Alternate wetting and drying for Climate Resilience:

Advancing Water Conservation and GHG abatement in Rice Cultivation in West Bengal

About The Organisation:

SwitchON Foundation (regd. as Environment Conservation Society) was established in 2008 to catalyze the adoption of sustainable technologies and practices, working at the intersection of climate-resilient agriculture, clean energy, green livelihoods and skills. With a dedicated team of **175+ members**, we operate across 8 states in India, empowering communities with climate-smart solutions. Through sustainability and innovation, we are committed to transforming **10 million lives**, ensuring that love and action for the Earth lead to better livelihoods, improved well-being, and a thriving planet for all.

Under its CRA program, SwitchON promotes **Alternate Wetting and Drying (AWD)** as a climate-smart rice cultivation practice that reduces water use without compromising yields. By periodically allowing rice fields to dry before re-irrigation, AWD conserves groundwater, lowers production costs, and reduces greenhouse gas emissions. The approach is integrated with SwitchON's broader work on climate-resilient agriculture, soil health improvement, and farmer training, helping smallholders adopt sustainable water management while sustaining productivity and livelihoods.

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ABSTRACT

This study assesses the effectiveness of alternate wetting and drying (AWD) irrigation as a climate-smart technique for water conservation and greenhouse gas reduction in irrigated rice systems in West Bengal, India. During the 2023-24 and 2024-25 *Boro* seasons, 527 smallholder farmers from six districts and seventeen administrative blocks used AWD on 285.67 hectares of farmed land. AWD substitutes continuous flooding with regulated intermittent drying cycles, which are monitored using perforated PVC field tubes planted in farm plots. Field observations revealed an average of 2.23 drying cycles every season, showing reasonable adherence to the AWD regimen.

Using the IPCC Tier-1 emission reduction coefficient (2 tCO_2e ha^{-1} $season^{-1}$), total methane mitigation was projected to be 571.34 tCO_2e across the intervention region. District-level variation revealed that Howrah (3.88 cycles) had the highest adoption rate, followed by Hooghly, Nadia, and Purba Bardhaman, while Bankura and Purulia had low adoption rates due to water scarcity and poor infrastructure. Water savings were estimated at 60 m^3 every drying cycle, resulting in 39,354 m^3 (39.35 million liters) of irrigation water saved and an economic benefit of ₹2.36 lakh from reduced pumping expenditure. Reduced irrigation events saved 4,778 gallons of diesel, resulting in a 12.80 tCO_2 reduction in fuel emissions.

The findings illustrate AWD as a cost-effective and scalable climate-resilient technology capable of lowering irrigation demand and greenhouse gas emissions while not affecting production. Because the project just provided training and monitoring tools, with no financial incentives, the outcomes show a high potential for large-scale replication, aided by capacity building and policy frameworks.

Keywords: Alternate Wetting and Drying, Methane Mitigation, Water Conservation, Rice Irrigation, Climate-Smart Agriculture, West Bengal.

1. INTRODUCTION

Alternate Wetting and Drying (AWD) irrigation is widely recognized as an agronomically viable and environmentally sustainable water management practice in irrigated rice cultivation. Unlike the traditional method of continuous flooding, which keeps paddy fields submerged throughout the crop cycle, AWD involves intermittently allowing the water level to drop below the soil surface before re-irrigation, thereby reducing anaerobic conditions that promote methane (CH_4) production. Rice cultivation consumes nearly 30% of the world's freshwater resources and contributes approximately 12% of global anthropogenic methane emissions (Lampayan et al., 2015), making water-efficient and low-emission cultivation techniques critical in the context of climate change and resource scarcity. AWD, promoted by the International Rice Research Institute (IRRI) and national agricultural research systems, commonly lowers the water table to 15 cm below the surface prior to irrigation and has been shown to reduce total irrigation water use by 20–40% without adversely affecting crop yield (IRRI, 2025). This approach is especially relevant for water-stressed regions such as Bankura and Purulia in West Bengal, where groundwater depletion, rising pumping costs, and climatic uncertainties are posing increasing threats to agricultural sustainability. Water scarcity is projected to affect 15–20 million hectares of irrigated rice land by 2025 (Mondal et al., 2017; Tuong et al., 2003), highlighting the need for alternative irrigation strategies capable of maintaining productivity under reduced water availability.

