption? This paper constructs China's spatio-temporal LMDI (the Logarithmic Mean Divisia Index) model to decompose water resources consumption into twelve driving factors with panel data from 2000 to 2015 and explores the main factors driving the rising water resource consumption. The results are summarized as following: (1) The intensity effect is the most important driving factor decreasing water resources consumption; (2) The loss of farmers reduces the water resources consumption in the agricultural sector, and the increase of urban population drives the rising water resource consumption in the residential sector; (3) The effect of industrial structure is different depending on regions; (4) In the agricultural sector, the driving factors have their own characteristics in each region.

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1. Introduction

Water resources are one of the most important factors to maintain the balance of the ecosystem, human survival and socio-economic development in China. However, along with the population growth, industrialization and urbanization, the shortage of water resources become apparent increasingly. This issue has been taken into account by the government and public, meanwhile, it has become one of the key factors

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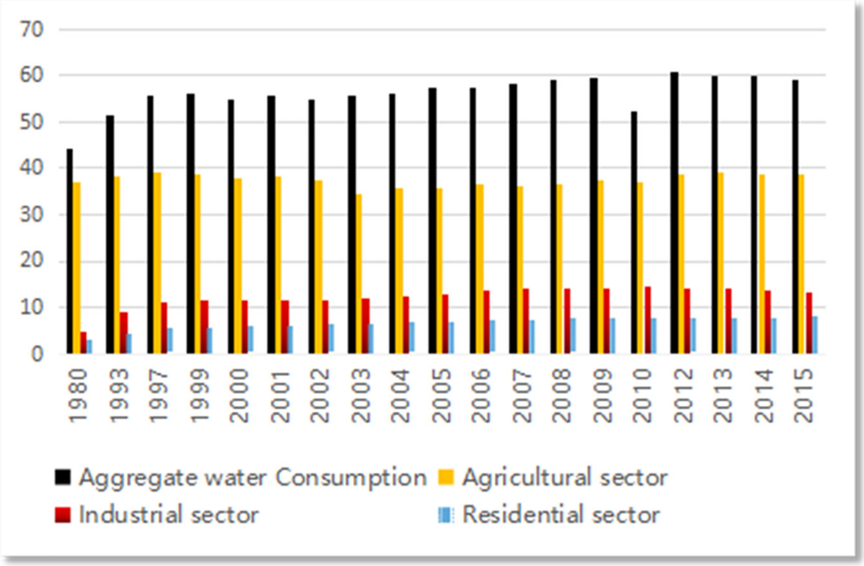

Fig. 1. Total consumption of water resources over the past year (100 million tons).
(data sources: China Statistical Yearbook)

hindering the sustainable development of a socio-economic and ecological environment in China.

From the perspective of total water resources consumption, China's total water resources consumption increased from 443.70 billion tons in 1980 to 507.50 billion tons in 2015 and peaked at 595.80 billion tons in 2008. Furthermore, in the industrial sector, water resources consumption increased from 45.70 billion tons to 133.40 billion tons, reaching a peak of 140.70 billion tons in 2007, and then gradually declined. In the residential sector, water resources consumption rose from 28 billion tons to 82.20 billion tons, with an average annual growth rate of 2.88%. Water resources consumption maintained invariably basically in the agricultural sector (Figs. 1 and 3). From the perspective of water structure, water resources consumption in the industrial sector accounted for 10.30% in 1980, while this in residential sector contributed about 6.30%. In 2015, the proportion was 26.20% in the industrial sector and 16.20% in the residential sector (Fig. 2).

The growth rate of water resources consumption is basically the same step with industrial development and mainly concentrate on high-energy consuming enterprises such as power, steel, petrochemical and textile. Gross industrial production increased from 515.40 billion yuan to 90.40 trillion yuan. The production of industrial products requires water resources for cooling, transmission, driving and cleaning, etc., which drives the rapid increase in water resources consumption. China population rose from 987 million in 1980 to 1375 million, and the urbanization rate increased from 19.39% in 1980 to 56.10% in 2015, which further pushed forward the increase in water resources consumption.

The increasing consumption of water resources has become one of the main factors restricting China's economic and social development. Reducing the growth rate of water resources consumption is taken more seriously. Based on the background, the paper pays attention to the influencing factors leading to increasing or decreasing water resources consumption. At the same time, in the light of their own characteristics in each region and in each sector, the paper studies water resources consumption by region and sector. This paper studies the above problems and promotes water resources conservation by altering the change speed of driving factors.

