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Social water cycle and sustainable consumption in the perspective of water footprint – taken the low water consumption patterns of Zhangye city as a case

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ABSTRACT

Population growth, technological change and increased consumption are considered the three main causes of the environmental crisis. However, the current environmental problems caused by consumption have not been paid enough attention to and studied in depth. Through the expansion of the IPAT equation, a new IHPACT frame is directed, which could be used to analyze the influencing factors of sustainable consumption, and also guide the policy making of sustainable consumption. Meanwhile, based on the study and accounting data in Zhangye city of Heihe River Basin, the feasibility and necessity of the analysis framework are discussed from the perspective of water footprint. The research results indicate that decreasing meat consumption known as water footprint luxury in food consuming can effectively adjust residential consumption water footprint. The improvement in the consumption capability will increase the footprint of the consumer water. However, the environmental Kuznets curve hypothesis between the environmental impact represented by water footprint and consumption ability still exists, which indicates that increasing consumer spending will ultimately reduce the impact of consumption on the environment.

Keywords: Water footprint; Social water cycle; IHPACT; Sustainable consumption

1. Introduction

On the World Summit on Sustainable Development (WSSD) of Johannesburg, the leaders of every country in the world have realized that it is necessary to change unsustainable patterns of consumption and production, called for a fundamental change in social production and consumption patterns, and determined to accelerate the transformation of sustainable consumption and production [1]. Sustainable consumption patterns can be defined as a consumption pattern that meets basic needs and provide human beings with the freedom to develop their potential and spread across the globe without affecting the Earth's undefined carrying capacity. The research of sustainable consumption strategy refers to taking measures to reduce these effects caused by consumer behavior or demands. The research interest for consumer is directed from the basic idea of ecological economics, that is, human economy is rooted in nature, and meanwhile it occupies the Earth's biosphere space more or less [2]. How to understand the consumption? What are the environmental conflicts brought by the consumption? What factors have contributed to the continuous growth of consumption? How do the limited resources meet the increasingly high level of consumption? What is the relationship between consumption and quality of life? How to change the consumption patterns? These questions are unavoidable in the study of ecological economics, and urgently need to be answered.

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Classical IPAT equation is raised by Ehrlich and Holdren in 1971, to study the impact of population on the environment [3]. Environmental impact (*I*) equals to the product of population (*P*), affluence (*A*, per capita consumption or production) and technology (*T*, unit production or environmental impact of consumption), which set up the account identity between human factors and environmental impact. In this paper, the feasibility and necessity of low water consumption patterns in the perspective of water footprint are analyzed; principal factors that effect sustainable consumption on the basis of IPAT equation and equation extension are discussed; and theoretical foundation is explored that guides sustainable consumption countermeasures.

2. Methodology

2.1. Classical IPAT equation and the expansion of equation

The continuous exploitation of nature has led to the deterioration of environmental quality. In the early 1970s, Ehrlich and Holdren, professors of Stanford University, first proposed the IPAT equation that analyzes the relationship between human activities and the environment. The IPAT equation is widely used in the analysis of environmental impacts of human activities because of its simplicity, systematism, and soundness. Its expression is:

$$I = P \times A \times T \tag{1}$$

Therein, *I* indicates ambient pressure, *P* indicates population factor, *A* indicates affluence, and *T* indicates technology. The IPAT equation quantitatively analyzes the influence level of human activities on the environment and shows that the impact of population and income on the environment can be compensated by technological advances to reduce the pressure on the environment.

After the IPAT equation was put forward, other scholars proposed models such as ImPACT, ImPACTS and IGT based on different research requirements. These models have been widely applied in researches on CO_2, virtual water, ecological footprint, water footprint, and carbon footprint, and are also innovatively applied in the analysis of the relationship between industrial agglomeration and environmental pollution [4]. Chinese scholars Xu Zhongmin and Cheng Guodong proposed the ImPACTS model on the basis of IPAT and ImPACT, which is a new research framework for sustainability evaluation. The IPAT and ImPACT equations have some limitations in practical applications [5]. The equation simply treats the environmental impact and human factors as a linear relationship which cannot accurately reflect the specific changes in the environmental impacts of human factors. Therefore, Dietz and Rosa proposed a random regression model in 1994, namely the STIRPAT model [6]. The STIRPAT model adds random variables and has been more widely used in research and analysis.

