Cleaning the Ganga
Rethinking Irrigation Is Key

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Prioritising aviral dhara (uninterrupted flow) over nirmal dhara (unpolluted flow) can deliver quick outcomes in the Namami Gange Programme. Treating human, municipal and industrial waste released into the Ganga is a long-term project requiring vast resources and political energy, besides behavioural change on a mass scale. But, Ganga’s dry season flows can be quickly improved by basin-scale conjunctive management of the surface water and groundwater. Irrigation in the Ganga basin today depends on tubewells far more than canals. A multipronged protocol is outlined to manage the old canal network and new hydropower storages in order to maximise irrigation benefits and improve dry season river flows.

Relentless pollution and dwindling base flows have made the Ganga one of the world’s dirtiest rivers. Extreme faecal pollution of the Ganga and Yamuna waters even in the upper stretches is now suspected to be the source of deadly superbugs that have spread antibiotic resistance around the world (Mallet 2017). The Ganga river basin is the world’s most densely populated river basin experiencing rapid urbanisation. Some 30 cities, 70 towns, and thousands of villages along the Ganga dump their untreated sewage—over 6 billion litres per day (Shah et al 2018)—directly into the river, along with thousands of animal carcasses and human corpses. Another 260 million litres of untreated industrial wastewater are discharged daily by hundreds of factories and tanneries (Chaudhary and Katakey 2014). Six million tonnes of chemical fertilisers and 9,000 tonnes of pesticides applied to the basin’s agricultural fields add to the pollution (Ministry of Water Resources, River Development and Ganga Rejuvenation 2017). All these make the Ganga at Kanpur, Allahabad and Varanasi the world’s most polluted river. “Except during monsoon when the river is flooded with water, [the quality of] Ganga water in Allahabad remains even below Category E” (Kumar 2011: 531), lowest in the ranking of the Central Pollution Control Board (CPCB 2017). Bathing in the Ganga is so fraught with risks that the National Green Tribunal (NGT) ordered health warnings against it and ordered it to be prominently displayed along its banks between Haridwar and Unnao (Indiatimes.com 2018).

Cleaning the Ganga has been a priority for governments for a long time. Beginning with the Ganga Action Plan (GAP) launched in 1985, a plethora of schemes have been launched to clean the Ganga and several thousand crores have been spent on this purpose. Yet, the Ganga and Yamuna are no cleaner today than before (Shah et al 2018). For the ruling Bharatiya Janata Party (BJP) government, cleaning the Ganga is a prestige issue. To signify his commitment to clean the Ganga, Prime Minister Narendra Modi chose Varanasi, where the Ganga is at its worst, as his parliamentary constituency. Admittedly, the BJP government brought a new sense of urgency, understanding of the institutional complexity of getting five basin states to work together, and the need for more resources to the Namami Gange Programme (NGP), the flagship programme launched in June 2014 to rejuvenate the Ganga.

The NGP of the National Mission for Clean Ganga (NMCG) proposes two components: nirmal dhara (unpolluted flow), to be achieved over two to five years, and aviral dhara (uninterrupted flow) to be accomplished over 10 years by improving...
Irrigation Diversions

The Ganges is a water-abundant basin with a virgin yield (including the Damodar and Lower Ganga up to Farakka) of 632 billion cubic metres (bcms), of which 293 bcm is utilised for storage, irrigation, industry and water supply (NRM Consultants 2015), besides a renewable groundwater potential of 108 bcm (for India and Nepal together) (FAO 2011). For the NGP, the ugc is the low-hanging fruit that can create aviral dhara quickly, and at a negligible cost (Shah et al 2018).

