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Regional Water Footprint Assessment: A Case Study of Leshan City

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Abstract: This paper presents an assessment of urban water footprint in the period of 2001 to 2012 by taking Leshan City, China as a typical case study. The water footprint is calculated by the sum of the water footprints of various sectors, *i.e.*, crop production, animal products, industrial processes, domestic waster, eco-environment, and virtual water trade. Results show that the water footprints of the various sectors rose by degrees varying from 19% to 55%, which gave rise to an increase of the total water footprint of 43.13% from 2001 to 2012. Crop production and animal products are identified as the major water intensive sectors, accounting for about 68.97% of the total water footprint. The water footprint in the Northeastern area of Leshan City is greater than that of the Southwestern area in the period 1992–2012, resulted in an expansion of water footprint in the Sha Wan and Wu Tongqiao Districts due to the development of urbanization. The application of water footprint assessment is expected to provide insight into the improvement of urban water efficiency, and thus aid in better water resources management.

Keywords: water footprint; water footprint assessment; Leshan City; water resources management

1. Introduction

With the development of urbanization, water scarcity has become more and more prominent [1–3]. In particular, the shortage of water resources has had a great impact on China's economic and social development, *i.e.*, whether sufficient food can be provided to feed such a large and growing population [4–8]. To promote water conservation, secure water efficiency corresponding to urban growth is an increasing challenge for China's policy makers [6,9].

The water footprint, as a comprehensive indicator for water resources management, is interpreted as the total amount of freshwater use to measure water consumption and pollution [10–13]. Proposed by Hoekstra in 2003, assessment of water footprint has been widely applied to various categories in the past decade, e.g., products, business services, geographical areas, *etc.* [7,12,14].

In the field of product assessment, Chapagain *et al.* [15] assessed its associated impacts on the water resources based upon the water footprint of cotton consumption, which were transitional. Ridoutt *et al.* [16] applied a LCA-based methodology to water footprint accounting of agricultural food products, by which the farming stage was identified as the major sector of water consumption, and was strongly influenced by the downstream food manufacturers. Similar results were found by Ercin *et al.* [17], Gerbens-Leenes and Hoekstra [18], Ridoutt *et al.* [19], Van Oel and Hoekstra [20], Chico *et al.* [21], Herath *et al.* [22], Ene *et al.* [23], who extended water footprint assessment to wider application for products, such as soy milk and soy burgers, sweeteners and bio-ethanol, paper, livestock, jeans and wines. Mekonnen and Hoekstra [24] measured the water footprint of crops and derived crop products in the period of 1996–2005. Three components of water footprints were assessed, *i.e.*, green, blue and grey, to indicate consumption of rainwater, surface and groundwater, and freshwater assimilating water with pollutants, in contrast to natural background concentration. On this basis, Mekonnen and Hoekstra [25] found that the blue and grey water footprint of the animal products derived from grazing were smaller than those from industrial manufacturing. Since a key issue has come up throughout the assessment of water footprint, namely the lack of a unified and well recognized evaluating principle and methodology, ISO 14046 is proposed to fill this gap by taking a life cycle perspective to assess water footprint, including scope division, inventory analysis, impact assessment, result interpretation *etc* [26,27]. For instance, Manzardo *et al.* [28] applied water footprint assessment based on the methodology of ISO14067 to a tomato sauce produced in U.S, and drew a comparison with the result obtained by conventional water footprint network accounting. The result showed that the consistent results were provided by the two methods, except for application to degradative water use.

With regard to the assessment of business water footprint, Ercin *et al.* [29] took a hypothetical factory of sugar-containing carbonated beverages as an example to examine freshwater use along the supply chain. Similarly, Ruini *et al.* [30], applied water footprint assessment to a pasta company, in order to measure the sustainability of the related manufacturing process. Li and Chen [31] applied water footprint evaluation to gaming service, which reflected that direct water consumption only accounted for a small proportion.

In applications of different geographic dimensions, a number of studies on national, regional water footprint assessment were proposed. For instance, each country's water footprint was calculated by Hoekstra and Chapagain [32], whilst the major influencing factors were identified as consumption volume, patter, growth conditions and water efficiency. A water footprint derived from the LCA is usually determined by a functional unit, which may result in lower comparability when applying to accounting of different sectors in a designated geographic area [33]. The input-output (I-O) method is thus recommended to provide a holistic assessment in a unified functional unit. For example, Zhao *et al.* [34] used the input-output method to assess China's water footprint in 2002, by which China was verified as a virtual water exporter. The result was validated by Chen and Chen [35], who indicated that China was the world largest exporter and deficit receiver according to the virtual water trade. Zhang and Anadon [36] further identified that China's domestically virtual water trade was twice than that embodied in exports in terms of a multi-regional input-output analysis. In the regional sector, Zhang *et al.* [37,38], Wang *et al.* [39] took Beijing as a typical case study, to evaluate the water footprint based on an input-output framework, through which Beijing was found to be a virtual water importer, *i.e.*, dependence on external water resources. In addition to the I-O application, Fiałkiewicz *et al.* [40] established Urban Water Footprint Labs in the towns of Vicenza, Innsbruck and Wroclaw, including a common water technology and management database available on the project web-site, through which policies were made to support better water management.

