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Towards a Healthy Ganga—Improving River Flows Through Understanding Trade Offs

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Scores of Indians living worldwide, since the times immemorial have revered river Ganga. The very presence of Ganga is not only critical from a socio-cultural perspective; but it contributes to various economic and livelihood activities for the people residing in the basin. It is one of the most complex river basins in the world, in terms of the number of people residing in its basin space and the pressure on its water resources. Thus, the river is facing multiple challenges. There is a growing debate in India for improving the health of the Ganga River, mainly at two fronts, i.e., its water quality and quantity. WWF-India along with its partners is working towards the conservation of Ganga since last decade. Whilst the work has been multi-dimensional, ranging from the issues of flows in the river to water pollution, climate change adaptation and habitat and biodiversity conservation; however, in this paper the aspect of adequate flows in the river Ganga is discussed. During 2015–16, along with partners, WWF-India conducted an action research study in over 2 million hectares of culturable command area of two irrigation systems taking off from River Ganga, to understand the barriers to implement Environmental Flows (E-Flows) in the critical stretch of river Ganga (between Haridwar and Triveni Sangam Allahabad). Under this initiative, the team tried to bridge the knowledge gap about potential trade-offs for implementation of E-Flows in a critical stretch of Ganga. The team made an attempt to understand the surface water allocation and water use scenario in western and central part of the state of Uttar Pradesh, where the Ganga water is used for agricultural purposes through major irrigation infrastructure. The E-Flows recommendations for critical locations downstream of two barrages, i.e., headworks of two major irrigation schemes, were developed. This paper discusses approaches for management of trade-offs to restore E-Flows in this stretch of Ganga and includes various management options—like (i) promotion of irrigation water use efficiency and (ii) institutional aspects. The paper argues that, whilst there is a widespread apprehension that, from the Ganga river water resources use, any curtailment in the allocation quota for irrigation would lead to an adverse impact on the farming community. However, actually

after assessing the trade-offs, it can be inferred that although the E-Flows implementation in this stretch of Ganga would require enhancement of water in the river, but that requirement may not be substantial. Toward the end of the paper, challenges and opportunities for E-Flows implementation in the Upper Ganga are discussed.

Keywords: Environmental Flows, water allocation, tradeoffs, Ganga, irrigation, water use efficiency, barrage

INTRODUCTION

The river Ganga, with over 2,525 km[1] long main-stem, is one resource that sustains multiple functions—pertaining to ecological, socio-cultural and livelihoods. The mythological stories and anecdotes about the river and its association with the people and the nature dates back to times immemorial. There have been instances when the river, its health, its aquatic life, its flows and its water levels are related to various socio-cultural and spiritual aspirations. For instance—the Gharial is considered to be the carrier of goddess Ganga. The dolphin (Platanista *gangetica gangetica*) in the Ganga is considered to be companion of goddess Ganga. The good quality water and desired water levels in the Ganga are essential for cultural activities, including *aachman* (an auspicious activity, under which a pilgrim takes some water from the river on his/her palm and drinks it) and *snan* (another auspicious activity, under which a pilgrim takes holy dip in the river, for which waist deep water close to the river bank is generally desirable for such activity).

Globally, today's annual human water withdrawals are to the tune of 3,480 km^3, i.e., 2,409 km^3 for irrigation and 1,071 km^3 for Household-Industries-Livelihoods (1980–2009 average), which harms many river stretches around the world (Jägermeyr et al., 2017). The Ganga is facing large-scale human interventions since 1850s, when major irrigation systems called the Upper Ganga Canal (UGC), whereas the Lower Ganga Canal (LGC) were constructed in 1870s; this led to diversion of Ganga water resources for irrigation and other purposes. One needs to appreciate that every change in flow regime of a river is associated with some form of compromise of the integrity of the ecosystem structure and functions (Richter and Thomas, 2007). The interventions cause changes in ecosystem functions, and consequent ecosystem services for human community. This makes the target Environmental Flows not necessarily natural flows, but rather negotiated flows, set by either objectives (deciding what you want to achieve and setting flows to achieve it) or by scenarios (negotiating between different users) (Acreman and Dunbar, 2004).

As per Brisbane Declaration (2007), "The Environmental Flows (E-Flows) describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems."

The Consortia of seven IITs (Indian Institute of Technology) and other partner organizations developed the Ganga River Basin Management Plan (GRBMP) for the Government of India and submitted the main GRBMP document (Ganga River Basin Management Plan, 2015). As per a report on "Environmental Flows: State-of-the-Art With Special Reference to Rivers in the Ganga River Basin" [which has been prepared in 2011 as part of Ganga River Basin Management Plan (2011) exercise] the E-Flows are defined as:

"The temporal and spatial variations in quantity and quality of water required for freshwater and estuarine systems to perform their natural ecological functions (including material transport) and support the spiritual, cultural and livelihood activities that depend on them."

The team follows the E-Flows definition of GRBMP and this one is recognized (in Indian context) by the National Mission for Clean Ganga (Ministry of Water Resources, River Development and Ganga Rejuvenation) Government of India.

In the year 2010, the WWF (World Wide Fund for Nature) along with TNC (The Nature Conservancy) came out with a global publication on E-Flows Implementation Challenges, which analyzed the "as-is" scenario in restoring E-Flows in many countries across the globe. Based on a study across 64 countries and with 272 respondents, Moore (2004)[2] examined the trends in six major regions; based on that study, Moore concluded that, (i) the understanding of socio-economic costs and benefits and (ii) political will, are the two most important critical challenges for implementation of E-Flows. In many ways, these two aspects are interrelated, as an informed political leadership, in terms of socio-economic costs and benefits would be more willing to take decisions in favor of E-Flows.

It is recognized that the large scale irrigation systems on Ganga has contributed immensely to the betterment of agricultural economy of the region, which has certainly enhanced the socio-economic status of people in the western and central Uttar Pradesh (second state, on the main-stem of Ganga). Besides this, the entire Indo-gangetic plains have become a fertile land with the help of Ganga water and the sediments that flow with this water. On the other hand, during the last half a century, many new challenges have compounded the pressures and stresses onto the Ganga, its water resources and its aquatic life. These challenges mainly include—(i) ever-growing towns into cities and cities into mega-cities on the banks of Ganga, (ii) industrialization along the settlements on the banks of Ganga, (iii) excessive groundwater exploitation and chemical inputs in agriculture, and (iv) changes in copping pattern, including water

[1]Source: https://nmcg.nic.in/courseofganga.aspx

[2]Source: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.540.8546&rep=rep1&type=pdf (Page No. 6).

intensive crops, which are leading to enhanced surface and ground water withdrawals.

