ANSF APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
14(4), 1264 - 1271 (2022)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Assessment of water footprint for a few major crops in Banas River Basin of Rajasthan

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Article Info
https://doi.org/10.31018/jans.v14i4.3896
Received: August 16, 2022
Revised: November 7, 2022
Accepted: November 14, 2022

How to Cite
Mehla, M. K. *et al.* (2022). Assessment of water footprint for a few major crops in Banas River Basin of Rajasthan. *Journal of Applied and Natural Science*, 14(4), 1264 - 1271. https://doi.org/10.31018/jans.v14i4.3896

Abstract
Water security is essential for socio-economic development, ecosystem management, and environmental sustainability. An improved understanding of the relationships between water demand and supply is needed to mitigate the impacts of diminishing water resources. The present study aimed to assess the crop water footprint of sixteen major crops in the basin namely, bajra/ pearl millet (*Pennisetum glaucum* L.), barley (*Hordeum vulgare* L.), cotton (*Gossypium herbaceum* L.), gram/chickpea (*Cicer arietinum* L.), groundnut (*Arachis hypogaea* L.), guar/cluster beans (*Cyamopsis tetragonoloba* L.), jowar/ sorghum (*Sorghum bicolor* L.), lentil/ masoor (*Lens culinaris* L.), maize (*Zea mays* L.), mungbean (*Vigna radiata* L.), rapeseed & mustard (*Brassica napus* L.), rice/paddy (*Oryza sativa* L.), sesame (*Sesamum indicum* L.), soybean (Glycine max L.), urad/ black gram (*Vigna mungo* L.) and wheat (*Triticum aestivum* L.) was estimated during 2008-2020 in the Banas river basin of Rajasthan. The average annual water footprint of crop production varied from 11365.8-23131.5 MCM/yr (Mean 19254.5 MCM/yr) during the study period. Wheat, bajra, maize, rapeseed & mustard make up 67.4 % of the total average annual water footprint of crop production. The blue water footprint of crop production was 3942.1 MCM/yr, with wheat, rapeseed & mustard accounting for almost 87.0 % of the average annual blue water footprint. Blue, green and grey water footprints comprised 20.8, 69.7 and 9.5 % of the total WF of crop production in the basin, respectively. This assessment can play a significant role in developing better policies for properly managing water footprints for sustainable crop production in the basin.

Keywords: Agricultural water footprint, Blue water footprint, Sustainable agriculture, Water scarcity, Water use

INTRODUCTION

The water footprint (WF) is a broad concept that indicates water consumption within a region for a product, commodity, process or service (Hoekstra *et al.*, 2009). Calculated by summing the volume of direct and indirect water used for a product, commodity, process, or service. There are three major components of virtual water content which are green (amount of rainwater), blue (amount of surface or groundwater) and grey water footprint (amount of water required to assimilate pollutants). Water is essential for agriculture and food production, accounting for about 85% of global freshwater consumption (Hoekstra and Chapagain, 2007). It is found that 78 % of the global agricultural WF is green, 12 % is blue, and 10 % is grey water footprint (Hoekstra *et al.*, 2011). Water footprint assessment accounts for not only water consumed but also the sustainability of water use. WF can help determine the optimal use of water and crop patterns by establishing water availability and the contribution of green, blue and grey water footprint. The water security indicators based on the water footprint concept are receiving more attention because they account for the return flow from the total water withdrawn from a watershed (Hoekstra, 2017). The water footprint of crops is most sensitive to reference evapotranspiration (ET_0) and crop coefficient (K_c), followed by the crop calendar. (Zhuo *et al.*, 2014). Water footprint assessment in agriculture varies based on location and environmental conditions, aiming to determine the region of high water consumption by comparing utilization rates. It also assesses the extent of water contamination caused by agricultural practices and its impact on water sources. Farmers should be made aware of water use efficiency and how they can increase that. Upgrading the water management practices by implementing precision irrigation methods, improving irrigation efficiency, and irrigation scheduling can significantly decrease water consumption in the agriculture sector while ensuring food security (Chukalla, 2017; Huang *et al.*, 2015; Nouri *et al.*, 2020; Zhuo and Hoekstra, 2017). Regional assessment of crops' WFs is important and necessary to reflect close to real-world conditions (Khan *et al.*, 2021)

