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Review of water footprint components of grain

Wan Amiza Amneera Wan Ahmad[1], Nik Meriam Nik Sulaiman[1,*] and Noor Zalina Mahmood[2]

[1]Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2]Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia

E-mail: meriam@um.edu.my

Abstract. Burgeoning global population, economic development, agriculture and prevailing climate pattern are among aspects contributed to water scarcity. In low and middle income countries, agriculture takes the highest share among water user sector. Demand for grain is widespread all over the globe. Hence, this study review published papers regarding quantification of water footprint of grain. Review shows there are various methods in quantifying water footprint. In ascertaining water footprint, three (green, blue, grey) or two (green, blue) components of water footprint involved. However, there was a study introduced new term in evaluating water footprint, white water footprint. The vulnerability of varying methods is difficulty in conducting comparative among water footprint. Salient source in contributing high water footprint also varies. In some studies, green water footprint play major role. Conversely, few studies found out blue water footprint most contributing component in water footprint. This fluctuate pattern influenced by various aspects, namely, regional climatic characteristics, crop yield and crop types.

1. Introduction

The significance of water on human being and environment is immense. Prevailing population growth and economic development has led to increase in freshwater demand. Water availability and agriculture is inextricably linked. As the demand for agriculture expand significantly, the menace on availability of water resource expanding as well. By 2025, it is expected that water withdrawal for agriculture will increase by 50% in developing countries and 18% in developed countries [1].

Agriculture takes the highest share among water user sector in both, low and middle income countries [2]. In order to attain the ascending food requirements of expansion global population, enlargement of irrigated agriculture is necessary. Nevertheless, waterlogging and soil salination are two consequences caused by enlargement of irrigated agriculture. These two environmental impacts however can be mitigated by implementing mitigating measures to reduce the inflow or by applying remedial measures to raise water and salt outflow [3]. In order to boost agriculture output, sufficient water resource for irrigation is pivotal. India, second largest world main paddy producers [4], has over 66 million hectares area equipped for irrigation [5].

So far, grains are the salient source of food not only for direct human consumption but also indirect use. Barley, rice, maize and wheat have become dominant crops globally [6]. For nearly 20 years, grains supply per capita has been declined for 17% resulted from shortage of freshwater [7]. Apprehensive with the future water crisis the world might face, research on water footprint (WF) exceptionally essential and gained worldwide attention. Water footprint has appeared as a pivotal technique in order to evaluate water consumption of both, goods and services. Evaluation methods proposed by two communities, namely water footprint network (WFN) and the life cycle assessment (LCA) [8].

2. Grains production

World production of maize in 2014 was 1037 million tonnes with the harvested area of 184 million hectares globally. The three top producers of maize were United States of America, China and Brazil [9]. While for rice, 741 million tonnes of rice produced in 2014 with 162 million hectares of arable land in 2014. China, India and Indonesia were the three major producers of rice [9]. Wetland and upland systems are two systems of rice production. Asia was the largest contributor for rice production with 90.8% of average production for the period of 1994-2014 [9]. In Asia, rice fields are prepared with tillage followed by puddling. During the growth period, the soil is saturated and there is standing water throughout the period [10].

World production of wheat is slightly lower than rice, 729 million tonnes and the harvested area was 220 million hectares. Similar to rice, China and India were the top two producers of wheat followed by United States of America [9]. For trading, wheat is categorized into well-defined categories of grain hardness, namely soft, medium-hard and hard and also colour based which are red, white and amber. In term of growing season, it can be sort into spring and winter wheat [11].

3. Water scarcity

Water accessibility which is below than 1000 m^3 per person per year is considered as water scarcity condition for a country or region. Nonetheless, most regions facing severe water scarcity whereby water availability is less than 500 m^3 per person per year [2]. Apart from water availability, water scarcity also related to quality of available water [12].

There are numerous factors that contribute significantly to water scarcity. Among them are burgeoning global population and economic development. Water availability per capita descended by 42% in Solomon Islands, 36% in Malaysia, Pakistan and Nepal, 29% in India and Bangladesh between 1990 and 2010. Apart from that, decreasing water availability also stem from agriculture sector as it consume 70% out of all withdrawals. Prevailing climate pattern also influence water resources. For instance few regions have been affected by extreme events such as drought, flood and cyclone. It is also accountable for rising sea level which directly increased salinization in river deltas and lake and eventually decreased the availability of freshwater [5].

4. Water footprint

Back in 1990s, in order to analyse food and water security, Prof Tony Allan coined the term ‘virtual water’ as amount of water needed in producing product or service by considering the whole supply chain [13]. Later, WFN defined water footprint as an indicator of water usage by considering water consumed directly and indirectly by consumers or producers [14]. WF expounds water consumption volumes by source and polluted volumes by type of pollution. All components involved in quantifying WF are specified in time and space [13].