The previous studies regarding water footprint assessment are useful in identification of the most water-intensive sector, thus to provide insight into better policy or decision-making on water saving and improvement of water efficiency. However, the variation of water footprint in a specific region is difficult to investigate. The spatial representation provides an opportunity not only to demonstrate the spatial-temporal evolution of the regional water footprint distribution, but also to identify the area with the greatest change of the water footprint in a certain temporal range, ultimately to promote the regional water resources management and allocation [41,42].

This study provides a holistic assessment for urban water footprint by using Leshan City, Sichuan Province as a case study, to measure the freshwater consumption of various sectors. Leshan City, because of its rapid urbanization and industrialization, is similar to the development of other cities in China. In this context, the area with the largest water consumption as well as the time variation of the utilization of water resources of a specific area can be identified, in order to lay out reasonable policy mechanisms for water resource allocation. In addition, a computational tool has been devised to help policy makers better understand and employ the method of water footprint assessment.

2. Methodology and Data

The total water footprint in a geographically delineated area is seen as a sum of the water footprint accounting process [12]. The actual water consumption of one region equals to the local demand of water resources and imported virtual water, in which the former is mainly divided into the demand for crop production, animal products, industrial processes, domestic water and eco-environment, as shown in Figure 1. Other sectors related to the water consumption are omitted in the system boundary. For example, water withdrawal and purification for domestic use are incorporated into the water footprint of domestic water, which is measured as direct water consumption. This is because the domestic sewage should be treated to discharge into nearby rivers, according to the National Standard of the second-class water quality [43].

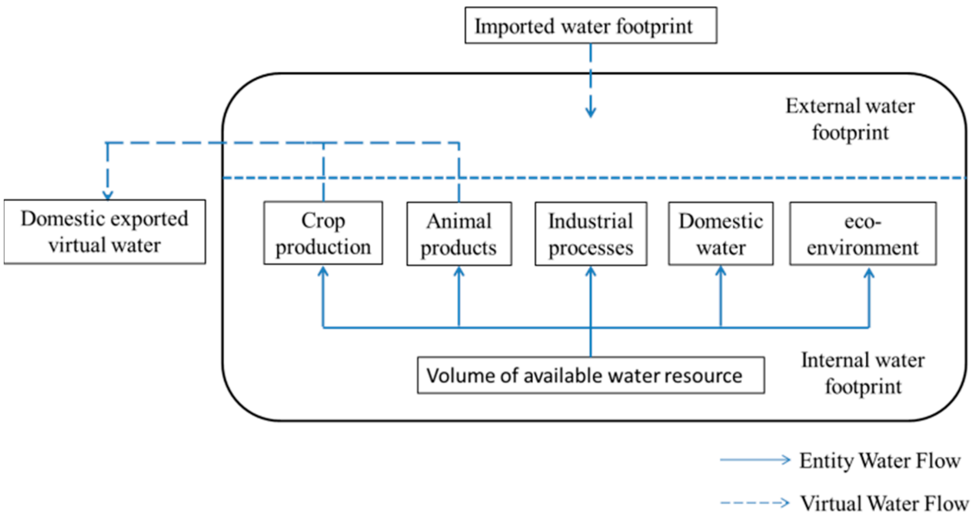

Figure 1. System boundary of regional water footprint assessment.

2.1. Water Footprint of Crop Production

The average water demand of crop production mainly depends on the types of crops, the region of growth, and the mode of irrigation system. For a specific crop, the average water demand is calculated per district, given as follows [44]:

$$AWD_{cd} = \frac{CWR_{cd}}{A_{cd}} \quad (1)$$

where AWD_{cd} is the average water demand (m^3 per tonne) of crop c in district d of a specific urban area, CWR_{cd} the water requirement of crop production (m^3 per ha), and A_{cd} the crop yield (tonne per ha).