Rapid population and economic growth have strained our already limited freshwater resources. In India, over time average annual per capita water availability has declined from 1816 to 1545 cubic meters in the year 2001 and 2011, respectively and is projected to be 1486 cubic meters in the year 2021 and will further go down to 1367 cubic meters by 2031 (PIB, 2020). Nowadays, the sector that consumes a significant amount of fresh water in India is agriculture. Due to the limitation and scarcity of freshwater resources, it is necessary to manage irrigation water resources rationally. Priority should be on selecting the most appropriate method of irrigation scheduling for irrigating the crops under suitable irrigation systems like drip irrigation to increase WUE and minimize wastage in irrigated agriculture (Chukalla *et al.*, 2015). Wheat, rice, barley and maize are major crops grown over the Indian subcontinent. Wheat and rice crops account for 45% of the global blue WF on their own (Mekonnen and Hoekstra, 2011). Wheat and rice production consumes the most considerable amount of water (80.6% of total water use). The highest consuming states are Uttar Pradesh, Punjab and Rajasthan (all explicitly being in the Northern region of India), accounting for 20.0%, 8.4% and 8.4% of total Indian water consumption for cereal production during 2005-06 and 2014-15, respectively (Kayatz *et al.*, 2019). There is a need for a better understanding of the actual blue WF accounting, particularly for flood irrigated crop production (Kashyap and Agarwal, 2020). Rajasthan has more than 10.40 per cent of the country's geographical area, supporting more than 5.50 per cent of the human population, 11.27 per cent of livestock has only 1.16 per cent of the total surface water and 1.72 per cent of total groundwater availability of the country (Singh *et al.*, 2019). Agriculture is the primary source of livelihood in Rajasthan, where significant parts of the state face severe water scarcity. Assessing vulnerabilities in agricultural management systems across various regions and times will help us prepare for actions to improve water productivity and promote sustainable water use. There is a need to take effective and practical steps toward efficient water utilization in agriculture. This study aimed to estimate the water footprint of agricultural crops in the Banas river basin of Rajasthan. This study integrates local data and robust modelling capabilities of the AquaCrop model to more precisely assess the WFs of major crops of the basin.

MATERIALS AND METHODS

Study area

The green, blue and grey components of the water footprint for the major crops were estimated at the basin level with the help of the AquaCrop model between 2008 to 2020 in the Banas River Basin (BRB) lying between 24°15'-27°20' latitudes and 73°25'-77°00' longitudes (Fig.1). It has a catchment area of 47,060 km^2 (4.7 Mha) within Rajasthan (WRD, 2014).

Methodology

Sixteen major crops namely bajra/ pearl millet (*Pennisetum glaucum* L.), barley (*Hordeum vulgare* L.), cotton (*Gossypium herbaceum* L.), gram/chickpea (*Cicer arietinum* L.), groundnut (*Arachis hypogaea* L.), guar/cluster beans (*Cyamopsis tetragonoloba* L.), jowar/ sorghum (*Sorghum bicolor* L.), lentil/ masoor (*Lens culinaris* L.), maize (*Zea mays* L.), mungbean (*Vigna radiata* L.), rapeseed & mustard (*Brassica napus* L.), rice/paddy (*Oryza sativa* L.), sesame (*Sesamum indicum* L.), soybean (Glycine max L.), urad/ black gram (*Vigna mungo* L.) and wheat (*Triticum aestivum* L.) which are mainly cultivated in the basin were selected for this study based on their total cultivated and irrigated area. Combined together they account for 94 % of total cultivated and 90 % of irrigated area annually. District level datasets of annual statistics related to production, productivity, cultivated and irrigated area under various crops during 2008-2020 for the districts coming under Banas basin was obtained from Agriculture Statistics Handbook, Directorate of Economics & Statistics, Department of Planning, Government of Rajasthan (https://agriculture.rajasthan.gov.in/). Data for the basin was derived from district-wise data by multiplying them with proportionality factors based on the area of districts within the basin. Basin area was divided into homogenous land units based on land use, soil and agro-climatological characteristic to account for spatial variations while reducing the number of simulations required (Mali, 2014). Local data and district-level estimates were used for the estimation of WF and other parameters.

