

## Article

# The Impact of Virtual Water on Sustainable Development in Gansu Province

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**Abstract:** The concept of virtual water, as a new approach for addressing water shortage and safety issues, can be applied to support sustainable development in water-scarce regions. Using the input-output method, the direct and the complete water use coefficients of industries categorized as primary, secondary, or tertiary, and the spatial flow patterns of the inter-provincial trade in the Gansu province region of China, were explored. The results show that in 2007, 2010, and 2012 the direct and complete water use coefficients of the primary industries were the greatest among the three industry categories, with direct water use coefficients of 1545.58, 882.28, and 762.16, respectively, and complete water use coefficients of 1692.22, 1005.38, and 873.44, respectively; whereas, the direct and complete water use coefficient values of the tertiary industry category were the lowest, with direct water use coefficients of 16.65, 7.74, and 66.89 for 2007, 2010, and 2012, respectively, and complete water use coefficients of 65.46, 66.89, and 72.81 for 2007, 2010, and 2012, respectively. In addition, study results suggest that the volume of virtual water supplied to Gansu province's local industries has decreased annually, while virtual water exports from the province have increased annually, with the primary industry accounting for 95% of virtual water output. Overall, the virtual water of Gansu province in 2010 showed a net output trend, with a total output of 0.506 billion m<sup>3</sup>, while in 2007 and 2012 it showed a net input trend with a total input of 0.104 and 1.235 billion m<sup>3</sup>, respectively. Beijing, Shanghai, Guangdong, Ningxia and other water-scarce areas were the main input, or import source for Gansu's virtual water; during the years studied, these provinces imported more than 50 million m<sup>3</sup> individually. Based on these results, it is clear that under the current structure, virtual water is mainly exported to the well-developed coastal areas and their adjacent provinces or other water-abundant regions. Therefore, Gansu province should (1) adjust the industrial structure and develop water-saving and high-tech industries; (2) adjust the current trade pattern to reduce virtual water output while increasing its input to achieve balanced economic development and water resource security.

**Keywords:** water resources; virtual water trade; input-output method; Gansu province

## 1. Introduction

The concept of virtual water was first proposed by Tony Allan in 1993 [1] to refer to the amount of water used in the production of goods and services [2]. Since 2002, the concept has received extensive attention around the world [3,4]. In China, virtual water has been forwarded as a potential approach to safeguard water resources, especially in water-scarce areas such as the northwest [5]. This interest has prompted many empirical studies on the quantification of virtual water in global crop and livestock products (2352 kg of water in 1 kg of crop, and 6333 kg of water in 1 kg of livestock product, respectively), in Netherlands's and Canada's grain products (1000–2000 kg of water in 1 kg of grain), in Canada's beef products (16,000 kg of water in 1 kg of beef), in American computer chip products (16 kg of water in 1 g of a 32-megabyte computer chip) [6–10], and in Brazil's, Chile's and American paper products (1052.8 kg, 1227.3 kg, 3345.8 kg of water in 1 kg of paper, respectively) [11]. Virtual water studies have also been completed for services, for example, the assessment of virtual water in the Spanish tourism industry (9.7 kg of water per € 1 of tourism income in 2004) [12]. Virtual water trade, which refers to the practice of transporting this hidden water from one country to another, has also been studied. For example, studies have examined the amount and direction of virtual water in agri-food products transported from Italy to China [13], and the factors influencing its characteristics [14]. When employed appropriately, virtual water trade can be used to alleviate water shortages in water-scarce regions and to ensure local water security through the import of water-rich products from water-abundant regions [15,16]. Researchers have investigated the links between virtual water, food security [17], and water footprints [18,19], which is different compared to carbon footprints [20,21]. The former means the cumulative virtual water of all goods and services consumed by one individual or one country [22], while the latter means a measure of the total amount of greenhouse gas emission directly and indirectly produced by an activity or accumulated over the life stages of a product [23,24]. As there is a mutual feedback mechanism between water and carbon footprint, an understanding of water footprint can contribute to reflecting carbon footprint and proposing policies on the utilization of energy resources, and to achieving sustainable development [25–27].

A review of the existing empirical studies on virtual water shows that most are large-scale in scope, and focused on economically developed areas. There is a need for studies at the provincial scale, particularly for the less developed, arid inland provinces of China. Gansu province is located in the central region of northwest China and covers a total area of 425,900 km<sup>2</sup>. It is a typical arid and semi-arid water-deficient area with a dry climate, sparse rainfall and severe water resource shortages. In addition, the unequitable distribution of industrial water use, low utilization efficiency, and over-exploitation of groundwater have resulted in a decrease in river water supply and an increase in desertification, with significant negative consequences for regional social and economic development [28].

The current paper analyzes virtual water content, the primary virtual water export industries and their export destinations, and the spatial patterns of virtual water in Gansu province between 2007 and 2012. The results of this study can be employed to support the sustainable use of water resources and the optimization of industry and trade structures in Gansu province.

