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Riverine water quality engendered by policy interventions, episodic socio-cultural activities, and the COVID-19 pandemic lockdown: A case study of upper and middle Ganga, India

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Abstract
Ganga is one of the most important rivers of India known for its unique anti-bacterial and self-purifying properties. While the river has been providing various direct and indirect services to the people in its densely populated basin, it has also been facing tremendous anthropogenic pressures in the past few decades due to developmental activities that deteriorated the riverine quality making it to the list of top ten world rivers at risk. The river also faces episodic challenges of pollution and health, due to frequent cultural and religious events involving mass bathing and rituals in Ganga waters by thousands of people. Considering the deteriorating quality of the river, various policy interventions such as Ganga Action Plan (GAP) in two phases, starting 1986, and the 'Namami Gange' programme under National Mission for Clean Ganga (NMCG) in 2014, have come into action to restore the river integrity. A historic deviation occurred during the Covid-19 pandemic lockdown in 2020-21, when all the anthropogenic activities came to a halt. The media and several studies reported rejuvenation of the river as a silver lining to the otherwise dark period. However, there were some studies that contradicted the same. To understand how and to what extent the river quality responded to the pressures and interventions, the present study critically analyses changes in some major water quality parameters (dissolved oxygen, biological oxygen demand, and coliform bacterial counts) in the upper and middle Ganga over the last four decades in response to various policy interventions, episodic mass bathing events, or minimal anthropogenic activities during the lockdown period, based on the available data and research studies by the authors. This is the first of its kind study comparing the river water quality changes through four decades assessing its changing suitability for ecological designated best use at different stretches bestowed by different management strategies and provides insight into the effectivity of various planning approaches for river restoration.

Keywords: Ganga, policy interventions, water quality, COVID 19 lockdown, mass bathing event, river health

1. Introduction
Rivers are one of the most indispensable natural resources and are deemed not only as the heritage of the country but also the lifeline of people. River Ganga holds a distinct reverend place in the cultural heritage of India. The river arises from the Gangotri glacier from the Himalayan ranges in the Uttarakhand region. The river Ganga is formed when Alaknanda joins Bhagirathi at Devprayag; before meandering its waters into the Bay of Bengal, it spans route of approximately 2525 km while passing through 11 states of the country. Its large basin is one of the world's most densely inhabited river basins. In terms of water discharge, it is the second largest river in the world. It is the most splendid silt load-bearing river in the world, and the deposition of this silt material forms the world's largest river delta in the Bay of Bengal. Ganga delivers both direct and indirect benefits to the people ranging from household use, irrigation, industrial, agricultural, transportation, to navigation purposes. It shelters almost 40 percent of the country's residents and contributes to more than one-third of the surface water resources. Its shores are havens for many indigenous and migratory species of birds. In addition, the Gangetic delta region sustains unique and rare species of flora and fauna. The river renders livelihood prospects for the communities residing in the basin. The unique self-purification property of the river makes it a sacred and holy river with tremendous religious and spiritual value.

Besides this, the river provides food in the form of fisheries, supports the hydrological cycle, and helps control floods and others, making it a river of conviction, fidelity, and regard. However, due to the dense human population of the river basin, the anthropogenic pressure on the river has been very high leading to large scale deterioration of the river quality over the past few decades. Due to enormous pollution burden, the river Ganga was placed in the list of top ten world rivers at risk that are so damaged that without serious restoration efforts they face massive degradation or even loss (World-Wide Fund for Nature,).

The Ganga basin receives approximately 12000 MLD (Million litres per day) of waste, whereas the pre-set restorative capacity is just one-third. Industrial pollution load is also contributing to around 20 percent following volume (nmcg.nic.in). The industrial pollution load contributed by the bulk of the grossly polluting industries along the river banks is one of the primary causes that influences the innate capacity of the river for assimilation. Toxic chemicals entering the river contain pesticides and fertilizers that come along with agricultural run-off. Besides this, several religious rituals like idol immersion, flower and other offerings in the river water mass bathing, laundry wastes from the dhobi (washermen) ghats on the river banks, cattle bathing, open defecation in some areas, disposal of partly burnt dead bodies, animal carcasses are some of the socio-cultural causes that degrade the water quality and health of the river (Gangapedia). The freshwater is over-abstracted for irrigational use due to high agricultural demand in the river basin even during the lean flow season, while hydro-electric projects at places also affect the river flow (Keeffe *et al*., 2012, Dutta *et al*., 2020) [16, 5].

