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Assessment of Rice Water Footprint in the Kashmir Valley

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ABSTRACT

Rice is a key crop in the Kashmir valley and it needs a lot of water during production, so managing water well is crucial for lasting sustainability. This study evaluated the water footprint of rice in Kashmir from 2010 to 2023 by separately assessing the green, blue, and grey water footprint components. The water footprint was measured using standard methods based on climate, crop, and yield data. The results indicated that the total water footprint of rice varies from 2868.32 to 8768.08 m^3 per ton, with an average of 3592.28 m^3 per ton. The blue water footprint contributed the largest part, making up 49.72% of the total. This was followed by green water at 35.27% and grey water at 15.00%. An especially high water footprint was observed in the year 2014, mainly because severe flooding caused big drops in yield, leading to higher water footprint values. The results emphasize how much climate changes and crop performance affect rice water footprints and also provide a useful basis for improving water efficiency and supporting sustainable rice farming in the Kashmir valley.

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INTRODUCTION

All life on Earth depends on water to survive. It is essential for maintaining ecosystem balance, guaranteeing food security and promoting social and economic wellbeing. Therefore, achieving sustainability needs to find a balance between water supply and demand (Pandya and Sharma, 2022). Growing international trade in water-intensive commodities is driving freshwater's transformation into a global resource. Water-intensive products like agricultural and livestock products, natural fibres and bioenergy have international markets in addition to regional ones. As a result, customers and water resource utilization are now spatially separated.

Rice farming takes up over 11% of the world's arable land and consumes almost one-third of global freshwater resources (World Water Assessment Programme [WWAP], 2021). Globally, 148 million hectares of land are used to grow rice, the staple food crop. Asia makes up almost 90% of the total, with smaller contributions from North and South America, Africa, Australia and Europe. Rice is the most important cereal in India and accounts for more than 43% of the nation's yearly food grain production. It supplies 65% of the population with food and calories. From Kashmir in the north to Kanyakumari in the south, Gujarat in the west to Arunachal Pradesh in the east, the crop is cultivated in a variety of soil types, terrain types, climates, and hydrological conditions (Rao et al., 2009). In comparison to other Indian states, rice cultivation in Jammu and Kashmir (J&K) is mostly a monocropped activity with a very high consumption and an important staple food. Both regions share the area under rice, with the Jammu division accounting for around 40% of production and the Kashmir division for 60%. Although the state's rice productivity is high at 3.1 t/ha compared to the national average of roughly 2.0 t/ha, J&K's rice-growing area has been steadily declining over time (CSAP of J&K, 2015; Kaloo et al., 2014). With population forecasts of 9.7 billion people by 2050 and rising per capita rice consumption in developing countries (FAO, 2021), understanding rice water flow dynamics is critical for sustainable water management.

The water footprint concept, developed by Hoekstra and Chapagain, has proven useful in quantifying agricultural water use through its three components: blue water (surface and groundwater for irrigation), green water (rainwater utilization), and grey water (pollution assimilation). Since Hoekstra introduced the "water footprint" concept in 2002, there has been an increase in interest in the idea of taking water use along supply chains into account (Hoekstra, 2003). The water footprint is a measure of freshwater consumption that considers both a producer's or consumer's direct and indirect water use. In addition to the conventional and limited measure of water extraction, the water footprint can be considered a comprehensive indicator of the utilization of freshwater resources. A product's water footprint is the amount of freshwater consumed throughout its entire supply chain. According to Hoekstra and Chapagain (2007), it is possible to measure the impact of trade and consumption on

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the usage of water resources as well as comprehend the global nature of freshwater by visualizing the hidden water use behind products. The increased knowledge may serve as a foundation for better freshwater resource management worldwide. Previous water footprint studies on rice have largely focused on national or regional scales, often masking local variability in climate, management and productivity. In this context, the present study undertakes a long-term assessment of rice water footprint in the Kashmir Valley, by quantifying the water footprint for the period 2010–2023, with separate estimation of the blue, green, and grey water footprint components. The study evaluates temporal variability and the relationships between water footprint components and key climatic and agronomic drivers such as rainfall, reference evapotranspiration and crop yield. The results are expected to contribute to a better understanding of water use efficiency and sustainability of rice production in the valley under ongoing climatic and management changes.

