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***Research Paper***


# Blue and green water footprint assessment of rice crop in high altitude temperate zone of Kashmir, India


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## ABSTRACT

The water footprint (WF) for rice has been calculated from 2010 to 2022 for three different districts viz Anantnag, Budgam and Baramulla representing three different climatic regions of Kashmir valley. CROPWAT 8.0 model was used to calculate effective rainfall, reference evapotranspiration (ETo), crop evapotranspiration (ETc), and thereby the green and blue water footprint of rice was determined. $ET_0$ was 117-133 mm in Budgam district, 100-112 mm in Baramulla district and 143-155 mm in Anantnag district. $ET_c$ in Budgam was found in the range of 136-149 $m^3ha^{-1}$, in Baramulla district it was found in the range of 115-140 $m^3ha^{-1}$ and in Anantnag district it was highest of the three districts ranging from 163-178 $m^3ha^{-1}$. The results showed that the WF was the highest (3444 l $kg^{-1}$) in Baramulla district followed by 2300 l $kg^{-1}$ in Anantnag and 2003 l $kg^{-1}$ in Budgam districts. The share of green and blue components of WF ($WF_{green}$ and $WF_{blue}$) also varied with the locations and in years. $WF_{green}$ and $WF_{blue}$ contributed more or less equally in Baramulla district, 68% and 32% respectively in Budgam district and 60% and 40 % in Anantnag districts respectively.



***Keyword:*** Green water footprint, blue water footprint, Rice cultivation, Evapotranspiration, Crop water usage, Effective rainfall


Rapid economic development has spurred industrial and agricultural expansion, prompting a focus on quantifying environmental impacts and implementing mitigation strategies especially for water resources. Resource-based consumption accounting is crucial for assessing limitations, with water footprint (WF) offering a method to quantify water use. WF analysis elucidates the connection between productive activities and the mounting pressure on water resources embedded in products and services, facilitating informed decision-making for sustainable management. (Romaguera *et al.,* 2010). The total amount of freshwater used during production across the whole supply chain is the product's "water footprint". (Mekonnen and Hoekstra, 2010)blue and grey water footprint of wheat in a spatially-explicit way, both from a production and consumption perspective. The assessment is global and improves upon earlier research by taking a high-resolution approach, estimating the water footprint of the crop at a 5 by 5 arc minute grid. We have used a grid-based dynamic water balance model to calculate crop water use over time, with a time step of one day. The model takes into account the daily soil water balance and climatic conditions for each grid cell. In addition, the water pollution associated with the use of nitrogen fertilizer in wheat production is estimated for each grid cell. We have used the water footprint and virtual water flow assessment framework as in the guideline of the Water Footprint Network. The global wheat production in the period 1996-2005 required about 108 billion cubic meters of water per year. The major portion of this water (70%. Water footprints include green (rainwater used), blue (surface or groundwater consumed for irrigation), and grey (water needed to absorb contaminants) footprints. Green and blue footprints contribute to consumptive water use, while grey footprint signifies water degradation. The sum of these footprints offers insight into a crop's overall water usage and its associated environmental and economic impacts. (Chapagain and Hoekstra, 2010). Wheat, the largest staple crop, had a water footprint of 1087 Gm3 year$^{-1}$, followed by rice at 992 Gm3 year$^{-1}$ and maize at 770 Gm3 year$^{-1}$ among cereal crops (Zhuo *et al.,* 2016). In India, rice is an essential food crop as it feeds morethan 60% of its population. The area under rice has increased 143%, *i.e.***,** from 30.8 million hectares in 1950-51 to 43.8 million hectares during 2017-18, and its production has increased from 20.6 million tons in 1950-51 to 112.8 million tons during 2017-18, an increase of about 5.5 times


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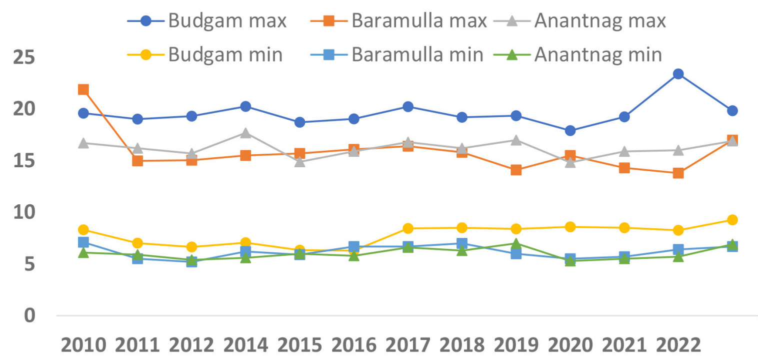


