Atomic Spectroscopy

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# Appraisal of Green and Blue Water Footprint for Rice Production in Uttar Pradesh, India

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**ABSTRACT:** As freshwater resources are increasingly being strained by population increase, urbanization, climate change and industrialization, sustainability and water scarcity have emerged as urgent worldwide challenge. The idea of the water footprint has become a useful tool for measuring and managing water use in a variety of sectors mainly in agriculture. Taking into account the significance of the water footprint concept, this paper aims at calculating the water foot-print of rice production in nine agro-climatic zones of Uttar Pradesh, India, using local meteorological data and a methodology outlined in the water footprint assessment manual. This assessment will provide valuable information for policymakers, water managers, farmers and government officials to formulate water management strategies implement water pricing mechanisms and develop agricultural policies that promote sustainable water use.

**Keywords:** Agro-climatic zones, Crop Water Requirement, Rice, Evapotranspiration, Water Footprint, Water Management

## INTRODUCTION

An estimated 9 to 10 billion people will be depending on the planet's resources for sustenance in the year 2050 (FAO, Rome 2010). We will require a significant amount of water to generate anything close to that quantity. Future generations will have a significant challenge in achieving food security while using water resources sustainably (FAO, 2017). Researchers have argued that it is crucial to put freshwater issues in a global framework as a result of the realization that freshwater resources are sensitive to global changes and globalisation (Vorosmarty et al. 2000). 90% of the fresh water used in India, a significant food producer, is used in agriculture (Government of India,2019).Every year India produces more food grains and it is one of the world's top producers of a number of different crops including wheat, rice, pulses, sugarcane and cotton (FAO, 2021). Among the many crops grown in India, rice is one of the most important staple foods grown here and requires a lot of water to thrive (Dhavan, 2017). Depending on the variety of rice, the growing environment, and the farming techniques employed, different amounts of water may be required to produce rice. Despite being a significant food crop, rice production in some areas can strain water supplies (Bouman et al .2002). Therefore, it is necessary to implement irrigation systems and farming techniques that use less water and produce less waste. In order to achieve the goals of food security and human well-being, increasing water and land scarcities are predicted to negatively affect the growth of the food production industry. These scarcities have also been a contributing factor to recent increases in food prices (UN, 2018).Consequently research into the idea of "Water footprint" is necessary .Crop water footprint research enables us to evaluate the environmental impact of agriculture practices and create mitigation plans for any unfavourable outcomes (Mekonnen and Hoekstra, 2012).This research delves into the study of various parameters which affect rice production and allows location specific calculation of water footprint in nine districts of Uttar Pradesh.

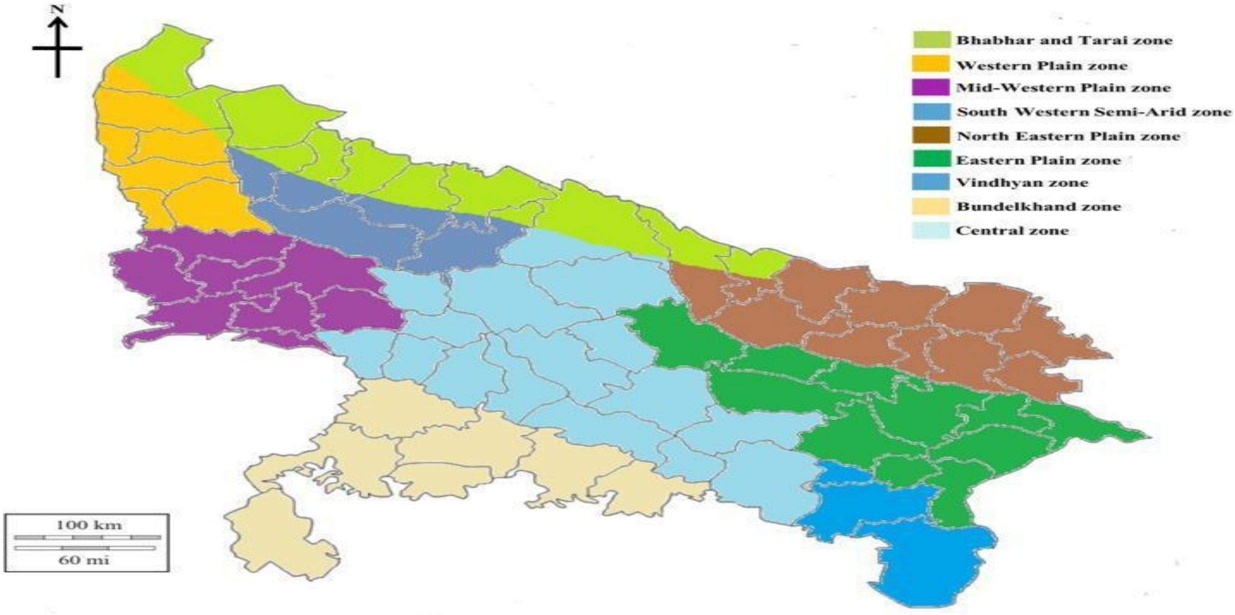
## The study area

Study has been conducted in Uttar Pradesh, which is the fourth largest state in the country in terms of area, and the first in terms of population, which is situated between 23°52′ N and 31°28′ N latitudes and 77°3′ E and 84°39′E longitude. Tropical monsoon weather prevails throughout the state. The average temperature varies in the plains from 3 to 4°C in January to 43 to 45°C in May and June. Agriculture is the main occupation of 66 percent of the population of the state with net cultivated area in the state is 164.17 lakh hectares. The state has been divided into 3 agro climatic zones, which has been further divided into 9 sub- zones (Gulati et al. 2021), as shown in table 1 and fig.1.

Table 1: Agroclimatic zones of Uttar Pradesh with selected stations

| S.No | Agro climatic Zones | Soil Type | Selected Stations |
|---|---|---|---|
| 1. | Bhabhar and Terai Zone (BTZ) | Alluvial Clay | Bahraich |
| 2. | Western Plain Zone (WPZ) | Sandy Clay | Aligarh |
| 3. | Central Western Plain Zone (CWPZ) | Alluvial Sandy | Bareilly |

| | | | |
|---|---|---|---|
| **4.** | South Western Semi-Arid Zone (SWSAZ) | Sandy and Alluvial Clay | Agra |
| **5.** | Central Plain Zone (CPZ) | Alluvial Clay | Lucknow |
| **6.** | Bundelkhand Zone (BZ) | Red and Black Rocky Soil | Jhansi |
| **7.** | North Eastern Plain Zone (NEPZ) | Sandy and Alluvial Calcareous Soil | Gorakhpur |
| **8.** | Eastern Plain Zone (EPZ) | Alluvial Clay | Varanasi |
| **9.** | Vindhyachal Zone (VZ) | Black and Red | Allahabad |




Source: Sankalp Misra et.al (2017)
Fig.1: Different Agro-climatic Zones of Uttar Pradesh

## Data Source

The local meteorological stations of the individual stations under consideration shown in fig.2 were used to collect the meteorological data necessary for the calculation of reference crop evapotranspiration, including maximum temperature, minimum temperature, sun shine hours, wind speed, humidity, and rainfall data. The Uttar Pradesh statistics abstract was used to obtain yield information for the production of rice in several districts for the years 2015 to 2021.(Directorate of Economics and Statistics, Government of Uttar Pradesh), (GOI, http://updes.up.nic.in). Kc value for the rice was derived from the earlier study on rice crop in the Mirzapur district of Uttar Pradesh (Bharteey, 2020).