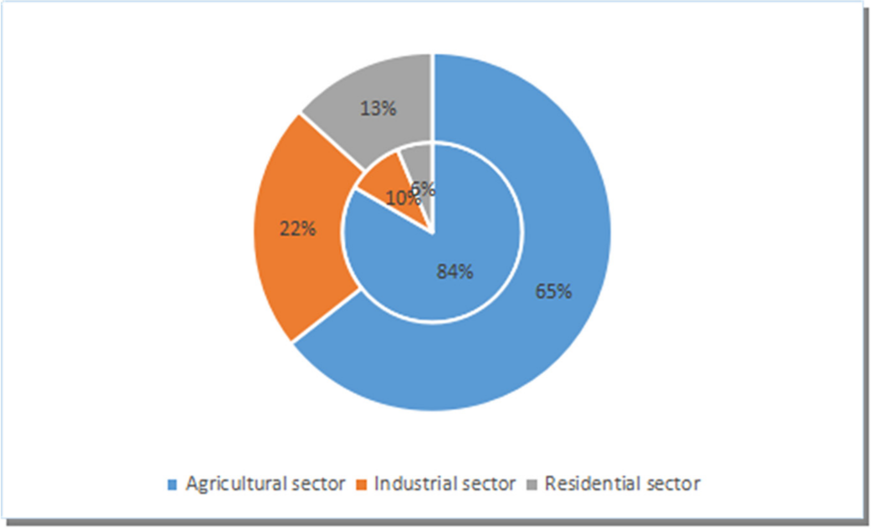

Fig. 2. Consumption structure of water resources.
(data sources: China Statistical Yearbook)

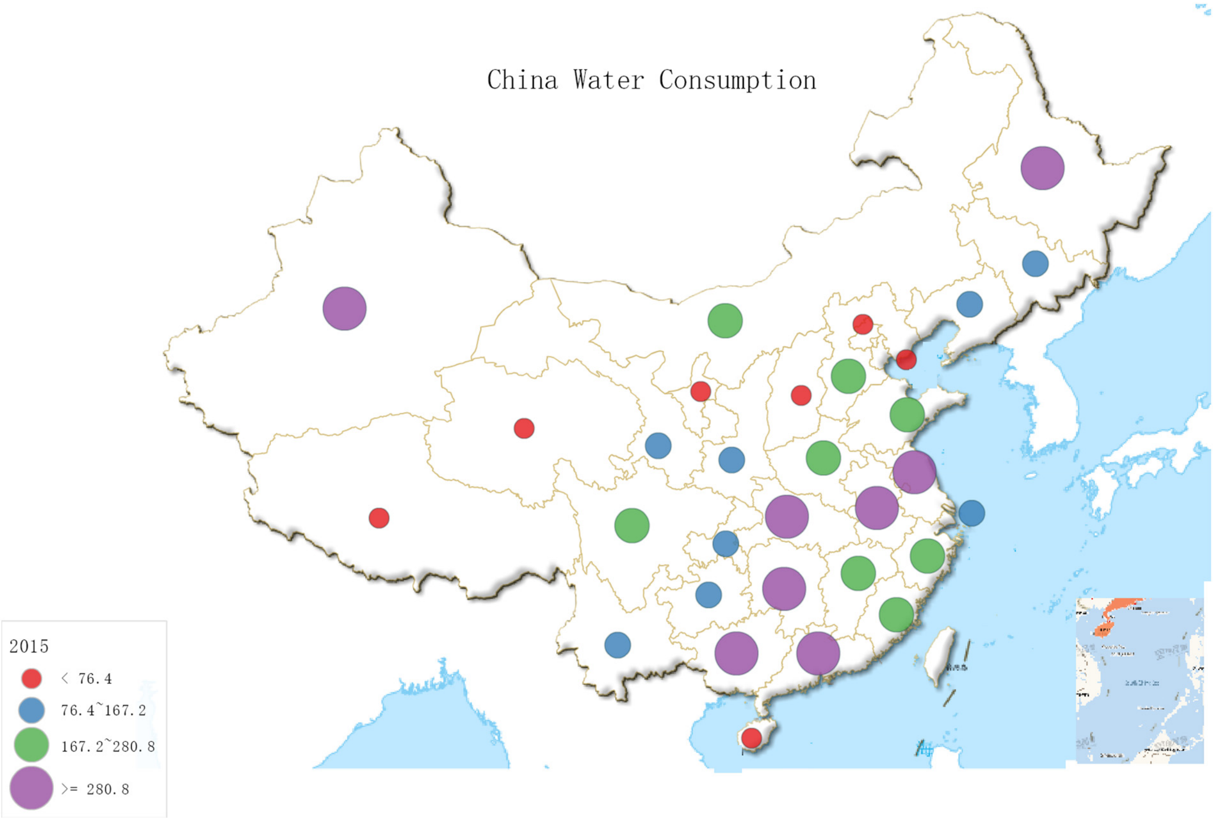

Fig. 3. China Water Consumption (2015).
(data sources: China Statistical Yearbook)

2. Literature review

Domestic and foreign scholars have numerous studies on water resources, mainly including five aspects. (1) The factor structure analysis of water resources consumption (Yu and Zhang, 2016); (2) The relationship between the consumption of water resources and economic development (Zhang and Zhang, 2014); (3) Predicting the gross of water resources consumption (Zhang and Shen, 2015); (4) Efficiency analysis of water resources consumption (Lei and Huang, 2015); (5) Efficiency analysis of wastewater discharge (Shen and Chen, 2015).