For simulating various crops, parameterization and calibration guidelines provided by the FAO were followed (Steduto *et al.*, 2012). As per their recommendation, crop parameters derived from the available literature were used for the first simulations and outputs were compared with observed values, then adjusting the parameters and rerunning the simulation. This approach was repeated until the simulation findings roughly matched the observed data. The initial simulation parameters were derived from the AquaCrop user manual (Raes *et al.*, 2016). Sensitivity analysis of AquaCrop model parameters suggests that, under water-stressed conditions, the model is most sensitive to soil water characteristics, root development, and emergence parameters (Vanuytrecht *et al.*, 2014). So, during calibration, more focus was placed on these parameters. The plug-in version of AquaCrop model 6.0 was used to assess crop WF over the basins because of its flexibility and ease of use for multiple simulations (Raes *et al.*, 2018). AquaCrop model output in terms of crop growth characteristics and water fluxes are divided into a crop's green and blue WF by following the post-processing procedure of soil water balances and

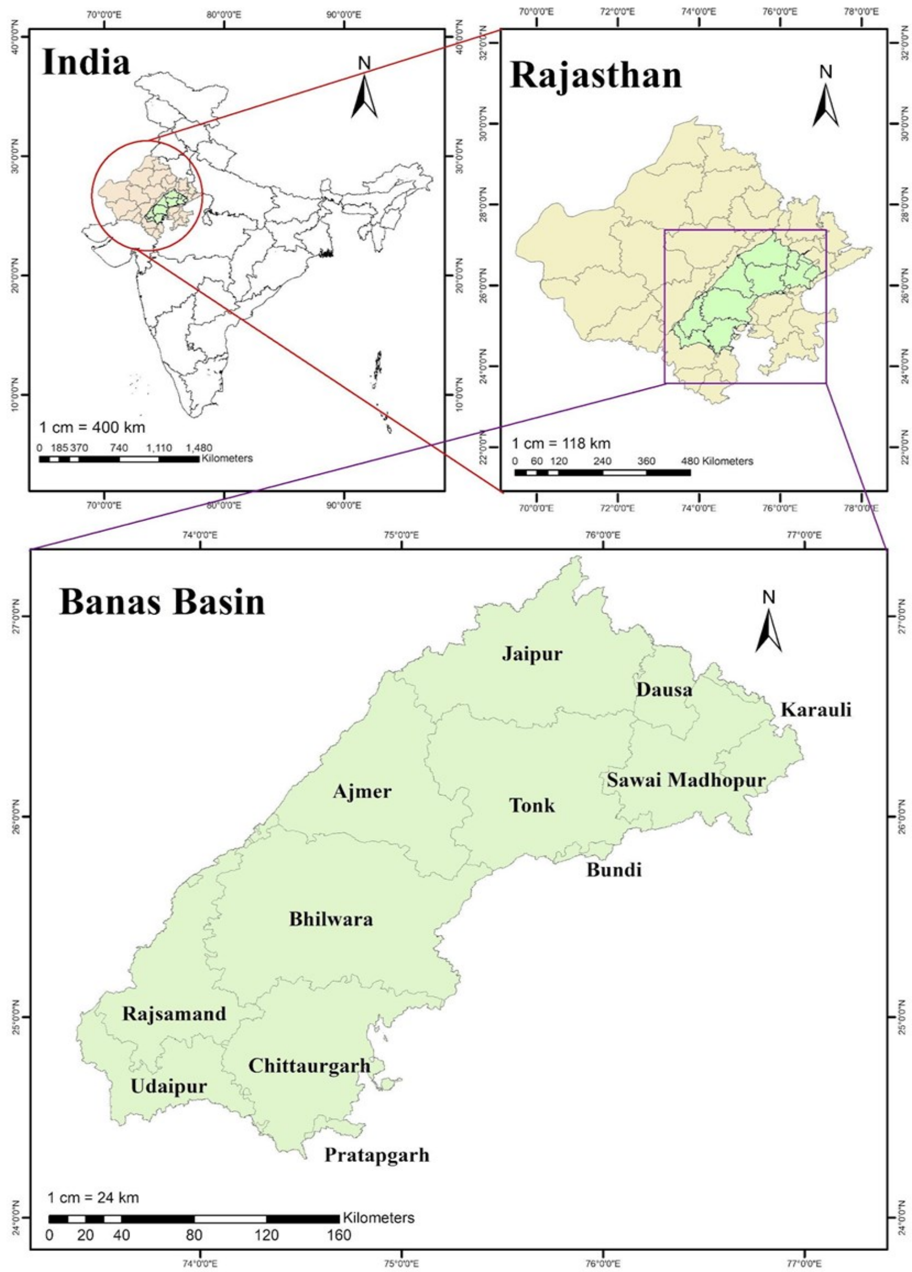

Fig. 1. *Location of Banas river basin in Rajasthan*

the WFN methodology (Hoekstra *et al.*, 2011; Chukalla, 2015). Obtain edgreen and blue WF by dividing the CWU with the yield (Y) over the season.

