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A re-look at canal irrigation system performance: a pilot study of the Sina irrigation system in Maharashtra, India

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Abstract

The general perception of canal irrigation systems in India is one of built infrastructure with low service performance. This paper presents an analytical framework, applied to the Sina medium irrigation system in Maharashtra state of India, to study the performance of an expanded water influence zone (WIZ) including a buffer zone outside the canal command area (CCA) influenced by the irrigation system's water resources. The framework used satellite-based estimates of land-use and cropping patterns. The results indicate that there is hardly any gap between the irrigation potential created (IPC) and the irrigation potential utilized (IPU) in the CCA. The fraction of consumptive water use (CWU) of irrigation is low in the CCA, but almost one in the WIZ, due to the reuse of return flows in the WIZ. Future investments should focus on increasing economic water productivity ($/m^3) in order to enhance the resilience of the farming community in the WIZ, which is frequently affected by water scarcity.

Keywords: Canal irrigation system; Consumptive water use; Economic water productivity; Irrigation potential; Water influence zone; Water-use efficiency

Highlights

- An expanded water influence zone shows a holistic approach to performance assessment of canal irrigation systems.
- The satellite-based estimate shows the underestimation of the cropped area.
- The consumptive fraction of water is high in the WIZ.

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- The assessment of an irrigated area and water-use efficiency requires a new direction.
- Increasing economic water productivity is the way forward for water-scarce canal command systems.

Introduction

Efficiency and productivity of water use are topical issues that dominate discourses of performance in the water sector in general and canal irrigation systems in particular. In India, low water-use efficiency (WUE) and productivity, and the widening gap between the irrigation potential utilized (IPU) and irrigation potential created (IPC) are major concerns in canal irrigation performance. Because of these concerns, the general perception of canal irrigation systems in India is that of massive physical infrastructure with low irrigation performance. Inadequate understanding of the benefits generated from return flows of canal irrigation, which some considered as wastage, leads to inaccurate performance assessment (Kumar *et al*., 2010; Jagadeesan *et al*., 2016). This paper re-looks the performance assessment of canal irrigation with crop area information derived from satellite data and improved water accounting. This re-look is increasingly essential for water-scarce irrigation systems given the increasingly variable weather patterns in recent years.

A persistence concerns of low performance are the widening gap between IPC and IPU, the low consumed fraction (CF) and water productivity (WP). The IPC and IPU are the potentially irrigable area and the actual irrigated area in an irrigation system, respectively. The CF is the ratio of crop evapotranspiration (from intended and unintended processes) to water withdrawals (Perry, 2007), which is popularly referred to, by irrigation managers and policy makers (GoI, 2013), as irrigation WUE. Water productivity (WP) has both physical (kg/m^3) and economic (\$/m^3) aspects of water use. These indicators play a vital role in the performance benchmarking of canal irrigation systems (Malano & Burton, 2001; Malano *et al*., 2004; Cameira & Pereira, 2019).

Given the importance of water and food security, an accurate assessment of the performance of India's canal irrigation systems is essential. India has the world's largest canal command area (CCA) equipped for irrigation (FAO, 2020). The western state of Maharashtra has over 3,350 surface irrigation systems, including 86 major (CCA $>$ 10,000 ha) and 258 medium-sized (2,000–10,000 ha CCA) systems. The others with a CCA less than 2,000 ha are minor irrigation systems. The state publishes water audits and benchmark (BM) reports of these canal irrigation systems annually (GoMH, 2018). The BM of 2013–14 reported on about 175 major and medium irrigation schemes using 12 indicators to assess system, agricultural, financial and social performance (GoMH, 2018). However, the accuracy of the IPU in these official BM publications has often been questioned (Purandare, 2012). An accurate estimate of IPU is critical, given that it contributes to estimating several other performance indicators, such as the consumptive water use (CWU) of crops, the CF or WUE, land and water productivity and financial performance.

The focus of performance assessment of canal irrigation systems at present is only on the CCA. For most irrigation managers, the designed CCA is the water influence zone (WIZ) of the water source, be it a reservoir, a run-of-the-river diversion or a lift irrigation project. For them, increasing the irrigation WUE and WP in the CCA is the main, and perhaps, the only goal. However, in many instances, canal irrigation supplies generate return flows for groundwater irrigation in areas inside and outside the CCA (Bhatia *et al*., 2007; Mirudhula, 2014; Jagadeesan *et al*., 2016). Canals create artificial aquatic ecosystems with benefits similar to those from natural streams (Carlson *et al.*, 2019). Many irrigation systems also have provisions for direct pumping from the water source to upland areas in the catchment. These complexities of water supply and use within and outside the CCA in canal irrigation systems require different approaches to performance assessment.

This collaborative pilot study by the International Water Management Institute (IWMI) and the Indian Council of Agricultural Research (ICAR) involved testing an analytical framework to study the performance of an expanded WIZ that included areas outside the CCA but influenced by the irrigation system's water resources. The study used satellite-based technologies (satellite data, RS/GIS, Google Earth maps and open data kit (ODK)) to compile land-use and cropping pattern data. It pilot tested the framework in the Sina irrigation system in Maharashtra, which is a microcosm of the water-scarce medium-sized irrigation system in Maharashtra in particular and India in general.