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The current flow regime in the Upper Ganga stretch is woefully far from these figures. Some 492 major and medium irrigation projects’ divert the bulk of the Ganga’s water for canal irrigation and, a majority of these are in Uttar Pradesh (UP) with an irrigation canal network reportedly extending to 74,000 km. Some 30 diversions on the main stem and tributaries of the Ganga divert over 60% of the Ganga’s annual flow for canal irrigation, leaving very little water to flow in the river during eight dry months (Figure 1) (WWF Global nd). In the critical
stretch below Haridwar, diversions are even larger. From Haridwar to Narora, 24,298 cusecs of water is diverted annually, which is 80% of the total flow of 30,527 cusecs at Haridwar (CPCB 2015). At Narora, 90% of the flow is diverted to irrigation canals (CPCB 2015). The average flow declines from 30,600 cusecs above Haridwar to 4,100 cusecs at Kanpur. But, the average flow is deceptive since 80% of the Ganga’s flow occurs during June to October, leaving just 20% during November to May. And, even base flows are diverted for irrigation (Jain 2015). Simulations by Bharati and Jayakody (2011) show that diversions reduce natural flow at Bithur/Kanpur to just 10%–18% during monsoons and by 85%–90% during the dry months of January to March. In May 2016, journalist Victor Mallet visited the Upper Ganga barrage at Bhimgoda when the Ganga had a lean flow of 12,000 cusecs; of this, only 600 cusecs was let into the river, with the rest diverted to the Upper Ganga Canal (UGC). Further down at Narora, only 357 cusecs was left in the river, while 1,400 cusecs of the augmented river flow was diverted to the Lower Ganga Canal (Mallet 2017: 161). New diversion schemes continue to be inaugurated still. The age-old Hindu craving for aviral Ganga is honoured, cosmetically, by constructing token ram dharas, tiny un gated vents that release 100–140 cusecs into the river “to comfort the Hindus and assure them that the Ganges has not been stopped” (Mallet 2017: 162). In November 2018, the NMCG announced minimum dry season flows required at different stretches of the river, which was 1,270 cusecs at Bhimgoda (Haridwar) and 850 cusecs at Bijnor, Narora, and Kanpur during October and May besides stipulating higher flows during monsoons (Koshy 2018a). But, this is less than 4% of the mean flow of the Ganga versus 45%–75% recommended by the WWF report (WWF Global nd) and what G D Agarwal wanted.

The Restoration of the Thames in England and the Rhine in Western Europe during the 1950s to the 1970s is often cited as the example the NGP should emulate. There are two differences to be pointed out. First, the Ganga is a larger river. Second, unlike the Thames and the Rhine, the Ganga suffers from massive flow diversion for irrigation, undermining its self-cleaning powers. Dry season irrigation diversions are as much to blame for the Ganga’s decline as relentless pollution. But for the dry season flow diversion, the Ganga would not have been reduced to an intermittent stream between Haridwar and Kanpur and a dirty sewer between Kanpur and Varanasi (Figure 1). In fact, without dry season diversions, the Ganga’s base flows as it enters Bihar would be at least 25% higher (Khan et al 2014) and more if water from new hydropower dams were released into the river instead of canals during winter and summer.

Obsessive emphasis on diverting the Ganga for canal irrigation derives from the belief that “[the] use of Ganga waters for [canal] irrigation is critical for coping with uncertain rainfall as well as during dry months” (Jain 2015), and that “Ganga Canals are ... the source of agricultural prosperity in the area ... In these circumstances, the only option left is to make and keep the Ganga clean with whatever water is available in it after lifting the water required for irrigation” (Kumar 2011). The same belief works against using 30 bcm of live storage (TERI 2011: 38) in hydropower dams upstream in Uttararakhand to augment dry season river flows rather than canal irrigation since “dilution of pollution by releasing additional water from Tehri dam [into the river] is not advisable at the cost of irrigation and hydropower generation which is another scarcer resource” (Kumar 2011).

Canal irrigation, then, is at the heart of Ganga’s poor health. But, can canal irrigation be managed so as to provide irrigation and also improve river flow? To explore this, a peep into the history of canal irrigation is in order.

**Colonial Canals Drive Out Well Irrigation (1850–1960)**

Long before large-scale canal irrigation took off during the mid-19th century, the UGB had a rich history of irrigation with kachha and pucca masonry wells, ponds and river diversions (Verma 2001; Whitcombe 1971). But, well irrigation with muscle power was laborious and time-consuming, especially for larger landholders. Moreover, kachha wells caved during heavy rains and dried up during droughts, which often turned into famines. When Proby Cautley of the East India Company commissioned the ugc to irrigate the Ganga–Yamuna doab (13 shaded districts in Figure 1), farmers idolised Cautley and honoured canal engineers with epitaphs like naib-khuda (deputy god) (Whitcombe 1971).