Here, CWR_{cd} can be approximately substituted by the accumulated crop evapo-transpiration ET_c (in mm/day), given as follows [45]:

$$ET_c = K_c \times ET_0 \quad (2)$$

where K_c is the crop coefficient, and ET_0 is the crop evapotranspiration in an ideal environment of growth (mm/d), which is calculated by using the Food and Agriculture Organization (FAO) Penman-Monteith equation [44,46,47]:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma\frac{900}{T+273}u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \tag{3}$$

where:

R_n = net radiation at the crop surface, $MJ/\left(m^2 d\right)$;
G = flux of soil heat, $MJ/\left(m^2 d\right)$;
T = average temperature, $^\circ C$;
u_2 = wind speed while measuring at 2 meters height, m/s;
e_s = pressure of saturation vapour, kPa;
e_a = actual vapour pressure, kPa;
Δ = slope of the curve between saturation vapour pressure and temperature, $kPa/^\circ C$;
γ = psychrometric constant, $kPa/^\circ C$.

2.2. Water Footprint of Animal Products

The water footprint of animal products is composed of the virtual water content of a live animal during its entire lifespan, and the water consumption while distributing various meat products from the animals [45]. The virtual water contains the water use of feeding, drinking water and servicing, calculated as follows [48]:

$$VWC = VWC_{feed} + VWC_{drink} + VWC_{servicing} \tag{4}$$

where VWC_{feed}, VWC_{drink}, and $VWC_{servicing}$ denote the virtual water contents corresponding to feeding, drinking and servicing respectively, m^3 per tonne.

VWC_{feed} can be measured as the sum of the water requirement of the prepared feed mix and the virtual water of various feed ingredients contained, shown as follows:

$$VWC_{feed} = \frac{\int_{birth}^{death}(Q_{mix} + \sum_{i=1}^{N} VWC_i \times C_i)dt}{W} \tag{5}$$

where:

Q_{mix} = water demand of mixing the feed, m^3/d;
VWC_i = virtual water content of the ith feed crop, m^3/t;
C_i = quantity of feed crop consumed by the animal daily, t/d;
W = average live weight of the animal at the end of its lifespan, t;

The virtual water content from drinking water VWC_{drink} can be calculated by:

$$VWC_{drink} = \frac{\int_{birth}^{death} Q_d dt}{W} \tag{6}$$

where:

Q_d = the daily drinking water consumed by the animal, m^3/d;
W = average live weight of the animal at the end of its lifespan, t;

The virtual water content from service water is deemed as the water consumed by the farmyard cleaning and maintaining, animal washing during the entire lifespan of the live animal, which is calculated by:

$$VWC_{servicing} = \frac{\int_{birth}^{death} Q_s dt}{W} \tag{7}$$

where:

Q_s = the daily service water requirement of the animal, m^3/d;
W = average live weight of the animal at the end of its lifespan, t;

2.3. Water Footprint of Industrial Processes

The crop and animal products as raw or auxiliary materials for industrial processes have not been taken into account in the calculation of water footprint of industrial sector, except for direct freshwater use, virtual water content, and water pollution [49]. Thus, the water footprint of the industrial sector can be measured by:

$$V_{Itotal} = V_{Iblue} + V_{Igrey} + V_{Ivirtual} \quad (8)$$

where V_{Iblue}, V_{Igrey}, $V_{Ivirtual}$ represent the blue, grey and virtual water footprint of the industrial processes.

The blue water footprint is regarded as the direct freshwater use in the industrial processes, calculated by [49]:

$$V_{Iblue} = V_{draft} - V_{effluent} \quad (9)$$

where V_{draft} indicates the water withdrawn by the stages related to production, transportation *etc.*, m^3/y; $V_{effluent}$ the waste water emissions, m^3/y.

The grey water footprint is used to indicate the degree of water pollution, defined as the volume of freshwater which is required to dilute pollutants, calculated by [12]:

$$V_{Igrey} = \frac{W_l}{C_{max} - C_{nat}} \quad (10)$$

where W_l is the load of pollutant, tonne/y; C_{max} the maximum acceptable concentration, tonne/y; C_{nat} the natural concentration in the receiving water body, tonne/y. In its real application, the industrial waste water is treated by compliance with the National Standard of the third-class water quality standard, and then discharged into nearby rivers, no matter what treatment process is implemented [50]. Thus, different cases can be only reflected by selecting the most typical pollutants of one industry, or the pollutants which have the most impact on the local water quality, to calculate the C_{max} and C_{nat}.

In the industrial sector, the most typical pollutants, e.g., COD, BOD_5, ammonia nitrogen *etc.*, are selected to reflect the degree of water pollution in the delineated region [49]. Thus, Equation (10) is transformed as:

$$V_{Igrey} = \frac{V_{effl} \times (C_{effl} - C_{nat})}{C_{max} - C_{nat}} \quad (11)$$

where:

V_{effl} = the waste water emissions, m^3/y;
C_{effl} = the concentration of the typical pollutants, tonne/y;
C_{max} = the maximum acceptable concentration, tonne/y;
C_{nat} = the natural concentration in the receiving water body, tonne/y.