AWD improves soil aeration, improves root development and nutrient uptake efficiency, reduces pest proliferation, and lowers operational costs by reducing irrigation frequency and energy usage (Yang et al., 2025; Alauddin et al., 2020). It also conserves water and reduces methane emissions.

Spatial variance in adoption intensity is linked to differences in farm size, irrigation infrastructure, access to extension services, and local agroecological circumstances, with larger farmers drying more frequently, indicating more scalability where technical help is available. The findings support AWD as a viable path to water-efficient, climate-resilient, and commercially beneficial rice farming in West Bengal. Institutional support, digital monitoring systems, targeted extension programs, and integration with carbon-credit mechanisms will be key to driving mainstream acceptance and maximizing environmental and economic benefits.

Thus, the current study analyzes AWD adoption among 527 smallholder farmers across six districts and seventeen administrative blocks in West Bengal over the Boro seasons of 2023-24 and 2024-25, covering a monitored area of 285.67 hectares. Based on field-tube readings and farmer-reported irrigation patterns, an average drying-cycle frequency of 2.23 cycles per season was determined, indicating moderate adherence to AWD guidelines. Using the standardized emission-reduction coefficient of 2 tCO_2e ha^{-1} $season^{-1}$, the study calculates a possible mitigation of around 365 tCO_2e within a single cropping cycle, proving AWD's substantial climate mitigation potential when scaled over rice landscapes.

The study was carried out during the Boro Paddy farming seasons of 2023-24 and 2024-25 in six districts spread across 17 administrative blocks, with Bankura district including Jaypur, Bishnupur, Patrasayar, Sonamukhi, Taldangra, Sarenga, and Indpur. The Hooghly or Howrah districts include Arambagh, Jangalpara, Chanditala, and Udaynaran Pur. Memari and Raina are in the Purba Bardhaman district, and Shantipur and Santipur Municipality are in the Nadia district. The Purulia district is divided into three blocks: Balorampur, Jhalda 2, and Manbazar.

Data collection covered a survey of 527 smallholder farmers actively engaged with AWD irrigation. Farmers received training and monitoring installations comprising perforated PVC pipes to measure soil water levels for guiding irrigation timing. Data on field characteristics, transplant and pipe installation dates, drying cycle frequency, and farmer management practices were collected through structured interviews and field verification visits. Water levels were manually measured, and drying cycles were counted as field-level water depletion events reaching approximately 15 cm below the soil surface. Land areas were converted from local units (bigha) to hectares for standardized analysis. Methane mitigation estimates used IPCC-endorsed factors of 2 tCO_2e per hectare per season (Richards & Sander, 2014).

2.DATA COLLECTION

The characteristics measured in this study included land acreage (in hectares), number of drying cycles per season, irrigation frequency, transplanting and AWD pipe installation dates, and farmer-reported water management practices collected through field monitoring and structured interviews. Water-saving performance under AWD was quantified using an empirical estimation approach. The percentage of irrigation water saved (WS%) when switching from conventional Continuous Flooding (CF) to Alternate Wetting and Drying (AWD) was calculated based on comparative irrigation requirements under the two management systems. The percentage of water saved (WS%) when switching from Continuous Flooding (CF) to Alternate Wetting and Drying (AWD) irrigation is calculated using:

$$WS(\%) = \frac{I_{CF} - I_{AWD}}{I_{CF}} \times 100 \quad ....(i)$$

Where:
= Total irrigation water used under Continuous Flooding (in mm or m^3/ha)
= Total irrigation water used under Alternate Wetting and Drying
= Percentage of water saved by adopting AWD instead of CF
Water Saved per Hectare (m^3/ha) under AWD

