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Applying the virtual water concept at regional level — The cases of the Prefectures of Xanthi and Rhodope, Greece

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ABSTRACT

Virtual Water is a recently introduced and widely recognized concept that is considered important for attaining regional and global water security. It refers to the water needed for the production of an agricultural or industrial product and it is contained in the product not in real but in virtual sense. The practical importance of the virtual water concept is mainly twofold, as virtual water trade can act as a tool to achieve water security and efficient water use, while water footprints can act as links between consumption patterns and the impacts on water. This paper applies the virtual water concept at regional level using the Prefectures of Xanthi and Rhodope as case studies. The ensuing results are juxtaposed and commented.

Keywords: Virtual water; Water footprint; Xanthi; Rhodope

1. Introduction

Virtual water (VW) is a recently introduced and widely recognized concept that is considered important for attaining regional and global water security. The term was introduced by Allan in 1993, who defined it as the water that is necessary for creating a product [1]. It refers to the water needed for the production of an agricultural or industrial product and it is contained in the product not in real but in virtual sense. For example, around 15.5 m^3 of water are required for the production of 1 kg of veal or beef meat, 6.1 m^3 of water for the production of 1 kg of lamb meat, 3,200 L of water for the production of 1 L of milk. This water quantity is called virtual because after the product is produced, the real water quantity that was used for its production is no longer contained in the product. The exact water volume that is required for the cultivation or the production of a product, its processing, its packaging, etc before it reaches the consumer depends on the climate of the region and practices that are followed in the region where the product is produced. The estimation of the VW of a region can be very useful for trade policymaking and water management, especially in water-scarce regions. The practical importance of the VW concept is mainly twofold, as Virtual Water Trade (VWT) can act as a tool to achieve water security and efficient water use, while water footprints can act as links between consumption patterns and the impacts on water [2].

Water footprint is the cumulative virtual water content of all goods and services consumed by one individual or by the individuals of one country [3]. The water footprint of an individual, community or business is defined as the total volume of freshwater used to produce the goods and services consumed by the individual or community or produced by the business, respectively. The water footprint is directly related to the nutritional and con-

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sumption habits of the population and is a geographically implicit indicator.

This paper aims at: (a) calculating the virtual water of the Prefectures of Xanthi and Rhodope and specifying its net value, and (b) estimating the water footprint of the Prefectures of Xanthi and Rhodope and comparing it to the national one. The present study offers a new dimension to water management through trade, which is an aspect that has not been considered previously for the Prefectures of Xanthi and Rhodope. The data provided in this study are as feasibly reliable and up-to-date as possible given the difficulties encountered in data collection and data flow. The provided information could prove to be useful in decision making processes of both public and private interest given the fact that the study focuses on regional level.

2. Study area

The neighbouring Prefectures of Xanthi and Rhodope are situated in the Thrace Region of northeastern mainland Greece. The region, due to its position — i.e. its proximity to both Turkey and Bulgaria — is increasingly important for the country's economy and therefore of great interest for special focus. It is also a region where substantial part of the industrial and agricultural production takes place.

The Prefecture of Xanthi has a population of 106,377, whereas Rhodope has a population of 111,237 [4]. Table 1 summarizes information regarding the land area used for the cultivation of different types of crops as well as the percentage of land that is irrigated for each type of crop.

The irrigation networks in the region are not adequate. The irrigated area accounts for 90% of the irrigable one. The current water collective networks are supplied by pumping groundwater or by surface waters from rivers, under the jurisdiction of the local organisations of land reclamation, and private groundwater wells. According to data provided by the Directorate of Land Reclamation of the Prefectures of Xanthi and Rhodope, there is a nationwide trend for water resources savings by reducing groundwater consumption per hectare. Lack of monitoring scheme has paved the way for the appearance of several unlicensed groundwater wells, which in turn makes it impossible to know the real consumption of water for irrigation, considering also that the status of older wells is unknown. As a result of unmonitored irrigation and groundwater overexploitation, sea water intrusion has been registered in several plain areas of both prefectures [6].