Green, blue and grey are three components of WF. Each component indicates different source and type of water to consider. Green WF elucidates as water that evaporated from soil moisture [13] and mostly used to produce agricultural products [14]. Whilst blue WF represents water by which withdrawn from ground or surface water sources [13] and grey WF can be defined as volume of water needed in assimilating waste water [14].

5. Water footprint of grain

Agriculture water management is crucial for Iran since most regions are situated in arid and semiarid area. Pattern of water withdrawal percentage for agricultural use in Iran were fluctuate. In 1995, 91.57% of total water withdrawal was consumed by agriculture. The value then increased to 93.37% in 2001 and showed slightly decreased in 2004 (92.18%) [15]. Study conducted by [16] assessed water footprint (WF) of wheat, barley and maize in fifteen main cereal producing provinces in Iran. The quantification of WF in this study modified existing WF method by Hoekstra by introducing new component in calculation, white water footprint, which indicates irrigation water losses. For the period of 2006 to 2012, national total water footprint (NTWF) of wheat, barley and maize were 36777, 7975 and 3744 million cubic meters (MCM) respectively. For wheat, the highest contributor for high NTWF was green (17222 MCM) followed by blue (7406), grey (6809 MCM) and white (5340 MCM). Similar to wheat, greatest contributor to NTWF of barley was green WF with the value of 3363 MCM followed by blue, grey and white with the value of 1761, 1518 and 1334 MCM respectively. Conversely for maize, green WF was the smallest NTWF contributor with the value of 83 MCM. The biggest was blue (1541 MCM) followed by grey (1084) and white (1056 MCM). The blue and green WF for the three grain was 31376 MCM with wheat is the biggest consumer since it is cultivated 4.7 and 23 times larger areas compared to barley and maize. Apart from that, in term of yield, wheat was produced 4.6 and 5.9 times more than barley and maize. Hence, efficient water management and allocation in wheat production is pivotal as to mitigate insufficient freshwater. Meanwhile, grey and white WF for wheat, barley and maize was 17231 MCM which elucidate that in producing cereal, huge amount of water loss during irrigation and might never reaches water table as well. Since Iran is located in an arid area, it is vital to alleviate this matter by improving irrigation management practice as to decrease the share of white WF.

WF of grain production in North China Plain (NCP) for past 35 years was ascertained by [17]. This study assessed WF of winter wheat and summer maize for 35 years period starting from 1980 to 2014. Study was conducted at Luancheng station, northern part of NCP and received annual precipitation of 480 mm. The quantification of WF for this study involved three WF components, namely, green, blue and grey. Nexus between irrigation and agriculture is very strong as to secure crop production. In order to retained soil water content above 65%, irrigation was applied 3 to 4 times per season for winter wheat and 1 to 2 times for summer maize. Based on the outcome from this study, WF for winter wheat was 0.89 m^3/kg which found stem from yield, N fertilizer, effective precipitation and irrigation whilst 0.70 m^3/kg for summer maize which solely driven by yield. The components of WF for winter wheat were 0.21 m^3/kg (green), 0.55 m^3/kg (blue) and 0.13 m^3/kg (grey) whilst for summer maize 0.42 m^3/kg (green), 0.19 m^3/kg (blue) and 0.09 m^3/kg (grey). Major contributor for both, winter wheat and summer maize were contrast. The dominant WF component for winter wheat was blue while green for summer maize. This circumstance was driven by regional climatic characteristics in NCP.

A study by [18] quantified WF in the second largest river basin of China, Yellow River Basin (YRC). The WF for maize is the highest (8419 m^3/t) followed by rice (5803 m^3/t), barley (3095 m^3/t) and wheat (2214 m^3/t). By comparing the WF components for all crops, grey WF are the highest for rice, maize and barley, meanwhile green WF highest for wheat. This might be the consequence from rising rate of artificial fertilizer application [18]. Blue WF remains the lowest contributor for all crops. Another study regards to WF was conducted by [19] which assessed WF of Italian wheat from 2011 to 2015. The study covered Northern, Central and Southern of Italy by considering seventeen regions. WF for wheat was 5327 m^3/ha with the highest component is green (4526 m^3/ha) followed by grey and blue with the value of 740 and 61 m^3/ha respectively. All three components were recorded highest at North part of Italy while the lowest at Southern of Italy.