This paper begins with a comparison of the official information on land-use and cropping patterns in the Sina irrigation system with satellite-derived estimates. It addresses the inaccuracies found in official data and their implications for performance assessment and investment in canal irrigation systems. Section 'Irrigation performance assessment' briefly reviews water-related issues figuring in the recent discourse on performance assessment and policy intervention. Section 'Methodology and data' introduces the analytical framework, methodologies and data employed by the study. Section 'Results' presents the RS/GIS-derived land- and water-use patterns in the Sina irrigation system, and compares the performance indicators of IPU/IPC, WUE and WP estimated from the data available in the official records. Section 'Conclusions' discusses the implications of these findings for irrigation investment in canal irrigation systems.

Irrigation performance assessment

A proper perspective and accurate statistics on performance indicators are essential for informed decision-making (Perry, 1999, 2007; Kumar, 2018; Carlson *et al.*, 2019). Performance metrics and assessments of canal irrigation systems have received considerable attention in water-related discourses over the past few decades due to a lack of clarity on terminology and use (Shah *et al.*, 2012; Shah, 2013; Grafton *et al.*, 2018; Kumar, 2018), and also due to increasing water scarcity along with growing demand for food and more intensive sectoral competition for water (Briscoe & Malik, 2006; Molle & Berkoff, 2006; Amarasinghe *et al.*, 2007; Molden, 2007; Turral *et al.*, 2010). This underlines the importance of accurate information while making water and food security assessments.

Climate change is another dimension that needs to be considered while discussing improvements in canal irrigation performance (Turral *et al.*, 2011; Deshpande *et al.*, 2016; Roxy & Chaithra, 2018). In India, the monsoon season between June and September contributes 75% of the total annual rainfall and is key to the Indian economy. Any significant changes in precipitation that affect water resources will impact growth and output of not only agriculture but also non-agricultural sectors, which at present contribute 85% of the country's gross domestic product (GoI, 2020).

The agricultural sector currently accounts for more than 80% of India's total water withdrawals (GOI, 2020). The figures for irrigation CF range from 25 to 45% (Dhawan, 2017; GOI, 2019), and physical WP varies between 0.08 and 0.9 kg/m^3 for rice, and between 0.24 and 2.03 kg/m^3 for wheat (Sharma *et al.*, 2018). Therefore, increasing both WUE and WP is critical for the country's water, food and rural livelihood security, given a population of 1.2 billion that is largely dependent on agriculture (Brauman *et al.*, 2013; Taheripour *et al.*, 2016; Sharma *et al.*, 2018). Rockström *et al.* (2017) have proposed an operational framework based on a paradigm shift toward sustainable intensification of agriculture. WUE and WP have a crucial role in this framework which integrates the dual and interdependent goals of using sustainable practices to meet rising human needs while contributing to the resilience and sustainability of landscapes, the biophysical system.

In India, the widening gap between IPU and IPC is a major concern relating to food security. The ratio of IPU to IPC has declined from 86% in 1997 to 80% in 2007 and 77% in 2012 (GOI, 2010, 2019). A study (Datta *et al.*, 2008) commissioned by the Ministry of Water Resources that included several experts from the Indian Institutes of Management (IIMs) found that both supply- and demand-side drivers, such as overestimated IPC or underestimated IPU, trigger this increasing gap. Another study on increasing WUE in an irrigation system (GoMH, 2016) identified rainfall variability, leakages in canal structures and dysfunctional distribution networks as the bottlenecks. However, as most studies on IPC and IPU tend to depend on secondary data from official records, the exact extent of and reasons for this gap vary.

Despite these shortcomings, many policy interventions target increasing canal irrigation performance. Command area development and renovation of canal conveyance and distribution systems constitute a significant thrust in bridging the gap between IPU and IPC. The Twelfth Five-Year Plan of India (GOI, 2013) allocated 15% of the water sector investments to command area development to bridge the gap between IPC and IPU and proposed a 20% increase in WUE during the plan period (2012–17). More recently, the Prime Minister's Krishi Sinchayee Yojana (PMKSY) proposed 'more crop per drop' (increasing water productivity) and *Har Kheth ko Paani* (irrigation for all) as its guiding principles. However, imprecise land- and water-use information relating to canal irrigation systems often inhibits proper investment decisions and their implementation.

Analytical framework

The main components of the analytical framework (Figure 1) are an information management system, a performance analysis system and a decision support system.

The information management system compiles climate, water supply, land and water use, agricultural production, financial and socioeconomic data. The Systematic Asset Management System, which stores the data and performance indicators of the irrigation system, can assist irrigation managers and policy makers in monitoring performance and evaluating investment decisions.

The performance analysis system includes water and energy accounting, benchmarks of indicators and the water cost curve. The water cost curve shows the financial tradeoff of increasing economic water productivity (EWP) of different crops. The EWP is the value of output per m^3 of irrigation CWU.

The decision support system assesses strategies for increasing WP to enhance the resilience of water-scarce canal irrigation systems. The main focus here is identifying financially viable potential strategies for increasing the EWP in order to enhance resilience in the WIZ.