$$WF_{green} = \frac{CWU_{green}}{y}$$ Eq. 1

$$WF_{blue} = \frac{CWU_{blue}}{y}$$ Eq. 2

Where,

CWU_{green}: Green water consumption (m^3)

CWU_{blue}: Blue water consumption (m^3)

WF_{green} : Green WF (m^3/ton)

WF_{blue} : Blue WF (m^3/ton)

Y : Yield (ton)

The grey water footprint (WF_{grey}, m^3/ton) refers to the quantity of water required to assimilate pollutants load as per the ambient water quality standards (generally refers to the maximum and permissible water quality standards). It is given by the equation,

$$WF_{grey} = \frac{(\propto \times AR)/(c_{max} - c_{nat})}{Y}$$ Eq. 3

Where,

AR: application rate of fertilizers to the field per hectare (kg/ha)

$\propto$: leaching run-off fraction (%)

c_{max}: maximum acceptable concentration (kg/m^3)

c_{nat}: natural concentration for the pollutant (kg/m^3)

Y: crop yield (ton/ha)

Crop production estimates for districts were distributed based on proportionality factors based on the area of a district within the basin. Similarly, green, blue and grey WF components for crop production can be calculated individually. The total WF of a crop (m^3/ton) is given by the summation of the green, blue and grey WF of the crop. Crop WF is multiplied by the production to estimate virtual water content (VWC)/WF crop production. The Annual WF of the agriculture sector was estimated, summing the total WF of major crops grown in a year within an area.

RESULTS AND DISCUSSION

Crop water footprint

Among the various crops highest total WF was found in sesame, followed by urad and moong under both irrigated (16203.6, 11892.1 and 11043.9 m^3/ton, respectively) and rainfed conditions (14261.4, 10359.1 and 9655.1 m^3/ton, respectively). As it is known, WF is directly proportional to crop water use (CWU) and inversely proportional to crop yield. The average productivity of these three crops was among the lowest and is the major reason for high WF. CWU in rainfed crops were lower in comparison with the irrigated crop. Total WF was found lowest in barley, followed by wheat, rapeseed & mustard under both irrigated (1498.6, 1824.1 and 3200.6 m^3/ton, respectively) and rainfed conditions (1241.3, 1508.3 and 2465.4 m^3/ton, respectively). These crops had a higher yield which could be the main factor in the lower WF. It should be noted that higher or lower WF does not mean higher or lower water use per hectare. Corps have lower WF under rainfed conditions mainly because crop yields do not necessarily decrease directly with water stress. There was significant spatial and temporal variation. In the present study, using local data, the AquaCrop model was used to estimate WF spatially over time. ET_o was calculated according to the Penman-Monteith equation, which is the most widely used technique. The WF of most crops