This paper mainly studies the factors influencing water resource consumption in various regions. Logarithmic Mean Divisia Index is chosen as the theoretical method. The exponential decomposition methods mainly include Laspeyres, Divisia, Sato-Vartia, thornqvist, Paasche, Marshall-Edgeworth, Stuvel, Fisher Ideal, etc. (Liu and Ang, 2003). Wherein, Divisia index is the method used in this paper. However, this method has two shortcomings. The first one is to decompose the remainder term. The sum of the total effect and each decomposition effect is not equal, that is, the error term is often not zero. If the error is too large, the decomposition is meaningless. The second one is that the zero value of data leads to the failure of decomposition (Ang and Choi, 1997). Therefore, introducing a logarithmic weight function, the problem of the remainder term would be effectively solved and the zero value problem would be significantly controlled.

The origin of the exponential decomposition method traced back to the 1980s, proposed by Hankinson and Rhys (1983), which was employed to study the change factors of electricity consumption in the UK. Reitler et al. (1987) pointed out that the decomposition method

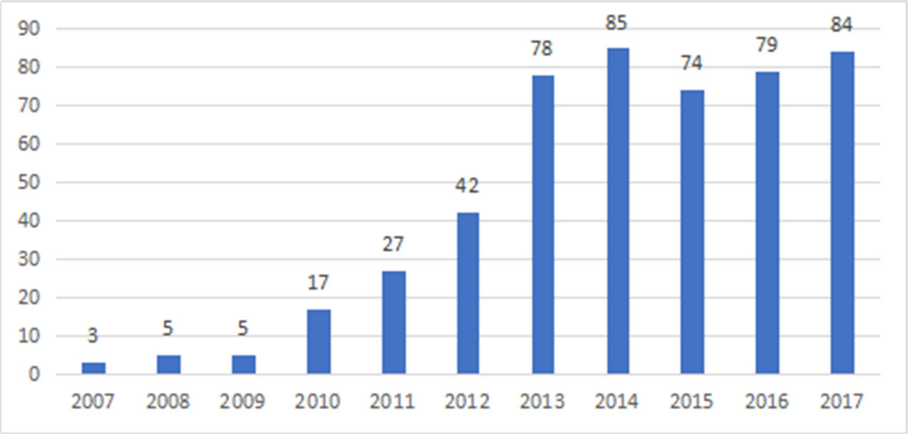

Fig. 4. The amount of relevant articles of LMDI in China.

Table 1
Indicator variable.

W_t	Total water resources consumption	PL_{it}	Agricultural labor productivity
AW_{it}	Agricultural water resources consumption	AP_{it}	Scale of farmers
IW_{it}	Industrial water resources consumption	GI_{it}	Industrial structure
LW_{it}	Residential water resources consumption	PG_{it}	Per capita GDP
AWI_{it}	The intensity of agricultural water resources consumption	P_{it}	Size of population
IWI_{it}	The intensity of industrial water resources consumption	WP_{it}	Per capita income
LWW_{it}	The intensity of residential water resources consumption	PH_{it}	Family size
LI_{it}	Agricultural output value per unit area of farmland	H_{it}	Number of households

produced different decomposition results because of the difference between the initial and final stages which were selected as the base years. And if they were both taken as the base years, the final effect was the average of the two effects. Boyd et al. (1987) was the first man who introduced the Divisia exponential decomposition method to study industrial energy consumption in the United States. Hpwarth et al. (1991) and Park (1992) introduced the Laspeyres index decomposition method. Liu et al. (1992) solved the integral path problem of Divisia exponential decomposition by the way of mean parameter estimation and included the methods of Reitler et al. (1987) and Boyd et al. (1987).Ang (1994) and Ang and Lee (1996) extended the method of Liu et al. (1992). Ang and Liu (2007) and Ang and Choi (1997) put forward the logarithmic weight function which can solve the problem of zero value and remainder term. Ang and Liu (2007) and Liu and Ang (2007) studied zero value data and negative value data respectively.

The LMDI method has been widely used in China. From 2007 to 2017, Twenty-eight articles were written on the study of water resources and water pollution, and forty-eight articles were about others. The chief representative of the study on the main influencing factors of water resource consumption was Zhang et al. (2014), while Zhang and Wu (2015) was the chief representative of the study on the main influencing factors of water pollution discharge (Fig. 4).

Research on water resources with LMDI is basically divided into two groups, regional group and sector group. In the aspect of regional group, Zhang et al. (2014b) studied the change of water intensity in the eastern, central and western regions of China, and found that the effect of industrial structure in the eastern region promoted the decline of total effect, and the degree of promotion was better than that in the central and western regions. Yao et al. (2019) and Zhang et al. (2018) used LMDI to study the spatio-temporal differences of water intensity in the Yangtze Economic Zone, and showed that technological progress and the adjustment of industrial structure were the main and secondary factors to restrain the increase of water resources consumption and promoted the decrease of water intensity. Chen et al. (2019) studied the driving factors of wastewater in the Yangtze Basin and found that the technical effect promoted the decline of wastewater discharge. Jia et al. (2004) found that industrial structure adjustment contributed to reducing average water resources consumption quota in Beijing. Liu and Bai (2012) found that scale effect was the main factor driving the increase of industrial water resources consumption in Anhui province. Zhang et al. (2014) believed that water-saving effect was also the main factor restraining the increase of industrial water resources consumption in Anhui province. In the aspect of sector group, Zhao et al. (2017) studied the water footprint of China's agricultural from 2001 to 2010 and found that the decline of the agricultural scale was the main reason for reducing agricultural water resources consumption. Chen (2012) thought that technological progress promotes the decline of water resources consumption in the industrial and agricultural sector. Chen and Wang (2011) show that the technological effect promotes the decline of industrial water resources consumption in China. Zhang and Wu (2015) studied that the driving factors of industrial wastewater discharge from 1998 to 2012, and found that economic growth was the main driving factor. Shang et al. (2017) studied industrial water resources consumption in Tianjin from 2003 to 2012 and found that economic growth played a leading role in the increase of water resources consumption.