**Fig. 1:** Maximum and minimum temperature ($^0$C) in three districts (Budgam, Baramulla and Anantnag) of Kashmir during 2010-2022

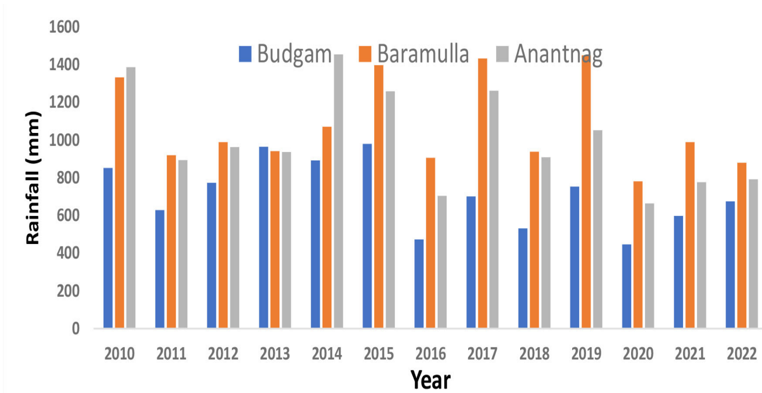


**Fig. 2:** Annual rainfall (mm) in three districts (Budgam, Baramulla and Anantnag) of Kashmir during 2010-2022

(Sidhu *et al.,* 2021). Compared to other Indian states, Jammu and Kashmir produces most of its rice as a monocrop, which is a staple food with a high consumption. The area used for rice cultivation is split between the two areas; roughly 40% of the total area is in the Jammu division and 60% is in the Kashmir division. The state's population depends heavily on rice, despite the crop's relatively tiny area—just 0.27 million hectares—when compared to other Indian states (Kaloo *et al.,* 2014)

Over the past 40 years (1980–2019), Kashmir has experienced increasing annual minimum and maximum temperatures by 0.02 and 0.017 °C year$^{-1}$ respectively, across all elevation zones. Conversely, annual precipitation has decreased by 5.01 mm year$^{-1}$, particularly affecting groundwater recharge and water supply, posing risks to crop cultivation in the Kashmir valley (Ahmad ***et al.,*** 2017)wheat, maize and pulses. Reference evapotranspiration was estimated by Penmen-Monteith method using standard meteorological data for a period of four years (2012-2015. In view of this, an attempt has been made to assess the water footprints of rice high altitude regions of Kashmir, India.

## MATERIALS AND METHODS

For the present study, three different stations Budgam (lat. 34.2°N, long.74.64°E and altitude 1593 m amsl), Baramulla (lat. 33.93°N, long.75.14°E and altitude 1610 m amsl) and Anantnag (lat. 33.73°N, long.74.34°E and altitude 1600 m amsl) respectively representing the Central, North and South zones of high-altitude regions of Kashmir were selected. The daily weather parameters viz maximum temperature, minimum temperature, rainfall, humidity and wind speed for the years 2010 to 2022 required for the study was procured from the Indian Metrological Department, Srinagar. The data related to the rice production in these areas was obtained from the Department of Agricultural Sciences, Sher-e- Kashmir University of Agricultural Sciences and Technology, Srinagar. The rice seeds are sown in the month of April. It can vary from 1 April to 30 April depending on the weather conditions. The plantation of rice takes place from 3rd week of May to 3rd week of June. The harvesting of rice is usually done in the month of September depending upon the day of planting and the weather conditions. The last stage involves separation of rice grain from the straw, also called as thrashing of rice and it is done in the month of October (may last to November sometimes). The length of growing period days varies from 130 to 145 days. The rice is sown in Spring season and is harvested in the Autumn season. It takes the whole summer season to develop, grow and mature. It is a kharif crop that is sown in Spring and harvested in Autumn.