## 2. Statistics and Methods

### 2.1. Inter-Regional Input-Output Model

In 1936, American economist W. Leontief proposed the input-output method to describe the relationships between inputs and outputs in all sectors of an economic system [29,30]. To inform the rational use of water resources, researches have applied the regional input-output method to the analysis of water consumption [31,32]. By compiling the resulting input-output tables and establishing mathematical models, researchers can identify the amount of virtual water in a system, the current direction of its movement [33], and calculate the ultimate water consumption and environmental emissions involved in product production [8,34].

The inter-regional input-output model (IO model) was first proposed by Isard [35] to reflect product trade between regions in a more systematic and comprehensive way compared to the single regional input-output model. The calculation of virtual water trade volumes in a certain area (Figure 1, specific meaning of each formula is presented in Table A1) is based on the assumption that an inter-regional input-output model contains  $n$  regions, and that each region has  $m$  sectors, so that the mathematical structure of the inter-regional input-output model contains  $m \times n$  linear equations [36].

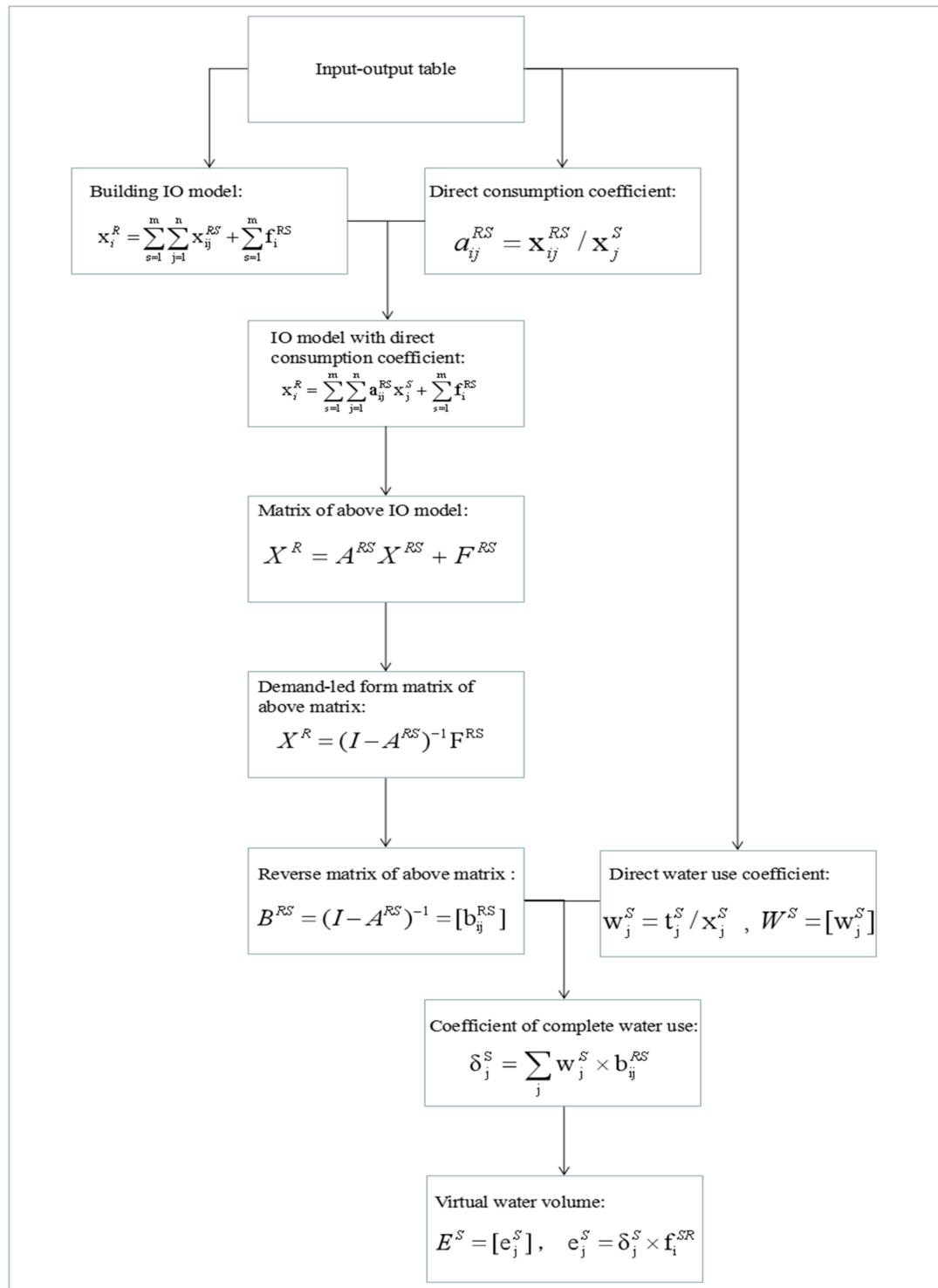


Figure 1. Flow chart of virtual water calculation [36].

