POLICY Brief

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Bridging the Irrigation Potential Gap in Canal Commands-

A Plausible Approach

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KEY MESSAGES

- Judicious irrigation scheduling in canal command through the volumetric supply of water as per crop water demand would not only save water but could bring more area under irrigation, minimizing the irrigation potential lag in canal commands.
- The present scenario of irrigation in canal command and, thereby, the expanding water influence zone necessitates modification of the protocol for estimating the irrigation potential utilized in the canal command.
- Alternative cropping patterns and crop diversification can generate income and enhance economic water productivity for farmers in canal commands.
- Climate-resilient, high-value, and less-water-intensive perennial crops can enhance climate resilience in canal irrigation systems.
- Designing irrigation systems that combine the use of surface and groundwater can ensure more crops per drop under the escalating climate vagaries.

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Problem Statement

The canal irrigation system in India plays a crucial role in agricultural productivity and rural livelihoods. However, its efficiency is hindered by suboptimal water management and agronomic practices, resulting in reduced economic water productivity. The increasing irregularities of monsoonal weather have a trickling impact on the canal irrigation systems in India. As is known, water availability is the primary constraint in irrigation systems, even under normal rainfall conditions. Therefore, there needs to be a higher focus on enhancing both Physical Water Productivity (PWP), which is the production from a unit of consumptive water use (CWU) (kg/m^3) and Economic Water Productivity (EWP), which is the value or profit generated from a unit of CWU (\$/m^3). The limited availability of CWU due to an irregular monsoon is a constraint for increasing crop yield and PWP. Therefore, it is critical to maximize the value and profit of agricultural production from every unit of CWU through climate-smart and resilient cropping patterns. Interventions in this area can help withstand the challenging effects of an irregular monsoon and ensure year-round irrigation for all farmers.

Furthermore, the non-availability of infrastructure for volumetric water supply and the non-adoption of standard irrigation scheduling in some irrigation systems is the reason for large gaps in IPU and IPC. However, in some other irrigation systems, with significant reuse of canal irrigation water in and outside the command area and direct pumping from the reservoir to the catchment areas, the water influence zone (WIZ) of the reservoir is larger than the canal command area. The WIZ includes the canal command area, a buffer zone outside the command area, and a lift-irrigated area from the reservoir. The current approach to canal irrigation management fails to account for the water influence zones beyond the Culturable Command Area (CCA), leading to a discrepancy between actual and perceived water availability and productivity. This oversight results in the underutilization of water resources and suboptimal agricultural output, perpetuating rural poverty and hindering overall economic development.

Thus, to better understand the design of intervention required to increase EWP in irrigation systems, researchers from the International Water Management Institute (IWMI), Indian Council of Agricultural Research (ICAR) - Indian Institute of Water Management (IIWM), Bhubaneswar and Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri Maharashtra performed two pilot studies in *Sina* medium irrigation system and *Kukadi* Left Bank Canal (KLBC) major irrigation system in Maharashtra, India. This policy brief highlights some of the key findings of an analytical framework derived from these pilot studies to inform policymakers on alternative cropping patterns and the hydro-economical trade-off to enhance resilience in irrigation systems.

Research Approach

The *Sina* and *Kukadi* commands with 8,444 ha and 138,000 ha of designed CCA are categorized

under medium and major irrigation systems, respectively. In India, a medium irrigation project command area is in the range of 2000 to 10000 ha, whereas, major and minor irrigation systems cover more than 10,000 ha and below 2000 ha CCA, respectively. The analytical framework in the study postulated that an irrigation system's typical WIZ encompasses the command area and an area outside the designated command. The study used groundwater modelling to demarcate the WIZ. The canal command area is in the WIZ by design. The WIZ also includes a buffer zone outside the command area that reuses irrigation return flows from the command area. Some irrigation systems may also have areas inside the reservoir catchment that receive irrigation from direct lifting from the reservoir (lift irrigated area). The land-use pattern (LUP) in the WIZ depends on the water availability from effective rainfall, reservoir water supply, groundwater withdrawals, and smaller surface water bodies in the WIZ. The groundwater resources in the WIZ mainly include recharge from rainfall, reservoir storage, and canal irrigation.