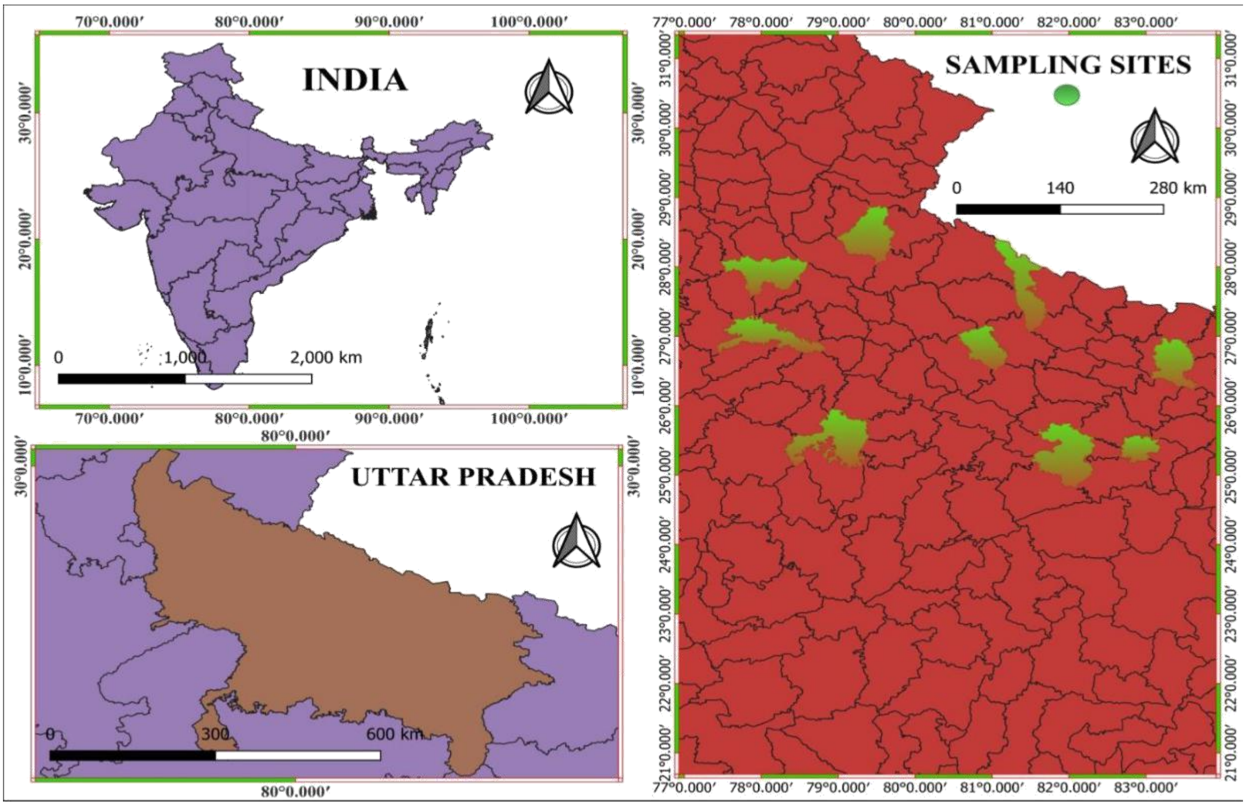


Fig.2: Location of the study area

**Water Footprint Concept**

The concept of water footprint is based on the virtual water concept introduced by Tony Allen in 1993 (Allan, 2003).However the water footprint concept was introduced by Hoekstra & Hung in 2002(Hoekstra and Hung, 2002).A multi-dimensional indicator, the water footprint provides water consumption volume by source and pollutant volume by kind of contamination. In order to provide a through picture of freshwater consumption and contamination, the tool distinguishes between green, blue and grey water (Leenes and Hoekstra, 2011).While grey WF is a measure of the volume of polluted water, or the amount of fresh water needed to assimilate the pollutant load in order to bring it to natural conditions or ambient standards green WF refers to the consumption of rainwater, blue WF refers to water consumption from surface or ground water sources (Hossain et al. 2021).

**Water Footprint Calculation**

WF is measured in terms of water volume per ton of product ($m^3$/t). Blue water, green water and grey water are its three main constituents. However, as groundwater and rainwater are influenced by various climatic factors, we have only concentrated on these two components in this analysis, that is, $WF_{green}$ which is the component of precipitation, and $WF_{blue}$ which is the component of groundwater. These have been computed by following the methodology explained in the "water footprint assessment manual", using the CROPWAT 8.0 software (Hoekstra et al. 2011), by applying the following equations:-

$$WF_{green} = \frac{CWU_{green}}{Y} \quad (1)$$

$$WF_{blue} = \frac{CWU_{blue}}{Y} \quad (2)$$

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green} \quad (3)$$

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue} \quad (4)$$

$$ET_{green} = \min(ET_c, P_{eff}) \quad (5)$$

$$ET_{blue} = \max(0, ET_c - P_{eff}) \quad (6)$$

Where CWU is the amount of water needed to replenish a crop's evapotranspiration losses and avoid crop water stress. Green component in crop water use is satisfied by precipitation whereas blue component is satisfied by irrigation (Chiarelli et al. 2020). $ET_{green}$ and $ET_{blue}$ stand for the green and blue water evapotranspiration respectively. The conversion factor 10 converts water depths measured in millimetre to water volume per hectare ($m^3$/ha).The summation is performed during the full growing season, that is from the first day to the day of harvest, where (lgp) stands for length of growing period in day (Sidhu et al. 2021). The crop evapotranspiration under standard conditions, abbreviated as $ET_c$, refers to the evapotranspiration from healthy, disease-free crops that have received adequate fertilization and are planted in wide fields with ideal soil water conditions. The values of $ET_c$ and CWR (Crop Water Requirements), where $ET_c$ denotes the volume of water lost through evapotranspiration and CWR denotes the volume of water required to make up for the loss, are the same(Kashyap and Agarwal ,2020).

$$ET_c = K_c \times ET_O \quad (7)$$

Where $K_c$ refers to crop coefficient, the $k_c$ value varies with the crop characteristics, such as the groundcover, crop height, and leaf area. The initial stage, crop development stage, mid-season stage, and late-season stage are the four growth stages that are recognized for the selection of $k_c$ (Doorenbos and Pruitt, 1984).For the present study, $K_c$ value for rice have been taken from Bharteey et al. (2020), they have estimated the $K_c$ value for different stages of rice growth in Mirzapur district of Uttar Pradesh (Bharteey et al. 2020). $ET_o$ is the reference crop evapotranspiration.