The virtual water footprint of the industrial sector is incorporated into the water required by the raw and auxiliary materials, fuels consumption [49], which is measured as follows:

$$V_{Ivirtual} = \sum_{i=1}^{n} M_i k_i \quad (12)$$

where M_i represents the consumption of the ith materials or fuels and k_i the water footprint coefficient of the ith materials or fuels.

2.4. Water Footprint of Domestic Water

The urban domestic water is regarded as a fundamental source for provision of goods and services consumed by the inhabitants' daily life, including the water demand for household use, personal hygiene, drinking, washing clothes and dishes, flushing toilets, *etc*. [11,12]. The water footprint of urban domestic water is measured as the direct water consumption in this study, by which the water withdrawal and purification for domestic use are incorporated.

2.5. Water Footprint of Eco-Environment

The eco-environmental water demand is defined as the amount of water used by the ecosystem to maintain the water balance of the living beings and improve the water environment as well as the environment in which human lives [51–53]. In this paper, the water footprint of urban eco-environment comprises the ecological water use of urban green spaces, water use of rivers and lakes, and water use of urban sanitation, aiming at the improvement of water quality, ecological environment, and urban landscape *etc.*, shown as follows [51]:

$$W_{etotal} = W_{gr} + W_{rl} + W_{sa} \tag{13}$$

where W_{gr} indicates the water footprint of urban green spaces, m^3/y; W_{rl} the water footprint of urban rivers and lakes, m^3/y; W_{sa} the water footprint of the urban sanitation, m^3/y.

The water footprint of urban green spaces W_{gr} is calculated by the quota method, shown as follows [52]:

$$W_{gr} = q_{gr} \times c_{gr} \tag{14}$$

where:

q_{gr} = the water quota of urban green spaces, $m^3/\left(ym^2\right)$;

c_{gr} = the urban green coverage, m^2.

The water footprint of urban rivers and lakes W_{rl} is calculated by the water budget method, shown as follows [54]:

$$W_{rl} = V_{ep} + V_{sp} + V_{rl} \times f_c \tag{15}$$

where V_e is the volume of evaporation from urban water surface, m^3; V_s the volume of seepage from urban water body, m^3; V_{rl} the volume of urban rivers and lakes, m^3; f_c the period of water replacement.

The evaporation from urban water surface V_{ep} is calculated by the following equation [54]:

$$V_{ep} = 10 \times A_S \times E_{urb} \tag{16}$$

where:

A_S = area of urban water surface, hm^2;

E_{urb} = urban evaporation potential, mm;

The seepage from urban water body V_{sp} is calculated by the following equation [54]:

$$V_{sp} = 10 \times A_S \times D_{sp} \tag{17}$$

where:

A_S = area of urban water surface, hm^2;

D_{sp} = depth of seepage, mm;

The water footprint of the urban sanitation W_{sa} is calculated by the quota method, given as follows [54]:

$$W_{sa} = q_{sa} \times c_{sa} \tag{18}$$

where:

q_{sa} = the water quota of urban sanitation, m^3/hm^2;
c_{sa} = the urban area, hm^2.

All of these coefficients, such as D_{sp}, E_{urb}, f_c, are derived from the local statistical data. For example, the D_{sp} represents the depth of seepage, which can be calculated by the permeability of sediment on the riverbed [54,55]. According to the local standard of hydrogeology and engineering geology, the permeability of sediment in Southwestern China is approximately 0.6m/d. Other empirical values of the coefficients can be determined in a similar way.

2.6. Water Footprint of Virtual Water Trade

Virtual water trade is used to indicate the water embedded in traded water intensive products, aiming at improvement of water use efficiency and mitigation of water crisis [10,34]. Especially in China, there is a closer connection between commodities trade among different regions or cities, which may result in virtual water trade. The water footprint of urban virtual water trade V_{trade} is calculated by the difference between the gross virtual water export V_{exp} and the gross virtual water import V_{imp}, shown as follows [10,12]:

$$V_{trade} = V_{imp} - V_{exp} \tag{19}$$

2.7. Case Background and Data Source

Leshan was selected as a typical case study city to assess its associated water footprint. It is a city with a history of more than 3,000 years, located in the southern part of Sichuan Province (102°15'–104°15' E, 28°28'–29°56' N). The administrative area's population is 12,827 including 4 districts, 7 country towns, and 211 village towns, with a total population of 3.56 million in 2013. Leshan's gross domestic production (GDP) has reached 113.479 billion Chinese Yuan, ranked as the 9th in Sichuan Province. As one of the most significant agricultural bases in Sichuan, Leshan City plays an important role in crop and livestock production, ranked the first based on the sales of farm products. In addition, the government of Leshan City pays greater attention to accelerating industrial development, by which a number of high-tech zones have been established in relation to electronics, poly-silicons, pharmaceutical etc [56,57]. Leshan city is abundant with water resources with 11.52 billion cubic meters , and located at the confluence of Minjing, Dadu and Qhing Yijiang rivers [58]. In this context, the dominant industries are water intensive [59].

