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HR water consumption marginal benefits and its spatial–temporal disparities in Henan Province, China

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ABSTRACT

Water is one of the essential resources to production and living. Agriculture, industry, and living are considered as the direct water consumption. This paper employs the concept of marginal product value to estimate the water consumption marginal benefits in Henan Province. We use data on agricultural water consumption, industrial water consumption, and domestic water consumption of 18 cities in Henan Province surveyed from 2006 to 2013 and considered the Cobb–Douglas production function. The results showed that, during the study period, except for the marginal benefit of agriculture in high developed area, the industrial and domestic water use increased, and the industrial and domestic water use benefits were much higher than agricultural. At the same time, the benefit of the developed area was higher than the developing area. The benefits of agricultural water consumption and industrial water consumption in high developed area have made great improvements gradually, while benefits in low developed area have made small changes; but the benefits of domestic water consumption presented the opposite trend. For the moment, the water consumption marginal benefit still has climbing space. The results are needed for determining the ways in which scarce water resources could be assigned to different areas and sectors.

Keywords: Marginal benefit; Cobb–Douglas production function; Temporal–spatial difference; Henan Province

1. Introduction

The production of goods or service requires a combination such as labor, capital, equipment, and materials. Each of these inputs contributes to the total benefits of production. Water is also an essential input in such production processes. Previous studies about water resources have examined the value or price of water consumption [1–3]. First, in industrial water consumption, Ku et al. [4] calculated the output elasticity and value of industrial water on the basis of data on 53,912 manufacturing firms in Korea, Mejías et al. [5] evaluated the efficiency of industrial water-charging systems in Spain and Ireland. Second, in irrigation water consumption, the economic value of irrigation water was analyzed [6] and estimated using the residual imputation method in the Teesta River, Bangladesh [7], and Ohab-Yazdi and Ahmadi [8] used genetic-algorithm-based optimization model to evaluate the potential maximum net benefit of irrigation water. Third, in urban water consumption, Hester and Larson [9] used breakpoint and decomposition analyses to study changes in water use for three North Carolina cities between 1990 and 2014, and Ghimire et al. [10] determined the price and income elasticity of household water demand under the unified water price.

Different regions have different water consumption values or benefits due to their different economy [11–13], climate change [14], water supply and demand [15], water consumption structure [16], and water price [17–20]. In China, agriculture, industry, and living are considered as the main water consumption. First, the agricultural sector is the most domain users of water, accounting for up to 60% of the

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freshwater usage over the past decade. Second, industrial water consumption includes water used for fabrication, processing, washing, and cooling during industrial production. Third, domestic water use is defined as the amount of water that is available to the populations that are residing in cities and towns. In the case of water supply shortage, water consumption may not be able to meet all the water demands, and thus, sharing of the restricted water supply may become a focus issue of water management.

The objective of this paper is to propose a framework for understanding the marginal benefits of water consumption. Specifically, this paper attempt to evaluate the marginal benefits of agricultural, industrial, and domestic water consumption, and analyzes spatial and temporal disparities in Henan Province, China, in order to make effective decision in water management.

The rest of this paper is clearly presented as follows. The next section illustrates the marginal productivity approach in order to value water consumption. Section 3 provides the data set and presents the marginal benefits results. Section 4 analyzes the temporal and spatial disparity of marginal benefits. Section 5 uncovers the relationship between water marginal benefits and economic development. Section 6 concludes.

2. Materials and methods

2.1. Study area and data sources

Henan Province lies in the middle-east of China and at the middle-lower reaches the Yellow River, between 31°23′–36°22′ N and 110°21′–116°39′ E. Under its jurisdiction, there are 17 provincial cities, namely Zhengzhou, Kaifeng, Luoyang, Pingdingshan, Anyang, Hebi, Xinxiang, Jiaozuo, Puyang, Xuchang, Luohe, Sanmenxia, Nanyang, Shangqiu, Xinyang, Zhoukou and Zhumadian, and Jiyuan, the city under Henan's direct control. Henan's diversified land types, including mountainous regions, hills, plains, and basins, provide satisfactory conditions for the development of agriculture, forestry, livestock farming, and fishery.

