WATER FOOTPRINT CONCEPT AS A SOLUTION FOR WATER SCARCITY IN ASIA

Dragan Cigoja, Bing Wu, Lynette Umuratwa, Philip Ochieng Ogada, Sosthene Mubera

Abstract— In the world of science, Water Footprint is well known but if we look into the very essence of this tool what can we expect as a foundation? Is it a tool for a deep scientific research about humanity impact assessment on the fresh water resources or perfect tool for raising awareness among the humanity and especially policy makers about world water scarcity and increase cooperation between countries? This study determines the percentage of data uncertainty and whether there is a possibility for improving this indicator. Furthermore, it is studied how this indicator can help to save water resources in fast developing countries as China and India, whose development is based mainly on the exports. The previous findings clearly indicate that virtual water trading on the global level can help the countries with water scarcity problems to mitigate that condition through trading with water abundant countries. There is still a gap in many publications; it is not yet clear whether the area in which the water footprint estimation is performed belong to water abundancy or water scarcity area. Finally this study will consider all these findings and emphasize the importance and relevance of this indicator for future sustainable development.

Index Terms— Water footprint, water scarcity, virtual water, agriculture, trade, Asia

◆

1 INTRODUCTION

Consumers don't value the water because it is the public resource, the free resource, with no incentives for efficient use. In the foreseeable future is not realistic to expect that any government or politician as an individual would start this type of initiative. Scientific community and organizations must look for another approach to reduce water use and deal with fresh water scarcity. This issue is not confined only to the poorest countries, but on almost the entire planet. In the beginning of 20th century Water footprint(WF) is introduced as a major tool for calculating the total water consumption. After many published works by the water footprint authors (Hoekstra and Mekonnen) and establishment of Water Footprint Network, most researchers adopted this method, which eventually showed how we irrational spending water. The water footprint approach is presented as superior to the traditional approaches applied in water management (Ma et al., 2015). Water footprint (WF) is indicator which together with ecological and carbon footprint makes footprint family. Its purpose is to define quantity of water used for every product or service which are used in day to day human life and for processes which are not seen by human eye as well (Hoekstra et al., 2012).

Several studies have highlighted that water-scarce regions could decrease their production of water intensive food commodities to alleviate their water scarcity problems by producing instead goods and services with higher value added per unit of water consumed (Faramarzi et al., 2010)(Feng et al., 2012)(Zeitoun et al., 2010). WF is determined by computing the quantity of fresh water from surface or ground sources used for production of some unit or service (Blue water), quantity of water which plants absorb from the soil or eventually evaporate (Green water) and water used for diluting the polluted water (Grey water) in purpose to meet quality standards (Hoekstra and Mekonnen, 2011). The future water scenario show increasing demand for water and increasing water footprint as well. This is not only consequence of growth population and big urbanization rate but also effect of growing economies in developing countries and changing diets. When we look about water footprint in food it can be noticed that people moving to eat more meat especially in India and China where economic development made a new middle class. Growing population also increase demand for agricultural products. Agriculture accounts for 92 % of the freshwater footprint of humanity and almost the one third relates to animal products (Mekonnen and Hoekstra, 2012).

Problem with water scarcity is a big issue for policy makers and government officials. Water footprint is predicted to be informative tool for initiating and supporting new policies in water scarcity matter. Institutions making water plans both to reduce water demand and increase supply. Decreasing water levels and draining of some lake in past years bring focus on the need for better policies which can secure sustainability and mitigate water scarcity as an important component of policy

---

- *Dragan Cigoja, Tongji University, College of Environmental Science and Engineering, IESD, Shanghai, China, PH-+8613162390809. E-mail: d.cigoja@gmail.com*
- *Wu Bing, College of Environmental Science and Engineering, Tongji University, Shanghai, China, PH-+8613701854067 E-mail: bingwu@tongji.edu.cn*

analysis (FAO, 2015). The water footprint and virtual water concepts provide the opportunity to link the use of water resources to the consumption of goods. These concepts have been brought into water management science in order to show the importance of consumption patterns and global dimensions in good water governance (Galli et al., 2012). But does a good policy can be made without considering some more indicators or footprints like social, economic and political. They are still in development stage and still are not tested so how relevant can be only water footprint for policy making. Some analysts also disagree with idea that WF conveys useful policy information. In his study Wichelns (2010a, 2010b, 2010c, and 2010d) argues that the relevance of water footprints to the selection of appropriate policies is quite limited. In study (Gawel and Bernsen, 2013) suggest the virtual water perspective has limited usefulness as a guide to policy. The main issue is can these problems be solved on global level rather than on the local level and without trade barriers.