**Calculation of reference crop evapotranspiration**:

The reference crop evapotranspiration, represented by $ET_o$, is the evapotranspiration from a reference surface that is not deficient in water. The only method currently advised for calculating reference crop evapotranspiration ($ET_o$) manually, is the FAO Penman-Monteith method (FAO, 1998a).

Penman-Monteith equation:

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (8)$$

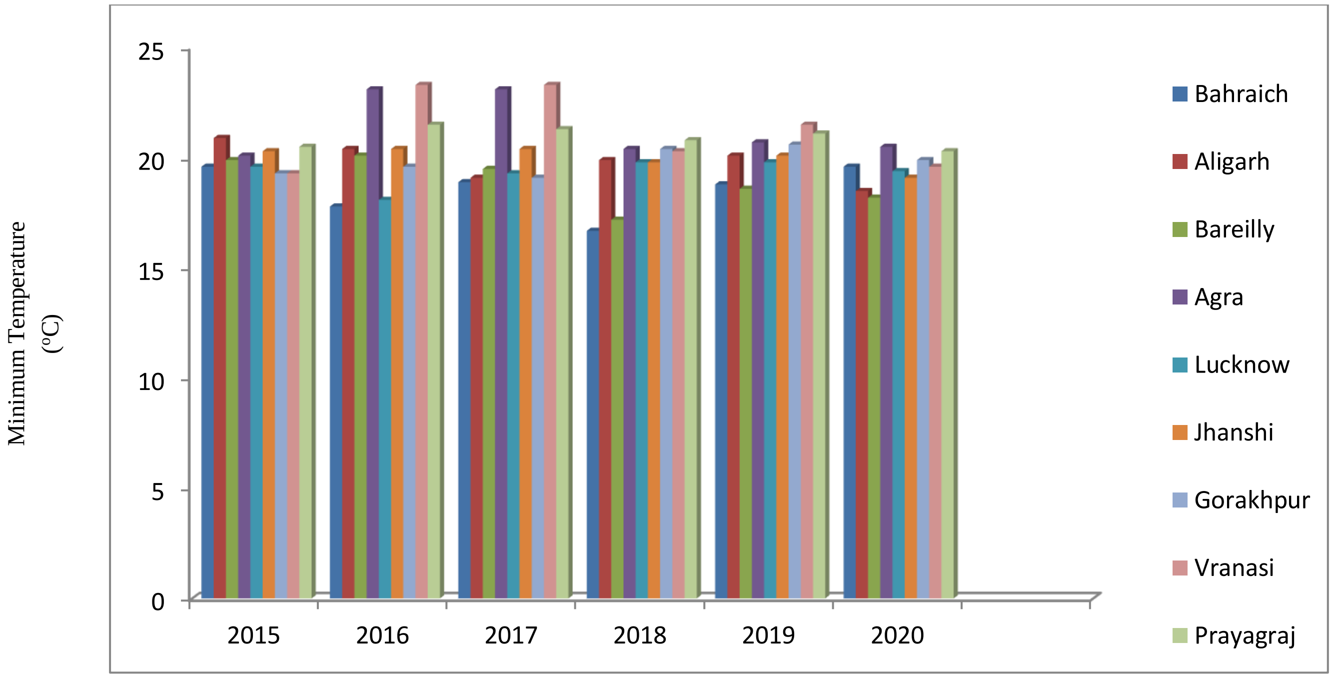
ETo = Reference evapotranspiration (mm/day)
Rn = Net radiation at the crop surface (MJ/m2 per day)
G = Soil heat flux density (MJ/m2 per day)
T = Mean daily air temperature at 2 m height (°C)
u2 = Wind speed at 2 m height (m/sec)
es = Saturation vapour pressure (kPa)
ea = Actual vapour pressure (kPa)
es - ea = Saturation vapour pressure deficit (kPa)
$\Delta$= Slope of saturation vapour pressure curve at temperature T (kPa/°C)
$\gamma$= Psychrometric constant (kPa/°C)

Manually calculating $ET_o$ is a time-consuming process that increases the likelihood of making arithmetic mistakes. Calculations may now be completed more quickly and with less effort with the help of computer software. The FAO CROPWAT computer program is one such software. (Savva and Frenken, 2002)The FAO-CROPWAT model developed by Land and Water Development Division of U.N. Food and Agriculture Organization (FAO), which uses the Penman-Monteith equation, was used in this study to calculate reference evapotranspiration ($ET_o$) and crop water requirement (CWR) or $ET_c$ which in turn was used to calculate Water Footprint of rice production in the respective districts.