The CROPWAT 8.0 software, the FAO-56-PM model (Allen et al., 1998) was used to calculate the reference evapotranspiration ($ET_0$); The $K_c$ value for initial stage, mid-season stage and the end stage has been taken as 1.15, 1.18, and 0.96 respectively for rice crop (Ahmad *et al.,* 2017)wheat, maize and pulses. Reference evapotranspiration was estimated by Penmen-Monteith method using standard meteorological data for a period of four years (2012-2015. $ET_o$ does not represent the properties of the soil or the crop; rather, it represents the evaporating power of the weather at a particular location and time of year (Sidhu *et al.,* 2021)

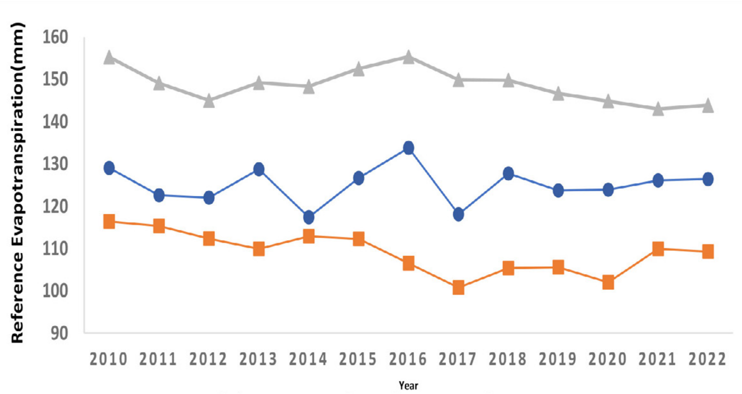


**Fig 3:** ETo (mm) in three districts (Budgam, Baramulla and Anantnag) of Kashmir during 2010-2022

**Table 1:** Effective rainfall ($P_{eff}$, $m^3 ha^{-1}$), crop evapotranspiration ($ET_c$, $m^3 ha^{-1}$) and irrigation required (IWR, $m^3 ha^{-1}$) in different districts during 2010-2022

| Year | Budgam | | | Baramulla | | | Anantnag | | |
|---|---|---|---|---|---|---|---|---|---|
| | $P_{eff}$ | $ET_c$ | IWR | $P_{eff}$ | $ET_c$ | IWR | $P_{eff}$ | $ET_c$ | IWR |
| 2010 | 148.4 | 149.7 | 55.4 | 232.9 | 140.9 | 6.1 | 268.4 | 178.6 | 13.4 |
| 2011 | 296.2 | 141.1 | 3.8 | 262.3 | 130.4 | 3.7 | 391.4 | 168.5 | 10.7 |
| 2012 | 187.0 | 144.0 | 35.9 | 264.4 | 128.1 | 1.7 | 313.4 | 166.8 | 23.9 |
| 2013 | 231.0 | 153.2 | 39.7 | 259.8 | 123.1 | 1.4 | 313.6 | 170.1 | 24.0 |
| 2014 | 215.9 | 136.2 | 53.5 | 231.0 | 129.9 | 5.1 | 275.1 | 169.1 | 53.0 |
| 2015 | 244.2 | 149.7 | 39.3 | 322.6 | 130.3 | 1.4 | 275.1 | 175.4 | 54.3 |
| 2016 | 88.6 | 155.3 | 86.3 | 193.3 | 122.5 | 4.5 | 149.4 | 177.1 | 70.9 |
| 2017 | 233.0 | 144.1 | 40.9 | 370.4 | 115.9 | 0.1 | 385.2 | 170.9 | 17.3 |
| 2018 | 158.4 | 149.5 | 64.2 | 179.4 | 122.3 | 1.4 | 221.7 | 170.8 | 51.0 |
| 2019 | 322.2 | 138.6 | 18.1 | 460.6 | 115.1 | 1.0 | 424.8 | 164.3 | 1.8 |
| 2020 | 189.3 | 142.5 | 47.9 | 280.0 | 116.3 | 1.6 | 210.3 | 166.6 | 38.7 |
| 2021 | 166.7 | 143.8 | 69.0 | 228.0 | 122.0 | 1.4 | 168.0 | 163.1 | 55.2 |
| 2022 | 244.8 | 144.1 | 26.6 | 230.0 | 123.5 | 2.4 | 176.7 | 165.5 | 28.6 |
| Mean | 209.6 | 145.5 | 41.8 | 270.3 | 210.0 | 2.4 | 274.8 | 169.7 | 34.0 |

The portion of the total rainfall that is held by the soil and may be used to satisfy crop water requirements is known as effective precipitation ($P_{eff}$). CROPWAT Model was used to calculate the $P_{eff}$. Due to rainfall in *kharif* season, Kashmir's average surface runoff factor is 15%, while deep percolation losses from rice fields are about 65% (Ahmad *et al.,* 2017)wheat, maize and pulses. Reference evapotranspiration was estimated by Penmen-Monteith method using standard mete orological data for a period of four years (2012-2015. The difference between the crop water requirement (CWR) and $P_{eff}$ was used to compute the irrigation requirement (IR). If $P_{eff}$ exceed the CWR, then there is no need for irrigation. Hence,

