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Cleaning the River Ganga: Impact of lockdown on water quality and future implications on river rejuvenation strategies

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HIGHLIGHTS

- Signs of rejuvenation and significant improvement on many parameters in Ganga River, following nationwide lockdown due to coronavirus pandemic
- Lockdown period coincides excess rainfall (60 percent above normal), reduced irrigation and power demands in the basin resulting in increased storages and more flow in the river improving the quality
- Increasing trends of dissolved oxygen (DO) and decreasing trends of biological oxygen demand (BOD) and nitrate (NO3-) concentration
- River becomes fit for drinking (Class A) in the upper stretches and for outdoor bathing (Class B) in the middle and lower stretches

GRAPHICAL ABSTRACT

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ABSTRACT

Clean rivers and healthy aquatic life symbolize that the ecosystem is functioning well. The Ganga River has shown signs of rejuvenation and a significant improvement on many parameters, following the eight-week nationwide lockdown due to coronavirus pandemic. Since industrial units and commercial establishments were closed, water was not being lifted by them with a negligible discharge of industrial wastewater. It was observed that during the lockdown period most of the districts falling under the Ganga basin observed 60% excess rainfall than the normal, which led to increased discharge in the river, further contributing towards the dilution of pollutants. Further, data analysis of live storages in the Ganga Basin revealed that the storage during the beginning of the third phase of lockdown was almost double than the storage during the same period the previous year. Analysis of the storage data of the last ten years revealed that the storage till May 6, 2020 was 82.83% more than the average of the previous ten years, which meant that more water was available for the river during the lockdown period. The impact could be seen in terms of increased dissolved oxygen (DO) and reduced biological oxygen demand (BOD), Faecal coliform, Total coliform and nitrate (NO_3-) concentration. A declining trend in nitrate concentration was observed in most of the locations due to limited industrial activities and reduction in agricultural run-off due to harvesting season. The gradual transformation in the quality of the water has given a sign of optimism from the point of restoration. Yet, it is believed that this improvement in water quality is 'short-lived' and quality would deteriorate once the normal industrial activities are resumed, indicating a strong influence of untreated commercial–industrial wastewater. The paper concludes that the river can be rejuvenated if issues of wastewater and adequate flow releases are addressed.

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1. Introduction

The Ganga alluvial plain is one of the most densely populated regions and the largest groundwater repositories on the earth (Misra, 2011; Pal et al., 2020). About 43% of the population of India lives in the Ganga basin that stretches over 860,000 km^2 covering 26.3% of the country's total geographical area (Trivedi, 2010; FAO, 2019). The basin extends over the states of Uttarakhand, Himachal Pradesh, Haryana, Delhi, Uttar Pradesh, Bihar, Jharkhand, Rajasthan, Madhya Pradesh, Chhattisgarh and West Bengal.

In 2008, Ganga River was declared as the 'National River' of India. There are over 29 cities, 97 towns and thousands of villages along the banks of the Ganga River (Bhutiani et al., 2016). The biogeomorphological functions of River Ganga have been significantly modified by various large-scale anthropogenic factors such as fragmentation of river habitats, dams and barrages, discharge of industrial and domestic wastewater and intensive agriculture relying on chemical fertilizers, pesticides and insecticides (Bhardwaj et al., 2010; Sinha et al., 2017). The major contributors to pollution are tanneries in Kanpur, distilleries, paper mills and sugar mills in the Yamuna, Kosi, Ramganga and Kali river catchments.

The nationwide lockdown to contain the spread of the novel coronavirus (COVID-19) in India was announced on March 25 till April 14, 2020 (Lockdown 1.0). It was further extended by 19 days till May 3, 2020 (Lockdown 2.0). The lockdown was again extended until May 17, 2020 (Lockdown 3.0). While aerosol levels over the Indo-Gangetic Plains reported a 20-year-low during the lockdown as per the satellite data on optical depth measurements published by NASA due to restrictions imposed on industries, surface and air transport (NASA, 2020); the impact on water quality in the Ganga River was arguable. Various news reports, as well as social media posts, indicated that '*life seemed to be returning to the river*' (India Today, 2020). It was reported that the lockdown had improved the health of River Ganga, which many projects of the government could not do during the past two decades. The water quality of Ganga River had witnessed visual improvement since enforcement of the nationwide lockdown started on March 24, 2020 that has led to a reduction in discharge of industrial effluents into it. The lockdown was extended for more than seven weeks, with its 1.3 billion people instructed to stay home in view of the coronavirus outbreak. With people staying indoors and industries shut during the lockdown period, it is crucial to assess if the water quality in the Ganga River has indeed seen a significant improvement. The paper analyses the impact of lockdown on water quality of Ganga River, and its major tributary Yamuna in Delhi, India. The paper also discusses issues and challenges to understand the magnitude of contamination and source relations and potential ways to improve the water quality. The paper finally provides important implications for future restoration strategies on Ganga River and approaches for

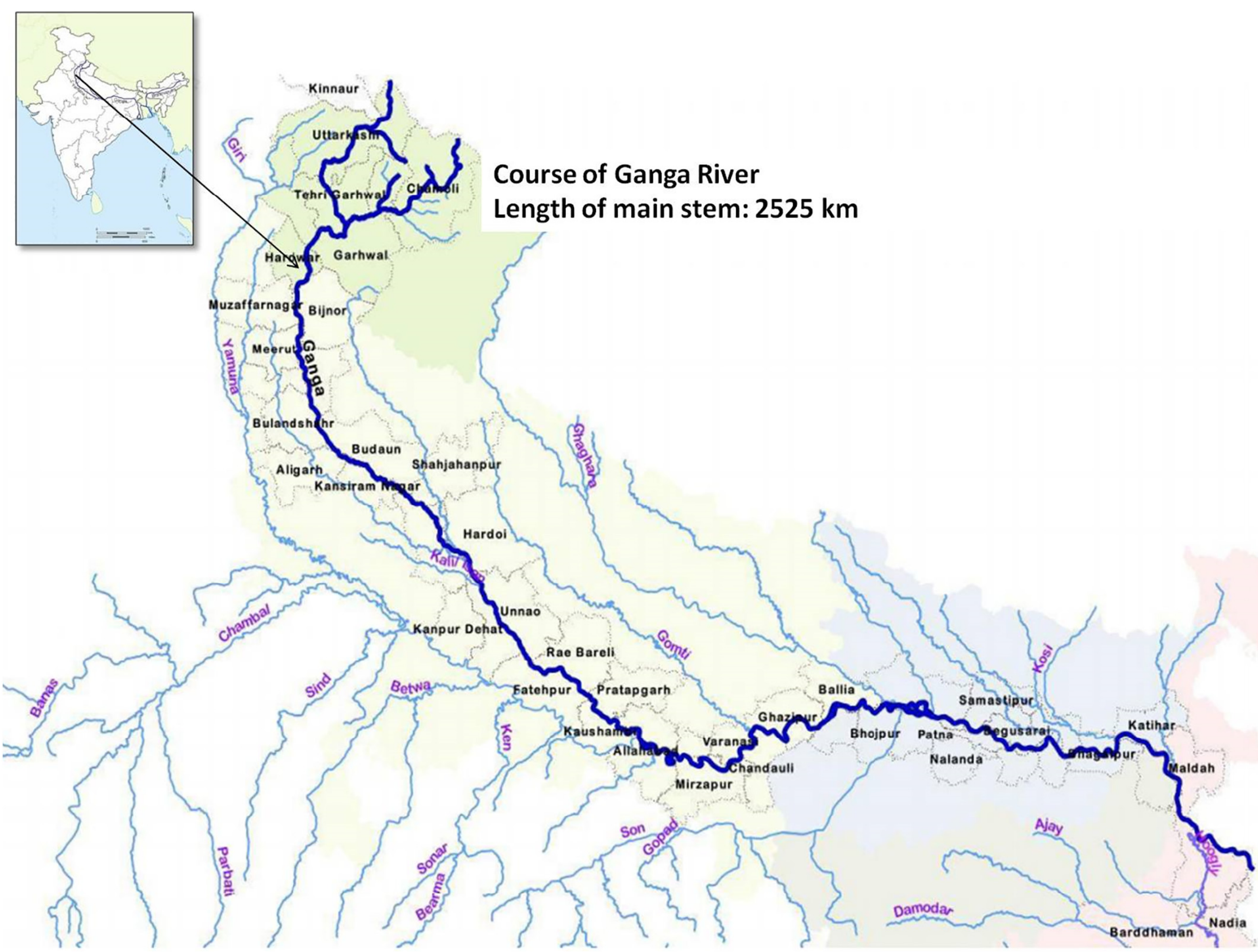

Fig. 1. The course of Ganga River in India along with its major tributaries.

designing appropriate control measures and action plans for river basin management.

2. About the study area

The Ganga River has been regarded as one of the holiest and sacred rivers of the world that witnesses high cultural and religious tourism on its banks, along with a heavy influx of tourists. The river has some of the most culturally significant stretches along with its courses, such as Rishikesh, Haridwar, and Allahabad where millions of people take holy dips during special days. The Bhagirathi river is the source stream of Ganga which originates from Gangotri glacier in the Himalaya in the Uttarkashi district of Uttarakhand State in India at an elevation of 3892 m (12,770 ft). Many small streams characterized by steep valleys and bedrock channels such as Alaknanda, Dhauliganga, Pindar, Mandakini and Bhilangana join together in the headwaters of Ganga. Alaknanda river joins Bhagirathi at Deoprayag, and the combined stream acquires the name of Ganga. It traverses 2525 km through a diverse climatic regime before flowing into the Bay of Bengal (Fig. 1). The entire course of the Ganga River in India can be divided into three stretches (Fig. 2): (i) upper stretch from the origin at Gomukh to Haridwar covering 294 km; (ii) middle stretch from Haridwar to Varanasi covering 1082 km, and (iii) lower stretch from Varanasi to its delta in Gangasagar covering 1134 km.

Major Himalayan tributaries of the Ganga are Yamuna, Ghagra, Gandak and Kosi which supply the majority of the water to the plains (van der Vat et al., 2019). The river flow exhibits a marked seasonality with average monsoon season discharge 6 to 7 times higher than the average dry season discharge (Singh and Pandey, 2019).

There has been a decline in fish catch along the river, suggesting a lack of supportive habitat and degradation of water quality. Destructive fishing, overfishing and the Farakka barrage were cited by fishers as the major causes of declines in fish catch from river–floodplain fisheries in Bihar (Dey et al., 2020). Due to less discharge during the summer season, priority species like Gangetic dolphin and Gharial find difficulty in movement and are confined to few fragmented habitats. Lack of sufficient depth and flow of water during lean season become the most restraining factor as only 38.7% of the river stretch has a depth of 4 m or above (WII, 2017).

3. Methodological approach

To have a better understanding of the transformation in the quality of water in Ganga, this paper analyses historical data on water quality and compares with quality observed during the lockdown period based upon the real-time water monitoring data of the Central Pollution Control Board (CPCB) and various state pollution control boards. Rainfall data obtained from Hydromet Division, India Meteorological Department New Delhi is analyzed to estimate the long-term departure from the normal in the Ganga Basin during the lockdown period and its possible contribution to the improvement of water quality. Basin storage data of the Central Water Commission (CWC) of the last ten years is analyzed and compared with the storage during the lockdown period. Minimum environmental -flow profile of river Ganga at Rishikesh is established following the flow norms prescribed by the Government of India and in view of water abstraction upstream. Summary of data points and significant parameters used in the study is provided in Table 1.

4. Flow obstructions and water abstractions

There are many dams and barrages on the main stem and tributaries of the Ganga River that have affected the natural flow regime and fragmented the habitat of aquatic wildlife, including the Gangetic dolphins, otters, wetland birds, freshwater turtles and fishes (Fig. 3). Tehri dam has been built on the Bhagirathi river for hydropower generation and regulates water discharge during the lean seasons. The hydroelectric potential of the Ganga basin has been assessed as 20,711 MW. Out of the 142 identified schemes in the basin, projects with a total installed capacity of 4987 MW are in operation and projects with an installed capacity of about 1751 MW are in various stages of construction.

