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Blue Water Scarcity Assessment in Banas River Basin using Water Footprint Approach

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ABSTRACT

In order to increase water availability, improve water quality, and ensure long-term sustainability, river basin-scale planning and management of water resources is crucial. Using the blue water scarcity index and the water footprint concept, this study assesses blue water scarcity in the Banas river basin from 2008 to 2020. Banas basin experiences considerable scarcity, with the value of the average annual blue water scarcity index being 140.9% which can be characterized as moderate. Banas river basin typically experiences significant blue water scarcity for three months of the year (November, December and January). Compared to these months, it is low for three months (August, September, and October), moderate for four (April, May, June, and July), and significant for two months of the year (February and March). Farmers in the basin should adopt improved water management practices to ensure sustainability and address water scarcity issues. This study can provide a framework for policy to solve some policy and water management-related issues in the basin. It can also help with more effective water resource allocation and utilization.

Key words: *Water Footprint, Water scarcity, Water footprint reduction, Sustainable agriculture and Crop water use.*

Introduction

The Earth's water supplies and arable land areas are under tremendous stress due to the increased global demand for food production. Water accounting has become a standard procedure for many countries and industries due to global water scarcity and shortages (Hoekstra *et al.*, 2009; Hoekstra, 2017). Water accounting estimates the amount of water being utilized and compares it with the available water. Water resource use and availability estimates help evaluate water scarcity at various scales and are the sole focus of study on basin-level water management in many regions worldwide. Total water withdrawal for multiple purposes (e.g. agricultural, domestic, industrial) conventionally act as an indicator of total freshwater use, but this is not the best indicator of water use at the basin scale as these withdrawals return into the catchment partially (Perry, 2007).

Water footprint (WF) is an important indicator that helps ascertain water's direct and indirect use in any process (Hoekstra and Chapagain, 2007; Hoekstra *et al.*, 2009). WF modelling in agriculture enables us to pinpoint the impacts and limitations of the current crop production system (Hoekstra *et al.*, 2011). WFs had been quantified at high spatial and temporal resolution (Mekonnen and Hoekstra, 2011, 2014; Hoekstra and Mekonnen, 2012). Mitigating water scarcity has become a major concern globally, and numerous studies have been conducted on it(Wada *et al.*, 2014; Kummu *et al.*, 2016; Liu *et al.*, 2017). Nearly two-thirds of the world population currently faces water scarcity for at least one month per year (Mekonnen and Hoekstra, 2015; Vanham and Mekonnen, 2021). The agriculture sector is responsible for 92% of the total WF of humanity (Mekonnen and Hoekstra, 2010). Numerous studies have concluded that WF can be reduced by adopting strategies, methods and technologies to reduce non-beneficial consumptive water use (Jovanovic *et al.,* 2020). Water security is essential for social and economic development, enhancing health, well-being, and economic progress, particularly in developing countries (Mekonnen and Hoekstra, 2013). This study deals with the assessment of blue water scarcity in the Banas river basin during 2008-2020 by using the blue water scarcity index and water footprint concept.

Materials and Methods

Study area

The Banas River originates in the Aravalli Range's Khamnor Hills, near Kumbhalgarh in Rajsamand. It is a tributary of the Chambal River with a length of about 512 kilometres. 'Van Ki Asha' is another name for it (Hope of the forest). In Rajasthan, there is another river called Banas, which flows in a western direction and is also known as the West Banas River. Although it is a seasonal river that dries up in the summer, it is still used for irrigation. The Government of Rajasthan completed the Bisalpur-Jaipur project in 2009, which provides drinking water from the Banas to Jaipur city. Banas river basin lies between 24°15'-27°20' latitudes and 73°25'-77°00' longitudes (Figure 1). It has a catchment area of 47,060 km^2 (4.7 Mha) within Rajasthan (WRD, 2014).

Water footprint assessment

According to the Water Footprint Network's guidelines, water footprint was calculated spatially over the study period using the AquaCrop model (Hoekstra *et al.,* 2011). AquaCrop model 6.0's plug-in version was utilized in the study to evaluate crop WF over the basins because of its adaptability and simplicity of use for numerous simulations (Raes *et al.,* 2018). To account for regional variations while