## 2.2. Data Sources and Processing

Due to technical limitations and other difficulties associated with data acquisition, compiling the inter-regional input-output tables is demanding in terms of time and resources. These challenges can contribute to delays and irregularities in input-output table publication schedules. In China, for example, the initial data acquisition process for the regional virtual water input-output assessment was initiated in 1987 and has since been repeated at 5-year intervals. Within this process, input-output tables are launched every 3-years, however, these are usually presented 2–6 years after data acquisition for the cycle. The current study utilizes the input-output tables for 2007, 2010 and 2012.

Water consumption data for all industries in Gansu province were derived from the Gansu Water Resources Bulletin in 2007, 2010, and 2012 [37–39]. Forty-two industry sectors were classified into primary, secondary and tertiary industries according to the Industry Classification Regulations [40]. Primary industries include agriculture, forestry, animal husbandry and fishery; secondary industries consist of those in the manufacturing and construction category, while the remaining industries were classified as tertiary (Table A2 presents industry specific classifications). The complete and direct water use coefficients, with the former referring to the water demand of the entire economic system from the perspective of product life cycles, and the latter referring to water used in the production of intermediate products [41,42], were calculated and the volume of virtual water exported from Gansu to other provinces was inferred.

## 3. Results and Discussion

### 3.1. Industrial Virtual Water Consumption in Gansu Province between 2007 and 2012

#### 3.1.1. Water Consumption Coefficients of Various Industries

Across all three industry categories, the complete water use coefficients are higher than the corresponding direct water use coefficients; this is expected as the concept of complete water use includes both direct and indirect water use (Table 1). In comparison to the secondary and tertiary industries, the complete water use coefficient of the primary industry category is much higher, and the difference between the complete water use coefficient and that of its direct water use coefficient is relatively insignificant, because large quantities of water are directly consumed by many of the industries in the primary industry and their production processes requiring few resources from the secondary and tertiary industries [40]. The secondary and tertiary industries complete water use is significantly higher than direct water use due to the high indirect water use of many of the composite industries that require considerable indirect water use [43,44]. The catering and lighting industries, for example, consume large amounts of agricultural and electrical products, respectively, resulting in large amounts of indirect water consumption during production. Consequently, these industries are labeled the “invisible water-consuming industries” [45,46]. In comparison with the tertiary industry class, the direct water use coefficient of the secondary industry category is relatively large. Secondary industries like the steel and electricity industries consume large amounts of direct water for cooling and rinsing [47,48]. These results suggest that improving water use efficiency in primary industries, and decreasing the use of primary industry products in secondary and tertiary industries, be employed to effectively reduce water consumption across all three industry classes [49]. From 2007 to 2012, the complete and direct water use coefficients of both the primary and secondary industries showed a trend of continuous decline. The decline in the complete water use coefficient in the primary industry is mainly related to the decline in the direct water use coefficient, while for the secondary industry the complete water use coefficient was influenced significantly by both direct water use and the use of water-abundant products of the primary industry [40,50]. The requirements of increasing water use efficiency and water recycling in Gansu province by the 11th Five-Year Plan (Outline of the Eleventh year plan for National Economy and Social Development in the People’s Republic of China) from 2006 to 2010 with “six necessities” principles, including maintaining steady and



rapid economic development, accelerating transformation of economic growth modalities, improving self-directed innovation capabilities, promoting the coordinated development of urban and rural areas, strengthening the construction of a harmonious society, and deepening reforms openings [51], also contributed to the decline of direct water use in the primary and secondary industries. It is estimated that about 43 provincial-level pilot projects were designed to promote water-saving, through optimized and upgraded agricultural and industrial sectors [52]. These measures had significant results. Primarily, Gansu focused on promoting water-saving agricultural techniques specific to local conditions [53]. These techniques contributed to a marked decrease in the agricultural irrigation quota, an increase in grain output, and a significant reduction in the direct water use coefficient of primary industry [54]. The success of promoting appropriate local techniques should be noted - since the impacts of technical and infrastructure changes often vary from region to region, it is suggested that each city in Gansu establish context specific measures towards the promotion of coordinated economic and ecological development province-wide.

**Table 1.** Direct and complete water consumption coefficients of primary, secondary, and tertiary industries in Gansu province from 2007 to 2012.

	Water Use Coefficient in 2007		Water Use Coefficient in 2010		Water Use Coefficient in 2012	
	Direct	Complete	Direct	Complete	Direct	Complete
Primary Industry	1545.58	1692.22	882.28	1005.38	762.16	873.44
Secondary Industry	32.69	450.32	20.21	371.90	17.08	309.87
Tertiary Industry	16.65	65.46	7.74	66.89	5.09	72.81