At Haridwar, Ganga opens to the Gangetic Plains, where a barrage (Bhimgowda barrage) diverts a large quantity of its waters

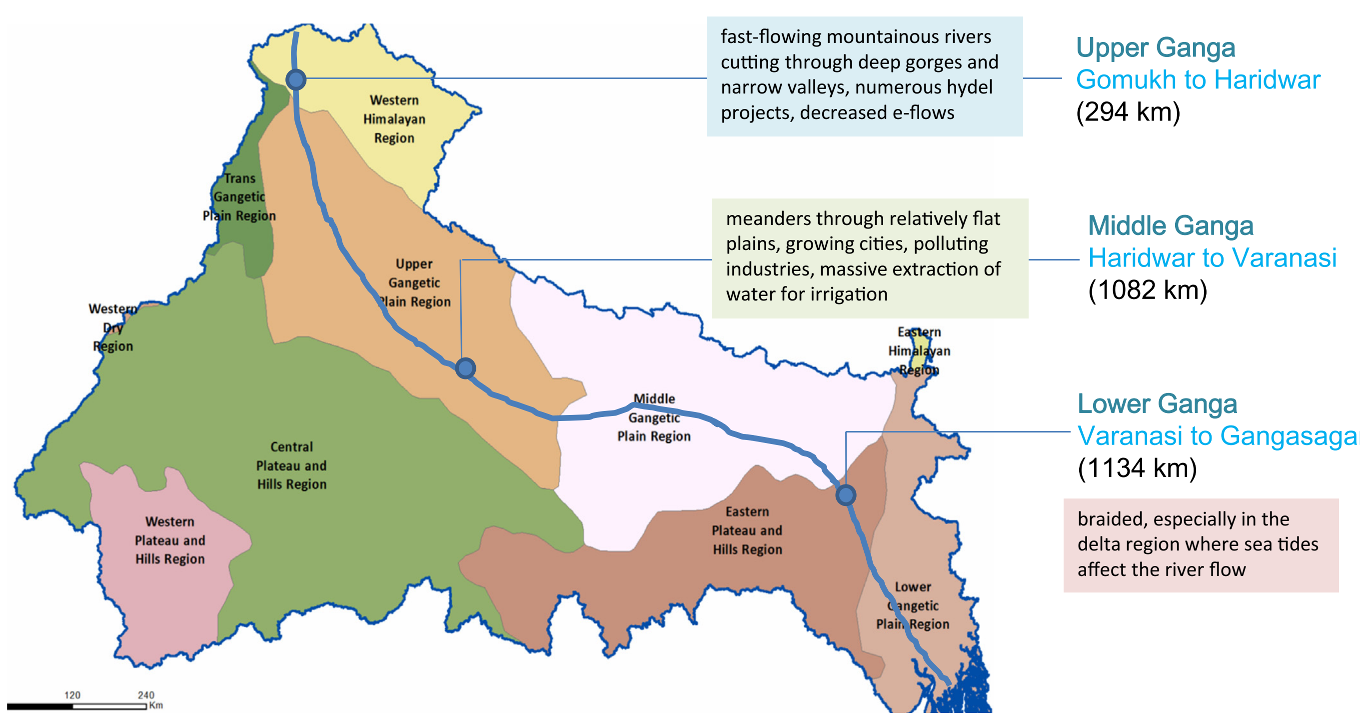

Fig. 2. Three major segments of the Ganga Basin.

into the Upper Ganga Canal (UGC), to provide water for irrigation. It is estimated that the discharge of UGC is about 297.5 cumec (m^3/s), which runs through 272 miles of the main canal and about 4000 miles of distribution canal irrigating over 900,000 ha of agricultural land of Uttarakhand and Uttar Pradesh (Acharya et al., 2016).

Further, about 76 km downstream of Haridwar, at Bijnore, another barrage diverts water into the Madhya Ganga Canal during monsoon months. At Narora, about 155 km downstream of Bijnor barrage, there is a further diversion of water into the Lower Ganga Canal. From the barrage at Kanpur, Ganga water is being diverted to meet the drinking water requirements.

About 492 major and medium irrigation projects divert a significant portion of water to the canals for irrigation. The majority of these projects are in Uttar Pradesh which has a canal network of about 74,000 km for irrigation (Shah and Rajan, 2019). The data of diversion schemes and water abstractions reveal that about 30 diversions on the main stem of the Ganga River and tributaries divert 40 to 60% of the annual flow of Ganga for canal irrigation. This leaves a minimal volume of water to flow in the river during the remaining eight dry months. The flow has been severely affected in the recent past due to the over-abstraction of groundwater in the basin, which has a marked effect on water quality of the river. If the dry season diversions from the main stem of Ganga is stopped, the base flows as the river enters Bihar would be at least 25% higher (Khan et al., 2014).

5. Environmental flow (e-flow) requirements and the prescribed flow standards

Due to increased abstraction from the river and flow impoundments, very less amount of water is left in the river channel, which adversely affects the natural self-purification process of the river. The stretch between Haridwar and Allahabad has the problem of low flows, especially from December to May. The river gets less water for the dilution of pollutants coming from domestic and industrial sources, which ultimately make the water unfit for a healthy ecosystem. The sedimentation in the riverbed also increases. Recognizing the minimum ecological needs of the river, Clause 3.3 of India's National Water Policy 2012 specifies that "a portion of river flows should be kept aside to meet ecological needs ensuring that the low and high releases are proportional to the natural flow regime, including base flow contribution in the low flow season through regulated groundwater uses" (NWP, 2012).

The National Green Tribunal (NGT) issued an order that requires all the riparian states to maintain a minimum 15% to 20% of the average lean season flow in all the rivers of the country (O.A. No.498/2015-Pushp Saini versus Ministry of Environment, Forests and Climate Change & Others dated 9.8.2017). However, the lean season flow is the lowest in the seasonal flow cycle of a river, and allocating only 15 to 20% will not be sufficient. The NGT has issued direction "*that as an interim measure, while diverting the water from Haridwar to the Ganga canal or even otherwise, the minimum e-flow in the main stem does not fall below 20% of the average monthly lean season flow, which will be referred to the status of the river at Haridwar pre-diversion*" (NGT, order dated 13.7.2017 in the matter of O.A. 2000/2014-M.C. Mehta Vs. Union of Indian and Others).

Earlier, the expert appraisal committee for sanctioning of the river valley projects used to recommend 20% of average lean flow (average discharge of 4 leanest months) in 90% dependable year as environment flow in the river. The consortium of seven Indian Institute of Technology (IITs) recommended more than one-third of the average virgin flows of the river in the wet period and more than 40% of the dry period (Consortium of 7 IITs, 2013). The Government of India (GoI) notified the minimum e-flows for Ganga River in October 2018 (PIB, 2018) that are required to be maintained at various locations, which have been categorized into two parts – (i) e-flow for the upper stretch of the Ganga till Haridwar (Table 2); and (ii) e-flow for the river from Haridwar to Unnao (Table 3). Those projects which are not meeting the stipulated e-flows have to ensure the desired flow norms within three years.

For example, required e-flows during November 11–20 ten daily periods shall be 20% of average inflows observed during ten daily periods between November 1–10. According to CWC (2020), at least four hydropower projects failed to comply with minimum e-flow requirements in the upper stretch of the Ganga river basin.

However, it is not clear on what basis the e-flow norms were calculated, as the flow volumes are too small for adequate river functions. The notification does not consider flow requirements to proliferate the aquatic biodiversity of the river. The standards for e-flows are too low to ensure a healthy river system (Fig. 4). These arbitrary and generic e-flow interpretations lack the spatio-temporal resolution required to maintain a healthy aquatic life in the river. In developing the standards, location of the hot-spots, requirements of aquatic species, and river-specific studies have not been taken into account. The current standards are so low that minimum depth requirements of priority species such as endangered Gangetic dolphins will not be met on the main stem of the Ganga. The e-flow norms on the remaining sections of the Ganga downstream of Kanpur and for other tributaries have still not been defined. The recommended e-flow norms are just 5 to 8% of the mean annual run-off (MAR) of the Ganga River, whereas, at least 30 to 50% of the annual flow is recommended for healthy river functions (Dutta et al., 2020).

6. Major hot spots of water pollution

Many cities and towns located in the catchment of Ganga generate vast quantities of wastewater, a major portion of which ultimately reaches the river untreated or partially treated through the natural drainage system. In the upper hilly stretches up to Rishikesh, the water quality is good throughout the year except for sediments. It is from Rishikesh onwards, disposal of sewage into Ganga begins. Downstream of Haridwar, the water quality starts declining due to the discharge of domestic and industrial wastewater; nevertheless, the river

Table 1
Data points and major parameters used in the study.

Data points and period	Major parameter(s)	Data source	Purpose
Historical data of water quality of Ganga River (2017–2019)	DO, BOD, nitrate, ammoniacal nitrogen	Central Pollution Control Board (CPCB), New Delhi; Uttarakhand Pollution Control Board; Delhi Pollution Control Committee	Long-term quality profile of various stretches
Water quality observed during the lockdown period (March–May 2020)	DO, BOD, nitrate, ammoniacal nitrogen, Faecal coliform, Total coliform	Real-Time Water Quality Monitoring Station (RTWQMS), CPCB, Uttar Pradesh Pollution Control Board	To develop a better understanding of the transformation in the quality of water in Ganga during the lockdown period
Rainfall in Ganga Basin (January to May 2020)	Daily rainfall	Hydromet Division, India Meteorological Department, New Delhi	To estimate the long-term departure from the normal rainfall in the Ganga Basin during the lockdown
Basin storage (2011–May 2020)	Weekly storages	Central Water Commission (CWC)	Data of the last ten years compared with the storage during the lockdown period