The corresponding data for calculation of water footprint of crop production, animal products, industrial processes, domestic water, eco-environment and virtual water trade are mainly sourced from: FAO Statistical Database [60], Sichuan Water Resources Bulletin (2001–2012) [61], Leshan Statistical Year Book (2001–2012) [62], Thematic Database for Human-earth System [63], China Meteorological Data Sharing Service System [64], China Crop Database by Ministry of Agriculture [65], China Soil Scientific Database [66], Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002) [43].

In order to assist policy makers in the application of the above methodology for water footprint assessment, as well as to simplify the computational complexity, a calculation tool was developed using the C programming language. Figure 2 shows the user log-in interface of the developed tool. When a user has registered by filling out the request form and agreed on use for academic purposes, the log-on account and the corresponding password are provided by sending them to the user's email address.

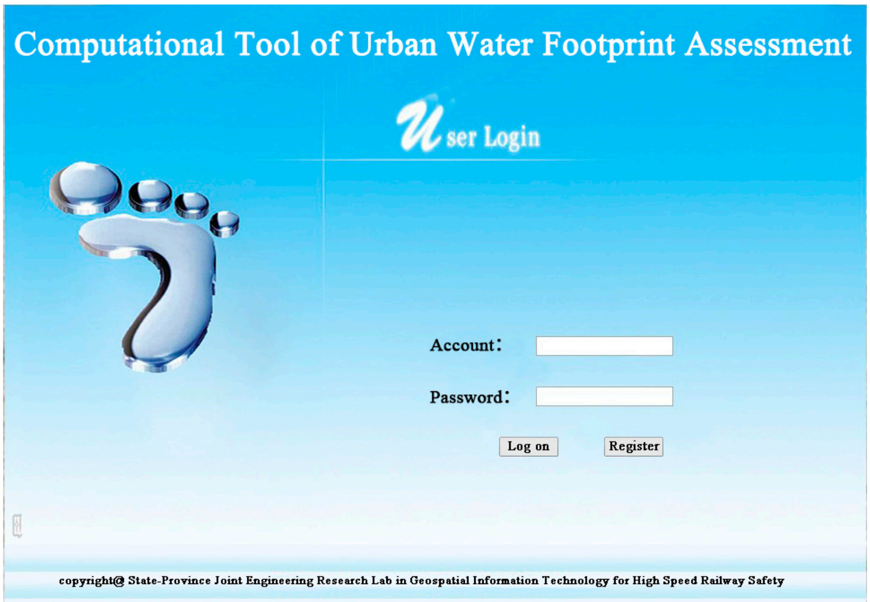

Figure 2. Log-on interface of the calculation tool.

Once the tool is logged on successfully, calculation of the water footprint of all the above mentioned sectors can be implemented, e.g., on submitting the corresponding data to climate, soil, crops, respectively, the water footprint of crop production can be calculated, as shown in Figure 3.

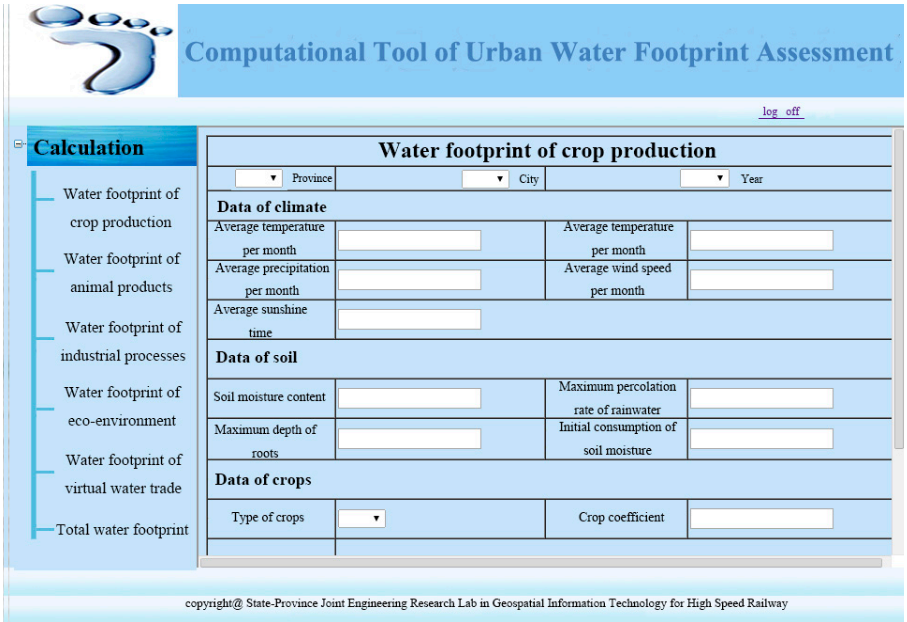

Figure 3. Water footprint calculation of crop production by using the calculation tool.