The total volume of water saved through AWD irrigation can be estimated using:

$$WS(m^3/ha) = DC \times 60 \quad ....(ii)$$

Where:

- $WS(m^3/ha)$ =Total water saved per hectare
- = Number of drying cycles implemented under AWD
- 60 m^3 = Assumed amount of water saved per drying cycle

Basis of the Assumption
The value 60 m^3 (or 60,000 liters) represents the average reduction in irrigation water during one AWD drying cycle.
Typically, skipping one irrigation interval saves approximately:

Emission Reduction Estimation
Methane mitigation was calculated as:
Mitigation (tCO_2e)=Area (ha)×2 tCO_2e ha^{-1} $season^{-1}$ .....(v) (IPCC/IRRI factors; Richards & Sander, 2014).... (iii)

Energy savings were computed based on the decrease in irrigation pumping events seen during AWD drying cycles. The diesel consumption per irrigation event was calculated using standard fuel consumption rates for 5-7.5 HP pumps (7.5 L/hour) with an average pumping time of 15-20 minutes per cycle. The fuel cost was estimated using the current diesel pricing (₹90/L), and the avoided CO_2 emissions were computed using the standard emission factor of 2.68 kg CO_2 per L of diesel. The sensitivity ranges accounted for changes in pump efficiency and groundwater lift depth.

3. RESULTS AND DISCUSSION

3.1 Understanding AWD and the Importance of Drying Cycles

Alternate Wetting and Drying (AWD) is a water-saving irrigation technique widely promoted in paddy cultivation to reduce continuous flooding. In this method, irrigation water is allowed to recede below the soil surface to a measurable threshold before re-irrigation is done. The number of drying cycles per bigha is therefore a direct indicator of how effectively AWD is being implemented. A higher number of drying events implies stronger adoption, better water-use efficiency, and improved environmental outcomes, including reduced methane emissions and potentially enhanced crop health. Figure 1 visually represents district-level variations in AWD implementation based on the average number of drying cycles recorded during the cropping season (Fig. 1).

3.2 District-Wise Patterns in AWD Adoption

The experimental analysis demonstrates significant differences in AWD adoption between districts. Howrah has the highest level of AWD application, averaging 3.88 drying cycles. This suggests that farmers in this district are actively using controlled irrigation, which is likely aided by increased technical expertise, dependable irrigation management, and access to monitoring instruments such as AWD field tubes. Hooghly follows with 1.51 drying cycles, indicating moderate adoption where AWD concepts are used but not fully optimized (Fig. 2). Districts like Nadia (1.39) and Purba-Bardhaman (1.36) have a low degree of adoption, indicating either insufficient training outreach or cautious farmer behavior due to perceived risks of production loss (Table 1).

Bankura (1.16) and, in particular, Purulia (0.70) indicate limited AWD installation. These low figures indicate issues such as reliance on rainfall, poor irrigation infrastructure, a lack of technical support, or traditional beliefs that promote continuous flooding of rice fields. The significant disparity between Howrah and the low-performing districts underlines the necessity for targeted interventions.

3.3 Methane Emission Reduction through Alternate Wetting and Drying (AWD)

The examination of greenhouse gas mitigation outcomes associated with the use of Alternate Wetting and Drying (AWD) irrigation practices revealed a significant reduction in methane emissions over the monitored rice crop area of 285.67 hectares. Using a standardized emission reduction coefficient of 2 $tCO_2e\ ha^{-1}\ season^{-1}$, the total methane abatement owing to AWD was estimated at 571.34 tCO_2e over the research period. This amount of emission reduction demonstrates the efficacy of AWD as an intervention capable of drastically decreasing methane fluxes when compared to traditional continuous flooding systems. The observed mitigating impact is due to AWD's repeated drying cycles, which disturb long-term anaerobic soil conditions and allow for temporary aerobic phases. These aerobic intervals restrict methanogenic archaea and alter microbial community dynamics, reducing the metabolic pathways that produce methane in flooded rice fields.

