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Research Paper

Crop water requirement of rice in different agroclimatic zones of Jharkhand

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ABSTRACT

The crop water requirement of rice in different agroclimatic zones of Jharkhand, India was estimated using the CROPWAT 8.0 and CLIMWAT 2.0 models with data collected through NASA data-access-viewer on climate, soil, crop, and water availability. The evapotranspiration (ET_o), effective rainfall (P_{eff}), and crop water requirement (CWR) for the four zones of the Jharkhand State were calculated. Results revealed that the reference evapotranspiration (ETo) varied from 420.4 mm to 516.5 mm during the crop growing season of rice in different zones. The effective precipitation varied from 748.4 mm to 760.8 mm. The crop water requirement of rice varied from 482.5 mm to 592.4 mm. Effective rainfall was sufficient to meet the water requirement of rice in most of the zones except Alluvial zone wherein the net irrigation water requirement was only 67.6 mm.

Keywords: Crop water requirement, CROPWAT 8.0, CLIMWAT 2.0, Evapotranspiration, Effective rainfall, Irrigation requirement

The water requirement of crops refers to the amount of water needed by plants to grow, develop, and produce a viable yield (Doorenbos and Kassam, 1979). Studying crop water requirements is important because it helps farmers and agricultural professionals to optimize their irrigation practices and improve crop yield (Giri *et al.,* 2017). Understanding the water needs of various crops is vital for precise irrigation scheduling (Bahadur *et al.,* 2021), optimizing timing and volume to prevent issues like waterlogging and nutrient leaching caused by over-irrigation or yield reduction related to under-irrigation. Amidst concerns about water scarcity and climate change, efficient water management is pivotal for sustainable agriculture, enabling farmers to reduce waste, enhance yields, and contribute to resource conservation.

Food and Agriculture Organisation (FAO) has developed CROPWAT model for determining the crop water requirement of different crops which has been widely used across the globe for various applications (Boualem, 2023; Lee and Dang, 2019; Thimmareddy *et al.,* 2023). The crop water requirement is determined using the reference evapotranspiration (ETo), which is defined as the loss of water to the atmosphere by evaporation and transpiration from an extended surface of 8-12 cm tall green grass cover, usually a well-watered, actively growing and completely shading the ground (Allen *et al.,* 1998). By applying a crop-coefficient (Kc) value, this ETo is used to estimate the crop evapotranspiration (ETc) (Doorenbos and Pruit, 1979). Understanding the water requirements of rice in Jharkhand and how to manage it, is crucial for farmers to increase rice production, improve its quality, and enhance their income. In view of the above, the present study aims to determine the irrigation water requirements of rice in different agro-climatic zones of Jharkhand.

MATERIALS AND METHODS

The study area is the State of Jharkhand, which has been strategically divided into four zones based on soil types (Table 1). Each zone encompasses specific districts characterized by distinct soil properties. The rice crop growing season has been shown in Table 2 which was considered for estimating the crop water requirements. Stages of rice growth were classified into nursery, initial, development, mid-season and late season stages (Allen *et al.,* 1998).

For this study, agro-climatic and location data spanning a 40-year period (1981 – 2020) were taken from the website of NASA

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Table 1: Distribution of zones based on soil types in different districts

Zone	Types of soil	Related districts
1	Red soil zone	Deoghar, Garhwa, Ranchi, Hazaribag, Giridh, Dumka, Saraikela, Godda and Khunti
2	Alluvial soil	Chatra, Koderma, Lohardaga, Ramgarh, Bokaro and Dhanbad
3	Black soil	Jamtara, Pakur, Sahibganj, West Singhbhum and East Singhbhum
4	Laterite soil	Gumla, Palamu, Simdega and Latehar

Table 2: Crop growing seasons of rice in Jharkhand

Month	Stages of rice	Duration (days)	Crop coefficient (Kc)
June	Nursery stage	15	1.20
July	Initial stage	20	1.05
July-August	Development stage	20	1.10
August- September	Mid-stage	40	1.20
September - October	Late stage	20	1.05