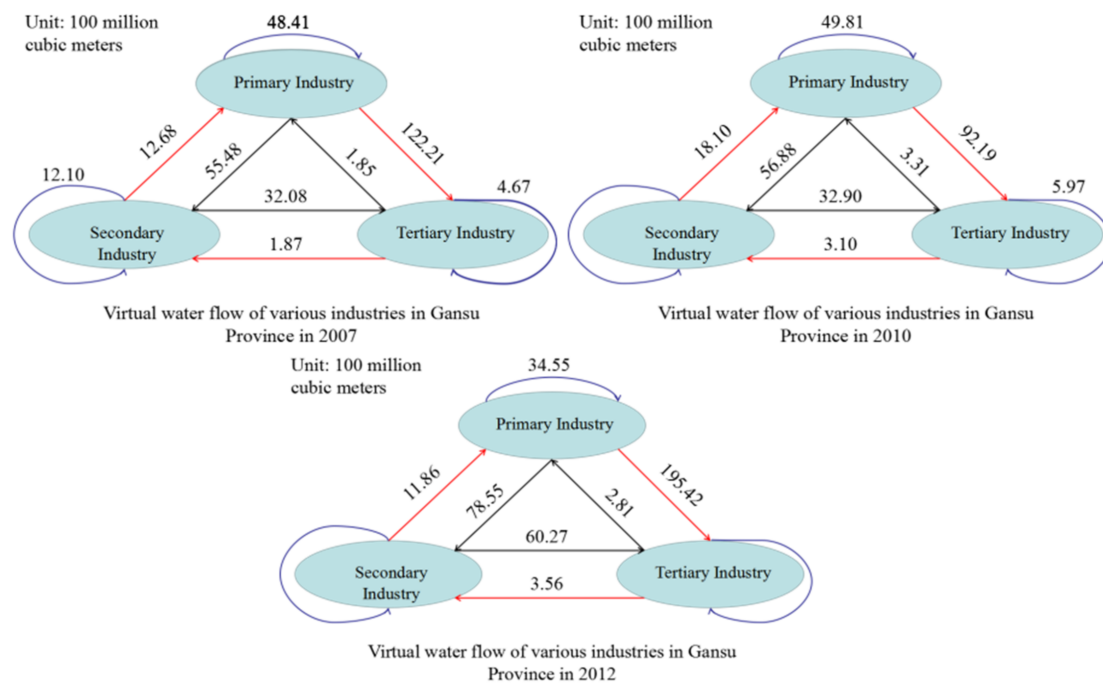
Unit: m<sup>3</sup>/million yuan.

During the study period, the complete water use coefficient of the tertiary industry class exhibited an increasing trend, while the direct water use coefficient decreased with time. This increase in the complete water use coefficient can be attributed primarily to infrastructure development in the western region of Gasnu Province in response to the ‘develop-the-west’ strategy under the 11th Five-Year Plan, in which tertiary industry consumed a large number of water-consuming products [48].

### 3.1.2. Virtual Water Flow and Water Resource Use among Primary, Secondary, and Tertiary Industries

Between 2007 and 2012, the majority of virtual water in Gansu province flowed towards tertiary industry and the smallest portion flowed towards primary industry (Figure 2). Under the ‘develop-the-west’ strategy of the 11th Five-Year Plan, Gansu focused on the development of infrastructure, basic industries and the tourism belt along the Silk Road. The “One Belt and One Road” has been one of the most important parts of China’s strategy of domestic economic and social development, as well as an important part of China’s foreign strategy. The “One Belt” refers to the Silk Road Economic Belt, and the “One Road” refers to the 21st Century Maritime Silk Road [55,56]. During this project, the transportation component of the tourism industry has consumed a large amount of water resources to this day [57].

The total volume of water resources demanded by the region is expressed in terms of gross, or total virtual water; this includes locally produced virtual water and that imported from other regions (Table 2) [58]. Compared to 2007, Gansu’s primary industry virtual water use decreased by 16.63% in 2010. This reduction is attributed primarily to the emphasis on “grain for green” (conversion of farmland to forests) in the ‘develop-the-west’ strategy [59], which not only supports reduced virtual water consumption by primary industry, but also affects consumption in the other industry classes that consume raw materials from primary industry. In 2012, the total amount of virtual water increased significantly; this can be ascribed to the continuous development of the national economy which has brought about significant changes in the income level and consumption structure of Gansu residents, and thus contributes to an increase in water resource consumption [48,60]. In addition, the emergence and advancement of the production and service industries has contributed to increased virtual water use across all three industry categories themselves [61].



**Figure 2.** Virtual water flow momentum of primary, secondary, and tertiary industries in Gansu province from 2007 to 2012.

**Table 2.** Total virtual water consumption of primary, secondary, and tertiary industries in Gansu province from 2007 to 2012.