The successive Governments, on its part, have been trying to improve the health of river Ganga since 1980s and despite creation of pollution control infrastructure, the health of the river Ganga has not visibly improved. The renewed impetus toward Ganga conservation since 2010 has raised hopes, and since then, the Government has taken several policy decisions, which are being implemented. However, such a task is full of challenges, especially, in a complex river basin, whose population density is 520 person/km² as compared to national average of 312 person/km²[3] as per "Demography of Ganga Basin" (National Mission for Clean Ganga, 2012). Another layer of complexity includes multiple departments—handling water related affairs. On the other hand, this time, the Government of India entrusted the task of development of Ganga River Basin Management Plan (GRBMP) to a consortia of 07 IITs[4]. As per the main document of GRBMP (released in January 2015), the vision for management of Ganga river includes two key aspects, i.e., *Arival dhara* (continuous flows)—*Nirmal dhara*[5] (unpolluted flows) in Ganga. As part of this work, the consortia of IITs, also did E-Flows assessment for the mountainous stretch of river Ganga, which has several hydropower projects. This work was built on the earlier work of WWF India, under which E-Flows assessment for Upper Ganga was done by improvising and using one of the holistic methodologies during 2008–2010. As per the GRBMP, the measures for sustainable management of Ganga river basin are given in three categories, i.e., short-term, medium-term and long-term. At present, various governmental agencies, multilateral and bilateral funding agencies are putting in resources to pick some of the measures from the GRBMP document to pilot them or implement them (as the case may be) on the ground. On the other hand, with the support from the Government of India, the Centre for Ganga River Basin Management Studies (cGanga) has been created at IIT Kanpur to guide and oversee the works around Ganga rejuvenation in light of the GRBMP.

There have been attempts to answer the E-Flows requirement in the Ganga, and therefore, besides the pollution discussions, the debate for Ganga conservation within the formal circles is around allocation of water for E-Flows. In this regard, two important and critical, but old irrigation systems (Upper Ganga Canal and Lower Ganga Canal, however both these systems have undergone modernizations drives from time to time) in upstream states on the Ganga main-stem (Uttarakhand and Uttar Pradesh) are generally discussed. It has been debated whether there are prospects and opportunities to enhance the flows in the river Ganga downstream of these interventions.

The National Commission on Integrated Water Resources Development Plan (NCIWRDP—Government of India), in the year 1999, has called for enhancement of water use efficiency across all sectors by at least 20%. In other words, irrigation efficiency should be improved from the present average of about 35–40% to the maximum achievable i.e., around 55–60% (Central Water Commission-Ministry of Water Resources, River Development and Ganga Rejuvenation, 2008). The National Water Mission of Government of India in the year 2009 called for enhancing 20% water use efficiency in its National Action Plan on Climate Change (National Action Plan on Climate Change, 2009)[6].

In the case of Uttar Pradesh (which is a critical state when it comes to large-scale withdrawal of Ganga water resources for irrigation),(Kaushal and Kansal, 2011) concluded that current proportion of water allocation for agriculture is bound to get reduced in near future. As per SWaRA (State Water Resources Agency—Uttar Pradesh), the agri-water allocation of about 96% in the year 2001 will get reduced to about 79% by the year 2050, which would mainly be due to increasing domestic and industrial demand.

The ongoing work around Environmental Flows (E-Flows) in the Ganga, which is more than a decade old now, leads to the "next-generation" questions, i.e.,

- ✓ if the E-Flows are to be maintained, from where the water will come?
- ✓ what would be the trade-offs for E-Flows implementation?
- ✓ what would be the implications onto the committed sectoral water uses?

This paper attempts to answer some of above policy questions, through summarizing a research study (2015–16) that WWF-India along with its partners (Indian Institute of Technology-Kanpur, *Aarthik Vikas Evam Jan Kalyan Sansthan*—Lucknow and Institute of Rural Management, Anand) have conducted, under a CGIAR (Consultative Group on Integrated Agricultural Research) Research Programme on Water Land and Ecosystems, funded by IWMI (International Water Management Institute—Sri Lanka) on "Healthy Ganga—Cleaner Water and More Productive Ecosystems[7]" The role of these institutions and organizations in the project is listed in **Table 1**.

The paper, in a way, attempts to package a complete picture—ranging from an understanding about the current water resources use pattern from the river Ganga at critical location, including ground realities in this regard and the E-Flows requirements at such a location; to, ascertaining how the recommended E-Flows can be secured in such an over-committed river system. It ties well with the general debate within the country and more specifically in the Ganga basin that, *"for the E-Flows realization, from where the water will come from and what is going to be the implication on other sectoral uses?"*

Efforts are made in this paper to provide insights and suggestions, that may find place in overall policy discourse on securing water for maintaining E-Flows in Ganga, in specific and in other river systems, in general (where heavy diversions for irrigation are existent). It is argued that there are opportunities which can support long term E-Flows realization in the Ganga.

[3]Source: National Mission for Clean Ganga. Information is referred from: https://nmcg.nic.in/demography.aspx

[4]Consortia of 07 IITs: Indian Institute of Technology – country's premier technical institutions. Seven IITs include: IIT Kanpur, IIT Roorkee, IIT Delhi, IIT Kharagpur, IIT Guwahati, IIT Bombay, IIT Madras.

[5]Source: information extracted from: https://nmcg.nic.in/grbmp.aspx

[6]Source: http://www.nicra-icar.in/nicrarevised/images/Mission%20Documents/WATER%20MISSION.pdf

[7]For project details, please refer to https://wle.cgiar.org/healthyganga

TABLE 1 | Name of institutions, organizations and their role in the project.