MATERIALS AND METHODS

Study area

Kashmir valley, the largest valley in Jammu and Kashmir Union Territory, is surrounded by the Pir-Panjal range (South-West) and the Greater Himalayas (North-East). Kashmir Valley is drained by the Jhelum River, which originates from a perennial spring known as Verinag, and stretches up to 725 km (450 miles) (Fig. 1). The total area of Kashmir Valley is 15,948 km2 with an average elevation of about 1730 m above the mean sea level. The valley of Kashmir is positioned between latitude 320 and 340 N and longitude 740 and 750 E (Parvaze et al., 2017).

Kashmir valley has a temperate climate due to its unique geographical setting, characterized by cold, wet winters and warm, dry summers. Climate of the valley is mainly governed by the elevation and amount of rainfall with temperatures varying from -90C in the months of winter to 380C in summer. ned images and drone acquired images are given in Table 1.

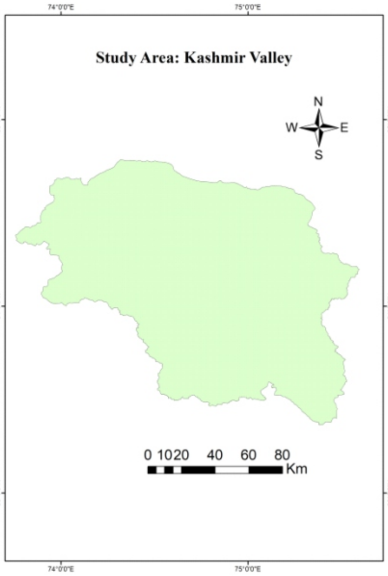

Fig. 1: Study area map of Kashmir valley

Data Requirements

The data required to carry out the assessment included the meteorological data, crop data and soil data as illustrated in table 1. The data was acquired for a period of 2010 – 2023 and was used as an input for the CROPWAT software.

Table 1: Data used for the study

Meteorological data	• Maximum temperature (oC) • Minimum temperature (oC) • Relative humidity (%) • Sunshine hours (hours) • Precipitation (mm) • Wind speed (m/s)
Crop	• Date of sowing • Crop coefficient (Kc) • Rooting depth (m) • Crop Yield
Soil	• Textural class • Field capacity (%) • Initial soil moisture condition • Initial available soil moisture (mm/m) • Average fertilizer application rate

Water footprint assessment

CROPWAT 8.0 (Crop Water and Irrigation Requirements Program) was used for the estimation of the reference evapotranspiration (ET_0). CROPWAT 8.0 is a decision support tool developed by the Land and Water Development Division of Food and Agricultural Organization (FAO), and has commonly been used in water footprint studies (Mekonnen and Hoekstra, 2011; Zhuo *et al*., 2016). Estimates of crop water and irrigation requirements was made based on soil, climate, crop and irrigation management data, and calculations were based on FAO Irrigation and Drainage Series No. 56 (Allen *et al*., 1998). The CROPWAT model estimated ET_0 over the cropping season using the Penman-Monteith equation. The crop evapotranspiration (ET_c) was then calculated from the reference evapotranspiration (ET_0) using the crop coefficient (K_c) as:

$$ET_c = ET_0 \times K_c$$

The WF assessments accounted for blue, green and grey water use by the rice cultivated within the study area. The three components of the crop water footprint: green (WF_{green}), blue (WF_{blue}), and grey (WF_{grey}) were estimated following the approach proposed by Hoekstra *et al.* (2011). The green water footprint (WF_{green}) represents the volume of rainwater stored in the soil and consumed by the crop through evapotranspiration, blue water footprint (WF_{blue}) refers to the volume of surface and groundwater used for irrigation and the grey water footprint (WF_{grey}) indicates the volume of freshwater required to assimilate pollutants resulted from fertilizer application to meet acceptable water quality standards. The total water footprint (WF_{total}) is the sum of these three components and expressed in cubic meters per tonne of rice produced ($m^3 t^{-1}$).

The green and blue components of a crop's WF in m^3/ton are calculated as follows:

$$\text{WF}_{\text{green}} = \frac{CWUgreen}{Y} = \frac{10 \times \sum_{d=1}^{lgp} ETgreen}{Y}$$

$$\text{WF}_{\text{blue}} = \frac{CWUblue}{Y} = \frac{10 \times \sum_{d=1}^{lgp} ETblue}{Y}$$

where, $\text{CWU}_{\text{green}}$ and CWU_{blue} represents the crop's green and blue water use measured in m^3/ha, respectively, ET_{green} and ET_{blue} is the crop's total green and blue water evapotranspiration, respectively, which is estimated with CROPWAT and Y is crop yield in tons/ha. The crop´s ET_{green} and ET_{blue} is multiplied by 10 in order to transform each crop's green and blue water use to m^3/ha. The summation is done over the period from the day of planting (day 1) to the day of harvest (lgp stands for length of growing period in days).