Water influence zone

The analytical framework presented in this paper postulates that the WIZ of a typical irrigation system encompasses areas outside the command area as well. By design, the CCA is within the WIZ. In many instances, however, the WIZ also includes a buffer zone outside the command area that reuses irrigation return flows from the CCA (Figure 2). Some irrigation systems may also include an area inside the

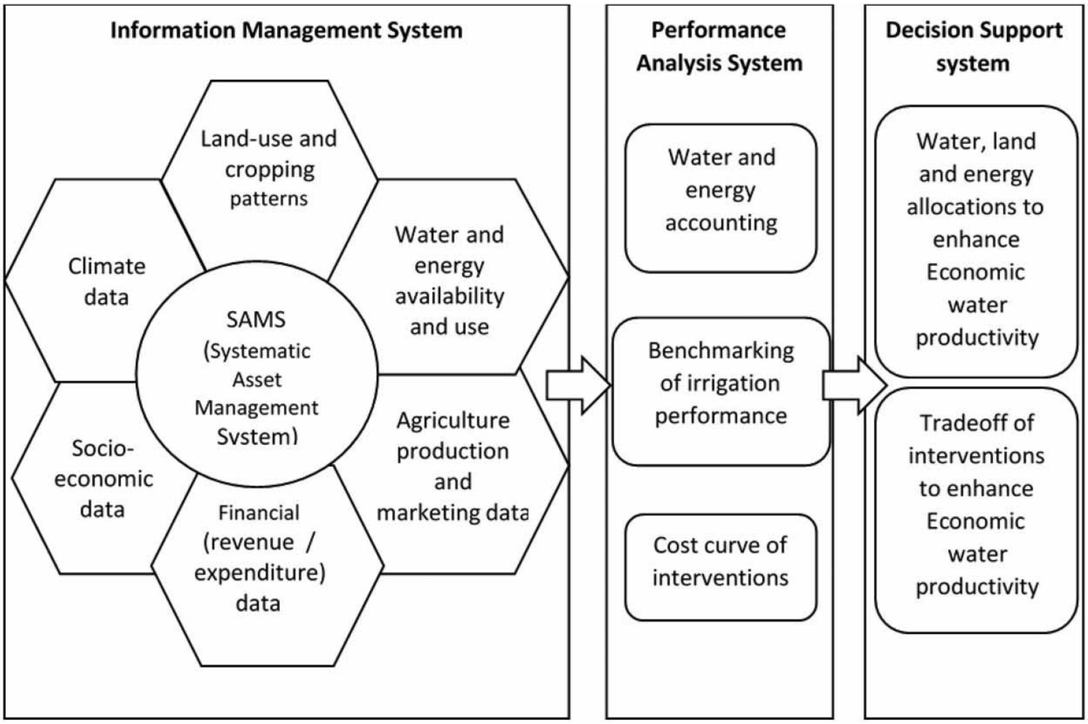

Fig. 1. An analytical framework for assessing strategies for enhancing economic water productivity. *Source*: Authors.

reservoir catchment that receives irrigation from direct lifting from the reservoir. The land-use patterns (LUPs) in the WIZ depend on the water availability in the reservoir and groundwater withdrawals available through recharge from rainfall, canal irrigation return flows and the reservoir, but also the water supply from a few smaller surface water bodies in the WIZ. Foster & Perry (2010) highlighted the need for a more rigorous and consistent concept of soil-water zone accounting in irrigated agriculture which permits the assessment of the impacts of change and prioritizing interventions.

The expanded WIZ supported by satellite data can help us to accurately assess the over- or underestimation of the actual irrigated area (IPU vs. IPC). Moreover, the CWU in the WIZ shows the extent of beneficial water use and the potential for increasing WUE and WP.

Sina irrigation system

The study tests the framework in the Sina irrigation scheme in the Pune irrigation circle of Ahmednagar district in the state of Maharashtra, India (Figure 2). Sina is a water-scarce medium irrigation system[1] as per the state classification. Its constructions were completed in 1983. The reservoir has gross and live storage capacities of 67.95 million cubic meters (Mm^3) and 52.30 Mm^3, respectively,

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[1] Maharashtra state classifies its irrigation systems based on the availability of water supply in river basins: severe water-deficit (<1,500 m^3/ha), water-deficit (1,501–3,000 m^3/ha), normal (3,001–8,000 m^3/ha), water-surplus (8,001–12,000 m^3/ha) and abundant (>12,000 m^3/ha).