S. No.	Name of Institution/Organization	Role under the project
1	WWF-India	Assessment of Ganga water resources, its allocation and use Understanding the baseline scenario from the perspective of the irrigation-department, with respect to irrigation that is dependent on Ganga's surface water resources Valuation of Ecosystem Services of Ganga river Implementation framework for E-Flows at 2 critical locations Cost-benefit analysis for E-Flows implementation
2	IIT Kanpur	E-Flows assessment for 2 critical locations on Ganga
3	Aarthik Vikas Evam Jan Kalyan Sansthan, Lucknow along with WWF-India	Baseline surveys—farmers in Upper Ganga Canal (UGC) and Lower Ganga Canal (LGC)
4	IRMA Anand	Understanding the gender aspects

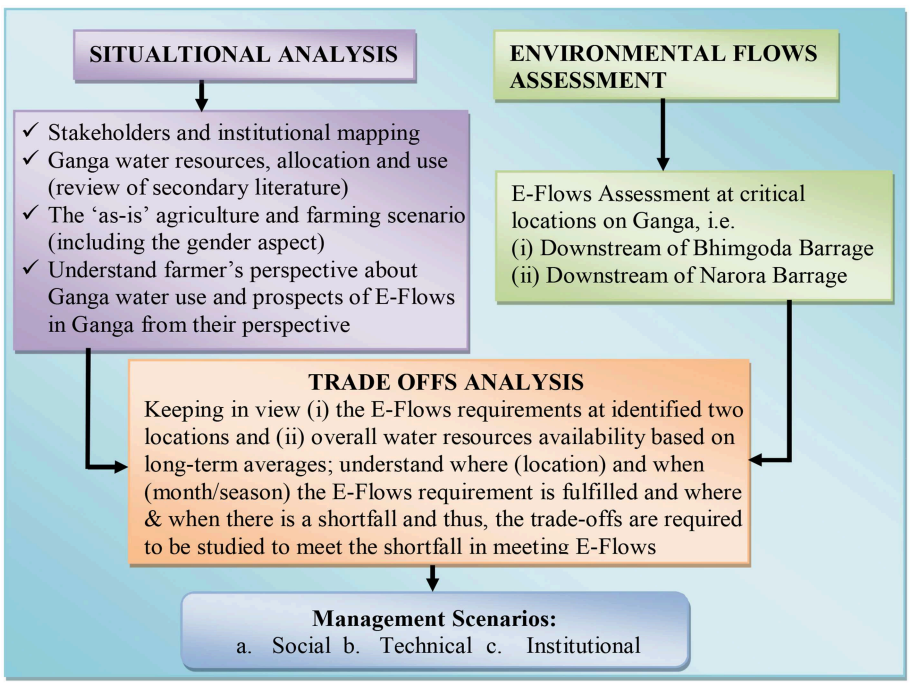


FIGURE 1 | Process chart exhibiting the methodology for the work.

Figure 1 illustrates the step-by-step approach for this work, in which each task-head is based on (i) field-oriented primary information and (ii) secondary literature, including formal documentation.

One of the preliminary aspects of the approach is to understand the "as-is" scenario. Therefore, the first and foremost task was to understand the key stakeholders, their significance and their current roles in allocation-management-use of Ganga water resources.

For this task, key stakeholders were identified and various modes of engagements were adopted to generate the required information, these modes included—one-to-one discussions, interactive sessions, Focused Group Discussions, individual interviews, workshops etc. The listing of stakeholders, type of engagements and objectives of the engagements is given in **Table 2**.

The wide spectrum of stakeholders with whom the team interacted can be seen in **Figure 2**. The review of secondary literature and field surveys were conducted almost simultaneously and the collected data was deliberated upon, initially within the team and later on with the stakeholders, i.e., officials from respective government departments, through Stakeholders Consultations.

The trade-offs are primarily assessed for the biggest user of Ganga water resources, i.e., irrigation. An attempt is made to ascertain how much irrigation water savings can be achieved at varying percentages of efficiency in irrigation water use; the idea is that the saved water can be used for enhancing the flows in the river.

PROJECT AREA AND SITUATIONAL ANALYSIS THROUGH ACTION RESEARCH

The implications of current policies on surface water allocation (withdrawals from the river) and use (at state level) are discussed

TABLE 2 | Key stakeholders and objective of interactions with them.

S. No.	Stakeholder	Type of engagement	Objective of engagement
1	Farming community who is dependent on the Ganga water resources through UGC, LGC, and groundwater which is often recharged by the river and the canal systems (as the canal system is largely earthen)	Surveys and Focused Group Discussions	To understand the overall agriculture scenario, dependence on surface water resources, problems and prospects of E-Flows implementation and willingness of farmers to contribute to this noble cause, as they also visit banks of Ganga during auspicious days for socio-cultural rituals, so a "healthy Ganga" is of their interest as well
2	State Irrigation Department, who is currently the "water-manager" when it comes to management of Ganga water resources for all the uses; primarily irrigation, but also domestic and industrial, wherever applicable	Individual interviews and Focused Group Discussions	To understand the overall surface water use scenario across the sectors, departmental challenges in dealing with this aspect. Their perception about enhancing flows in the river Ganga and potential approaches for implementation
3	National Mission for Clean Ganga and other State Departments	Focused Group Discussions	To ascertain their perspectives about the E-Flows maintenance in Ganga vis-à-vis committed uses