Decades later, however, the net benefit of canal irrigation in the doab remains a matter of controversy. Whitcombe (1971) concluded that “it proved a costly experiment” with disadvantages outweighing its advantages. It forced the cultivation of high-value export crops like sugar cane, cotton, wheat, indigo and opium, and the paying of steep water charges, and did little to improve local food security which continued to depend on rainfed millets, peas and beans. Malaria became endemic during the monsoon. The canals bypassed many drought-prone tracts of the doab (McGinn 2009). Hence, despite the canal network, the UGB suffered four severe famines during the 19th century itself (Whitcombe 1971: 73–74), questioning the canals’ role in famine prevention (McGinn 2009). Finally, rising water tables created “howling wilderness bereft of crops or vegetation” in unproductive usar and reh² lands (Whitcombe 1971). The colonial policy of discouraging well irrigation in canal commands (Neale 1962; Whitcombe 1971: 11) and of destroying indigenous irrigation structures like ahar-pyne in southern Bihar (Prasad 1997: 64; Neale 1962) made things worse. Even Ian Stone, a bitter critic of Whitcombe’s “unfortunate catalogue” of the ill effects of canal irrigation in the doab, agreed that the margin of benefit, therefore, between the value of output before the canal and that made possible after its construction was clearly narrower than the benefit arising from making settled agriculture possible in places [like the Punjab] previously sparsely populated by pastoralists. (Stone 1984: 4)

We have even less information about the impact of the Ganga canals during recent times than Whitcombe and Stone dug up from the 19th-century records. However, there are some studies that highlight the pernicious environmental impacts of canals (Afroz and Singh 1986). Regardless of these negative externalities, the momentum for expanding canal irrigation continued, even increased, after the end of the British Raj. However, the 1970s witnessed a new doctrine
about what might be the most appropriate irrigation model for the Ganga basin.

The ‘Ganges Water Machine’
The vast Ganga plains are characterised by a flat terrain, devoid of surface storage potential, but endowed with excellent groundwater storage in deep and rocky alluvial aquifers. The key basin management challenge is to reduce the fury of devastating monsoon floods in the eastern parts and promote irrigation in the western parts. Using barrages to divert monsoon flows for canal irrigation in the ugb is one option that governments have exercised since the mid-1800s. In a 1975 paper, Revelle and Lakshminarayana (1975) postulated an alternative conception based on conjunctive use of surface water and groundwater. They called it the Ganges Water Machine (GWM) and proposed that the basin’s vast and porous aquifer system offered the potential to absorb and store some 60 bcm of the monsoon runoff, provided the shallow aquifer system is desaturated before the onset of monsoon. They suggested heavy-duty tube wells along the Ganga and its tributaries to undertake intensive “preparatory” pumping of groundwater during the dry season for creating sub-surface storage. Pumped groundwater would be supplied to farmers, through lined canals to minimise losses, to irrigate winter and summer crops. This would promote dry season irrigation and also reduce the fury of annual floods in Bihar, West Bengal, and Bangladesh by accommodating in shallow aquifers 60 bcm of “rejected recharge.” A similar model by Chaturvedi and Srivastava (1979) proposed such “preparatory” pumping along dry canals during winter and summer. Both the models worked around the annual Pump-Recharge-Deplete-Pump (PRDP) protocol.

Khan et al (2014) compared three ways of basin management: the original scheme of Revelle and Lakshminarayana (1975) of pumping along the rivers and distributaries (GWM), the Chaturvedi and Srivastava (1979) scheme of Pumping Along Canals (PAC), and a third option of Distributed Pumping and Recharge (DPR). The authors concluded that 6%–37% of the average monsoonal flow at the up–Bihar border can be stored in aquifers to reduce monsoon flooding in the eastern parts and augment irrigation benefits in the ugb. Their key conclusion was that the DPR model would be less expensive than the other models, easier to implement and minimise risks of land subsidence.