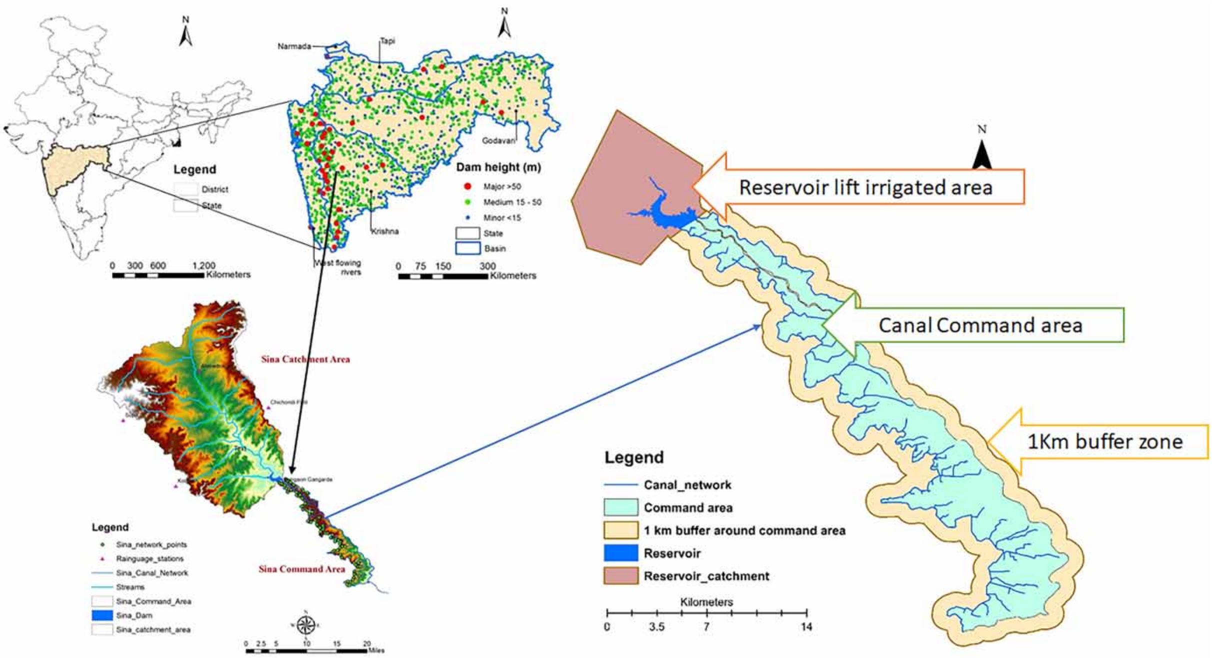

Fig. 2. The water influence zone (WIZ) of the Sina irrigation system in Maharashtra, India. *Source*: Authors.

with a 75% dependable yield of 61.3 Mm^3. The IPC of the Sina CCA is 8,445 ha. It also has a provision for irrigating 1,350 ha in the catchment through direct pumping from the reservoir.

The WIZ in Sina includes the gross CCA of 11,220 ha, and the reservoir lift-irrigated area (RLIA) of about 8,900 ha. After consultations with local stakeholders, our study decided to also consider a one-kilometer buffer (1 km buffer) zone, containing 10,000 ha (Figure 2), outside the command area.

Located in a semi-arid climatic zone, Sina has a monsoon-driven rainfall pattern. The system has three cropping seasons: *kharif* (the monsoon season from June to October), *rabi* (the postmonsoon season from November to March) and hot-weather (or summer season from March to June). More than 90% of the total annual rainfall occurs during the monsoon season. The average annual rainfall and potential evapotranspiration (ET_p) in Sina are about 517 and 1,533 mm, respectively. In the non-monsoon period (November to May), the average rainfall is only 115 mm, whereas ET_p is about 960 mm. Therefore, irrigation is critical for crop production in the postmonsoon (November to March) and hot-weather (March to May) seasons. For the Sina command area, irrigation releases from the reservoir generally start in mid-October.

The study identified the LUPs in the Sina WIZ. First, it developed the crop signatures of the 2016–17 postmonsoon season. In that year of above-average monsoon rainfall, reservoir storage was at full capacity by October 15, before the irrigation flow started for the postmonsoon season.

Next, the analysis used the crop signatures developed for the 2016–17 postmonsoon season to classify the LUPs in 1990–91 and 2010–11, to assess the change over time. Both these years too were above-average rainfall years, which help to determine the extent of irrigation and cropping patterns existing in the WIZ. Due to cloud cover, however, RS/GIS statistics were not available for the monsoon season. In the hot-weather season, only a small area is used for seasonal crops (vegetables, oilseeds) apart from annual crops.

The study combined remote-sensing (RS) images with ground truth data to assess LUPs in the WIZ. A combination of maximum-likelihood and object-oriented classification methods were used for image classification. This methodology included the following:

- Masking of crop areas by delineating non-agriculture areas such as settlements, bushes and areas covered with trees separately. The study also used unsupervised classification and Google Earth images of a recent year, matching the same season for which Sentinel images were used for classification.
- Maximum-likelihood classification and further editing for corrections based on visual interpretation to classify the first crop area map.
- Next, crop signature development and post-classification corrections using ground truth data and Google Earth images.
- The results were combined with object-oriented segmentation classification using a majority rule classifier to create the final map.
- Spectral profiles and visual characteristics of various crop types in a recent Landsat 8 image of a current year assessed the reflectance patterns. The crop signatures developed for the current year provide the visual interpretation and signature identification for past years. Spectral profiles of signatures of both the years were compared visually to ensure that they broadly have the same characteristics.

The study combined Google Earth images with ground information collected through an ODK to assess groundwater use patterns. The official records of agricultural yield and farm gate prices of crops are available from the irrigation agency and cost of cultivation surveys conducted by the Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, a key partner of this study.

The water accounting guidelines of Molden (1997) were adopted to assess the water depletion patterns in the WIZ. The RS/GIS, water accounts and BM reports were used to assess the land, cropping, water-use patterns and water productivity. In the context of water accounting in irrigation systems, the essential components are as follows:

- the storage and water releases from the reservoir and change in groundwater availability in the WIZ;
- beneficial depletion through process evaporation from surface irrigation, and unintended process evapotranspiration from the reuse of return flows, i.e., groundwater withdrawals;
- non-beneficial evaporation including evaporation from the surface of reservoir, canals and bare land; and
- committed (drinking water supply) and uncommitted outflows (leakages).

The total consumptive water use (TCWU) or evapotranspiration (ET_a) of crops was estimated using the methodology in CROPWAT (Allen *et al.*, 1998).

The CWU from irrigation (IRCWU) is TCWU minus the rainfall CWU (RFCWU). The RFCWU is the effective rainfall at the root zone, which is assessed using the methodology used by the United States Department of Agriculture (USDA) Soil Conservation Service (Smith, 1992).

This paper presents the estimates of performance indicators of irrigation per unit area (m^3/ha), IPU/IPC, CF (or irrigation WUE), and land and WP (USD (constant 2010) per ha or m^3 CWU) in different components of the WIZ. The total value of crop output is the sum of the value of output over all crops, estimated by multiplying the production and farmgate prices of different crops.