The main crops cultivated in the region are wheat, barley, maize, tobacco, cotton, industrial tomatoes, and alfalfa. A part of these crops is locally consumed, while the rest is exported. Other crops cultivated regionally but in smaller numbers include edible pulses like beans, broad beans and chickpeas, sunflower, rape (*Brassica napus*), aromatic plants, vegetables (leeks, onions, table tomatoes, green beans, marrows, okras, eggplants, cabbages and cauliflowers), and fruits (grapes/raisins, watermelons, melons, apples, pears, apricots, peaches, cherries), almonds, walnuts, and olives. The produced quantity of the aforementioned goods is consumed within the prefecture but is still not adequate to cover the needs of the local population [5].

According to data from the National Statistic Service of Greece (NSSG) for the year 2005 [7] and further data provided by the Directorate of Agriculture of the Prefectures of Xanthi and Rhodope for the years 2005–2008, a general decrease in most cultivations is registered [8]. The cultivation of oats and sugar beets was abandoned by 2007, while the production of industrial tomatoes decreased significantly in 2008, mainly due to the closure of factories that processed these crops. Other crops such as barley, cotton, chickpeas, onions, grapes, sesame, alfalfa, and aromatic plants were cultivated in greater numbers. The trend regarding the choice of crop is directly related to the price and demand of each product exhibited the year before, as well as whether the product is subsidized or not.

The water amount consumed for industrial purposes has dropped by 50% mainly due to the closure of factories and to a lesser extent due to the introduction of new less water intensive technologies.

Table 1
The land area ($\times 10^3$ m^2) used for cultivating different types of crops and the corresponding percentage of land, irrigated for each crop type, in the Prefectures of Xanthi and Rhodope [5]

	Prefecture of Xanthi		Prefecture of Rhodope	
	Area ($\times 10^3$ m^2)	% irrigated	Area ($\times 10^3$ m^2)	% irrigated
Arable land crops	381,673	66	682,332	56
Garden crops	18,489	100	13,150	100
Orchards	11,539	100	17,568	50
Olive groves	5,771	—	6,631	—
Vineyards	685	45	2,036	50

3. Materials and methods

3.1. Input data

A wide range of data was required for the estimation of the virtual water trade (VWT) and the water footprint. The information needed included data on the population, the land and its uses, the use of water resources, the crops and livestock products, climatic information, the gross domestic production, gross prefecture income and gross prefecture exports.

The data required for the calculations were collected from various sources. Listed below are the data gathered for the calculations and the sources that provided the data:

(a) The land area per crop and the annual production of agricultural crops, products and their derivatives that were cultivated and produced within the prefecture were either provided by the Directorate of Agriculture of each prefecture or found through the NSSG.
(b) The annual production of agricultural products exported from the prefecture was provided from the Directorate of Agriculture and the Union of Agriculture Associations of each prefecture.
(c) The annual production of agricultural goods that were imported in each prefecture was provided by wholesale trade of fruits and vegetables, local super market chains and the Directorate of Agriculture of each prefecture.
(d) The livestock that was produced, for local consumption was provided by the NSSG and the Veterinarian Directorate of each prefecture, while the livestock that was exported and imported in each prefecture was provided by the Abattoir, the Butchers' Union, the Veterinarian Directorate of each prefecture and local super market chains.
(e) The consumption of water for urban, agricultural and industrial use was taken from the water supply and drainage boroughs and the administrations of the industrial regions.
(f) The consumption of treated water for urban use (i.e. bottled water) was provided by local super market chains.
(g) The consumption of non treated groundwater for agricultural and industrial use was given by the Directorate of Land Reclamation of the Region.
(i) The industrial products produced within each prefecture, the quantities of products exported from each prefecture and the quantities of industrial products imported in each prefecture were found through the Commercial Society and the Chamber of Commerce.