Review of water footprint methodology with discussion about possible shortcomings and improvements will be present in this paper. The rate of data uncertainty is determined and all possibilities for improving this indicator are considered. Further, it is studied how this indicator can help to save water resources in fast developing countries as China and India, which development is based mainly on the export. Finally this study will consider all these findings and emphasize the importance and relevance of this indicator for future sustainable development.

2. WATER FOOTPRINT METHODOLOGY

Certainly we're not aware of how much water we consume in a day. Apart from the obvious consumption, there is “virtual water" consumed in the production of food, electricity, and other industries. Food products trade means virtual water trade (Karandish and Salari, 2015). Close connection between virtual water and water footprint we can recognize in fact that human organism need only 2 to 4 liter of water per day to provide normal life. But quantity of water needed to satisfy basic human requirements is multiplied thousands times. That difference represents the content of virtual water as a major part of water footprint. As it is mentioned in the introduction, agriculture uses the biggest amount of fresh water and represents the major part of virtual water trade. Most overseas studies usually calculate the water footprint of agricultural and animal products (Ma et al., 2015).

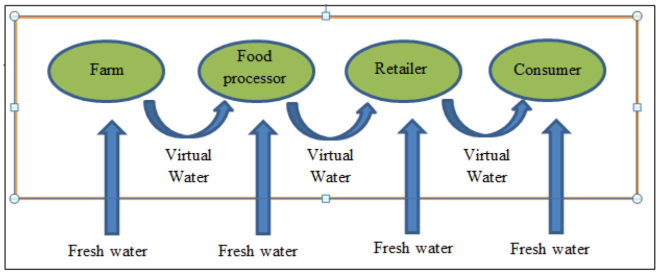


Fig. 1 The virtual water chain

In attempt to calculate national consumption water footprint (Mekonnen and Hoekstra, 2010) used data from the AQUASTAT database (FAO, 2010), EUROSTAT (2011) and United Nations Statistical Division database (UNSD, 2010). The water footprint of national consumption (WFcons) in m3/year is calculated by adding the direct water footprint of consumers (WFcond dir) and two indirect water footprint components (WFcond ind) from agriculture and industrial commodities

$$\begin{aligned} WFcons &= WFcons\ dir + WFcons\ ind(agriculture\ commodities) \\ &+ WFcons\ ind.(industrial\ comodities) \end{aligned} \tag{1}$$

Water used to make consumed commodities is related to the indirect water footprint of consumers. Consumption and pollution of water refer to the direct water footprint of consumers.

For product water footprint calculations (WFprod) are related production process water footprint (WFproc) and production quantity (P) what refer to the following equation

$$WFprod = \sum \frac{WFproc}{P} \tag{2}$$

International virtual-water flows are calculated by multiplying, per trade commodity, the volume of trade by the respective average water footprint per ton of product in the exporting nation. When a product is exported from a country that does not produce it, for that product we accept the global average product water footprint for that trade flow. Other equations are more detailed explained in the Water footprint assessment manual (Hoekstra et al., 2011).

3 DISCUSSION

3.1 Figures and Tables

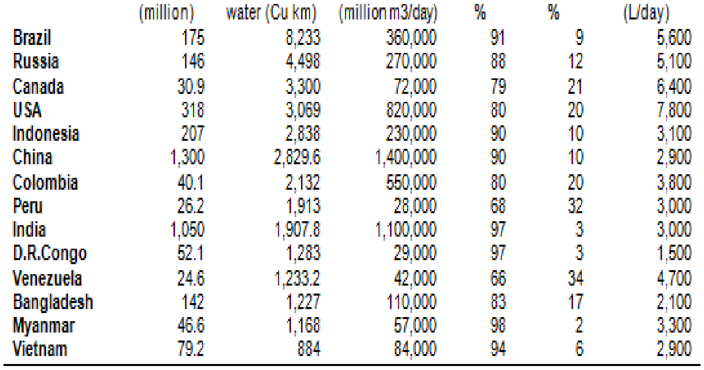
In developed countries using recycled water for irrigation and in production processes is quite common and unquestionable will be used more in the future. Though it satisfy high quality standards it is very difficult to use recycled water for human direct and indirect consumption. As opposed to that it is a perfect solution for decreasing "blue water" volume in production processes and irrigation systems. In that case it should be considered possibility to use amount of the recycled water in equation for product water footprint in a following manner