Considering the deteriorating conditions of the river, The Department of Environment, Govt. of India, drafted a legal policy document in 1984, based on the pollution data, which led to the formulation of the Central Ganga Authority (CGA) a year later considering the emergent need for intervention, and with the major aim to reduce the pollution and the activities at the source to minimise the damage and to restore the water quality and the river basin. Subsequently, in 1986, the first phase of Ganga Action Plan (GAP-I) was implemented with a major focus on pollution reduction strategies in 25 class-1 riverfront towns in three states with more polluted stretches. The second phase GAP-II was launched 1993 onwards, which covered 59 towns alongside the main branch of River Ganga encompassing five states. To give more focussed attention to the river, National River Ganga Basin Authority (NRGBA) was created in 2009 under section 3(3) of the Environmental Protection Act, 1986 and the Ganga (Ganges) was declared as the country's National River with the participation of both central and state governments of the five river states in effectively abating the pollution of River Ganga, thus directing to its protection (cpcb.nic.in). Regular monitoring by the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs) have since then been monitoring the river pollution and taking corrective actions as required. In 2015, the National Mission for Clean Ganga (NMCG) was launched for ensuring the environmental protection and rejuvenation of River Ganga and its tributaries. Thus, several national level policy interventions in the country have been framed over the past few decades for protecting and rejuvenating the Ganga. Along with this, many private organisations including NGOs have joined hands in cleaning of Ganga waters and restoring its health.

While efforts are underway to prevent pollution and restore the river quality through policy interventions, interestingly, the river also faces episodic anthropogenic pressures during certain mass religious events like Kumbh and Ardh Kumbh that happen along the banks of the river at specific sites when people in millions perform religious activities and there is mass bathing in the river leading to fresh pollution challenges affecting the river quality and overall health of the river ecosystem and people. In recent years special attention has been paid by the government to maintain cleanliness and protect the river quality when such events happen.

A historic change in the dynamics of river pollution by industrial discharge and many other anthropogenic sources occurred in 2020-21 during the COVID 19 pandemic, when nation-wide sequential lockdowns were implemented in India, just like that done in most of the countries across the globe. While several reports started appearing on clean river water quality all over the world (Mishra *et al*., 2020, Garg *et al*., 2020, Mukherjee *et al*.,2020, Dhar *et al*., 2020) [12, 6, 14, 4], it led to fresh reflections on the self- rejuvenating capacities of the river *vis-a-vis* pollution loads and stressors.

In view of the foregoing narrative, it becomes quite pertinent to analyse how Ganga, the National River of India, has come up with all the policy interventions in the midst of increasing population, socio- cultural and development activities, episodic mass religious events, and the once in a century complete lockdown condition during the pandemic. The present study is therefore aimed at analysing the water quality dynamics of the river in the upper and middle stretch (from Devprayag to Varanasi) over four decades in response to various interventions, mass religious events and the pandemic lockdown, based on reports and data available and also on primary experimental data of some recent years. The major objective of the investigation in this case study on the selected stretch of the river Ganga (upper and middle) is to understand the impacts of very low to high range of pollution load and stressors on the river water with possible futuristic insights for its restoration and rejuvenation over past four decades.

2. Materials and Methods

2.1 Study Area

The study area includes the Upper and Middle Ganga basin sites, covering the states of Uttarakhand (UK) and Uttar Pradesh (UP). River Ganga travels a length of 2525 km along its whole stretch, from which Uttarakhand shares a length of 110 km, and Uttar Pradesh shares 1450 km. The studied stretch of the river passes through Devprayag, Haridwar, Rishikesh, Bithoor, Kanpur, Jajmau, Allahabad, Mirzapur, Ghazipur and Varanasi. The study area is depicted in Fig. 1.