The main influencing factors of water resources consumption can be summarized as economic growth, industrial restructure and technological progress. Some papers have made an analysis of regional heterogeneity from the perspective of the local region, but few papers have made a comprehensive analysis by region and sector. This paper has the following innovations on the basis of previous studies: (1) in the existing research results, the decomposition in the evolution trend of water resources consumption or in water intensity is mainly from the perspective of time, and there are few studies on the exponential decomposition of the factors affecting by region. That is to say, some papers studied the spatial factors or temporal factors respectively, without considering the comprehensive influence of spatio-temporal factors.

Table 2
2000–2015 the variation of driving factors in agricultural sector.

Year	aggregate of water resources consumption (100 million tons)	The variation of water resources consumption (100 million tons)	The intensity of water resources consumption (100 million tons/100 million Yuan)	Output value per unit area of farmland (100 million Yuan/thousand hectares)	Agricultural labor productivity (thousand hectares/100million people)	Scale of farmers (100 million people)
2000	4104.51					
2001	4066.84	−37.67	−153.33	83.56	49.05	−58.39
2002	3731.44	−335.40	−495.96	158.01	41.23	−632.11
2003	3432.81	−298.63	−359.73	96.54	18.49	−543.33
2004	3585.62	152.81	−351.88	473.89	86.42	361.23
2005	3580.02	−5.60	−264.78	216.31	105.60	51.53
2006	3664.45	84.43	−224.06	255.82	106.98	223.18
2007	3599.51	−64.94	−383.57	263.32	119.09	−66.10
2008	3663.47	63.96	−144.05	11.31	229.38	160.59
2009	3723.11	59.64	−265.19	270.81	80.85	146.11
2010	3689.04	−34.07	−678.47	578.09	100.56	−33.89
2011	3784.67	95.62	−199.17	208.61	94.01	199.06
2012	3880.29	95.62	−264.82	269.17	120.62	220.60
2013	3921.52	41.23	−214.86	159.23	143.98	129.57
2014	3869.00	−52.52	−221.84	113.41	101.54	−59.40
2015	3851.50	−17.50	−156.25	64.51	119.62	10.38

Table 3
2000–2015 the variation of driving factors in industrial sector.

Year	Aggregate of water resources consumption (100 million tons)	The variation of water resources consumption (100 million tons)	The intensity of water resources consumption (100 million tons/100 million Yuan)	Industrial structure (100 million Yuan/100 million Yuan)	Per capita GDP (100 million Yuan/100 million people)	Scale of population (100million people)
2000	665.34					
2001	710.12	44.78	−15.60	−4.65	59.19	83.71
2002	1141.80	431.68	334.25	−0.82	91.22	856.32
2003	1177.24	35.44	−154.62	43.70	136.68	61.21
2004	1228.75	51.51	−154.51	33.16	162.26	92.41
2005	1285.20	56.45	−172.64	43.89	186.33	114.03
2006	1343.76	58.56	−160.80	38.27	169.02	105.06
2007	1403.04	59.28	−139.38	7.98	177.95	105.83
2008	1397.09	−5.95	−182.99	11.29	153.25	−24.40
2009	1390.90	−6.19	−116.06	−36.26	134.47	−24.03
2010	1447.30	56.40	−211.56	52.35	205.86	103.05
2011	1435.59	−11.71	−209.95	10.71	180.05	−30.90
2012	1423.88	−11.71	−93.24	−30.25	104.43	−30.77
2013	1406.40	−17.48	−61.69	−59.96	96.92	−42.22
2014	1356.40	−50.00	−103.98	−30.91	78.05	−106.85
2015	1334.80	−21.60	−5.71	−78.62	55.29	−50.64

(2) The research on regional heterogeneity mainly focuses on the regional economy and regional population, while studies on regional economy mainly focus on economic growth, the adjustment of industrial structure and technological progress. There are few studies on regional population. As China is in the process of industrialization and urbanization, industrialization causes inter-province population flow and urbanization causes the transformation of population from countryside to city. This paper studies the effect of population flow between regions and industries. (3) Previous studies mainly focused on a certain region or industry, and there were almost no comprehensive studies on water resources by region and sector. This paper analyzes the comprehensive effect for the first time.