Modified Water Cost Curve (WCC) was developed from these two case studies to assess the hydro-economical trade-off that included the financial trade-off of conventional crop cultivation methods with micro irrigation technologies (*viz.* drip and sprinkler irrigation, sub-surface drip, drip with fertigation, etc.), and with advanced agronomic and irrigation practices (*viz.* system of rice intensification, alternative wet and dry irrigation, direct seedling, ridge and furrow planting method, integrated nutrient management etc.).

Due to flat topography, field observations and key expert opinions were sufficient to assess the extent of the buffer zone in *Sina*; however, the sloping topography required groundwater modelling to identify the buffer zone in the KLBC command. The scope of irrigation performance assessment in *Sina* was at the system level, and in *Kukadi* was at the Water User Association (WUA) level. The analytical framework for the performance assessment includes:

- Land use and cropping patterns assessment in the WIZ and WUAs using geo-spatial, Google Earth Engine (GEE), and subsequent ground truthing.
- Water use efficiency estimation by conducting water accounting procedures.
- PWP of individual crops and EWP of crops and cropping patterns of WUA and in the WIZ.
- Water cost curve development for assessing crop diversification trade-offs in the canal commands.
- Scenario assessment of alternative crop and technology use for enhancing EWP in *Sina* and KLBC systems.
- The farmer's perspective on the performance of WUAs.

Water Influence Zone vis-a-vis Cropping Patterns

With a flat topography, the *Sina* WIZ is substantially larger than the CCA while undulating and sloping topography on one side and the *Kukadi* river being the boundary on the other side, KLBC's WIZ is more or less similar to the CCA (Fig. 1). The groundwater recharge in the KLBC was estimated to vary from 8-9% of the annual rainfall. Due to the presence of the *Kukadi* river on the left, the WIZ of the KLBC is spread towards the right bank. However, the WIZ is limited to a relatively smaller area because of high elevated lands at the right bank of KLBC. Results of groundwater modelling revealed that at the canal head reach, WIZ is spread to only 1 km, while 2.5-3 km at the middle and tail reaches of the canal command.

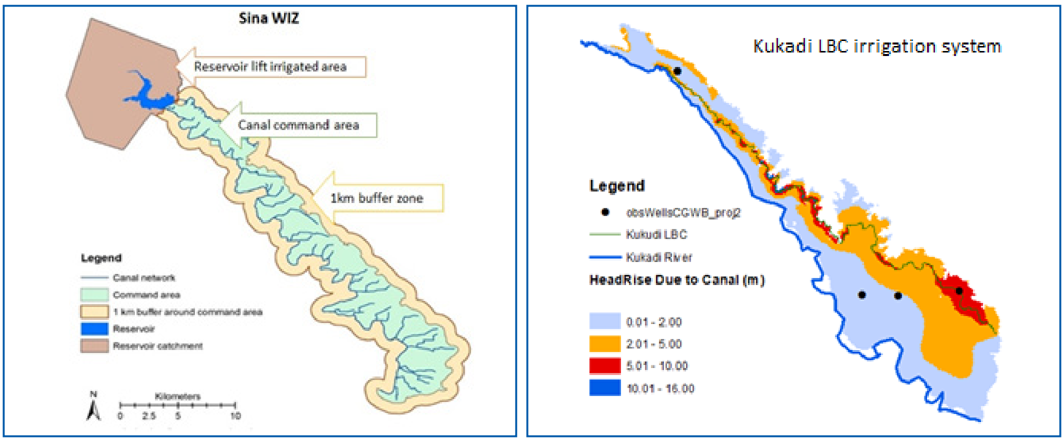

Fig.1. Water influence zone (WIZ) in *Sina* and *Kukadi* canal commands

Geo-spatial data-based analysis indicated 8000 ha and 225000 ha cropped area in *Sina* and *Kukadi* canal command CCA, respectively (Fig. 2A and 2B). The cropped area estimates in *Rabi* and summer seasons are substantially underestimated compared to the data of line department (Fig. 2C and 2D). Much of the underestimation is in perennial crops.