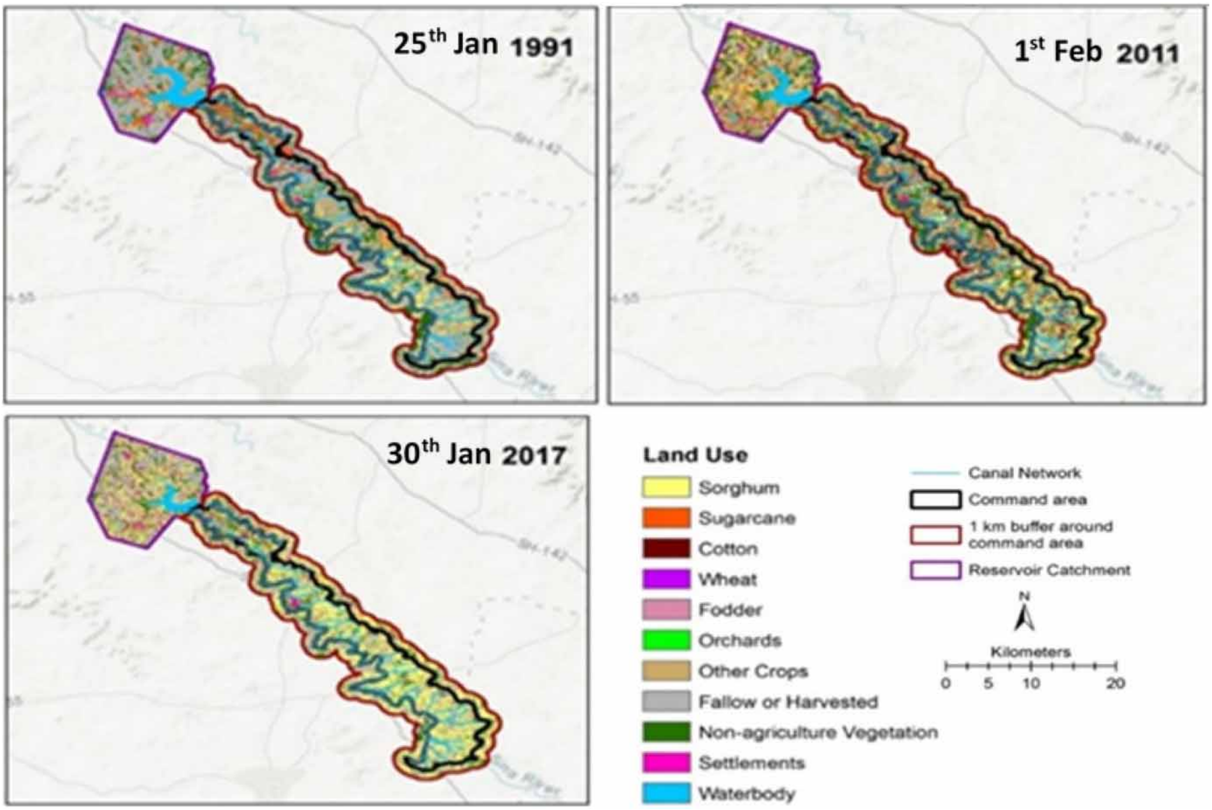

Fig. 3. Temporal variation of crop types and land use in the postmonsoon season. *Source*: Authors.

Results

Land-use patterns

The RS/GIS analysis shows changes in the LUPs of the postmonsoon season in the WIZ (Figure 3 and Table 1). The satellite data taken during March 1–7 capture the LUPs as they existed in the 1990–91, 2010–11 and 2016–17 postmonsoon seasons. The RS/GIS cropping patterns highlight the differences between the actual and official estimates.

Table 1 shows a summary of the LUPs at three points in time: 1990–91, 2010–11 and 2016–17. The total cropped area in the

- CCA in 2010–11 was almost equal to the designed command area of 8,445 ha;
- CCA and RLIA, which the official records show as IPU, is substantially higher than the designed command area; and
- WIZ is 17,353 ha, which is 105% more than the designed command area. This irrigation would not have been possible without groundwater being recharged from the canal irrigation and reservoir storage, and a large number of open and deep tube wells withdraw groundwater in the Sina WIZ (Figure 4).

Table 1. Land-use pattern in the WIZ of the Sina irrigation system.

Land-use pattern in postmonsoon season (ha)	Canal command area (CCA)			Reservoir lift-irrigated area (RLIA)			1 km buffer zone (1 km buffer)		
	1990–91	2010–11	2016–17	1990–91	2010–11	2016–17	1990–91	2010–11	2016–17
Cropped area	4,200	7,946	7,549	1,360	4,488	3,815	2,227	6,134	5,989
Fallow land	5,615	1,850	2,626	4,476	1,526	3,011	5,970	2,292	3,438
Non-agricultural land	1,434	1,544	1,100	1,214	1,402	784	2,472	2,479	1,431
Settlement land	60	92	154	60	86	123	45	60	98
Area of water bodies	127	4	7	1,085	693	461	307	45	64
Total area	11,436	11,436	11,436	8,195	8,195	8,195	11,020	11,020	11,020

Source: Authors' estimates.