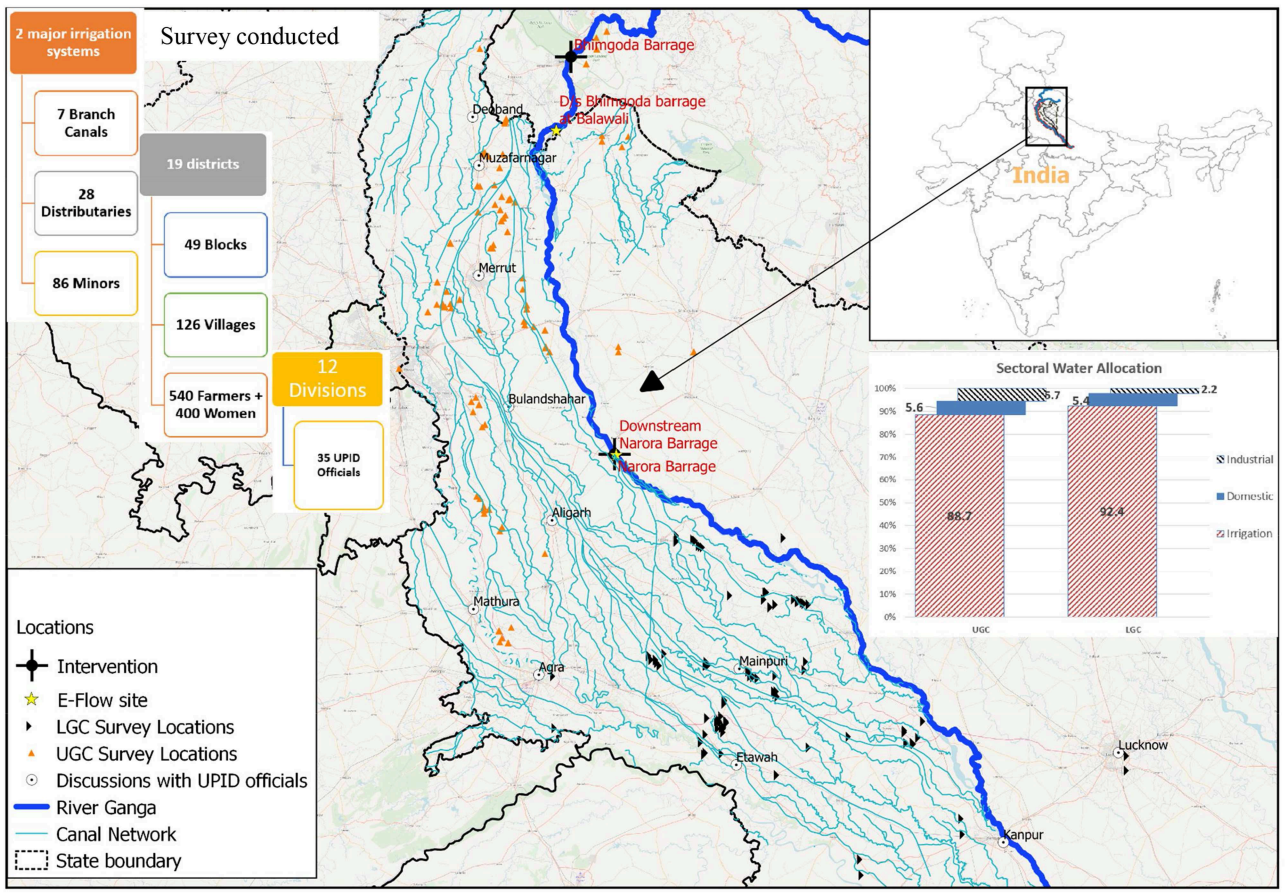


FIGURE 2 | Map of project area with intervention (irrigation projects), survey locations, and sectoral Ganga water allocation (Source: WWF India).

through an action research study that was conducted in the upper Ganga. The surface water allocation at state level is generally governed by populist considerations around ensuring water for irrigation; however, the aspects of National Water Policy are also considered, nevertheless the key motivation remains the earlier one. The management of water resources and its efficient use is something that is very much there in policy realm, but in practice, this is not close to anticipated targets and objectives of both, Governments of India and of the state of Uttar Pradesh.

This research was conducted in catchment of critical stretch of River Ganga, where the river faces heavy abstractions, which are perennial in nature, i.e., the relevant districts of state of Uttar Pradesh (UP) and a district in state of Uttarakhand, which borders with UP, i.e., Haridwar. The project area map along with

information about intervention and survey locations is given in **Figure 2**.

There are two major perennial irrigation systems taking off from river Ganga, one at Bhimgoda Barrage located in the holy city of Haridwar, which is the headwork of Upper Ganga Canal (UGC) and supports irrigation in about 11 administrative districts in Uttar Pradesh and one district in Uttarakhand[8] (Uttar Pradesh Irrigation & Water Resources Department - formerly called Uttar Pradesh irrigation Department).

On the other hand, another key intervention is at Narora Barrage, which is the headwork of Lower Ganga Canal (LGC) system that supports irrigation in about 10 districts of UP. Together these two irrigation systems have a Cultivable Command Area of over 2 million hectares (Uttar Pradesh Irrigation and Water Resources Department, 2017a). **Figure 1** exhibits the project area, i.e., all the districts falling in UGC and LGC. Additionally, the figure indicates precise sites, where interactions, interviews and FGDs (Focused Group Discussions) were conducted. The figure also illustrates the sector-wise percentage of water use through these two interventions and the sample size of respondents.

This information in **Figure 2** indicates heavy water resources usage for irrigation and other purposes (as these canal systems also provide water for domestic supplies to some of the cities within the basin—including National Capital Region (NCR) and in Uttar Pradesh, plus some industrial supplies) from Ganga's water resources. Therefore, any effort for implementation of E-Flows in Ganga will have to closely look into these "committed" uses.

Field Survey Findings

The findings were used as inputs for developing the overall understanding about trade-offs, associated cost and benefits of maintaining E-Flows in the critical stretch of River Ganga. In this section, the findings are organized in a thematic manner.

Farming Practices and Their Perception for Healthy Ganga

There is a plethora of inferences that one can draw from the field investigations in the LGC command with different stakeholders, and the same is summarized below in bullet points. These points can be considered while devising policy and strategy for long term E-Flows implementation in Ganga through sustained irrigation water use efficiency measures.

- Over 95% farmers adopt "flooding" as the medium for irrigating their fields, which indicates huge scope for promotion of irrigation water use efficiency. The main crop (in around 80% of command area) is wheat in *Rabi* (November-April) and paddy (in about 57% of command area) in *Kharif* (June–October). There has been a steep rise in sugarcane cultivation since last few decades and that has tremendously put pressure on available water resources.
- The water distributions method amongst farmers is mainly on a rotational (*Warabandi*) basis, the figure about water distribution through "*Warabandi*" (on rotational basis) and "mutual-understanding" (for rotational distribution) approach are about 72%. The majority of farmers use earthen channels for conveyance of water from the canal to field.
- The knowledge and awareness about Participatory Irrigation Management (PIM) and Water Users Associations (WUAs) is a mere 3%. However, now the Uttar Pradesh Irrigation Department is forming Water Users Associations (WUAs) in the entire LGC command area; to be followed by formation of WUAs across all irrigation schemes in the State.
- About 90% of farmers felt the need for training and capacity building toward modern agriculture and irrigation techniques. Less than 12% of farmers go for "soil-health" testing at the farms.
- The data collected over literacy status among the farmers suggests that, over 37% farmers are high school (tenth standard) passed, and about 10% are graduate or above. This indicates great scope for andragogy based extension services for disseminating water efficient agriculture practices.
- Close to 90% farmers visit Ganga for various festivities and 51% of them are satisfied with current water levels and its cleanliness.
- About 73% farmers realize that, the aquatic life in river Ganga is on negative trajectory. About 81% farmers felt that, additional water supplies should be ensured in Ganga to sustain Ganga's aquatic biodiversity.

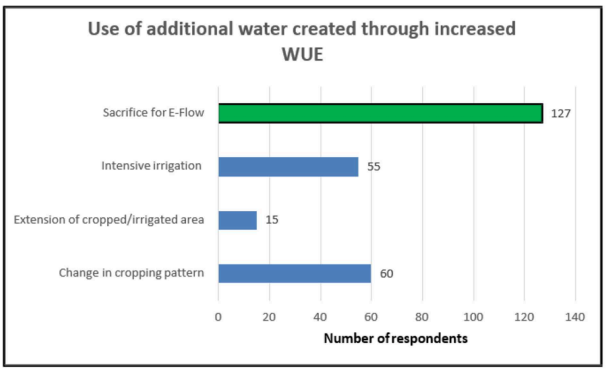


FIGURE 3 | Preference of farmers to use saved water through WUE initiatives in LGC.