3. Results and Discussion

3.1. Results

Table 1 shows the water footprint of each sector in the period 2001–2012, in which the total water footprint of 2012 is 7.79 billion m^3, increased by 43.13% in contrast to 2001. Crop production accounts for the most at 41.53% on average, animal products 27.44%, virtual water trade 11.74%, industrial processes 7.71%, domestic water 6.75%, and eco-environment the least, at 4.82%. This indicates that crop production and animal products are the major water consumed sectors, which highlights Leshan City in its advantage of agricultural production within Sichuan Province [67]. Thus, it is suggested that advanced technologies of water-saving irrigation should be developed to enhance the water productivity of crops and minimize loss of water delivery.

Table 1. Water footprint of Leshan City in the period 2001–2012 (billion cubic meters).

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Crop production	2.54	2.57	2.57	2.62	2.80	2.74	2.85	3.05	3.05	3.13	3.28	3.15
Animal products	1.69	1.71	1.78	1.74	1.86	1.83	1.90	2.03	2.03	2.08	2.05	2.10
Industrial processes	0.47	0.48	0.51	0.49	0.53	0.52	0.57	0.58	0.52	0.59	0.58	0.67
Domestic water	0.42	0.42	0.44	0.43	0.46	0.45	0.46	0.50	0.50	0.52	0.51	0.55
Eco-environment	0.31	0.30	0.32	0.31	0.34	0.32	0.37	0.39	0.39	0.37	0.36	0.37
Virtual water trade	0.60	0.61	0.63	0.68	0.66	0.65	0.67	0.79	0.72	0.81	0.89	0.93
Total water footprint	6.06	6.12	6.27	6.30	6.68	6.54	6.84	7.37	7.24	7.52	7.69	7.79

In spite of the minor fluctuation, the water footprint of each sector presents an underlying trend of growth in the period 2001–2012, as shown in Figure 4. The water footprint of virtual water trade increases substantially, by approximately 55%, followed by industrial processes as 43%, domestic water as 31%, crop production and animal products as 24%. The water footprint of eco-environment is slightly changed, with its increase of 19% up to 2012. For Leshan city, the per capita water resource is 3326 m^3, which is far greater than the water stress indicator, as the annual water supplies below 1700 m^3 per person [58,68]. Since Leshan is rich in water resources, it is targeted to export water intensive products to other cities or regions, such as ceramic and pottery, stainless steel, phosphorus chemical products, *etc.* [59,69].

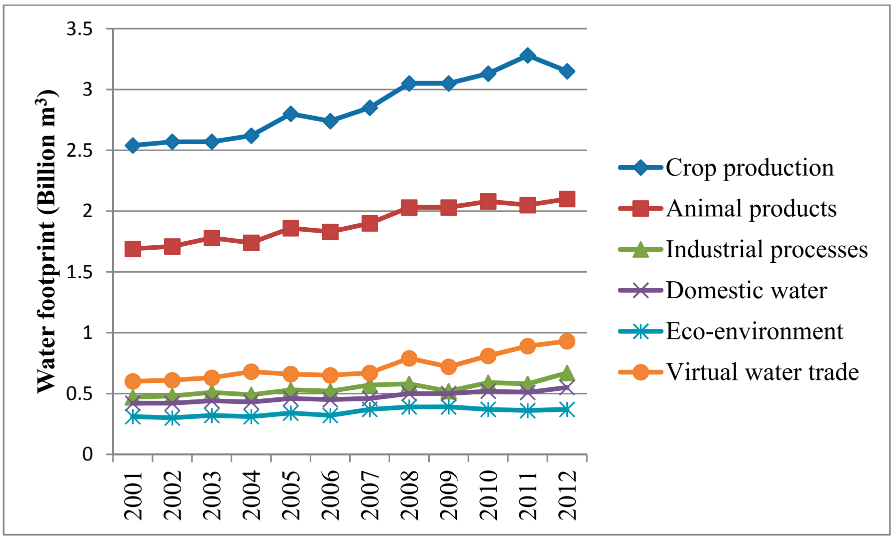

Figure 4. Variation trend of water footprint for each sector in the period 2001–2012.