There are four water systems, Yellow River, Huai River, Hai River, and Yangtze River, flowing across Henan. In 2013, the total water resources amount was 21.52 billion m^3, including surface water resources amount of 12.38 billion m^3, groundwater resources amount of 14.71 billion m^3 and repeated calculation amount of 5.57 billion m^3; water consumption per capita of 256 m^3 and if comparing with internationally minimum line of 1,000 m^3 for survival, Henan is of drastic shortage of water resources. Water resources have considerable changes in both space and time. In terms of time, Zhengzhou's per capita water resources was 160 m^3 in 2006 and 110 m^3 in 2013, 32% decrease over 7 years. In terms of space, there's an obvious difference in per capita water resources in different cities. In 2013, the maximum per capita water resources was 498 m^3 in Sanmenxia, and Zhengzhou only 110 m^3, less than 1/4 of that in Sanmenxia.

Henan's agricultural, industrial, domestic, and ecological water consumption accounted for 58.88%, 24.71%, 13.89%, and 2.52% in 2013. Apart from agricultural water consumption, all remaining ratios were higher than those at national average level (63.42%, 22.74%, 12.13%, and 1.71%), especially ecological water, 47.36% higher than the national average level.

The data laterally cover Henan's 18 cities including 17 provincial cities and 1 city under Henan's direct control, and longitudinally cover from 2006 to 2013. Data about output values and input indicators such as fixed assets investment and labors are mainly sourced from Henan Statistical Yearbook (2006–2013) [21], while data on water consumption are sourced from Henan Water Resources Bulletin (2006–2013) [22].

2.2. Cobb–Douglas production function

The Cobb–Douglas functional form of production functions is widely applied in relationships expression of an output to inputs in economics, which was proposed by Knut Wicksell, and withstand the test of statistical evidence by Charles Cobb and Paul Douglas [23]. They considered a simplified view of the economy in which production output is determined by the amount of labor involved and capital invested. While there are many other factors influencing economic performance, their model was proved to be significantly accurate. The function they used to simulate production was of the form:

$$P(L, K) = bL^{\alpha}K^{\beta} \quad (1)$$

where P is total production (the monetary value of all goods produced in a year); L is labor input (the total number of person hours worked in a year); K is capital input (the monetary worth of all machinery, equipment, and buildings); b is total factor productivity; α and β are the output elasticities of labor and capital, respectively. These values are constants determined by available technology. Output elasticity measures the responsiveness of output to a change in levels of either labor or capital used in production, ceteris paribus.

Further, if $\alpha + \beta = 1$, the production function has constant returns to scale. That is, if L and K are each increased by 20%, then P increases by 20%.

Returns to scale refer to a technical property of production that examines changes in output, which is subsequent to a proportional change in all inputs (where all inputs increase by a constant factor). If output increases by less than proportional change, there are decreasing returns to scale. If output increases by more than proportion, there are increasing returns to scale.

However, if $\alpha + \beta < 1$, returns to scale are decreasing, and if $\alpha + \beta > 1$, returns to scale are increasing. Assuming perfect competition, α and β can be shown to be labor and capital's share of output.

2.3. Marginal productivity function of water based on C-D

A marginal productivity function of water can be presented by adopting a routine derivative of a production function [24–29]. A production function can be established as $Y = f(L, K, M)$, where Y is the production or output, K is capital, L is labor, and W is water. Then, the marginal productivity of water is $\partial Y/\partial W$.

In particular, the production function with capital, labor, and water can be defined as

$$\ln Y = \ln A + \alpha \ln L + \beta \ln K + \gamma \ln W \quad (2)$$

The elasticity of production for each factor of production is calculated by taking the partial derivative of the production in regard to the factor. For water, this elasticity can be represented as

$$\gamma=\frac{\partial Y/Y}{\partial W/W} \tag{3}$$

The marginal productivity of water in production then is

$$\frac{\partial Y}{\partial W}=\gamma\cdot\frac{Y}{W} \tag{4}$$

3. Results

The marginal benefits of water consumption can be calculated by marginal productivity function of water based on C-D. Regression analysis adopted by modeling used special computer analysis software, such as SPSS. The results are shown in Tables 1–3.