The cropping intensity (*i.e.* total cropped area/CCA) estimated using geo-spatial tools and techniques is significantly higher than the records by line department (Table 1). In KLBC, the cropping intensity obtained using geo-spatial data analysis is double the area as compared to official records. The geo-spatial analysis pertaining to land use intensity (LUI) estimated by adjusting the contribution of annual crops is substantially higher due to the difference in the annual cropped area, which includes sugarcane and fruits (*viz.* Grapes, Pomegranates, bananas, etc.).

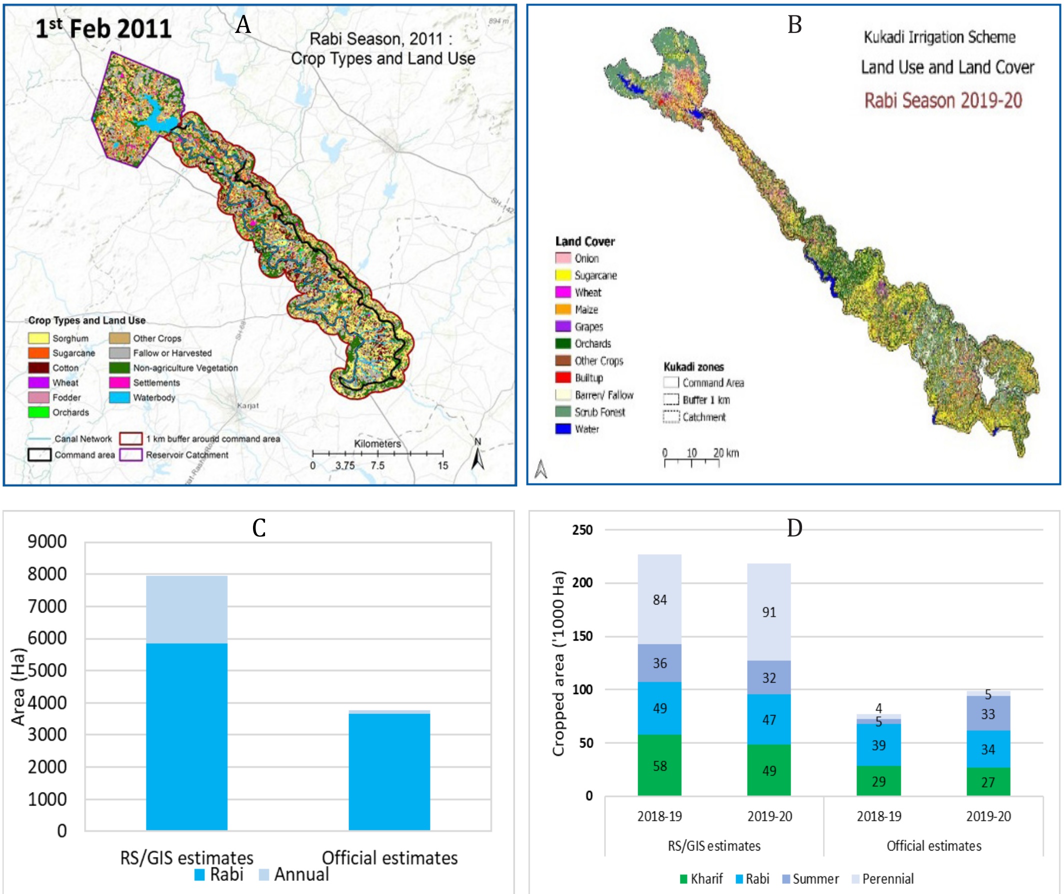

Fig.2. Land use and land cover patterns analyses and cropped area using geo-spatial tools

Table 1. Cropped area (ha) and Cropping Intensity (%) in the KLBC

Type	Year	Kharif season		Rabi season		Summer season		Annual	Total		
		Cropped Area	CI	Cropped Area	CI	Cropped Area	CI	Cropped Area	Cropped Area	CI	LUI (%)
Geospatial	2018-19	58067	103	49195	96	35700	86	83603	226564	164	220
	2019-20	48753	101	46541	100	32155	92	91136	222130	161	233
Data archive of line department	2018-19	30093	25	41049	33	5038	7	4571	80751	59	30
	2018-20	28535	25	35986	30	33873	29	5495	103889	75	38