Based on the above background, this paper uses the method of LMDI to explore the main factors influencing the increase of water resource consumption from the time-space-sector perspectives. This paper is divided into five parts: the first part mainly introduces the aggregate and structure of water resources consumption in China; the second part mainly reviews the relevant research literature on water resources; the third part mainly establishes the LMDI model of water resources; the fourth part conducts empirical analysis and results in analysis; the fifth part mainly provide the conclusions and policy suggestions.

3. Method and variable declaration

According to the calculation types, LMDI methods are divided into addition and multiplication. According to the decomposition object, it is divided into aggregate decomposition and intensity decomposition. In this paper, the method of addition and aggregate decomposition are used to decompose the total effect of water resources consumption in two levels. In the first level, the effect is divided into three sectors: the agricultural sector, industrial sector and residential sector. In the second level, the effect of water resources consumption in the agricultural sector includes the intensity of agricultural water resources consumption, the agricultural output value per unit area of farmland, agricultural labor productivity and the scale of farmers; the effect of water resources consumption in industrial sector comprises the intensity of industrial water resources consumption, industrial structure, the per capita GDP and the size of population; the effect of water resources consumption in the residential sector involves the intensity of residential water resources consumption, per capita income, family size, and number of households. (Table 1).

$$\text{That is,}\ Wt = \sum_{i} AWit + IWit + LWit \tag{1}$$

Table 4
2000–2015 the variation of driving factors in residential sector.

Year	Aggregate of water resources consumption(100 million tons)	The variation of water resources consumption(100 million tons)	The intensity of water resources consumption (100 million tons/100 million Yuan)	Per capita income (100 million Yuan/100 million people)	Family size(100 million people/100 million households)	Number of households (100 million households)
2000	591.10					
2001	612.08	20.97	−29.28	46.77	3.91	42.37
2002	618.58	6.50	−57.11	59.35	0.69	9.44
2003	630.89	12.31	−25.39	32.66	0.63	20.20
2004	651.19	20.30	−39.45	54.59	−8.11	27.33
2005	675.09	23.90	−47.72	73.58	49.74	99.50
2006	693.76	18.67	−57.10	69.08	2.57	33.22
2007	710.39	16.64	−64.05	74.10	−1.11	25.58
2008	729.23	18.84	−48.77	60.36	15.14	45.57
2009	748.17	18.94	−62.08	74.00	−2.94	27.91
2010	765.83	17.66	−80.36	92.11	36.86	66.28
2011	747.33	−18.50	−88.22	65.56	8.41	−32.76
2012	728.82	−18.50	−103.10	80.29	−71.75	−113.06
2013	750.10	21.28	−43.98	61.18	−80.53	−42.06
2014	766.50	16.40	−45.60	57.85	−1.92	26.73
2015	794.00	27.50	−33.42	55.97	36.09	86.13

Table 5
the variation of driving factors in each region (100 million tons).

Area	North China	East China	Central China	Southwest China	Northeast China	South China	Northwest China
Agricultural sector	−64.93	−60.82	−317.85	−17.37	51.73	57.11	99.12
The intensity of water resources consumption	−435.16	−773.02	−971.34	−376.85	−515.55	−459.2	−846.83
Agricultural output value per unit area of farmland	334.71	648.59	553.95	278.72	296.77	444.76	665.11
Agricultural labor productivity	64.93	494.35	251.69	147.37	293.55	119.88	145.63
The scale of farmers	−29.41	−430.74	−152.15	−66.6	−23.04	−48.33	135.21
Industrial sector	29.67	250.44	215.65	74.66	15.27	58.87	24.9
The intensity of water resources consumption	−73.99	−514.31	−289.19	−182.03	−93.5	−247.68	−47.78
Industrial structure	−2.27	−46.48	46.83	8.39	−20.04	13.16	0.28
Per capita GDP	96.1	743.25	447.51	245.65	127.51	263.04	67.91
The size of population	9.82	67.97	10.5	2.65	1.3	30.34	4.49
Residential sector	10.7	78.52	29.65	34.38	0.41	40.45	8.8
The intensity of water resources consumption	−93.24	−213.83	−161.28	−95.08	−78.12	−134.15	−49.92
Per capita income	90.6	268.5	186.04	127.18	77.22	153.66	54.25
Family size	−2.41	−2.62	0.04	−1.07	−1.47	−3.61	−1.21
Number of households	15.75	26.47	4.85	3.34	2.78	24.55	5.68

$$\text{That is, } AWit = \mathrm{AWIit} * \mathrm{LIit} * \mathrm{PLit} * \mathrm{APit} \tag{2}$$

$$\text{That is, } \mathrm{IWit} = \mathrm{IWIit} * \mathrm{GIit} * \mathrm{PGit} * \mathrm{Pit} \tag{3}$$

$$\text{That is, } \mathrm{LWit} = \mathrm{LWWit} * \mathrm{WPit} * \mathrm{PHit} * \mathrm{Hit} \tag{4}$$

Derivation of formula (1) at both ends:

$$\frac{\mathrm{dWit}}{\mathrm{dt}} = \frac{dAWit}{\mathrm{dt}} + \frac{dIWit}{\mathrm{dt}} + \frac{dLWit}{\mathrm{dt}} \tag{5}$$

