Chapter 34
An Analysis on Relationship Between Municipal Water Saving and Economic Development Based on Water Pricing Schemes

W. C. Huang, B. Wu, X. Wang, and H. T. Wang

Abstract In recent years, China has been facing water scarcity extensively, thus water saving has become an increasingly popular and crucial topic. In this study, it is analyzed how economic development has effect on municipal water saving in terms of water price changes. The proportion of water prices in residents' incomes and expenses was calculated, and then their relationship was investigated across the nation. Afterwards a phase-division model between water consumption and water price was established to have a closer analysis on the residents' attitude towards water price variation and their corresponding action for water saving. It is also indicated that an Increasing Block Tariff (IBT), with distinction between intensive and non-intensive consumers in the exponential phase, can be a better way compared with simply technical efforts. With these findings water communities may have a better idea on how user consumption reacts with the change in water price, along with how economical and reasonable water consumption could be achieved in a water-scarce environment through price adjustment.

Keywords Economic development · Elasticity theory · Increasing Block Tariff (IBT) · Phase-division model · Water price

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W. C. Huang · B. Wu · H. T. Wang (✉)
College of Environmental Science and Engineering, Tongji University, Shanghai, China
e-mail: hongtao@tongji.edu.cn

X. Wang
UNEP-Tongji Institute of Environment for Sustainable Development, Sino-U.S. Eco Urban Lab, Tongji University, Shanghai, China

H. T. Wang
Key Laboratory of Yangtze River Water Environment, Ministry of Education, Shanghai, China

B. Wu · H. T. Wang
State Key Laboratory of Pollution Control and Resource Reuse, Shanghai, China

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34.1 Introduction

In the past decades, China has been witnessing water scarcity, to which the extent can no longer be ignored. In the year of 2014, income flow of major rivers in this country was reported to be less than normal years. This problem was especially serious in north China, where the Yellow River collected more than 30 percent less water than normal while in its middle reaches precipitation even increased by 30% to 60% (MoWR 2015). Direct economic loss of equivalently 0.29% GDP was resulted from drought during the past nine years since 2006, on average (MoWR 2015).

Multiple examinations have been assessed for the imbalance between supply and demand in this country. Among these discussions listed the agricultural water dissipation due to the extensive employment of paddy fields for rice as a major grain in this nation of cuisine (Chapagain and Hoekstra, 2010; OH et al. 2017). More concerns were raised in the low water-use efficiency within Chinese agricultural departments for lack of effective control in groundwater extraction and economical solution to lower water footprint for chiefly small-scale tillage in China, where Mao and Zhong (2002) estimated that inefficient use of cultivation water could be up to 60%. What stayed also among the criticisms was the insufficient water resources in this nation, resulting from both climate and water quality attributions. From this aspect water quality issues, along with their influence on efficient water consumption and water price tariff, are of intensive concerns and arguments, especially in recent years and in better developed urban areas.

Urban areas have led the country's economic development for almost forty years. Despite the fact that municipal water supply was merely the least component in this industry, occupying 12.6% (MoWR 2015) of the total use of water resources, tap water price has always been raising attention. As a kind of public service that monopolies the need as a whole, the price of tap water holds an absolute domination over how much water the users would consume, by contrast the industrial need can be met through water right trades, and agricultural need is satisfied by individual water intake from groundwater to a large extent (Herzfeld et al. 2017).

Various potable water tariffs have been studied, in which Single-Price Tariff (SPT), Two-Part Tariff (TPT) and Increasing Block Tariff (IBT) are the most introduced applications (Chan 2015). Nevertheless, common principles as meeting the expectation of household food, drinking and hygiene needs apply to all tariffs. Detailed price composition was divided into three parts: resource value, engineering value, and public value. With the resource value as the base value of water extraction, this part of water price was generally regarded as non-adjustable by market. On the other hand, the engineering value from extraction itself and the public value introduced as a common welfare which stands for sewage treatment costs, were more or less fluctuating with market demand (Wu 2001).

The water tariff in China has been developing ever since its industrialization. The first fifteen years since 1949 during the people's republic witnessed a government-paid water tariff, where water consumption was free for residents, as a public service. Explicit charging scheme was not in consideration until after the opening-up and economic revolution in 1978 of this country, where regulations were launched to bring resource and engineering value into water prices (Mao et al. 2002). With increasing social attention to environmental protection, the government issued laws by the end of last century on water resource protection, adding public value into water price. It was only in the latest decade that cities in China started to try on per-capita IBT schemes, which largely depends on strictly metered water consumption (Binet et al. 2014).

It has been generally perceived that the demand of tap water is in close relationship to water price as well as personal income (Renzetti 2002). It was also concluded by Liao et al (2016) that IBT could eliminate more notably on water dissipation, in view of the discrete strategy of household consumption (Lopez-Mayan 2013). With an integrated pricing framework where the governmental authority (Dong 2002; Wang 2007) and market efforts both work on a rising supply side, it still remains a question how water supply should be valued and priced for a more reasonable demand (Wang et al. 2011).