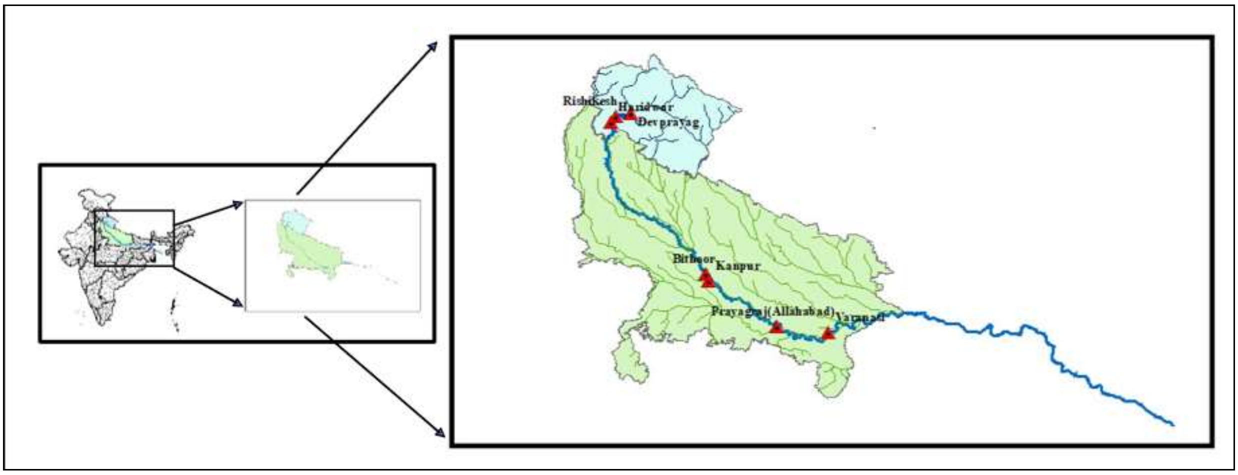

Fig 1: The study area covering the Upper and Middle Ganga basin, showing its course, including states of Uttarakhand and Uttar Pradesh (UG: Devprayag, Rishikesh, Haridwar; MG1: Bithoor, Kanpur; MG2: Prayagraj (Allahabad), Varanasi.

2.2 Methodology

2.2.1 Data collection

The dataset for the comparative assessment of water quality of the river Ganga comprised various sites starting from Devprayag to Haridwar (d/s) in the Upper Ganga (UG) Basin, Bithoor to Kanpur (d/s) in the Middle Ganga Basin-1(MG1), and Varanasi (u/s) to Trighat (d/s) in the Middle Ganga Basin-2 (MG2).

It may be mentioned here that the data available over the years was not uniform. While some data corresponded to seasonal mean, others represented annual means or few months' means. The total number of stations along the river from which samples were taken for water quality assessment varied in different period in each stretch. Care was taken to include the data from same station or nearest available ones along the river stretch throughout the period for reasonable comparison. Detailed description of number of sampling stations and total data sets of samples in the upper Ganga, middle Ganga stretch-1 and 2, along with time period of the study are presented in Table 1. For the sake of comparison, mean values of the three important water quality parameters (DO, BOD, coliform bacterial count), data for which were available right from the pre-GAP I period for the upper and middle Ganga stretch, were computed from all the data set for different sites over the years.

Table 1: Details of sampling data of the river Ganga obtained from different sources during different time periods of policy interventions and the Covid-19 pandemic lockdown.

Period	No. of monitoring stations and total data points along the stretch of the river Ganga			Comments on data set used from available literature
	UG	MG1	MG2	
Pre-Ganga Action Plan (1982)	2 (6) *	2(6)	2(6)	Mean data of 3 seasons
Post-GAP Period (2002-2008)	5(35)	3(21)	3(21)	Mean annual data of 7 years
CPCB Report (2013)	6 (60)	3(30)	3(30)	Mean annual data of 10 years (2002-2011)
Sharma & Kaushik (2017-2018) [24] (After the launch of NMCG's Namami Gange Programme)	6(18)	8(24)	5(15)	Mean data of 3 Seasons
Period of active NMCG interventions in Pre-lockdown period (October 2019)	7(70)	4(40)	3(30)	Mean data of 10 Months (Jan-Oct)
Post-lockdown I (Jun-Sep.2020)	3(12)	4(16)	6(24)	Monthly data of four months
Pre-Lockdown -II (Jan-April 2021)	6(18)	4(16)	3(12)	Monthly data of 3 months (UG) & 4 months (MG)

(*Values in parentheses denote total data points (n) considered in the stretch over a period).