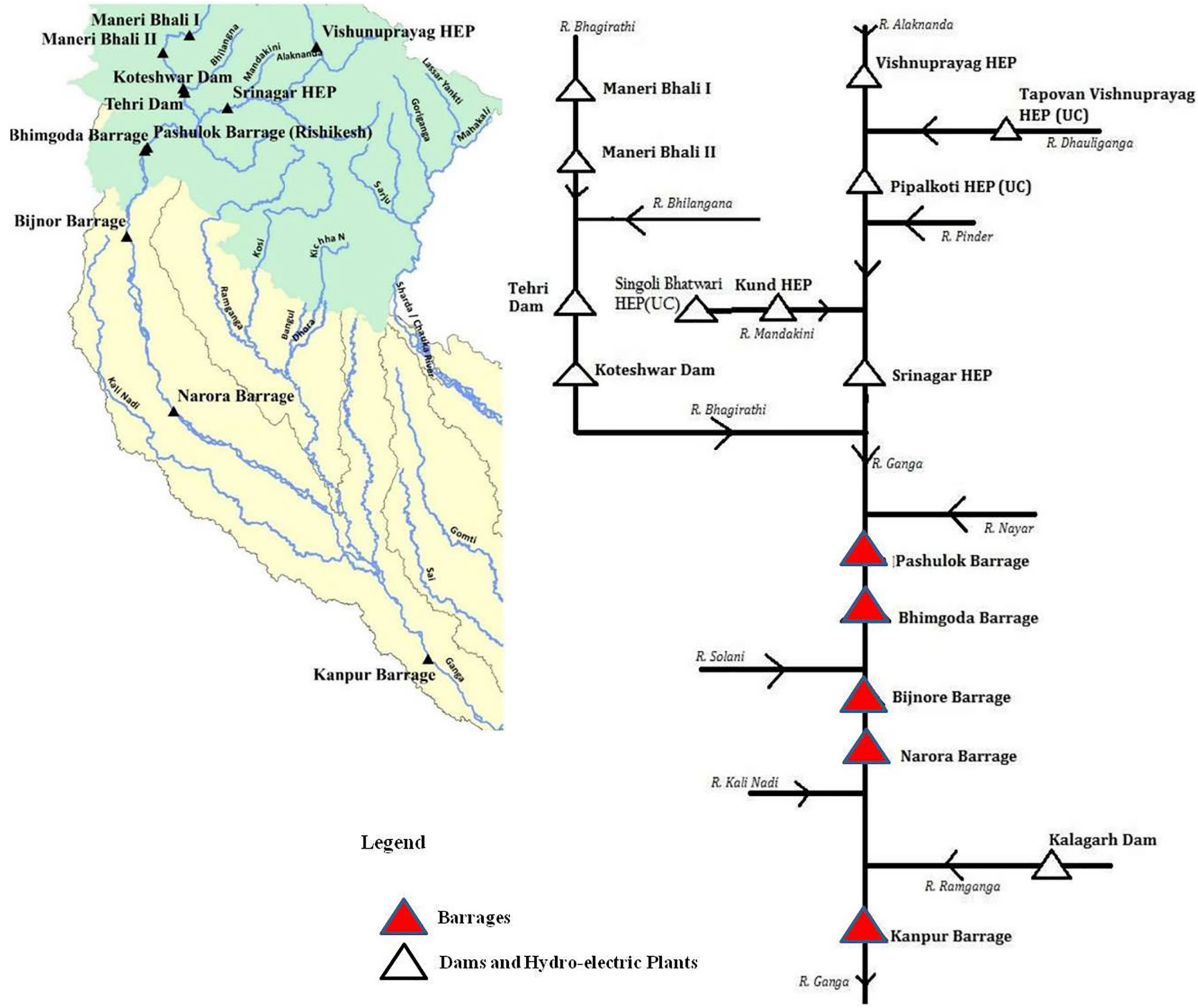

Fig. 3. Dams, barrages and hydro-electric plants on Ganga upstream of Kanpur.

is intensively used in its entire stretch for holy dips or bathing by a large number of people.

There are many polluting industries such as paper and pulp, sugar, fertilizers, textiles, automobiles and distilleries along the tributaries of Ganga such as Yamuna, Kali, Hindon and Ramganga rivers that contribute to the pollution load in the Ganga. The number of Grossly Polluting Industries (GPIs) in April 2019 were 1072 (Namami Gange, 2020). The main water quality issues are organic pollution indicated by BOD and pathogens indicated by coliform count, which are recorded much above the critical limit prescribed for 'outdoor bathing' as the designated best use. The water quality in terms of Faecal coliform (FC) count has been poor virtually all along the river downstream of Haridwar due to the discharge of domestic sewage. According to Trivedi (2010), the amount of industrial wastewater by volume is about 20% of the total volume of wastewater generated in the Ganga Basin, out of which nearly 55% comes from Uttar Pradesh. An earlier study indicated that the worst affected stretch is 350 km long between Kannauj and Allahabad in Uttar Pradesh (Trivedi, 2010). Sewage from

Table 2
Mandated e-flow notified for Upper Ganga River Basin starting from originating glaciers and through respective confluences finally meeting at Devprayag up to Haridwar.

Season	Months	(%) Percentage of monthly average flow observed during each of preceding 10-daily period
Dry	November to March	20
Lean	October, April and May	25
High flow	June to September	30 (i.e. 30% of monthly flow of high flow season)

Table 3
Mandated e-flow notified for the main stem of Ganga River from Haridwar, Uttarakhand to Unnao, Uttar Pradesh.

Location of barrage	Minimum flow releases immediately downstream of barrages (*in cumecs*)	
	Non-monsoon (October to May)	Monsoon (June to September)
Bhimgoda (Haridwar)	36	57
Bijnor	24	48
Narora	24	48
Kanpur	24	48

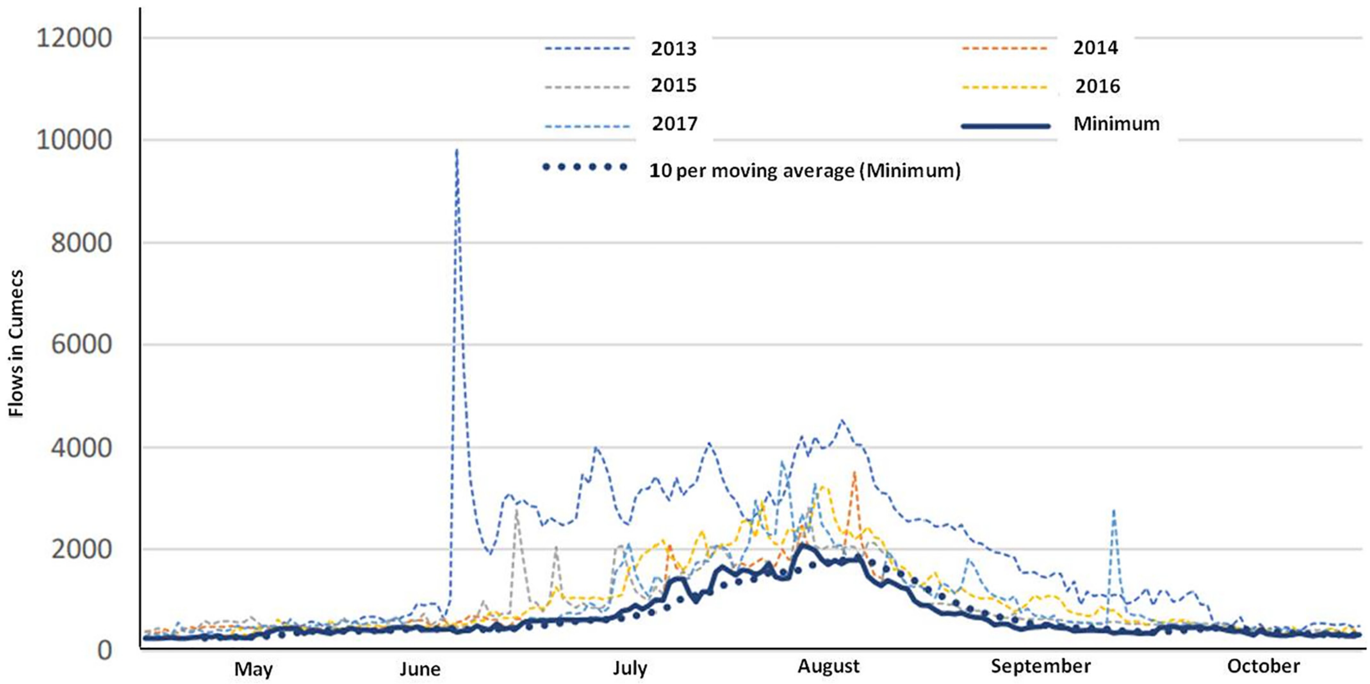

Fig. 4. Minimum e-flow profile of river Ganga at Rishikesh as per the CWC (2020) status report, the low flow allocation is 'residual' and will not support a healthy ecosystem.

Kanpur coupled with untreated toxic waste discharge from about 400 industrial units, many of them tanneries, results in severe deterioration of water quality.

About 3250 million liters per day (MLD) of sewage is generated by the 97 towns situated on the main stem of the Ganga River, approximately 20% of this comes from industrial and commercial sources. Against this, 2074 MLD is treated and the remaining 1176 MLD is discharged without any treatment. National Mission for Clean Ganga has sanctioned projects for creation of an additional 1240 MLD which will increase the capacity to 3314 MLD, and these projects are at various stages of implementation (Fig. 5).

Due to high BOD and FC in the river, along the major cities of Kanpur, Allahabad and Varanasi, the river is not fit for its designated best use of 'outdoor bathing'. The river along the urban segments receives a large amount of treated and untreated wastewater. Sah et al. (2020) observed the presence of 13 banned and restricted organochlorine pesticides (OCPs) in the surface water along the Ganga River with lower stretch most contaminated posing highest

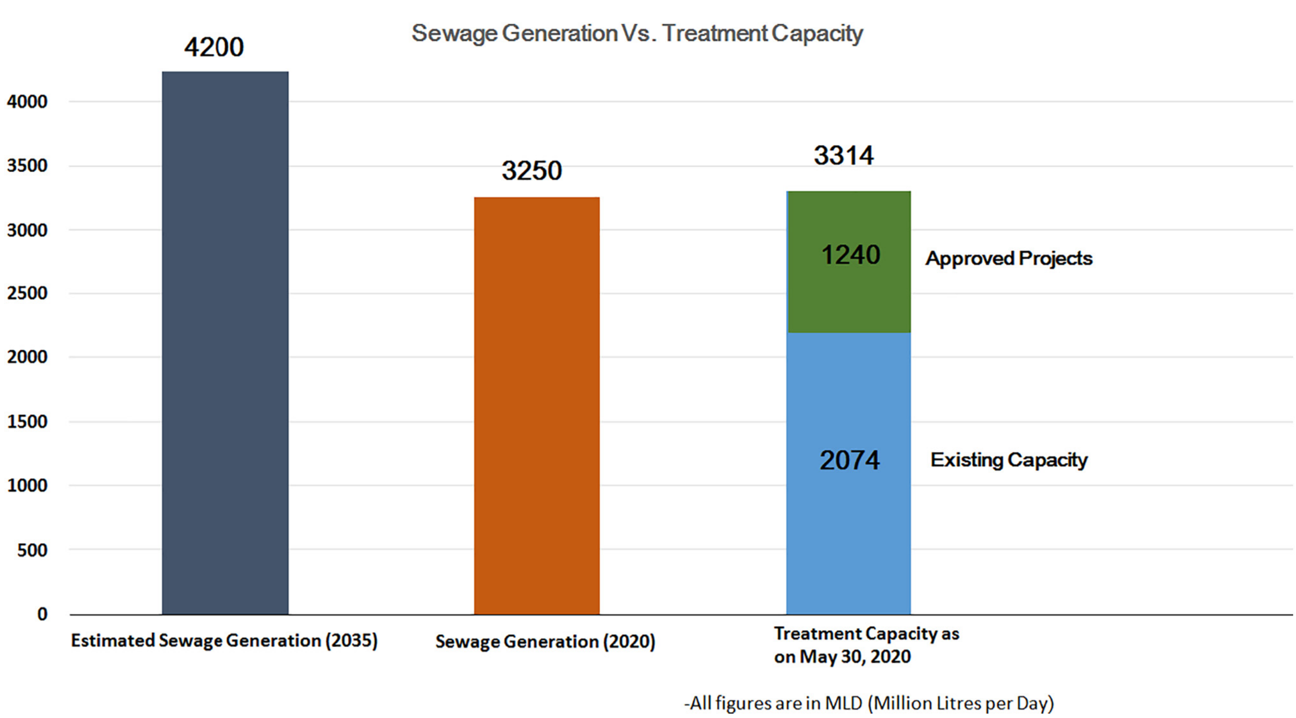

Fig. 5. Status of existing sewage generation and treatment capacity in 97 towns along the main stem of the Ganga River.

ecological risk. Lindane (γ-HCH) was found to be the most dominant and frequently detected pesticide, indicating continued use of this pesticide in agricultural practices even after banning. In the urban stretch of Varanasi, the concentration of heavy metals in the river sediment was found highest for Fe followed by Mn, Zn, Cr, Cu, Ni, Pb, and Cd as compared to upstream and downstream stretches suggesting greater contamination in anthropogenic impacted river stretches (Pandey and Singh, 2017).

7. Impact of lockdown on water quality

The notable level of improvement in water quality was due to the absence of industrial pollutants and reduction in the amount of solid waste that spanned for eight weeks. While the discharge of domestic sewerage has not reduced in this period, industrial effluent has nearly ended, which provided temporary improvements to the water quality. Amid the nationwide lockdown to contain the spread

Fig. 6. Improvement in the water quality in the Ganga River upstream of Kanpur, stretch up to Haridwar was fit for dirking after disinfection (Class A) whereas water downstream of Haridwar was fit for outdoor bathing (Class B).