Dividing the total water footprint by the urban acreage, water footprint intensity (WFI) is thus calculated by using the ArcGIS software to create a water footprint map (WFM). The WFM is intended to visualize the water footprint intensity in order to reflect its variation in a determined spatial and temporal distribution, e.g., the spatial distribution is limited to the administrative area of Leshan City, whilst the temporal ranges from 2001 to 2012. The WFM is based on the "Three Elements of map design", which involves mathematical element, geographic elements and decorative elements [70]. The satellite imagery of Leshan City is rasterized to create the basic elements layers, such as administrative division, rivers, *etc.* Related data, e.g., regional area, water footprints of different sectors *etc.*, are input into the database. By using the anti-gravity weighting method and interpolation, the preliminary WFM is generated through further colour rendering. The annotation is labeled on the map, such as legend, plotting scale, *etc.*

Figure 5 shows the WFI variation of Leshan City in the period 2001–2012. The ranges are highlighted using a background colour which gradually changes from blue to red, indicated that the water footprint intensity increased from 100 to 120,000. Accordingly, the features of water resources utilization in Leshan City can be summarized as follows from the figure:

(1) Variation of spatial distribution: The spatial representation of water usage is helpful in identifying the water scarce area. For instance, the WFI of the Northeastern area is apparently larger than that of the Southwestern area, which is consistent with the regional characteristics of demographic and geographic distribution, *i.e.*, the Northeastern area is the comparatively economic developed area in Leshan City, with dense population and water intensive industries.

(2) Variation of temporal distribution: the distribution of total water footprint has led to an expansion during the period of 2001 to 2012, e.g., the water footprint intensity in Sha Wan and Wu Tongqiao Districts is increased, as shown in Figure 4. This situation is resulted from the development of urbanization, as these districts are gradually incorporated into the central urban areas, which can be verified by "Leshan City Planning in the period 2010–2030", indicated that Sha Wan and Wu Tongqiao Districts are merged as the central urban areas, with the urban land-use reaching 100 square kilometers in the year of 2020 [62].

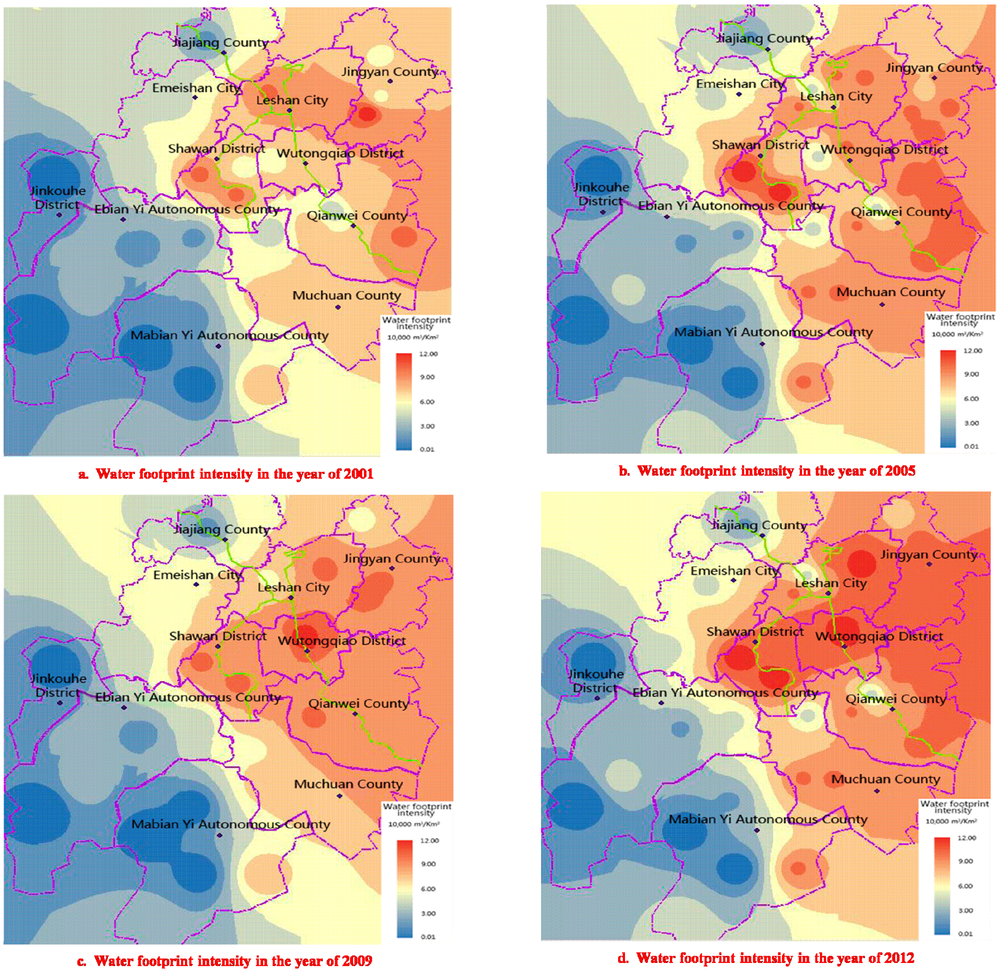

Figure 5. Variation of water footprint intensity of Leshan City in the period 2001–2012.