4. Discussion

In terms of marginal benefits of water consumption, its temporal disparity uses year as the decision-making unit to reflect changes of water benefits at different stages in different areas; while its spatial disparity uses city as the decision-making unit to reflect differences in water benefits in different regions at the same stage.

4.1. Temporal disparity

First, we analyzed Henan's year by year changes in marginal benefits of water consumption. The average agricultural, industrial, and domestic water marginal benefits demonstrated an upgrade tendency from 2006 to 2013, showing that Henan's value of output constantly elevated along with the economic development and the scarcity of water resources. The average marginal benefit of agricultural water owned the biggest increase, which increased 132%.

Second, we divided 18 cities in high development areas, moderate development areas and low development areas by GDP (Gross Domestic Product) per capita. High development areas with GDP per capita over RMB (Ren Min Bi,¥) 50,000, which contains Zhengzhou, Jiyuan, and Sanmenxia; moderate development areas with GDP per capita of RMB 50,000–30,000 mainly in northern Henan; low development areas with per capita less than RMB 30,000, mainly in southeastern Henan (as shown in Fig. 1(a)). Based on Figs. 1(b)–(d), we found that apart from marginal benefit of agricultural water in high development areas in 2013, all marginal benefits increased year by year during the period of research, and the marginal benefits of high development areas were higher than those of high development areas. The growth rates of marginal benefits from 2006 to 2013 are described in Table 4. In terms of growth rates, the agricultural and industrial marginal benefits in high development areas were all higher than those in moderate and low development areas. That means benefits of agricultural and industrial water in high development areas were significantly promoted over time and benefits in moderate and low development areas were elevated in a slight manner. But the marginal benefit growth rate of domestic water showed an opposite trend. The results indicated that Henan's high development areas get high outputs of water resources for their advance science and technology and reasonable industrial structure, however, their output of investments in water resources is less than that in low development areas because of their well-developed tertiary industry.

Table 1
Marginal benefit of agricultural water consumption (￥/m³)

Area	2006	2007	2008	2009	2010	2011	2012	2013	Average
Zhengzhou	7.82	8.49	10.27	11.54	15.45	21.56	23.11	21.80	15.00
Kaifeng	1.35	1.55	1.21	1.21	2.38	2.62	2.95	2.82	2.01
Luoyang	13.12	17.69	18.79	21.16	22.60	25.28	26.36	26.33	21.42
Pingdingshan	5.74	7.17	9.55	10.64	13.16	16.71	19.01	24.54	13.31
Anyang	0.65	0.73	1.18	1.29	1.62	1.98	1.86	1.57	1.36
Hebi	2.72	2.48	3.40	3.42	4.47	5.99	6.02	5.66	4.27
Xinxiang	2.64	3.76	4.50	4.09	5.15	6.24	6.27	5.94	4.82
Jiaozuo	0.41	0.56	0.65	0.65	0.87	1.09	1.11	1.12	0.81
Puyang	3.71	4.58	5.92	5.68	6.94	7.79	8.44	8.09	6.39
Xuchang	2.87	4.23	6.06	5.34	6.09	6.35	5.98	6.79	5.47
Luohe	3.59	4.22	4.41	4.76	5.75	6.55	5.37	5.43	5.01
Sanmenxia	2.89	3.76	4.32	4.73	5.41	5.95	6.81	6.77	5.08
Nanyang	0.40	0.50	0.48	0.46	0.64	0.60	0.58	0.58	0.53
Shangqiu	1.61	2.97	2.10	2.15	2.53	2.61	2.48	2.33	2.35
Xinyang	0.86	1.75	1.36	1.47	1.70	1.87	2.17	2.44	1.70
Zhoukou	1.23	1.30	1.34	1.34	1.55	1.76	1.85	2.04	1.55
Zhumadian	5.70	6.40	6.07	6.25	6.71	6.37	6.70	10.66	6.86
Jiyuan	2.94	3.54	4.44	3.99	3.87	6.57	4.92	5.06	4.42