Table 2: Details of sampling data of the river Ganga obtained from different sources during different religious *Melas* accompanied by mass bathing events. *Values in parentheses denote' n' indicating total data points taken in the stretch over a period.

Religious event (*Mela*) with period	No. of monitoring stations along the stretch of the Ganga along with total data points			Comments on data set used from available literature
	UG	MG1	MG2	
Ardh Kumbh *Mela*, Haridwar -UG (Jan-May, 2016) (Report: UPPCB and UKPCB)	5 (25)	3(15)	3(15)	Monthly data of 5 Months
Magh *Mela*, Allahabad-MG2 (Jan-April, 2018) (Report: UPPCB and UKPCB)	5(20)	4(16)	3(12)	Monthly data of 4 months
Ardh Kumbh *Mela*, Allahabad- MG2 (Jan-April, 2019) (Report: UPPCB and UKPCB)	6(24)	4(16)	3(12)	Monthly data of 4 months
Maha Kumbh *Mela*, Haridwar-UG (Jan-April, 2021) (Report: UPPCB and UKPCB)	6(18)	4(16)	3(12)	Monthly data 3 months (UG) & 4 months (MG1, MG2)

Dissolved oxygen (DO), BOD, FC and TC are critical indicators of water quality and river health. The data available on these attributes were compiled and compared to assess the water quality condition in River Ganga through different phases.

Data available in the official Reports were obtained and compared for the Pre-GAP (1982), and post-GAP period (2002-2008) (MINARS Report, 2009-2010) which focussed on two important parameters *viz*. Dissolved oxygen (DO) and Biological Oxygen demand (BOD) in the pre-GAP period, while the number of faecal coliforms (FC) was included in the later stages. Subsequent monitoring by Central Pollution Control Board (CPCB) during 2002-2011 compiled as CPCB Report (2012) provided water quality data on the above mentioned three important parameters.

National Mission for Clean Ganga was launched in 2014, and various action plans were formulated and implemented gradually for protection and prevention of pollution of the river. River water quality was studied by the authors by the authors in post-monsoon (2017) and pre-monsoon (2018) from 6 stations along UG, 8 from MG1, and 5 from MG2 (Sharma & Kaushik, 2018) [24].

The data on the river water quality during the mass bathing events of '*Ardh Kumbh'* held at Haridwar (UG) in 2016, at Prayagraj (upstream Varanasi- MG2) in 2019, and '*Magh Mela'* at Prayagraj (MG2), in 2018, were obtained from the Reports of State Pollution Control Boards *viz*. Uttarakhand Pollution Control Board (UKPCB) and Uttar Pradesh Pollution Control Board (UPPCB). For the *Maha Kumbh'* that happened at Haridwar (UG) during March 2021, just before lockdown-II, the water quality data was taken the Reports of the state Pollution Control Boards UKPCB and UPPCB.

3. Results and Discussion

3.1 Changes in river water quality (upper and middle Ganga) in response to policy interventions over time

Variations in river water quality of upper Ganga (UG) and middle Ganga (MG01, MG02) stretches in terms of mean values of DO (mg/l), BOD (mg/l), and faecal coliform bacteria (MPN/100 ml) over a span of 40 years (1982-2021) have been shown in Figs.1-3 along with the Designated Best Use (DBU) Class in which the water quality falls for that particular parameter.

