Quantitative analysis of Virtual Water Trade of rice and its implications on Water Sustainability: a case study of India

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Abstract

Limited and declining water resources, increasing demand of water resources from different sectors has posed a major challenge for maintaining water sustainability and thus overall sustainability for a populous and water scarce country like India. Over extraction and changing climate have put additional pressure to maintain water sustainability. Therefore, there is a need of proper planning of utilization and management of water resource. Recently, virtual water trade has received much attention and become important tool for balancing the water budget. On the other hand, virtual water trade has become a threat that can adversely effects water balance of exporter's country as well as economy. Analysis of virtual water trade with its implications on water resources are missing, there is a need of such analysis that will help in management of water resources. We present a quantitative analysis of virtual water trade and its implications on water sustainability. We have considered rice crop only due to its characteristics as rice is major water consumer and water exporter crop of India

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Key Points:

- Implications of virtual water export on water sustainability is less explored
- Virtual water export of Indian rice is about 18 billion m^3 which is irreversible and resulted India has become major water exporter country
- Water saving through virtual water import is negligible; there is need of policy interventions to balance the virtual water trade for India

Abstract

Limited and declining water resources, increasing demand of water resources from different sectors has posed a major challenge for maintaining water sustainability and thus overall sustainability for a populous and water scarce country like India. Over extraction and changing climate have put additional pressure to maintain water sustainability. Therefore, there is a need of proper planning of utilization and management of water resource. Recently, virtual water trade has received much attention and become important tool for balancing the water budget. On the other hand, virtual water trade has become a threat that can adversely effects water balance of exporter's country as well as economy. Analysis of virtual water trade with its implications on water resources are missing, there is a need of such analysis that will help in management of water resources. We present a quantitative analysis of virtual water trade and its implications on water sustainability. We have considered rice crop only due to its characteristics as rice is major water consumer and water exporter crop of India

Plain Language Summary

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1 Introduction

Increasing food demand with population growth, lifestyle changes and changing consumption pattern affect the global food supply, food availability and trade. Food supply and availability are directly interlinked with available water resources for overall sustainability; any significant changes may affect the sustainability of water resource and thus food sustainability (Goswami & Nishad, 2018). On the other hand, several studies have emphasized the severe water scarcity from regional to global scale (Fallenmark, 2013; Grey et al. 2013; Mekinnen & Hoekstra, 2016). Water sustainability has emerged as a major challenge to maintain the water sustainability and to provide the sustainable supply of basic necessities of the increasing population (Goswami & Nishad, 2017; Goswami and Nishad, 2015; Mohammed & Darwish, 2017; Oki & Quiocho, 2020 [5-9]. World economic Forum has declared water scarcity as one of the top five risks for the last four consecutive years (Mohammed & Darwish, 2017). This necessitates the water resources management for food security and food production. Virtual water trade has gained attention in the recent year for water resource management. Virtual water trade has become a medium for globalization of fresh water resources, sharing of fresh water resources and better management of water resources (Zhan-Ming and Chen, 2013; Hoekstra and Hung, 2005; Konar et al. 2011; Dalin et al., 2012; Oki and Kanes, 2003; Yang et al., 2006;Yang & Zehnder, 2007). Though, virtual water provides a better approach for the water management and utilization of water resources; there are several studies have shown that the implications of net virtual water export on water sustainability through irreversible losses and lead the loss of water sustainability (Saleth, 2011; Kumar & singh, 2005; Wichelns, 2010; Goswami & Nishad, 2015). Virtual water trade can affect water sustainability and thus food sustainability from regional to global scale (Goswami & Nishad, 2015). Several studies have emphasized the importance of the virtual water trade and its impact on water and food sustainability from regional to global scale (Sadek, 2011; Wichlens, 2001; Chapagain & Hoekstra, 2008; Chittaranjan et al., 2018; Hoekstra & Hug, 2002; Hoekstra and Mekonnen, 2012; Liu & Savnije, 2008; Liu et al. 2009; Allan, 2003; Allan, 1998). Assessment of water footprint and virtual water trade are important for national policy planning for resource management and sustainable supply of food and water of a water scarce country like India (Goswami & Nishad, 2015).

The virtual water can be defined in terms of production and consumption perspective. In terms of agricultural production, virtual water can be defined as the amount of water used to produce 1 ton of the particular agricultural product (Hoekstra & Hug, 2002; Mekonnen and Hoekstra, 2020). Water footprint depends on agricultural practices, water use efficiency, time, place and local climatic conditions (Hoekstra & Hug, 2002; Hoekstra and Mekonnen, 2012). For an example, virtual water for producing 1 ton crop in the arid region is higher than wet region or semi-arid region. Therefore, assessment of water sustainability adopts regional perspective for agricultural production (Goswami & Nishad, 2015).Virtual water, in consumption perspective, is defined as the amount of water to produce the minimum food requirement of a person for healthy life (Liu & Savnije, 2008; Liu et al. 2009). Similarly, some studies have defined virtual water trade in terms of water embedded in the crop at the time of trade (Goswami & Nishad, 2015). For an example, the water content is available about 10-15 % in food grains. While the water content, in vegetables and fruits, is about 70-95% of their weight (Agricultural Research Service , USDA; Transport Information Services).