The finding around willingness of farmers to transfer saved water from irrigation to the river Ganga threw some interesting perspectives, and the same is illustrated in **Figure 3**; however about 50% of farmers are willing to transfer their saved water to river Ganga.

Perspective of Departmental Officers

The mandate of state Irrigation Department is to provide water for irrigation to the command farmers, which has been the priority of the officials; however, they understand the implications of reduced flows in River Ganga upon its health. The key messages from them include:

[8]Source: Uttar Pradesh Irrigation Department website: http://idup.gov.in/pages/en/topmenu/dept.-activities/civil/en-irrigation-by-canalsirrigation-by-canals

- In view of growing demand for water for irrigation, due to some of the changes in cropping patterns, the canal systems are over-stretched to deliver water up to the tail end and this often leads to reduced water supplies at the tail-end. The canal systems are developed and designed to provide "protective" irrigation, whereas the current demand is to the tune of "intensive" irrigation.
- Gauges at the head of minors are often in dilapidated state; hence precise water discharge monitoring is a challenge.

Most of the officials were positive about enhancing flows in Ganga to improve the health of the river; however, they feel that rationalizing the allocations of Ganga water resources from existing commitments would be a key challenge. Their suggestions include following:

✓ Farm level water use efficiency is required to be promoted and practiced; if feasible, such efforts should be incentivized.
✓ Awareness campaign and demonstration drives should be carried out toward irrigation water use efficiency.
✓ Organic farming, usage of less water consuming crops should be promoted.

Environmental Flows at Critical Locations on River Ganga

As part of the study, the team from IIT Kanpur (Indian Institute of Technology Kanpur) conducted E-Flows assessment at two main intervention locations on Ganga river (i) Downstream Bhimgoda Barrage and (ii) Downstream Narora Barrage. The process of arriving at E-Flows values is illustrated in **Figure 4**.

For the purpose of this paper, the actual-flows gap vis-à-vis E-Flows requirements are presented only for one intervention, i.e., downstream of Narora Barrage (as the key E-Flows gaps during the lean season are observed at this location); on the other hand, in case of downstream of Bhimgoda Barrage, the lean season flows were not that far off from E-Flows requirements (as per this study). Therefore, the trade-offs are not as challenging as in the case of downstream of Narora Barrage. The percentage[9] of shortfall from present water availability downstream of Narora Barrage vis-à-vis E-Flows recommendations are presented in **Figure 5**.

It is to be noted that the crisis time, in terms of shortfall in present day flows vis-à-vis recommended E-Flows, is during the months of December, January, February and April. The December-January month coincides with the timing of maximum water requirement for irrigation as well.

Whilst the E-Flows recommendations are largely based on the requirements (during different life-phases) of Indian Major Carps (*Labeo calbasu, Catla catla, Labeo rohita, Cirrhinus mrigala*), it was also correlated whether the water levels, thus achieved through this aquatic biodiversity-centric E-Flows recommendations, are able to provide desired water levels for the socio-cultural aspirations/activities, which were discussed in the beginning of the paper. It is the lean season when most of the socio-cultural festivities are organized, and therefore, the desired water-levels are critical for having satisfactory socio-cultural rituals. It was observed that the water levels required by these fish species are able to meet socio-cultural requirements. On the other hand, the current flows are unable to meet various biological requirements of above-mentioned fish species during "lean-season." O'Keeffe et al. (2012) discussed the presence of dolphins around Narora in the Ganga main-stem, as this stretch is a conducive dolphin habitat in the upstream of Narora Barrage.

It is worth mentioning that the hydrological information that has been used in this E-Flows assessment is of pre-Tehri dam timeframe (as long-term hydrological information is required to be used as a standard practice in E-Flows assessment). However, since the commissioning of the Tehri dam (in 2006), the flows scenario in the Ganga might have changed, and thus, the E-Flows requirements may vary. This is a matter of further research.

With a developed understanding so far, in terms of present Ganga water resources allocation-management-use vis-à-vis desired E-Flows; the next task was to ascertain the trade-offs and generate scenarios for potential consideration, which is discussed in the upcoming section on recommendations.

RECOMMENDATIONS

Looking at the field findings, there is a clear case for improvement in the current irrigation and agricultural practices; which would not only benefit the river but also the farmers. On the other hand, an assessment of shortfall in E-Flows at downstream of Narora Barrage was done by comparing the present-day flows and the E-Flows requirements. After ascertaining the E-Flows shortfalls at downstream of Narora Barrage, various options (that will allow realization of E-Flows) were explored and the same are categorized as different "Management Scenarios." These "Management-Scenarios" may be considered by the policy makers and the water managers.

Social and Technical—At Farm Level

In order to achieve the objective of E-Flows maintenance, both "on farm efficiency" and "conveyance efficiency" need to be enhanced. It is worth understanding at this juncture what we mean by irrigation water use efficiency; keeping in view the current irrigation scenario, we look forward to following asks through which water use efficiency can be enhanced in irrigation in the command area of LGC:

a. Flood irrigation is the key means of irrigation at the moment and that needs to change to furrow irrigation initially and later on micro-irrigation should be considered. However, furrow irrigation alone has the potential to save over 20% irrigation water.
b. Introduction of different varieties (less water intensive or the ones requiring lesser time-period) of the same crop and gradually explore the possibility of marginally changing the cropping pattern to less water intensive crops.

As part of another project (Rivers for Life Programme 2012–2017: supported by HSBC Water Programme), the team (comprise of some authors and other colleagues at WWF

[9]NOTE: Due to 'classified' nature of Ganga river flows information, the authors have reported the E-Flows shortfall in terms of percentages rather than in absolute values.