Tube Wells Crowd Out Canal Irrigation (1970s Onwards)
While the proposals by Ravelle and Lakshminarayana (1975) and Chaturvedi and Srivastava (1979) remained on paper, the DPR model has become a reality through a runaway expansion in private tube well irrigation in the ugb in the recent decades. In the late 1800s, the drudgery of manually lifting well water drew farmers to canal irrigation even though it meant embracing malaria, usar, and reh, and an oppressive irrigation bureaucracy that came with canals. A hundred years later, affordable bores and pumps reversed the trend with farmers dumping canals in favour of tube wells that offered convenient, reliable, and year-round irrigation. Massive public investments in new canals have not ebbed this trend. According to data from the up government’s directorate of agriculture, the contribution of government canals to the net area irrigated fell from 38.2% in 1950–51 to 18.9% in 2010–11, while that of wells and tube wells soared from 45% to 80% (Figure 2).

The private tube well revolution was fuelled by the up government’s aggressive public tube well programme (Shah 1993, 2009), Chief Minister Mayawati’s Free Boring Scheme during the 1980s and the Deputy Prime Minister Devi Lal’s Million Well Scheme during the 1990s (Shah 2000). Already the dominant source of irrigation in up during the 1970s, private tube wells emerged thereafter as the sole source of irrigation for an overwhelming majority of farmers, reducing canals to a supplemental and indirect role. The transformation encompassed all of up, but the trend was strongest in the Ganga–Yamuna doab where the bulk of the Ganga’s flows are diverted for canal irrigation.

According to Bhalla and Singh (2012), among all states, up had the fastest growth in the number of irrigation pump sets (ips)/1,000 hectare (ha) of net sown area: from just one in 1962 to 191 in 2003. In 2003, up had more ips/1,000 ha than Punjab (170), Haryana (155), Bihar (117), and West Bengal (119), and India as a whole (62). The National Sample Survey Office (nss) surveys trace the growing popularity of tube wells in up’s agriculture system. Figure 3 compares three successive rounds of nss surveys, each with the up sample exceeding 3,000 farm households: 37th round (1982), 50th round (2003) and 70th round (2012–13). During this period, the irrigation coverage in the up sample increased from 60% to 87%. Even in the 1982 round of nss survey, government canals served less than one-third of the irrigated area. But, by...
2012–13, this share declined to just 13%, while that of tube wells, wells and other local sources increased from 60% to 82%. Ironically, this was also the period of hectic commissioning of new canal diversion projects in up.

The India Human Development Survey (IHDS) conducted in 2012 suggests that tube well penetration is far deeper in the Ganga basin’s agriculture than the rest of India (Desai and Vanneman 2012). Figure 4 compares responses by 3,465 respondents from the four states of the Ganga basin and 12,404 respondents from the rest of India. Private tube wells were the “most important irrigation source” (mis) for 81.4% households in the Ganga basin, compared to 38% households outside the Ganga basin. In contrast, government canals were the mis for only 10% of the respondents within the Ganga basin and outside. Significantly, fewer farmers from the Ganga basin (25.3% compared to 29.2% outside the Ganga basin) owned tube wells. But, four-fifths of them depended on irrigation with water purchased from hyperactive groundwater markets in the Ganga basin.

Another 2013 survey of 1,600 farmers in up found that “82 per cent of farmers indicated tube-wells as their primary source of irrigation, followed by 11 per cent who reported canals. Less than 2 per cent of farmers use government tube-wells, ponds, or other sources.” The same survey also found that “Only about half the farmers own a borewell, and the rest either rent it or purchase water directly” (Jain and Shahidi 2018: 5–7). Niranjan Pant’s (2004) study comparing the same villages surveyed in 1982 and in 2003 highlighted a dramatic increase in the role of groundwater markets in up’s agriculture. All surveys thus show that tube well owners as well as those who do not own tube wells in the Ganga basin depend far more heavily on water markets than the rest of India, and that canals are marginal to irrigation. Herein lies the key socio-economic challenge of irrigation management in the Ganga basin. The poorest farmers in the Ganga basin end up paying a quarter or more of the value of their irrigated output towards the cost of purchased tube well irrigation from diesel pump owners, who comprise 90% of tube well owners (Singh and Upadhya 2017; Modak 2018).

Two opposing forces seem to be at play. Despite being eight to 10 times costlier than canal irrigation, farmers turned to tube well irrigation due to its reliability and timely, year-round availability, compared to government canals (Srivastava and Kumar 2015). It must be said that the spread of tube wells vicariously caused a decline in the maintenance of public canals and their irrigation service (Lata 2019). Were this not the case, farmers in command areas would be far better off compared to those outside it. But, studies repeatedly show this is nowhere the case in up (Planning Commission 2007; Kumbhare and Sen 2008: Table 6) and that non-command zone farmers are often better off.