Table 2
Marginal benefit of industrial water consumption (￥/m³)

Area	2006	2007	2008	2009	2010	2011	2012	2013	Average
Zhengzhou	61.35	73.78	86.20	103.09	123.96	155.03	167.81	181.42	119.08
Kaifeng	24.78	26.06	28.16	25.67	26.62	30.98	33.90	36.58	29.09
Luoyang	26.54	31.99	35.96	34.46	40.06	47.12	49.63	52.52	39.79
Pingdingshan	22.20	25.99	32.31	32.45	33.55	34.57	19.76	19.78	27.58
Anyang	49.64	73.10	100.13	91.54	106.57	96.78	94.30	110.19	90.28
Hebi	26.51	33.44	40.39	49.86	61.96	67.08	66.56	84.42	53.78
Xinxiang	59.66	64.12	72.94	78.89	99.63	125.18	128.24	146.06	96.84
Jiaozuo	41.31	57.23	60.48	62.40	71.26	81.10	82.97	96.71	69.18
Puyang	65.42	65.85	76.84	76.40	86.35	85.43	92.83	106.16	81.91
Xuchang	2.80	3.10	5.20	5.10	5.80	6.60	6.90	8.60	5.51
Luohe	22.81	45.67	51.16	53.56	55.45	55.87	57.58	73.56	51.96
Sanmenxia	74.11	84.69	100.20	101.42	137.91	149.58	156.53	181.99	123.30
Nanyang	14.20	15.96	22.93	23.76	27.13	36.47	41.33	37.31	27.39
Shangqiu	7.34	7.77	9.70	10.20	14.20	15.21	14.66	15.81	11.86
Xinyang	32.49	38.49	46.19	44.01	49.15	59.05	59.16	73.76	50.29
Zhoukou	46.66	46.85	54.77	55.36	57.65	67.96	78.14	90.17	62.20
Zhumadian	87.25	94.06	109.27	114.99	132.87	136.45	147.25	164.42	123.32
Jiyuan	17.75	19.59	23.46	21.68	30.16	27.41	28.83	37.85	25.84

Table 3
Marginal benefit of domestic water consumption (￥/m³)

Area	2006	2007	2008	2009	2010	2011	2012	2013	Average
Zhengzhou	198.82	213.89	237.95	267.63	294.38	307.41	351.05	370	280.14
Kaifeng	59.63	80.33	104.29	105.29	128.82	152.02	162.09	181.58	121.76
Luoyang	6.62	7.78	8.65	10.02	10.41	11.52	13.62	14.18	10.35
Pingdingshan	71.95	85.29	97.48	110.08	123.98	131.69	158.78	173.18	119.05
Anyang	10.06	12.3	15.75	17.27	18.66	23.34	25.29	25.71	18.55
Hebi	10.4	13.7	12.44	13.96	14.06	16.04	16.86	17.76	14.4
Xinxiang	81.32	103.13	100.2	100.9	114.97	142.96	162.37	185.93	123.97
Jiaozuo	62.87	84.16	82.63	88.43	95.14	106.41	111.6	118.35	93.7
Puyang	57.42	62.56	64.52	71.72	82.2	88.37	103.02	107.21	79.63
Xuchang	50.07	63.72	46.47	50.89	57.5	73.38	83.23	92.83	64.76
Luohe	23.15	27.83	35.46	46.61	53.65	47.79	52.13	56.51	42.89
Sanmenxia	38.78	45.5	54.83	58.03	65.7	91.38	89.13	88.92	66.53
Nanyang	9.96	10.32	11.34	12.5	12.46	15.73	18.26	19.66	13.78
Shangqiu	5.87	4.95	6.09	6.64	7.59	9.96	11.37	11.8	8.03
Xinyang	45.58	52.07	62.20	66.01	81.46	82.26	80.01	92.43	70.25
Zhoukou	5.93	6.99	6.27	7.6	8.92	9.86	11.28	12.55	8.68
Zhumadian	23.77	29.52	34.08	37.44	46.89	59.02	62.83	63.15	44.59
Jiyuan	49.55	48.49	54.37	63.99	78.36	81.32	74.22	76.91	65.90

4.2. Spatial disparity

To further analyzing Henan's spatial disparities in marginal benefits of water consumption, we divided average marginal benefits of agricultural, industrial, and domestic water from 2006 to 2013 into high, moderate, and low areas as shown in Fig. 2.