As an essential part of climate dynamics, water cycle at both global and watershed scale has been found to have a feedback mechanism to climate changes, where massive water consumption could have negative impact on a sustainable watershed-level climate (Mo et al. 2009), and deteriorating climate may in turn decrease water resource efficiency and availability (Haddeland et al. 2013; Hanjra and Qureshi 2010). The aim of this study is to analyze the relationship between municipal water saving and regional economic development. Also it is included in this paper how policy affects the relationship, and a modified model of water price-user response is suggested. With this water-price-economy framework, the article is expected to provide a theoretical approach for making water price policy, for an objective of sustainable feedback on watershed water-climate relationship.

34.2 Review on Existing Literatures

As a country with massive agricultural and industrial production, Chinese literatures have been focusing on water pricing for these two categories. Mao et al. (2002) has concluded that with an alternative pricing scheme, the peasants could make up the increased water cost through the reduction of water consumption. It is also analyzed by Jia et al. (2000) that agricultural water consumption is more elastic than industrial and municipal uses, with the increase in water price. On the other hand, industrial water cost can be negligible based on different industries since the average cost of water in budget could be as low as 1%. However, China still shows some distinguishing characteristics that municipal water demands illustrate fewer relationships with climate than reported by Rinaudo (2012), probably due to rare garden uses of water in this country than that in European countries and the U.S.

The relationship among population, economy and water resources was found to have spatial imbalance characteristic, that the spatial distributions of population and economy were inverted with that of water resources, through an analysis by Zhang et al (2015) in Northeast China, while Chen et al. (2006) established a model of an estimated water use under Increasing Block Tariff (IBT) for water. Lei et al (2002) provided a model between water use and water price as:

$$Q_1 = Q_0 \cdot \left(\frac{P_1}{P_0}\right)^{\varepsilon} \quad (34.1)$$

Where Q_0, P_0 stands for original water consumption and price respectively, and Q_1, P_1 stands for adjusted water consumption and price respectively. Another model based on elasticity theory was provided by Ma et al (2013) as follow:

$$Y = a{X_1}^{E_1}{X_2}^{E_2} \quad (34.2)$$

Where Y is the monthly individual water need; X_1 stands for actual water price, X_2 stands for monthly expenses on water services; E_1 and E_2 represents the elasticity of price and personal income respectively; and a works as a constant. As Rivers and Groves (2013) calculated, the general elasticity of water demand was around −0.4, giving a moderate regulation on water-price nexus. Moreover, Luckmann et al. (2015) found that the elasticity of potable water could be, on a proportion, affected by the corresponding marginal cost and income from water consumptions. It is determined by Chen et al. (2016) that with a higher marginal income, the elasticity of water price could decrease for lack of interest.

As we can see, a basic model is needed to analyze how water demand is related to its price. Nevertheless there is hardly a theory to figure out the correlation between economic development and water price within a region.

34.3 Methodology and Data Analysis

34.3.1 Economic Development in China

To reveal the relationship, an indicator must be chosen among the economic indexes to serve as a reference. In economics GDP is widely used to evaluate the standard of development within a certain region. It provides a comprehensive view of the regional development resulting from agricultural, industrial and servicing production. To be specific on individual water need, GDP per capita is required.

Note that data of Hongkong, Macau and Taiwan are not included in Fig. 34.1 and figures hereinafter.

In this figure, we can see a great difference among different regions in China. In north and east China, there was a relatively higher GDP per capita over 60,000 Yuan on average, while Southwest China had an average number even less than half of that in metropolises as Beijing, Tianjin and Shanghai. This phenomenon may cause conspicuous divergence of the attitude to water prices.

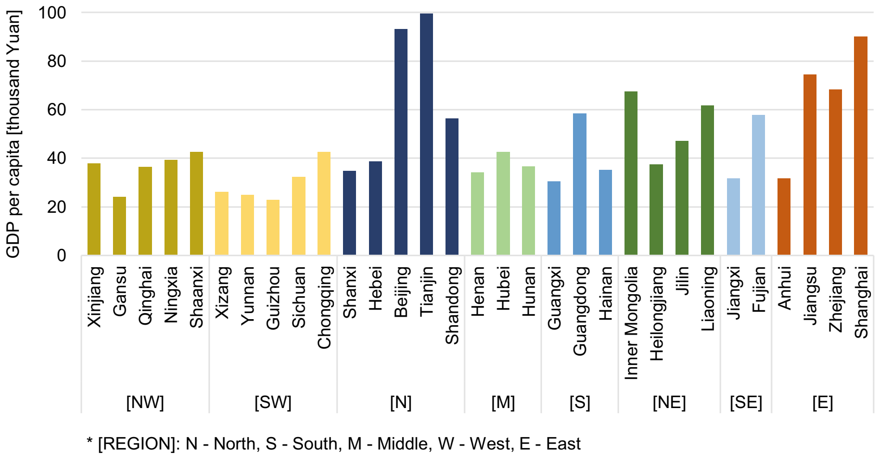

Fig. 34.1 GDP per capita (thousand RMB Yuan) by provinces in China in 2013 (CESDSD 2014)