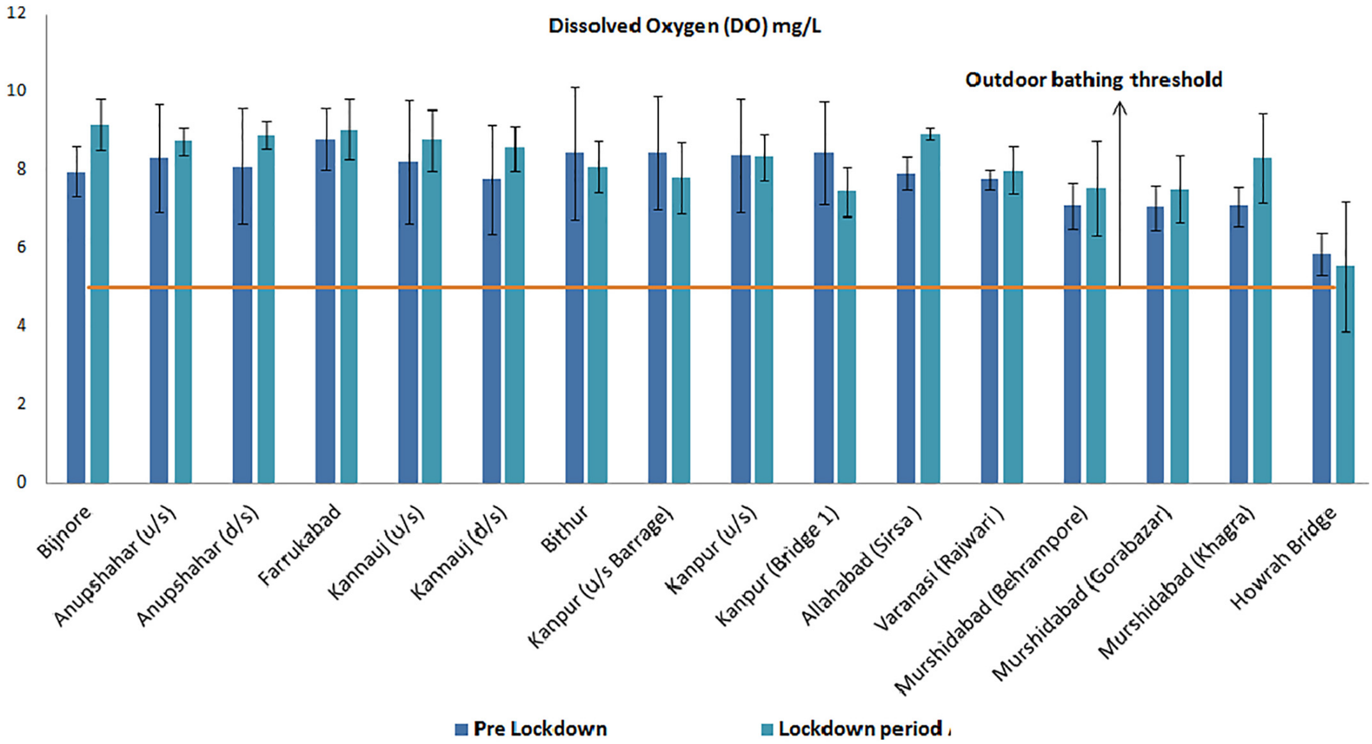

Fig. 7. Trend in the observed DO (mg/L) values in the main stem of the Ganga River during 2019 (pre-lockdown) and 2020 (lockdown), showing increase in DO during the lockdown period.

of the Covid-19 outbreak, the water quality of river Ganga at Haridwar was classified as 'fit for drinking' as per the report of Uttarakhand Pollution Control Board. The sections of media described it as an unprecedented success that the ambitious schemes of the government could not do for years, even after spending a significant amount of money. Due to the lockdown, water in Har-ki-Pauri, Haridwar ranked as Class A for the first time in the last two decades. The water had always been placed in Class B since the state of Uttarakhand was formed in the year 2000. Earlier, the river water was not found to be suitable for bathing at most of the monitoring centers along the river, except the upper stretch till Haridwar (Kamboj and Kamboj, 2019). The quality of water between Rishikesh to Haridwar in Uttarakhand was fit for drinking with conventional treatment (Class A) as DO, BOD and TC level were within the prescribed water quality criteria. Improvement in the water quality was also observed between Haridwar and Kanpur which was fit outdoor bathing (Class B). A noticeable improvement was observed during the lockdown phase along the entire stretch of the river, specially upstream of Kanpur (Fig. 6).

Since most of the factories and commercial establishments were closed due to the lockdown, the Ganga River had become comparatively cleaner. However, the assessment of data shows that there was not much improvement in the organic load in the river as domestic discharges witnessed no change after lockdown.

The DO concentrations remained above 5 mg/L at all the locations which met the bathing criteria (Fig. 7). The impact is attributed to the combined effect of reduced release of industrial wastewater and increased freshwater inflows due to excessive rainfall observed during the lockdown. Water-intensive agriculture was not practiced in the northern plains of the Ganga basin during the lockdown, as the period was harvesting season. Therefore, huge extraction of water for irrigation was avoided both from the canal network and the groundwater aquifers. The additional water could also be the source of dilution. This increasing value of DO may also be attributed to a

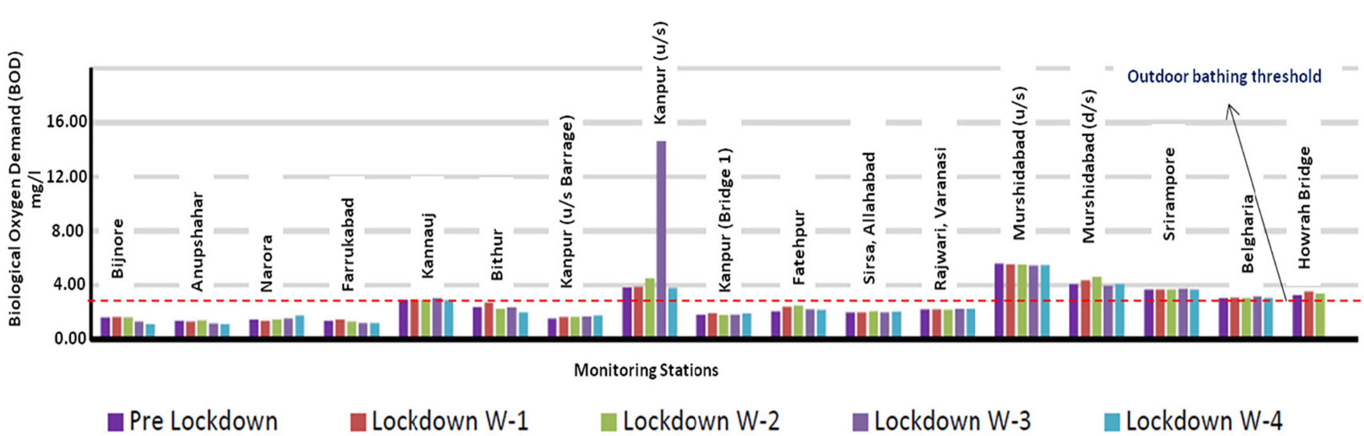

Fig. 8. Trend in the observed BOD (mg/L) values in the main stem of the Ganga River.
Data source: Real time monitoring of water quality, CPCB.

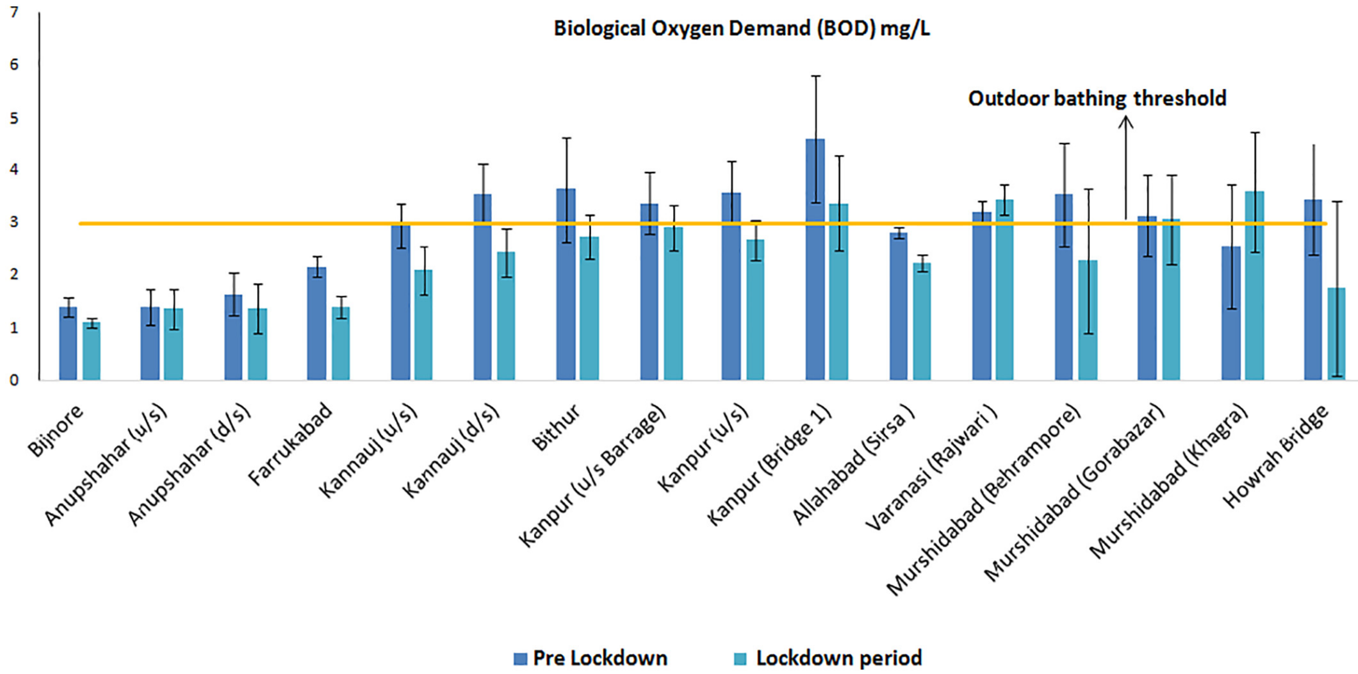

Fig. 9. Comparative assessment of BOD (mg/L) of Ganga River during 2019 (pre-lockdown) and 2020 (lockdown), showing decrease in BOD during the lockdown period, except two stations.

reduction in wastes from various non-point sources. The suspended solids and turbidity in the river increased immediately after the lockdown due to heavy rains.

There was no major reduction in BOD at most of the monitoring stations during the first three weeks, though lower BOD values were observed during fourth week as compared to previous weeks (Fig. 8). A comparative assessment of BOD (mg/L) of Ganga River during the three months-period in 2019 (pre-lockdown average of March to May) and 2020 (lockdown average of March to May), shows decrease in BOD during the lockdown period, except for two stations (Fig. 9).

There has been marginal reduction in COD values during the first four weeks of the lockdown period (Fig. 10), which can be attributed to continued wastewater discharge from municipal sources and secondly, due to longer time requirements for COD reduction as compared to BOD.

A declining trend in nitrate concentration was observed in most of the locations due to limited industrial activities and reduction in agricultural run-off during the lockdown (Fig. 11). Nitrate level on an average varied from 0.69 to 2 mg/L during the beginning of third phase of lockdown.

All the locations except Bijnore have shown increasing trends in the observed values of Ammoniacal nitrogen in both weeks of the lockdown (Fig. 12). The reason could be the increased discharge of the untreated and partially treated wastewater from the municipal sewage and slower rate of dilution during the first phase of the lockdown. However, during the beginning of the third phase of the lockdown, all the locations showed Ammoniacal nitrogen less than the prescribed criteria of 1.2 mg/L limit.