Agriculture is a major sector of water consumer across the world, it accounts 90% of the total water withdrawal for agricultural purposes for India. While, it accounts 92% of global water resources for agricultural purposes (Hoekstra and Mekonnen, 2012). On the other hand, the per capita water availability of India is less than standard water requirement of a person; 1700 m^3 per capita per year. While India has only 3.83% of total world's fresh water resource to fulfil the necessities of 1300 million population. The annual water precipitation is about 4000 billion m^3 (Central water Commission, Govt. of India) and the total annual water is availability 1911 billion m^3 (AQUASTAT) . Out of this available water, only some fraction of water is utilizable; which is about 1123 billion m^3. The surface water and ground water, respectively, are 690 billion m3 and 433 billion m^3 available of utilization (Central water Commission, Govt. of India).

Rice is one of the major staple food items that feeds more than 60% of the population of India. India is also the major producer of rice in the world, accounts 22% of world's rice production. Production has increased approximately four times in the period 1961-2018, quantitatively from 30 million tons in 1961 to 172 million tons in 2018. In addition, rice paddy occupies around 45 million ha which is about 18% of total harvested area in India. Along with these, Rice is a major water intensive crops that consumes 318 billion m^3 water resource (28% of total utilizable water) to produce 172 million ton rice paddy. Similarly, rice consumption is also an important issue for water and food security in terms of water footprint. With increasing demand due to rapid population growth and changing consumption pattern, India' food demand has increased over the years and this trend will continue in the future. On the other hand, per capita water availability has reached in critical level which is below the standard per capita water requirement. In addition, the virtual water export has shown increasing trend in the recent years resulted India has become major virtual water exporter while the water saving through virtual water import is negligible. Water footprint and virtual water trade are important for water-food indicators.

Therefore, there is a need of assessment of water footprint and virtual water trade for sustainable management of water resources for sustainable supply for long term.

Several approaches and frameworks are available for the assessment of virtual water trade (Sadek, 2011; Wichlens, 2001; Chapagain & Hoekstra, 2008; Chittaranjan et al., 2018; Hoekstra & Hug, 2002; Hoekstra and Mekonnen, 2012; Liu & Savnije, 2008; Liu et al. 2009; Allan, 2003; Allan, 1998), a quantitative study of virtual water trade and its impact on water sustainability through trade of food products. A quantitative analysis of virtual water trade combining with constraints like declining water resource can provide a significant insights and its implications on water sustainability. There is a need of such assessment and analysis for alternate solution and inputs to the policymakers for better management of water resources. We present a quantitative analysis of virtual water trade and its implication on water sustainability for India as well as other countries. In the present study, we have considered agricultural product rice only due to major water intensive crops that consumes 300 billion m^3 water (17% of total water available) and major virtual water exporter (about 18 billion m^3, 1.5% of total water available). Rice is the largest crop and substantial export of rice from India which is the rationale behind to study virtual water export through rice.

2 Materials and Methods

2.1 Total water available and demand

The total available water depends annual rainfall and it is defined as the sum of ground water and surface water. For India, the average annual precipitation in about 4000 billion m^3 (BCM), natural runoff is about 1911 billion m^3[AQUASTAT] and the total utilizable water is about 1123 billion m^3 that is sum of surface water and ground water, respectively 690 billion m^3 and 433 billion m^3 [Central water Commission, Govt. of India]. For quantitative assessment of total water available, we define total water available as

$$W_A(t) = \alpha * R(t) * A + W_G(t) \tag{1}$$

Here $R(t)$ represents the area-average annual rainfall at the year t and A represents the total land area. While $W_G(t)$ represents the available ground water resource in the year t. We have considered fix value of ground water here, although there is inter-annual variability and declining trend in the water table. We have not considered the depletion of ground water resource here. Generally only fraction of rainfall is available for utilization which is about 28% of total water precipitation for India. Thus, the value of α depends on surface characteristics of the country. The total water available, surface water and the ground water available for utilization is adopted from AQUASTAT and Central water Commission, Govt of India.

Water demand can be defined in production and consumption perspective. In production perspective, water demand is the water used to produce the food commodity to meet the demand. The total water demand to produce the crops depends on the production of crops and the water footprint of the crop which is defined as

$$W_P(t) = F_P(t) * W_{FP} \tag{2}$$

Here $F_P(t)$ represents the total rice production in the year t and W_{FP} represents the water footprint of the crop. $W_P(t)$ represents the total water required to produce the crop[13].

Similarly the total water demand to produce the total food supply, in terms of food consumption, is estimated as

$$W_D(t) = F_D(t) * W_{FP} \tag{3}$$

Here $F_D(t) = N(t) * F_{CP}(t) + F_E(t) - F_I(t)$

Here $W_D(t)$ represents the water demand to produce the food supply. Here $F_{CP}(t)$ represents the per capita supply of rice for food, $N(t)$ represents the population of India in the year t. While $F_E(t)$ and $F_I(t)$, respectively, are rice export and rice import in the year t.