Although GDP per capita gives a general view on regional economic development and its data is easy to access, this indicator does not suit well as a reference. It is much too broad and meanwhile its calculation covering every production unit within statistics rather than every municipal water consumer makes it incapable of the comparison with water prices. On this account, the indexes to assess the income of municipal residents come forth. In the database two indicators turned out to fit this assessment: Resident Disposable Income per capita in Cities and Towns (RDI^0_{CT}) and Resident Disposable Income per capita in Cities and Towns by family ($RDI^0_{CT,F}$). Between them the difference is mainly on that RDI^0_{CT} contains only labour as a base number while $RDI^0_{CT,F}$ includes all residents from the infant to the senior. Since water is a kind of vital resource of which the absence is prohibited, to every single person alive, $RDI^0_{CT,F}$ is obviously better for analysis (Fig. 34.2).

We can find that the difference of regions has been reduced in comparison with GDP, since GDP reflects more on manufacturing and RDI is much closer to the residential possession, which is our expected base number. Only developed areas such as Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian and Guangdong stood out in this figure.

We can also assess the water prices on base of economic consumption. When we take Resident Average Consumption in Cities and Towns (RAC^0_{CT}) as the indicator, we can see a similar picture as RDI, except for some minor difference in ranking. Seeing from Fig. 34.3, the provincial difference based on RAC is relatively smaller than RDI since the deposit and investment mainly covers their difference.

There are also other indicators other than these three ones, like Consumer Price Index (CPI) and Resident Disposable Income of different income levels. Nevertheless, they all have problems as missing data or being too broad. Thus RDI and RAC was chosen in this paper to serve as the reference number of water prices.

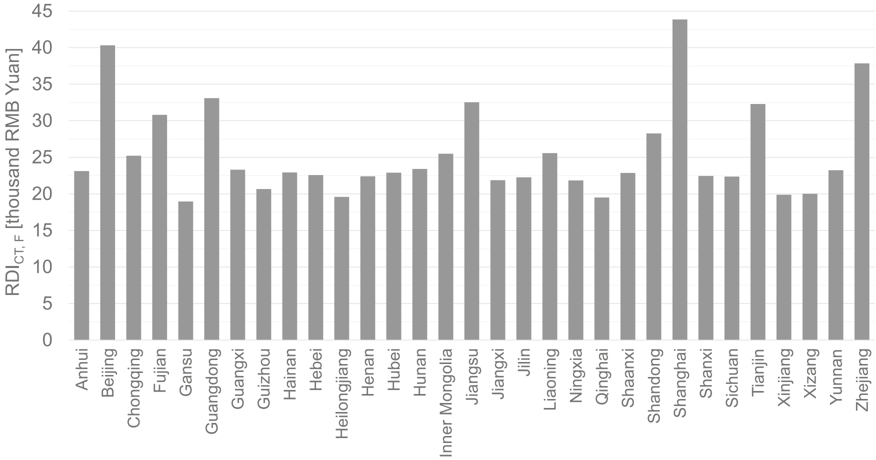

Fig. 34.2 Resident Disposable Income per capita in Cities and Towns by family [$RDI^0_{CT,F}$] (RMB Yuan) by provinces in China in 2013 (CESDSD 2014)

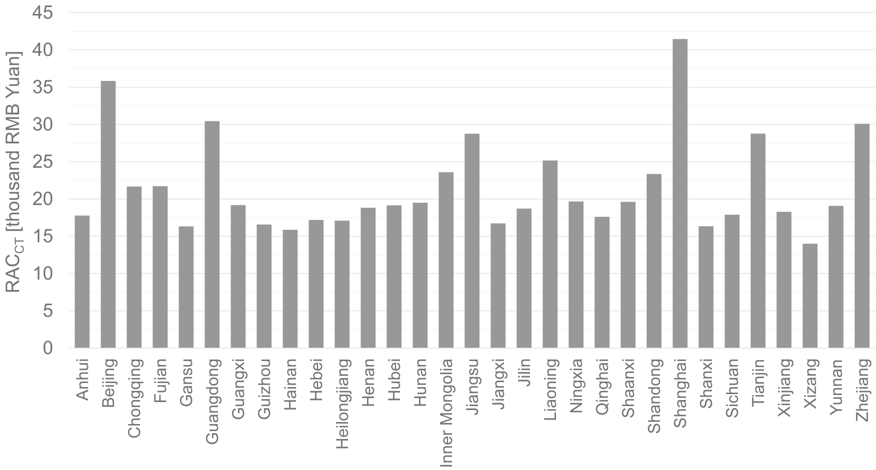

Fig. 34.3 Resident Average Consumption in Cities and Towns [RAC^0_{CT}] (RMB Yuan) by provinces in China in 2013 (CESDSD 2014)