There was also improvement in the bacteriological quality of the Ganga River during the lockdown period. Most of the stations recorded large reductions in the Total coliform and Faecal coliform counts (Table 4).

The improvement in the quality of water has also been observed in the most polluted stretch of Ganga's major tributary – Yamuna River in Delhi during April 2020 as compared to the previous year (Fig. 13). Delhi covers only 0.2% of the Yamuna sub-basin in Ganga basin, but it

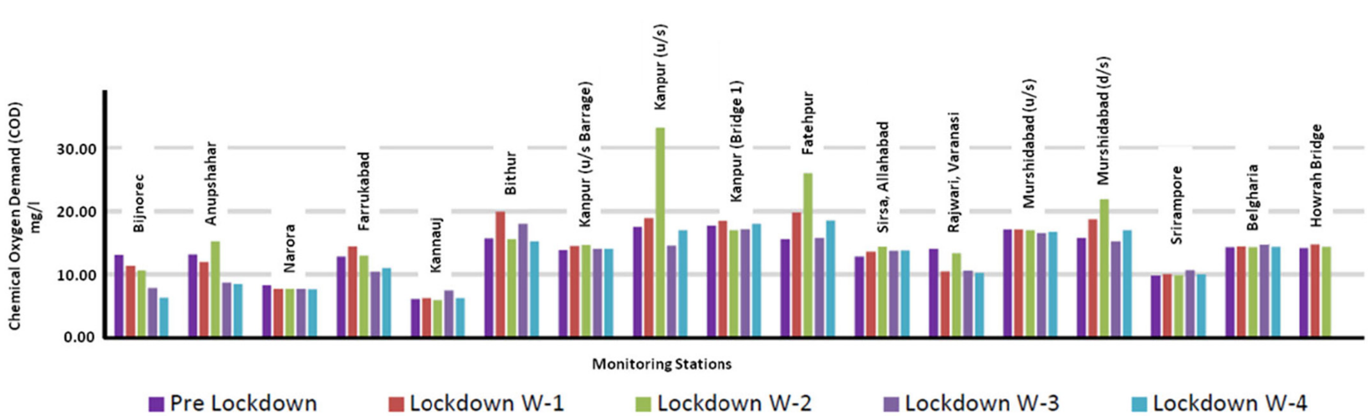

Fig. 10. Trend in the observed COD (mg/L) values in the main stem of the Ganga River.
Data source: Real time monitoring of water quality, CPCB.

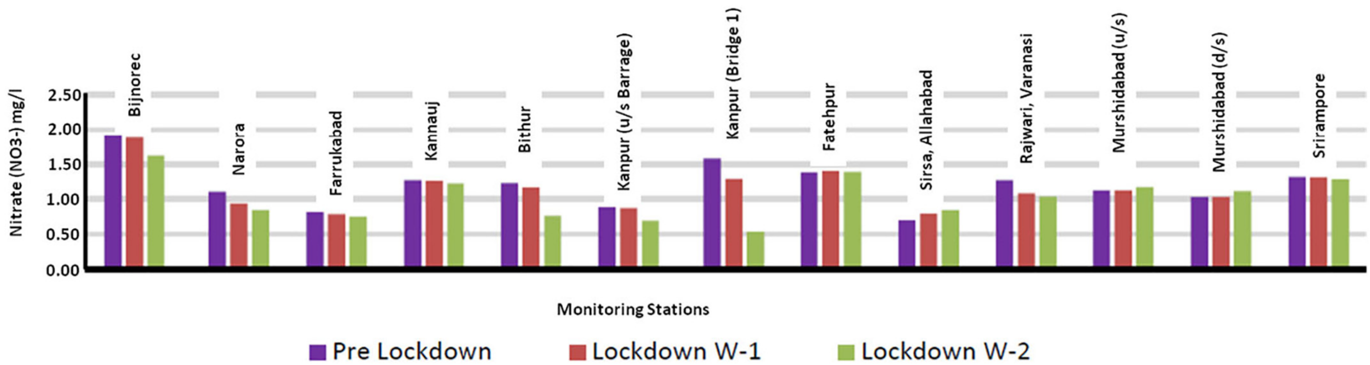

Fig. 11. Trend in the observed values of Nitrate (NO_3-) in the main stem of the Ganga River.
Data source: Real-time monitoring of water quality, CPCB.

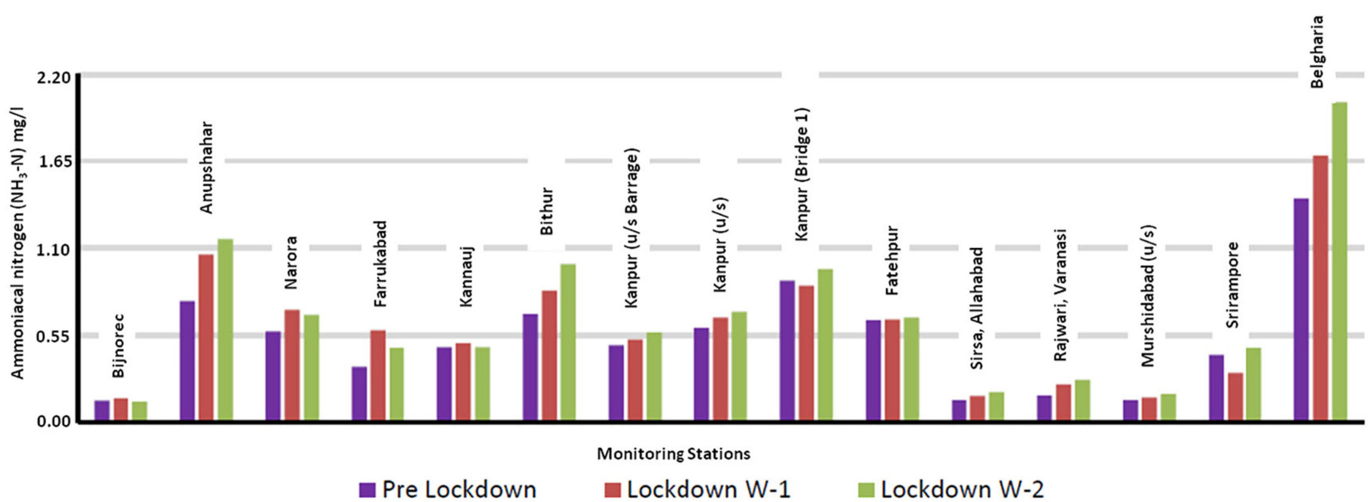

Fig. 12. Trend in the observed values of Ammoniacal nitrogen (NH_3—N) in the main stem of the Ganga River.
Data source: Real-time monitoring of water quality, CPCB.

Table 4
Comparative assessment of Total coliform (MPN/100 mL) and Faecal coliform (MPN/100 mL) in the main stem of the Ganga River during 2019 (pre-lockdown) and 2020 (lockdown period), (mean ± SD).
Data source: Uttar Pradesh Pollution Control Board.

	Total coliform (MPN/100 mL)		Faecal coliform (MPN/100 mL)	
	Pre-lockdown (March to May 2019)	Lockdown period average (March to May 2020)	Pre-lockdown (March to May 2019)	Lockdown period average (March to May 2020)
Bijnore	NA	NA	NA	NA
Anupshahar (u/s)	540 ± 10	NA	233 ± 15	NA
Anupshahar (d/s)	423 ± 12	NA	220 ± 10	NA
Farrukabad	2333 ± 208	2333 ± 709	1400 ± 0	1087 ± 363
Kannauj (u/s)	4000 ± 100	3700 ± 346	2567 ± 115	1600 ± 173
Kannauj (d/s)	4700 ± 100	4500 ± 346	3033 ± 306	2367 ± 252
Bithur	3500 ± 265	4067 ± 252	2100 ± 100	1733 ± 58
Kanpur (u/s barrage)	3667 ± 416	4700 ± 346	2233 ± 252	2100 ± 100
Kanpur (u/s)	4167 ± 231	4333 ± 493	2667 ± 378	1900 ± 436
Kanpur (bridge 1)	8733 ± 577	23,467 ± 20,510	4800 ± 557	11,667 ± 12,419
Allahabad (Sirsa)	16,333 ± 1155	2567 ± 666	8033 ± 1168	1033 ± 584
Varanasi (Rajwari)	15,000 ± 1732	11,333 ± 3786	9000 ± 1732	5433 ± 2380
Murshidabad (Behrampore)	210,000 ± 134,907	6500 ± 5815	154,167 ± 91,892	3283 ± 3961
Murshidabad (Gorabazar)	198,333 ± 81,342	15,167 ± 17,821	141,667 ± 56,006	8167 ± 11,209
Murshidabad (Khagra)	210,833 ± 106,038	32,600 ± 69,316	85,892 ± 85,892	26,617 ± 57,185
Howrah bridge	73,417 ± 45,280	50,000 ± 20,000	38,752 ± 38,752	21,667 ± 4509

NA: data not available.

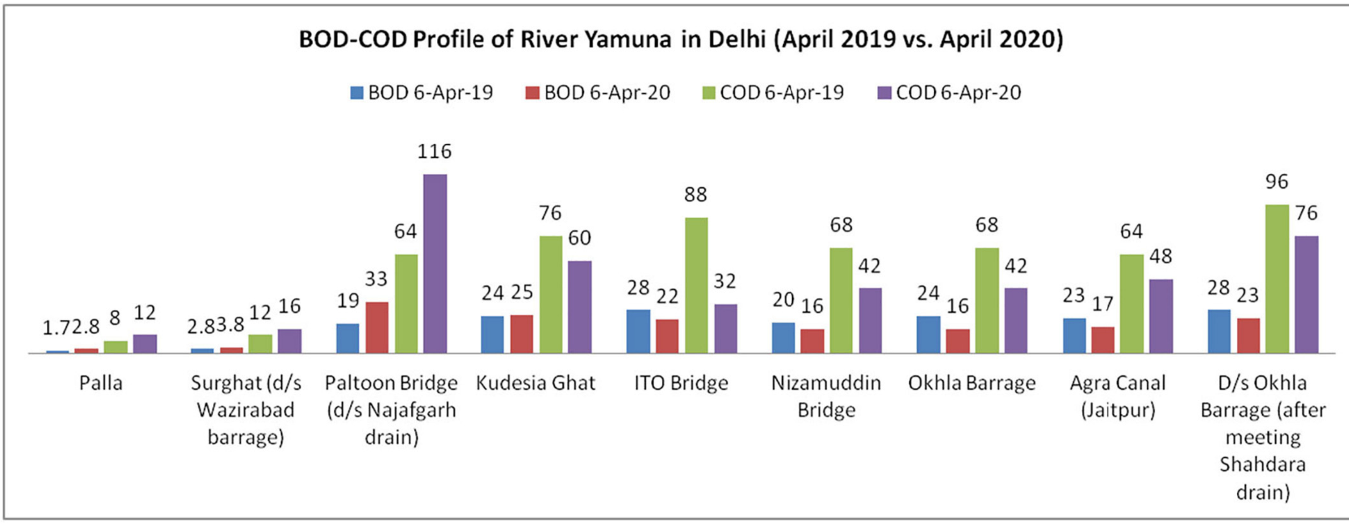

Fig. 13. BOD and COD values (mg/L) of River Yamuna in Delhi in April 2019 and 2020.
Data obtained from Delhi Pollution Control Committee.

impacts badly due to discharge of untreated municipal wastewater. BOD and COD values increased during the lockdown for first three sampling sites, the remaining sites showed decreasing trend. However, the values were still very high – rendering the water only suitable for propagation of wildlife and fisheries (Class D) and for irrigation and industrial cooling (Class E) (Table 5).