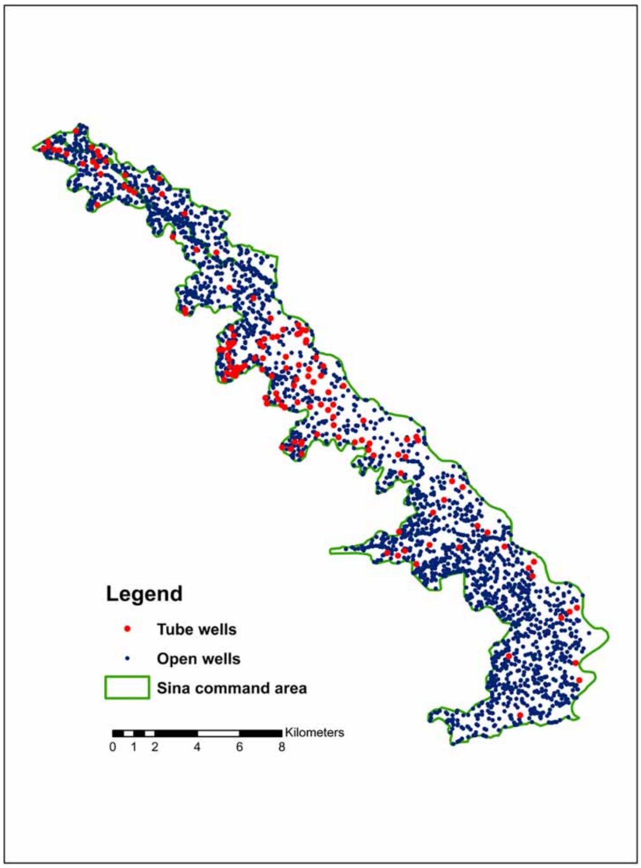

Fig. 4. Open wells and tube wells in the WIZ of the Sina irrigation system.

The RIS/GIS-based LUPs also show a sharp decline in the surface water spread area, especially in the reservoir. The increased process CWU from crops explains this declining trend.

Table 2 highlights the difference in total cropped area in the official records and RS/GIS estimates during 2010–11, a very high rainfall year when the reservoir was at full capacity for irrigation. The

Table 2. Irrigated cropping patterns in the Sina WIZ in the 2010–11 postmonsoon season.

		Official estimates (ha)		RS/GIS estimates (ha)		
Season	Crop	CCA	CCA + RLIA	CCA	CCA + RLIA	CCA + RLIA + 1 km buffer
Postmonsoon season	Wheat	0	0	186	351	474
	Sorghum[a]	3,655	3,989	2,799	4,050	6,164
	Fodder	0	0	45	76	101
	Others[b]	6	680	2,828	4,783	6,949
Annual crops	Sugarcane	98	731	544	1,027	1,371
	Fruits	0	0	102	161	332
	Cotton	0	0	1,442	1,986	3,177
Total		3,753	5,400	7,946	12,434	18,568

Sources: RS/GIS estimates are authors' estimates; Official estimates are from the Sina irrigation agency records.

[a] Offical records include the groundwater irrigated area.

[b] Others include other cereals, pulses and oilseeds in the postmonsoon season.

difference clearly shows the underestimation of the cropped area in the official records. The year 2010–11 had the largest cropped area in the official records.

- The RS/GIS estimates show that the actual irrigated area is almost two times the officially recorded area in the Sina CCA. This includes the substantial underestimation of pulses and oilseed, sugarcane, fruits and cotton.
- As regards CCA and RLIA, the RS/GIS estimates are more than double the officially recorded area. The actual cropping patterns on the ground are substantially different from those in the official records.

Water accounts

Water storage and releases of the Sina reservoir. The Sina reservoir, filled mainly by monsoon rainfall, is the primary source of surface water supply to the WIZ. It reached full storage capacity by October 15 in only 4 years (2008, 2009, 2010 and 2017) in the past 10 years since 2007. In 2016–17, rainfall was at its highest level, but storage did not reach full capacity, perhaps due to the low storage in the five preceding years (Figure 5).

Official records of irrigation releases from the Sina reservoir to the CCA and RLIA show high temporal variability.

- There was virtually no irrigation supply in 2 years of the past decade (2012–13 and 2015–16).
- In 4 years (2011–12, 2013–14, 2014–15 and 2016–17), irrigation supply was less than half of what it had been in 2010–11, the year in which irrigation supply was highest as per official records.
- The RLIA accounts for a substantial part of the irrigation supply from the Sina reservoir. Although irrigation to the CCA starts only after October 15, RLIA farmers pump water from the reservoir even in the monsoon season. As a result, RLIA has a large irrigation supply, at times larger than the CCA.

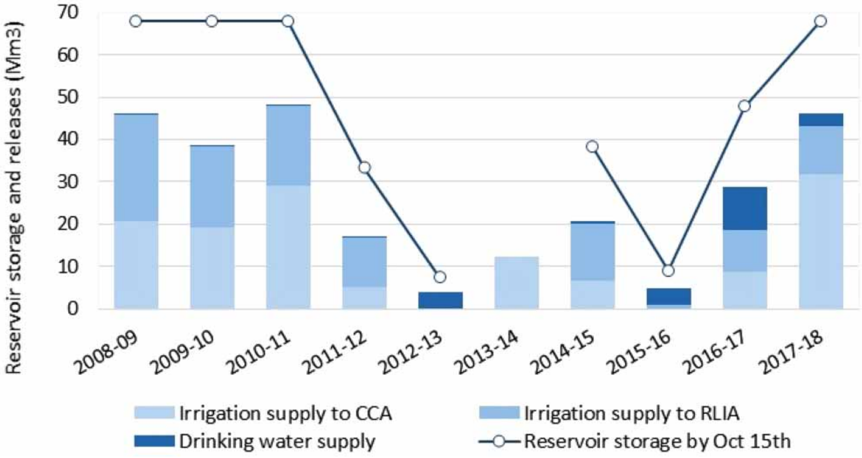

Fig. 5. Storage in the Sina reservoir by October 15 each year, and releases for irrigation and drinking water supply purposes. *Source*: Authors' estimates based on daily water releases data from the Sina irrigation agency.