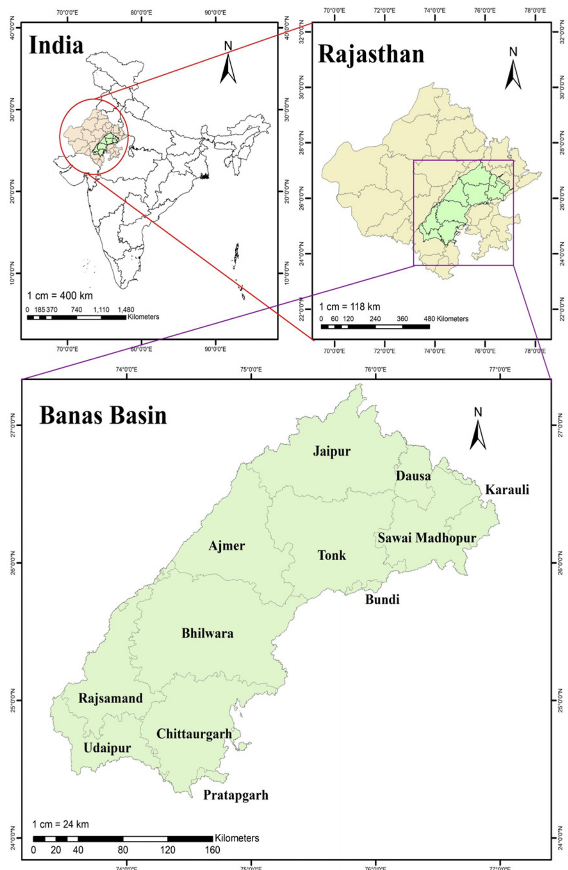

Fig. 1. Map of Study Area

minimizing the number of simulations needed, the basin area was separated into homogenous land units based on land use, soil, and agro-climatological characteristics (Mali *et al.,* 2017, 2019). Data from the Agriculture Statistics Handbook, Directorate of Economics and Statistics, Department of Planning, Government of Rajasthan, was used in this study (https://agriculture.rajasthan.gov.in/). District level datasets of annual statistics related to production, productivity, cultivated and irrigated area under various crops during 2008-2020 for the districts falling under the Banas basin was obtained. The crop WF was multiplied by production data for the crop to determine the water footprint of crop production (blue, green, and grey), which is displayed in million cubic metres annually.

Blue water scarcity assessment

Sustainability assessment is performed based on estimates of WFs and water availability. The sustainability of blue WF was assessed using the

Blue Water Scarcity Index (BWSI) monthly. The blue water scarcity index is defined as the ratio of the blue WF to the blue water availability during that period, expressed as a percentage (Hoekstra *et al.*, 2012). Natural runoff is defined as the sum of actual runoff and the total blue WF within the river basin. From the total withdrawal of other sectors, 10 % was taken as blue consumptive water use (Mali, 2014; Nouri *et al.*, 2019). Environmental flow requirements of the basin were estimated using the Variable Flow Method (Pastor *et al.*, 2013). This was done as a consideration of the natural variability of river flow. The blue water scarcity index is given as follows,

$$BWSI = \frac{WF_{blue}}{WA_{blue}} \quad .. (1)$$

$$WA_{blue} = R_{nat} \quad .. (2)$$

Where,

BWSI : Blue water scarcity index (%)
WF_{blue} : Total blue WF (MCM per month)
WA_{blue} : Water availability (MCM per month)
R_{nat} : Natural runoff (MCM per month)
EFR : Environmental flow requirements

Table 1. Classification of blue water scarcity index (Hoekstra *et al.*, 2012)

BWSI (%)	Water scarcity levels
<100 %	Low
100-150 %	Moderate
150-200 %	Significant
>200 %	Severe

Results and Discussion

The monthly blue water scarcity of the Banas river basin was assessed by comparing the total blue WF to the sustainable blue water availability during a month. The monthly blue WF of crops was assessed using the Aqua Crop-OS model. A safety margin of 20% of the blue water WF of crops was included to account for additional losses and the rest of cropped area. Blue WF of other sectors, namely (domestic, industries and livestock etc.) were considered. Of the total water demand of the other sectors, 10 % was taken as blue consumptive water use (Mali, 2014; Nouri *et al.*, 2019). Monthly runoff was determined based on the SCS curve number method. The monthly WF for all crops from 2008 to 2020 was compared with the calculated blue water availability in the basin to assess the blue water scarcity. Monthly values of BWSI, WF_{blue}, WA_{blue} and actual runoff in the Banas basin in a year are presented in Figure 2. On average, the Banas river basin faces severe blue water scarcity in three months of the year (November, December and January). In comparison, it is low for the three months (August, September and October), moderate for four months (April, May, June and July) and significant for two months in a year (February and March). Typically, runoff availability remains high from July through October due to high rainfall during the monsoon period. During this period, crops meet a significant portion of their water requirement from rainfall (WF green). Blue WF remains higher from January to March and November to December than in the other months because this is the period of scanty rainfall, and crop water requirements are met through irrigation.

