Can the water rate be the only criteria to assess the viability of a canal irrigation system? a case of Eastern Yamuna Canal, India

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Canal irrigation system, besides providing irrigation, generate many ecosystem services for command areas, viz. lesser groundwater extraction and carbon emissions, energy savings, groundwater recharge, recreational services for inhabitants, etc. However, existing studies primarily emphasize irrigation services provided by canals while overlooking other ecosystem services. Therefore, this study monetizes key ecosystem services rendered by the Eastern Yamuna Canal (EYC) and collates government expenditures incurred. The result shows that the ecosystem services delivered by EYC are worth Rs 1122.86 million, nearly 48.27% more than working expenses. Further, the result highlights that anchoring only on revenue generated to exchequer with water rates, to compare the performance of any canal will not be sufficient. The present study suggests that if the government facilitates the timely availability of canal water to the farms and collects water charges equal to working expenses from the water users, it could be a much better trade-off for the stakeholders.

Keywords: Carbon emission, ecosystem services, energy, groundwater, Shapley value.

PRIOR to the Green Revolution era in India, especially in the colonial period, canal irrigation system was considered a prospective commercial enterprise, and it yielded about 8–10% return on investment until 1945 (refs 1, 2). At that time, the capital cost of canal construction in a year was nearly equal to the value of the crop irrigated by it[1], and the government could generate nearly one-tenth of the capital cost as irrigation fees, which was nearly 280% of the working expenses incurred (Supplementary Table 1). After independence, the prevailing scenario changed drastically, and the evaluation of public irrigation system was carried out on social and economic aspects rather than financial[2,3]. This resulted in the shrinkage of budgetary allocations for creating and maintaining major and medium irrigation infrastructure in the post-green revolution era[4,5].

On the other side, with the advent of green revolution era, assured and timely irrigation for high-yielding crop varieties became indispensable. The government policy support to facilitate irrigation water requirements resulted in the unfolding of cheaper and timely irrigation technologies anchored on groundwater and helped realize the potential to take more than one crop in a year[6,7]. Therefore, the supply-driven nature and laxity in the upkeep of canal irrigation infrastructure became an unattractive investment that led to the downswing of canal irrigation in India (bringing down the share of canal area from 42.05% in 1960–01 to 22.63% in 2017–18)[8]. However, besides providing irrigation requirements, the canal system delivers many services to command areas, such as groundwater and energy savings[9,10], aquifer recharge[4,11–14], reduction in carbon emissions, wallowing for buffalo that helps increase milk production[15,16], transportation facilities alongside the canal, and recreational activities like walking, bathing, washing, etc. for villagers and others.

Therefore, the government's rationality to neglect or support the canal irrigation system should not depend only on the revenue generated from water rates from its user; instead, it should be a collective of all the benefits rendered by the canal to its command ecosystem. In India, there have been many studies on ecosystem services provided by traditional tank water bodies used for irrigation and domestic use[17–19], but few on canal ecosystem. Therefore, this paper aims to quantify and monetize the key ecosystem services delivered by one of the distributaries of the Yamuna river, the Eastern Yamuna Canal (EYC), in its command area.

Materials and methods

Study area

The study was conducted in the Eastern Yamuna canal (EYC) which originates from the left bank of Hatnikund barrage and has an assigned discharge capacity of 4400 cusecs. EYC supports crop cultivation in Saharanpur, Shamli, Baghpat, Ghaziabad, and some parts of the Muzzafarnagar districts of Uttar Pradesh. Under the EYC system, the length of main the canal is 204.15 km, and the length of major and minor distributaries is 926.794 km and 434.991 km respectively[20]. Figure 1 depicts the EYC command area.