34.3.2 Water Supply and Pricing in China

In China, the industry of water supplies spans both public service and manufacture market (Dong 1989). Under this circumstance water price can have a significant influence on water consumption, as illustrated in Fig. 34.4. Judging from the figure we can see the Daily Household Water Consumption per capita (DWC_0) drops with

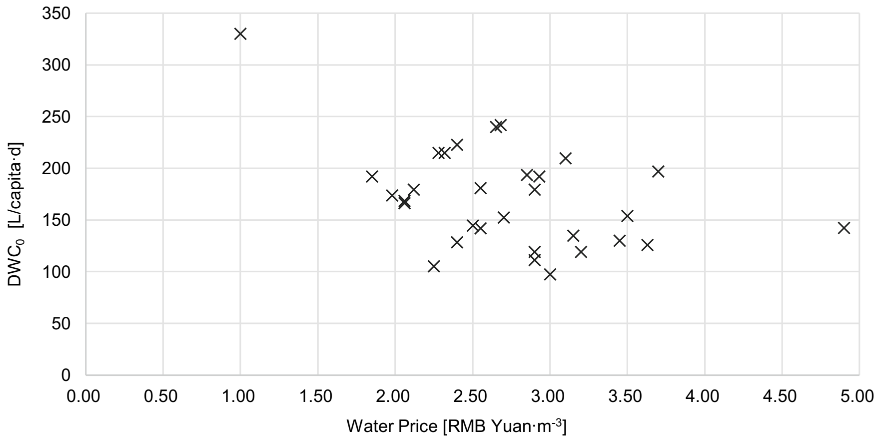

Fig. 34.4 Water price-consumption relationship in China in 2013 (CWN 2014)

the increase of Municipal Water Price (WP). However, their relationship remains unclear since it is non-linear and may have a complex mechanism.

Where DWC_0 stand for Daily Household Water Consumption per capita.

Now that water price rises do indeed help decrease water consumption, question comes out as to what extent can we and should we raise the price of water, to take water scarcity in control and maintain a similar living standard. To answer this question, we must figure out the relationship between economic development and water price.

First, the Monthly Water Cost (MWC) is calculated. Here we assume that all citizens have the same attitude to water prices, and take 30 days for one month. Thus MWC is taken as the money one single resident in cities or towns should pay for water using within a month (RMB Yuan):

$$MWC = DWC_0/1000 \times WP \times 30 \tag{34.3}$$

Afterwards a comparison can be made through water cost (MWC) and the economic indicators (RDI & RAC):

(i) Take the proportion of Monthly Water Cost in Resident Disposable Income as the Index of Water Cost based on Resident Disposable Income,

$$IWC_{RDI} = MWC/RDI^0_{CT,F} \tag{34.4}$$

where higher IWC_{RDI} indicates a larger part of one's income goes to payment of water using (Fig. 34.5).

Where $IWC_{RDI} =$ Monthly Water Cost /Resident Disposable Income.

While a composition of IWC_{RDI} as high as more than 0.08% can illustrate a lower development in this region or water price above average, a much smaller