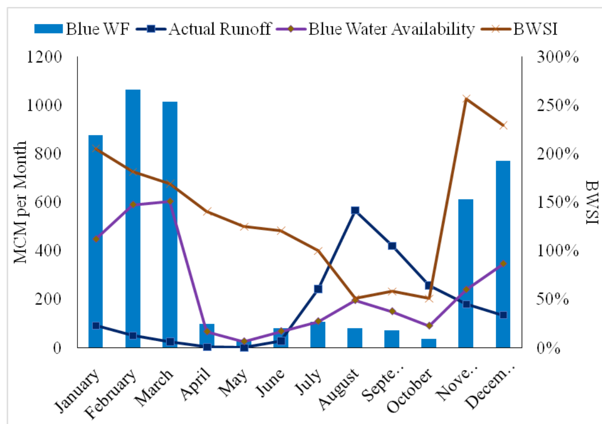

Fig. 2. Monthly BWSI, WF_{blue}, WA_{blue} and actual runoff in Banas basin in a year

Annual BWSI, WF_{blue}, WA_{blue} and actual runoff in the Banas basin during the years 2008-2020 are presented in Figure 3. The average annual value of BWSI during the study was 140.9 %. The lowest value of annual BWSI was 114.2 % in 2019, and the highest was 171.7 % in 2015. Annual runoff was highest in 2019, which could be the reason for lower BWSI. However, 2009 had a lower annual runoff than 2015, but WF_{blue} was higher, resulting in lower BWSI. Annually, moderate blue water scarcity was observed in the ten years and significant scarcity in the three years of the study period. During the study period, the Banas basin faced severe blue water scarcity in 35 months, significant scarcity in 35 months, moderate scarcity in 40 months and low scarcity in 46 months.

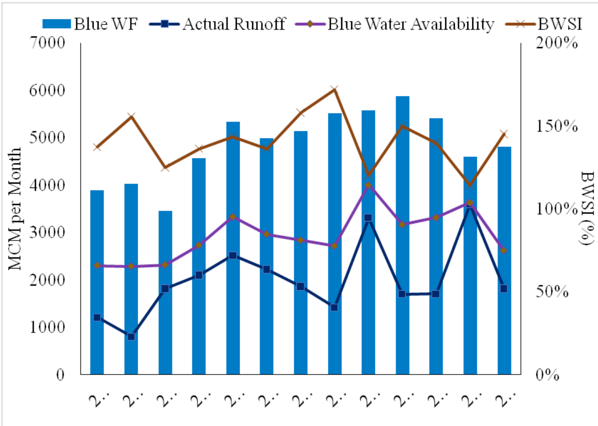

Fig. 3. BWSI, WF_{blue}, WA_{blue} and actual runoff in Banas during the years 2008-2020

The results of this study provide helpful insights into the current situation in the basin. Appropriate measures are required to develop adaptation approaches to overcome water scarcity challenges in the basin. Sustainability and blue water scarcity (BWS)assessment within the Heihe River Basin (HRB) in northwest China, found that the average annual BWS in HRB was 154 %(Zeng *et al.,* 2012). Based on this, they concluded that human activities significantly modified runoff in the HRB. Mali (2014) evaluated water scarcity and sustainability of the Gomti and Betwa basins using BWSI. Results of the study showed that BWSI and WPI were within acceptable limits in the Gomti basin, and the WF was sustainable. While they exceeded permissible limits in the Betwa basin for five and two months in a year, indicating unsustainable water use. High WF was observed from January to March and October to November compared to the other months because of the insufficient rainfall, and crop water requirements are majorly met through irrigation. In a study of the inter and intra-annual variation and blue water scarcity in the Yellow River basin (YRB) from 1961 to 2009 (Zhuo *et al.,* 2016). Annually, the blue WF generally peaked in (May-July, nearly two months earlier than the start of rainfall season and the occurrence of natural runoff in July-September. The study depicts that the basin experiences moderate to severe blue water scarcity for seven months in a year during the period of January-July, from which approximately five months have severe blue water scarcity (March-July). These results are in line with the results of this study and can be used as baseline information for further research.To ensure the sustainability of WF in the basins, the farmers should adopt the optimal cropping pattern, better irrigation practices, rainwater harvesting and improved water management.

Conclusion

There is grave concern about sustainability, especially during the times when the blue WF exceeds blue water availability and environmental flow requirement are not met. The average annual blue water scarcity in the Banas basin can be characterized as moderate (140.9 %). On average, the Banas river basin faces severe blue water scarcity in 3 months of the year (November, December and January). In comparison, it is low for three months (August, September and October), moderate for four months (April, May, June and July) and significant for two months in a year (February and March). Assessment of blue water scarcity can assist in planning appropriate measures to overcome water scarcity challenges and reduce the water footprint in the basin.

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