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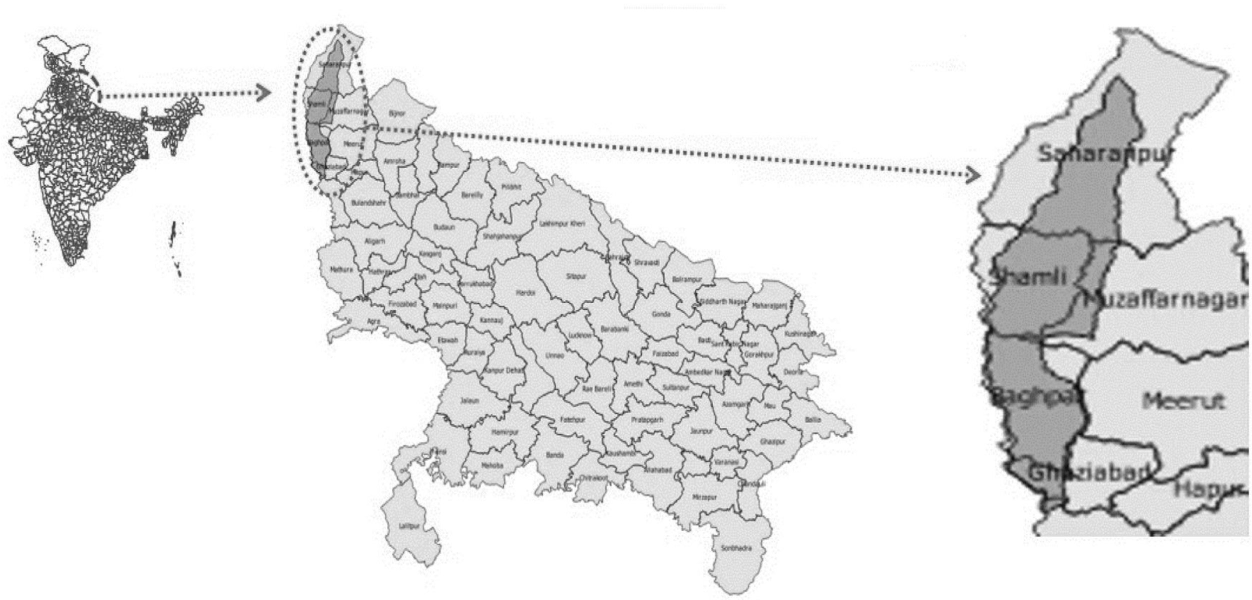

Figure 1. Location map of Eastern Yamuna Canal (EYC).

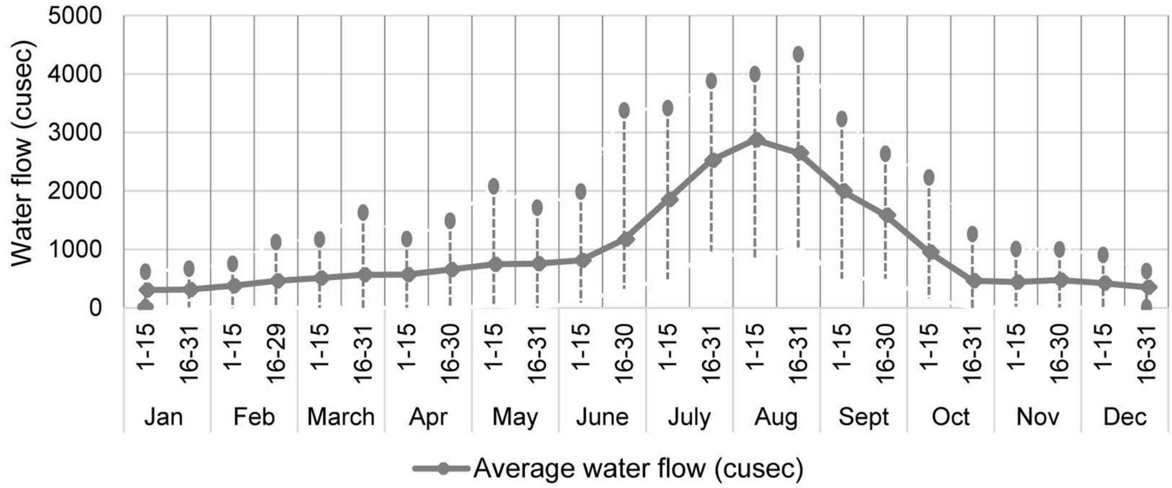

Figure 2. Average water flow and variation in water discharge of EYC. Note: Range (max–min) of canal water flow is based on daily water discharge data since the commission of the Hathnikund barrage (2002–2018). Source: UYRB, 2019.