2.2. IHPACT equation

Consumption activities are tightly combined with natural ecological environment by means of asking for, processing, circulating and abandoning. When the speed or amount of natural resource consumption exceeds a certain limit, the structure and state of natural environment system will change qualitatively, which makes the original consumption behavior and pattern unsustainable [7]. Residents' consumption is finally enslaved to the influence and effect of resource stock and environmental capacity. Residents undefined consumption behavior must correctly handle the relationship between human beings and natural ecological environment. Only in this way can we realize the sustainable development of society, economy, resources and environment. The relationship between the pattern, scale and intensity of human consumption behavior and resource environment is not only expression of relationship between human and nature but also leads to the change between the two.

Based on the above discussion, the classical IPAT equation ignores the impact of consumer groups and consumer impact intensity on the environment. Therefore, in this study the IHPACT equation is used instead of IPAT equation. In the new equation, *H* represents different consumer groups (*H*), defined by per capita spending power (*A*), consumption frequency (*f*) and corresponding consumption patterns (*h*); *C* represents the degree of influence of consumption. Classical IPAT equation and the extended analysis framework aims to confirming the determinants of environmental influence caused by human activities, and are especially used for confirming effects of humanity factors. From the classical IPAT equation, environmental impact of human consumption (*I*) similarly depends on population (*P*), per capita consumption ability (*A*), and technology (*T*). While, per capita consumption ability (*A*), consuming frequency (*f*) and corresponding consumption pattern (*h*) can further define different consumers herd (*H*). Classical IPAT equation can be expended to a new equation IHPACT which was for analyzing sustainable consumption, that is:

$$I = H \times P \times A \times C \times T \tag{2}$$

Therein, *I* is environmental impact of consumption, *H* is characteristics of consumers herd, *C* is influential intensity, *T* is technology, that is $(I - A)^{-1}$. Rewriting for further is:

$$I = h \times f \times P \times A \times C \times (I - A)^{-1} \tag{3}$$

Analysis of differences in environmental impacts of different consumption patterns can be achieved through changes in consumption patterns (*h*), that is:

$$\Delta I = C \times (I - A)^{-1} \times (h_1^m - h_2^m + \Delta h^{nm}) \tag{4}$$

Therein, ΔI is environmental effect difference, $h_1{}^m$, $h_2{}^m$ are two consumption models to compare, Δh^{nm} is the rebound effect. Rebound effect refers to the percentage of potential reduction in environmental impact of consumers' re-spending behavior. Ignoring such substitution behavior might seriously overstate the environmental benefits attached to isolated consumption behavior changes, leading to faulty conclusions that category-specific changes are sufficient to lead society toward more sustainable consumption patterns.

Residents' consumption is finally enslaved to the influence and effect of resource stock and environmental capacity. So that residential consumption behavior must correctly deal with the relationship between human and natural ecological environment. Only in this way, the sustainable development of society, economy, resource and environment could be realized [8]. It could say that the relationship between the pattern, scale and intensity of human consumption behavior and the resource environment is not only the expression of the relationship between man and nature, but also can change the relationship between the two. The change of resident's consumption models, for example, from mainly of meat to vegetarian, represents consumption model changes from h_1^m to h_2^m. So in the assessment of the environmental impact changes (ΔI) caused by this change in consumption patterns, we still need to specifically examine the differences between meat-based consumption patterns and vegan consumption patterns in addition to eating meat, which is Δh^{nm} in the equation. IHPACT gives out the basis for controlling policies of sustainable consumption, explains the role of adjusting consumption environmental effect in theory.