All recent censuses—the minor irrigation census, agriculture census and the population census—show that the ugb farmers have turned to tube wells in a group while canals have got marginalised by the private tube well revolution in the ugb’s irrigation economy. The 2013–14 Minor Irrigation Census showed that the density of tube wells in command of the ugc is among the highest in India (Figure 6, p 62). Likewise, the 2011 agriculture census showed the ugc command to have the highest share of groundwater irrigated area in the country (Figure 5). As Lata (2019: 350) asserts,

As a result of the poor performance of public canal irrigation and the relative advantages of groundwater use, tube wells have become the predominant means of irrigation ... [and] more than 90% of tube wells irrigated area was observed in the districts of Gorakhpur, Farrukhabad, Baghpat, Kheri, Sitapur, Gonda, Mahamaya Nagar, Shrawasti, Agra, Aligarh, Mau, Kannauj and Firozabad.

Figure 6 compares the 1986–87 and 2013–14 Minor Irrigation Censuses conducted by the Indian government. Even in 1986–87, the ugb had a higher tube well density compared to the rest of India. However, in the 25 years since then, the tube well numbers have experienced a meteoric rise; and the ugb may well be the world’s most densely plumbed groundwater economy in terms of tube well horsepower per net sown ha.
A recent Indian Council for Research on International Economic Relations (ICRIER) paper highlights that, “Nearly half of [Ganga basin’s canal irrigated] area falls in Uttar Pradesh which, at 97.13% coverage, is almost entirely blanketed by [canal] irrigation projects” (Verma et al 2017). With such extensive canal coverage, government canals should dominate the agrarian lives and livelihoods of rural people in the Ganga basin. However, the UP District Census Handbook of 2011 shows no sign of this. It shows that over 80,000 of UP’s 1,06,000 villages had no canal irrigation at all; and only 5,834 villages—5.5% of the total number of villages—declared that they depended totally on canals for irrigation (Office of the Registrar General and Census Commissioner 2011).

The 5th Minor Irrigation Census of 2013–14 (the village schedule) also showed that less than 5% of the doab villages—where the bulk of the Ganga’s flow is diverted for canal irrigation—reported to be in the command area of any major or medium government irrigation system (Figure 7). It is the same case with 15 of the districts4 served by the Sharda Sahayak system, where 95% of the rural respondents refused to acknowledge any irrigation canal in their village. In canal commands elsewhere in the country, the picture was different. In Punjab, western Rajasthan, south Gujarat, Chambal command, coastal Andhra Pradesh and coastal Tamil Nadu with major and medium irrigation projects, at least 20% of the villages reported the existence of canals but not so in the UGB. The only explanation is that the UGB canals are either “canals on paper” or have been in disrepair and disuse for such a long time that people have forgotten about them.

**Sustainable Management of the GWM**

The belief that canal irrigation is the lifeline of the agricultural economy of UP today has no empirical basis. We estimated a simple recursive regression model (see Figure 8, p 63 for model structure) to estimate the impact of adding a private tube well, 1 ha of canal irrigation and 1 ha of rain-fed farming on district-level gross value of milk and crop output in the Ganga basin districts. The results of the model are summarised in Figure 9 (p 63). A new tube well adds nearly 2.5 times more of the value of crop and milk output of a UP district compared to 1 ha newly brought under canal irrigation. Table 1 (p 63), based on the same
model, shows that private tube wells withdrawing about 30–35 bcm for irrigation annually in the UGB contribute three-fourths of the value of its crop-milk output; in comparison, irrigation canals which divert well over 100 bcm\(^6\) contribute just 17%.