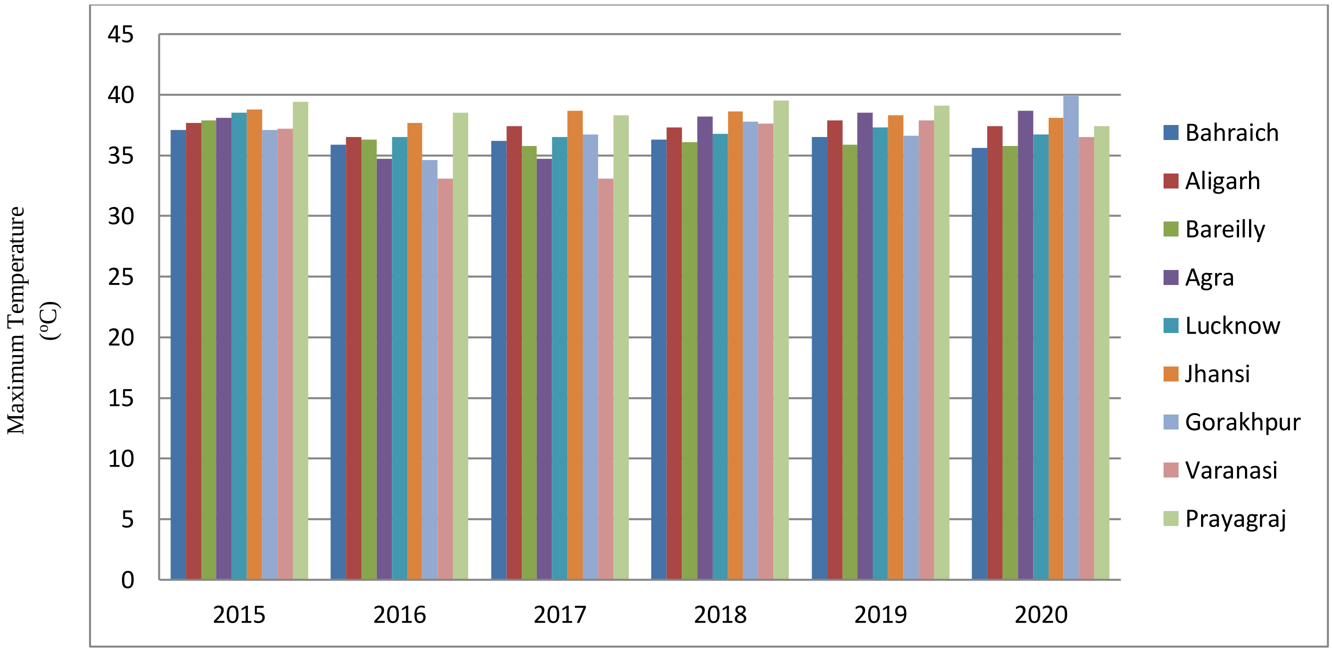
## RESULT AND DISCUSSION

**Trends in weather condition**

The average minimum and maximum temperatures for the study period (2015–2020) varied between 16.7–23.3°C and 33.1–39.9°C, respectively, during the rice-growing season (June–November). Bundelkhand zone (Jhansi), which recorded the mean highest temperature of 38.2°C, was followed by Vindhyachal zone (Prayagraj), which recorded a mean maximum temperature of 38.7°C. The central western plain zone (Bareilly), with a mean average minimum temperature of 18.9°C, was followed by the bhabhar and terai zone (Bahraich) where the mean minimum temperature observed was 18.6°C during the rice growing season. The lowest temperature recorded was 16.7°C in the bhabhar and terai zone (Bahraich) in 2018, and the highest temperature recorded was 39.9°C in the north eastern plain zone (Gorakhpur) in 2020.



Minimum Temperature (ºC)
25
20
15
10
5
0
2015
2016
2017
2018
2019
2020
Bahraich
Aligarh
Bareilly
Agra
Lucknow
Jhanshi
Gorakhpur
Vranasi
Prayagraj

Maximum Temperature (ºC)
45
40
35
30
25
20
15
10
5
0
2015
2016
2017
2018
2019
2020
Bahraich
Aligarh
Bareilly
Agra
Lucknow
Jhansi
Gorakhpur
Varanasi
Prayagraj

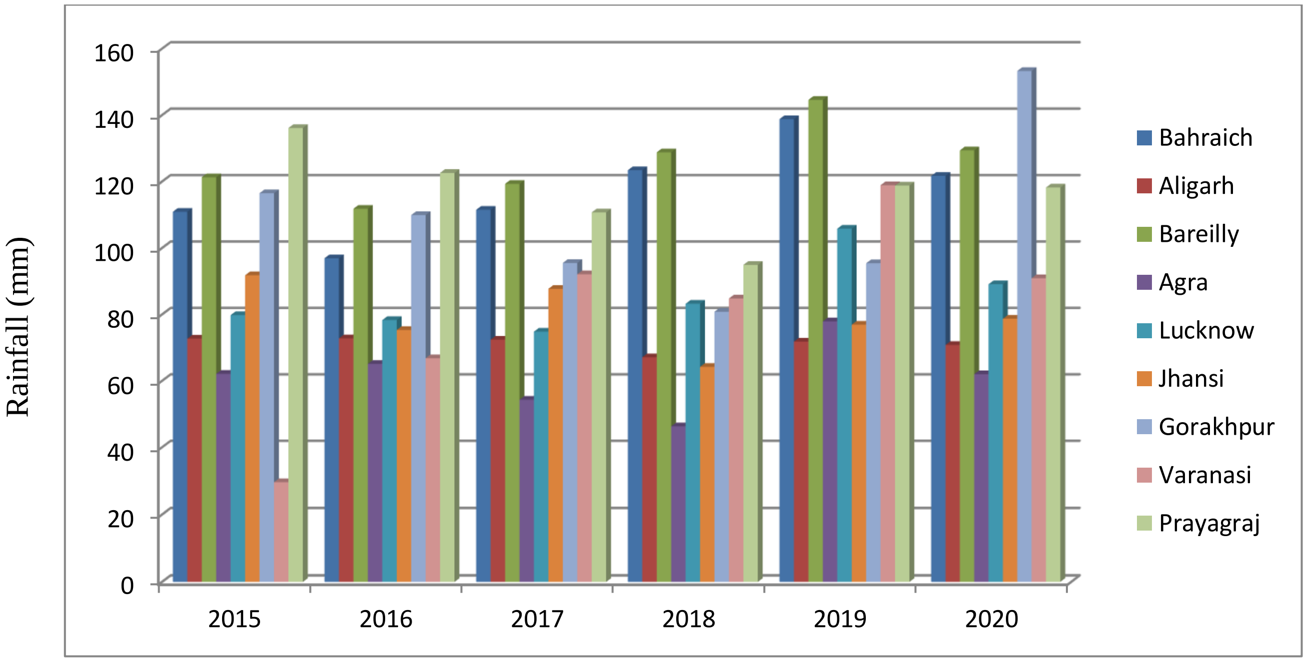



Fig. 3: Trends in Weather Parameters in different zones

The mean average rainfall during the growing season (2015–2020) varied greatly by zone. Agra has the lowest mean annual rainfall (62 mm), followed by Aligarh (70.8 mm), Jhansi (78.7 mm), Lucknow (89.1 mm), Varanasi (90.9 mm), Allahabad (118.2 mm), Bahraich (121.7 mm), Bareilly (129.4 mm), and Gorakhpur (153.3 mm), as shown in fig.3. However during the study period the maximum rainfall recorded was1093.1 mm in north eastern plain zone (Gorakhpur) in July 2020.

**Reference Evapotranspiration (ETo):** Because of the larger temperature rise and fluctuation in rainfall over the study period (2015-2020), the crop planting month of May–June experienced the highest evapotranspiration. This gradually reduced during the harvesting months of October and November. The Prayagraj district of the VZ had the highest $ET_o$ value, 5.11 mm/day, and the Lucknow district of the CPZ had the lowest $ET_o$ value, 3.86 mm/day, among the selected stations of the respective zones as shown in table 2. However, when there has been an abundance of rain, the soil gets saturated, reducing infiltration and increasing surface runoff. Since saturated soil prevents water from percolating deeply into the soil and resists evapotranspiration losses, the rate of evapotranspiration reduces during months with heavy rainfall.