Green water evapotranspiration (ET_{green}), can be equated with the minimum of total crop evapotranspiration (ET_c) and effective rainfall (P_{eff}). Blue water evapotranspiration (ET_{blue}), in other words, field-evapotranspiration of irrigation water, is equal to the total crop evapotranspiration minus effective rainfall (P_{eff}), but zero when effective rainfall exceeds crop evapotranspiration.

$$\text{ET}_{\text{green}} = \min(\text{ET}_c, \text{P}_{\text{eff}})$$

$$\text{ET}_{\text{blue}} = \max(0, \text{ET}_c - \text{P}_{\text{eff}})$$

The grey WF, on the other hand, is estimated as follows:

$$\text{WF}_{\text{grey}} = \frac{(\alpha \times AR)/(Cmax - Cnat)}{Y}$$

Where,

AR is the chemical application rate to the field per hectare (kg/ha),

α indicates the leaching-run-off fraction,

C_{max} is the maximum acceptable concentration (kg/m^3),

C_{nat} represents the natural concentration for the pollutant considered (kg/m^3) and

Y is the crop yield (ton/ha).

RESULTS AND DISCUSSION

The assessment of the water footprint of rice in the Kashmir Valley for the period 2010–2023 revealed interannual variability in both total and component-wise water footprints (Table 2 & Fig. 2).With a long-term average of 3592.28 m^3 ton^{-1}, the total water footprint varied from 2868.32 m^3 ton^{-1} in 2015 to 8768.08 m^3 ton^{-1} in 2014 (Table 2). Over the course of the study, yield changes, irrigation requirements, and weather conditions all contributed to this variability.

Table 2: Year-wise Water Footprint Values for Rice in Kashmir

Year	Green Water Footprint (m^3/ton)	Blue Water Footprint (m^3/ton)	Grey Water Footprint (m^3/ton)	Total Water Footprint (m^3/ton)
2010	1559.634	1247.002	534.8962	3341.533
2011	1011.120	2035.863	520.8738	3567.858
2012	1159.016	1813.167	522.0825	3494.266
2013	1127.840	1622.061	482.0565	3231.958
2014	3674.373	3791.991	1301.718	8768.082
2015	1429.754	982.1511	456.4137	2868.319
2016	660.8436	1975.536	455.7451	3092.125
2017	865.6948	1918.701	481.3443	3265.740
2018	1034.026	1509.548	454.8657	2998.439
2019	1120.197	1481.613	456.3860	3058.196
2020	816.1049	1970.110	471.9768	3258.192
2021	1080.649	1689.452	475.6990	3245.800
2022	1218.903	1324.314	472.3228	3015.540
2023	982.2482	1645.271	458.3661	3085.886
Average	1267.172	1786.199	538.9105	3592.281

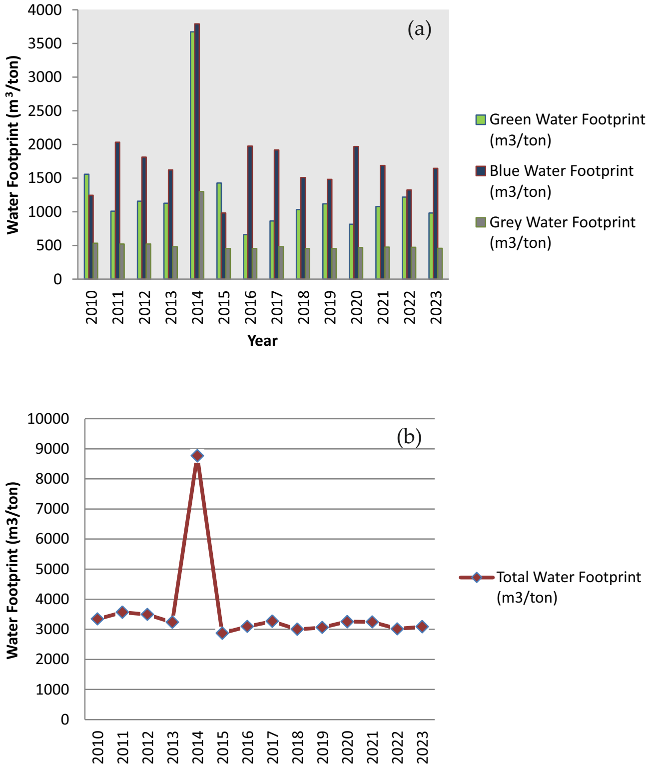

Fig. 2 : (a) Component wise water footprint over the study period and (b) Total water footprint over the study period