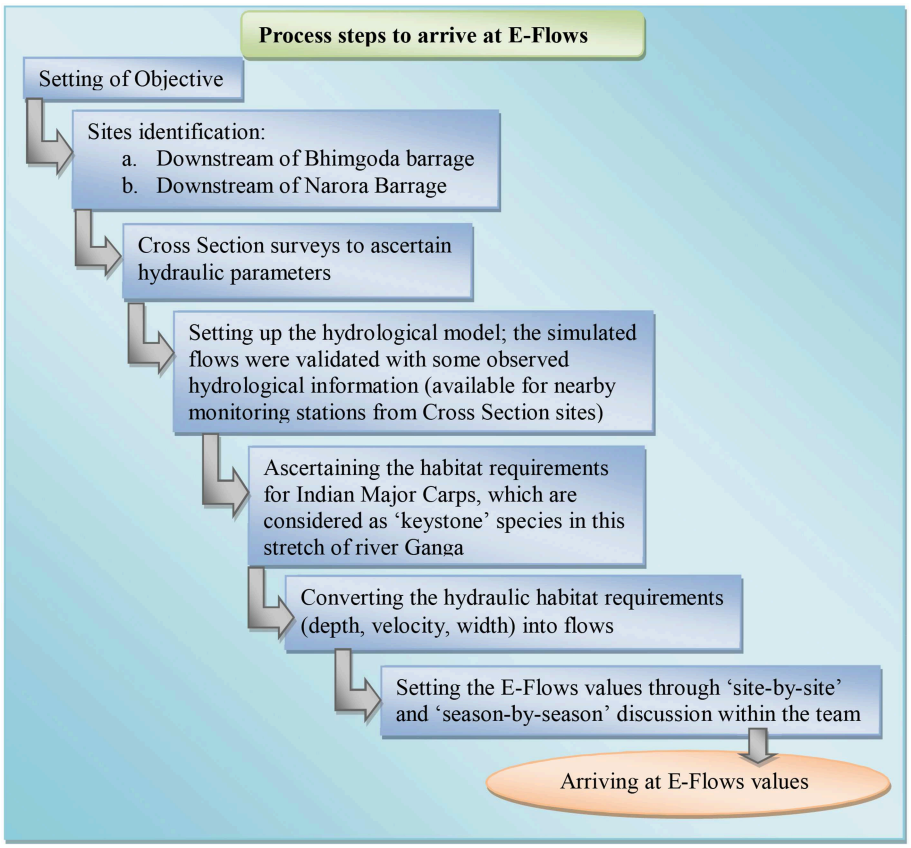


FIGURE 4 | Flow chart to illustrate the process to arrive at E-Flows recommendations (Source: WWF India and IIT Kanpur).

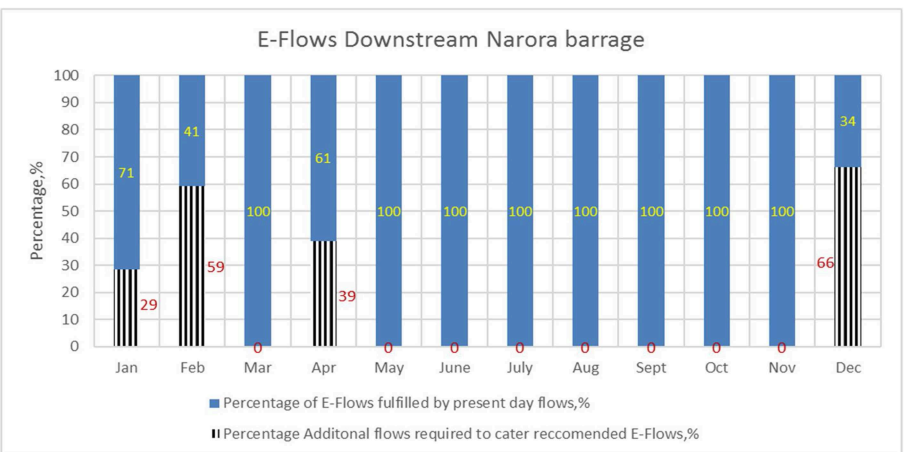


FIGURE 5 | Percentage of E-Flows and its shortfall in comparison to percentage in present day flows from Narora Barrage (headworks of Lower Ganga Canal) (Source: developed by WWF India, based on the information and data from IIT Kanpur).

India) is working with over 2,000 farmers in 40 villages of 8 districts of Uttar Pradesh in Ganga Basin. This work includes the demonstration of Package of Practices (Soil-Health testing, formation and the application of organic fertilizers and pesticides, introduction of drought tolerant varieties etc.), which is helpful for reduction of chemical inputs at the farms along with improving current levels of irrigation water use efficiency.

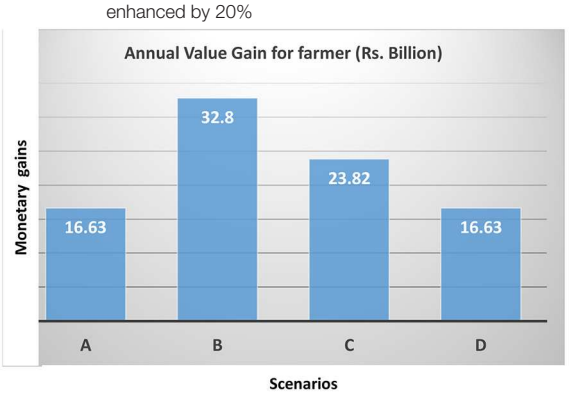
In no way do the authors call for lining of canal systems (as a means of enhancing water use efficiency), because it is recognized that, in this region which is largely alluvial in nature, the ground-water recharge function of canal systems is critical for maintaining ground-water levels and there is no intention to disturb that process, at the moment.

It has been assumed that if current irrigation efficiency levels are increased by varying percentages, then what would be the benefit in terms of water availability at head for maintaining E-Flows. For the purpose of this project, water use efficiency relates to reduction in canal water use for irrigation while maintaining the crop yield, which essentially implies demand management. Under this category, Scenario A–D is presented in **Table 3** for both interventions. It can be inferred from that table that, under Scenario B with achievement of 3% irrigation Water Use Efficiency in the LGC system from current levels, the E-Flows in the Ganga at downstream of Narora Barrage would be realized.

Very recently, the Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India came out with a Notification on E-Flows on 10 October 2018 (Notification on Environmental Flows by Ministry of Water Resources, River Development and Ganga Rejuvenation, 2018). In this Notification, the absolute values of E-Flows for different seasons are given for the locations downstream of different barrages, including both Bhimgoda Barrage and Narora Barrage. However, in the case of the mountainous stretch of Ganga, the required E-Flows are given in percentages.

TABLE 3 | Different WUE scenarios for LGC systems for fulfillment of E-Flows in Ganga.

Scenarios	Description	Whether E-Flows would be achieved	Percentage of E-Flows gap fulfilled, %
NARORA BARRAGE			
	BAU	No	–
A	Water-use-efficiency enhanced by 1%	No	46
B	Water-use-efficiency enhanced by 3%	Yes	137
C	Water-use-efficiency enhanced by 5%	Yes	228
D	Water-use-efficiency enhanced by 20%	Yes	910



A closer comparative analysis of the E-Flows recommendations for lean season (the one recommended as per the Government Notification and the ones recommended as part of this study) informs that the E-Flows recommended as per the Notification cannot meet the E-Flows requirements desired under this study during some of the critical lean months.