3. Empirical analysis

3.1. Calculation and analysis for water footprint of residents' consumption in Zhangye city

According to virtual water theory, on the basis of water indexes of traditional sector, Hoekstra [6] proposed an indicator of water resources utilization based on consumption, and introduced a consumption-based indicator, that is, water footprint. Water footprint can truly reflect possession of water resources by human consumption and offer a new method for scientific management of water resources. Taking Zhangye city in continental river basin in the northwest middle reaches as a study case, by means of consumption water footprint surveying and calculating, measuring the effect of human behavior on the natural environment, has very important realistic representation. This paper carried out the social investigation on Zhangye city of Heihe River basin during April to July of 2014. A total of 500 questionnaires of water footprint consumption were sent out, and 471 copies of effective questionnaires were recollected, including 351 copies of rural questionnaires, 120 copies of urban questionnaires. In which, there were 425 people of the Han nationality, and 18 people of minority in the respondents; respondents ages were among 31–50 years old; education status was mainly junior high school, senior high school or technical secondary school, and the proportion of a degree beyond college was 2.6%.

From the perspective of the income distribution of respondents in Table 1, informants of household income more than 20,000 yuan were in the majority (53%). Household income of urban family usually exceeded those of rural family; urban households with incomes above 20,000 account for 82% of the total number of urban households, while rural households with incomes above 10,000 yuan account for 88% of the total number of rural households.

Details of the water footprint are listed in the relevant literature [9,10]. According to the data collected by the questionnaire survey, the water consumption footprint of the residents in the study area was calculated as shown in Table 2.

3.2. Low water patterns in food consumption structures

Sustainable assessments of consumer water footprint include evaluation of its consumption structure components and overall evaluation. In fact, many consumers' water footprints are determined by minority components. For example, for a meat eater, his water footprint is mainly decided by consuming meat products. If a consumer's water footprint is bigger, we need to focus more on those high water footprint products "water footprint luxurys". The production of high water footprint products will require more adequate environmental water supply or more production of agricultural products, such as meat, cosmetics, biodiesel and bioethanol, etc. For the sustainable analysis of the water footprint of food consumption in the diet structure, we should not only focus on the component evaluation and the overall evaluation of the consumption but also pay special attention to the health

Table 2
Households water footprint calculations ($m^3 \cdot cap^{-1} \cdot y^{-1}$)

Township	Water footprint	Villages and towns	Water footprint
Da He	1,781	Li Qiao	761
Bai Yin	1,998	Wei Qi	911
Kang Le	1,614	Nan Hua	652
Ban Qiao	1,003	Luotuocheng	892
Ping Chuan	886	Chang An	539
Liangjiadun	939	Lin Ze	1,843
Long Qu	761	Min Le	1,629
Da Man	1,185	Shan Dan	1,277
Jian Tan	820	Gao Tai	1,662
Dang Zhai	1,044	Gan Zhou	1,730
Liangjiadun	1,034	Su Nan	1,853

Table 1
Analysis of the economic status of the population surveyed in 2013

Household income (yuan)	Urban (family)	%	Rural (family)	%	Total (family)	%
Less than 5,000	0	0	1	0.36	1	0.27
5,001–10,000	0	0	54	15.36	54	11.44
10,001–20,000	21	17.71	109	31.07	130	27.65
More than 20,001	99	82.29	187	53.21	286	60.64
Totalize	120	100	351	100	471	100

of the diet structure. Low water consumption pattern of dietary structure food consumption should be a healthy and sustainable model on the basis of satisfying the normal physiological needs of human beings. Table 3 calculated water footprint of food in residents' diet structure of Zhangye city.

From the results in Table 3, water footprint was just high in countries of Zhangye city. From the point of food consumption water footprint components, meat in food consumption, which is a kind of "water footprint luxury", made a great contribution. The water footprint of meat consumption in Sunan County was as high as 66%, the proportion of county Shandan, county Gaotai and the area of Ganzhou were higher too, which reached to 44%–49%, the proportion of Linze and Minle was slightly lower, but was also beyond 30%. The dairy products consumption in Zhangye were obviously insufficient, but the difference about water footprint components of the dairy product consumption was not obvious, the reason was mainly that there was little difference between local dietary patterns and living habits, but the larger proportion of farmers in the interviewees was one of the important reasons for this phenomenon.

According to the IHPACT framework which got from the above analysis, reducing water footprint of food consumption in the diet should preferentially consider to reduce the consumption of water footprint products such as meat. At the same time, the adjustment of consumption patterns is not arbitrary, and certain principles should be followed. In Table 4, several consumption pattern adjustment schemes are given. In the schemes, the ratio of meat products to vegetable products were changed in accordance with the principle of constant calorie intake, the consumption of meat products in current consumption patterns was reduced, and vegetable consumption increased.