According to the data from real-time water monitoring of the CPCB, the water quality at 27 monitoring stations was suitable for bathing (Class B) and 9 stations suitable for propagation of wildlife and fisheries (Class C), out of the 36 monitoring stations placed on the main channel of the Ganga River. Earlier, except upper stretches in Uttarakhand and a couple of places in Uttar Pradesh, the water quality was found to be unfit for bathing for the remaining stretch till it merged into the Bay of Bengal. It is important to mention here that such speedy improvement spanning almost the entire stretch had not been witnessed in the past three to four decades. The data from various monitoring stations clearly show an increasing trend in DO values of the river at most of the locations during the second and third week since lockdown started (Table 6).

8. Reasons for the improvement of water quality in Ganga during the lockdown period

8.1. Higher rainfall events

The period also coincided with a high number of western disturbances, which brought excess rainfall in the basin, improving the flow in the river leading to dilution of the pollutants. Analysis of rainfall data obtained from Hydromet Division, India Meteorological Department New Delhi indicated that from March 1 to May 6, 2020 most of the districts falling under the Ganga basin observed 60% excess rainfall than the normal, which led to increased discharge in the river, further contributing towards the dilution of pollutants (Fig. 14).

8.2. Increase in the surface storages in the basin

Snowmelt after April contributes a significant amount of water to the river. The last two winters of 2018–19 and 2019–20 have seen plentiful snowfall in Uttarakhand, in 2019 the state received six times more snowfall than it did in 2018. During the start of 2020, the state recorded almost 17 in. of snowfall (Singh, 2020). During the last two winter seasons, significant snowfall events improved the snow cover on the glaciers. It was after 15 years that regions at an altitude of 2000 m witnessed snowfall. This increase in snowfall had a beneficial impact on reservoir storage and flow in the river. Storage on 6th May 2020 was 49.27%, which was almost double than the storage during the previous year (25.89%). Analyzing the data of the last ten years, the storage till May 6th, 2020 was 82.83% more than the average of previous 10 years (Table 7).

8.3. Increase in baseflow due to harvesting season

In the Ganga Basin, the eight weeks of lockdown period coincided with the harvesting season; therefore, the agriculture sector was also not withdrawing much water. As the abstraction of groundwater in the Ganga Basin is very high, it affects the baseflow in the river (Maheswaran et al., 2016). Due to unabated long term groundwater extraction, a sharp decrease in critical dry weather baseflow contributions has been observed (MacDonald et al., 2016; de Graaf et al., 2019). The

Table 5
Average concentration of contaminants in the Yamuna river at different locations (January to April 2020) (mean ± SD).

S No.	Locations	pH	COD (mg/L)	BOD (mg/L)	DO (mg/L)	Faecal coliform (MPN/100 mL)
1	Palla	7.70 ± 0.26	32.5 ± 45.70	2.73 ± 0.22	7.83 ± 0.86	506
2	Surghat (downstream of Wazirabad barrage)	7.63 ± 0.42	11.5 ± 3.42	3.45 ± 0.53	5.03 ± 1.21	3567
3	Khajori Palton pool (downstream of Najafgarh drain)	6.99 ± 0.94	103 ± 17.70	31.25 ± 2.75	Nil	44×10^5
4	Kudesia ghat	7.37 ± 0.26	80 ± 14.24	28.25 ± 2.87	Nil	36×10^5
5	ITO bridge	7.61 ± 0.25	69 ± 26.81	26.75 ± 4.27	2.3	46×10^5
6	Nizamudin bridge	7.64 ± 0.19	68.5 ± 17.77	25 ± 6.83	1.73 ± 0.64	94×10^4
7	Agra canal (Okhla)	7.72 ± 0.09	103.5 ± 42.53	31.5 ± 11.47	4.8	25×10^5
8	After meeting Shahdara drain (downstream Okhla barrage)	7.91 ± 0.19	141 ± 45.88	51 ± 18.96	Nil	47×10^5
9	Agra canal (Jaitpur)	7.64 ± 0.19	76 ± 20.91	26 ± 7.35	4.2	70×10^5

Note: Nil means DO value is zero in all four months; data obtained from Delhi Pollution Control Committee, Delhi.

Table 6
Trends in observed quality of water during lockdown on the main stream of the River Ganga based on real time water quality data.

Parameter	Pre-lockdown	During lockdown	Overall trend in water quality
Dissolve oxygen (DO)	Pre-lockdown DO at most of the stations were above 7 mg/L	A slight decrease in DO at all places, due to an increase in turbidity and suspended solids coming from heavy rain spells is observed during the first phase of the lockdown. Bijnaur in UP recorded a 40% decrease in DO. DO showed slight improvement during the second phase. On average, there is an increase in DO by 3 to 20% at various locations. During the third phase of the lockdown, DO increased in UP and West Bengal, except at Belgharia. DO at all the locations was more than 5 mg/L. Narora reported maximum DO of 9.71 mg/L. At Varanasi, DO increased to 6.8 mg/L against 3.6 mg/L pre-lockdown, showcasing major improvement.	DO for all the locations above outdoor bathing criteria. Increased trend of DO in week 2 and 3 of the lockdown due to reduced released of the industrial waste and discharge from non-point sources. The flow due to snow melt contribution and rainfall increased and the parameters of river water quality have shown signs of improvement.
Biochemical oxygen demand (BOD)	Pre-lockdown range of the BOD between 1.37 mg/L to 5.58 mg/L BOD level of Madhya Ganga Barrage Anupshahar, Narora Barrage, Ghatiyaghat Bridge has remained below 3 mg/L	BOD level of Madhya Ganga Barrage Anupshahar, Narora Barrage, Ghatiya ghat Bridge remained below 3 mg/L during the first phase of the lockdown. Fatehpur showed higher BOD values due to the discharge of wastewater through the polluted Pandu river. BOD has shown an increasing trend at Kanpur, a gradual increase in BOD also noticed in the downstream stretch with maximum being in West Bengal during the first phase of the lockdown. Increase in BOD at Kannauj, Kanpur, Fatehpur and Behrampore indicated continual discharge of the wastewater. BOD averaged between 1.8 and 2.5 mg/L prior to the lockdown at Patna, which further decreased to 1.6 to 2.0 mg/L during the second phase of the lockdown. BOD at most of the locations remained below 3 mg/L. BOD in West Bengal stretch varied from 3 to 5 mg/L, slightly higher than preceding week. Minimum BOD of 0.20 mg/L was reported at Murshidabad. Downstream of Srirampore and Howrah bridge reported a declining BOD trend of 1.04 and 0.59 mg/L, respectively.	Steep reduction in BOD at most of the locations during 7th week of lockdown. Water quality good for outdoor bathing; in some stretches upstream of Haridwar, the water became fit for drinking after conventional treatment.
Chemical oxygen demand (COD)	COD varied between 6.14 and 17.7 mg/L during pre-lockdown period	Kannauj and Fatehpur in UP recorded the highest COD in first two weeks of lockdown. Highest COD was recorded in Kanpur, Fatehpur and Behrampur West Bengal. Kannauj, Shuklaganj Bridge, Bridge at Ansi in UP and Bridge at Behrampore in West Bengal recorded high COD values indicating longer time requirements for COD reduction as compared to BOD. All locations reported COD of 9 mg/L or less. Downstream of Srirampore in West Bengal reported COD of 1.59 mg/L and Murshidabad d/s reported COD of 0.90 mg/L	Reduction was observed during lockdown periods for most of the stations except Bithur, Kanpur and Fatehpur in UP and Behrampore in West Bengal. The range of COD after six weeks of lockdown ranged from 0.9 mg/L to 9 mg/L.
Nitrate (NO_3-)	Highest nitrate values were recorded in Madhya Ganga Barrage, UP	Marginal changes were observed in first week in comparison to the pre-lockdown condition. Bijnaur, Narora, Kanpur record decrease in nitrate concentration in the second week of the lockdown. Most stations recorded a decrease in nitrate concentration except Fatehpur, Allahabad in UP and Behrampore, and Srirampore in WB. Kachla Bridge in UP reported a maximum nitrate level of 9 mg/L with Narora reporting nitrate level of 0.69 mg/L. During the third phase of the lockdown, maximum stations reported nitrate level less than 2.40 mg/L.	Due to limited industrial and agricultural run-off, a decline trend in nitrate concentration was observed. The nitrate level on an average varied from 0.69 to 2 mg/L.
Ammoniacal nitrogen (NH_3-N)	Anupshahar, Pariyal Bridge, Kanpur in UP and Belgharia in West Bengal record highest ammoniacal nitrogen	An increasing trend in comparison to pre-lockdown for most of the locations is observed during the first phase of the lockdown. The increasing trend observed in the second phase also, with the highest value recorded at Anupshahar in UP and at Belgharia in West Bengal. Narora, Kachla Bridge, Kannauj, Madhya Ganga Barrage, in UP and Murshidabad, d/s of Srirampore and Howrah Bridge in West Bengal reported 1.1 mg/L of Ammoniacal nitrogen less than the prescribed criteria of 1.2 mg/L limit during the thithird phase of the lockdown.	Ammoniacal nitrogen has shown increased levels from 0.15 to 2 mg/L during the first two phases of the lockdown. During the beginning of the third phase of the lockdown, all the locations showed ammoniacal nitrogen less than the prescribed criteria of 1.2 mg/L limit. The main reason being the increased discharge of the untreated and partially treated wastewater.

surge in groundwater extraction coincides with the demand for dry season irrigation for intensive agriculture. The baseflows are diverted for meeting the demand from irrigation (Jain, 2015). It has been observed that when groundwater levels decline, discharges from groundwater to streams also decline (Sharma and Dutta, 2020), which decreases streamflow, with potentially distressing effects on the health of the aquatic ecosystems. Apart from groundwater, over 40% of the annual flow of Ganga till Kanpur is diverted for canal irrigation. Since there was no sowing of crops or irrigation requirements, the amount of diversion also declined.

8.4. Reduction in the discharge of wastewater from industrial and commercial units

Almost zero industrial pollution due to complete lockdown increased the quality of water in the Ganga River. The water quality improved significantly at Kanpur, Varanasi and Allahabad since the enforcement of the lockdown, especially around the industrial clusters. This indicates that industrial effluents were not being adequately treated before being discharged into the river. The wastewater discharged into the Ganga basin ranged between 6500 and 6700 MLD