Taking formula (2) as an example, the following derivations are similar:

$$\begin{aligned} \frac{dAWit}{\mathrm{dt}} &= \frac{d(AWIit * \mathrm{LIit} * \mathrm{PLit} * \mathrm{APit})}{\mathrm{dt}} \\ &= \frac{dAWIit}{\mathrm{dt}} * \mathrm{LIit} * \mathrm{PLit} * \mathrm{APit} + AWIit * \frac{\mathrm{dLIit}}{\mathrm{dt}} * \mathrm{PLit} * \mathrm{APit} \\ &\quad + \mathrm{AWIit} * \mathrm{LIit} * \frac{\mathrm{dPLit}}{\mathrm{dt}} * \mathrm{APit} + AWIit * \mathrm{LIit} * \mathrm{PLit} * \frac{\mathrm{dAPit}}{\mathrm{dt}} \end{aligned} \tag{6}$$

Fig. 5. Agricultural sector in seven regions.

Integrate on both sides of formula (6):

$$\begin{aligned}
\int_{t\text{-}1}^{t} \frac{dAW_{\mathrm{it}}}{\mathrm{dt}}\mathrm{dt} &= \int_{t-1}^{t} \frac{d(AWI_{it} * \mathrm{LI_{it}} * \mathrm{PL_{it}} * \mathrm{AP_{it}})}{\mathrm{dt}}\mathrm{dt} = \int_{t\text{-}1}^{t} \frac{dAWI_{\mathrm{it}}}{\mathrm{dt}} * \mathrm{LI_{it}} * \mathrm{PL_{it}} * \mathrm{AP_{it}dt} \\
&\quad + \int_{t-1}^{t} AWI_{it} * \frac{\mathrm{dLI_{it}}}{\mathrm{dt}} * \mathrm{PL_{it}} * \mathrm{AP_{it}dt} + \int_{t-1}^{t} \mathrm{AWI_{it}} * \mathrm{LI_{it}} * \frac{\mathrm{dPL_{it}}}{\mathrm{dt}} * \mathrm{AP_{it}dt} \\
&\quad + \int_{t-1}^{t} AWI_{it} * \mathrm{LI_{it}} * \mathrm{PL_{it}} * \frac{\mathrm{dAP_{it}}}{\mathrm{dt}}\mathrm{dt} \\
&= \int_{t-1}^{t} \frac{dAWI_{\mathrm{it}}}{AWI_{it} * \mathrm{dt}} * AWI_{it} * \mathrm{LI_{it}} * \mathrm{PL_{it}} * \mathrm{AP_{it}dt} \\
&\quad + \int_{t-1}^{t} \frac{\mathrm{dLI_{it}}}{\mathrm{LI_{it}} * \mathrm{dt}} * AWI_{it} * \mathrm{LI_{it}} * \mathrm{PL_{it}} * \mathrm{AP_{it}dt} \\
&\quad + \int_{t\text{-}1}^{t} \frac{\mathrm{dPL_{it}}}{\mathrm{PL_{it}} * \mathrm{dt}} * AWI_{it} * \mathrm{LI_{it}} * \mathrm{PL_{it}} * \mathrm{AP_{it}dt} \qquad (7) \\
&\quad + \int_{t\text{-}1}^{t} \frac{\mathrm{dAP_{it}}}{\mathrm{AP_{it}} * \mathrm{dt}} * AWI_{it} * \mathrm{LI_{it}} * \mathrm{PL_{it}} * \mathrm{AP_{it}dtGiven} : wit \\
&= \mathrm{AWIit} * \mathrm{LIit} * \mathrm{PLit} * \mathrm{AP_{it}} = \int_{t-1}^{t} \frac{d\ \ln(AWIit)}{dt} * witdt \\
&\quad + \int_{t-1}^{t} \frac{d\ \ln(LIit)}{dt} * witdt + \int_{t-1}^{t} \frac{d\ \ln(PLit)}{dt} * witdt \\
&\quad + \int_{t-1}^{t} \frac{d\ \ln(APit)}{dt} * witdt
\end{aligned}$$

Because the $\mathrm{W_{it}}$ exact form of the function is uncertain, a logarithmic mean smoothing function is used. (Ang and Liu, 2007; Ang and Choi, 1997).

$$wit = L(AWit, AWit\text{-}1)\begin{cases} \dfrac{AWit - AWit\text{-}1}{\ln(AWit) - \ln(AWit\text{-}1)} & AWit \neq AWit\text{-}1 \\ AWit & AWit = AWit\text{-}1 \\ 0 & \mathrm{other}else \end{cases} \qquad (8)$$

Formula (7) becomes:

$$\begin{aligned}
&= L(AWit, AWiit\text{-}1)\left[\ln\left(\frac{AWIit}{AWIit-1}\right) + \ln\left(\frac{LIit}{LIit-1}\right) + \ln\left(\frac{PLit}{PLit-1}\right) + \ln\left(\frac{APit)}{APit}\right)\right] \\
&= L(AWit, AWiit\text{-}1)\ \ln\left(\frac{AWIit}{AWIit-1} * \frac{LIit}{LIit-1} * \frac{PLit}{PLit-1} * \frac{APit)}{APit}\right) \qquad (9) \\
&= \frac{AW_{it} - AW_{it\text{-}1}}{\ln(AW_{it}) - \ln(AW_{it\text{-}1})}\ \ln\frac{AW_{it}}{AW_{it-1}} = AWit - AWit\text{-}1
\end{aligned}$$

The logarithmic mean smoothing function is selected to solve the problem of remainder term. For the zero value problem, please refer to Ang and Liu (2007) and Ang and Choi (1997).