2.2 Virtual water trade (export/import)

2.2.1 Virtual water export

The virtual water export through rice export is calculated as

$$W_{EP}(t) = F_E(t) * W_{FP} \tag{4}$$

Here $W_{EP}(t)$ represents the virtual water export in the year t.

2.2.2 Virtual water Import

The virtual water import is calculated as

$$W_{IP}(t) = F_I(t) * W_{FP} \tag{5}$$

Here $W_{IP}(t)$ represents the virtual water import in terms of total water required in the year t. Here, W_{FP} represents the water footprint the respective country in which India is imported rice.

2.2.3Virtual water Net export (Trade balance)

The net virtual water export is calculated as

$$W_{TBP}(t) = W_{EP}(t) - W_{IP}(t) \tag{6}$$

Here $W_{TBP}(t)$ represents the virtual water trade balance in terms of water required for production of rice in the year t.

3 Data, or a descriptive heading about data

The observed data of production, consumption, export and import of the crop rice is adopted from public domain FAOSTAT. The observed data of surface water, ground water and total water withdrawal is taken from AQUASTAT and Central Water Commission, Govt. of India. In the present study we have considered only rice crop. The observed data of harvested area and yield of rice is adopted from FAOSTAT. The virtual water footprints of rice is based on water footprint proposed by Mekonnen and Hoekstra (2010). The water footprint of a crop is the sum of green, blue and grey water footprint. The green water footprint is the volume of water required to produce 1 ton of the crop from rainfall. While, the blue water footprint is the volume of fresh water required to produce 1 ton of the crop from surface water and ground water. Similarly, grey water footprint represents the amount of water required to dilute the pollutants to produce the 1 ton of the crop. In the presents study, we have considered only blue and green water footprint. Grey water footprint is not considered here due to not usage for production purpose. We have assumed total water footprint of a crop is the sum of blue and green water footprint only. The blue water footprint and green water footprint of rice, respectively, are 452 m^3/ton and 1394 m^3/ton.

4 Results

4.1 Water footprint of Rice production and consumption

The total water required to produce the rice 300 billion m^3 which is about 16% of total fresh water available (Fig. 1,solid line) for India in the year 2017. The total water requirement for production of rice has risen from 98 billion m^3 to 318 billion m^3 from 1961 to 2018. The contribution of green water in total water footprint for the production of rice has increased from 70 billion m^3 to 240 billion m^3 in the same period. While the contribution of blue water in water requirement for production of rice has increased from 24 billion m3 to 74 billion m3 in the last 60 years (Fig. 1). There is increasing trend water requirement for production of rice to meet the demand. . In percentage of total water availability, the water requirement for rice production has increases from 5% to 17% during this period. Similar trends have shown in blue water and green water requirement for the production (Fig. 1B). Green water is used for production that increased from 4% to 12%. Similarly, the blue water is used about 4% of total water available. The total rice production, basically, depends on green water in India that is 12% of total water availability.

Similarly, the total water footprint in consumption perspective is 280 billion m^3 which is approximately 15% of total water available that has increased from 4% in 1961 to 15% in 2018. While the green and blue water footprint, respectively, 11% and 4% of total water available. The green water foot print has increased from 63 billion m^3 to 211 billion m3 in the period 1961 to 2018. While the blue water has risen from 20 billion m^3 to 68 billion m^3 (Fig. 1C, 1D).