Green water evapotranspiration ($ET_{green}$) represents the minimum of actual evapotranspiration (ETc) and effective rainfall ($P_{eff}$). Blue water evapotranspiration ($ET_{blue}$) equals ETc minus $P_{eff}$, but it is zero when $P_{eff}$ exceeds $Et_c$. $ET_{green}$ and $ET_{blue}$ provide insights into water usage dynamics in agricultural systems.

The $WF_{blue}$ and $WF_{green}$ serve as indications of how much water the rice crop uses. The $WF_{grey}$, however, represents water quality. The calculation of the green and blue components of crop water usage (CWU, $m^3ha^{-1}$) involved accumulating daily ET (mm $day^{-1}$) during the growing season.

Where the evapotranspiration of blue water is represented by $ET_{blue}$, and that of green water by $ET_{green}$. The conversion of water depths in millimetres to water volumes per land surface in $m^3ha^{-1}$ was done by factor 10, where lgp is the growth period's duration in days.

The total WF is equal to the sum of Green WF, Blue WF and Grey WF (Hoekstra *et al.,* 2011). The formula for calculating the $WF_{green}$ in crop production is green component in crop water divided by crop yield and the $WF_{blue}$ is also calculated in the same way. The water footprints in forestry and agriculture are typically expressed as m3 $ton^{-1}$, or l $kg^{-1}$.

## RESULTS AND DISCUSSION

### *Fluctuations in the weather conditions*

During the rice-growing season in Kashmir (May-October), maximum temperatures typically range from 15°C-30°C, while minimum temperatures range between 10°C-20°C. Among the 3 zones South Kashmir, North Kashmir, and Central Kashmir—South Kashmir experiences relatively colder temperatures compared to the others, while Central Kashmir stands out as the hottest (Fig. 1).

**Table 2:** Water footprint of rice in Budgam, Baramulla and Anantnag districts

| Year | Budgam | | | | Baramulla | | | | Anantnag | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yield (kg ha$^{-1}$) | WFP (l kg$^{-1}$) | | | Yield (kg ha$^{-1}$) | WFP (l kg$^{-1}$) | | | Yield (kg ha$^{-1}$) | WFP (l kg$^{-1}$) | | |
| | | Green | Blue | Total | | Green | Blue | Total | | Green | Blue | Total |
| 2010 | 11.81 | 1265 | 10.9 | 1276 | 7.9 | 1750 | 144 | 1894 | 11.79 | 1478 | 743 | 2221 |
| 2011 | 8.71 | 1612 | 236 | 1848 | 8.10 | 1645 | 1664 | 3309 | 12.07 | 1404 | 1857 | 3261 |
| 2012 | 9.09 | 1600 | 477 | 2077 | 8.79 | 1464 | 1557 | 3021 | 9.16 | 853 | 1177 | 3030 |
| 2013 | 9.14 | 1702 | 866 | 2568 | 8.95 | 1447 | 1640 | 3087 | 12.56 | 1369 | 1155 | 2524 |
| 2014 | 12.71 | 1095 | 641 | 1736 | 8.80 | 1609 | 1252 | 2861 | 12.16 | 1399 | 877 | 2276 |
| 2015 | 12.27 | 1256 | 783 | 2039 | 10.65 | 1383 | 1935 | 3318 | 13.85 | 1299 | 740 | 2039 |
| 2016 | 10.77 | 850 | 1490 | 2340 | 8.15 | 1814 | 1048 | 2862 | 11.21 | 1379 | 255 | 1634 |
| 2017 | 11.23 | 1383 | 853 | 2236 | 12.52 | 1103 | 2423 | 4637 | 14.79 | 1171 | 1469 | 2640 |
| 2018 | 12.73 | 1428 | 79 | 1507 | 7.48 | 1956 | 913 | 2869 | 16.30 | 1191 | 355 | 1546 |
| 2019 | 16.96 | 918 | 1217 | 2135 | 11.93 | 1159 | 3478 | 4637 | 15.67 | 1173 | 1860 | 3033 |
| 2020 | 12.61 | 1276 | 419 | 1695 | 8.81 | 1585 | 223 | 3817 | 9.34 | 1369 | 359 | 1728 |
| 2021 | 10.12 | 1597 | 254 | 1851 | 6.51 | 2252 | 1956 | 4208 | 10.13 | 1918 | 57 | 1975 |
| 2022 | 10.23 | 1614 | 1121 | 2735 | 6.5 | 2280 | 1966 | 4246 | 10.54 | 1873 | 125 | 1998 |
| Mean | 11.4 | 1354 | 650 | 2003 | 8.9 | 1650 | 1554 | 3444 | 12.3 | 1375 | 848 | 2300 |