Table 2: $ET_o$ of different zones in Uttar Pradesh

| | **Zone** | **ETo (mm/day)** |
|---|---|---|
| **1.** | BTZ | 4.43 |
| **2.** | WPZ | 4.46 |
| **3.** | CWPZ | 4.00 |
| **4.** | SWSAZ | 3.87 |
| **5.** | CPZ | 3.86 |
| **6.** | BZ | 4.49 |
| **7.** | NEPZ | 3.98 |
| **8.** | EPZ | 4.33 |
| **9.** | VZ | 5.11 |

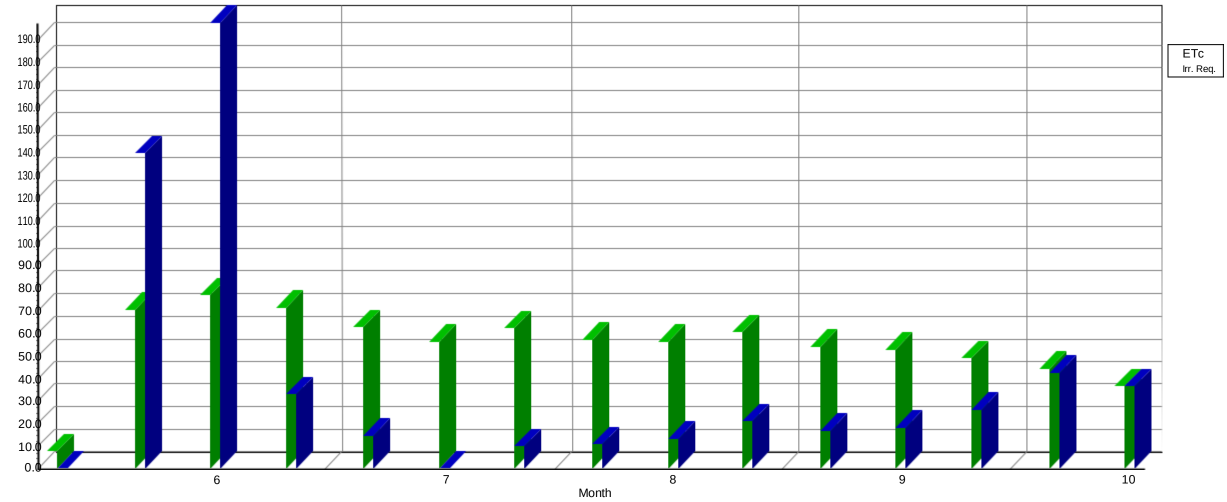
**Crop Evapotranspiration ($ET_c$)**

The $ET_c$ value in the selected sites in the state of Uttar Pradesh throughout the study period (2015-2020) ranged from 670 mm to 881 mm. Results in table 3 and fig.4 clearly shows that a significant portion of crop evapotranspiration losses were covered by irrigation in zones where effective rainfall was lower, as SWSAZ (Agra), at 59%. The NEPZ (Gorakhpur) had the most rainfall among the chosen stations, and as a result precipitation contributed the most to $ET_c$ losses (73%), whilst irrigation was only relied upon in 27% of cases.

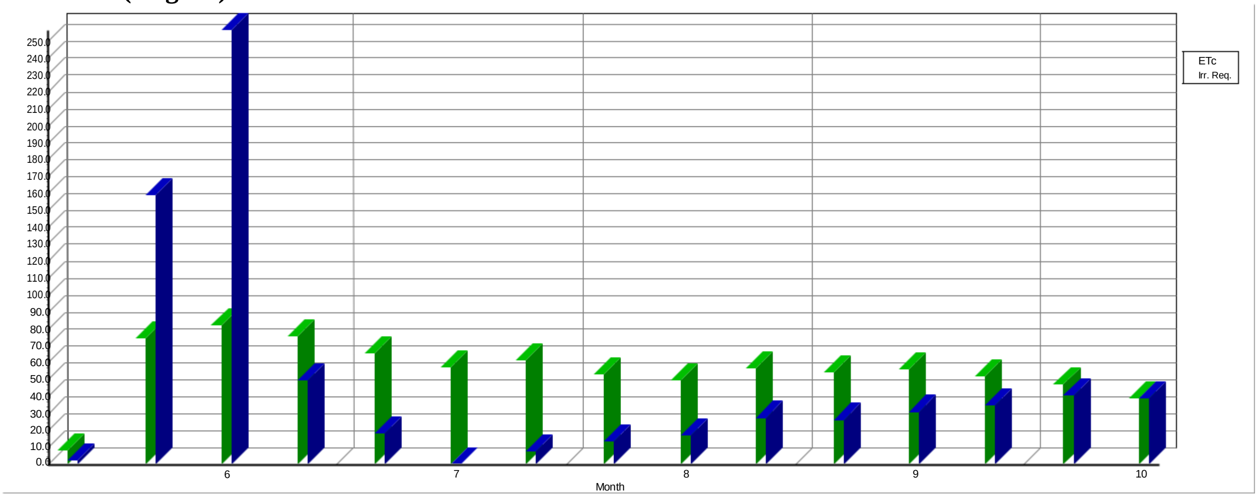
Table 3: Evapotranspiration and Crop Water Use for rice in different zones of U.P

| S.No | Zones | $ET_{green}$ (mm) | $ET_{blue}$ (mm) | $ET_c$ (mm) | $CWU_{green}$ ($m^3$/ha) | $CWU_{blue}$ ($m^3$/ha) | $CWU_{total}$ ($m^3$/ha) |
|---|---|---|---|---|---|---|---|
| 1. | BTZ | 483 | 335 | 818 | 4830 | 3370 | 8200 |
| 2. | WPZ | 387 | 444 | 831 | 3870 | 4440 | 8310 |
| 3. | CWPZ | 429 | 280 | 709 | 4290 | 2800 | 7090 |
| 4. | SWSAZ | 293 | 415 | 708 | 2930 | 4150 | 7080 |
| 5. | CPZ | 385 | 304 | 689 | 3850 | 3040 | 6890 |
| 6 | BZ | 362 | 472 | 834 | 3620 | 4720 | 8340 |
| 7. | NEPZ | 556 | 130 | 686 | 5560 | 1300 | 6860 |
| 8. | EPZ | 490 | 180 | 670 | 4900 | 1800 | 6700 |
| 9. | VZ | 467 | 414 | 881 | 4670 | 4140 | 8810 |