3.2. Methodology

3.2.1. Calculating the net virtual water (NVW)

The estimation of the net VW of agricultural products includes the following steps [9,10]:

(i) Collecting information regarding: (a) the land area occupied by each kind of crop (CA_i), expressed in ha, and (b) the production that has been obtained by each kind of crop, named crop production (CP_i), expressed in tons. It should be noted that the quantity, which corresponds to the term "production" of a product, includes the amount of product that is consumed locally and the amount of product that is exported from the region. The crop yield (CY_i) is obtained, expressed in ton ha^{-1}, by:

$$CY_i = \frac{CP_i}{CA_i} \ (\text{ton ha}^{-1}) \quad (1)$$

(ii) The water requirements for each crop (CWR_i) expressed in m^3 ha^{-1}, are estimated using the FAO's CropWat model for Windows (www.fao.org) [11]. The specific water use of each crop (SWU_i) is obtained, expressed in m^3 ton^{-1}, by:

$$SWU_i = \frac{CWR_i}{CY_i} \quad (\text{m}^3\text{ton}^{-1}) \quad (2)$$

(iii) Gathering information regarding the consumed quantity of each kind of crop during a certain year in a specific region (Con_i) expressed in tons. The term "consumption" refers to the amount of product consumed in the region and is produced locally plus the amount of product that is consumed locally and is imported in the region.
(iv) The net virtual water used in a certain region during a certain year ($CNetVW_i$) expressed in m^3, is obtained by subtracting the Con_i from the CP_i and by multiplying the outcome by the SWU_i,:

$$CNetVW_i = (CP_i - Con_i)SWU_i \ \ (\text{m}^3) \quad (3)$$

To estimate the net VW of livestock products by using VW content of this kind of products (Appendix XVI) [11], the steps listed below need to be followed:

(i) Collecting information regarding the production of each type livestock product, i.e. livestock production (LP_i) expressed in pieces of animals.
(ii) Each type of animal has an average weight (LW_i), expressed in kg. The total weight production (LTW_i) expressed in kg, is obtained by:

$$LTW_i = LP_i \cdot LW_i \quad (\text{kg}) \quad (4)$$

(iii) Using the Appendix XVI [11], the water requirements per kg of each type of livestock (LWR_i) expressed in m^3/kg, is estimated.
(iv) Gathering information regarding the consumed quantity of each type of livestock during a certain year in a certain region (Lon_i) expressed in kg.
(v) The net virtual water used in a certain region during a certain year ($LNetVW_i$) expressed in m^3, is

obtained by subtracting the Lon_i from the LTW_i and by multiplying the outcome by the LWR_i:

$$\text{LNetVW}_i = (\text{LTW}_i - \text{Lon}_i)\,\text{LWR}_i \quad (\text{m}^3) \tag{5}$$

Similarly, the Virtual Water of super markets commodities (agricultural or livestock) has been estimated, using the Appendix XVI of Chapagain and Hoekstra (2004) for the water requirements per kilo for each commodity [12].

The total annual water requirement for domestic industrial products was provided by the administrations of industrial areas. The total amount of virtual water imported in the prefecture (IVW_in), resulting from the import of industrial products, was calculated using the global average virtual water content in the industrial sector (IVW_g), expressed in m^3 per dollar, multiplied by the import value of industrial products in dollars:

$$\text{IVW}_\text{in} = \text{IVW}_\text{g} \cdot \text{Import value of industrial products } (\text{m}^3) \tag{6}$$

The total amount of virtual water exported from the prefecture (IVW_ex), related to the export of industrial products, was calculated using the virtual water content per dollar (IVW_e), expressed in m^3 per dollar multiplied by the export value of industrial products in dollars:

$$\text{IVW}_\text{ex} = \text{IVW}_e \cdot \text{Export value of industrial products } (\text{m}^3) \tag{7}$$

where the virtual water content per dollar (IVW_e) was calculated by:

$$\text{IVW}_\text{e} = \frac{\text{IWc}}{\text{GDP}_\text{i}} \quad (\text{m}^3\ \text{US\$}^{-1}) \tag{8}$$

where IWc is the industrial water withdrawal from the region, expressed in m^3/y, and GDP_i is the added value of the industrial sector, expressed in dollars per year.