	Total Virtual Water in 2007		Total Virtual Water in 2010		Total Virtual Water in 2012	
	Local Production	Field Input	Local Production	Field Input	Local Production	Field Input
Primary Industry	210.92	1.11	175.84	1.11	226.64	1.61
Secondary Industry	56.13	12.94	65.05	19.68	80.40	57.40
Tertiary Industry	8.16	2.07	11.70	3.73	18.89	27.65
Total	291.33		277.11		412.59	

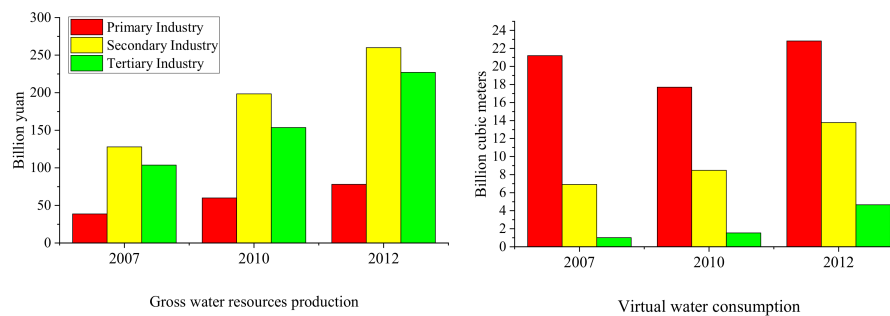
Unit: 100 million m<sup>3</sup>.

### 3.1.3. Benefit Analysis of Virtual Water in Gansu Province

The results of the current study show a large gap in virtual water use between the three industry categories in Gansu between 2007 and 2012, but the total combined water use did not change significantly during this period. These findings indicate that, although Gansu province has made advances in various industries, inequitable distribution of water resources among the industries is still an issue. Upon examination of both gross production value and virtual water distribution, it appears that water consumption remains stable for each individual industry class, but that gross production value increases, suggesting an improvement in utilization efficiency. The primary industry class consumed the highest proportion of virtual water but exhibited the lowest production value, while the secondary and tertiary industry classes showed the opposite trend (Figure 3).

The added value of primary industries in Gansu province between 2007 and 2012 (17.063, 19.412 and 20.079 billion yuan, respectively) was lower than the added value of the national primary industry class (27.075, 37.895 and 49.391 billion yuan, respectively) [62–67]. This trend is related to grain output and prices; Gansu province's grain output and grain prices were lower than the national level, further indicating that the virtual water distribution in Gansu province in the primary industry is not appropriate. It is suggested that, to remedy this result, Gansu should adjust the distribution of water according to specific conditions (e.g., spatial distribution of water resources within Gansu

province) through trade within the province, encourage the development of water-saving and profitable industries, and reform those industries that are water-consuming and less profitable [68,69].



**Figure 3.** Comparison of the total water production and virtual water consumption in Gansu province from 2007 to 2012.

### 3.2. Virtual Water Trade in Gansu Province from 2007 to 2012

#### 3.2.1. Spatial Patterns of Virtual Water Flow in and around Gansu Province

Patterns of virtual water supply and demand between Gansu province and other regions are important to consider. The results of the current study show that, in comparison with 2007, the use of locally produced virtual water in Gansu decreased by 2.262 billion  $\text{m}^3$  in 2010 (Table 2). According to the Gansu Provincial Water Resources Bulletin in 2007 and 2010, in 2010 the water-saving irrigated area reached 3 million mu (1/15 ha) more than that in 2007. In 2012, the total amount of virtual water contained in products was 41.259 billion  $\text{m}^3$ , and 32.593 billion  $\text{m}^3$  of virtual water was provided for local use, accounting for 79.00% of the total. On the basis of 2007 and 2010 statistics, the use of locally produced virtual water increased by 50.72 and 7.334 billion  $\text{m}^3$ , respectively in 2012 (Table 2); this is related to the increase in virtual water consumption across all three industry categories. The proportion of virtual water employed locally verses total virtual water decreased annually from 94.8%, 89.52% to 81.43%, while exports have been mounting, from 5.2%, 10.48%, to 18.57% (Table 3). This trend suggests that the increase in total virtual water may be due to a rise in the import of products with high virtual water content, rather than to the decline of virtual water exports. The industries with the highest direct water use are the dominant exporters, such as those in the primary industry category (Table 4). Therefore, Gansu should focus on improving water use efficiency and minimizing the development of industries with high direct water use to alleviate the pressure on water resources.

**Table 3.** The proportion of local usage and output of virtual water in Gansu province from 2007 to 2012.

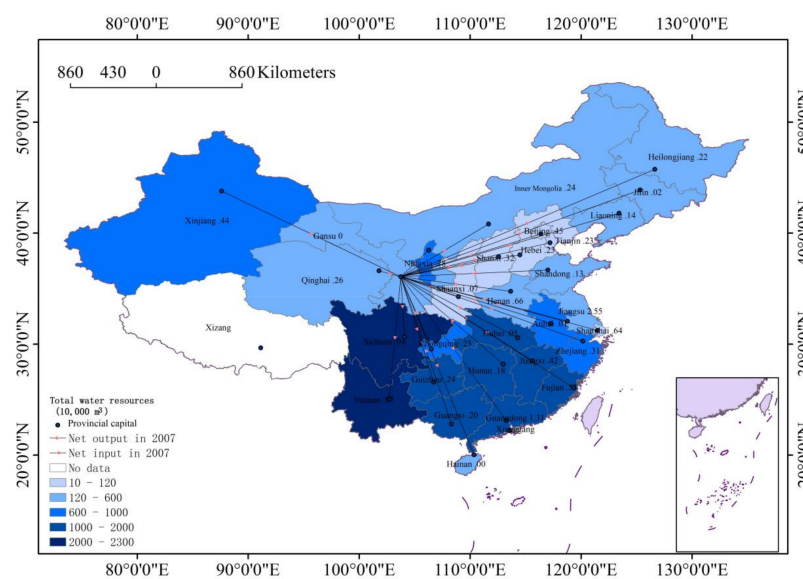
	2007	2010	2012
Total amount of virtual water	100%	100%	100%
Local usage ratio (%)	94.80%	89.52%	81.43%
Output ratio (%)	5.2%	10.48%	18.57%