Apprehensive with water resources which threatened by the fluctuate patterns of precipitation periods and distribution in Taiwan, [20] conduct a WF assessment for rice and corn in three regions in central and southern Taiwan, namely Yunlin, Tainan and Chiayi. Corn was planted during autumn, October to February involving only two regions, Tainan and Chiayi whilst rice was planted from July to October involving all the three regions. Based on data collected from 2007-2011, WF of rice was 4809 m^3/t, 1521 m^3/t for Chiayi and Tainan meanwhile 3288 m^3/t for Yunlin. While for corn, WF for Tainan and Chiayi were 704 and 669 m^3/t respectively. In Taiwan, rice cultivation is predominantly depends on irrigation while corn is rain-fed, thus blue WF was high for rice (3671 m^3/t) compared to corn (538 m^3/t). In contrast, corn indicate highest grey WF (484 m^3/t) as compared to rice (220 m^3/t) stem from excessive used of nitrogen fertilizer (160-171 kg/ha) which eventually lead to abundance water usage to dilute pollutants as to comply to environmental quality standards.

Another study with regards to WF of rice conducted by [21] which contemplates two rice growing areas in Argentina, Entre Rios and Santa Fe for the period of 2009-2013. In this study, grey WF was considered inconsequential by the researchers based on several reviewed publications, claimed that the level of residue found were below established standard, hence no large anxiety for the ecosystem. WF of rice Santa Fe (987 m^3/t) was slightly higher as compared to Entre Rios (845 m^3/t). High WF in Santa Fe was due to higher blue WF (627 m^3/t) as compared to Entre Rios (477 m^3/t). Green WF was not obviously different for both regions, Entre Rios (367 m^3/t) whereas Santa Fe (360 m^3/t). This circumstance was view of the fact that rice yields were higher in Entre Rios compared to Santa Fe in all season analysed.

Be in distress of high water scarcity since located in arid country in Mediterranean, has caused Tunisia to face constraints in producing food stem from shortage of water resource [22]. A study conducted by [22] determine WF of wheat in Tunisia from 1996-2005. The findings show that the contrast in WF for North (2550 m^3/t) and Central Tunisia (2710 m^3/t) is small, however values in South Tunisia (4220 m^3/t) contrast significantly. The difference for green and grey WF was not significant for all three areas. But for blue WF, the difference is clearly noticeable in the southern Tunisia where blue WF is almost three times more than the north and five times more than central. This was mainly due to difference in production systems, whereby in South, irrigation is the dominant production system whilst rain fed is dominant in North and Central. Another study regarding WF in China conducted by [23] discovered WF of rice, wheat and corn for 8 regions of China by considering data in 2010. Among the three crops, rice (1.39 m^3/kg) had the highest WF while corn (0.91 m^3/kg) indicates the lowest. Although water consumption is highest for rice, but if viewed in terms of WF component, corn (the lowest WF) has the highest green WF while wheat has the greatest impact on blue WF. This circumstance was result from various crop pattern implemented in each region involved.

Beijing, located in North China Plain is an exceptionally water-scarce region in China [24]. A study on WF was carried out by [24] in Beijing municipality. Based on the study, for 2009, WF of wheat was 711.8 m^3/t while 868.2 m^3/t for maize planted in Beijing. A very significant gap can be seen for blue WF as the highest was from wheat (377.5 m^3/t) compared to maize (4.8 m^3/t). Wheat had the largest blue WF stem from excessive amount of irrigation water consumed as to cater large planted area. Contras for maize, the blue WF was small but had the largest green WF (422.3 m^3/t) due to large-scale cultivation of rain fed maize and its growth period is during rainy season. A global WF assessment for wheat was conducted by [11] for the period of 19966-2005. The average global WF was 1830 m^3/t with the major contributor was green WF (1279 m^3/t) followed by blue (343 m^3/t) and grey (208 m^3/t). The first three salient contributors were Morocco (3710 m^3/t), Iran (3690 m^3/t) and Kazakhstan (3629 m^3/t) even though the contribution towards global wheat production less than 2.0%.

6. Conclusion

Based on reviews, the most contributor component in contributing high water footprint fluctuating. Type of crop is among major sources that influence blue or green component of WF. Crop that predominantly depends on irrigation will indicates high blue WF as compared to green whilst rain-fed crops will result in high green WF. Climate pattern for particular region also play an important role in determining which component of WF will contribute highest. For instance, for arid regions, irrigation is crucial for crop growth which leads to high blue WF. From economic view, blue WF should be scrutinized as blue water costly as compare to green water. Implementation of efficient water management is pivotal in controlling blue WF. For grey WF, in most cases, grey component is lower than blue and green. In spite of that, it's still required attention too. Crop producers should not only engrossed in what increase crop yield but also comprehend and implement sustainable agriculture without effect the quality of crops.

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