3.2. Discussion

In this study, the sectors division is similar to that has been proposed by Aldaya *et al.* (2010) and Rui *et al.* (2011), who place emphasis on evaluating regional water resources utilization from the perspective of factors of production [71,72]. From the decomposition of water footprint, the sector of crop production accounts for the largest proportion, at 41.53% averagely. This has been validated by a number of similar studies using different accounting methods, to indicate that the agricultural sector consumes a large amount of freshwater, and contributes to the largest water footprint [7,37,73,74]. At the same time, it has great potential to enhance agricultural water efficiency, by which water saving irrigation is thus strongly encouraged [75]. For instance, drip irrigation is proposed by using networks of pipes to water the soil surface or root zone of plants directly, which is a management option to reduce water consumption and maintain agricultural production and productivity [76]. Compared with the conventional surface flooding irrigation commonly used in China, drip irrigation is more efficient in reduction of energy consumption and carbon emissions [77]. Significant efforts should be also made by policy makers regarding identification of advanced water resource management to promote water saving irrigation, e.g., remote sensing and satellite imagery are useful to identify losses in agricultural productivity by assessing agricultural water use, which supports better agricultural planning [78]. Besides, a number of policy instruments, such as pricing strategy, economic sanctions, financial subsidies, *etc.*, may give rise to internalization of the external cost of water, thus to drive development of less water intensive industries and services [7,79].

Water footprint accounting provides better implications to illustrate the potential links among human demand, water consumption and global trade, in order to improve water resource management [40,80]. However, the accounting methods of water footprint are still in progress, which may result in uncertainties of the associated results, e.g., lack of a unified methodology for the accounting [81,82]. The accounting methods can be mainly divided into the bottom-up and top-down methods in general, in which the former focuses on water footprint assessment in the process of manufacture, whilst the latter emphasizes the product consumption process [12,83]. The incomparability of the final accounting result thus gives rise to a variety of data demands and division of systems boundary. In our study, water footprint is calculated by the sum of the water footprints of various sectors, which can be attributed to a typical application of the top-down method, to evaluate regional water resources utilization in a perspective of factors of production. It is expected to confirm the validity and sensitivity of this approach by applying it to a wider range of case scenarios.

Apart from that, it is noteworthy that no water footprints can completely enhance the understanding of water resource issues and contribute to policy analysis, except for bringing increased attention to discussions on water scarcity [84–86]. A single indicator like a water footprint is not sufficient to provide policy guidance, but more information that involves variables regarding physical, social and economic dimensions should be taken into account in order to determine an optimal framework of policy making related to water resources management [86,87].

4. Conclusions

This study applies water footprint assessment to measuring the water consumption of Leshan City in the period 1992–2012. The water footprints of various sectors show an increasing trend to varying degrees, in which the virtual water trade increases substantially by approximately 55% up to 2012, followed by the industrial processes at 43%, domestic water at 31%, crop production and animal products at 24%, and eco-environment at 19%. In contrast to 2001, the total water footprint of 2012 increased by 43.13%. Crop production and animal products are identified as the major water consumption sectors, accounting for about 41.53% and 27.44% of the total water footprint.

From the perspective of the geographic distribution of Leshan City, the water footprint in the Northeastern area is greater than that of the Southwestern area in the period 1992–2012. In particular, the distribution of total water footprint has led to an expansion in Sha Wan and Wu Tongqiao Districts in the Northeastern area, with the development of urbanization.

It is expected that the water footprint assessment can provide insight into the improvement of urban water management. For example, crop production and animal products are identified as the major water consumed sectors in the study. Water saving irrigation is thus recommended to enhance the water productivity of crops and minimize loss of water delivery, in order to ultimately reduce the associated water footprint.

However, there are some limitations in this study. First, the specific water requirement from different sources in a designated sector, e.g., the origin of that water, has not been taken into account. Second, the internal structure of water footprint accounting, such as the water balance between blue and green water, has been omitted in this study. Further study will center on improvement of the assessment, in order to examine the internal structure and establish a more precise system boundary for the accounting, to promote sustainable water management.

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