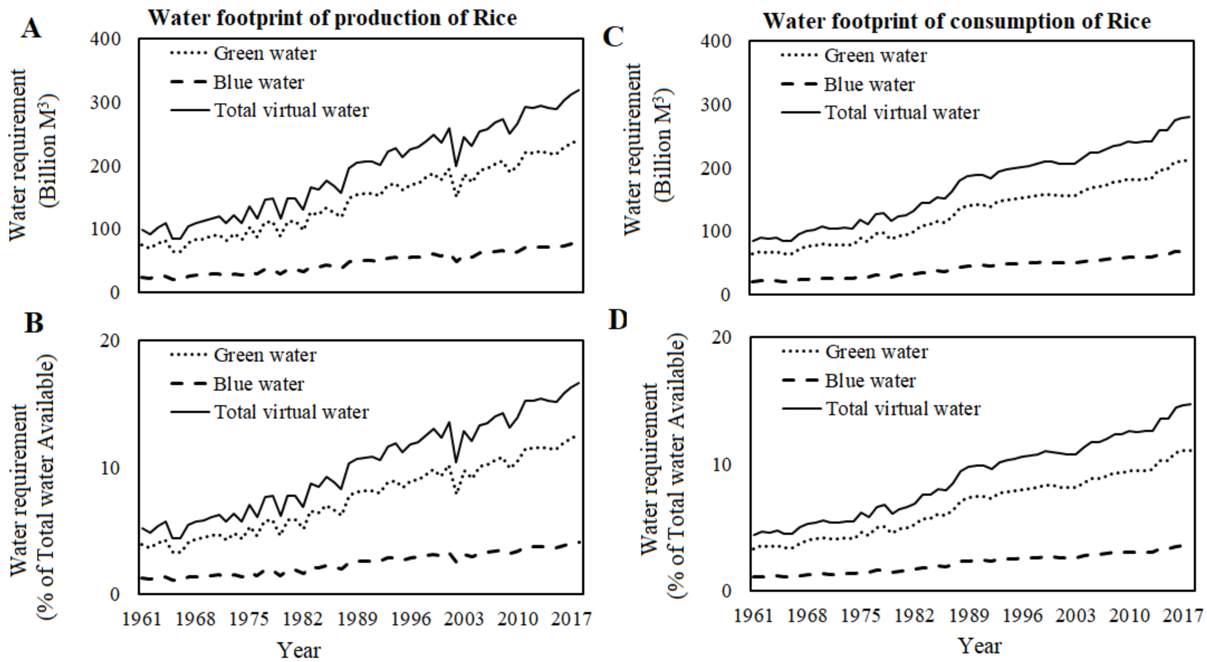

Figure 1. Temporal analysis of green (dotted line), blue (dash line) and total water footprint (solid line) for production (left panel) and consumption (right panel) perspective are given in terms of quantity (A,C) and in % of total water available (B,D) for the period 1961 to 2018.

Similarly, global analysis of water footprint of rice shows that the India has the largest water footprint in the world in the range 200 to 320 billion m^3. While, China is the second largest country of water footprint 170 billion m^3. The major top countries of high water footprint of rice are India, China, Bangladesh, Indonesia, Thailand, Vietnam and Myanmar in which the water footprint is more than 50 billion m3. The water footprint of rice in United States of America is about 13 billion m^3. European countries, African countries, American countries have water footprint less than 1 to 10 billion m^3. The global analysis of green water footprint of rice production shows that the India, China, Bangladesh, Indonesia, Thailand are the major countries. While global analysis of blue water footprint for rice production reveals India and China are the major countries of using highest blue water for rice production. While other countries using least blue water for rice production (Fig. 2).

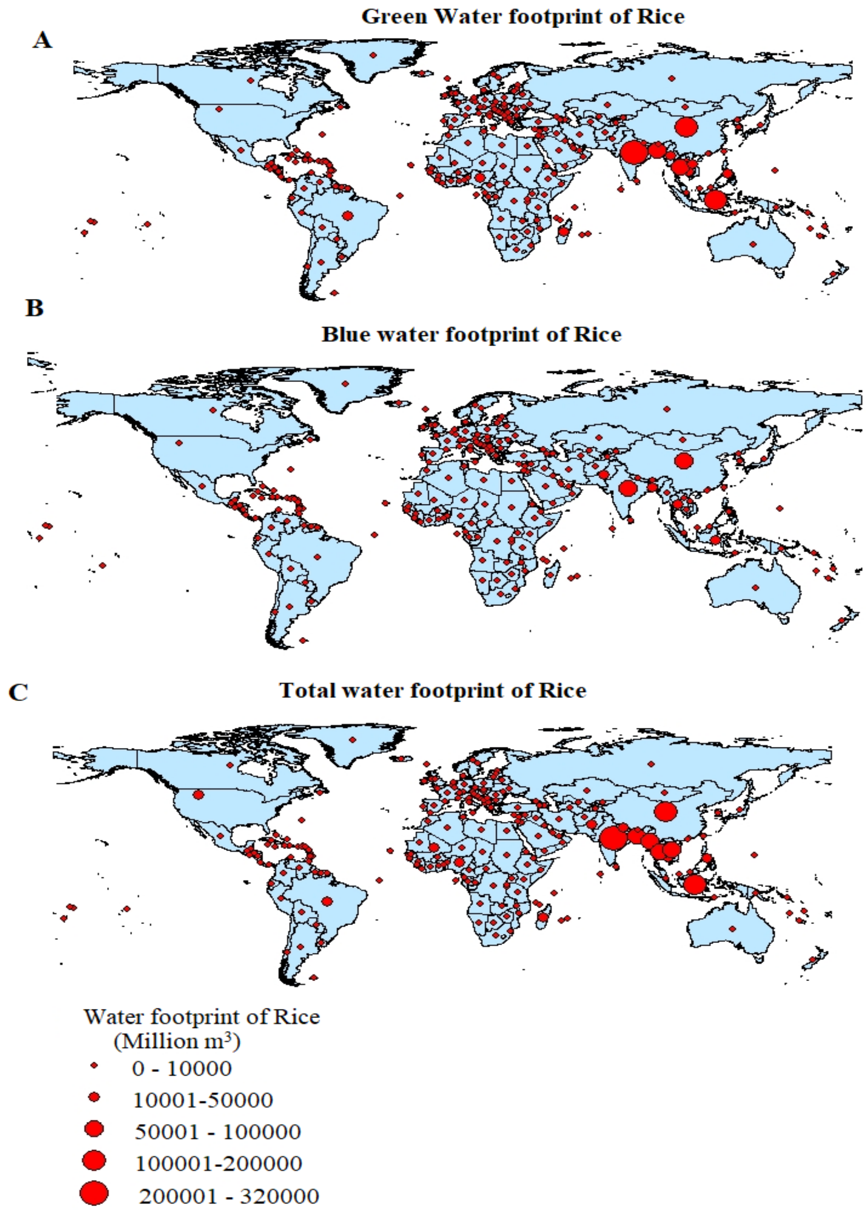

Figure 2. Global analysis of Green, Blue and total water use for production of rice. The data is taken for the year 2018.