Irrigation performance

The estimates of the area, irrigation CWU and the value of production of cropping systems in the Sina irrigation system based on official data too are significantly lower than the RS/GIS estimates (Table 3).

- The actual IPU/IPC ratio in the CCA is almost one, compared with just 0.1 if the official figures were taken into reckoning.

Table 3. Comparison of official and RS/GIS estimates of the irrigation performance in 2010–11.

	Official data		RS/GIS-based estimate		
Variable	CCA	CCA + RLIA	CCA	CCA + RLIA	CCA + RLIA + 1 km buffer
Water supply (Mm^3)[a]	29.1	47.8	38.8	63.4	72.6
Irrigated area (1,000 ha)[b]	0.8	4.8	8.4	14.9	21.0
Consumptive water use (Mm^3)	4.1	19.9	29.5	52.5	72.7
Value of output (million USD)[c]	2.1	9.3	8.1	17.1	22.4
Irrigation performance indicators					
IPU/IPC	0.10	0.57	0.94	1.47	2.19
CF (or WUE) (%)	14	42	76	82	106
EWP (USD/m^3 of CWU)	0.50	0.27	0.47	0.33	0.29
EWP (USD/m^3 of water supply)	0.07	0.21	0.19	0.27	0.31

Sources: Data on water supply and cropped area are from the irrigation agency records. Others are authors' estimates.

[a] The water supply figures in the RS/GIS columns include natural groundwater recharge estimates as per the guidelines issued by the Central Groundwater Board (CGWB, 2007). Natural groundwater recharge for the semi-arid region of Sina is about 10% of total rainfall.

[b] Irrigated area includes vegetable and oilseed crops area in the hot-weather season as reported in the official records.

[c] The value of production is the sum of the value of production of each crop estimated by multiplying the crop production by farm gate prices. The final value of production is shown in constant 2010 US dollars. The exchange rate in 2011 was 46.70 INR/USD.

- The ratio of irrigated area to IPC is substantially more than one for the CCA and RLIA, and more than two times for the WIZ as a whole.
- In 2010–11, the CWU of the official cropping pattern in the CCA was only one-seventh of the RS/GIS-based estimate.
- The CF or WUE for the CCA based on official figures is only 14%, whereas the actual value is 76%. The WUE estimated for the CCA and RLIA on the basis of official data is half of the actual figure estimated using RS/GIS data.

These results show that reservoir storage has contributed, directly through canal irrigation and indirectly through groundwater irrigation, to a substantial irrigated area, CWU and output. In fact, the total output in the WIZ is almost three times the output in the CCA. The underestimation of the irrigated area gives a completely different picture of the irrigation service delivery performance of the Sina water source and its releases.

The much-discussed IPU/IPC ratio is close to one in the Sina irrigation command, and more than one if land- and water-use patterns outside the CCA are taken into account. Similarly, the CF or water beneficially depleted through intended and unintended processes (surface and groundwater irrigation) is significantly higher than what the official figures show. However, the EWP ($\$/m^3$) of the present cropping patterns is low due to large areas being under low-value crops, such as cereals, pulses and oilseeds (Table 4).

Low-value, high water-consuming crops dominate the current cropping patterns in Sina. In 2010–11, sorghum, pulses and oil crops were a large part of the cropped area. The annual crop area was only one-third of the postmonsoon season cropped area but generated a higher output. The hot-weather season crops, primarily vegetables, too generated a higher value of production than those in the postmonsoon season.

This difference in the water productivity of seasonal and annual crops shows the scope for improving the value of output with limited water resources. Fruits, vegetables and fodder (as a feed-supporting milk production) have significantly different irrigation water productivity. These can form an ideal cropping pattern with lower irrigation CWU and higher EWP.

Fruits can provide sustainable income even under water-scarce conditions by using a smaller share of irrigation CWU. Fodder contributing to milk production can not only offer sustainable income but also contribute to the nutritional security of households.

Discussion and conclusion

The general perception of the performance of the Sina irrigation system, or for that matter many other canal irrigation systems, is of low utilization of irrigation potential, low WUE and low productivity. The analytical framework used in this paper found that the IPU/IPC ratio and WUE are substantially higher than what official statistics show with due consideration of the WIZ. The low value of this performance indicator is partly due to the underestimation of the irrigated area.

Performance assessment of canal irrigation systems often focuses on the CWU within the designed CCA. However, the reuse of canal irrigation return flows with groundwater irrigation generates many socioeconomic benefits within and outside the CCA. The Sina irrigation system is a perfect example

Table 4. Seasonal crop water productivity in 2010–11.