Figure 2 presents the maximum–minimum water discharge rate of EYC canal since 2002, when the Hathnikund barrage was commissioned. The maximum discharge rate of EYC is observed from June to September (monsoon/rainy), and the canal has never dried up. However, for most of the year, the discharge rate of canal water in EYC was lower than half of its capacity during 2002–2018. In 2009, the government-linked EYC with a parallel Deoband branch (1100 cusec capacity) originating from the Upper Ganga canal at Roorkee to increase its water supply[20]. In EYC, about 2/3rd of the canal water is available during rainy months, which coincide with the *kharif* (monsoon/rainy) season of the agricultural crop calendar, and other seasons receive nearly 1/3rd of the water.

Research design

The EYC water flows through districts of western Uttar Pradesh, where Saharanpur and the upper region of Shamli were categorized as the head, the lower region of Shamli and upper region of Baghpat as the middle and lower regions of Baghpat, and Ghaziabad as the tail of the canal. A farm household survey of six villages was conducted to determine household access to the canal in each categorized canal command area, located in the head, middle and tail of distributaries emerging from the categorized main canal. From each village, 13 farm households were surveyed for their socio-economic parameters, canal and groundwater access, input use pattern for crops grown, and recognized benefits of canal existence. Overall, 240 farmers distributed equally in the categorized EYC from 18 villages were surveyed during the crop calendar of 2019–20. Household characteristics of the sampled farm are given in Supplementary Table 2.

Quantification and valuation of canal ecosystem services

Provisioning services (crop production and groundwater savings), regulating services (groundwater recharge and carbon emission), supporting services (wallowing, drinking and bathing for buffaloes), and cultural services (recreational and facilitative) were considered for the study. The value of ecosystem services delivered by EYC was estimated using economic valuation methods. The details are presented in the following section.

Provisioning services

Crop production: Physical quantity of crop produced with canal water was estimated using the eq. (1).

$$CPC_{id} = CP_{id} * iaf_c * SV_i * SCI_{id}, \tag{1}$$

where CPC_{id} is quantity of *i*th crop produced (tonnes) in *d*th district with canal irrigation, CP_{id} the total quantity of *i*th crop produced (tonnes) in *d*th districts, iaf_c the share of canal irrigated area to total irrigated area, SV_i the Shapley value of *i*th crop indicating relative contribution of irrigation in crop production, and SCI_{id} is the share of canal irrigation to total number of irrigation given to *i*th crops in *d*th district. The valuation of the crop produced was done using farm harvest price (eq. (2))

$$VoP_{id} = CPC_{id} * FHP_{id}, \tag{2}$$

where VOP_{id} is the value of *i*th crop output in *d*th district, and FHP_{id} is the farm harvest price of *i*th crop in *d*th district.

Groundwater saving: The valuation of groundwater was done by employing avoided cost method. The avoided cost is the extraction cost of groundwater (energy savings) with either diesel or electric-operated wells that would have been incurred in the absence of the canal (eq. (3)).

$$GWS_{id} = CAC_{id} * NCI_{id} * IH_{id} * DRW_d, \tag{3}$$

where GWS_{id} is the groundwater savings (m^3) with existence of canal, CAC_{id} the *i*th crop area under canal in *d*th district, NCI_{id} the number of canal irrigation in *i*th crop in *d*th district, IH_{id} the irrigation hours required for one hectare of *i*th crop in *d*th district, and DRW_d is the discharge rate (m^3/h) of canal irrigation in *d*th district.

Energy savings

$$ESWC = \sum GWS_{id} * EU_{gwd,d}, \tag{4}$$

ESWC is the energy savings (kWh) with the existence of canal irrigation, and $EU_{gwd,d}$ is the energy to be used for drafting groundwater (kWh/m^3) in the absence of a canal. The value of energy saved was estimated using eq. (5).

$$VoES = GWS_{id} * EC_{gwd,d/e}, \tag{5}$$

where *VoES* is the monetary value of energy saved with existence of canal, and $EC_{gwd,d/e}$ is the extraction cost of groundwater (Rs/m^3) with either diesel or electric operated wells.