4.2 Virtual water export and virtual water import:India and the other countries

From a negligible value of virtual water export until 1990, India's virtual water export has risen to 18 billion m3 in the period 1990 to 2013 (Fig. 3A, solid line) which is about 1.2 % of total available water or about 6% of annual water used for production of rice. In contrast, India's virtual water import was about 0.1% of its total available water in 1960-70, which then fell to negligible values from 1990 onwards. In terms of production, the virtual water import was about 2% in 1960-70, which then fell to negligible value from 1990 onwards. India has moved from an import-intensive paradigm to an export intensive regime in virtual water trade (Fig. 3).

The comparative global analysis shows that India is a major virtual water exporter country. Along with these, Thailand, Pakistan and Vietnam are also other major virtual water exporter countries, which is about 76% (including India) of total virtual water export across the world. In terms of green water, India and Thailand are the major countries dependent on green water for rice production (Fig. 4A) in the range 10-21 billion m3 that has exported to other countries. While the virtual water export of Vietnam is in the range 5-10 billion m^3 (Fig. 4A). Similarly, the analysis of virtual water export of green water shows that the Pakistan is the highest blue water exporter in the world which is about 8 billion m3 while India, USA, Thailand and Vietnam are the second largest blue water exporter in the world in the range 1-5 billion m^3 (Fig. 4B).

The contribution in virtual water export of India, Thailand, Pakistan and Vietnam, respectively, are 24%, 28%, 14% and 10% of the total virtual water export across the world. In terms of quantity, the virtual water export of India, Thailand and Pakistan varies in the range 10 billion m3 to 21 billion m^3. While the virtual water export of Vietnam lies in the range 5-10 billion m^3. Similarly, the virtual water export of the USA, Brazil and Uruguay lies in the range 1-5 billion m^3 (Fig. 4C)