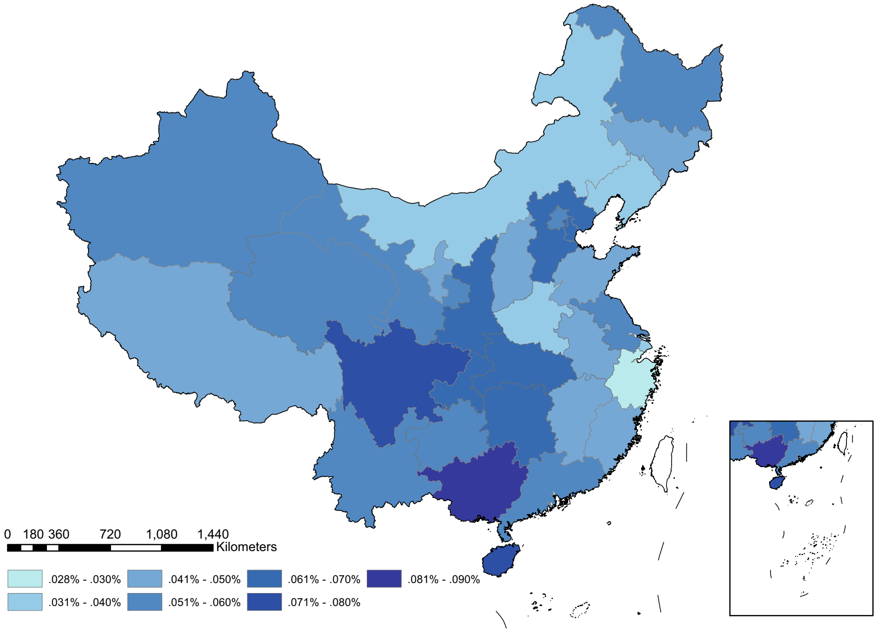

Fig. 34.5 IWC_{RDI} Distribution of Provinces in China in 2013

IWC_{RDI} can also state that the water in such region may be undervalued. Seeing from this figure, the highest IWC_{RDI} shows up in Guangxi and Sichuan, whose water price were still moderate (ranked 26th and 14th, respectively) in China, indicating a lower development of economy in these regions. After them comes the provinces in middle reaches of the Yellow River and the Yangtze River, additionally, Hebei and Tianjin. It appears that Shaanxi, Hubei and Hunan are in similar situations as Sichuan and Guangxi, where a low average income leads to relatively higher water prices; while in Hebei, Tianjin and Chongqing, things are different. Three positions in the highest four water prices were taken by these provinces, especially in Tianjin and Chongqing, where both price of water resources and of wastewater treatment are among the highest throughout the country (Table 34.1).

Of all provinces listed, Zhejiang is the lowest in IWC_{RDI}. This is owing to its elevated economic and living standard and plentiful of water resources such as Xin'anjiang Reservoir and the famous Qiandaohu. However, water resources in this

Table 34.1 Ranks of different parts in water price in 3 Provinces in China

Provinces/Cities	Ranked by price of water resources	Ranked by price of wastewater treatment	Ranked by Total Price
Hebei	2nd	30th	3rd
Tianjin	1st	6th	1st
Chongqing	4th	4th	4th

Table 34.2 Ranks of different parts in water price in Zhejiang Province

Provinces/Cities	Ranked by price of water resources	Ranked by price of wastewater treatment	Ranked by Total Price
Zhejiang	28th	27th	30th

province are absolutely not satisfying as there are still issues of poor water quality, north Zhejiang in especial. Water in Zhejiang is still much too cheap to sustain a clearer waterbody (Table 34.2).

(ii) Take the proportion of Monthly Water Cost in Resident Average Consumption as the Index of Water Cost based on Resident Average Consumption,

$$IWC_{RAC} = MWC/RAC^{0}_{CT} \tag{34.5}$$

where higher IWC_{RAC} indicates that payment of water using shares a larger part of one's daily expenses (Fig. 34.6).

Where IWC_{RAC} = Monthly Water Cost / Resident Average Consumption.

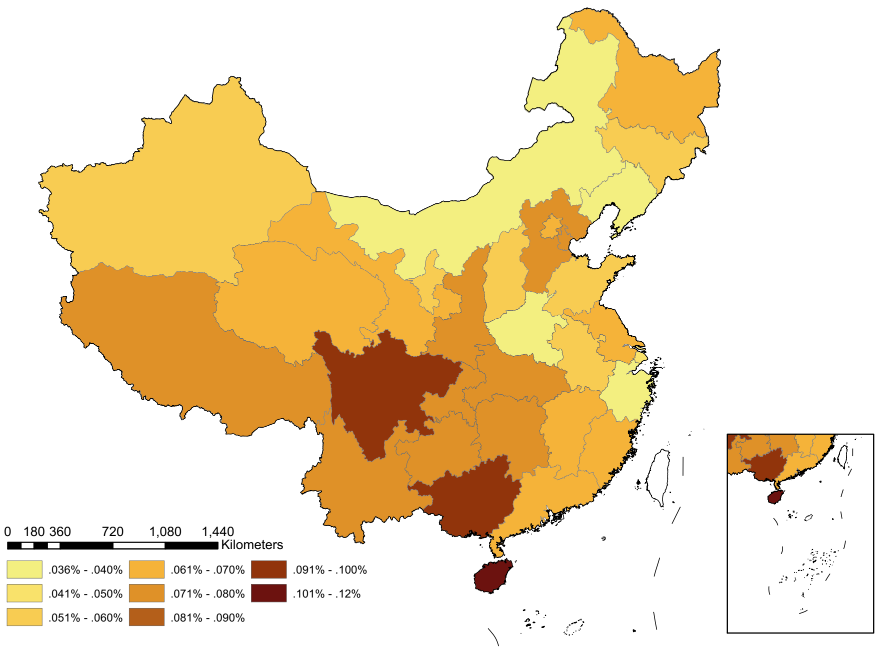

Fig. 34.6 IWC_{RAC} Distribution of Provinces in China in 2013

IWC_{RAC} shares a similar theory with IWC_{RDI} that if this figure goes too small, it implies that too cheap the water is; when it rises high, it can result from an insufficient economic development or a high cost in obtaining fresh water and processing wastewater.