Regulating services

Groundwater recharge: Canals provide the service of groundwater recharge through a network of canals, surface drainage and flood irrigation system. The volume of groundwater recharge was estimated using eqs (6) and (7).

$$V_{cif} = CA * CWD * rfc, \tag{6}$$

where V_{cif} is the volume of groundwater recharge (m^3) with canal infrastructure, *CA* the canal infrastructure area, *CWD* the canal wetted days assumed to be canal water flow days in a year, and *rfc* is the recharge factor of canal as recommended by Central Ground Water Board (CGWB), India.

$$V_{ciar} = CAC_{id} * NCI_{id} * IH_{id} * rfc, \tag{7}$$

where V_{ciar} is the volume of groundwater recharge (m^3) with canal irrigation (flood irrigation in command area), CAC_{id} the *i*th crop area under canal in *d*th district, NCI_{id} the number of canal irrigation in *i*th crop in *d*th district, IH_{id} the irrigation hours required for one hectare of *i*th crop in *d*th district, and *rfc* is the recharge factor of canal. Once volume of groundwater recharge was quantified, the value of recharged water was estimated by applying the market price of irrigation in the study area (eq. (8)).

$$MV_{gwr} = (V_{ciar} + V_{cif}) * MGW, \tag{8}$$

where MV_{gwr} is the monetary value of groundwater recharge, and *MGW* is the monetized value of a unit groundwater recharge (Rs/m^3).

Carbon emission: The amount of carbon emission generated by groundwater pumping can be controlled by the existence of a canal irrigation system. The quantification and valuation of carbon emission reduction with the canal were estimated using eqs (9) and (10) respectively. Thus, the valuation of carbon emission reduction was done by applying avoided cost method.

$$CE_t = \sum ITH_{saved,d/e} * E_{d/e} * cf_{d/e}, \quad (9)$$

$$VCE = CE_t * \text{carbon tax}, \quad (10)$$

where CE_t is the total carbon emission equivalent (tonnes), $ITH_{saved,d/e}$ the irrigation hours saved under diesel and electric operated well with existence of canal, $E_{d/e}$ the energization of wells either with diesel or electric, $cf_{d/e}$ the conversion factor for diesel fuel and electric energy into carbon emission quantity, and VCE is the value of reduced carbon emission with existence of canal.

Supporting services

The canal system also provides the service of wallowing, drinking and bathing water for buffaloes which ultimately leads to increased milk productivity and decreased groundwater pumping. The amount of milk production increased due to wallowing service was estimated using eqs (11)–(13).

$$Q_{milk} = \Delta_{milk} * N_{buffalo} * d_{wallowing}, \quad (11)$$

$$N_{buffalo} = N_{total} * caf * msf * 0.5, \quad (12)$$

$$M_{milk} = Q_{milk} * P_{milk}, \quad (13)$$

where Q_{milk} is the quantity of extra milk produced with wallowing of buffaloes in canal water, Δ_{milk} the change in milk quantity with wallowing, $N_{buffalo}$ is number of buffaloes in canal command area, $d_{wallowing}$ the number of days buffaloes visited canal water for wallowing, N_{total} the total number of buffaloes in the districts where EYC flowed, caf the fraction of area irrigated by EYC water, msf the share of marginal and small farmers, M_{milk} the monetary value of milk produced with wallowing of buffaloes in canal water, and P_{milk} is the price of milk in study region.

The amount of drinking and bathing water for buffaloes was estimated using eq. (14). The value of this service was determined by applying the same methods used for the valuation of water saving (eq. (15))

$$Q_{water} = DB_{water} * N_{buffalo} * d_{wallowing}, \quad (14)$$

$$M_{water} = Q_{water} * EC_{gw}, \quad (15)$$

where Q_{water} is the total quantity of water (litres) augmented in drinking and bathing of buffaloes, DB_{water} the quantity of water required by a buffalo in a day (litres/day/buffalo), M_{water} the monetized value of water used by a buffalo, and EC_{gw} is the extraction cost of groundwater (Rs/litre).