Row	Season[a]	Area/crops	Irrigated area[a] ha	Value of output (Million USD[b])	Irrigation CWU Mm^3	Total CWU Mm^3	Land productivity USD/ha	Water productivity	
								USD/m^3 of ICWU	USD/m^3 of TCWU
1	Postmonsoon season crops	CCA	5,858	3.2	17.5	21.5	551	0.18	0.15
2		RLIA	3,401	1.8	10.7	12.9	565	0.18	0.15
3		1 km buffer	4,429	2.4	15.7	16.3	548	0.15	0.15
4		Total	13,688	7.6	43.9	50.7	553	0.17	0.15
5		*Sorghum*	6,165	1.9	21.1	23.5	309	0.09	0.08
6		*Wheat*	474	0.3	1.9	2.1	683	0.17	0.15
7		*Pulses/ oilseeds*	6,948	5.1	20.5	24.5	735	0.25	0.21
8		*Fodder*	101	0.2	0.5	0.6	2,369	0.53	0.42
9	Annual crops	CCA	2,088	3.2	9.6	16.6	1,526	0.33	0.19
10		RLIA	1,087	2.4	6.3	10.2	2,183	0.38	0.23
11		1 km buffer	1,705	2.8	9.5	13.1	1,660	0.30	0.22
12		Total	4,880	8.4	25.4	39.9	1,719	0.33	0.21
13		*Sugarcane*	1,371	5.1	13.1	18.7	3,705	0.39	0.27
14		*Fruits*	332	2.2	2.3	3.4	6,779	0.97	0.66
15		*Cotton*	3,177	1.1	10.0	17.8	334	0.11	0.06
16	Hot-weather season[b]	CCA	490	1.6	2.4	2.5	3,367	0.68	0.65
17		RLIA	1,024	4.3	5.2	5.5	4,113	0.81	0.77
18		1 km buffer	–	–	–	–			
19		Total	1,514	5.9	7.6	8.0	3,872	0.77	0.73
20		*Vegetables*	1,414	5.8	7.2	7.5	4,113	0.81	0.77
21		*Groundnut*	100	0.0	0.4	0.5	442	0.10	0.10

Source: Authors' estimates.

[a] Postmonsoon season and annual area data are RS/GIS-based data; hot-weather season area figures are official estimates.

[b] The value of production of crops for estimating total production are estimated using the farm gate prices. The productivity values are in constant 2010 US dollars, where the exchange rate and GDP deflator in 2011 was 46.70 INR/USD and 109.5%.

of this. The indicators estimated from the satellite data in and outside the command area of the Sina WIZ show a very high IPU/IPC ratio and WUE.

The Sina irrigation system, in good rainfall years, generates substantial crop production benefits within and outside the command area. The overall benefits could be much higher if we consider the forward and backward linkages in the agricultural economy (Bhatia & Malik, 2013), and total benefits of agricultural and non-agricultural sectors (Bhattarai *et al.*, 2007). Major and medium reservoirs generate substantial socioeconomic benefits, including crop production and forward and backward linkages. The large extent of groundwater irrigation reported within the WIZ would not be possible without the groundwater recharge from reservoir storage and return flows from canal irrigation supply in this area with a low annual rainfall of 517 mm and hard rock aquifers with less natural rainfall recharge.

However, the Sina irrigation system has low EWP despite its increasing water scarcities. In fact, Sina is a physically water-scarce system with no further potential for increasing canal irrigated area and CWU. If it does increase the irrigated area within the canal command, it will affect crop cultivation in areas outside the command. Therefore, one should consider water supply and depletion accounts in the WIZ before deciding water allocation strategies for increasing irrigated areas in the command area.

The present cropping pattern and EWP do show potential for change in the Sina WIZ, which faces frequent dry spells. The extremely dry years will not allow any canal water releases and seasonal crop production. But a slight increase in high-value crops that are drought-tolerant and can utilize the available groundwater in low rainfall years can provide a sustainable income for the farming community. This requires assessing crop choices, EWP and their tradeoff, which is the focus of research of the companion paper to this paper (Amarasinghe *et al.*, 2020). Crop choices such as sugarcane, a water-intensive crop, need to be regulated and/or raised with drip irrigation in future cropping patterns. Thokal (2012) concurs with this finding in a study on the spatial decision support system for the allocation of limited water in the Sina irrigation system using a SWAT model.

Our study leads us to the following policy recommendations pertinent to the Sina irrigation system in particular and to canal irrigation systems in water-scarce areas in general.

The accurate estimate of the actual irrigated area in the WIZ of an irrigation system is necessary before making further investments aimed at bridging the gap between IPU and IPC in canal irrigation systems. The estimation methods can use satellite data, which are available freely in the public domain. Small-field studies of ground-truthing to develop crop signatures are required for crop classification. If satellite data are used in estimating the irrigated area, the annual IPU/IPC in the CCA of many water-scarce irrigation systems could give us a different picture.

The estimation of an irrigated area influenced by a reservoir and the irrigation CWU needs to consider the entire WIZ. Postmonsoon and summer season crop cultivation outside the Sina CCA would not have been possible without the groundwater recharged by the reservoir and surface irrigation in the CCA. This situation would be similar in other water-scarce irrigation systems in Maharashtra and in India at large.

It is necessary to reassess the estimation method of WUE in canal irrigation systems. The current approach of estimating the beneficial CWU of intended processes focuses only on surface irrigation in the CCA. However, groundwater and conjunctive irrigation are prevalent in the WIZ. Much of the beneficial CWU from groundwater irrigation within and outside the CCA in the WIZ would not be possible without the groundwater recharged from reservoir storage and canal irrigation supply. It requires us to consider the unintended processes also within the WIZ in assessing the WUE. CCA-centric policy interventions for improving WUE can no longer ignore the socioeconomic benefits influenced by reservoir storage outside the command area.

Water-scarce irrigation systems such as Sina should focus on increasing the EWP. The present cropping patterns in Sina contribute to a low EWP. And it indicates the potential of reallocation of CWU to increase the value of output. In water-scarce systems, allocation of CWU for agricultural production patterns that increase the EWP is the way forward. This approach not only increases the income of farmers using irrigation supply in good rainfall years but also enhances their resilience with sustainable income in severe water-deficit years during which there is no canal irrigation supply.

Data availability statement

Data cannot be made publicly available; readers should contact the corresponding author for details.

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