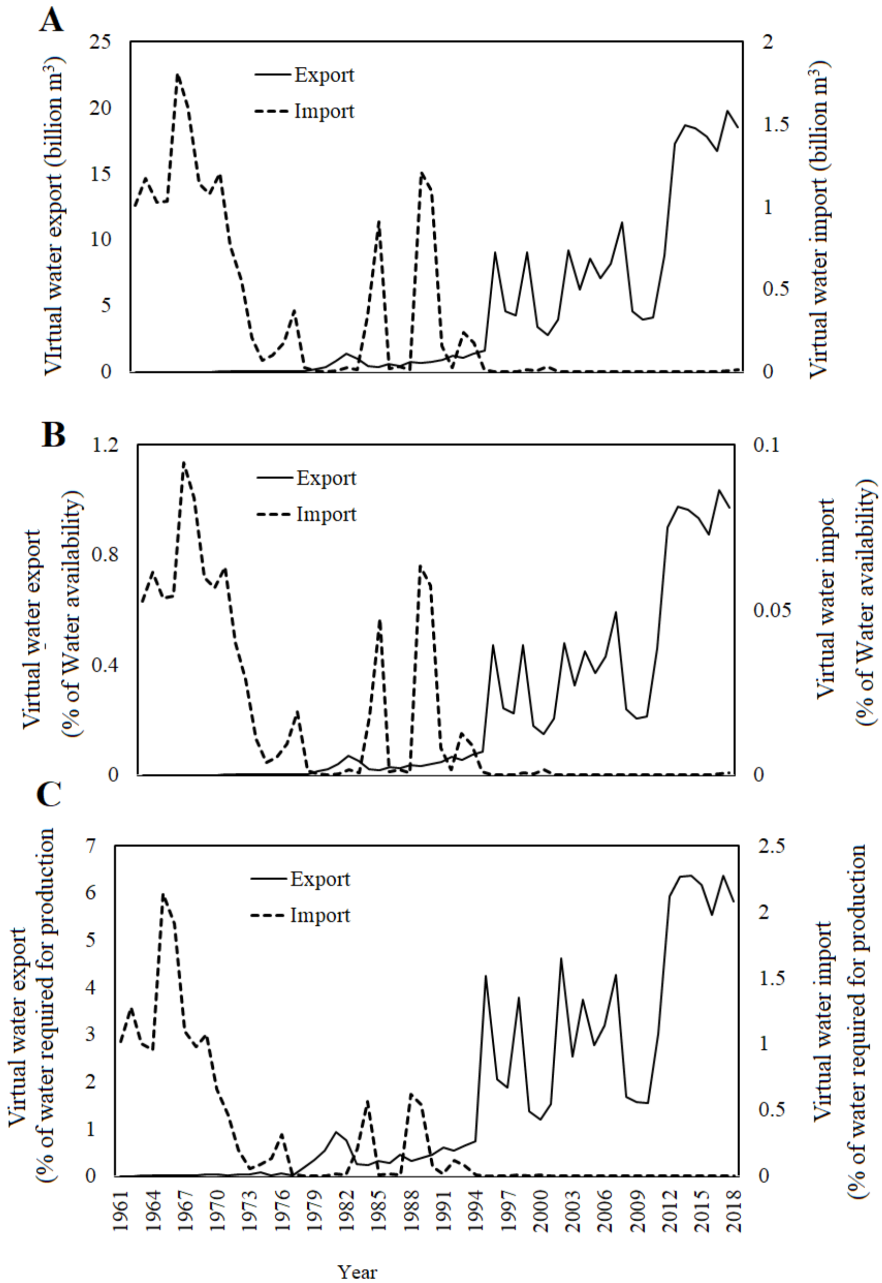

Figure 3. Virtual water export (left y axis, solid line) and virtual water import (right y axis, dash line) in terms of quantity (A), percentage of total water available (B) and percentage of total water required for production of rice (C).

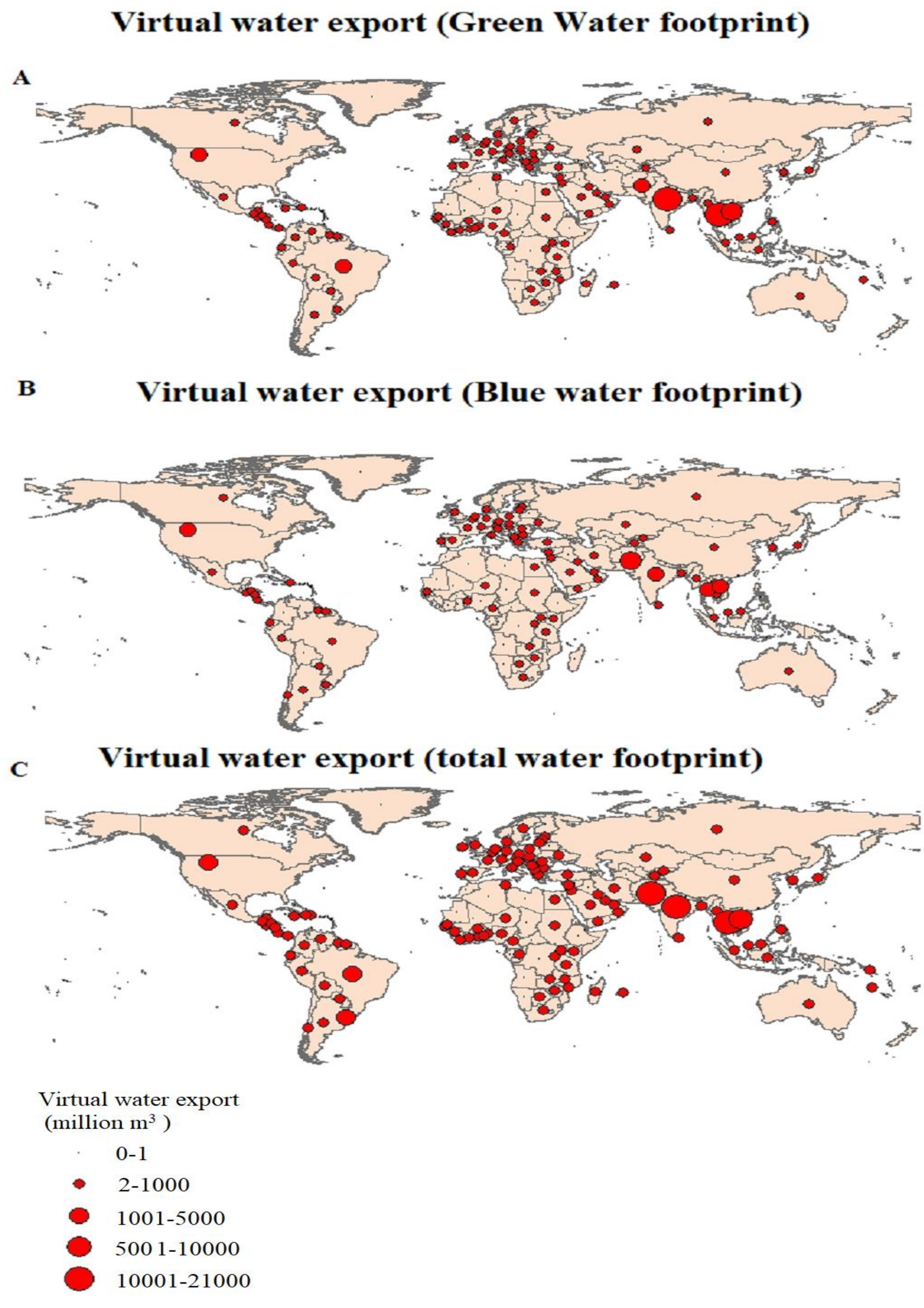

Figure 4. Spatial analysis of green virtual water export (A), blue virtual water export (B) and total virtual water export (C).