Cultural services

The value of cultural ecosystem services was estimated by applying the contingent valuation method (CVM). A focus group discussion and farm households survey were conducted to determine the willingness to pay (WTP) for the valuation of recreational and facilitative services generated by the canal. We inquired why the respondents considered the canal important, and subsequently, we asked the respondents how much they were willing to pay for maintaining and using the roads alongside the canal.

$$VES_{canal\ road} = L_{canal\ road} * D_{operational} * C_{canal\ road}, \quad (16)$$

where $VES_{canal\ road}$ is the value of facilitative and recreational services generated by canal, $L_{canala\ road}$ the length of canal, $D_{operational}$ the number of days canal road is operative and $C_{canal\ road}$ is the charge for using canal road.

For the study, the authors used certain coefficients, listed in Table 1, to compute the total value of ecosystem services delivered by EYC in its command area.

Results and discussion

Provisioning services

In the study area, sugarcane, wheat and paddy were the major crops having a share of 36%, 31% and 12% in the gross cropped area respectively. The estimate showed that about 27,018 thousand tonnes of sugarcane (95%), wheat (4%) and paddy (1%) were produced in the districts of Uttar Pradesh where EYC unloaded its water. Out of the total production, it was estimated that nearly 8.37% of the total production, worth Rs 7798 million was contributed by the EYC command area (Table 2).

In case of accounting irrigation share in total production based on Shapley value estimate, the result indicated that irrigation helped produce 158 thousand tonnes of sugarcane, paddy and wheat worth Rs 1398 million in the command area. The contribution of canal irrigation to total crop production and its generated value was segregated based on the share of canal irrigation in total number of irrigation given to the crops using farm households survey data in canal command area. The result showed that EYC water augmented water supply for irrigation which helped generate crop value worth Rs 559 million (Table 2). We also developed a scenario for the contribution of EYC in 1986 (30 years back) with the assumption that the same cropping pattern existed in the past and estimated its contribution backing the same procedures. The estimate showed that EYC helped generate crop value worth Rs 1749 million (Supplementary Table 4).

Canal water reduces the burden on groundwater by augmenting irrigation water requirements and also reducing farmers' irrigation costs. With the existence of EYC, it was estimated that farmers saved nearly 85 million cubic meters (MCM) of groundwater that could have been drafted if the canal did not exist. Based on a farm household survey in command area, it was estimated that, on average, 0.123–0.202 kWh is required to draft one cubic meter of water.

Table 1. Coefficients used in estimation of ecosystem services

Coefficient used in estimation	Value
Canal irrigated area fraction to total irrigated area	0.02–0.24 (ref. 21)
Canal irrigation fraction to total number of irrigation	7.87–30.77 (estimate based on primary survey)
Shapley value	Wheat – 0.69 (ref. 22) Paddy – 0.61 (ref. 22) Sugarcane – 0.04 (ref. 22) (Supplementary Table 3)
Farm harvest price (Rs/quintal)	Wheat – 1582 (ref. 23) Paddy – 1650 (ref. 23) Sugarcane – 280 (ref. 23)
Discharge rate of aquifer (m^3/hour)	38–54
Energy used in extraction (kWh/m^3)	0.123–0.202
Extraction cost (Rs/m^3)	0.97–2.74 (estimate based on primary survey)
Groundwater recharge factor (ham/day/million square meters of wetted area)	17.5 (ref. 24)
Canal flow days	155–188 (ref. 25)
Monetary value of groundwater recharge (Rs/m^3)	0.18–0.50 (ref. 26) (estimate based on primary survey)
Diesel (kg/kWh)	0.32–0.41 (refs 27–31)
Electric (kg/kWh)	0.65–1.49 (refs 27–31)
Carbon tax (Rs/tonnes)	400 (ref. 32)
Wallowing of buffalo help increase milk production (litre/day)	0.50–1.50 (refs 15, 16)
Road facilities to farmers (Rs/km)	2.50–7.50
Road facilities to other villagers, bikers, vehicles, etc. (Rs/km)	5.00–15.00
Road facilities for walking and bathing (Rs/km)	0.25–1.00 (estimate based on primary survey)

Table 2. Crop output and its value generated with EYC water in 2019–20

	Crop production ('000 tonnes)				Crop value (Rs millions)			
	Rice	Sugarcane	Wheat	Total	Rice	Sugarcane	Wheat	Total
Districts total where EYC water flow	245	25705	1067	27018	4047	71974	16886	92906
Total of EYC command area	23	2153	87	2264	387	6030	1582	7798
Contribution of irrigation	14	86	58	158	237	240	920	1398
Contribution of canal irrigation	4	32	25	62	68	91	400	559

Source: Authors' estimate.