Google Earth Image analysis showed extensive spatial scattering of open wells and farm ponds in the command areas (Fig. 3). There are about 10640 open wells and 4330 farm ponds in the KLBC command area. Additionally, ground surveys revealed that KLBC has substantial water augmentation in the middle and tail reaches of the CCA with direct lifting from the *Ghod* and other reservoirs. Open wells encourage reusing the recharge due to the irrigation in the canal command. It was observed that due to the farm pond, the stored water was able to meet the water shortages in middle-to-tail reaches of the canal command. Farmers fill the ponds once or twice a year by lifting water from the canal or open/tube wells to meet the lean season water requirement. The contribution from these water sources in canal command areas is substantial and needs to be included while carrying out the performance assessment of other canal commands in the country.

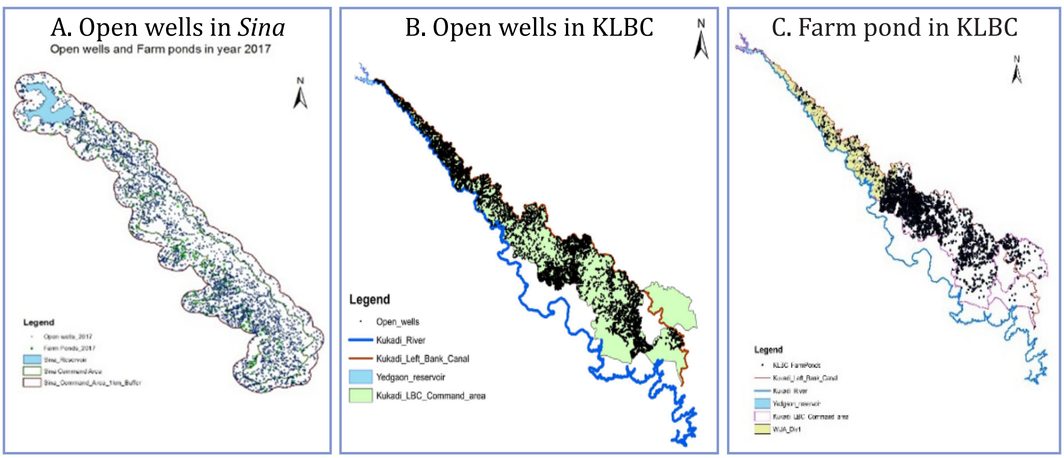

Fig. 3. Open wells and farm ponds in the CCA of both commands.

Climate-Resilient, High-Value and Less-Water Intensive Perennial Crops under Changing Climate

Based on geo-spatial estimates and water accounting, the water use efficiency (WUE), i.e., the ratio of irrigation CWU to the total water supply of both irrigation systems, is substantially higher than the official estimates (Table 2). The total water supply is the sum of irrigation released from the reservoir and groundwater recharged from rainfall, which was assumed to be 11% of the total rainfall in the command area.

The WUE in both systems was about 50%, as per the official data. However, with the larger cropped areas under geo-spatial methods, the WUE in *Sina* and KLBC are 56 and 100% higher, respectively. Further increase in actual evapotranspiration or irrigation CWU in both systems to increase the WUE would be extremely difficult. Keeping in view that the average annual rainfall during 2010-11 and 2019-2020, which were above the average for *Sina* & KLBC command, respectively, it will be even more challenging to increase irrigation CWU and thereby increase WUE in low to moderate rainfall years.