$$WFprod = \sum \frac{WFproc - Wrecycled}{P} \quad (3)$$

where *Wrecycled* is volume or percentage of recycled water used in production. For national consumption water footprint authors (Mekonnen and Hoekstra, 2011) assumed that 5 % of the water withdrawn for industrial purposes is actual consumption (blue water footprint) and for domestic water supply assumed a consumptive portion of 10 % but they didn't highlight the uncertainty or fluctuation of these assumptions.

With intention to consider benefits of WF indicator in Asia this study reviews some earlier cases from other regions. From Table 1 and Table 2 it can be seen that most of countries do not use WF recommendations that less water abundant countries should trade with products which demand less water for production. In the top five exporting countries we have three with modest amount of available fresh water. Further it is not clear how Netherland's ratio between internal and external footprint is 5 % to 95 % when that country is second largest exporter of agricultural products. The external water footprint is defined as the volume of water resources used in other nations to produce goods and services consumed by the population in the nation under consideration (Mekonnen and Hoekstra, 2011).

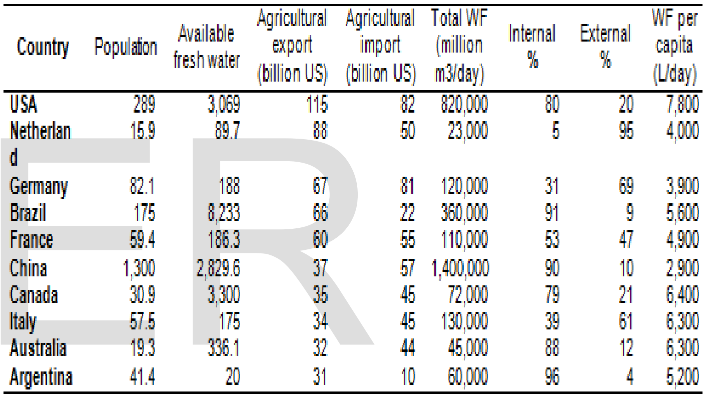
Table 1. Top 14 countries with renewable fresh water availability – source (FAO)



Country	Population (million)	Available fresh water (Cu km)	Total WF (million m3/day)	Internal %	External %	WF per capita (L/day)
Brazil	175	8,233	360,000	91	9	5,600
Russia	146	4,498	270,000	88	12	5,100
Canada	30.9	3,300	72,000	79	21	6,400
USA	318	3,069	820,000	80	20	7,800
Indonesia	207	2,838	230,000	90	10	3,100
China	1,300	2,829.6	1,400,000	90	10	2,900
Colombia	40.1	2,132	550,000	80	20	3,800
Peru	26.2	1,913	28,000	68	32	3,000
India	1,050	1,907.8	1,100,000	97	3	3,000
D.R.Congo	52.1	1,283	29,000	97	3	1,500
Venezuela	24.6	1,233.2	42,000	66	34	4,700
Bangladesh	142	1,227	110,000	83	17	2,100
Myanmar	46.6	1,168	57,000	98	2	3,300
Vietnam	79.2	884	84,000	94	6	2,900

In their previous works they estimated that 86 % of the water footprint of humanity is within the agricultural sector (Hoekstra and Chapagain, 2008). Following this, Netherland should be country depending on the external water sources. This is denied with fact that they are second largest agricultural exporter with a large surplus comparing with agricultural import. Also during this review it can be noticed that in the direct water footprint of consumers (Wfcons dir) it wasn't considered wastage of water in distribution pipelines. Depending from region and quality of the pipelines water wastage rate is from 3 to 20 % (Inc., 2009). That is especially important during the calculation of urban WF. Further we cannot find storm water effects in WF analysis connected for the consumption in urban environment. It is noticed that uncertainty analysis missing as well.