From the change of water footprint of adjusted food consumption patterns in Table 5, "Eating more vegetables and less meat" had a significant impact on the per capita water footprint: in pattern 1, the impact of a quarter of a reduction in meat consumption on the per capita water footprint of all regions was basically more than 30%, especially for the groups which had larger meat intake, the effect was the most significant (such as Sunan region, per capita water footprint reduced by 53.34%), Only the impact on Linze County was small, which was 23.29%. Compared with pattern 0, the influence for regional per capita water footprint was different in pattern 2. The per capita food water footprint of Sunan County was 1,523.2 L·cap^{-1}·d^{-1}, with a decrease of 46.97%, and the per capita food consumption water footprint of Linze County was 1,211.5 L·cap^{-1}·d^{-1}, with a decrease of 18.66%. In pattern 3, the impact on the per capita water footprint of the region was weakened.

Fig. 1 analyzes the effect of the three adjustment modes on the adjustment of per capita water footprint and showed the difference of regulation effect in per capita water footprint spacing between regulation effect curve changes. Compared with pattern 1, both the pattern 2 and pattern 3 had some decline in adjusting the effect of per capita water footprint; In two "mode hops" (from Mode 1 to Mode 2, and from Mode 2 to Mode 3) the latter hop was more effective in adjusting the per capita water footprint, with a reduction in proportion of more than 9%. At the same time, it is still important to note that in pattern 3 (Tables 4 and 5), with the continuous reduction of their meat intake (from 1/3 to 1/2), and increase of vegetable consumption (from 8/3 to 4/2), the water footprint increased in the regions. The results showed that "eating more vegetables and less meat" had a certain limitation on reducing the per capita water footprint, rather than "panacea".

3.3. Factors analysis of influencing low water consumption patterns

To further examine the influencing factors of low water consumption patterns, the IHPACT equation needs to be transformed into a random model. The process of transformation is detailed in the literature. [11,12]. Reformed random pattern and logarithm processing is:

$$\ln(I) = a + b\ln(H) + c\ln(P) + d\ln(A) + c\ln(C) \tag{5}$$

Table 4
Three presumed replaceable consumption patterns

Food consuming patterns	Adjusting measure
Pattern 0	Nothing
Pattern 1	Meat reduce 1/4, vegetables increase by 2 times
Pattern 2	Meat reduce 1/3, vegetables increase by 8/3 times
Pattern 3	Meat reduce 1/2, vegetables increase by 2 times

Table 3
Analysis of citizens' water footprint of Zhangye city (L·cap^{-1}·d^{-1})

County (district)	Cereal and rice	Sugar	Vegetable oil	Vegetables	Fruit	Meat	Animal oil	Dairy products	Eggs
Su Nan	307.1	3.0	108.1	22.3	14.0	2,102.3	32.2	301.1	289.2
Lin Ze	363.3	5.1	96.2	36.2	14.0	559.1	62.4	419.3	297.1
Min Le	412.2	9.2	155.0	36.1	22.3	986.2	81.3	448.2	388.0
Shan Dan	321.0	6.1	81.0	25.2	20.1	868.1	108.2	270.1	252.1
Gao Tai	298.2	10.0	111.1	34.3	26.2	1,202.0	149.1	301.0	326.2
Gan Zhou	264.6	6.1	122.4	27.1	21.4	1,131.3	107.3	352.2	362.3

Table 5
Changes of per capita water footprint with modes' adjustment

County (district)	Pattern 0		Pattern 1		Pattern 2		Pattern 3	
	Water footprint	Reduce (%)	Water footprint	Reduce (%)	Water footprint	Reduce (%)	Water footprint	Reduce (%)
Su Nan	2,872.2	–	1,340.1	53.34	1,523.2	46.97	1,910.3	33.49
Lin Ze	1,489.4	–	1,142.5	23.29	1,211.5	18.66	1,354.7	9.05
Min Le	2,126.3	–	1,458.9	31.39	1,561.9	26.54	1,777.6	16.40
Shan Dan	1,630.9	–	1,030.2	36.83	1,116.6	31.54	1,297.7	20.43
Gao Tai	2,159.9	–	1,327.0	38.56	1,446.1	33.05	1,696.1	21.47
Gan Zhou	2,007.7	–	1,213.4	39.56	1,322.1	34.15	1,550.5	22.77