**Table 4.** Export of virtual water from Gansu and import of virtual water into Gansu across primary, secondary, and tertiary industries.

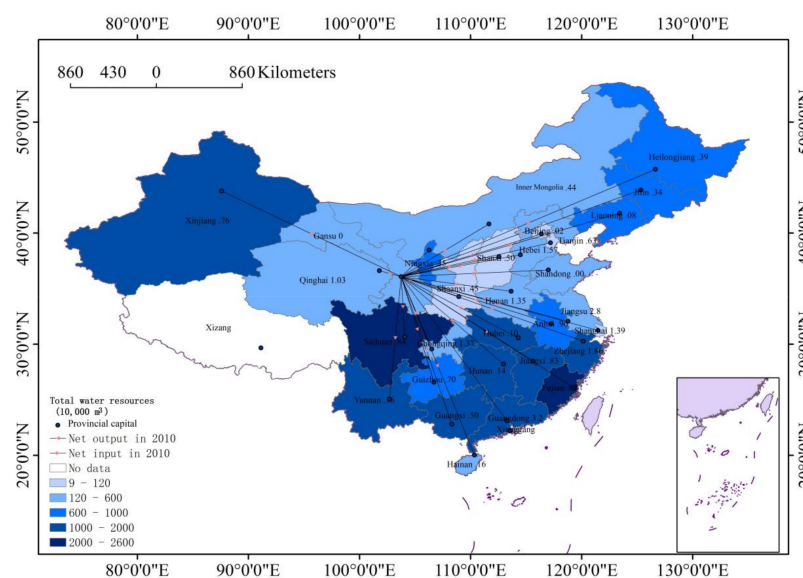
	2007		2010		2012	
	Output	Input	Output	Input	Output	Input
Primary Industry	14.62	1.11	28.62	1.11	72.15	1.61
Secondary Industry	0.32	12.94	0.70	19.68	1.67	57.40
Tertiary Industry	0.16	2.09	0.26	3.73	0.49	27.65
Total	15.10	16.14	29.58	24.52	74.31	86.66

Unit: 100 million  $\text{m}^3$ .

Between 2007 and 2012, virtual water in Gansu mainly flowed towards developed coastal cities (Figure 4) such as Beijing, Shanghai, Guangdong and Tianjin. This is partially due to the encouragement of advances and reforms in emerging and traditional industries, and the implementation of virtual water strategies in these centers [70,71]. Over 80 million  $m^3$  of virtual water flowed to the provinces of Jiangsu, Zhejiang and Hebei in 2007, 2010, and 2012, respectively. Gansu, as a water-scarce province, consistently exported large volumes of virtual water to water-rich areas from 2007 to 2012. Such a trade pattern no doubt increases the pressure on water resources and affects economic development in Gansu [72,73]. The spatial pattern of virtual water trade in Gansu province was developed by ranking the output volume of virtual water flowing from Gansu to different export regions. The export area included China's eastern coast along with the central, western, and northeast regions. Virtual water output volume was divided into three ranges: less than 80 million  $m^3$ , 40 million to 80 million  $m^3$ , and higher than 40 million  $m^3$ .

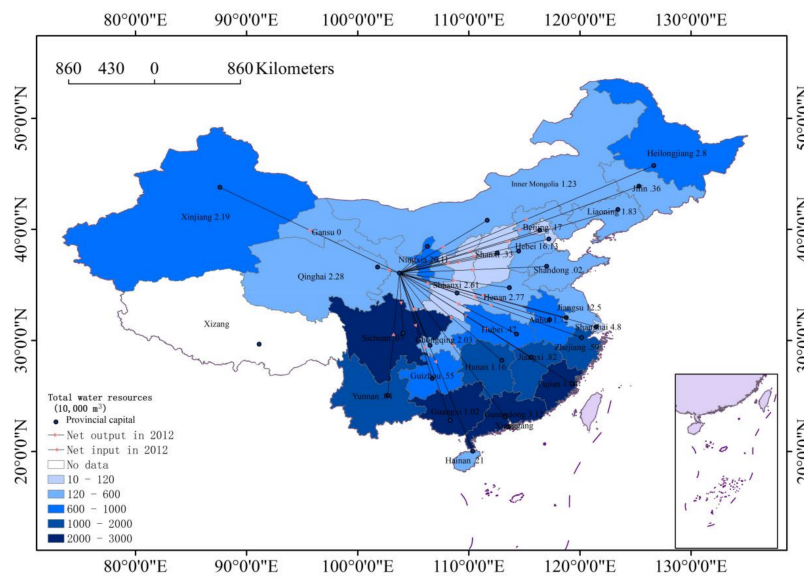


(a) Spatial pattern of interprovincial flow of virtual water from Gansu province in 2007



(b) Spatial pattern of interprovincial flow of virtual water from Gansu province in 2010

Figure 4. Cont.