The blue water footprint made up the biggest portion of the total water footprint (49.72%), followed by the green water footprint (35.27%) and the grey water footprint (15.00%), (Table 3 and Figure 3). Even though the area receives a lot of precipitation throughout the growing season, the predominance of the blue water component suggests that rice farming in the Kashmir Valley is heavily dependent on irrigation water. This emphasizes how crucial controlled irrigation is to maintaining rice output, especially when rainfall distribution is uneven.

Table 3: Percentage contribution of the water footprint components to total water footprint

Water Footprint Component	Percentage Contribution (%)
Green Water Footprint	35.27485
Blue Water Footprint	49.72324
Grey Water Footprint	15.0019

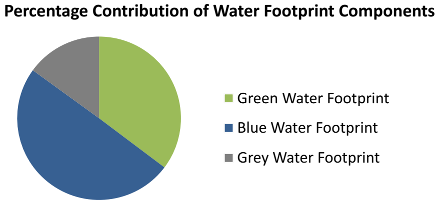

Fig. 3: Percentage contribution of the water footprint components to total water footprint

The green water footprint showed wide year-to-year variation, ranging from 660.84 m³ ton⁻¹ in 2016 to 3674.37 m³ ton⁻¹ in 2014. These fluctuations are largely attributable to variability in effective rainfall and crop water use efficiency across years. The blue water footprint also exhibited significant variation, with values between 982.15 m³ ton⁻¹ and 3791.99 m³ ton⁻¹, reflecting changes in irrigation demand under varying climatic and agronomic conditions. In contrast, the grey water footprint remained comparatively stable throughout the study period.

The year 2014 saw a noticeably high overall water footprint, mostly as a result of the devastating floods that affected most of the Kashmir Valley. Even though there was plenty of water available this year, the floods severely damaged standing rice crops, which resulted in a sharp decline in yield. The dramatic drop in yield led to disproportionately large green, blue, and grey water footprint values since water footprint values are expressed per unit of production. This result highlights how sensitive water footprint indicators are to extreme weather events, since yield losses can greatly inflate estimates of water footprints even in years with enough crop water.

Overall, the results emphasize that improving water use efficiency, stabilizing yields and adopting balanced nutrient management practices are key pathways for reducing both consumptive water use and pollution related water footprints in Kashmir Valley. The observed interannual variability highlights the necessity of evaluating water footprint results in conjunction with climate anomalies and yield performance, especially the extreme values recorded during flood-affected years. These long-term evaluations offer insightful information about the sustainability of rice production systems and can help develop strategies for water management and adaptation to changing climate conditions.

Recommendations

- Promote agronomic practices that enhance yield stability to reduce water footprint per unit production
- Encourage efficient irrigation scheduling during low-rainfall years
- Improve nutrient management to further reduce grey water footprint
- Incorporate water footprint indicators into regional agricultural water planning

CONCLUSION

The current study assessed the water footprint of rice cultivation in the Kashmir valley, India, over a long-term period from 2010 to 2023. It separately measured the green, blue, and grey water footprint components. The results showed variations in the total water footprint of rice each year, which highlights how water use changes in the regions rice production system. On average, the total water footprint of rice in the Kashmir Valley was estimated at 3592.28 m³ ton⁻¹.

The blue water footprint made up the largest share at 49.72%, followed by the green water footprint at 35.27% and the grey water footprint at 15.00%. The large portion of the blue water component indicates a strong reliance on irrigation water. The green water footprint varied year to year, reflecting changes in effective rainfall. An unusually high water footprint occurred in 2014, mainly due to severe flooding in the Kashmir Valley, which caused significant yield reductions. This resulted in higher water footprint values across all components, showing how sensitive water footprint indicators are to extreme weather events and yield fluctuations. Overall, the findings emphasize that both weather variability and crop productivity are crucial in determining the water footprint of rice cultivation in the region.

This long-term assessment gives a clear understanding of rice water use patterns in the Kashmir valley and provides a solid baseline for evaluating the sustainability of rice production systems.

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