When we use the residents' total cost in daily life (IWC_{RAC}) as a reference instead of their average income (IWC_{RDI}), the figure becomes more distinguishable as it wipes out factors other than merely expenditure. It can be noticed that in lower developed regions like Tibet, legends go darker more quickly than highly developed regions, indicating the cost of water prices occupies more proportion in expense than in earning.

34.3.3 Water Price and Water Consumption

As is mentioned in Review of existing analyses, the models to explain how water consumption reacts with its price are generally illustrated as an exponential function like in Fig. 34.7.

$$Consumption = k \cdot Price^{-\varepsilon} \tag{34.6}$$

where ε stands for the elasticity of water price, and k serves as a constant.

In view of the characteristic of water as both public service and commodity, a phase-division model is proposed (Fig. 34.8). With water price per unit rises, residential water users can think differently on price increase during different phases. In the first phase called Linear Phase, people are merely aware of a rise in price and start to launch a reduction in using water parallel to the percentage of price elevation.

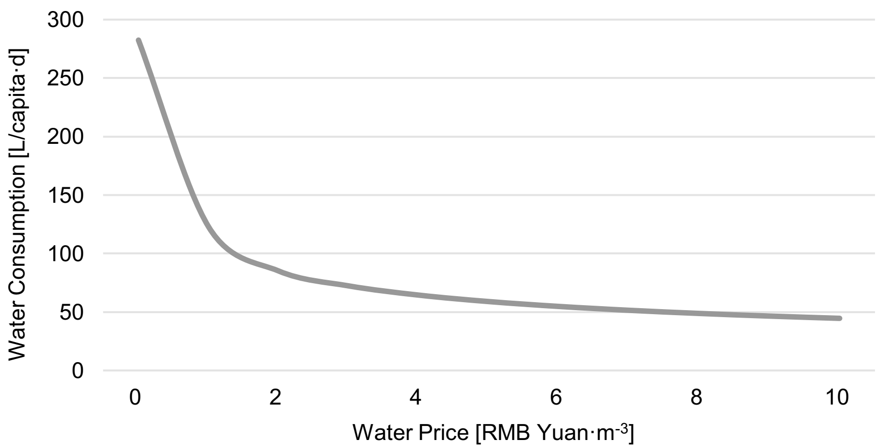

Fig. 34.7 Exponential correlation model

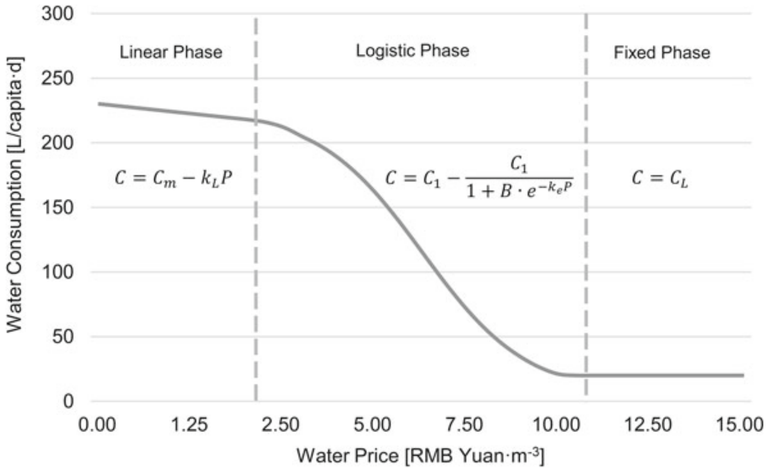

Fig. 34.8 Phase-division model

This phase may last long or short, depending on IWC_{RDI}. If water costs take quite an amount of income, an individual can be more sensitive and easier to enter the next phase. On the other hand, when IWC_{RDI} becomes too low, people may be ignorant of the price rises and hardly enter the next phase. The second phase is the Exponential Phase. Dramatic decline in water consumption occurs in this phase, as a similar way as an exponential function, on account of the water price beyond expectation. Finally it will come to the third phase named Fixed Phase, where water consumption sustains a fixed fundamental need as the least water income for an individual, as in Fig. 34.8.

Where C: Water Consumption; C_m: Maximum Water Consumption; C_L: Minimum Water Requirement; C_0: First (Linear) Diversion Point; k_L: Consumption Reduction Rate in Linear Phase; k_e: Consumption Reduction Rate in Exponential Phase; B: Destination Coefficient in Exponential Phase.

34.3.4 Measures on Water Price and the effect

Generally, there are two types of methods to control water consumption. One is technical, like Water Reuse, and the other one is economical, like Water Price Leverage. In this section, these two kinds of methods will be synergized with the phase-division model to analyze their effect on water prices and water saving. For a certain Phase-division Model where the function (indicating resident's need for water), if water is supplied with a certain price, the area below Resident Need and right of Price of Supply will be Consumer Surplus as illustrated in Fig. 34.9, which means the difference between the actual price and the highest price consumer (here the residents) would like to pay.