Table 2. Water budgeting parameters in the *Sina* and KLBC commands

Water accounts and Indicators	*Sina*		KLBC	
	Official	Geo-spatial	Official	Geo-spatial
Total rainfall on CCA (Mm^3)	72		1554	
Irrigation supply (Mm^3)	29		611	
Rainfall recharge @11% of rainfall (Mm^3)	8		171	
Total water supply (Mm^3)	37		782	
Cropped area in *Rabi* & Hot Weather (1000 ha)	4.8	8.4	74.2	169.8
Total cropped area (1000 ha)	4.8	8.4	101.4	218.6
Irrigation CWU (Mm^3)	18.8	29.5	395.8	1087.3
Total CWU (Mm^3)	20.3	40.6	535.9	1732.0
Value of production (MUSD)	2.1	8.1	163.3	666.1
Irrigation supply (m^3/ha)	6045	3453	6028	2796
Water Supply (m^3/ha)	7688	4391	7714	3578
Water supply/IRCWU	1.97	1.26	1.40	0.72
WUE	0.65	0.80	0.65	1.39
Land Productivity (USD/ha)	431	956	1647	3127
EWP (\$/m^3 of TCWU)	0.10	0.20	0.31	0.39

Notes: Only *rabi* and hot weather areas is considered for the irrigated area

The productivity indicators estimated using the official and geo-spatial data sources are also substantially different. In both the systems, the land productivity (USD/ha), analysed using geo-spatial data was estimated to be twice than that estimated from the official statistics. The economic water productivity estimates based on geo-spatial data is 100% higher in *Sina* and more than 50% in KLBC. Such estimates can be attributable to these productivity differences due to higher high-value cropped area estimated in the canal commands.

Substantial variation of economic water productivity existed between crops. Orchard crops had higher land and water productivity (Fig. 4). Sugarcane, an annual crop had higher land productivity but substantially lower water productivity. Tomatoes grown in the hot weather season were observed to have more land and water productivity, contributing to higher water and land productivity than *Kharif* or *Rabi* seasons. There is scope for improvement of EWP through higher-value crops, mainly by reallocating water from water-intensive crops such as sugarcane to low water-intensive perennial crops such as pomegranate or remunerative seasonal crops such as vegetables.

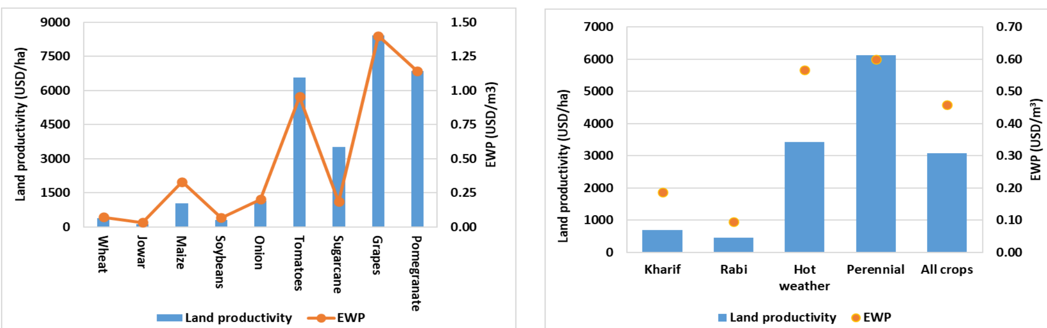

Fig. 4. Crop and seasonal land productivity and EWP of *Kukadi* irrigation system

Substantial productivity variation existed between water user associations (WUAs) (Fig. 5). Land productivity varied from 2354 to 4189 USD/ha, and EWP varied from 0.36 to 0.65 USD/m^3. EWP was generally higher in WUAs with larger annual crop areas, and the EWP was even larger without sugarcane in annual cropping patterns (Fig. 5).