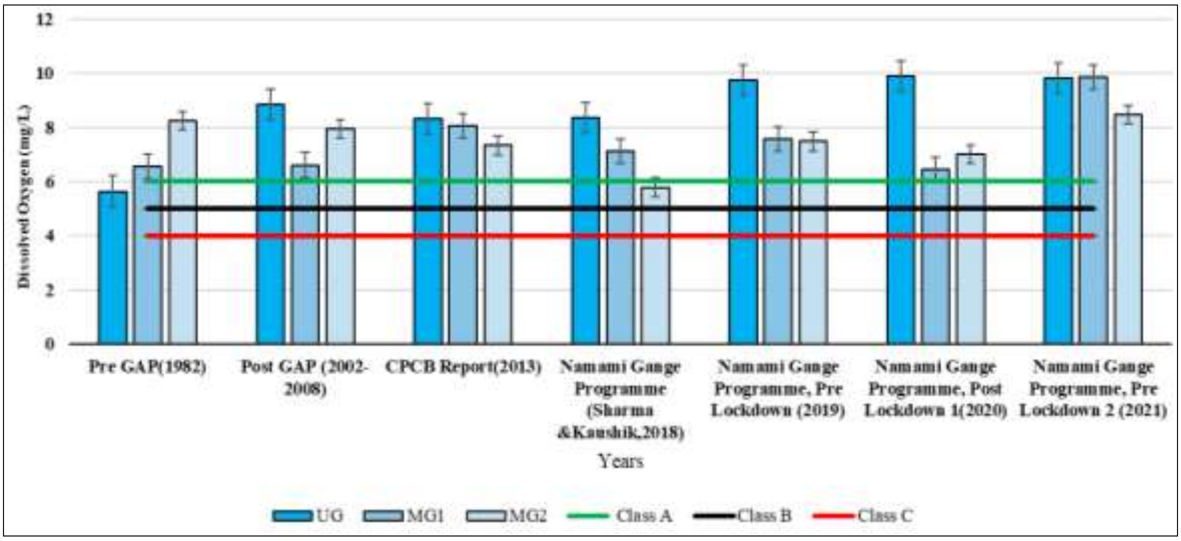

Fig 1: Changes in dissolved oxygen, DO (mg/L) of river water in Upper and middle Ganga in response to Ganga Action Plan and Namami Gange Programme.

Average dissolved oxygen content (Fig 1) in the three stretches studied showed greater values in UG stretch (8.3-9.9 mg/l), where the upper site (Devprayag) was exposed to much fewer human impacts, while there were more anthropogenic pressures at Hardwar and Rishikesh, which besides being centres of religious and cultural activities also show industrial and urban development. The MG1 and MG2 stretches cover densely populated river basin with industrial, agricultural and socio-cultural activities, and affect dissolved oxygen in river water.

Temporal variations indicated lower DO values (5.64 -8.25 mg/L in UG) in pre-GAP period, which improved (6.6-8.85 mg/L) after GAP intervention (2002-08) in the studied region. However, the positive response to intervention did not last long. The CPCB report (2013) again showed a decline in DO level in UG and MG02, which indicated inadequate measures being taken to check the river pollution. The trend continued even in 2017-18 as reported by the authors (Sharma and Kaushik, 2018) [24] although NMCG's 'Namami Gange' programme was launched in 2014. In the initial phase, majorly monitoring of the river was carried out followed by identification of highly polluted stretches, grossly polluting industries (GPIs) and drains in the river basin. By 2019, the water quality showed improvement with rise in DO level to 7.48-9.74mg/L indicating implementation of effective corrective interventions under the "Namami Gange "programme. The post-lockdown I report showed improved DO in upper Ganga, while middle Ganga basin did not show improvement. The 2021 reports of post-lockdown II showed still higher DO levels throughout the UG, MG01 and MG02 stretches.

In the Upper Ganga (Devprayag-Haridwar) and Middle Ganga basins (MG01-Bithoor-Kanpur, MG02-u/s Varanasi-d/s Trighat), the dissolved oxygen (DO) almost exceeds 6 mg/L, which meets the DO criteria of Class A as per Designated Best Use (DBU) in terms of standards developed by CPCB for nearly all the phases. The DBU classes categorized by the CPCB have been used earlier by our research group to assess the quality and suitability of

Yamuna, a tributary of river Ganga (Khaiwal *et al*., 2003) [8].

Similar trend in BOD of river water was observed (Fig 2) that was higher in pre-GAP period (6-14.4 mg/L), the value being the highest in MG01, which improved in post-GAP period showing a decline in mean BOD values in UG (1.65 mg/L) and MG01(4.27 mg/L), while BOD in MG02 stretch was almost the same.