The findings are consistent with global research demonstrating AWD's ability to reduce emissions by altering soil redox potential, reducing labile carbon availability for methanogenesis, and enhancing methane oxidation rates. Overall, the observed reduction in emissions demonstrates AWD's high potential as a climate-smart agricultural strategy, particularly when applied to large irrigated rice fields with considerable cumulative emission effects.

3.4 Comparison with Global Emission Mitigation Estimates

The estimated mitigation value closely matches global empirical evidence. According to Sylvera (2025) and Ceezer Earth (2025), AWD systems in South Asia can reduce methane by 1.5 to 3.0 $tCO_2e\ ha^{-1}\ season^{-1}$, depending on irrigation frequency, soil texture, and measurement methodology. The current study's emission reduction coefficient of 2 $tCO_2e\ ha^{-1}$ falls within the globally approved interval, ensuring the results' trustworthiness and comparability.

3.5 Implications for Climate-Smart Rice Production

The demonstrated mitigation potential confirms AWD as a high-impact climate-smart agricultural practice with the dual benefits of irrigation water savings and measurable greenhouse gas reduction. When extrapolated to larger command areas, AWD adoption presents significant opportunities for strengthening national methane reduction strategies and advancing carbon market participation through validated, scalable abatement outcomes. These results reinforce AWD as a viable nature-based solution contributing toward low-carbon rice production systems and sustainable intensification objectives.

3.6 Implications for Water Savings, Climate Benefits, and Yield

Higher drying cycles correspond to increased periods of aerobic soil conditions, which significantly reduce methane emissions—a major greenhouse gas produced under continuously flooded rice cultivation. Therefore, high-adoption districts such as Howrah are likely contributing more effectively to climate mitigation and irrigation resource conservation. Moreover, AWD has demonstrated the potential to maintain or even improve yields when executed correctly, emphasizing that awareness and training gaps—rather than agronomic barriers—may be the primary reason behind low adoption in regions like Purulia and Bankura.

The results demonstrate measurable water-use efficiency improvements attributable to the adoption of AWD. Using a standard baseline of 25 irrigation events per season under continuous flooding, the reduction in irrigation frequency facilitated by drying cycles directly determines water conservation potential. Each drying event prevents one irrigation cycle, saving approximately 60 $m^3\ ha^{-1}$ (FAO, 2020; IRRI, 2025), enabling a quantifiable estimate of water savings.

District-wise drying cycle averages showed that Howrah achieved the highest water savings of 15.52%, equivalent to 232.8 $m^3\ ha^{-1}$ of irrigation water preserved per season. Moderate savings were recorded in Hooghly (6.04%), Nadia (5.56%), and Purba-Bardhaman (5.44%), while relatively low-adoption regions such as Bankura (4.64%) and Purulia (2.80%) demonstrated limited water savings (Table 2).

These results affirm the potential of AWD as a sustainable water management mechanism capable of reducing irrigation water demand without compromising crop productivity. When scaled across larger irrigated rice landscapes, these savings translate into millions of cubic meters of conserved water while supporting groundwater recharge and energy-use reduction.

3.7 Economic Valuation of Water Savings Under AWD Irrigation

The implementation of Alternate Wetting and Drying (AWD) irrigation across 285.67 hectares of rice cultivation demonstrated substantial potential for methane emission mitigation. Based on the application of the standardized IPCC Tier-1 emission reduction coefficient for AWD (2 tCO_2e ha^{-1} $season^{-1}$), the estimated total methane abatement achieved during the study period was 571.34 tCO_2e. This reduction reflects the biogeochemical impacts of AWD on soil microbial processes, wherein periodic drying cycles induce temporary aerobic conditions that restrict the activity of methanogenic archaea responsible for methane production under continuously flooded anaerobic environments. The alternation between aerobic and anaerobic phases under AWD alters soil redox potential, decreases labile carbon availability for methanogenesis, and enhances the oxidation of methane prior to its release to the atmosphere. The observed mitigation performance aligns with global empirical evidence that recognizes AWD as an effective methane-reduction strategy in irrigated rice ecosystems. These findings reinforce the relevance of AWD as a scalable climate-smart agricultural practice capable of significantly reducing greenhouse gas emissions while maintaining agronomic viability and supporting regional mitigation targets. Further large-scale adoption could therefore contribute meaningfully to national commitments on low-carbon agricultural development and climate policy frameworks.