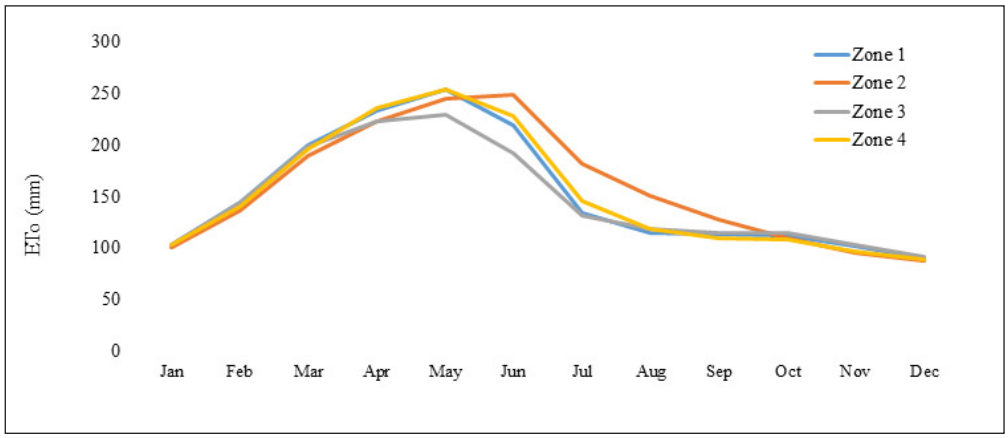

Fig. 1: Monthly variation in evapotranspiration (ET_o) across different zones of Jharkhand

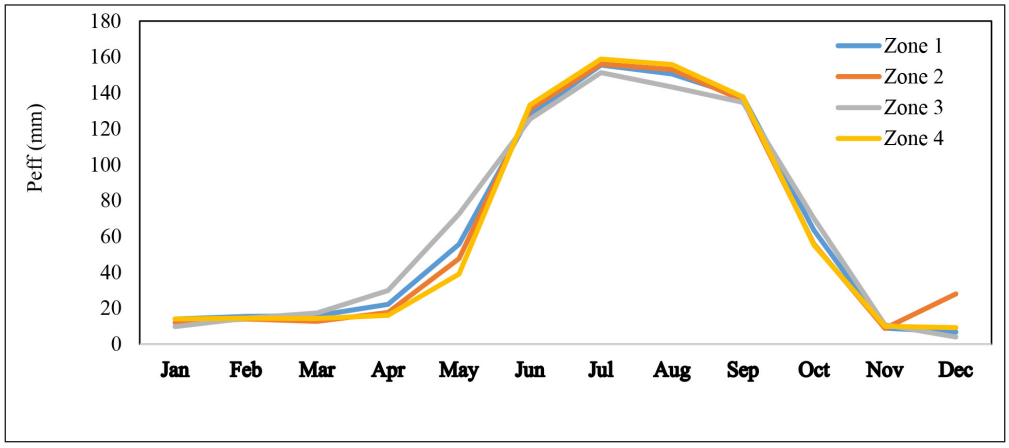

Fig. 2: Monthly variation of effective rainfall in different zones of Jharkhand

[https://power.larc.nasa.gov/data-access-viewer/]. The climatic data, including temperature, humidity, wind speed, and solar radiation of NASA were utilized to calculate the reference evapotranspiration (ETo), employing the modified Penman-Monteith method (Allen *et al.,* 1998). Crop data encompasses the crop coefficient (Kc) which is the ratio of ETc to ETo and it varies with the crop development stages. Kc values for the rice have been considered as per the FAO recommended values (Table 2). Soil data includes total available soil moisture, maximum rooting depth, drainage porosity, and maximum rain infiltration rate which significantly influence water availability, plant growth, and soil health, making them critical factors for effective water management strategies. The crop water