For agricultural water, Zhengzhou, Luoyang, and Pingdingshan had the highest marginal benefits, Puyang, Xuchang, Luohe, Sanmen, and Zhumadian came second, while others had the lowest. (1) High benefit areas are represented by Zhengzhou, whose marginal benefit of agricultural water decreased from its extremum of RMB 23.11/m³ in 2012 to RMB 21.80/m³ in 2013. Zhengzhou had a high benefit of agricultural water because of its advanced agricultural irrigation and planting technology, but the low elastic coefficient of agricultural water (−0.882) suggested that water input was in

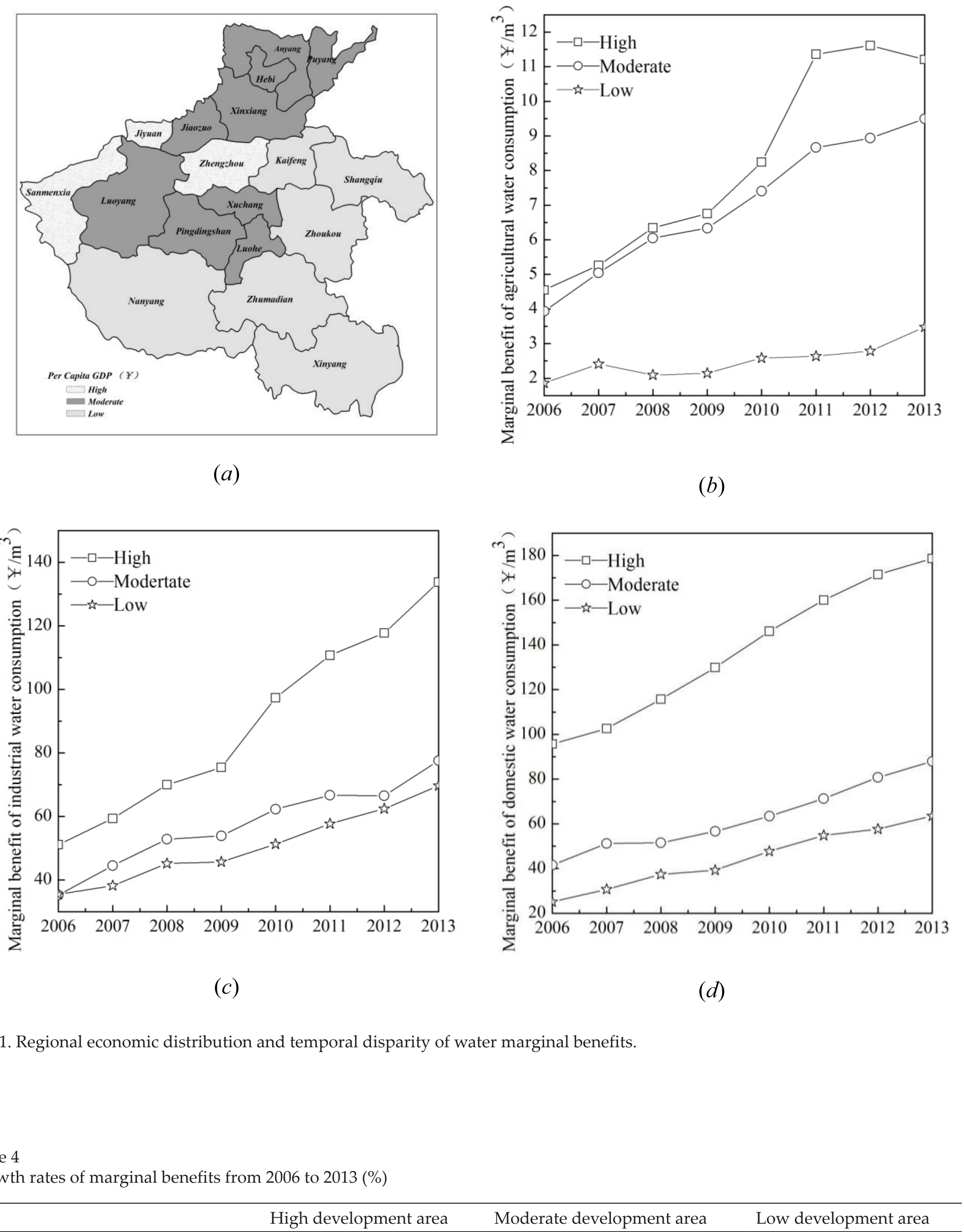

Fig. 1. Regional economic distribution and temporal disparity of water marginal benefits.

Table 4
Growth rates of marginal benefits from 2006 to 2013 (%)

	High development area	Moderate development area	Low development area
Agricultural water consumption	146.37	141.10	87.18
Industrial water consumption	161.90	120.27	96.53
Domestic water consumption	86.60	111.75	152.87