4. Data sources

Data of agricultural sector, industrial sector and residential sector used in various regions (provinces, municipalities, autonomous regions, and the following regions are the same) from 2000 to 2015 were obtained from *China Statistical Yearbook*. The missing data of 2011 have been completed with the average value of the data of 2010 and 2012. The per capita disposable income of urban residents (missing data of 2010, which has been supplemented by interpolation method) and the per capita net income of rural households all come from *China Statistical Yearbook*.

Rural population is equal to permanent resident population minus urban population. The number of households is equal to the ratio of permanent resident population to the population of each household multiplied by 100. Per capita households, disposable income is the sum of per capita disposable income of urban and rural households. Per capita, disposable income is derived from the ratio of per capita household disposable income to permanent resident population. Disposable income per household is equal to per capita disposable income multiplied by the population of each household. Total household income is equal to disposable income per household multiplied by the number of households.

5. Empirical analysis

According to formula (1)–(9) and data of each region from 2000 to 2015, this paper constructs China's spatio-temporal LMDI model to decompose water resources consumption into twelve driving factors and make an empirical analysis.

5.1. Temporal analysis on driving factors of water resources consumption

In terms of the agricultural sector (Table 2), both the intensity of agricultural water resources consumption and the scale of farmers have a decreasing effect on water resource consumption in the time series. Whereas, agricultural output value per unit area of farmland and agricultural labor productivity have an increasing effect.

The intensity effect of agricultural water resources consumption leads to the continuous decline of water resources consumption because of the improvement of sowing irrigation technology in agricultural sector.

sowing irrigation technology promotes the increase of production, then reduces the consumption of water resources per unit intensity. Due to the process of industrialization and urbanization, many farmers have moved from rural area to urban area. The decrease in farmers also reduces water resources consumption. Chemical fertilizer promotes agricultural output value per unit area of farmland, then drives the increase of water resources consumption. Agricultural labor productivity enhances cultivated area per farmer, then stimulate the increase of water resources consumption.

In the aspect of industrial sector (Table 3), there is an increase in water resources consumption before 2008, but it turns down after 2008. The intensity of water resources consumption drives the decline of water resources consumption because technological progress is beneficial to water-saving and lead to a decrease in water resources consumption per unit of output value. Industrial structure makes water resources consumption arose initially and decline at the end. The main reason is industrial upgrading after 2012, that the growth momentum shifts from the secondary industry to the tertiary industry. The per capita GDP and the size of population promote the growth of water resources consumption. Because they represent total consumption capacity of the region. The increase in total consumption capacity enhances water resources consumption.

In terms of residential sector (Table 4), the basic trend of water resources consumption is steadily increasing year by year, except a little fluctuation. The intensity of water resources consumption drives the decline of water resources consumption, and residents purchase more water-saving household appliance after the increase of income, then reduces the consumption of water resources. In the other side, the increase of per capita income makes residents buy more durable goods. For example, the number of washing machines per 100 households increased from 28 in 2000 to 86 in 2015, and the number of water heaters increased from 49 to 85, thus driving the increase of water resources consumption. The effect of family size and number of households is uncertain respectively, but the total effect is to promote the increase of water resources consumption because of urbanization.

Fig. 6. Industrial sector in seven regions.

5.2. Spatial analysis on driving factors of water resources consumption

This paper divides the country into seven regions, including North China, Northeast China, East China, South China, Central China, Southwest China and Northwest China, and calculates in each region. (Table 5).

In terms of agricultural sector, the positive and negative signs of every effect in all seven regions are the same not numerical values. Similarly, the positive and negative signs in all these seven regions are consistent with those of the whole country. The intensity effect of water resources consumption is negative, indicating that technological progress is the main factor decreasing the consumption of water resources. The effect of farmers scale is also negative, due to the development of urbanization, especially in East China where the speed of urbanization is fastest. While agricultural output value per unit area of farmland and agricultural labor productivity have an increasing effect (Fig. 5).

Water resources consumption declined in North, East, Central and Southwest China, but increased in Northeast, South and Northwest China. In the aspect of agricultural output, there is still room for further improvement in Northeast, South and Northwest China. The transfer speed of the rural population is relatively low, especially in Northwest China where the rural population has increased instead of transferring to cities.