Table 3: Stage wise reference evapotranspiration (ET_o), effective rainfall (P_{eff}), and crop water requirement (CWR) across different zones of Jharkhand

Stages	Rainfall (mm)	Effective rainfall (mm)	ETo (mm)	CWR (mm)	NIR (mm)
Red soil (Zone 1)					
Nursery	343.2	274.5	54.9	65.9	0.0
Initial	86.4	69.1	59.3	62.3	0.0
Developmental	85.0	68.0	55.3	60.8	0.0
Mid-season	320.2	256.2	203.2	243.8	0.0
Late season	110.3	88.2	50.0	52.5	0.0
Total	945.0	756.0	422.7	485.3	0.0
Alluvial soil (Zone 2)					
Nursery	338.9	271.1	62.0	74.4	0.0
Initial	86.7	69.4	80.7	84.7	15.3
Developmental	85.9	68.7	73.7	81.1	12.4
Mid-season	321.0	256.8	247.2	296.6	39.9
Late season	103.1	82.5	52.9	55.5	0.0
Total	935.5	748.4	516.5	592.4	67.6
Black soil (Zone 3)					
Nursery	361.9	289.5	47.9	57.5	0.0
Initial	84.0	67.2	58.1	61.0	0.0
Developmental	81.8	65.4	55.4	60.9	0.0
Mid-season	308.8	247.1	207.7	249.3	2.2
Late season	114.5	91.6	51.2	53.8	0.0
Total	951.0	760.8	420.4	482.5	2.2
Laterite soil (Zone 4)					
Nursery	331.8	265.4	56.9	68.3	0.0
Initial	88.2	70.6	64.9	68.2	0.0
Developmental	87.4	69.9	58.7	64.6	0.0
Mid-season	326.1	260.9	202.7	243.2	0.0
Late season	103.3	82.7	48.4	50.8	0.0
Total	936.8	749.4	431.7	495.1	0.0

requirement was estimated using systematically the CROPWAT 8.0 and CLIMWAT 2.0 models.

The effective rainfall was estimated using the USDA SCS method (Patwardhan *et al.,* 1990). The USDA SCS method for calculating effective rainfall is outlined below.

$P_{eff} = P_{tot} (125\text{-}0.2\ P_{tot}) / 125,\ P_{tot} < 250$ mm

$P_{eff} = 125 + 0.1P_{tot},\ P_{tot} > 250$ mm

Crop water requirement (ETc) was calculated using following equation

$ETc = ETo * Kc$

The net irrigation requirement (NIR) was calculated as

NIR= ETc-Peff

RESULTS AND DISCUSSION

Reference evapotranspiration (ETo)

The analysis of reference evapotranspiration (ETo) across these zones, as depicted in Fig. 1, reveals variation in modelled ETo from 87.9 mm in December to 253.8 mm in May among all zones of Jharkhand. The highest annual evapotranspiration reached 1896 mm in Zone 2, while the lowest was noted as 1763.1 mm in Zone 3. Monthly analysis indicates maximum ETo values in May for Zone 1 (253.5 mm), Zone 3 (229.8 mm), and Zone 4 (253.8 mm). Zone 2 recorded its peak ETo of 248.1 mm in June. Additionally, the minimum ETo was observed in December for all zones of Jharkhand, with values of 90.3 mm, 87.9 mm, 90.9 mm, and 89.1 mm respectively.

Effective rainfall (P_{eff})

The analysis of effective rainfall data for various zones

of Jharkhand, as depicted in Fig. 2 reveals variation in modelled effective rainfall. The peak effective rainfall observed in July as 155.4 mm (zone 1), 156.0 mm (zone 2), 151.2mm (zone 3) and 158.8 mm (zone 4). The maximum annual effective rainfall of 783.2 mm is observed in zone 3 and minimum annual effective rainfall of 757.6 mm in zone 4. It is noteworthy that the uniformity in effective rainfall patterns across all zones. Starting in April there is a consistent uptrend reaching its peak in July. This pattern underscores a crucial observation i.e. during the rainy season the effective rainfall is significantly higher compared to other seasons.