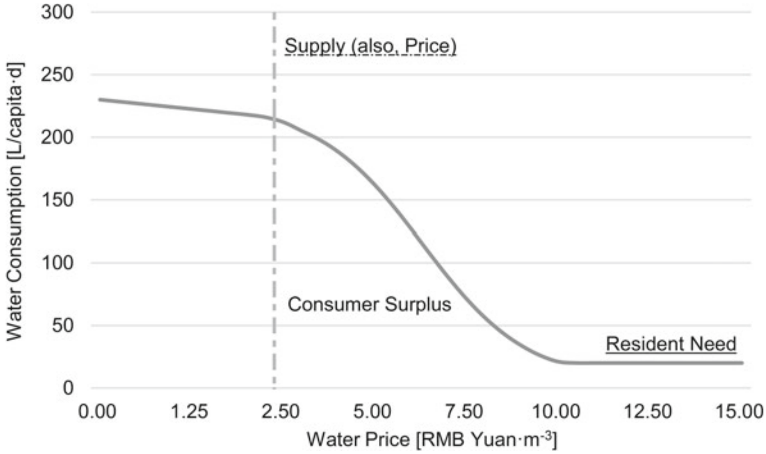

Fig. 34.9 Water consumption variation with a certain price

At the same time, the Producer Surplus, which means the difference between the actual price and the minimum profit they need, is zero in Fig. 34.9 since it should have been between the lines of Supply and the Price (Fig. 34.10).

(i). When technical methods are adopted, residents require less water from the taps, illustrated as:

We can find that while the Producer Surplus remains zero, the Consumer Surplus goes down. It appears to be ‘a loss’ of the residents and that is part of the reason why citizens are sometimes reluctant to adopt technical methods, not to speak of time and sometimes even money to spend in these constructions. Nonetheless, the residents

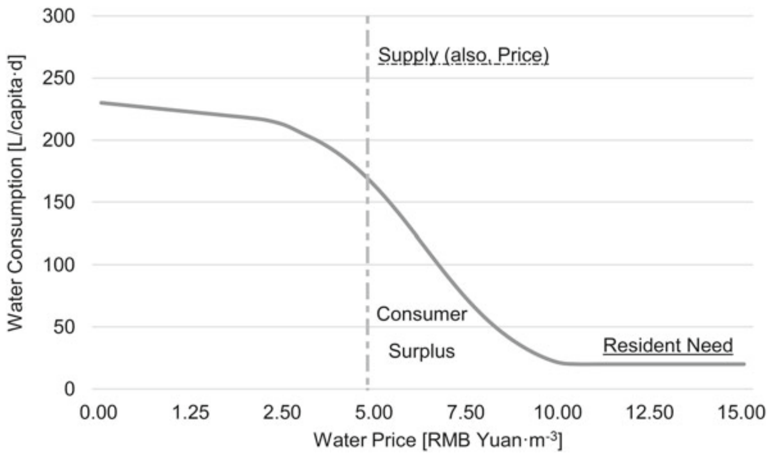

Fig. 34.10 Water consumption variation with technical methods (Supply Raise) adopted

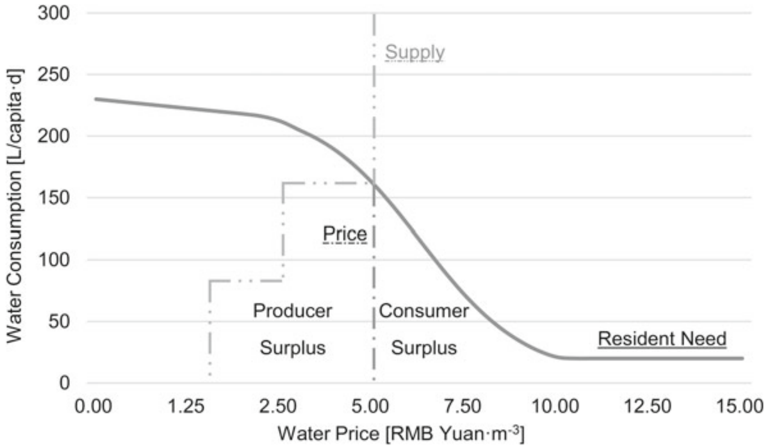

Fig. 34.11 Water consumption variation with increasing block tariff (IBT) pricing adopted

actually lose nothing (if technical methods are paid by the government) since the reduction of Consumer Surplus is just because of the reduction of their own need for water. In this situation, technical methods can be a long-lasting solution, but it is scarcely an easy one.