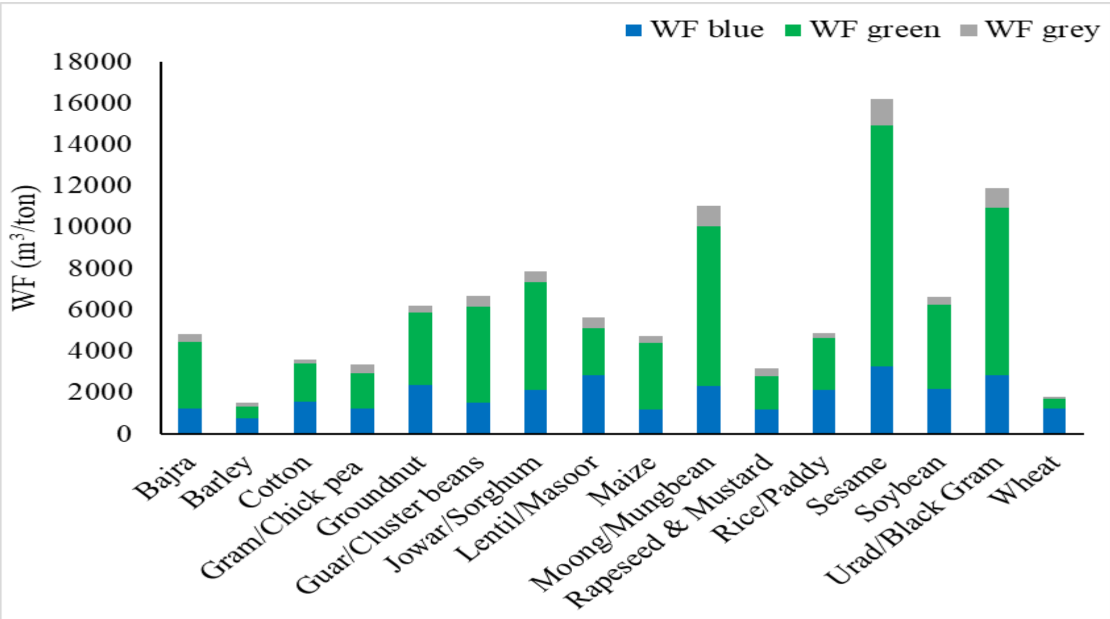

Fig. 2. *WFs of major crops in Banas river basin of Rajasthan under irrigated condition*

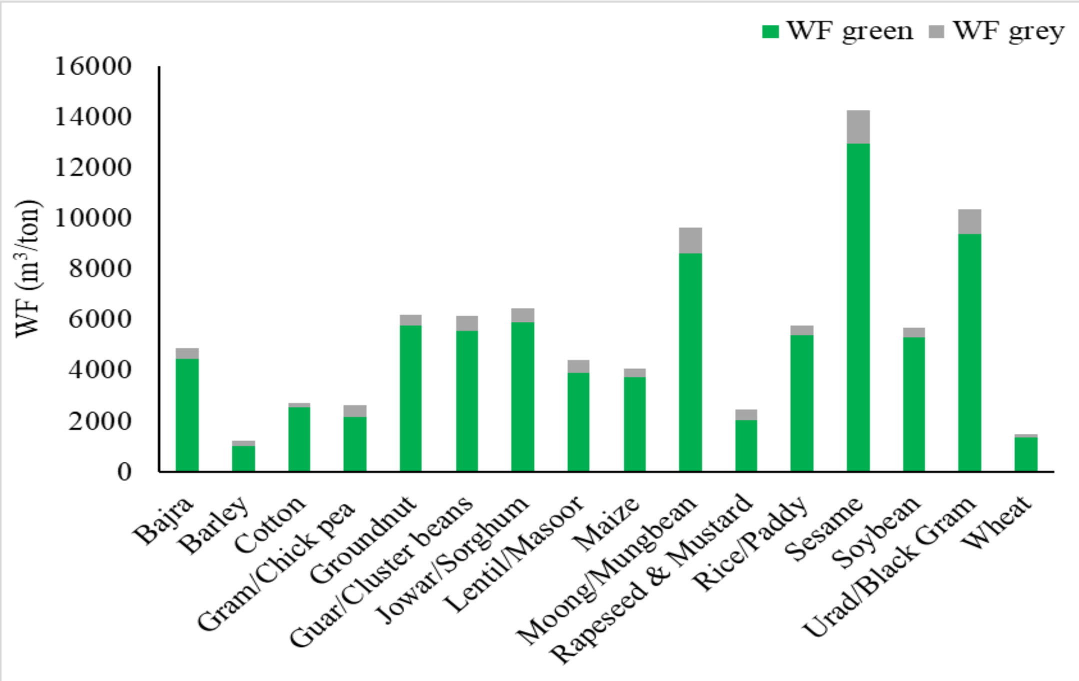

Fig. 3. *WFs of major crops in Banas river basin of Rajasthan under rainfed condition*

in the Banas basin was higher than the global averages (Mekonnen and Hoekstra, 2011). The major reason for differences in computed WFs could be the variances in the methodology adopted, the technique used for ET estimation, input data, the model used, scale and the scope of the studies. WF of major crops in the Banas basin under irrigated and rainfed conditions is presented in Fig. 2 and Fig. 3.