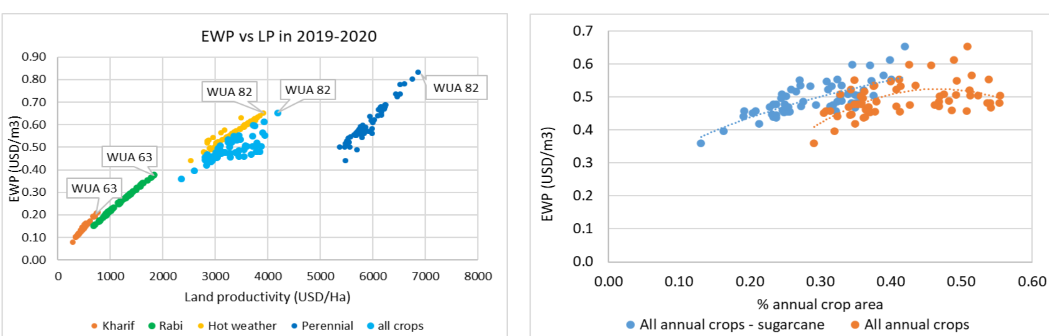

Fig. 5. Productivity variations across WUAs in *Kukadi* irrigation system

The productivity of WUAs was positively associated with cropping intensity and negatively with crop diversification.

The cost curve for EWP showed the potential to combine crops with technologies to increase EWP, the net production value, or reduce the irrigation CWU. It also showed the water and financial trade-off of allocating irrigation CWU of one crop with the other. The Y-axis of the cost curve showed the net value of output, *i.e.*, (value of production – total cost of production) per unit of irrigation CWU of different crops with conventional production or combined with advanced technologies and agronomic practices (Fig. 6). The X-axis indicated the EWP per irrigation CWU. The cost curve showed that tomatoes with drip irrigation had the highest net value of output per unit of irrigation CWU. Even with advanced technologies or agronomic practices, sugarcane had lower EWP and net output value than other perennial crops (*viz.* orchards) or vegetables such as tomatoes.

Two alternative scenarios of cropping and technology use patterns or irrigation CWU allocation patterns are presented in Table 3. These alternative patterns resulted in either net value of output (NVOUP) gains, or irrigation CWU savings, or both.

- The base scenario (BAU) was the cropping pattern in 2019-20. It was observed that about 1105 Mm^3 was needed to generates 38 B USD of NVOUP.
- Scenario-1 exhibited the differences when existing cropping patterns used advanced technologies or agronomic practices. Under such scenario, the NVOUP would increase by 80%. Since the CWU estimation used the potential evapotranspiration and was based on the assumption that the irrigation will require no extra transpiration to increase crop yield.
- Scenario-2 was based on the diversion of 10% of irrigation CWU of sugarcane to other crops. Under such a scenario, the sugarcane area would be reduced by 3319 ha. Because most of the CCA is already cropped in the *Kharif* and *Rabi* seasons, it was assumed that only the reduced sugarcane area can be replaced with another annual crop, such as pomegranate. Because pomegranate uses less irrigation CWU. Thus, the saved CWU could be allocated to increase the summer season cropped area. Water savings were observed to be sufficient to double the summer tomato crop area. Therefore, the new cropping patterns as per the scenario would generate 7% more net output value over the base scenario.

In the KLBC command, entrepreneurial farmers had adopted diversified cropping patterns to reap substantial benefits, contributing to high WUA performance. Case study pertaining to one entrepreneur in the command *viz.* Mr. Rahul Rasal in WUA 21, initiated farm activity with only two acres and presently owns 40 acres of land. His farming operations under the 300-400 mm rainfall regime were genuinely entrepreneurial. Fully equipped with a weather station, Mr. Rasal grows high-value crops such as grapes and pomegranates on 10 acres and exports the product to get high returns. Mr. Rasal adopted a diversified cropping pattern, including vegetables, grape and pomegranate fruit crops, cereals, and pulses in other areas. Besides this, Mr. Rasal uses advanced water-saving irrigation methods and water management technologies pertaining to the use of drip, sprinkler, and underground irrigation. Beyond the climate and agronomic services, Mr. Rasal's contribution to society by providing employment and other benefits to 40 farm families was a success story in the canal command and can be replicated by other stakeholders.