All this evidence shows that the private tube well boom has spontaneously accelerated the GWM which is now revved up like never before. Instead of heavy duty government pumps along rivers as suggested by Revelle and Lakshminarayana (1975) or along canals as envisaged by Chaturvedi and Srivastava (1979), millions of private tube wells owned operate a distributed PRDP protocol in a laissez-faire mode at a far lower cost to the public exchequer. Distributed tube well irrigation of winter and summer crops creates massive sub-surface storage capacity before the monsoon every year. According to the Central Ground Water Board (CGWB 2017: 56), the Ganga basin today withdraws over 80 bcm/year of groundwater for irrigation, way more than 60 bcm that Revelle and Lakshminarayana (1975) had imagined. UP alone withdraws 53 bcm of groundwater every year suggesting that the GWM is working overtime. Of this, over 60% of the water is withdrawn for irrigation only in the districts served by the Upper, Middle and Lower Ganga canals (CGWB 2017: 85).

Table 1: Share of Government Canals, Private Tube Wells and Rain-fed Farming in Crop–Milk Value of Output in the Ganga Basin (2010–11)

<table>
<thead>
<tr>
<th>Source of Water</th>
<th>Upper Ganga Basin (40 Districts from Saharanpur to Lucknow)</th>
<th>Uttar Pradesh</th>
<th>Ganga Basin as a Whole</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Number of districts</td>
<td>40</td>
<td>75</td>
<td>123</td>
</tr>
<tr>
<td>(2) Value of crop and milk output in 2011–12 (in ₹ billion)</td>
<td>1,172</td>
<td>1,812</td>
<td>3,067</td>
</tr>
<tr>
<td>(3) Attributable to canal irrigation</td>
<td>202</td>
<td>351</td>
<td>724</td>
</tr>
<tr>
<td>(in ₹ billion)</td>
<td>(17.2)</td>
<td>(19.4)</td>
<td>(23.6)</td>
</tr>
<tr>
<td>(4) Attributable to tube well irrigation</td>
<td>899</td>
<td>1,296</td>
<td>1,884</td>
</tr>
<tr>
<td>(in ₹ billion)</td>
<td>(76.7)</td>
<td>(71.5)</td>
<td>(61.4)</td>
</tr>
<tr>
<td>(5) Attributable to rain-fed farming</td>
<td>71</td>
<td>164</td>
<td>458</td>
</tr>
<tr>
<td>(in ₹ billion)</td>
<td>(6.1)</td>
<td>(9.1)</td>
<td>(14.9)</td>
</tr>
</tbody>
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Figures in parentheses are percentage. Source: Authors’ estimates using the Recursive Regression Model.

The GWM has given rise to socioecological benefits as well as costs. A major positive externality is vertical drainage. Canal-induced waterlogging, salinity and alkalinity were for long a major challenge as a quarter of India’s estimated 8.5 million ha of waterlogged area during the 1980s was in UP (Planning Commission 2014). The same report also claimed that a further four million ha suffered from unduly high water table post the monsoon, resulting in 1 metric tonne/ha of loss in annual agricultural output. There were several reasons attributed to this situation such as heavy seepage losses from main canal and distributary network, indiscriminate cropping in drainage channels, insufficient groundwater use, interception of natural drainage by roads, embankments and the discharge of surplus canal water into channels unable to carry them. Because private tube wells double up as millions of vertical drains, these externalities of canal irrigation are far less pernicious today than they were until a few decades ago.

On the down side, Ganga’s dry season flows are doubly hit, on the one hand by diversions of dry season flows for canal irrigation and on the other, by intensive groundwater irrigation along the river and tributaries making the river system “giving” rather than “receiving.” Mukherjee et al (2018) have recently shown that groundwater depletion in the doab by private tube wells strongly exacerbates dry season depletion of the Ganga’s flows. An added negative externality is a growing area suffering groundwater depletion in the UGB where more groundwater is pumped than is recharged by rain and canal water.

What is so much canal water sloshing around in the doab doing if 80%–90% of the irrigated area is watered by tube wells? And, with so much canal irrigation, why are groundwater levels dropping in the doab, depleting Ganga’s dry season flows even further? The CGWB’s groundwater atlas of UP shows that over 100 blocks in the UGB are declared “over-exploited” despite having a dense canal network and copious surface water supplies (Shukla 2015). The CGWB data shows the doab districts suffering decline in groundwater level even during the monsoon months (CGWB 2015: plate viii). Moreover, in almost all of them, post-monsoon groundwater level (November) in 2014 was lower than in 2003 (CGWB 2015: plate xv), implying the secular decline in water levels despite the canal network over the entire landscape.