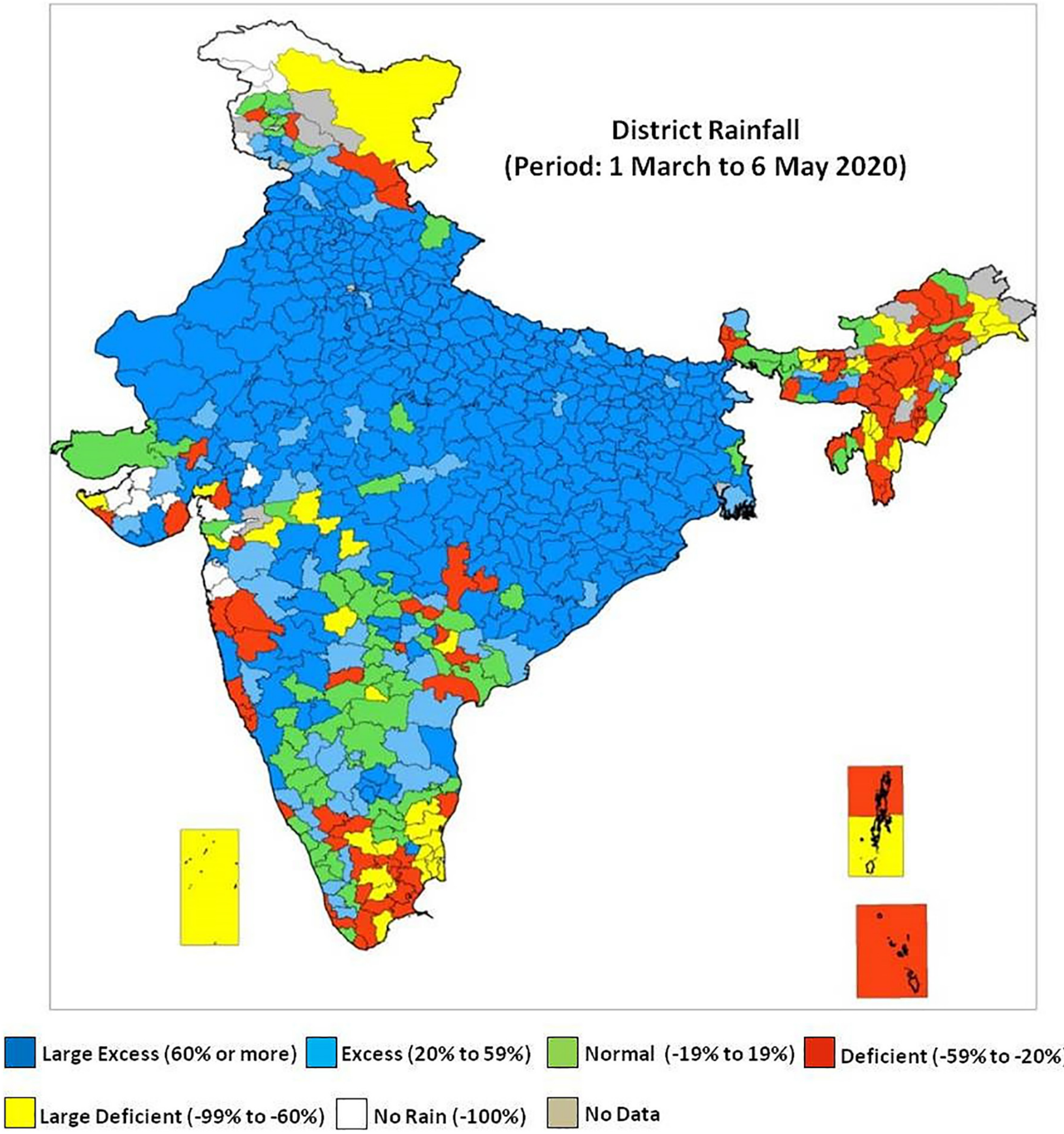

Fig. 14. Rainfall in the Ganga Basin showing large excess (60% above the normal) which contributed to higher storage and discharge.

in its middle and downstream stretch, of which around 20% was toxic load from industries. Therefore, there was a reduction of about 1300 to 1340 MLD of industrial wastewater during the lockdown period. When sewage is mixed with industrial effluents, it negatively affects the self-cleaning abilities of the stream. The organic pollution level from domestic sewage gets diluted in the river comparatively at a faster rate than the inorganic pollution (Bhaskar et al., 2020). Still, it is the chemical pollution by industries (high COD) that destroys the river's self-cleaning properties in a big way due to complex nature of pollutants. The self-cleaning properties had improved due to which the water quality also improved.

8.5. Decrease in electricity demand

The daily requirement for electricity dipped by a minimum 15% across the globe based upon data from 30 countries on account of the shutting of industrial and commercial operations during lockdown (IEA, 2020). In India, according to the Power System Operation Corporation, electricity production fell by 32.2% to 1.91 billion units (kilowatt-hours) per day, compared to the 2019 levels (DTE, 2020). As per the statistics of all India installed capacity of power stations during and of March 2020, hydropower constituted about 23.01% of the total power production (CEA, 2020). There are 39 hydro-electric projects in the Ganga basin in India, out of which 27 are major, and 12 are small hydro-electric projects. Due to a reduction in electricity demand, hydropower production may have dipped, allowing more water releases to the river. The water in Yamuna increased to 3900 cusec in April 2020 as compared to 1000 cusec in April 2019. This has allowed significant dilution to the pollutants coming from various drains.

8.6. Complete restriction on other activities such as tourism, fairs, bathing and cloth washing

As the public were not allowed to congregate for religious activities and fair, it reduced the local impacts of solid waste coming to the river. The activities near the *ghats* (river banks) were curtailed. River during lockdown was free from the problems of solid waste dumping and littering along its banks by visitors. The visual perception and aesthetics of river banks and accessible *ghats* along major cities improved due to the public not accessing the river for rituals and bathing.

Table 7
Storage in the Ganga River Basin based on weekly storages and percentage departure with respect to last year and previous 10 years (data period 2 January, 2020 to 6 May, 2020). Data source: Central Water Commission (CWC), Govt. of India.

Date	Live capacity at FRL	This year storage (2020)		Last year storage (2019)		Last 10 year average storage		Percentage departure w.r.t. average of 10 years
02.01.2020	30.184	22.657	75.06%	14.769	48.93%	15.575	51.60%	45.47
09.01.2020	30.184	22.067	73.11%	14.210	47.08%	15.494	51.33%	42.42
16.01.2020	30.184	21.524	71.31%	13.517	44.78%	14.535	48.15%	48.08
23.01.2020	30.184	21.042	69.71%	12.996	43.06%	14.775	48.95%	42.42
30.01.2020	30.184	20.713	68.62%	13.145	43.55%	14.441	47.84%	43.43
06.02.2020	30.184	19.888	65.89%	12.040	39.89%	13.324	44.14%	49.26
13.02.2020	30.184	19.150	63.44%	11.565	38.32%	12.708	42.10%	50.69
20.02.2020	30.184	18.518	61.35%	11.355	37.62%	12.530	41.51%	47.79
27.02.2020	30.184	17.699	58.64%	10.699	35.45%	12.260	40.62%	44.36
05.03.2020	30.184	17.125	56.74%	10.309	34.15%	11.678	38.69%	46.64
12.03.2020	30.184	16.616	55.05%	10.181	33.73%	11.330	37.54%	46.65
26.03.2020	30.184	16.084	53.29%	9.685	32.09%	10.899	36.11%	47.57
09.04.2020	30.184	15.199	50.35%	8.176	27.09%	9.761	32.34%	55.71
16.04.2020	30.184	14.933	49.47%	7.890	26.14%	9.507	31.50%	57.07
23.04.2020	30.184	14.871	49.27%	7.601	25.18%	9.153	30.32%	62.47
30.04.2020	30.184	14.654	48.55%	7.536	24.97%	9.020	29.88%	62.46
06.05.2020	30.184	14.534	48.15%	7.503	24.89%	7.950	26.34%	82.83

9. Impact of infrastructure put up by national schemes and action plans

Significant improvement has been seen around Ganga in Kanpur, an industrial town, from where a large volume of industrial waste is generated and discharged into the rivers. In Kanpur, the Sisamau drain which used to discharge about 183.29 MLD of untreated water into the river was stopped in 2019 under the *Namami Gange* project (Fig. 15). This has brought down the water pollution considerably during the lockdown pweriod. About 16 large drains used to discharge untreated wastewater in Kanpur, out of which 8 drains have been tapped and diverted to sewage treatment plant (STP) till December 2019.

A total of 254 projects worth Rs. 246,720 million have been sanctioned under *Namami Gange* programme for sewage infrastructure, river banks and crematoria development, riverfront development, river surface cleaning, biodiversity conservation, afforestation, rural sanitation, and public participation (PIB, 2018a). There are about 63 sewerage management projects which are under implementation, while 12 new sewerage projects were completed before the lockdown started. About 30 new STPs in Uttarakhand have been installed. Three STPs of total treatment capacity of 38.5 MLD started functioning at Rishikesh upstream of Haridwar from March 2020. A 14 MLD STP was also completed at Haridwar in July 2019. Till April 2019, 1930 MLD of sewerage treatment capacity in 97 towns has been developed, whereas the sewerage generation in these towns is 2953 MLD (Dutta, 2020). In view of the current treatment capacity and wastewater generation, the gap in treatment capacity in the riparian states is very large which amounts to 6321 MLD (Fig. 16). The various sanctioned projects would create additional 2205 MLD sewage treatment capacity and 4762 km of sewerage network in addition to rehabilitating older STPs of 564 MLD capacity.

There have been several ambitious projects to clean the Ganga river, from Ganga Action Plan (GAP) – Phase I, and II to the *Namami Gange* project (Table 8). The previous projects have yielded sub-optimal results, mainly due to (a) insufficient capacity of STPs as effluents from municipalities and industries flew untreated into the river, contaminating it and making the water unfit; (b) the amount of wastewater from non-point sources such as agricultural run-off is challenging to check. It is also due to the fact that, efforts of expanding sewage treatment infrastructure to achieve the target of cleaner Ganga were not adequate in comparison to the fast rate of urbanization. Water scarcity resulting from over-abstraction of surface and groundwater in the basin due to the rapid increase in water demand also exacerbates the problem.

GAP was launched by Government of India in 1985 to assist the urban local bodies to install sewage treatment plants in the 27 priority towns along the Ganga River to restore its water quality. Under GAP, 1098.31 MLD sewage treatment capacities were created. In Phase-I of the GAP, a total treatment capacity of 870 MLD was created (Ministry of Environment and Forests, Government of India, 2009, http://www.envfor.nic.in/nrcd). Subsequently, during Phase-II of the GAP, an

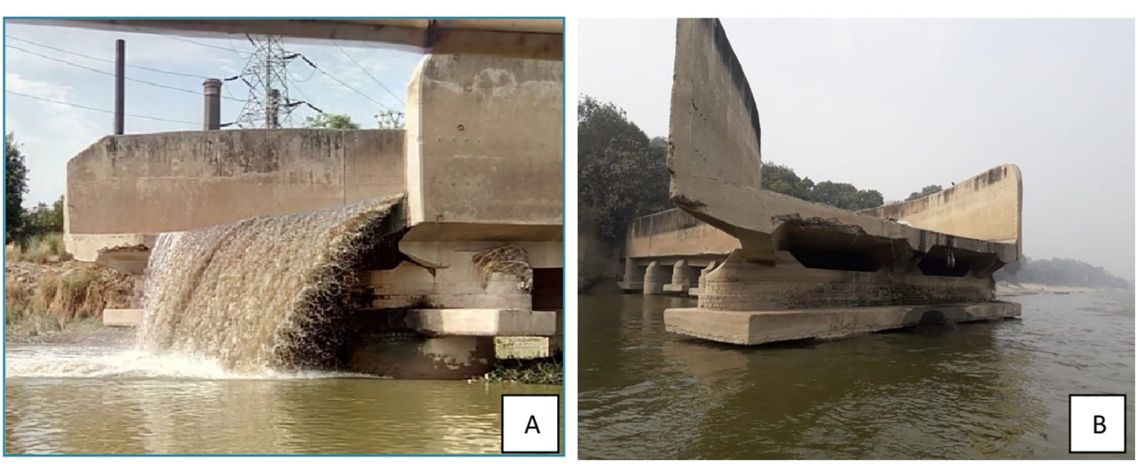

Fig. 15. Sisamau drain – the biggest source of untreated municipal wastewater (183.29 MLD discharge rate) in the Ganga River in the heavily polluted urban segment of Kanpur City, A: before lockdown (2019) B: during lockdown (2020).