Table 2. Countries with biggest export of agricultural products – source World Bank and water footprint network



Country	Population	Available fresh water	Agricultural export (billion US)	Agricultural import (billion US)	Total WF (million m3/day)	Internal %	External %	WF per capita (L/day)
USA	289	3,069	115	82	820,000	80	20	7,800
Netherland	15.9	89.7	88	50	23,000	5	95	4,000
Germany	82.1	188	67	81	120,000	31	69	3,900
Brazil	175	8,233	66	22	360,000	91	9	5,600
France	59.4	186.3	60	55	110,000	53	47	4,900
China	1,300	2,829.6	37	57	1,400,000	90	10	2,900
Canada	30.9	3,300	35	45	72,000	79	21	6,400
Italy	57.5	175	34	45	130,000	39	61	6,300
Australia	19.3	336.1	32	44	45,000	88	12	6,300
Argentina	41.4	20	31	10	60,000	96	4	5,200

As authors (Mekonnen and Hoekstra, 2014) said, currently no uncertainty analyses are available. Many have ignored the fact that uncertainty could be great and continue work without any analysis or at least notes that some uncertainties exist.

3.2 China water footprint

The situation is arguably made dreadful by the reality that the entire Asia-Pacific region boasts only 36% of global water resources, making per capita water availability the lowest in the world (Who and Unicef, 2012). China, in particular its water-scarce regions, are facing a serious water crisis driven by rapid economic growth. China has put a lot of efforts in dealing with its virtual water trade. In recent years by importing water intensive crops significantly, China increased its net virtual water import from 7.02 cubic km in 1986 to 137.14 cubic km in 2009 (Shi et al., 2014). In internal trade this is not the case. In particular, the water-scarce North China tends to produce water intensive goods for consumption in the South amplifying the serious water shortage in the North (Figure 2).

Shanghai and Zhejiang are between most developed regions in China and Asia. Though they are water rich regions, still they are the biggest importers of goods from water scarcity regions as Xinjiang, Hebei, Inner Mongolia and Jiangsu. Main pressure on water scarcity in these regions is not their own economic development as it is believed. Major pressure coming from fast developing trading partners in water abundant regions as it is Shanghai, Zhejiang, Jiangsu, Guangdong and Shandong. These provinces are ranked at the top in terms of consumptive water footprint (CWF) mainly due to the large quantity of goods and services imported from other provinces for local consumption, and more strikingly, their CWF is much larger than their local water consumption (Feng et all, 2014). These provinces are also among biggest generators of Municipal Solid Waste especially its food content which is related to WF.