The irrigation water use efficiency scenario essentially entails water savings for the purpose of realizing E-Flows, without compromising with agricultural productivity. It is realized that, besides the achievement of E-Flows through irrigation water use efficiency; there would be value gain to farmers as well, because there have been instances of overwatering leading to lesser agricultural productivity, thereby resulting in negative marginal product. Based on this understanding, some broad calculations are completed to estimate monetary gains to the farmers under Scenario A to D and the same is available along with **Table 3**. Thus, it is possible to attain E-Flows without compromising with farm incomes, and rather it would be economically beneficial to farmers. A separate exercise is being conducted to understand economic gains, in a detailed manner, for farmers through irrigation water use efficiency and other means, which is not part of this paper.

Institutional

There are various reforms underway; one is to hand-over operation and maintenance of canal systems at minor canal level to the farmer groups, i.e., Water Users Associations (WUAs) by bringing necessary legislations and executive orders with an objective to empower the farmers in decision-making. There are national and global examples, where the WUAs are able to successfully demonstrate higher levels of irrigation water use efficiency and they have saved lot of water in the system for the respective department. The idea of "buy-back," on the lines of several other countries, is also being looked at.

There is a growing debate within the government that, by extending necessary services to farmers, i.e., Soil-Health Card and pressure irrigation (drip and sprinkler), there is a lot of scope of water use efficiency and this can effectively be run through the WUAs, as it is a group of farmers and the scheme or idea can be implemented in one go.

The Governments, both national and state ones, are implementing programmes and projects, which would help in this larger cause. Notably amongst them include—"*Namami Gange*[10]," *Pradhan Mantri Krishi Sinchai Yojana*[11] (Pradhan Mantri Krishi Sinchai Yojana, 2017-PMKSY), renewed push for improvised District Plans, ongoing Uttar Pradesh Water Sector Restructuring Project (UPWSRP) of the World Bank and so on (Uttar Pradesh Irrigation and Water Resources Department, 2017b).

As part of the *"Namami Gange"* programme, the District Ganga Conservation Committees (DGCCs) are formed under the chairmanship of respective District Magistrate (administrative head of a district) in all the Ganga basin districts. One

[10] *Namami Gange* – name of National Government's flagship programme on Ganga rejuvenation.
[11] English translation – Prime Minister Agriculture Irrigation Scheme.

of the mandates of the DGCCs is about furthering the cause of E-Flows in Ganga, as some of the measures at village-level can be implemented through them, and since these bodies are at local level, the monitoring can also be done effectively. Plus, the "Ganga-*Grams*[12]" (Ganga villages) are identified for furthering the cause of Ganga rejuvenation and conservation. The DGCCs can play a key role in successfully accomplishing the tasks entrusted to Ganga-*Grams*. These Ganga-*Grams* can also implement a package of better management practices in agriculture and irrigation, and can therefore contribute toward enhancing irrigation water use efficiency and reduction of chemical inputs in agriculture.

Under PMKSY, the main aim is "water-to-every-farm" and "more-crop-per-drop." As part of these two aims, one of the objectives is to push for pressure and micro irrigation techniques with an aim to conserve water and doing-away with "flood" irrigation. For this, the Government is extending subsidies to farmers who are willing to adopt these modes of irrigation. If this scheme is enforced properly in the villages falling within the command of LGC, a lot of water saving can be done.

The renewed push for improvised District Plans, in a way, calls for integration of recently announced and enforced governmental schemes into the planning phase; so that the schemes can be smoothly implemented through the district-led processes. The integration of programmes and schemes like "*Namami Gange*" and PMKSY into District Plans can go a long way to help the larger cause of improving the health of river Ganga.

The Government of Uttar Pradesh promulgated Participatory Irrigation Management Act in the year 2009. This Act calls for formation of Water Users Associations with a key mandate of managing the water use within the command of their jurisdiction. There are examples in India (central, southern and western India) where some of the WUAs are doing pioneering work in regards to irrigation water use efficiency and such WUAs are also promoted and incentivized by the concerned governments. Along similar lines, if the WUAs in LGC command are facilitated, then these WUAs can play key role in water savings within their command. In this regard, the UPWSRP is playing a critical role in intensifying the efforts toward formation of WUAs. The WUAs, taking benefit from various governmental schemes (like PMKSY) can save lot of water allocated for irrigation and negotiate with the department and government to incentivize such efforts. Besides this, as per the PIM Act, the WUAs can decide on water charges (higher than the governmental water charges), which are to be collected from the command farmers and incentivize irrigation water use efficiency and discourage water overuse. The Irrigation Department, in a long run, can explore the possibilities of "buying-back" the water from farmers for the cause of enhancing flows in the river; which could be one way of incentivizing the WUAs.

[12]Ganga – *Grams (English meaning Ganga Villages)*: The Central Government in 2016 declared to develop 206 villages located along the main stem of river Ganga which have historic, cultural, and religious and/or tourist importance. The works related to Ganga *Grams* will encompass comprehensive rural sanitation, development of water bodies and river *ghats* (stairs and platforms to facilitate rituals), construction/modernization of crematoria etc. more information can be accessed at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=137672

LIMITATIONS

Whilst this study has been enlightening in many ways, there were some limitations that the team worked with. It is worth capturing those limitations so that the findings in this paper and the way forward is seen in that light.

As mentioned earlier, the flows regime might have changed a bit in view of commissioning of Tehri Dam, but in this study the hydrological data, that the team has used is of pre-Tehri time. This is one of the limitation of the study. One aspect that can be argued is that the team has not explicitly considered the costs associated with each flow regime, the costs associated in moving from one flow regime to other flow regime, and whether the costs would have overturned the benefit figures. While not acknowledging the costs explicitly might be considered as a limitation of this study, one need to note here that the costs are largely non-monetary in nature, and the monetary costs are too negligible even in the forms of capital expenditures.

On the other hand, there are certain datasets that are "classified" in nature, and hence cannot be shared in this paper; however the team ensured that validation of information generated through standard models is done with the actual data.

Both the UGC and LGC are fairly large irrigation systems and a statistically viable sample number (in terms of farmers) is difficult to consider, however, the team ensured that all the sections of head-middle-tail reaches of canal systems are taken care of.

It is recognized that, since there is substantial surface-ground water interaction happening in the gangetic plains, long term E-Flows implementation across the river system would call for better understanding of "loosing" and "gaining" streams/stretches in the Ganga, which would therefore call for regulation of ground-water use for irrigation. There is currently a "knowledge-gap" existing in this respect, and thus it can be a forthcoming research opportunity.