The import and export values of industrial products were provided by the Commercial Chambers of the respective prefectures and the GDP_i was given by the NSSG.

3.2.2. Calculating the virtual water balance (VWB)

The net virtual water balance of each category of products can be calculated by subtracting the virtual water of the exported products (VWex_i), expressed in m^3, from the respective virtual water of the imported products (VWin_i), expressed in m^3:

$$\text{Net VWB}_i = \text{VWin}_i - \text{VWex}_i \quad (\text{m}^3) \tag{9}$$

The sum of all Net VWB_i, in the specified time period, is the VWB of the region respectively:

$$\text{VWB} = \sum_{i=1}^{n} \text{Net VWB}_i \quad (\text{m}^3) \tag{10}$$

A positive VWB means that the region imports VW, while a negative VWB suggests that VW is exported from the region.

3.2.3. Calculating the water footprint (WF)

Water footprint of a region is the water used from domestic sources plus the water used from external sources that are utilized for consumption, for the production of local products and for other local activities, plus the virtual water of the products that are imported in the region and minus the virtual water of the products that are exported from the region. Therefore, for the calculation of the water footprint of a region it is necessary to know not only the real water consumption from domestic and external sources, but also the VW of the imported and exported products.

The water footprint of a region, in a certain year, can be calculated by subtracting the sum of VW of the exported products $\sum_{i=1}^{n} \text{VWex}_i$, in that year, from the sum of VW of the imported products $\sum_{i=1}^{n} \text{VWin}_i$ and the total amount of water consumed from domestic and external sources $\sum_{i=1}^{n} \text{VWcd}_i$ in the same year, expressed in m^3/y [12]:

$$\text{WF} = \sum_{i=1}^{n} \text{VWcd}_i + \sum_{i=1}^{n} \text{VWin}_i - \sum_{i=1}^{n} \text{VWex}_i \quad (\text{m}^3\text{y}^{-1}) \tag{11}$$

The water footprint of each prefecture per capita per year for the different types of consumption (i.e. domestic water, agricultural goods, and industrial goods) can be calculated by dividing the prefecture's WF for each type of consumption WF_{ij}, expressed in m^3/y, by its population P_j, expressed in capita [12]:

$$\text{WF / capita/y} = \frac{\text{WF}_{ij}}{\text{P}_j} \quad (\text{m}^3\text{capita}^{-1}\text{y}^{-1}) \tag{12}$$

4. Results and discussion

The virtual water consumed for the production of different products in the Prefectures of Xanthi and Rhodope in 2007 is presented in Table 2.

Based on Table 2, it is obvious that the VW consumption is greater in the Prefecture of Xanthi compared to the Prefecture of Rhodope despite the fact that the cultivated land area in the former is smaller and with a greater % of it irrigated than the latter. For the year 2007 the virtual water consumption in the Prefecture of Xanthi is 247×10^6 m^3/y, while in the Prefecture of Rhodope is 204×10^6 m^3/y. This is mainly due to the different crops that have been selected and to the different quantities of available irrigated water. The crop products that were exported from the Prefecture of Xanthi were mainly industrial tomato, kiwi, asparagus, durum and soft wheat, maize, barley, rape, tobacco and

Table 2
The virtual water consumed for the production of different products in the Prefectures of Xanthi and Rhodope in 2007