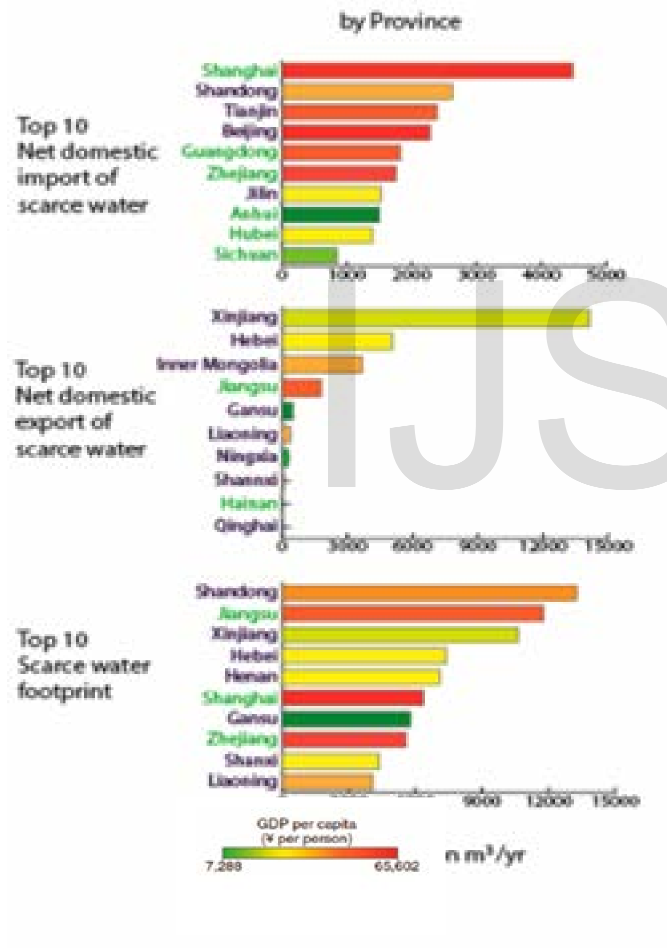


Fig. 2 Top 10 provinces by net domestic import of scarce water (row 1), net domestic export of scarce water (row 2), and domestic scarce water footprint (row 3), all presented as regional totals. Dark blue names indicate provinces in north China, whereas light green indicates provinces in south China. The colors of the bars reflect GDP per capita in each region (Feng et al., 2014)

3.3 Municipal solid waste water footprint

Another significance of waste separation and classification is in contribution regarding to sustainable management and interconnection of MSW and water resources. To achieve the goal of MSW management, consumer awareness, private sector initiatives, governmental regulation and targeted investments are urgently needed to move towards sustainable water use (Ercin and Hoekstra, 2014). Virtual water content of food remnants (average value 4414.7m3 tones) is dominantly higher than other MSW components in which there is also significant variation in virtual water content, i.e. annual virtual water in food remnants accounting for more than 85% of total virtual water in MSW what clearly indicate importance of MSW separation and recycling (Huang et al., 2016). Following this data, average virtual water content of disposed food waste in Shanghai and Zhejiang MSW are 15341.9 x 10^6 m^3 and 32104 x 10^6 m^3 respectively.

Paper, wood and bamboo have even more significant content of virtual water but this study consider food remnant as most dominant in composition of MSW not only in Shanghai and Zhejiang but in all China and most of others developing countries as well. Increasing generation and disposal of MSW accelerating water shortage whilst causing environmental pollution what clearly show urgency of waste separation and classification as prerequisite for successful reuse and recycling of valuable materials.

4 CONCLUSION

Still after more than ten years there is no valid proof that one country with water scarcity has achieved water security by trading mostly with the water abundant country. On the contrary, this review found that fresh water scarcity countries and regions are biggest exporter of agriculture products and other products with high WF of production. Yet it cannot be denied the great success that this concept has made. Decreasing number of uncertainties especially in green and grey water footprint can lead to more accurate results. Both cases, European and Chinese, showed that water scarcity must be considered. Further, virtual water flows from water-rich regions to water scarcity regions must be identified and quantified. According to high urbanization rate in Asian region, water pipeline system quality must be evaluated and considered during WF calculations. Water Footprint Assessment can be valuable as support for businesses in Asian growing market. It can help on achieving sustainable water management within their internal operations and supply chain. The significant value WF brought to the society raising awareness on water sustainability issues related to water use. People become aware of water issues especially in fast growing megacities in Asia.

ACKNOWLEDGMENT

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

REFERENCES

Ercin, A.E., Hoekstra, A.Y., 2014. Water footprint scenarios for 2050□: A global analysis. Environ. Int. 64, 71–82. doi:10.1016/j.envint.2013.11.019

FAO, F. and A.O. of the U.N., 2015. Towards a water Critical Perspectives for Policy-makers 62.

Faramarzi, M., Yang, H., Mousavi, J., Schulin, R., Binder, C.R., Abbaspour, K.C., 2010. Analysis of intra-country virtual water trade strategy to alleviate water scarcity in Iran. Hydrol. Earth Syst. Sci. 14, 1417–1433. doi:10.5194/hess-14-1417-2010

Feng, K., Hubacek, K., Pfister, S., Yu, Y., Sun, L., 2014. Virtual scarce water in China. Environ. Sci. Technol. 48, 7704–7713. doi:10.1021/es500502q

Feng, K., Siu, Y.L., Guan, D., Hubacek, K., 2012. Assessing regional virtual water flows and water footprints in the Yellow River Basin, China: A consumption based approach. Appl. Geogr. 32, 691–701. doi:10.1016/j.apgeog.2011.08.004

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., Giljum, S., 2012. Integrating Ecological , Carbon and Water footprint into a “ Footprint Family ” of indicators□: Definition and role in tracking human pressure on the planet. Ecol. Indic. 16, 100–112. doi:10.1016/j.ecolind.2011.06.017

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., n.d. The Water Footprint Assessment Manual.