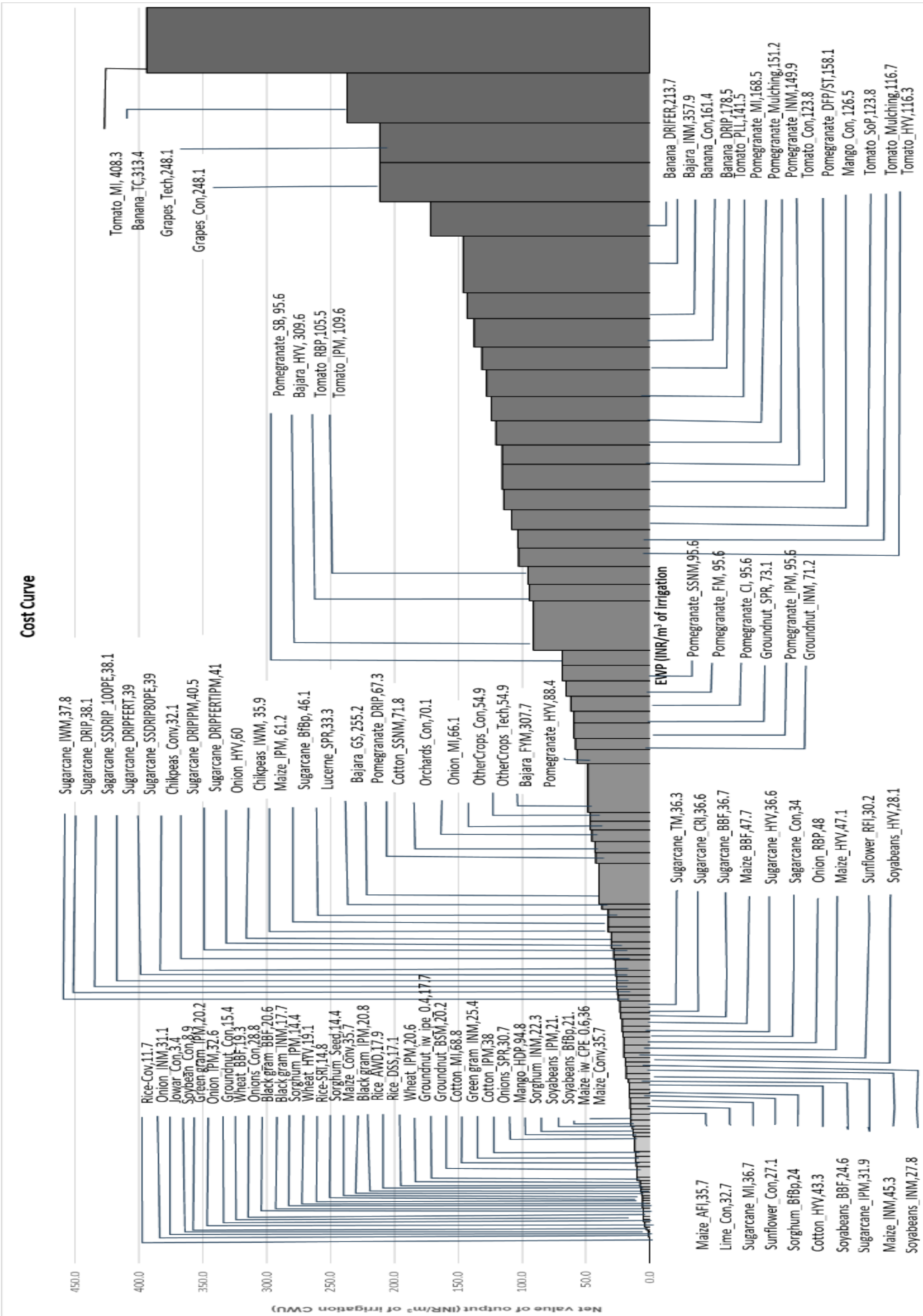

Fig. 6. Cost curve for EWP

Table 3. Alternative scenarios of cropping or irrigation patterns

Crops	Area in 2019-2020 (ha)			Irrigation consumptive water use (IRCWU) m³/ha			BAU Scenario			Scenario -1			Scenario -2	
Crops	*Kharif*	*Rabi*	Summer	*Kharif*	*Rabi*	Summer	NVOUP/ IRCWU (USD/ m³)	Total IR CWU (Mm³)	Total NVOUP (B USD)	Crop and technology	NVOUP/ IRCWU (USD/ m³)	Change in total VOUP (B USD)	Change Total IR CWU (Mm³)	Change in Total NVOUP (B USD)
Wheat	0	5400	0		4992			27	0.0	Wheat-IPM	7	+0.2		
Maize	5526	5283	3448	555	2585	5423	15	35	0.5	Maize + IPM	32	+0.6		
Sorghum	5388	13732	4186	469	4120	4763	-4	79	-0.3	Sorghum+BfBp	16	+1.6		
Soybean	7642	0	0	1374			1	11	0.0	Soybean+HYV	19	+0.2		
Onions	1569	7440	3905	682	3073	6739	5	50	0.3	Onions+MI	46	+2.0		
Tomato	0	0	4185			5124	116	21	2.5	Tomato+MI	131	+0.3	+25	+2.9
Sugarcane	33192	33192	33192	13545			21	450	9.6	Sugarcane+BfBp	33	+5.1	-45	+1.0
Grapes+drip	18210	18210	18210	2238			211	41	8.6	Grapes+Drip	211	+0.0		
Pomegranate	39734	39734	39734	5890			43	234	10.1	Pomegran-ate+MI	128	+19.8	+20	+0.8
Other Crops (Pulses)	27739	12212	-	555	3073	-	36	61	2.2	Others (Pulses)	36	+0.0		
Other vegetables	-	-	3343	-	-	5870	47	96	4.5	Other vegeta-bles	47	+0.0		
Total	139889	137473	123087					1105	37.9			+29.8	0	+2.7

Notes: IPM – Integrated pest management; Bf Bp – Bio fertilizer and Bio pesticide; HYV- High yielding varieties; MI- Micro irrigation

Recommendations for Enhancing Water Productivity in the Canal Command

- Comprehensive assessment using modern technologies and techniques, such as geo-spatial tools are required to delineate and quantify the extent of water influence zones beyond the CCA and its cropping patterns. The cropping pattern in the WIZ is important information in assessing the potential for further increase in the cropped area.
- The Departments of Water Resources of the State Government should reassess the existing databases before deciding on investments for expanding irrigated areas and increasing WUE.
- Estimate of groundwater use from the recharge from canal irrigation and rainfall is important for assessing the further potential for increasing the irrigated area. WUE of irrigation systems depends on the cropping pattern and extent of water use in the WIZ.