Product		VW (×10³m³)	
		Xanthi	Rhodope
Crop	Cereals	140,579	69,195
	Edible pulses	182	285
	Industrial plants	40,932	55,821
	Feed plants	1,894	7,428
	Vegetables	3,879	4,283
	Fruits-nuts	2,967	14,445
	Total	190,432	151,457
Livestock	Cattle	31,984	29,593
	Pigs	9,978	736
	Sheep	3,207	6,596
	Poultry	10,546	14,073
	Total	55,715	50,998
Industrial	Total	0,560	1,400
Total		246,707	203,855

cotton. The respective products that were imported were watermelons, melons, oranges, lemons, pears and apples, fresh tomatoes, cucumbers, onions, potatoes, grapes and raisins, vegetables, olive oil, sunflower and maize oil, sugar, hard wheat. The products that were exported from the Prefecture of Rhodope were mainly durum and soft wheat, barley, tobacco, cotton, industrial tomatoes, sugar been, potatoes, garlic and cherries. The respective products that were imported, included sesame, sunflower, walnuts, oranges, lemons, pears, fresh tomatoes, cucumbers, peppers, marrows, onions, potatoes, vegetables, olive oil, sunflower and maize oil, sugar, hard wheat and roasted chickpeas [8]. Crops account for more than 74% of the VW in both prefectures that are considered agricultural region. Over 77% (77.19%) of the VW in the Prefecture of Xanthi is consumed for crops while livestock production requires 22.58% of the VW; for the prefecture of Rhodope livestock accounts for 25% of the VW consumption.

The livestock products that were exported from both prefectures were cattle, pigs, sheep and poultry. The products that were imported in the Prefecture of Xanthi were cattle and pigs, while in the Prefecture of Rhodope cattle and sheep were imported [8]. This can be attributed to the high percentage of Muslim population that resides in Rhodope and for religious reasons does not consume pork.

In Figs. 1 and 2, the annual gross VW imports and exports, respectively, per consumption category for the Prefectures of Xanthi and Rhodope are presented. It is obvious that the Prefecture of Rhodope imports more VW than the Prefecture of Xanthi and at the same time the Prefecture of Rhodope exports less VW than the Prefecture of Xanthi.

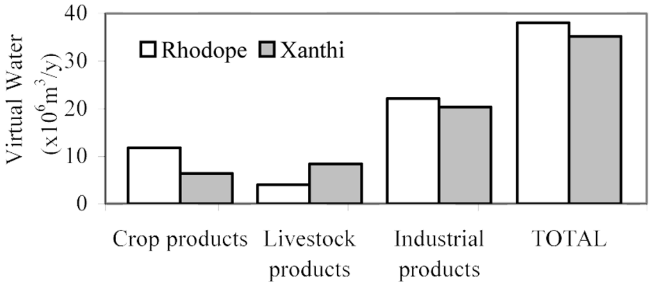

Fig. 1. Annual gross virtual water imports per consumption category during 2007.

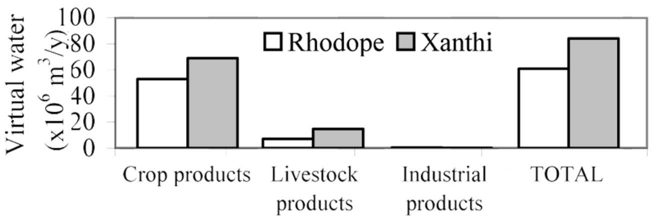

Fig. 2. Annual gross virtual water exports per consumption category during 2007.

Table 3 presents the VW (m³) quantities for the products that were imported, exported and consumed locally during the year 2007 in the Prefectures of Xanthi and Rhodope, and their corresponding VW balance. Over than 65% accounts for locally consumed products, while the rest is used for exported products. The Prefecture of Rhodope is more self-sufficient than that of Xanthi, as it consumes less water and manages its water resources more carefully.