3.8 Fuel Savings and Associated Cost Reductions

Implementation of AWD reduced the frequency of irrigation pumping events across the monitored 285.67 ha. Based on an average of 2.23 drying cycles, approximately 637 irrigation events were avoided, resulting in 4,778 liters of diesel saved under the central estimate (with sensitivity variations between 2,548 and 7,645 liters depending on pump performance and lift conditions). At a prevailing diesel price of ₹90 per liter, this corresponds to an avoided expenditure of ₹4.30 lakh, or ₹1,503 ha^{-1}, demonstrating significant cost savings for smallholders through reduced irrigation energy demand. These results indicate that AWD delivers substantial economic gains even without subsidies or carbon-credit incentives, establishing clear financial value as a standalone intervention (Table 3 and Table 4).

3.9 Energy-Linked Carbon Emission Reductions

The reduction in diesel usage also generated measurable climate benefits. Using the standard emission factor of 2.68 kg CO_2 per liter, total avoided fuel combustion corresponds to 12.80 tCO_2 across the intervention area (range: 6.83–20.49 tCO_2). This quantification demonstrates the additional mitigation value generated through reduced fossil fuel dependence, complementing methane-related benefits typically emphasized in AWD studies (Table 3 and Table 4).

3.10 Methane Abatement Contribution and Combined Emission Reduction

Methane mitigation resulting from intermittent drying was estimated at 2.0 tCO_2e ha^{-1}, totaling 571.34 tCO_2e avoided across the 285.67 ha area. Combined with diesel-linked reductions, the total avoided emissions reach 584.14 tCO_2e (range: 578.17–591.83 tCO_2e), equivalent to 2.045 tCO_2e ha^{-1}. While methane reduction remains the dominant component, energy-related reductions add meaningful incremental climate benefit, reinforcing AWD as a dual-pathway mitigation strategy (Table 3 and Table 4).

3.11 District-Level Comparative Performance

District-wise analysis of diesel savings and associated carbon reductions (Table 4) indicates clear variability aligned with AWD adoption intensity measured through drying cycle frequency. Howrah, with the highest mean drying cycles (3.88), recorded the largest per-hectare savings (29.12 L diesel and 78 kg CO_2 avoided per ha). In contrast, Purulia, with the lowest adoption (0.70 cycles), achieved limited reductions (5.25 L and 14.1 kg CO_2 per ha), highlighting barriers in local adoption dynamics related to irrigation access, system readiness, or awareness. Intermediate performance in Hooghly, Nadia, and Purba Bardhaman reflects proportional relationships between drying-cycle adherence and performance outcomes. These results validate drying-cycle frequency as a reliable field-level indicator for efficiency and climate performance, identifying priority districts for targeted extension and monitoring support.

4. IMPLICATIONS FOR CLIMATE-SMART AGRICULTURAL SCALING

The unified findings confirm AWD as a high-impact, climate-smart practice that delivers significant economic savings, reduced fossil-fuel emissions, and substantial methane abatement without compromising productivity. Notably, the intervention in this study was limited to training support and the installation of monitoring pipes, with no financial incentives or subsidies provided, demonstrating that even as a standalone solution—without carbon-credit mechanisms—AWD offers a compelling economic and environmental rationale for large-scale adoption. Effective scaling across irrigated rice systems will require strengthened capacity-building, continuous monitoring infrastructure, and enabling policy frameworks aligned with climate and energy transition goals. The heatmap analysis further indicates the need for location-specific strategies: districts with lower adoption levels demand focused interventions such as demonstration plots, farmer field schools, enhanced digital and social media outreach, and community-based irrigation scheduling supported by field water tubes for real-time monitoring, while high-performing districts like Howrah can act as knowledge hubs and peer-learning platforms to accelerate regional diffusion and foster cross-district experience sharing.