(c) Spatial pattern of interprovincial flow of virtual water from Gansu province from 2007 to 2012

**Figure 4.** Spatial pattern of interprovincial flow of virtual water from Gansu province from 2007 to 2012.

### 3.2.2. Industrial Structure of Virtual Water Inter-Provincial Flow Direction from Gansu Province

The inter-provincial trade of virtual water is carried out using industrial and agricultural products as carriers [74]. From 2007 to 2012, the largest virtual water exporter was primary industry, exporting 1.462 billion  $\text{m}^3$ , 2.862 billion  $\text{m}^3$  and 7.215 billion  $\text{m}^3$  of virtual water in 2007, 2010, and 2012, respectively, accounting for 96.81%, 96.78%, and 97.13% of the total output (Table 4). As such, the virtual water flow of the primary industry determines the trend of the virtual water current in Gansu province as a whole [75]. Because the agricultural sector dominates in Gansu province, it is the main contributor to virtual water exports. From 2007 to 2012, virtual water from primary industries mainly flowed to Beijing, Shanghai, Guangdong, Tianjin, Jiangsu, Zhejiang and Hebei, and the total output volume was over 80 million  $\text{m}^3$ , consistently increasing over time. These large export destinations are also the principal virtual water sinks, further supporting the concept that the basic pattern of virtual water output in Gansu province is affected by the trade flow of primary industry products [76]. However, most virtual water produced in Gansu province was consumed there, as agriculture, the primary industry of the province, suffers from low utilization efficiency in terms of irrigation water and rainfall [52,54].

In Gansu province, the secondary industry imported the highest virtual water volume from 2007 to 2012 (Table 4), at 1.294, 1.968 and 5.740 billion  $\text{m}^3$ , accounting for 80.17%, 80.26% and 66.24% of the total virtual water import, respectively. This virtual water stream flowed from Jiangsu, Zhejiang, and Henan, each of which retained more than 80 million  $\text{m}^3$  during the study time period. This trend increased consistently, as these regions, in the midst of industrialization, consumed large amounts of water for industrial processes [77,78].

### 3.2.3. Variations and Rationality Analysis of Inter-Provincial Virtual Water Trade in Gansu Province

A net import trend was observed for all virtual water trade in Gansu province in 2007 and 2012; however, in 2010 virtual water displayed a net export trend (Table 4). Gansu province received 104 million  $\text{m}^3$  of virtual water in 2007 because the import volume in the secondary and tertiary industry was higher than the export volume of the primary industry. The ‘develop-the-west’ strategy required the mid-eastern regions to provide facilities, resources, and techniques for the west during that period [55]. The volume of virtual water imported from the primary industry in 2010 was similar



to that of 2007, yet the import volume from the secondary and the tertiary industries increased by 52.09% and 78.47%, respectively.

The export volume of virtual water for the three industry categories combined was two-times greater in 2010 than in 2007; net output of virtual water in 2010 was 506 million m<sup>3</sup>. There are two primary reasons for this; first, although the number of export destinations were reduced, the export volume is extremely large, and second, Gansu increased intermediate inputs and final product exports to other provinces.

Net imports of virtual water were observed in 2012, with a virtual water import volume of 1.235 billion m<sup>3</sup>. The output of the three industry classes combined was twice that of 2010, with the import of the second and tertiary industries, respectively, reaching 2.92 and 7.41 times that of their 2010 counterparts. This is likely related to the policy orientation, industry distribution and state of development of Gansu province, along with the important position of Gansu province in the construction of the “One Belt and One Road” [55].

The distribution of water resources in China is extremely unbalanced. Water resources are more plentiful, and the average annual precipitation is much higher, in coastal areas than in inland areas [79]. The main receivers of Gansu’s virtual water exports include Zhejiang, Guangdong and other water-abundant areas, as well as Inner Mongolia, Chongqing, Shaanxi; all regions with more water storage than Gansu [72,80]. Conversely, Ningxia, Beijing, Shanghai and other regions with low water reserve capacity have been exporting water resources to Gansu province. These patterns reflect the regional failure to match the inter-provincial flow of virtual water trade with water source storage.

#### 4. Conclusions and Recommendation

The current paper systematically explored virtual water flow among industries in Gansu province as well as the inter-provincial virtual water trade patterns. The results of this research indicate that the dynamic variations in virtual water patterns in Gansu province were mediated primarily by the primary and secondary industries from 2007 to 2012. During this period, virtual water for local use decreased, while virtual water exports to developed and water-abundant coastal areas, increased. In addition, it was found that a significant imbalance in virtual water distribution exists across primary, secondary, and tertiary industries, with the majority of virtual water flowing towards tertiary industries, and the smallest volumes flowing towards primary industries.