Water footprint of crop production

The WF was multiplied with crop statistics to estimate WFs of crop production given in million cubic meters (MCM) per year. The total annual WF of major crops in the basin was 19254.5 MCM/yr. Wheat, bajra, maize and rapeseed & mustard make up 67.4 % of the total average annual WF of crop production in the Banas basin (20.2, 18.3, 15.8 and 13.1 %, respectively). The annual blue WF of crop production was 3942.1 (MCM/yr). Wheat and rapeseed & mustard make up almost 87.0 % of the average annual blue WF (66.7 and 20.3 %, respectively). The largest total WF in the basin was found in wheat (3890.5 MCM/yr), followed by bajra (3532.7 MCM/yr) and then maize (3040.5 MCM/yr). Green WF was highest in bajra (3213.5 MCM/yr), maize (2776.1 MCM/yr) and rapeseed & mustard (1371.2 MCM/yr). Blue WF of Wheat was highest (2629.8 MCM/yr), followed by rapeseed and mustard (799.9 MCM/yr) and Barley (209.8 MCM/yr). The largest grey WF was seen in rapeseed and mustard (348.0 MCM/yr), bajra (306.2 MCM/yr) and wheat (295.5 MCM/yr), respectively. Large WF is directly linked with the crop's average WF and the crop's production in the basin. Crop with high production has higher WF in general. The average annual WF of major crops produced in the Banas basin is shown in Fig. 4.

The average annual WF of crop production during the study period is depicted in Fig. 5. The total WF for crop production was found to be highest at 23131.5 MCM/yr in 2019-20 and the lowest at 11365.8 MCM/yr in 2009-10, respectively. This is mainly due to increased area under cultivation and more availability of water for irrigation. On average, the WF of crop production was 69.7 % green, 20.8 % blue and 9.5 % grey in the basin. Rainfed agriculture is prominent in the Banas river basin and is the reason for higher green WF. In general, the WF of crop production is increasing as more area comes under cultivation of crops, high-yielding varieties of crops are being developed, improved irrigation technologies become available, and more water storage structures are being constructed. These results are in line with previous results from similar studies (Kampman et al., 2008; Mali, 2014; Mekonnen and Hoekstra, 2011; Rao et al., 2019). The blue WF accounted for 47.3% and 43.6% of the total WF of Gomti and Betwa basins of Uttar Pradesh, respectively, while the share of grey WF was about 9.1% and 10.9% of total WF (Mali *et al.*, 2018, 2019). It is shown that 78 % of the global agricultural WF is green, 12 % is blue, and 10 % is grey WF (Mekonnen and Hoekstra, 2013).

Spatial variation of blue, green, grey and total WF of agriculture production for major crops in the Banas basin is presented in Fig. 6. The blue WF of crop production varies between 82.2-668.5 MCM/yr (Mean 328.5 MCM/yr) in the various districts in the region of the