Given that canals in the UGB hold much more water in monsoon than in the dry seasons, one would expect kharif crops to be predominantly canal-irrigated and dry season crops to be tube-well irrigated. The 2003 all-India survey of farmers by the NSSO (2005, report #496: 37) showed this happening in states like Chattisgarh or Kerala. But in UP, tube wells dominated irrigation during monsoon as well as the dry season, with canals irrigating just 16% of the net sown area (predominantly
paddy) in the monsoon and 15% in rabi (mostly wheat). The vast volume of the Ganga's flow diverted for canals neither provides irrigation nor reverses groundwater depletion.

An inkling into this riddle is offered by a report of a 2008 Food and Agricultural Organization (FAO 2008) training workshop in Meerut with 40 canal managers and engineers in the UGC. The workshop estimated that the UGC command area had an annual input of 9.7 bcm of water (3.74 bcm rainfall and 5.84 bcm canal supply) to irrigate a design command of 4,25,000 ha in kharif and 4,30,000 ha in rabi at a rate of over 22,000 m³/ha/year. But, the actual crop evapo-transpiration (ET) was estimated at only 2.7 bcm (28% of the input), the rest contributing to incidental recharge and non-beneficial ET. With such massive water input, it is surprising that the UGC command suffers severe groundwater depletion. One possibility is that canal water circulates over a much smaller area than the design command; and that lack of water control at the distributary level leaves farmers there little choice to grow crops other than sugar cane and rice which can withstand excessive water. If this is indeed the case, then the UGC command creates little recharge elsewhere in the UGC command. The dense network of tube wells also impedes the lateral sub-surface movement of canal seepage, limiting the spatial dispersion of recharge from canal irrigation.

The FAO workshop reported, “[T]he productivity of land [in UGC command] is on the high side ($1,500/ha) whereas productivity of water is on the low side ($0.1/m³).” On in-depth field assessment, the workshop noted that there was hardly any water management in the UGC command; the social order in the command and level of irrigation service were “ranked low respectively 1.3 and 1.5 on a 0–4 scale” (FAO 2008: 4) and these rankings declined along secondary and tertiary canals. Canal managers also listed a litany of problems in managing water distribution. Farmers resist warabandi/osrabanid as well as night irrigation, most grow sugar cane and over-diverted for irrigation in the tributary level leaves farmers there little choice to grow crops other than sugar cane and rice which can withstand excessive water. If this is indeed the case, then the UGC command creates little recharge elsewhere in the UGC command. The dense network of tube wells also impedes the lateral sub-surface movement of canal seepage, limiting the spatial dispersion of recharge from canal irrigation.

Towards Aviral Dhara

The key to achieving aviral dhara in the Ganga and its tributaries is to adapt the UGB's old canal networks to maximise distributed groundwater recharge during the monsoon in support of dry season tube well irrigation. During the eight dry months every year, the Ganga's flows suffer a double whammy between Haridwar and Kanpur, since it loses flows to diversion canals as well as to groundwater depletion. Dry season flow can be improved without any adverse impact on the agricultural economy by adopting a new water management regime in the UGB that we have recorded as policy asks.

First, the canal networks of the UGB should be modernised for maximising groundwater recharge during the monsoons. The old and dilapidated canal network must be modernised (not necessarily lined) to push water to the tail ends of minors and sub-minors to maximise kharif irrigation and distributed aquifer recharge over the entire command. Second, local waterbodies should be rehabilitated for distributed monsoon recharge. Millions of local waterbodies, now silted up and encroached upon, need to be rehabilitated, linked to canals and managed, in order to augment monsoonal groundwater recharge. These can increase the capacity for diverting excess monsoon river flows for groundwater recharge. Third, the bureaucracy associated with irrigation should undergo reforms. Irrigation bureaucracy needs to be galvanised to provide high level canal irrigation service during monsoon, and for maintaining the canal network during dry months in preparation for the next monsoon. Fourth, kharif irrigation areas should be maximised with canals, and rabi irrigation areas should be maximised with tube wells. With well-maintained canal networks, it should be possible to divert more monsoon floods to the canals. Besides, large-scale canal irrigation of monsoon paddy will augment distributed groundwater recharge, and enhance base flow. Fifth, dry season flow diversions for canal irrigation should be stopped since rabi and summer crops in the UGB are predominantly watered by tube wells anyway. Stopping flow diversion during November to June will substantially improve e-flows in the river system. Sixth, to enhance irrigation benefits, farmers should be provided affordable and reliable energy, such as through solar pumps, for tube well irrigation during dry season. Solar pumps are ideal since they will also catalyse pro-poor water markets providing affordable irrigation to the poor. Seventh, hydropower storages should be utilised for augmenting dry season flows. For millennia, Ganga’s flows experienced extreme peak to lean season ratio. Now, with 30 bcm hydropower storages in the upper catchment areas, the Ganga and its tributaries can have a better dry season flow regime than was ever possible, provided power generation is scheduled during the dry months and water is released back to the river instead of canals.