5.CONCLUSION

The implementation of Alternate Wetting and Drying (AWD) irrigation in major rice-producing regions in West Bengal shows great promise for increasing irrigation efficiency and lowering greenhouse gas emissions in smallholder systems. AWD implementation resulted in notable environmental improvements, including an estimated methane reduction of 365 tCO_2e and significant irrigation water savings, with an average of 2.23 drying cycles recorded across 285.67 hectares. These findings show AWD as a viable, climate-smart solution capable of increasing water efficiency and cutting production costs while maintaining yield.

However, adoption patterns varied significantly across districts due to differences in irrigation access, extension support, farm size, and local agroecological factors. enhanced adoption in districts such as Howrah highlights the need of targeted capacity-building operations, real-time monitoring technologies, and enhanced farmer knowledge in Bankura and Purulia.
To accelerate scale, coordinated governmental support, incentives for water and energy conservation, and possibilities through carbon credit systems are required. Future study should focus on precisely measuring methane flux, analyzing long-term yields, and developing digital decision-support technologies. Overall, AWD is a viable approach for increasing climatic resilience, resource efficiency, and sustainability in West Bengal rice cultivation.

Table 1: Average Drying per bigha

District	Avg. Drying Cycles	Interpretation
Howrah (3.88)	Highest	Strong AWD adoption and farmers practicing multiple drying events, indicating effective water management, potential reduction in methane emissions, and higher awareness levels.
Hooghly (1.51)	Moderate	Indicates partial adoption; AWD practiced but with fewer cycles, possibly due to water availability or traditional preferences.
Nadia (1.39) & PURBA-BARDHAMAN (1.36)	Moderate-Low	Indicates reluctance or limited technical support for regular drying.
Bankura (1.16)	Low	Possibly due to rain-fed conditions or low irrigation access affecting controlled drying cycles.
Purulia (0.70)	Lowest	Minimal AWD adoption; fields may remain continuously flooded or drying is not systematically monitored.

Table 2: District-Wise Estimation of Water Savings

District	Avg. Drying Cycles (DC)	(%) Water Saving	Water Saved (m^3/ha)	Water Saved (Liters/ha)
Howrah	3.88	15.52	232.8	232,800 L
Hooghly	1.51	6.04	90.6	90,600 L
Nadia	1.39	5.56	83.4	83,400 L
Purba Bardhaman	1.36	5.44	81.6	81,600 L
Bankura	1.16	4.64	69.6	69,600 L
Purulia	0.7	2.8	42.0	42,000 L

Table 3. Combined Benefits of AWD implemented blocks

Parameter	Low Scenario	Central Estimate	High Scenario
Diesel saved (L)	2,548	4,778	7,645
Diesel cost savings (₹)	₹229,320	₹430,020	₹688,050
CO_2 avoided from diesel (tCO_2)	6.83	12.8	20.49
Methane abatement (tCO_2e)	571.34	571.34	571.34
Total emissions avoided (tCO_2e)	**578.17**	**584.14**	**591.83**
Total per-hectare avoided ($tCO_2e\ ha^{-1}$)	2.024	2.045	2.072