Table 3. Value of groundwater savings with EYC water

	Groundwater savings (MCM)					Energy savings (mWh)	Value of irrigation hours saved (Rs millions)		
Canal area	Sugarcane	Paddy	Wheat	Other crops	Total		Electric	Diesel	Average
Saharanpur	34.80	19.34	9.16	0.02	63.32	7,788	61.42	173.50	118.41
Shamli	6.25	2.36	1.22	0.02	9.84	1,210	9.55	26.97	18.40
Muzaffarnagar	4.95	0.36	0.55	0.02	5.88	723	5.70	16.11	10.99
Baghpat	1.90	0.11	0.40	0.04	2.45	496	2.38	6.72	4.59
Ghaziabad	1.85	0.41	0.79	0.03	3.09	581	3.00	8.46	5.78
Total	49.75	22.59	12.12	0.12	84.58	10,798	82.04	231.76	158.17

Source: Authors' estimate.

Rooting on this value it was estimated that there was a saving of nearly 10,798 megawatt-hours (mWh) of energy (Table 3). Following the amortization and depreciation method, we estimated the cost of groundwater extraction with electric and diesel tube wells to be Rs 0.97 and Rs 2.74 per cubic meter of water respectively. Using this coefficient, the total value of reduced irrigation hours due to lesser pumping hours with electricity and diesel was estimated to be Rs 158 million with the existence of a canal system. The estimated value of irrigation hours saved was Rs 607 million in the 1980s due to higher crop area under the canal irrigation system (Supplementary Table 5).

Regulating services

We quantified groundwater recharge augmented by EYC following the standard methodology and coefficient developed by CGWB. The result showed that the application of canal water as irrigation helped recharge groundwater with

Table 4. Quantity of groundwater recharge with EYC water and its monetary value

Canal area	Groundwater recharge (MCM)					Value of groundwater recharge (Rs millions)		
	Sugarcane	Paddy	Wheat	Other crops	Total	Rs 0.18/m^3	Rs 0.30/m^3	Rs 0.50/m^3
Saharanpur	46.95	26.10	12.36	0.02	85.44	15.38	25.63	42.72
Shamli	8.43	3.19	1.64	0.02	13.28	2.39	3.98	6.64
Muzaffarnagar	6.68	0.49	0.74	0.02	7.93	1.43	2.38	3.97
Baghpat	3.51	0.21	0.74	0.07	4.53	0.81	1.36	2.26
Ghaziabad	3.54	0.79	1.52	0.07	5.92	1.07	1.78	2.96
Region total	69.11	30.77	17.00	0.20	117.09	21.08	35.13	58.55
Recharge by occupied area under canal and its distributaries					481.00	86.58	144.3	240.5
Grand total					598.09	107.66	179.43	299.05

Source: Authors' estimate.

Table 5. Reduction in carbon emissions with the existence of EYC and its monetary value

		Diesel operated wells			Electric operated wells				
	Total irrigation hours saved (000)	Irrigation hours (000)	Reduced energy consumption (mWh)	Reduced CO_2 emission (tonnes)	Irrigation hours (000)	Reduced energy consumption (mWh)	CO_2 emission (tonnes)	Total reduced CO_2 emission (tonnes)	Value of reduced CO_2 emission (Rs millions)
Saharanpur	1171	798	4762	1953	374	2787	2581	4534	1.81
Shamli	182	48	286	117	134	996	923	1040	0.42
Muzaffarnagar	109	81	482	198	28	210.38	195	392.52	0.16
Baghpat	61	13	78	32	49	363	336	386	0.15
Ghaziabad	80	52	310	127	29	213	197	324	0.13
Total	1604	991	5915	2425	613	4570	4232	6656	2.66

Source: Authors' estimate.