Table 3
The virtual water consumed for the products imported, exported and consumed locally in the Prefectures of Xanthi and Rhodope during 2007, and the respective virtual water balance

VW (×10^3 m^3)	Prefecture of Xanthi	Prefecture of Rhodope
Imports	26,779	33,959
Exports	86,207	66,010
Local production consumption	160,59	137,890
VWB	–59,428	–32,051

Figs. 3 and 4 present the virtual water balance of the main agricultural products in the Prefectures of Rhodope and Xanthi during 2007. It is obvious that the net VW balance is negative in both prefectures, –48.8×10^6 m^3/y in the Prefecture of Xanthi and –27.4×10^6 m^3/y in the Prefecture of Rhodope, which means that both prefectures export goods (i.e. agricultural crops and livestock) that require greater amounts of virtual water than the goods (i.e. agricultural crops and livestock) they import.

To improve the virtual water trade, the region should opt to cultivate crops that are less water intensive (i.e. cucumber, potatoes, apples) and avoid instead the water intensive crops (for example cotton, asparagus). The state could also help by giving the farmers incentives to opt for crops that are less water intensive.

The calculation of the water footprint of the Prefectures of Xanthi and Rhodope, was done according to Eq. (11) and is presented in Table 4. The term agricultural goods includes both crop and livestock products. The water footprint of each Prefecture per capita per year for the different types of consumption (i.e. domestic water, agricultural goods and industrial goods), which was estimated according to Eq. (12), is presented in Table 5.

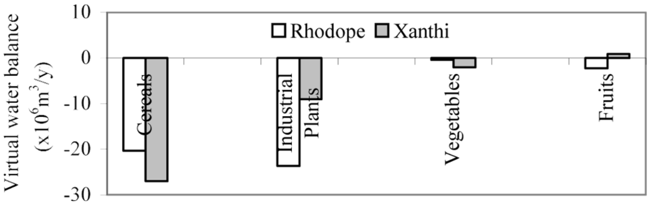

Fig. 3. Virtual water balance of the main crops in the Prefectures of Rhodope and Xanthi in 2007.

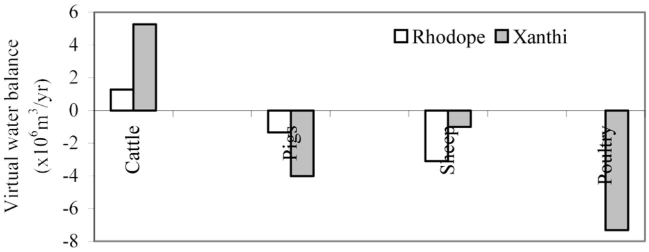

Fig. 4. Virtual water balance of the main livestock products in the Prefectures of Rhodope and Xanthi in 2007.

The water footprints of the Prefectures of Xanthi and Rhodope are 995.99 m^3/capita/y and 996.97 m^3/capita/y, respectively, whereas the national water footprint is 2389 m^3/capita/y. It has to be noted, though, that the national water footprint refers to 2001, whereas the water footprints of both Prefectures were calculated based on 2007 data, and there seems to be a downward trend regarding water footprints. The water footprints of the two neighboring Prefectures, with similar characteristics, are quite similar.

Table 4
The total water footprint of the Prefectures of Rhodope and Xanthi in 2007

Use of (×10^6 m^3/y)	Prefecture of Xanthi			Prefecture of Rhodope		
	Total	Dom. cons.	Export	Total	Dom. cons.	Export
Domestic water resources						
Domestic water withdrawal	4.79	4.79	—	5.056	5.056	—
Agricultural goods	246.24	160.40	85.84	202.50	137.42	65.08
Industrial goods	0.56	0.19	0.37	1.40	0.47	0.93
Foreign water resources						
Domestic water		Insignificant			Insignificant	
Agricultural goods	6.409			11.794		
Industrial goods	20.371			22.165		
Total (×10^6 m^3/y)		192.16	–86.21		176.91	–66.01
Total water footprint (×10^6 m^3/y)		105.95			110.90	
Water footprint per capita (m^3/capita/y)		995.99			996.97	

Table 5
The water footprint of the Prefectures of Rhodope and Xanthi for the different types of consumption in 2007