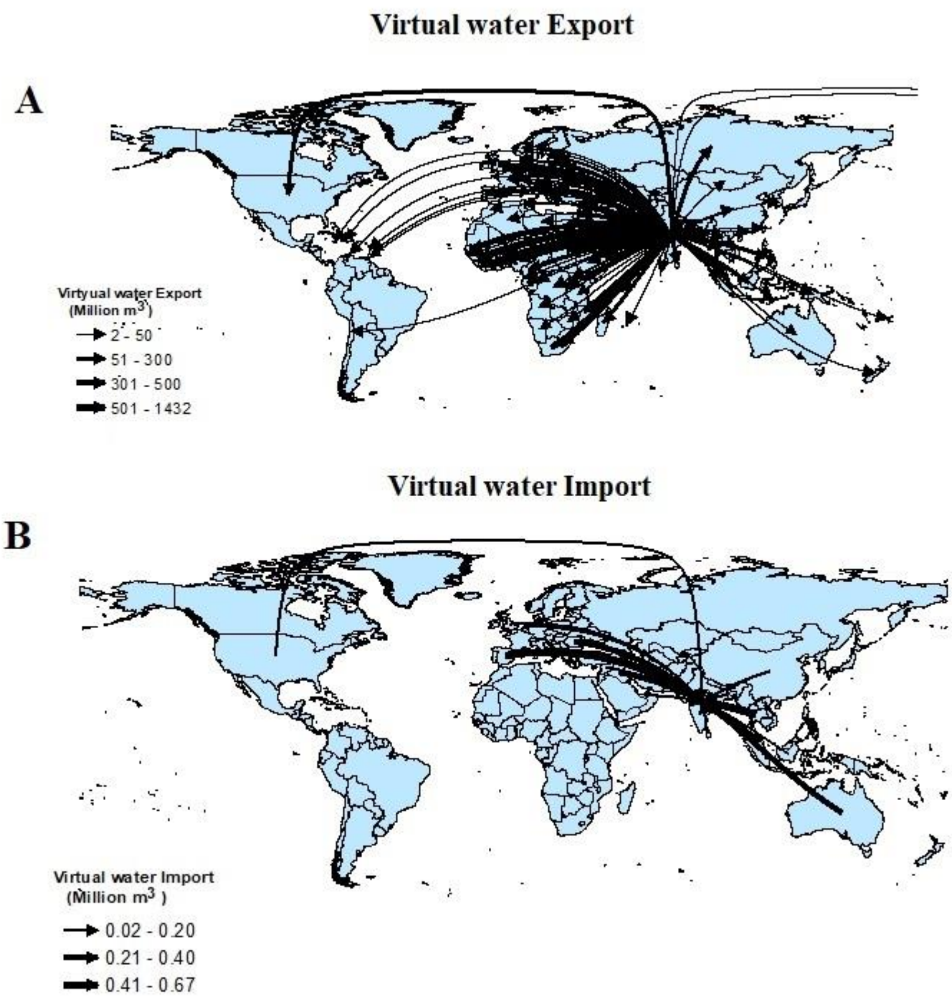

Figure 5. low map virtual water export in terms of export Rice from India and virtual water import through import of rice.

4.3 Virtual water trade network

The flow digram in figure 5 shows that India is one of the major virtual water exporter through export of rice across the world; the virtual water export is around 18 billion m^3 that has exported across the world. The major countries arenamely African countries, European and the USA which are importing virtual water embedded in rice from India (Fig. 5A). In contrast, the virtual water import through rice to India is negligible and from only few countiries (Fig.5B). the water saving through virtual water import is almost zero in comparison of the virtual waer export from India (Fig. 5B).

4.4 Net Virtual water export (Trade balance)

The net virtual water export through export of rice was negative until 1990s and turned positive afterwards (Fig. 6A). The net virtual water exports is 18 billion m^3 in the year 2018 which ia about 1% f total water available of India (Fgure 6B). In terms of water required for production, the virtual water export is about 6% (Figure 6C). The current deficit of water is about 18 billion m^3.