Crop water requirements (CWR)

Assessments of crop water requirements (CWR) for rice were conducted using the CROPWAT 8.0 and CLIMWAT 2.0 models, as shown in Table 3. The crop parameters used to estimate the crop water requirements of rice for different zones of Jharkhand. During the preparation phase of the soil, 65.9 mm of water is required for the rice crop and irrigation water is not required for nursery stage in all zones of Jharkhand. In zone 2, 74.4 mm of water is required for the rice crop. In zone 3, 57.5 mm of water is required for the rice crop. In zone 4, 68.3 mm of water required for the rice crop.

During initial stage, 62 to 84.7 mm of water is required for the rice crop in different zones (Table 3). It is noteworthy that the irrigation water is not required for initial stages in all zone of Jharkhand except zone 2, where 15.3 mm of water is required for irrigation. It is due to the fact that effective rainfall is naturally fulfilling the crop water requirement demands in zone1, zone3 and zone 4. During development stage, the crop water requirement of rice varies between 60.8 mm and 81.1 mm in different zones. While due to more effective rainfall occurred, irrigation water is not required in development stage in all zone of Jharkhand except zone 2 where 12.4 mm of irrigation water is required.

During the mid - season stage the crop water requirement are 243.8 mm, 296.6 mm, 249.3 mm and 243.2 mm in zone 1, zone 2, zone 3 and zone 4 respectively. The irrigation water needed during mid - season stages in zone 2 and zone 3 are 39.9 mm and 2.2 mm respectively. No irrigation water is required in zone 1 and zone 4 during mid - season stage.

In the last phase of rice crop, 52.5 mm of water is required for the rice crop. In zone 2, 55.5 mm of water is required for the rice crop. In zone 3, 53.8 mm of water is required and in zone 4, 50.4 mm of water is required for the rice crop. The irrigation water is not required in any zone of Jharkhand during last phase of rice crop.

It is observed that 64.2 % of total CWR for rice in zone 1 has been fulfilled by rainfall and thus 485.3 mm of rice crop water is required. In zone 2, 79.2 % of total CWR is met by rainfall and 592.4 mm of rice crop water required. Also, 67.6 mm irrigation water is required in zone 2. In zone 3, 63.4 % of total CWR is met by rainfall and 482.5 mm crop water required. Also 2.2 mm water required for irrigation. In zone 4, 66.1 % of total CWR is met by rainfall and 495.1 mm crop water required. Zone 2, alluvial soil zone, required more irrigation water as compared to zone 1, zone 3 and zone 4 (Table 3). It is due to alluvial soil is high fertile and is also associated with high drainage rates, meaning that water tends to percolate through it quickly.

CONCLUSIONS

The crop water requirement and irrigation water requirement of rice computed for different agroclimatic zones of Jharkhand using CROPWAT model revealed that the crop water requirement varied of rice with the stage of crops as well as among the zones. The CWR varied from 482.5 mm in zone 3 (black soil) to 592.4 mm in zone 3 (alluvial soil). The above analysis provides in-depth insight into crop water management for rice crop. The effective rainfall was sufficient to meet the water requirement in all the zones except alluvial soil zone with need additional water of 67.6 mm as irrigation.

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Data availability: All the climatic data are freely available on the NASA Website (https://power.larc.nasa.gov/data-access-viewer/) for research purposes and other crop and soil data are available at Cropwat and Climwat software.

Author's contribution: **S. Kumar**: Data collection and analysis and model development; **R. Kumar**: Executed and conducted and project; **M. K. Singh:** Executed and conducted and project and interpretation; **S. Yadav:** Manuscript writing and data compilation; **P.K. Parhi:** Provide over all guidance in conducting the project work; **A. Bardhan:** Provided guidance.

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