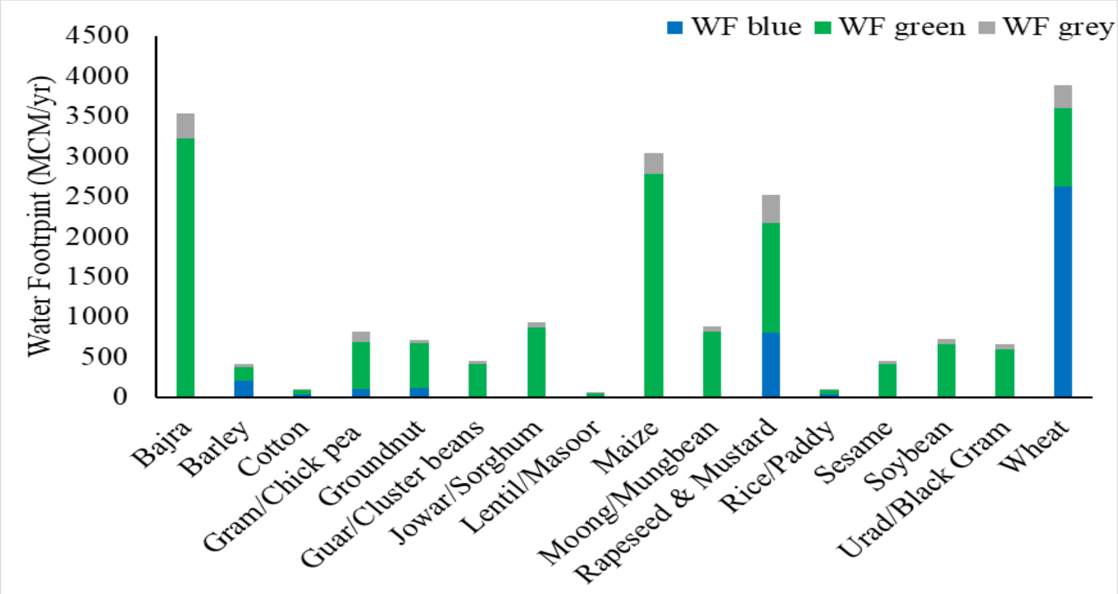

Fig. 4. *Average annual WF of major crops produced in Banas River Basin*

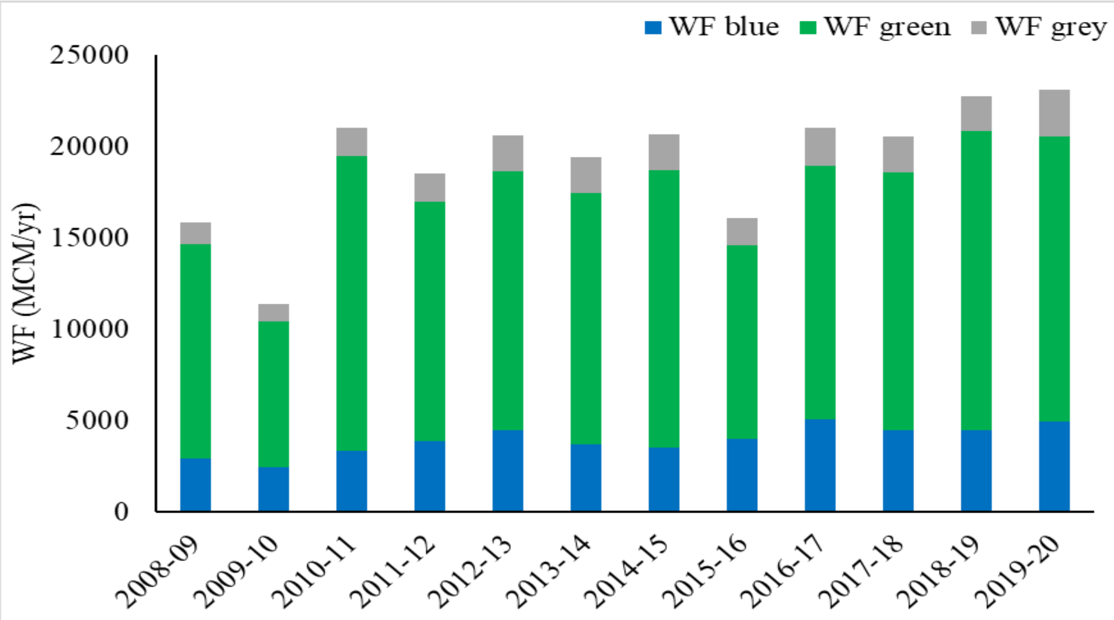

Fig. 5. *Average annual WF of crop production during 2008-2020*

Banas basin namely, Ajmer, Bhilwara, Bundi, Chittaurgarh, Dausa, Jaipur, Karauli, Pratapgarh, Rajsamand, Sawai Madhopur, Tonk and Udaipur (Fig. 1). Similarly, green WF ranges between 232.3-2625.5 MCM/yr (Mean 1129.9 MCM/yr) in the basin districts. Grey WF of crop production varies between 30.8-303.8 MCM/yr (Mean 146.1 MCM/yr). The highest total WF in the basin was seen in the Jaipur district (3557.1 MCM/yr), followed by Chittaurgarh (2860.6 MCM/yr) district of Rajasthan. The lowest total WF in the basin was found in Pratapgarh (408.6 MCM/yr), followed by the Bundi district (427.1 MCM/yr) district of Rajasthan. The WF of agriculture is directly linked with the crop production, area cultivated and yield. Hence, districts with a smaller area in the basin have lower annual WF.

On-farm application of alternative practices (irrigation methods, irrigation management and scheduling, crop management, plant conditioners, mulching, soil management and micro-climate regulation) can result in water savings to a limited extent compared to conventional practices (Flood irrigation, Unlevelled fields, Transplanted paddy and Not using mulch *etc.*), but this can assimilate into larger water savings at catchments and regional scales (Jovanovic *et al.*, 2020). Sustainable agricultural management practices should be evaluated at regional as well as field scale to understand their applicability and introduced in farmers' fields to improve WUE and production. This will be important to ensure food security and fulfill the increasing demand for food, fibre and fuel while properly managing availa-