- The conjunctive use of groundwater, surface water, and rainfall is required for deciding the cropping patterns that will increase economic water productivity. Further, policy interventions and institutional mechanisms must be implemented to facilitate the equitable distribution and efficient utilization of water resources, taking into account both the canal command area and the water influence zones.
- Crop diversification with the inclusion of high-value crops in water-scarce regions should be devised to improve economic water productivity and enhance farmers' resilience even in dry years. Such protocol would assist the canal command areas in water-scarce irrigation systems and under changing climate situations.
- Linkages with the state agricultural universities, Line Departments of State Government, ICAR Institutes and KVK should be established to enable farmers to use best management and good agricultural practices pertaining to crop diversification and implementation of water management technologies in the canal command.
- Young entrepreneurs should be promoted through capacity-building programs in canal commands to serve as service providers. They will be a vital part of the value chain for increasing WUE and EWP.

Scope and Limitations of the Study

- Spatial variation of crop yields was not available for a detailed analysis. The district-level data did not exhibit the variation across WUA. Given the extent of canal command, it is impossible to do extensive crop-cutting surveys across the WUAs. Studies must use artificial intelligence and machine learning techniques with satellite data to gauge the spatial variation of crop yields.
- Due to limitations of data availability, the spatial and temporal variation in the rainfall depth was not accounted for in the present study. Groundwater recharged from rainfall, reservoir storage and canal irrigation requires further assessment. The present assessment used observations from only a few observational wells. However, data at a finer resolution would assist in better assessment of groundwater availability and recharge in the canal command leading to a more plausible performance assessment of the canal command.
- The understanding of water governance for transformative changes in irrigated agriculture in canal command areas was inadequate. Therefore, a comprehensive investigation for identifying water governance framework with proper accounting principles to address income disparities among stakeholders and to ascertain the better performing water user associations.