The highest amount of rainfall in Budgam district was in 980.5 mm in 2015 and lowest amount of rainfall in Budgam district was in 446.8 mm in 2020, similarly in Baramulla district the highest amount of was 1448.9 mm in 2019 and lowest amount was found in 879.3 in 2022 and in Anantnag district the highest amount of rainfall was 1454.5 mm in 2014 and lowest was found in 664.4 in 2020 (Fig. 2).

The reference evapotranspiration (ETo) as determined by using CROPWAT model for three districts shows distinct variation across the locations as well as over the years (Fig. 3). The ETo at Anantnag was always higher than those of Budgam and Baramulla while it was lowest in Baramulla district.

***Effective rainfall ($P_{eff}$), crop evapotranspiration ($ET_c$) and irrigation required (IWR)***

The effective rainfall, crop evapotranspiration and irrigation water requirement computed for three districts of Kashmir by CROPWAT model for 2010 to 2020 are presented in Table 1. In Budgam district the effective rainfall was 209.6 $m^3$ $ha^{-1}$ which varied between 88.6 $m^3$ $ha^{-1}$ to 322.2 $m^3$ $ha^{-1}$, crop evapotranspiration was 145.5 $m^3$ $ha^{-1}$ which varied between 136.2 to 155.3 $m^3$ $ha^{-1}$ as a result the irrigation requirement was 41.8 $m^3$ $ha^{-1}$ with variation of 3.8 to 86.3 $m^3$ $ha^{-1}$ during 2010-2020. In Baramulla district, the effective rainfall was generally higher than the crop evapotranspiration in all the years as a result the mean the irrigation requirement was only 2.4 $m^3$ $ha^{-1}$. In Anantnag district, the effective rainfall varied between 149.4 $m^3$ $ha^{-1}$ to 424.8 $m^3$ $ha^{-1}$, crop evapotranspiration varied between 163.1 to 178.6 $m^3$ $ha^{-1}$ leaving the irrigation requirement of 34.0 $m^3$ $ha^{-1}$ with variation of 1.8 to 70.9 $m^3$ $ha^{-1}$ during 2010-2020 (Table 1).

***Water footprint assessment***

Table 1 shows the notable variation over the time and locations in the water footprint (WF) of rice production in three districts of Kashmir. The total WF of rice in Budgam district was 2003 l $kg^{-1}$ and varied between 1276 to 2735 l $kg^{-1}$. $WF_{blue}$ contributed about 32% and $WF_{green}$ contributed 68% of total WF in Budgam district. In Baramulla district, the WF was the highest among all the districts. The total WF in Baramulla district was 3444 l $kg^{-1}$ which varied between 1894 to 4637 l $kg^{-1}$. $WF_{blue}$ and $WF_{green}$ components contributed more or less equally. In Anantnag district, the total foot print was 2300 l $kg^{-1}$ which varied between 1546 to 3261 l $kg^{-1}$. Out of total WF about 40% was $WF_{blue}$ and 60% was $WF_{green}$.

## CONCLUSION

Results reveals that Budgam experiences relatively hotter temperatures compared to Baramulla, while Anantnag stands out as the coldest among the three. Reference evapotranspiration rates are highest in Anantnag and lowest in Baramulla, with Budgam falling in between. Anantnag receives the highest amount of rainfall compared to the other districts. Water footprint (WF) analysis reveals variations across districts, with Budgam generally exhibiting lower $WF_{green}$ and $WF_{blue}$ compared to Baramulla and Anantnag. Notably, $WF_{blue}$ tends to increase when rainfall is lower, corresponding to lower $WF_{green}$. The highest $WF_{green}$ and $WF_{blue}$ values vary across districts and years. The analysis will be helpful for better planning of rice cultivation in these districts.

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***Authors contribution*: S.** Hassan: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Data collection, Data analysis and interpretation; A. Rana: Conception or design of the work, Data analysis and interpretation, Critical revision of the article, Final approval of the version to be published.

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