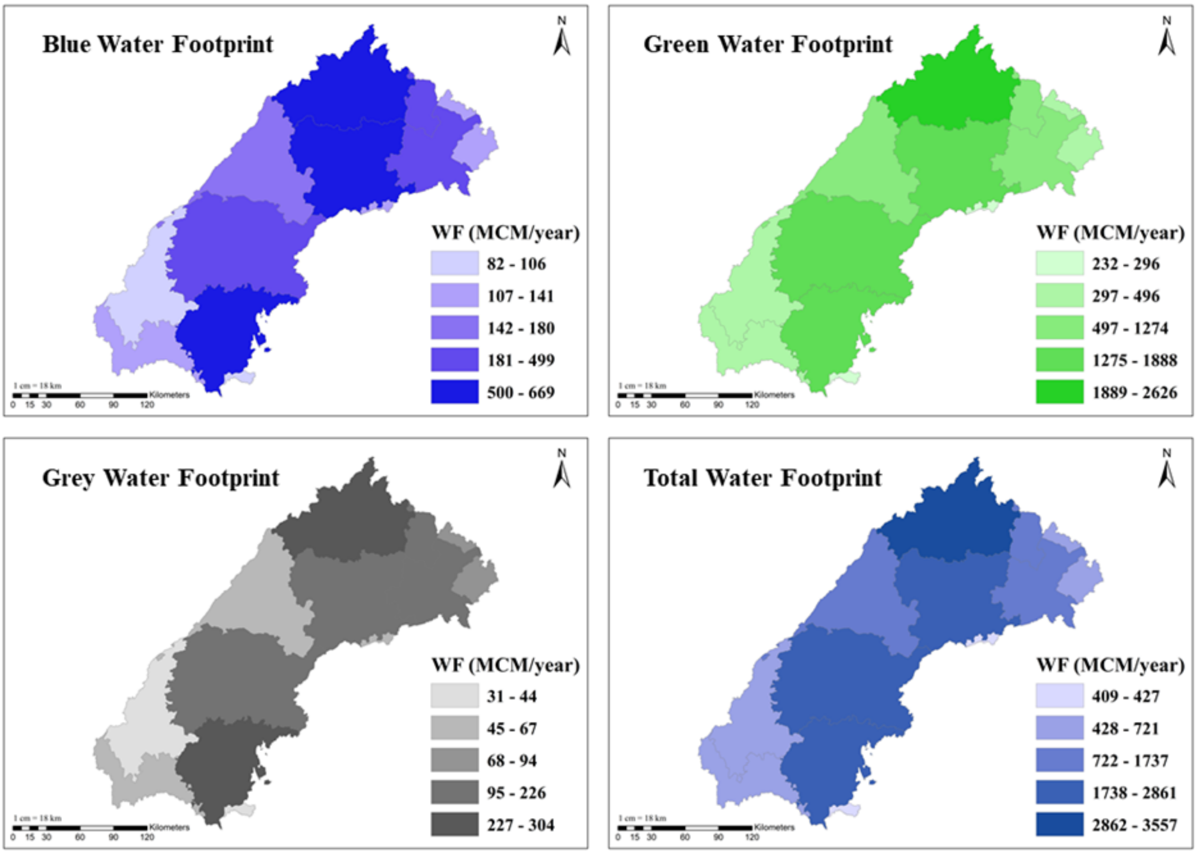

Fig. 6. *Spatial variation of blue, green, grey and total water footprint in Banas river Basin of Rajasthan*

ble water resources.

Conclusion

The average water footprints of bajra, barley, groundnut, jowar/sorghum, maize, rapeseed & mustard, rice/paddy, sesame, soybean crops in the Banas basin of Rajasthan were higher than the global averages due to lower yield and climatic variation. The water footprint of crop production in the basin was 19254.5 MCM/yr. Wheat, bajra, maize, rapeseed, and mustard make up 67.4 % of the total average annual water footprint of crop production. The blue water footprint of crop production was 3942.1 MCM/yr, with wheat, rapeseed, and mustard accounting for almost 87.0 % of the average annual blue water footprint. The larger WF is directly linked to the cultivated area and production of the crop in the basin. Promoting practices like mulching and micro-irrigation is necessary to reduce water footprint. Assessing water footprint can help to formulate suitable actions for improving water productivity and promoting sustainable water use to reduce water scarcity in the region.

ACKNOWLEDGEMENTS

The author will like to acknowledge receipt of financial assistance from the Indian Council of Agricultural Research in the form of a Senior Research Fellowship (ICAR-SRF) for pursuing Ph.D. programme.

Conflict of interest
The authors declare that they have no conflict of interest.

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