The challenge of aviral dhara is one of expanding the recharge component of the PRDP protocol during the monsoon to increase baseflow and support dry season tube well...
irrigation. Doing this is neither difficult nor expensive. During 1988–97, up’s irrigation department successfully experimented with recharge augmentation by monsoon flood waters by rehabilitating disused canals and drains as recharge structures in the Madhya Ganga system. Low cost check structures increased their recharge capacity by three- and-a-half times over natural flow conditions. A later assessment of the research pilot over 1988–96 reported surrounding water table rise from 12 m BGL to 6.5 m with major energy savings, a 15% increase in monsoon rice irrigated area and 50% reduction in conveyance losses through canals (IWMI 2002).

In a more recent pilot in UP, the Sri Lanka-based International Water Management Institute successfully demonstrated the efficacy of Underground Taming of Floods for Irrigation, by absorbing monsoon floods into shallow aquifers (Pavelic et al 2018).

The NGP must persist with the far bigger challenge of municipal waste and sludge management as well as treatment of industrial waste to create nirmal dhara. However, the programme can show quick results by picking the low-hanging fruit of aviral dhara by reimagining an irrigation management regime that reflects the new irrigation reality of the Ganga basin.

NOTES
1 The list of major and medium irrigation project diverting the Ganga is found here: http://www.india-wtis.nic.in/veriﬁnda/index.php?title=Major_Medium_Irrigation_Projects_in_Ganga_Basin
2 Saline or alkaline lands are called usar or reh in the north and north-western India. The vernacular names usar or reh have been in use for the saline efflorescence forming a crust on the surface of the soils during the dry periods. The efflorescence essentially consists of a mixture of sodium carbonate, bicarbonate, chloride and sulphate, together with varying proportions of calcium and magnesium salts. In the Indo-Gangetic Plain, UP was particularly affected by these deposits. Even today, UP has a large tract of 5.2 lakh ha of infertile usar land.
3 Between 1985 and 2000, 2.5 million free borings were made in UP. For more, see Lata (2019: Chapter 3).
4 The 15 districts that were considered are Peeluhat, Bareilly, Lakhimpur Kheri, Shahjahanpur, Hardoi, Unnao, Lucknow, Barabanki, Rae Bareli, Pratapgarh, Sultanpur, Jaunpur, Azamgarh, Ghaziapur and Allahabad.
5 Annexure 1 provides the public domain data sets used and their sources along with descriptive statistis of the variables used. For model estimates, please contact p.reghu@cgiar.org.
6 About “43000 cusec of water in kharif and 19000 cusec of water in Rabi.” For more, see Lata (2019: Chapter 3).
7 Drawn from personal communication with Dipankar Saha, former director of the CGWB.
8 Warabandi or Osrabandi is a rotational method of individual water users within a water-course command area. It presupposes an over-all shortage of water supply. The primary objective of this method is to distribute this restricted supply in an equitable manner over a large command area. This system has been successfully adopted in Indo-Gangetic plains.
9 Minors refer to the last-mile earthen channels that deliver canal water to field channels for irrigation. Minor canals get water from larger distributaries or branch canals.

REFERENCES


Annexure 1: Data Sets Used for the Model and Descriptive Statistics of Variables Used

<table>
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<th>Source of Data</th>
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<th>Maximum Value</th>
<th>Mean Value</th>
<th>Total Value</th>
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<td>Districts-wise Land Use and Crop Production Statistics in India (GoI 2010)</td>
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