Hoekstra, A.Y., Mekonnen, M.M., 2011. The water footprint of humanity. Proc. Natl. Acad. Sci. 109, 3232–3237. doi:10.1016/B978-0-12-799968-5.00007-5

Hoekstra, A.Y., Mekonnen, M.M., Chapagain, A.K., Mathews, R.E., Richter, B.D., 2012. Global monthly water scarcity: Blue water footprints versus blue water availability. PLoS One 7. doi:10.1371/journal.pone.0032688

Huang, C., Yu, C., Lin, T., Ye, Z., 2016. Water conservation significance of municipal solid waste management□: a case of Xiamen in China *. J. Clean. Prod. 129, 693–703. doi:10.1016/j.jclepro.2016.03.062

Inc., I.S., 2009. Control and Mitigation of Drinking Water Losses in Distribution Systems 1–128.

Karandish, F., Salari, S., 2015. Application of Virtual Water Trade to Evaluate Cropping Pattern in Arid Regions 4061–4074. doi:10.1007/s11269-015-1045-4

Ma, D., Xian, C., Zhang, J., Zhang, R., Ouyang, Z., 2015. The Evaluation of Water Footprints and Sustainable Water Utilization in Beijing 13206–13221. doi:10.3390/su71013206

Mekonnen, M., Hoekstra, A.Y., 2014. Water footprint benchmarks for crop production□: A first global assessment 46, 214–223. doi:10.1016/j.ecolind.2014.06.013

Mekonnen, M.M., Hoekstra, A.Y., 2012. A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems 15, 401–415. doi:10.1007/s10021-011-9517-8

Mekonnen, M.M., Hoekstra, A.Y., 2011. Volume 1□: Main Report 1.

Mekonnen, M.M., Hoekstra, A.Y., 2010. A global and high-resolution assessment of the green, blue and grey water footprint of wheat. Hydrol. Earth Syst. Sci. 14, 1259–1276. doi:10.5194/hess-14-1259-2010

Shi, J., Liu, J., Pinter, L., 2014. Recent evolution of China’s virtual water trade: Analysis of selected crops and considerations for policy. Hydrol. Earth Syst. Sci. 18, 1349–1357. doi:10.5194/hess-18-1349-2014

Who, Unicef, 2012. Drinking Water, Update. doi:978-924-1503279

Zeitoun, M., Allan, J.A. (Tony), Mohieldeen, Y., 2010. Virtual water “flows” of the Nile Basin, 1998-2004: A first approximation and implications for water security. Glob. Environ. Chang. 20, 229–242. doi:10.1016/j.gloenvcha.2009.11.003

Wichelns, D., 2010a. An Economic Analysis of the Virtual Water Concept in Relation to the Agri-Food Sector. Hanover College, Indiana, United States of America, www.oecd.org/water.

Wichelns, D., 2010b. Virtual water and water footprints offer limited insight regarding important policy questions. Int. J. Water Resour. D. 26 (4), 639– 651.

Wichelns, D., 2010c. Virtual water and water foot prints: policy relevant or simply descriptive. Int. J. Water Resour. D. 26 (4), 689–695.

Wichelns, D., 2010d. Virtual water: a helpful perspective, but not a sufficient policy criterion. Water Resour. Manag. 24 (10), 2203–2219.

Erik Gawel, Kristina Bernsen, 2013, What is Wrong with Virtual Water Trading? On the Limitations of the Virtual Water Concept, Environment and Planning

C: Politics and Space,Vol 31, Issue 1

Arjen Y. Hoekstra, Ashok K. Chapagain, 2008, Globalization of Water: Sharing the Planet's Freshwater Resources, ISBN: 978-1-4051-6335-4

AQUASTAT database, 2010, Assessed last time 15.04.2017. http://www.fao.org/nr/water/aquastat/data

EUROSTAT database, 2010, http://ec.europa.eu/eurostat

United Nations Statistical Division database, 2010, https://unstats.un.org/unsd/publications/statistical-yearbook/past-issues