Table:4 Diesel Cost and CO_2 Reduction—Total Area Perspective

District	Avg. Drying Cycles	Relative AWD Intensity	Diesel Saved (L/ha)	Cost Saved (₹/ha @₹90/L)	CO_2 Avoided (kg/ha)
Howrah	3.88	Highest	29.12	₹2,621	78
Hooghly	1.51	Moderate	11.33	₹1,020	30.4
Nadia	1.39	Mod-Low	10.43	₹939	28
Purba Bardhaman	1.36	Mod-Low	10.2	₹918	27.3
Bankura	1.16	Low	8.7	₹783	23.3
Purulia	0.7	Lowest	5.25	₹472	14.1
Overall AWD Mean (Study)	**2.23**	–	**16.73 L/ha**	**₹1,503/ha**	**45.0 kg/ha**

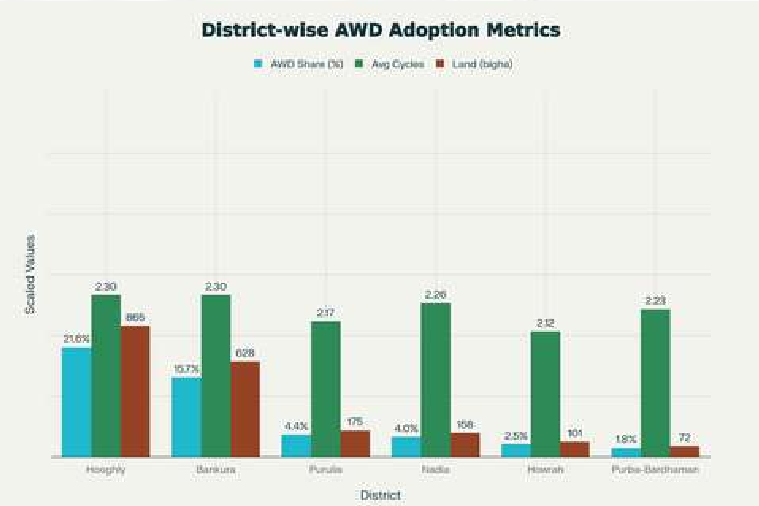

Fig. 1 AWD Implementing regions (land holdings) and average drying cycles

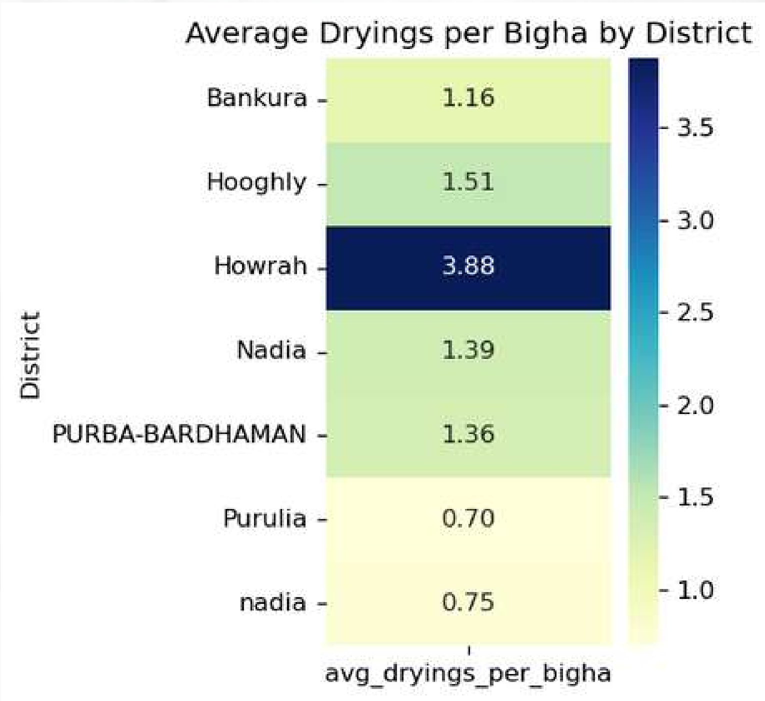

Fig. 2 AWD Implementing regions (land holdings) and average drying cycles

Fig. 3(a): Districtwise Irrigation Water saving (a) and Economics (b) due to AWD interventions

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