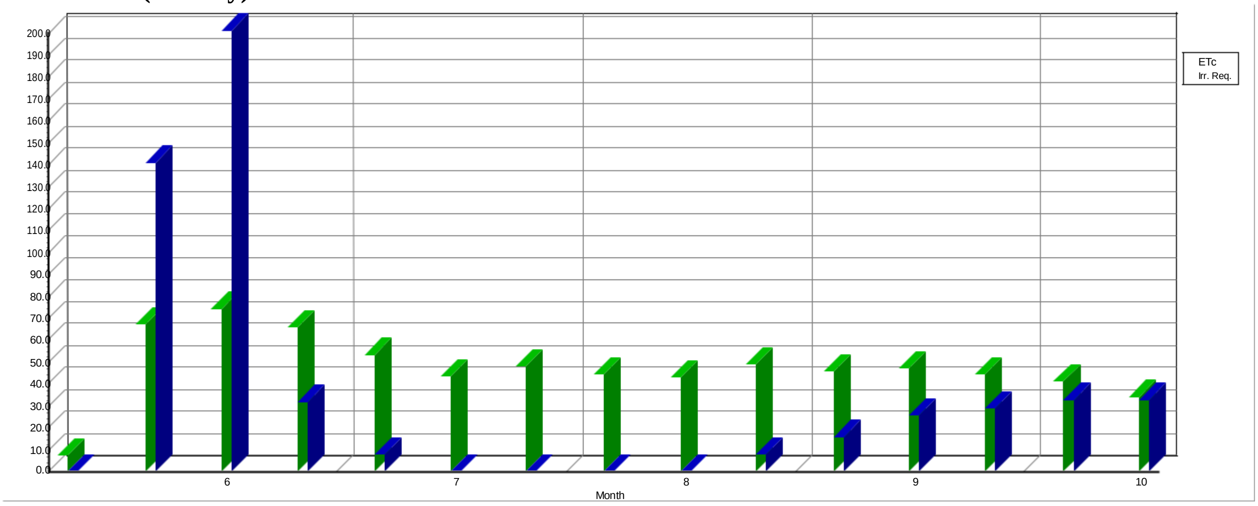
**$ET_c$ –BTZ (Bahraich)**



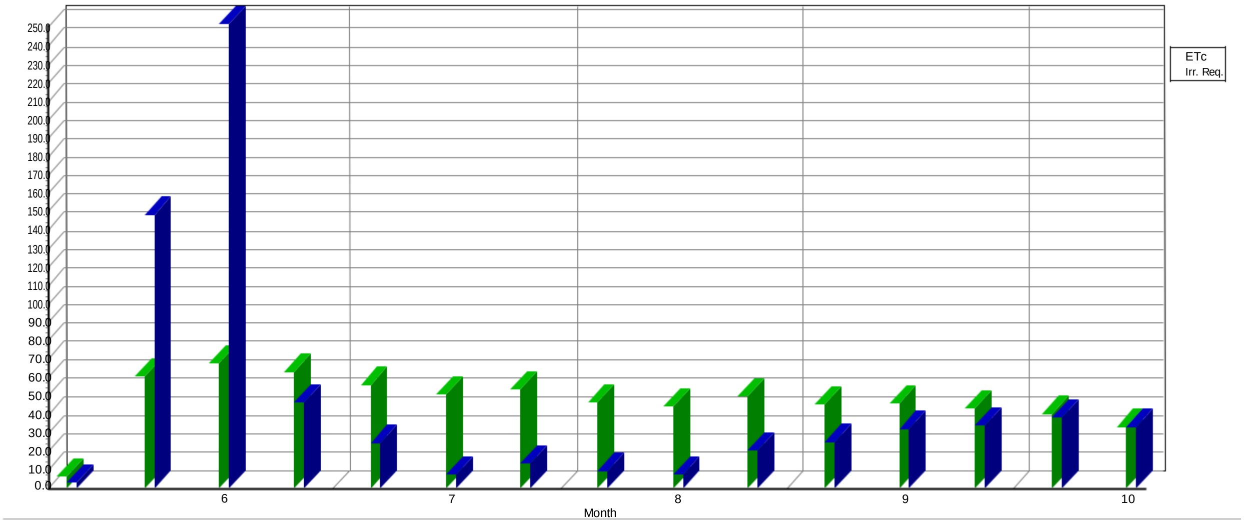

**$ET_c$-WPZ (Aligarh)**



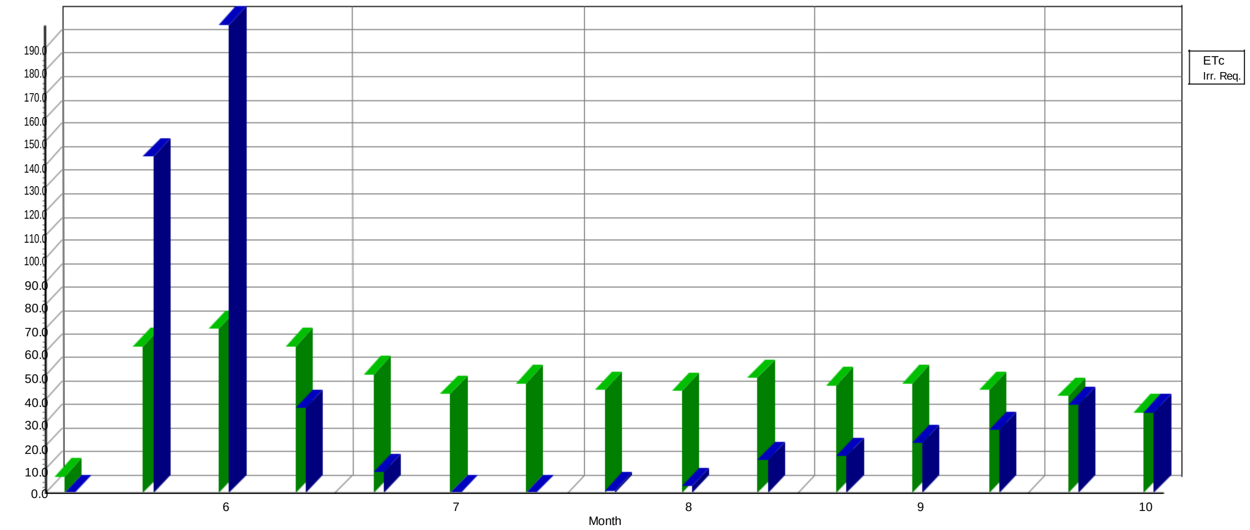
**ETc-CWPZ (Bareilly)**



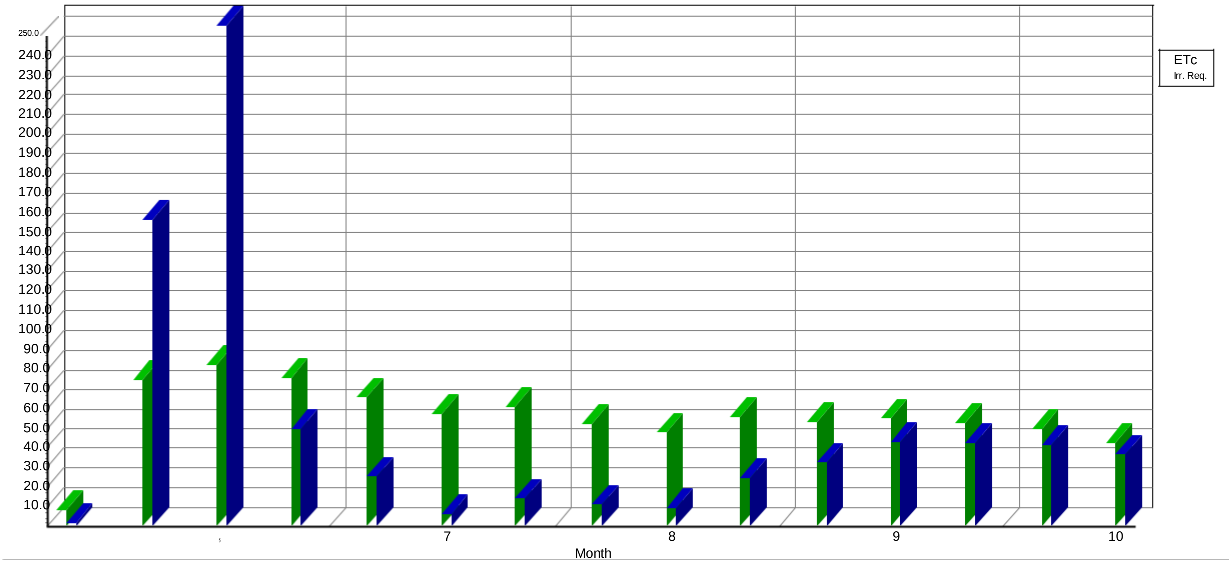

**ETc- SWSAZ (Agra)**



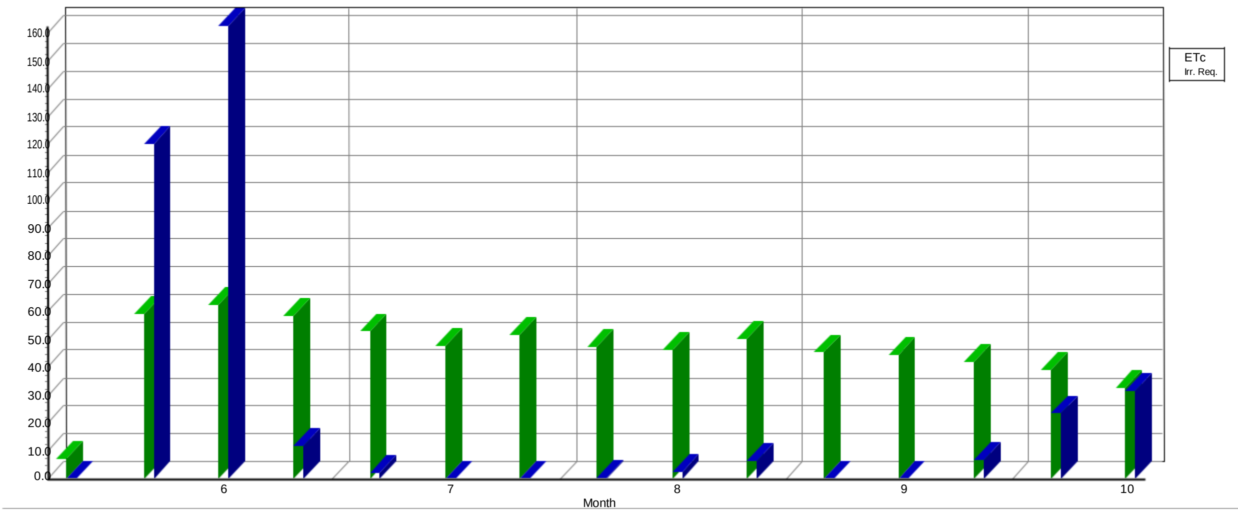