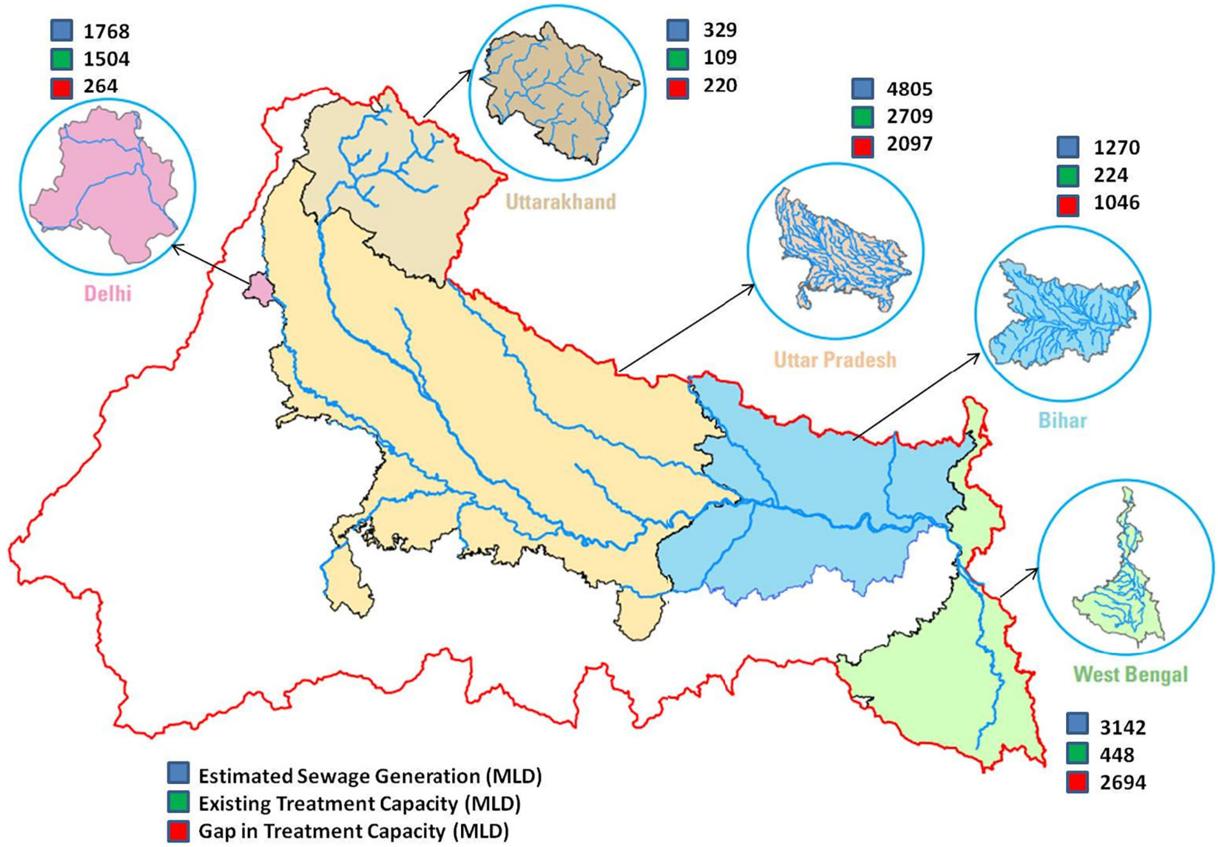

Fig. 16. Sewage generation, treatment capacity and shortfall in sewage treatment in the major riparian states of the Ganga Basin.

additional capacity of 130 MLD was created in 48 smaller towns along the river. Similarly, a treatment capacity of 720 MLD was created under the Yamuna Action Plan, (YAP) and a capacity of 2330 MLD was created by Government of Delhi for the restoration of water quality in the Yamuna River. About 84 STPs having a combined treatment capacity of 1579 MLD were constructed under GAP – I and II, NGRBA, and state projects along the main stem of river Ganga. Various studies reported that many of these STPs are (a) *underutilized as per design standards*; (b) *non-functional* and (c) *do not meet the quality standards suggested by the regulatory bodies*. Central Pollution Control Board (CPCB) initiated

Table 8
River rejuvenation schemes to clean River Ganga and their shortcoming.

River rejuvenation schemes	Period	Total investment[a]	Major shortcomings
Ganga Action Plan (GAP) Phase I	1985–2000	Rs. 462.04 Cr. (360.96 million USD)	The focus was restricted to augmentation of wastewater treatment facilities only Technologies adopted for sewage treatment did not meet of suitability and efficiency criteria Lack of efforts on water resources management, conservation or its judicious use Lack of mass awareness, public participation, and involvement of various stakeholders
Ganga Action Plan (GAP) Phase II (It also covered Yamuna, Gomti and Damodar rivers)	1993–1999	Rs. 2285.48 Cr. (749.58 million USD)	Lack of sufficient budgetary allocations and resources for operation and maintenance of the wastewater treatment facilities created Primary focus on the engineering-centric approach no focus on ecological entities of the river lack of cooperation between central and state governments and municipal authorities
National Ganga River Basin Authority (NGRBA)	20th February 2009–20th September 2016	Rs. 4607.82 Cr. (951.82 million USD)	Ecological flows in the Ganga and its tributaries was not integrated in the basin management plan Basin-wide environment management plan ignored the role of large and small tributaries lack of long term involvement of municipal and planning authorities
National Mission for Clean Ganga (NMCG)[b]	12th August 2011–7th October 2016		Lack of enabling policy and legal framework Lack of coordination between various riparian states
Namami Gange Programme	Continuing since June 2014	Rs. 20,000 Cr. (3208.72 million USD)	Diminutive focus on ecological and geological integrity of the river Smaller tributaries of Ganga have not been included so far Environmental flow allocations are low sub-optimal control of industrial pollution

Note:
[a] The exchange rate of conversion of INR to USD follows the date of sanction of the project. The value of 1 USD was 12.37 INR, 30.49 INR, 48.41 INR and 62.33 INR in 1985, 1993, 2009 and 2014 respectively.
[b] NMCG was implementation arm of NGRBA which was dissolved in October 2016 as National Ganga Council. NGRBA was transferred to the Ministry of Water Resources from the Ministry of Environment and Forests in July 2014.

a project called Pollution Inventorization Assessment and Surveillance (PIAS) to assess the functioning and treatment efficiencies of 67 STPs located on the main stem of Ganga River. These STPs were having a total treatment capacity of 1209 MLD. As per their findings, only 32 STPs with a capacity of 675.7 MLD were observed to be functional.

Due to the paucity of sufficient financial resources to run the treatment plants created under GAP or YAP, and due to technical and operational disruptions, there has been no marked impact on improvement in water quality of the rivers (Trivedi, 2010). India's National Green Tribunal (NGT) in its judgment order (O.A. No. 200/2014 in the matter of M.C. Mehta vs. Union of India for Segment B, Phase I dated 13th July 2017) observed that "*even after spending Rs.7304.64 crore up to March 2017, by the Central, State Government and local authorities of the State of UP, the status of river Ganga has not improved in terms of quality or otherwise and it continues to be a serious environmental issue*" (Bhagirath, 2017).

After GAP Phase I and II, the GoI intensified its efforts for pollution abatement of river Ganga through various projects, mainly targeting at the treatment of municipal sewage, industrial effluents, river surface cleaning, rural sanitation, afforestation and biodiversity conservation. Realizing the shortcoming of GAP I and II, NMCG sanctioned projects for up-gradation and rehabilitation of 23 existing STPs. These projects are centered around cities located on the banks of the Ganga and heavily depend upon the construction of sewerage networks, interception and diversion projects and development of STPs.

10. Key lessons from the lockdown and future perspectives

The population in the Ganga basin will increase in the future with an increase in industries and urban settlements. This is expected to generate a huge demand for additional water. As the water in the main channel and its various tributaries are limited, the substantial increase in demand would further deteriorate the water quality. It is worthwhile to examine key lessons that the pandemic signaled for river management – most importantly, river can be rejuvenated if issues of industrial effluents and adequate flow releases are addressed. The six major recommendations from the lockdown period are outlined below as crucial lessons for developing future perspectives on river rejuvenation.

10.1. Requirement of more stringent regulatory controls

Strict quality regulation and enforcement are required to check the incompliance related to wastewater treatment and discharge. The state pollution control boards are not equipped to handle this and a new system may be devised. There is a need for third-party compliance verification against stipulated environmental norms for existing STPs and industries to bring in more efficiency and transparency.

10.2. Reducing the burden of water abstraction

It is clear from the flow profile that lean season flows in the basin will not be sufficient to meet the human demands and, at the same time, fulfill the ecological requirements. Even though the UGC and LGC are relatively large irrigation systems, irrigation in the Ganga basin today depends on tubewells far more than canals (Shah and Rajan, 2019). A multipronged strategy is required to optimally manage the old canal network and storages in order to maximize water use efficiency and irrigation benefits. This would improve the dry season river flows.

10.3. Increasing the speed of project implementation

It has been observed that there is a slow implementation of projects sanctioned by NMCG, with many projects still in the conceptual and planning stage (CAG, 2017). Monitoring and evaluation mechanisms of ongoing and completed projects have been far from adequate.

10.4. Redefining the standards for industries in view of the impact on water quality

The river entering a watershed boundary should leave with at least the same quality of water as it entered with. The wastewater must be treated up to freshwater levels before putting it back into the river. The volume-wise contribution of industrial pollution in Ganga is about 20%, but due to toxicity and high inorganic impurities, this has much more significant damage on the aquatic ecosystem. The industries are allowed based on meeting the required standards and compliances, but the level of pollution is high. In view of this, it is desirable to revisit the prescribed standards and make suitable amendments.

10.5. Moving to ecological flow regimes from the current conservative e-flow estimates

The current e-flow norms are treated as residual, which is insufficient to meet the requirements of the aquatic ecosystem. Several water abstraction, diversion, and storage projects have been designed on the Ganga River without looking at the needs of supporting its own ecosystem. Excessive water abstraction coupled with pollution ingress not only hampers aquatic life but also diminishes river's self-purification and dilution prospects. It appears that e-flow norms have been developed as a reference to water only; the other critical aspects such as sediment transport, biota and nutrients have been ignored. The holistic flow regime of adequate magnitude, timing, frequency and duration are required to sustain aquatic ecosystems. This would also sustainably ensure other supporting services by the river, such as sedimentation, flooding, river landscape and connected water bodies.

10.6. Designing different strategies for hot-spots and grossly polluting industries (GPIs)

The primary cause of water pollution in Kanpur and the catchment of Yamuna river is the discharge of untreated and partially treated toxic industrial waste mainly from tanneries, paper and pulp industries, electroplating and distilleries which is discharged into the river. As of April 2019, the number of GPI stood at 1072 (Namami Gange, 2020). Therefore, stringent actions are required for checking the pollution form these hot-spots and GPIs.

11. Conclusion

During the lockdown, all major polluting industries were closed; the toxic load was off the river. The improvement in water quality has been seen especially around the industrial clusters and urban areas, which used to witness huge pollution load due to the discharge of untreated and partially treated wastewater. The contributing factor of municipal sewage generation and treatment capacities remained the same since commissioned STPs were running as they used to run before the lockdown period. The lockdown period also witnessed large rainfall events resulting in more flow in the river with better prospects of dilution of pollutants. The way the quality of water has improved in the river during the lockdown, it is evident that the problem of water quality deterioration is largely anthropogenic – (i) stemming from discharge of untreated or partially treated effluents from industries, commercial establishments and municipalities; and (ii) reduced dilution prospects due to over-allocation to canals. The findings also reflected that domestic sewerage was not the only cause of concern; adequate flow is crucial for dilution of the pollutants. During the lockdown, industrial activities were stopped and the production of essential items was allowed after four weeks since lockdown began. There was definitely less effluent generation and discharge. However, it also indicated poor implementation of environmental regulation from various central and state regulatory bodies. In the past several elaborate plans with the allocation of budgets were made to clean the river. But there was no apparent improvement in the health of the river. The improvement in water quality is a temporary reprieve as major schemes to regulate the grossly polluting industries in the river's catchments are still awaited. There should be a rethink on the whole issue of river rejuvenation efforts—establishing the role of industrial discharges and the need for compliances of discharge standards. Various ambitious rejuvenation projects by multiple governments could not bring the desired results in such a short period. Keeping in mind the increasing rate of urbanization and pollution loading in the river, necessary measures should be taken to reduce future deterioration of water quality in the river. The challenge would be to keep the river in similar conditions post-lockdown, which can be possible with two times increases in the existing treatment capacity, stringent industrial pollution control measures and behavioral change to supplement infrastructure creation.

CRediT authorship contribution statement

Venkatesh Dutta: Conceptualization, Methodology, Writing - original draft. **Divya Dubey:** Data curation, Methodology. **Saroj Kumar:** Formal analysis, Visualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.140756.

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