Type of consumption	Xanthi (m^3/capita/y)	Rhodope (m^3/capita/y)
Consumption of domestic water (internal water)	45.03	45.45
Consumption of agricultural goods		
Internal water	700.90	650.33
External water	60.25	106.03
Consumption of industrial goods		
Internal water	–1.69	–4.12
External water	191.50	199.26
Total	995.99	996.95

5. Conclusions

The virtual water consumption in the Prefecture of Xanthi is 247×10^6 m^3/y, while in the Prefecture of Rhodope is 204×10^6 m^3/y (Table 2). Crops account for at least 74% of the VW consumption, whereas livestock production accounts for at least 22% of the VW consumption in both prefectures (Table 2). Therefore, over 96% of the water consumption is used for agricultural purposes and both Prefectures are considered agricultural regions. Almost 65% accounts for locally consumed products, while the rest is used for exported products (Table 3). For the year 2007, the virtual water balance is negative in both Prefectures: –59,428×10^6 m^3/y in the Prefecture of Xanthi and –32,051×10^6 m^3/y in the Prefecture of Rhodope (Table 3). This is a worrying sign and a more sustainable management of the crops production and policy is required. To improve the virtual water trade, the region should opt to cultivate crops that are less water intensive (i.e. cucumber, potatoes, apples) and avoid instead the water intensive crops (for example cotton, asparagus). The state could also help by giving the farmers incentives to opt for crops that are less water intensive.

The water footprints of the Prefectures of Xanthi and Rhodope are similar, 995.99 m^3/capita/y and 996.97 m^3/capita/y, respectively (Table 5). The Prefecture of Rhodope is more self-sufficient than that of Xanthi, as it consumes less water and manages its water resources more carefully (Table 3).

Combining the aforementioned information with the fact that the water supply index exhibits an upward trend, it is obvious that the value of water is constantly rising. Virtual water is an important factor for the geopolitical and economic growth of a region.Virtual water trade enables water-scarce regions to import water-intensive products and export products that do not require too much water, therefore saving water for different uses and purposes.

Symbols

CA_i — Crop area of crop *i*, ha
$CNetVW_i$ — Net virtual water used in a certain region during a certain year for crops, m^3
Con_i — Consumed quantity of crop *i* during a certain year in a specific region, ton
CP_i — Crop production of crop *i*, ton
CWR_i — Water requirements for crop *i*, m^3 ha^{-1}
CY_i — Crop yield of crop *i*, ton ha^{-1}
GDP_i — Added value of the industrial sector, US\$ y^{-1}
IVW_c — Annual industrial water withdrawal form the region, m^3 y^{-1}
IVW_e — Virtual water content in the industrial sector, m^3 US\$$^{-1}$
IVW_{ex} — Total amount of virtual water for industrial products exported from the region, m^3
IVW_g — Global average virtual water content in the industrial sector, m^3 US\$$^{-1}$
IVW_{in} — Total amount of virtual water for industrial products imported in the region, m^3
$LNetVW_i$ — Net virtual water used in a certain region during a certain year for livestock, m^3
Lon_i — consumed quantity of livestock *i* during a certain year in a certain region, kg
LP_i – Livestock production of livestock product *i*, pieces of animals
LTW_i — Total weight production of animal *i*, kg
LW_i — Average weight of animal *i*, kg
LWR_i — Water requirements per kilogram of livestock *i*, m^3 kg^{-1}
NetVWB — Net virtual water balance of product *i*, m^3
P_j — Population of region *j*, capita
SWU_i — Specific water use for crop *i*, m^3 ton^{-1}
VWB — Virtual water balance, m^3
$VWcd_i$ — Virtual water consumed from domestic and external sources, m^3
$VWex_i$ — Virtual water of the exported product *i*, m^3
$VWin_i$ — Virtual water of the imported product *i*, m^3
WF — Water footprint, m^3 y^{-1}
WF_{ij} — Water footprint for type of consumption *i* in region *j*, m^3 y^{-1}

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