**ETc-CPZ (Lucknow)**



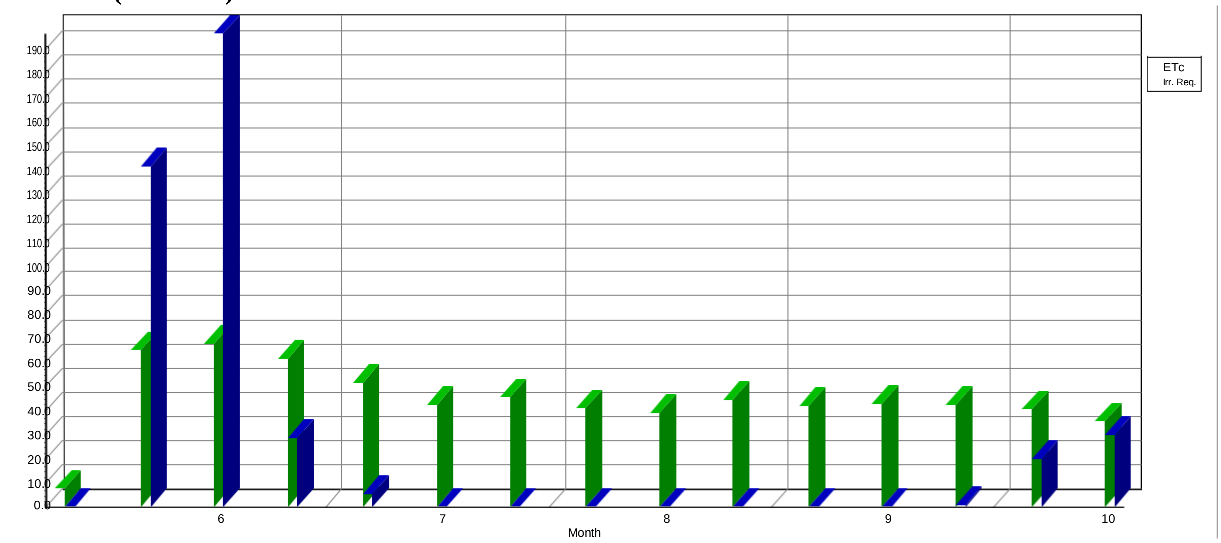
**ETc-BZ (Jhansi)**




**ETc-NEZ (Gorakhpur)**




**ETc-EPZ (Varanasi)**



**$ET_c$-VZ (Prayagraj)**

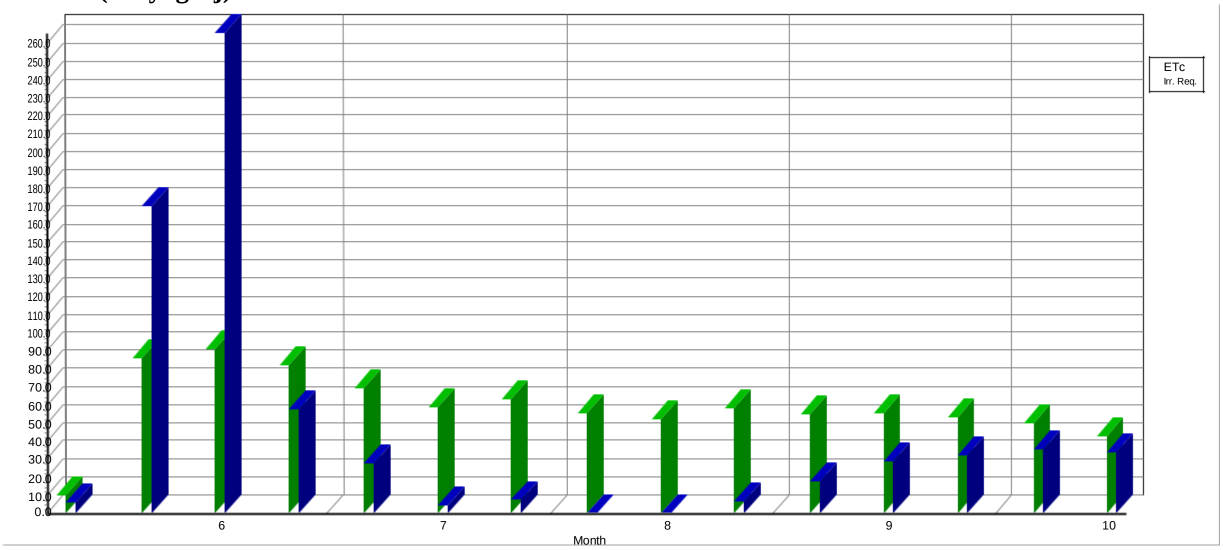



Fig.4: Irrigation Requirements and crop Evapotranspiration in different months for 9 zones.