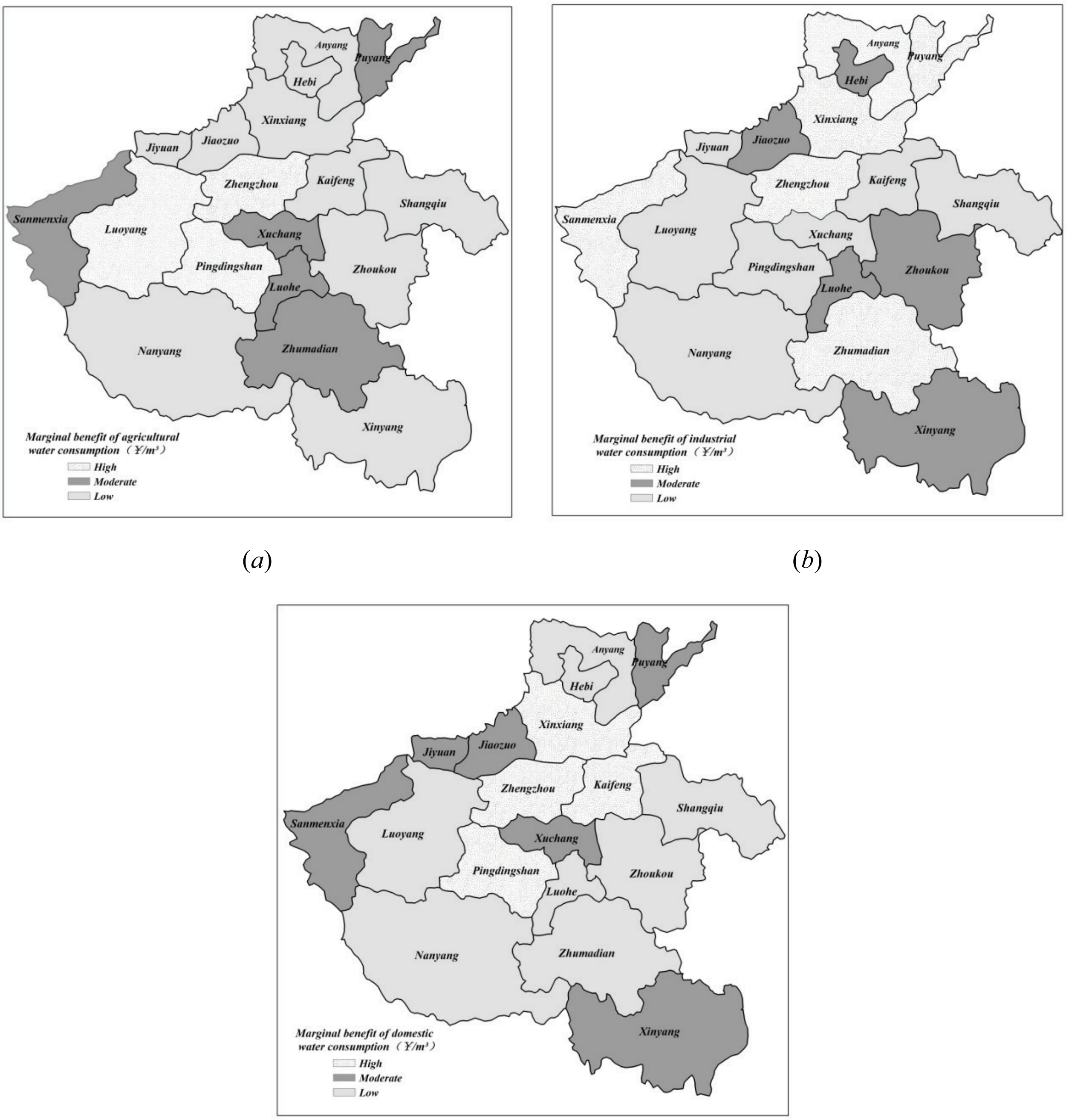

Fig. 2. Spatial disparity of water marginal benefits.

negative correlation with agricultural output when economy and technology have progressed to certain advanced levels. Zhengzhou's elastic coefficients of agricultural labor and fixed assets investment were −0.188 and 0.212, respectively, showing that at present technology level, marginal benefit of agricultural water could be added by investing in water conservancy facilities, and agricultural machines. (2) Moderate benefit areas are represented by Zhumadian, whose marginal benefit of agricultural water lifted from RMB 5.70/m^3 to RMB 10.66/m^3 during the period of 2006–2013, an increase of 87%, with an increase of agricultural water consumption amount of 14%. There are two major reasons why Zhumandian had a considerable benefit increase with scarce water resources. One reason is its sub-humid warm temperate continental monsoon climate featured by moderate