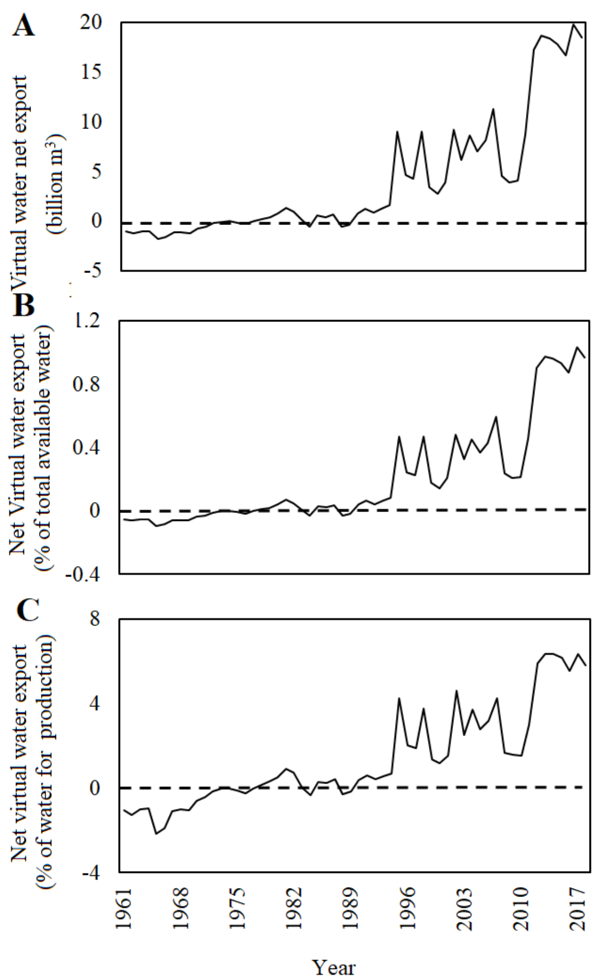

Figure 6. Net virtual water export of rice in terms of quantity (A), percentage of total water resources (B) and percentage of total water required for production of rice (C) from 1961 to 2018. The horizontal dash line represents the trade balance.

5 Conclusions

Overall food sustainability depends primary resources like arable land and water, any changes may pose the significant impact on the sustainable availability. The arable land is immobile while the other primary resource water that can be transported across the countries through export of agricultural commodities. This export of agricultural commodities is indirectly accompanied with virtual water that is exported. Rice is a major food products that is consumed in large scale in India and across the world. Along with these, rice is a major crop that consumes large volume of water for the production and the major exported crop across the world from India.

The water foorprint of rice has increased about 320 billion m^3 which is about 17% of total water available. The major contribution in water footprint of rice is green water water contributes around 240 billion m^3. While the contribution of blue water is about 74 billion m^3 for production of rice crop only. The contribution of blue water utilization for production of rice has become double due to advancement of irrigation facilities. Rice is major crop that dependent on availability of green water; water deficit due to uncertain rainfall and changing climate may affect the availability of green water for production of rice. While dependency on blue water have accelerated the over extraction of ground water in India resulted decline in ground water level across India.

Along with these the virtual water export may have large impact on water sustainability due to loss of water in irreversible manner. The virtual water export through rice is about 18 billion m3 which is irreversible that indicates the water loss. India is major water scarce countries and exporting of such huge amount of water may increase the level of water scarcity. Along with these, there are evidences of potential impact of changing climate on water availability, quality and accessibility that may affect the water sustainability.

A global analysis of virtual water export reveals that India is major water exporter country which exports around 18 billion m3 water or 1.2% of total available water and contribute 24% share in the global virtual water export while virtual water import is almost negligible. Our analysis shows that India has become the major virtual water exporter in terms export of rice across the world. Such magnitude of virtual water trade may affect the water sustainability and thus food sustainability. The present analysis shows that the export of virtual water is much higher than the import of virtual water in result; India has become major water exporter from 1990 onwards. Such increasing trend in virtual water trade may significant impact on overall sustainability of a nation like India in which per capita water availability is less than standard minimum water requirement. In contrast, virtual water import of India is negligible from 1990 onwards. Therefore, the net virtual export of water through export of rice only can lead to irreversible loss of water sustainability.

Analysis also shows that the India is mainly dependent on green water for production of rice that represent India is highly dependent on monsoon rainfall, any changes on monsoon rainfall affect the rice production. Shrinking of rainfall, declining trend in rainfall, changing rainfall pattern with potential climate change may reduce the water availability for production of rice that will affect the overall food sustainability. Thus virtual water export in this trend may affect the overall water sustainability of India. There is need of water balance in virtual water trade of water scarce country like India. While dependency on blue water for rice production have accelerated to over extraction of ground water in India resulted ground water scarcity. Therefore, there is need to take actions to reduce the virtual water export. Here, we have found clear indications of significant impacts of virtual water export on water sustainability. Inclusion of other crops may affect the water sustainability.

Acknowledgments, Samples, and Data

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All the data used in this study is based on data available in the public domain FOASTAT (http://www.fao.org/faostat/en/#home), AQUASTAT (http://www.fao.org/aquastat/). The virtual water footprint data is adopted from Mekonnen, M.M, Hoekstra, A.Y. (2011) National Water footprints: The green, Blue and Grey Water footprint of production and Consumption. Research Report, 50 UNESCO-IHE, Delft, Netherlands. Derived data set may available as per requirement.

Author Contribution

The contributions of S.N. are in conceptualization, methodology, formal analysis, writing, review and editing of manuscript, visualization, validation. The contributions of N.K. are investigation, analysis, review, writing, and editing the manuscript.

Declaration of conflict interest

The authors declare that they have no conflict of interest.

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