Evaporation losses are greater than transpiration losses in the early stages of crop growth because there is less ground cover and more exposure to light; however, as crop cover increases, more light is focused on the crop rather than the ground, so transpiration losses become greater than evaporation losses. Fig. 4 clearly illustrates how irrigation requirements are prominent during the first months of rice cultivation in all 9 stations mainly due to high temperature and low precipitation.

**Water Footprint Analysis:**

When referring to the amount of water consumed during crop growth, whether it be groundwater or surface water, $WF_{green}$ and $WF_{blue}$ are also known as the consumption water footprint. Our findings demonstrate that the NEPZ (Gorakhpur) requires the least amount of irrigation due to the $WF_{blue}$ in this zone being at a minimum of 577 litres/kg, which contributes to only 18.9% of the total water footprint ($WF_{total}$), and the $WF_{green}$ being at a major contribution of 81.1%. Additionally, the yield response was also quite good in this zone, making it a suitable location for rice cultivation in any improbable circumstances. Following this zone, the EPZ (Varanasi) also had lower $WF_{blue}$ 735 liters/kg, which only contributes 28.9% to $WF_{total}$ in contrast to $WF_{green}$, which makes up 71.1% , as shown in table 4 and fig.5.

Table 4: Green, blue and total water footprint of rice (2015-2020) in Uttar Pradesh

| S.No | Zones | Yield (kg/ha) | $WF_{green}$(liters/kg) | $WF_{blue}$(litres/kg) | $WF_{total}$(litres/kg) |
|---|---|---|---|---|---|
| 1. | BTZ | 2385 | 2025 | 1413 | 3438 |
| 2. | WPZ | 2515 | 1539 | 1765 | 3304 |
| 3. | CWPZ | 2365 | 1814 | 1184 | 2998 |
| 4. | SWSAZ | 2541 | 1153 | 1633 | 2786 |
| 5. | CPZ | 2370 | 1624 | 1283 | 2907 |
| 6. | BZ | 1844 | 1963 | 2560 | 4523 |
| 7. | NEPZ | 2252 | 2469 | 577 | 3046 |
| 8. | EPZ | 2450 | 2000 | 735 | 2735 |
| 9. | VZ | 2716 | 1719 | 1524 | 3243 |

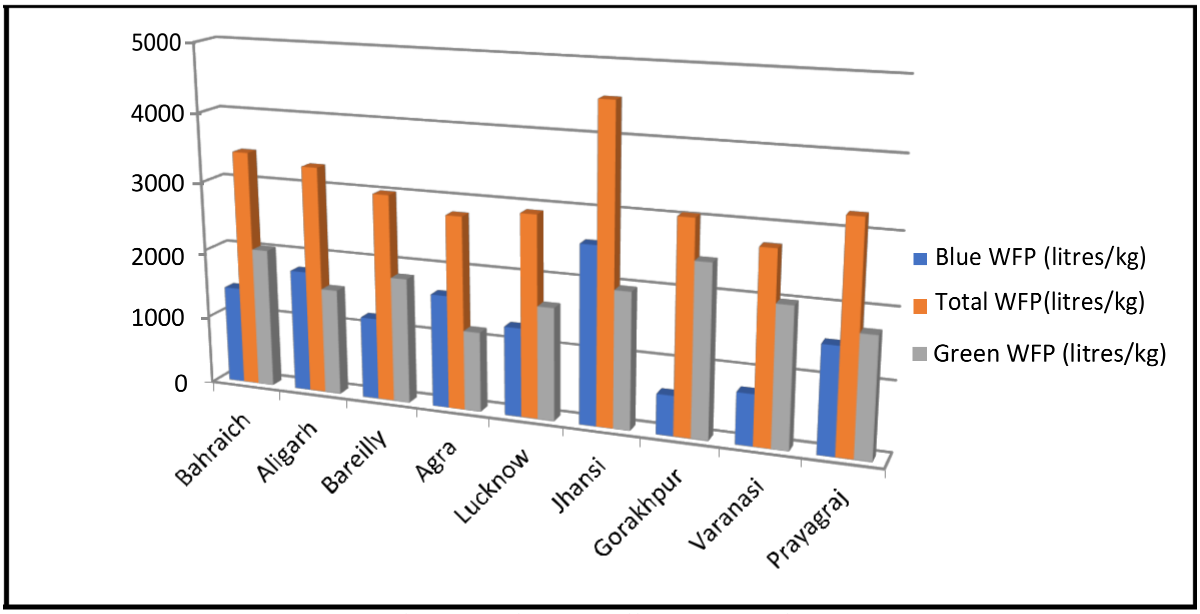



Fig.5: Water footprint of rice in different zones of Uttar Pradesh

Our research over the study period (2015-2020) revealed that BZ (Jhansi) had the highest WFP, 4523 litres/kg. Additionally, the amount of precipitation was insufficient to cover evapotranspiration losses, therefore $WF_{blue}$ was higher than WFgreen. Total WFP ($WF_{total}$) is the sum of $WF_{blue}$ and WFgreen. WPZ (Aligarh) and SWSAZ (Agra) are also the zones where the $WF_{blue}$ is greater than the $WF_{green}$, indicating that these zones demand better water management techniques and are more dependent on irrigation for crop growth.

## CONCLUSION

The sum of $WF_{blue}$ and $WF_{green}$ is known as total WFP ($WF_{total}$). The aim of this study was to determine how dependent rice farming is on available water supplies across nine different agro-ecological zones in Uttar Pradesh. The findings of the current study make it abundantly evident that every region's WFP is greatly influenced by its meteorological characteristics. Our research highlights a significant variation in water footprints for rice production across different zones in Uttar Pradesh. The Bundelkhand Zone exhibited the highest WF (4523 litres/kg) while the Eastern Plain zone recorded the lowest (2735 litres/kg) making it most suitable for rice cultivation. Additionally, it was discovered that the NEPZ (Gorakhpur) and the EPZ (Varanasi) had the least blue water footprint, indicating that these areas are least dependent on ground water for the production of rice and that the majority of their needs are met by precipitation. As a result, taking extra care and using the right production techniques in these areas to increase the yield will help to keep a check on water resources. This disparity in water usage is crucial to address, particularly in Uttar Pradesh, given its status as the most populous state in India. The implications of water management in Uttar Pradesh extend beyond regional concerns, as the state's water consumption directly influences the nation at large.

Importantly, by concentrating on the precise water footprint of rice cultivation across various geographical zones within Uttar Pradesh, our study adds innovation to the body of current research. While earlier studies have looked at water use in agriculture, very few of them have explored the variations within a single state. Our research provides a more nuanced perspective on water usage trends by revealing these variances, enabling targeted interventions and policies to promote sustainable resource management. This work offers doors for further research into maximising water use and boosting agricultural productivity across several zones in Uttar Pradesh, as our findings highlight the crucial importance of regional settings.

**Conflict of Interest:**

The author declares that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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