117 MCM of water (Table 4). In addition, EYC main canal and its distributary system with a nearly 1566 km network recharged groundwater with 481 MCM of water. Monetary valuation of groundwater recharge rationalized with the CGWB report worked out under different scenarios was worth Rs 108–299 million. In the 1980s, groundwater recharge with EYC was 1037 MCM, and monetary value ranged between Rs 187 and 518 million (Supplementary Table 6).

With access to EYC water, farmers operate their diesel or electric pumps for fewer hours when extracting groundwater, which results in lower carbon emissions to the environment. We segregated total irrigation hours saved with the availability of canal water into diesel and electric operated based on minor irrigation report. Research literature shows carbon emissions with diesel-operated wells range from 0.32 to 0.41 kg/kWh and electric-operated wells from 0.65 to 1.49 kg/kWh (Table 1). Drawing insight and relevancy for our study, we anchored on 0.41 and 0.92 kg/kWh for diesel and electric-operated wells respectively. The estimate showed that EYC helped reduce about 6656 tonnes of carbon emissions in the environment worth Rs 2.66 million (Table 5). If the estimate is pulled back to the 1980s scenario, then the reduction in carbon emission would be 28,393 tonnes, worth Rs 11.36 million (Supplementary Table 7).

Supporting services

Buffalo, a primary source of milk in the command area, has adaptive behaviour traits that allow it to wallow or submerge in water to reduce heat and lactation stress. Research literature suggests that methods that reduce heat stress, such as wallowing, submerging, misting, etc. improve milk production per day between 0.50 and 1.50 litres compared to other lactating buffalo without these methods (Table 1). The total number of buffalo was bifurcated into canal command and non-canal command areas based on the proportion of canal area in study zone. It was then assumed that half of the buffalo owned by small and marginal farmers would go to the canal for wallowing. For the analysis, this study used many rational scenarios with different combinations of the total number of wallowing days in canal water and increased milk quantity for buffalo (Table 6). Under different scenarios, it was estimated that wallowing in canal water helped in additional milk production of 1.97–9.43 million litres worth Rs 78.60–377.28 million. At the same time, canal water also serves as drinking water for visiting buffaloes. It is estimated that nearly 157–550 million litres of canal water utilized by buffaloes in a year would have been extracted in its absence (Table 7). The monetary value of drinking water was estimated to be between Rs 0.29 and 1.03 million.

Table 6. Estimation of buffalo's wallowing in EYC water on additional quantity of milk production and its value

Milk increases by (litres/buffalo/ wallowing days)	Wallowing days in canal water					
	Milk production (million litres)			Milk value (Rs millions)		
	50	75	100	50	75	100
0.50	1.97	2.95	3.93	78.60	117.9	157.2
0.75	2.95	4.42	5.90	117.9	176.85	235.8
1.00	3.93	5.90	7.86	157.2	235.8	314.4
1.20	4.72	7.07	9.43	188.64	282.96	377.28

Source: Authors' estimate.

Table 7. Quantity and value of EYC water used by buffalo for drinking and bathing

Water used for drinking and bathing (litres/day)	Wallowing days in canal water					
	Drinking and bathing water (million litres)			Cost saving in groundwater extraction (Rs millions)		
	50	75	100	50	75	100
40	157.20	235.80	314.40	0.29	0.44	0.59
50	196.50	294.75	393.00	0.37	0.55	0.73
60	235.80	353.70	471.60	0.44	0.66	0.88
70	275.10	412.65	550.20	0.51	0.77	1.03

Source: Authors' estimate.

Cultural services

The area alongside the canal is endowed with a road that facilitates farmers to reach their farms. The road alongside main and major distributaries connect villages and towns, allowing vehicular movements, and sometimes it gives easy access with a shorter route. In addition, the roads alongside the canal are used for recreation – walking and bathing by the farmers and villagers. Based on different scenarios for road charges and operational days in a year, it was estimated that roads alongside the canal provided services worth Rs 0.98–4.29, Rs 1.42–6.20 and Rs 0.10–0.57 million to farmers and other villagers for their various activities (Table 8).