In view of the imbalance between virtual water distribution across the three industry categories, and the mismatch of inter-provincial virtual water trade with their water resources storage, it is suggested that Gansu emphasizes the promotion of water-saving agricultural techniques, adjusting the structure of the industrial sector by encouraging water-saving and highly-profitable industries, and reducing virtual water export while broadening their import paths, especially from water-abundant areas such as the import of virtual water from adjacent water-abundant areas (Shanxi province and Inner Mongolia), through the establishment of long-term cooperative relationships using appropriate economic policies, to reduce the proportion of water-reliant productions in all industries.

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**Conflicts of Interest:** The authors declare no conflict of interest.



## Appendix A Calculation of the Direct and Complete Water Use Coefficient and Virtual Water Use

**Table A1.** Calculation of the direct and complete water use coefficient and virtual water use [35,36].

Formula	Explanation
$x_i^R = \sum_{s=1}^m \sum_{j=1}^n x_{ij}^{RS} + \sum_{s=1}^m f_i^{RS}$	$x_i^R$ is the total output of the $R$ area $i$ department; $x_{ij}^{RS}$ is the intermediate input of the $R$ area $i$ department to the $S$ area $j$ department; $f_i^{RS}$ is the $R$ area $i$ department's input to the final demand of the $S$ area.
$a_{ij}^{RS} = x_{ij}^{RS} / x_j^S$	The direct input coefficient $a_{ij}^{RS}$ indicates the direct input of the $i$ -sector products of the $R$ region when the unit $j$ department produces the unit products.
$x_i^R = \sum_{s=1}^m \sum_{j=1}^n a_{ij}^{RS} x_j^S + \sum_{s=1}^m f_i^{RS}$ $X^R = A^{RS} X^R + F^{RS}$	A variation of $x_i^R = \sum_{s=1}^m \sum_{j=1}^n x_{ij}^{RS} + \sum_{s=1}^m f_i^{RS}$ containing $a_{ij}^{RS}$ and its matrix representation, where $X^R$ , $A^{RS}$ and $F^{RS}$ are respectively the output matrix, the direct input coefficient matrix, and the final demand matrix.
$x^R = (I - A^{RS})^{-1} F^{RS}$ $B^{RS} = (I - A^{RS})^{-1} = [b_{ij}^{RS}]$	$(I - A^{RS})^{-1}$ is the inverse of the Leontief matrix; its matrix element $b_{ij}^{RS}$ indicates the amount of input to the $R$ -region $i$ department that is needed to meet the final demand of the $j$ -sector in a unit $S$ region. Through the Leontief inverse coefficient matrix, the relationship between demand and output is finally established.
$E^B = [e_j^B]$ $e_j^B = w_j^B / x_j^B$	In order to further establish the output relationship between water consumption and input, it is necessary to determine the direct water use and complete water use coefficient. Among them, $E^B$ is the direct water use coefficient matrix of $B$ area; $e_j^B$ is the direct water use coefficient of department $j$ of $B$ area; $w_j^B$ is the direct water consumption of department $j$ of $B$ area; $x_j^B$ is the total output of department $j$ of $B$ area.
$\delta = \sum_j e_j^B \times b_{ij}^{BR}$	The complete water use coefficient $\delta_j^B$ can be obtained by multiplying the direct water use coefficient by the Leontief inverse coefficient matrix, that is, the water consumption of the product in the $B$ area by adding one unit of the final demand product. Among them, $R$ indicates other areas outside the $B$ area of the study area, and $b_{ij}^{BR}$ indicates the complete water use coefficient of the $R$ area $B$ in other areas.
$T^B = t_j^B; t_j^B = \delta_j^B \times f_i^{BR}$	The virtual water volume is calculated from the complete water use coefficient. $T^B$ is the virtual water matrix of the province $B$ output; $t_j^B$ is the virtual water of the $j$ department, $f_i^{BR}$ is the final use amount of the $R$ area to the $B$ area.

**Table A2.** Industry Specific Classification.

Primary Industry	Agriculture, Forestry, Animal Husbandry, Fishery Services.
Secondary Industry	Coal mining, Petroleum and gas, Metal mining, Nonmetal mining, Food processing and tobaccos, Textile, Clothing, leather, fur, etc. Wood processing and furnishing, Paper making, printing, stationery, etc. Petroleum refining, coking, etc. Chemical industry, Nonmetal products, Metallurgy, Metal products, General and specialist machinery, Transport equipment, Electrical equipment, Electronic equipment, Instrument and meter, Other manufacturing, Electricity and hot water production and supply, Gas and water production and supply, Construction.
Tertiary Industry	Transport and storage, Wholesale and retailing, Hotel and restaurant, Leasing and commercial services, Scientific research, Other services.

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