In terms of industrial sector, the increase of water resources consumption in all regions indicates that China is still in the stage of late-industrialization. The intensity effect of water resources consumption pulls down water resources consumption. While the effect of industrial structure is not consistent in each region. There is a negative effect in North China, East China and Northeast China, and a positive effect in other regions, indicating that the adjustment of industrial structure holds a leading position in North China, East China and Northeast China. The increase of per capita GDP drives the growth of per capita consumption, while the rising scale of population promotes the increase of total demand, so the combined effect of per capita GDP and scale of population result in the enhancement of water resources consumption. From the perspective of the region, the influence of population scale is the smallest in Northeast China, the main reason is a great loss of population. About 3.42 million people were relocated from the three provinces in Northeast China from 2000 to 2015 (Qi et al., 2017) (Fig. 6).

In terms of residential sector, water resources consumption increased in every region. Therefore, the intensity of water resources consumption is negative, and the technical progress is the main reason. The increase of per capita income and the improvement of life quality will increase the consumption of water resources, coming from the use of household appliances, such as washing machines and water heaters. The effect of family size is negative, while the number of households has an opposite effect on water resources consumption. This is mainly because Chinese citizens who born in the third baby boom period from 1981 to 1990 gradually establish new families, and the original family size decreases and the number of households increases (Fig. 7).

The effect of population flow consists of the scale of farmers in agricultural sector and the size of population in the industrial sector. In the paper, the industrialization effect is the size of population and the urbanization effect is the sum of family size and number of households, Population flow effect is the sum of industrialization effect and urbanization effect. Every effect is in the following Table 6. The industrialization effect, the urbanization effect and total effect in every region are all positive values. That is to say, the process of industrialization and urbanization really promotes the increase in water resources consumption.

Fig. 7. residential sector in seven regions.

6. Conclusions and suggestions

6.1. Conclusions

In this paper, the LMDI method is adopted to analyze twelve driving factors of water resources consumption by region and sector, including intensity effect, income effect, scale effect, etc., with an emphasis on observing the impact of population flow and urban scale on water resources consumption.

In terms of agricultural sector, there are two sides of technological progress, one is the positive effect on agricultural output value per unit area of farmland, the other is the negative effect on intensity of water resources consumption. Finally, the comprehensive effect of technological progress is negative. The scale of farmers and agricultural labor productivity are the reverse effects of each other. The increase of labor productivity causes more labor flows to cities, and result in the decrease of farmers. Above all, technological progress and population mobility are the main reason for the decline of water resources consumption.

In terms of industrial sector, intensity effect of water resources consumption (that is, the progress of industrial technology) promotes the decline of water resources consumption. The effect of industrial structure is different in different regions, and both per capita GDP and population size have a positive effect on water resources consumption.

In terms of residential sector, the intensity of water resources consumption (technical progress of household appliances) promotes the decline of water resources consumption. Per capita income is the main factor in increasing water resources consumption, and the family size and the number of households have a negative effect on each other.

6.2. Suggestions

Based on the main results of the analysis, the following policy suggestions are put forward:

First, increasing equipment investment in agricultural, industrial and residential sector, which is related to the technology progress and intensity effects. The decreasing intensity effect basically depends on improving technical equipment improvement. The intensity effect is

Table 6
The effect of population flow (100 million tons).

Area	North China	East China	Central China	Southwest China	Northeast China	South China	Northwest China
The size of population	9.82	67.97	10.5	2.65	1.3	30.34	4.49
Industrialization effect	**9.82**	**67.97**	**10.5**	**2.65**	**1.3**	**30.34**	**4.49**
Family size	−2.41	−2.62	−0.04	−1.07	−1.47	−3.61	−1.21
Number of households	15.75	26.47	4.85	3.34	2.78	24.55	5.68
Urbanization effect	**13.34**	**23.85**	**4.89**	**2.27**	**1.31**	**20.94**	**4.47**
Total effect	**23.16**	**91.82**	**15.39**	**4.92**	**2.61**	**51.28**	**8.96**

The significance of bold is negative sign.

negative, indicating that technological progress is the main driving factor in decreasing water resources consumption. In the agricultural sector, we will increase input in agricultural irrigation, accelerate the replacement of irrigation equipment, reduce unnecessary waste in the process of irrigation, and make irrigation by pumping well more scientific in rural areas. In the industrial sector, the intensity of water resources consumption is taken as the main index to evaluate enterprises, forcing enterprises to invest more water-saving equipment. In the residential sector, the water-saving standards for newly-built communities should be improved, and the water facilities for old communities should be reconstructed.

Second, strengthening technical standard management during the process of urbanization. Urbanization is the population transformation from country to city， which is corresponded with population mobility (the scale of farmers and the size of the population) and population growth (family size and number of households). Urbanization is a necessary stage of China's development. People move to cities and increase water resources consumption. The government needs to make a formulation, guides the design of the community, strengthens publicity of water-saving, and controls water resources consumption at the source.

Last, guiding the adjustment of industrial structure, which is related to the driving factor of industrial structure. The adjustment of industrial structure in East and North China promotes the decline of water resources consumption, while the industrial structure in other regions urgently needs further adjustment. The government has issued corresponding measures to guide the decrease of water resources consumption through the adjustment of industrial structure.

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