climate and ample rainfall. The other reason is political and financial support, for instance, the Ministry of Finance and Ministry of Water Resources have arranged Zhengyang, Shangcai, Runan, and

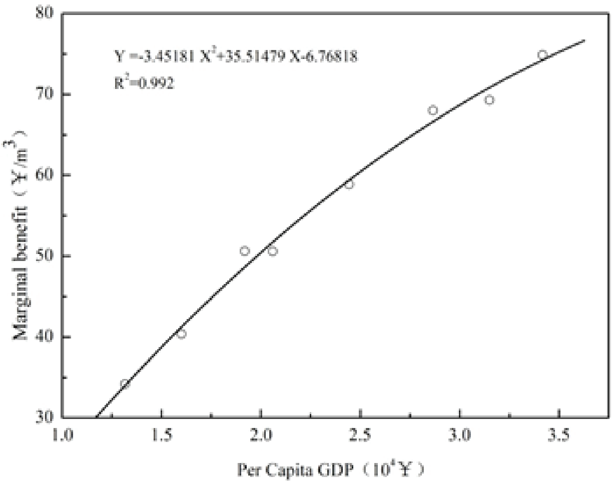

Fig. 3. Simulation effect between water marginal benefits and economic development.

other small key irrigation and water conservancy countries in Zhumadian to commit to invest in water-saving irrigation projects and improve efficiency of agriculture water since 2009. (3) Low benefit areas have kept an average marginal benefit of agricultural water of RMB between 0.53 and 4.82/m^3. For example, Xinyang has a larger amount of agriculture water consumption at lower marginal benefit due to its rice cultivation. These cities should not only pursue low agricultural water consumption and high benefit, but reduce water consumption and lift output by technological improvement in the premise of ensuring the food production.