Monetization of key services rendered by the EYC

Total water allocated to EYC in triennium ending (TE)-2018 was nearly 1106 MCM. Nearly 54% of the canal water percolates down recharging aquifers with some time-lapse and has repercussions on the long-term sustainability of groundwater (Table 9). The crops use the remaining canal water (metabolic process and evapotranspiration) and water loss (evaporation and seepage). Out of the total groundwater recharge with EYC, canal and its distributaries play a key role contributing about 80% and the remaining is contributed by return flow from canal irrigation. Accounting the working expenses, it was estimated that Rs 757.28 million per year is incurred by the government exchequer to maintain EYC command area. Based on the previous water rate for canal (presently the government has waived all water charges for canal), the government could generate only Rs 22.83 million, which is about 3% of the total working expenses for the EYC. A comprehensive accounting of all the benefits delivered by EYC to the ecosystem in its command area shows that the canal generates a minimum monetary worth more than its working expenses. Anchoring on average statistics, EYC renders ecosystem services worth Rs 1122.86 million, nearly 48.27% higher than its working expenses incurred by the government. The monetary valuation of canal ecosystem could be much larger if one could include services such as habitats for plants and animals, drinking water for stray and wild animals, and washing facilities for farm implements, fruits and vegetables, clothes, etc. In the total monetized ecosystem services delivered by EYC, nearly half of the monetized value is contributed by the marketed services.

Conclusion

The advent of individual-centric, low-cost groundwater extraction technology and the declining reliability of canal water have induced a downturn in the Indian canal irrigation system over the years. The existence of canal infrastructure augments water supply for irrigation, reduces groundwater extraction and carbon emissions, recharges aquifers, benefits livestock, especially buffalo, and facilitates farmers and other villagers. For the EYC command area, the government

Table 8. Value of services delivered by roads alongside the EYC

	Value of services generated by canal roads (Rs millions)								
	By farmers for farm field visit			By bikes/vehicles owner residing in villages			For recreation–walking, bathing, etc.		
	Road charge (Rs/km)								
Road operational days	2.50	5.00	7.50	5.00	10.00	15.00	0.25	0.50	1.00
250	0.98	1.96	2.94	1.42	2.83	4.25	0.10	0.20	0.39
300	1.17	2.35	3.52	1.70	3.40	5.09	0.12	0.23	0.47
350	1.43	2.86	4.29	2.07	4.13	6.20	0.14	0.29	0.57

Source: Authors' estimate.

Table 9. Ecosystem services delivered by the EYC

Particulars	Estimates
Total available water in EYC (MCM)	1106.02
Total groundwater recharge (MCM)	598.09
Share of recharge with cropped area	19.58
Share of recharge with canal and its distributaries area	80.42
Crop water use and water loss in form of evaporation, seepage and others (MCM)	507.93
Cost incurred to the exchequer as working expenses for EYC command (Rs millions)	757.28
Estimated gross receipt based on irrigation charge fixed by government (Rs millions)	22.83
% recovery of working expenses (%)	3.01
Total value of canal ecosystem	
Minimum	837.2
Maximum	1499.19
Average	1122.86
Share of marketed services	
Minimum	37.29
Maximum	66.77
Average	49.78

exchequer incurs about Rs 757.28 million each year as working expenses, and recovery is just 3% of the expenses as water charge from canal water users. Accounting key services of the EYC, the result shows that EYC bestows services to the ecosystem worth Rs 1122.86 million, which is nearly 48.27% higher than the working expenses of the canal. These prodigious benefits to ecosystem with existence of canals could proponent for its revival even though people adopt individual water extraction mechanisms in their fields. Therefore, in a business-like scenario, canal irrigation system generates services for the ecosystem that are worth more than its working expenses, despite yielding low revenue to the government. Moreover, under a pragmatic scenario, if the government ensures the timely availability of canal water as per crop water requirements and collects water charges equal to working expenses from its users, it will be a much better trade-off between the government and farm households. Also, the canal's existence and increased command areas will subdue the negative externalities of groundwater extraction in its command and water influence zones, which all the stakeholders are concerned about.

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