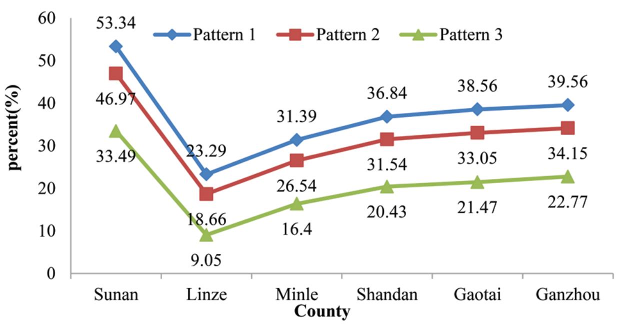

Fig. 1. Analysis of modes' effect on per capita water footprint.

From the above analysis, it was found that the main factors influencing low water consumption patterns include consumption ability, environment impact strength of consumption, the characteristics of consumer groups, and the progress of technology. Usually, a family's consumption ability (A) is mainly depended by disposable income. The characteristics of consumer groups usually manifest the size of the consumer groups (P) and the consumption patterns of consumer groups ($H = h \times F$). In this study, the survey data of each villages and towns in Zhangye city were used to estimate the relevant parameters. Meanwhile, whether the environmental Kuznets curve hypothesis was suitable in explaining the relationship between consumption and environmental impact was also invested. Relevant parameters estimation and test results were shown in Table 6.

From the results on the parameter estimates of various affecting factors in Table 6, the significance of consumption ability and impact strength was good, while the significance of consumption patterns and scale of consuming groups was worse. The coefficients of consumption power and influence intensity are both positive, which indicated that with the increase of consumption power, the environmental impact intensity of consumption will also increase, and its increasing degree was much larger than that of consumption ability. Comparing with the analysis of the three models of "eat more vegetables and less meat", the results were consistent with the conclusion that reducing the consumption of luxury goods (meat) in food can effectively control the water footprint of residents. Although the effect of consumption patterns and consumer groups was not significant, the coefficients of

Table 6
Parameter estimation and testing of affecting factors

	Coefficient	Standard deviation	t	Significance
Constant	–531.95	316.24	–1.68	0.12
H	2.21	48.55	0.04	0.97
P	2.18	3.27	–0.68	0.51
A	0.06	0.01	6.24	0.00
C	11,665.43	1,112.82	10.48	0.00
A2	–1,055.10	241.63	–4.37	0.00

the consumer characteristics (H) and the consumer groups planning (P) were positive. This showed that the shift to lower water consumption patterns (change consumption pattern h_1^m to h_2^m), and reduction in the scale of consumer groups (ΔP change the scene mode 0 to scene mode 1) could also reduce the environmental impact of consumption. In addition, the relationship between the quadratic terms of consumption power and the environmental impact of consumption was significant, and the coefficient was negative, which indicated that there was an environmental Kuznets curve hypothesis between consumption power and the environmental impact of consumption. That is, when the consumption ability reaches a certain level, the environmental impact of consumption starts to decline with the increase of consumption. Such findings proved the possibility and necessity of low water consumption patterns.

4. Conclusion

The water crisis is one of the most severe practical problems which humanity is now facing within the 21st century, which forces us to pay early attention to the "low water" problem. Water is a key resource for the coordinated development between ecological environment and economic social in inland river basins. Consumption is not only the disturbance factor in the economic system, but also the disturbance factor in the larger ecological economy system.

Based on classical IPAT equation, this paper presented a IHPACT framework for the analysis of sustainable consumption patterns, and discussed the policy implications of the equation. In the perspective of water footprint, based on the survey and calculation of residents' water footprint in

Zhangye city in continental river basin in the northwest middle reaches, this paper discussed that low water consumption patterns promoted achieving sustainable consumption, and used IHPACT to analyze factors and effects which affect low water consumption patterns. It proved the feasibility of realizing low water consumption pattern and promoting sustainable consumption by adjusting consumption pattern.

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