For industrial water, Zhengzhou, Sanmenxia, Zhumadian, Xinxiang, Anyang, and Puyang had the highest marginal benefits, Jiaozuo, Zhoukou, Hebi, Luohe, and Xinyang came second, while others had the lowest. (1) Zhengzhou had an average marginal benefit of industrial water of RMB 119.08/m^3, secondary to Zhumadian and Sanmenxia. However, during the period of 2006 and 2013, Zhengzhou generated an increase in water benefit of 195% with 11% of industrial water consumption, an increase of 228% in industrial output. That is to say, Zhengzhou has realized the biggest water output with the least water input. It is closely related to Zhengzhou's strong industrial base, advanced industrial technology and high economic level. (2) There were negative water elastic coefficients in low-benefit regions represented by Nanyang and Shangqiu, where economic development levels are lower. Immature industrial water-saving technologies, large ratio of water-intensive industries and water waste have lowered marginal benefits of industrial water in these regions.

Zhengzhou, Xinxiang, Kaifeng, and Pingdingshan are cities with high marginal benefits of domestic water consumption. Zhengzhou owned the highest marginal benefit of domestic water of RMB 280.14/m^3, 30 times higher than the lowest benefit in Shangqiu. As the key city of Henan urban agglomeration and an important national comprehensive transportation hub, Zhengzhou radiates and drives regions around in modern logistics, cultural tourism, wholesale trade and financial transaction to some extent. For instance, compared with other cities, Kaifeng has poor industrial base but rich tourism resources and cultural resources, so it has been developed by attracting and making use of various elements in Zhengzhou by means of regional cooperation and technology diffusion after the integration of Zhengzhou and Kaifeng. In 2013, Shangqiu's domestic water took up 14.24% of the total water consumption, water input was 1/2 of Zhengzhou, plus its behindhand economy, management, and water-saving technologies have resulted in its low water consumption efficiency and benefit.

4.3. Relationship between water marginal benefits and economic development

For the current economic development level, the above analysis revealed that marginal benefits of agricultural, industrial, and domestic water in high development areas are all obviously higher than those in low development areas, suggesting a positive correlation between economic development level and water marginal benefit. Apart from advanced water-saving technologies and intensive water consumption means, mass input of water resources is another assignable cause positively pulling the water marginal benefit. But as the economy develops and water consumption technologies optimize, the scale effect of water resources should be lessened and water marginal benefit should be decreased, which accords with the "law of diminishing marginal return".

We obtained R^2 = 0.992 by model fitting and observed value of F test statistics (334.932) by analysis of variance (Fig. 3). The probability of significance test is 0.000, below significance level of 0.05, so the regression equation has a considerable significance. As issues presently, Henan's water marginal benefit can be further lifted and when per capita GDP reaches near 51 thousand Yuan, Henan's water marginal benefit will reach up to its peak value.

5. Conclusions

Based on marginal benefit theory, after including water resources into C-D production function, accounting marginal benefit of agricultural, industrial, and domestic water and analyzing spatial and temporal disparities in 18 cities in Henan Province from 2006 to 2013, this paper arrived at the following conclusions:

- During the period of 2006–2013, the marginal benefits of agricultural, industrial, and domestic water in Henan basically increased year by year, wherein marginal benefits of industrial and domestic water consumption were obviously higher than that of agricultural water consumption, and marginal benefits in high development areas were higher than those in low development regions; increase rates of marginal benefits of agricultural and industrial water raised constantly along with the economic development, while agricultural water was just the other way. Based on the agricultural water features, improving the benefit of agricultural water cannot only rely on water input, but also on aspects of irrigation technology and agriculture subsidies in Henan Province.
- The analysis on spatial disparities in 18 cities in Henan showed that regions with high marginal benefits of agricultural, industrial, and domestic water all have their advanced water-saving technologies, intensive water

consumption, and strong political supports. Those regions with low marginal benefits are suggested to properly carry out industrial updating based on their own resources and economic development to maximize the output of limited water resources.

- Through economic development has a positive pulling role for marginal benefit; the latter cannot be increased forever. Henan's current economic development level reveals that its water marginal benefit is still on the rise. The water marginal benefits reflect the economic value of water resources. However, this is merely an aspect of water resources, so we should comprehensively consider economic, ecological, and social benefit of water resources at the same time, so as to promote the sustainable utilization of water resources in Henan Province.

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