(ii). When economical methods are adopted, such as Increasing Block Tariff (IBT), where water price rises as the consumption increases (Fig. 34.11):

Things become different when IBT Pricing Scheme is adopted. According to economics, water will be produced where the Need and the Supply crosses, and on its left lies the Producer Surplus, on the right the Consumer's. Obviously IBT Pricing provides more motivation for tap water suppliers.

34.3.5 Policy Implications

There are three 'blocks' representing certain prices in this example for IBT Pricing Scheme, shown as the double-dot dashed lines in Fig. 34.12. We can deduct from this figure that:

1) If the first or second block moves right, that is to say, the producer now raise the price in a larger scale each time. The residents may come to the second block from the third, but they have to pay more for water instead of paying less.
2) If the first or second block extends in height, that is to say, the residents now consume more water to meet the next block. This actually encourages water use since when people use more water, they may even pay less.

The key to a suitable water price is actually a balance between Producer Surplus and Consumer Surplus, which is the key factor in commodity, and the control of total

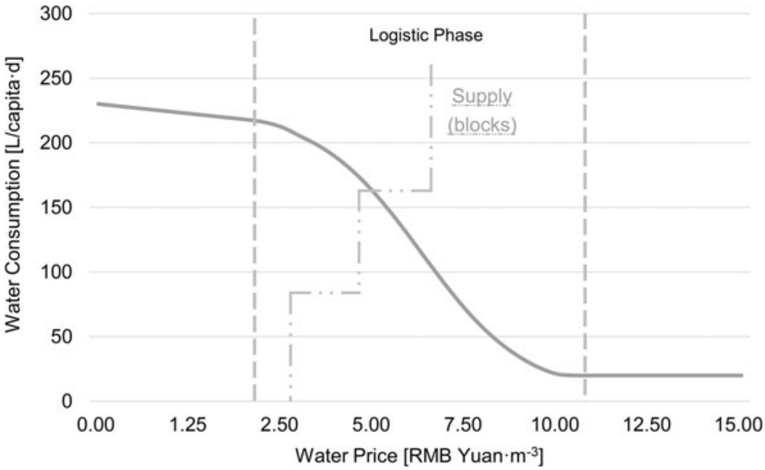

Fig. 34.12 Blocks put inside exponential phase

water consumption, which is the key factor in public service. Despite the general practice which places the first block at median water consumption (Rinaudo et al. 2012), three essential aspects are still open for discussion as how many blocks to set, where to set the blocks and what should the unit cost within each block (Liao et al. 2016). As we may suggest for the second question, the blocks in IBT Pricing Scheme should be put inside the exponential phase, where the effect of blocks can be sufficiently utilized.

34.4 Conclusions

Based on the analysis on the economic indicators and water prices of provinces in China, conclusions could be drawn that with distinct conditions of development and water scarcity levels, the water price in each region with respect to residential incomes and expenses could vary enormously, as a consequence of resource limitation or social-economical limitation, or sometimes both; yet a general trend stated that with increasing water price, residential water consumption will decrease, but within a limited elasticity alterability. Further assessment into pricing extended from a simple exponential relationship to a Phase-division model between water consumption and water price, proposed to be much closer to reality. With an Increasing Block Tariff (IBT) scheme embedded into this model, it was suggested from figures that not only IBT scheme could make social welfare in water economy on reducing overall water consumption, but also the blocks of IBT scheme should be set inside the exponential phase to make better benefits.

With these findings water communities and policy makers are supposed to get a better picture on the localization of water-pricing scheme, where highly developed economy in a certain region can prevent water saving from further progress, but insufficiently developed areas may also meet problems as difficulty in tap water withdrawal and insufficient water processing. It is also revealed from illustrations of both technical and economical methods that under this phase division model, economic method obviously gives more chance to call on residents to save water. Suggestion should be of policy-makers' interests comes that identical elasticity model put forward by existing literatures may not necessarily depict the actual pricing-consumption interaction, especially with limiting resources or mismatched schemes. Specific proposal of putting the 'blocks' inside the exponential phase is put forward, for reference of policy making within an Increasing Block Tariff pricing framework. We suggest that through the complementary schemes of IBT and phase division model, local communities would be able to have extensive control on reach- or region-based water balance for municipal water supply. We are also looking forward to a country-based coordination on watershed-level water balance in a water-economy nexus based on our findings in province distinctions of water scarcity, water pricing, and the relationship behind different schemes and their effects. We hope these mechanisms would benefit the sustainability on a larger extent in both spatial and temporal aspects, with positive feedback on water-climate relationship.

Nevertheless we still realized that the methods to calculate the margin of three phases and the deduction of residents' consumption reduction rate are not yet under sufficient research. These parameters are not easy to find out and requires vast labor in data collecting and analyzing, thus more is to be done to make this model better. Also there comes suggestions that a simple water nexus pricing may lead to increasing energy consumption (Wu et al. 2003), calling on a closer analysis on the relationship between pricing and consumption under an integrated water-energy nexus.

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