Besides this, it is understood that there would be "return-flows" from agriculture to the river, however its estimation in specific terms has not been done on current agricultural practices in this region, and thus the team refrained from doing any general broad estimation of "return-flows" through standard modeling exercises. In view of this, the "return-flows" phenomena have been kept aside; however, it is a crucial research question that should be taken up by researchers.

Whilst it is recognized that issues like—domestic and industrial pollution, urbanization and floodplains encroachment are other critical challenges the river Ganga faces, and thus addressing these issues are critical to improving the overall health of river Ganga, it is equally pertinent that the desired freshwater flows in the river are maintained. Together, with all these aspects, a basin-wide approach is required for ensuring a healthy state of river Ganga and that has been the thrust of GRBMP; however, this paper deals with the specific aspect of flows in the river Ganga.

CONCLUSION: CHALLENGES AND OPPORTUNITIES AHEAD

When water resources are allocated to economic uses and water needs to be recovered for the environment, this is always difficult. There are various options for obtaining this water, one of the main options is:

- Instituting water efficiency improvements in the economic uses through technical improvements, with some of the "saved" water being used for the environment (Hirji and Davis, 2007).

Whilst this argument holds true for Ganga, without required support the desirable results would be difficult to achieve. On the other hand, given the scale of challenges the river and the basin face, the implementation of E-Flows in the Ganga is a long-drawn and highly complex process. Right from growing population, and thus the need to have more agricultural produce, coupled with growing economy leading to changing food habits, improved life-styles and individual expectations; all this pushes the boundaries and limits of existing facilities and infrastructures. The current irrigation and agricultural practices, aging canal and associated facilities further aggravates the scenario.

There has been a feeling amongst a section of policy makers and the water managers that there would be widespread dissatisfaction amongst the farming community if the allocation of surface water resources for irrigation are rationalized to accommodate E-Flows requirement of the Ganga. In many ways, this study attempted to burst this myth about potential dissatisfaction amongst the farmers; however, it is to be noted that the path toward E-Flows implementation is going to be complex due to various reasons, some of which are as follows –

a. **Promotion of Efficient Irrigation and Agriculture Practices**—Starting with furrow, similar easy-to-adopt better management practices in irrigation and the gradual movement toward micro-irrigation techniques. This approach also needs to be coupled with marginal change in cropping pattern (in terms of using less-water intensive crops) in the command area based on soil health improvement, as this marginal change would mean substantial water savings. This is going to be a slow process, mainly because of the scale (major perennial irrigation systems feeding about 2 million hectare of agricultural land), which is a big challenge as the change "at-scale" would be a long, complex and persuasive process.
b. **Hand-Holding and Incentivizing the Farmers**—Whilst there is a huge "reverence-value" amongst the farmers, as about 90% of them visit the banks of river Ganga for various socio-cultural festivities and they are supportive to compromise part of the water (allocated to them) for raising water levels in the Ganga for improvement of Ganga's health. However, this needs to be done with proper "hand-holding" of the farmers (in terms of institutional support, adequate knowledge of BMPs in irrigation and agriculture, effective extension services, pilot demonstrations). The Water Users Association can play crucial role here.
c. **Overcoming Technical Challenges**—The existing irrigation systems are designed to take certain designed discharges and any reduction in discharges would mean reduction in hydraulic head that is required to transfer water to tail ends. This will essentially lead to inequitable distribution of water; therefore, some level of technological intervention would be required. The ongoing UPWSRP and PMKSY could be a useful medium for looking at technical upgradation of some sort and may be on pilot basis in a small command area, to start with.
d. **Clear Understanding About Influent and Effluent Streams**—One of the critical research questions or rather a "gap," is about the understanding of "influent" (a stream located above the water table and discharges into the underlying groundwater system) and "effluent" (a stream that get their water from the groundwater) nature of streams in the Ganga basin or even for the Ganga river itself. In absence of this understanding, the additional waters from the barrages into the river may not bear desired results in totality; such an understanding can extend long-lasting support for maintaining E-Flows in the Ganga. Parallel to this, conjunctive use of surface water and ground water is required to be thoroughly promoted in irrigation, as this will significantly help in ground water recharge as well. At the moment, this is something farmers are practicing based on their needs, and thus its uptake is inadequate.

The ongoing dialogue within the government, researchers and civil society to secure water resources for E-Flows in Ganga by looking at withdrawals for irrigation is a positive sign. This study strengthens the hypothesis that, in current agricultural scenario where there are ample technical-social-institutional opportunities to push for savings of water in the irrigation sector, E-Flows for the river Ganga are achievable. On the other hand, the farmers are going to benefit toward the end, after resolving initial challenges. This narrative needs to find place in the policy discourse and thereby lead to translation of this idea into some concrete steps at the ground level.

With renewed impetus and some fresh thinking in approach, the current scenario appears to be "a hopeful" one. The coming 5–10 years, would be the testimony of the applicability and efficacy of the measures the governments and civil society are putting forth for the conservation of river Ganga to transform it into a healthy river, throughout its entire length!

ETHICS STATEMENT

Does the study presented in the manuscript involve human or animal subjects: No.

An ethics approval for this research was not required, as per organizational guidelines and national regulations; however, necessary project approvals were sought from Competent Authorities at an organizational level.

Before the start of the interview/survey/Focused Group Discussion with the respondents (farmers and departmental field

officers/functionaries); they were informed about the project and once they were adequately briefed; afterwards further interactions took place. An informed verbal consent was obtained from research participants. No written consent was required as per the project requirement; however, all the questionnaires were filled and duly signed by the recording researcher, as most of the farmers do not have a tertiary level education background, so writing the responses and then signing the same was not possible for them.

AUTHOR CONTRIBUTIONS

NK conceived, structured, and drafted the paper. SB did an overall review of the paper and provided inputs. He also made suggestions on structural aspects of the paper. He also played key role in designing the work around trade-offs and in selecting the Management Scenarios with NG. AM supported with water use efficiency scenario and refinement of figures. He also conducted individual interviews with field functionaries of Irrigation Department, hence provided inputs in appropriate section. NG conducted the water use efficiency scenario, economic valuation exercise and he contributed the appropriate section. Besides this, he also did an overall review of the paper from an academic perspective. VT and his team conducted E-Flows assessment and provided inputs to the appropriate section. PS reviewed and analyzed the farmer data and developed top-line messages emerging out of the mammoth data that was generated as part of farmer surveys and he provided inputs to appropriate section. RK did an overall review of the paper and provided contextual inputs and suggestions related to irrigation projects and related aspects. RV and his team conducted farmer surveys across two irrigation systems and the farmer's arguments are built on that data.

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