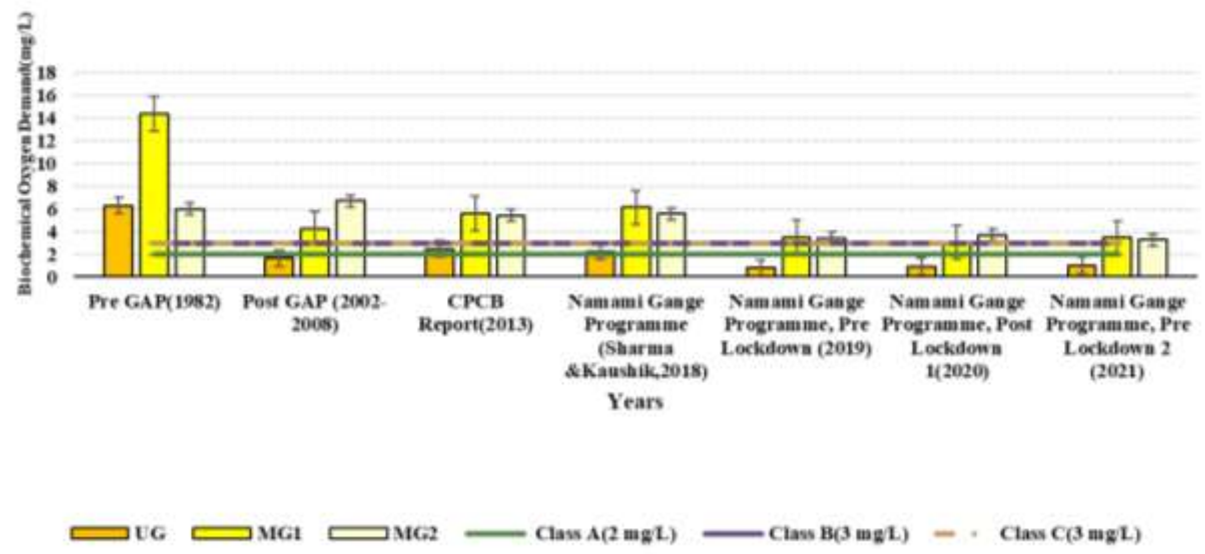

Fig 2: Changes in Biochemical oxygen demand (BOD) of river water in Upper and middle Ganga in response to Ganga Action Plan and Namami Gange Programme.

All through, the BOD in MG1 and MG2 were much higher than that in UG indicating higher organic pollution load in the midde Ganga streches. In the GAP phase I and II, initiatives were taken to install sewage treatment Plants (STPs) in major 27 towns followed by that in 48 smaller towns in the Ganga basin. Though the emphasis was on augmenting wastewater treatment but the treatment efficiency remained inadequate and management of water resources were poor. Though the BOD levels declined but these were >2 mg/L, thus exceeding the maximum desirable limits for Class A of Designated Best Use. Thus, the desired output was not achieved despite huge (Rs. 2747. 5 crores) investments (Terrasustain.com, 2021) [33]. Little attention in GAP was paid to the river ecology, while wastewater treatment engineering was the major focus. A significant decline in BOD could be seen in all the stretches after 2017, which indicates that the NMCG interventions helped improve water quality of the river by controlling the inputs of organic pollutants. In upper Ganga stretch, the BOD values a little higher than 2 mg/L were reported in 2013 and 2017-18 indicating some organic pollution, which declined to >2 mg/L, the permissible limits for Class A, after 2018, attributable to NMCG action. The BOD in MG1 and MG2 (4.3-6.7 mg/L), was much higher than 3 mg/L, the desirable concentration for Class B of Best Designated Use Class of Surface Water (CPCB) and Primary Water Quality Criteria for outdoor bathing (cpcb.nic.in), thus indicating that these stretches did not meet the criteria for safe bathing up to 2018. Organic pollution of river waters is caused by discharge of organic pollutant containing industrial wastewaters, municipal sewage, and agricultural or urban runoff, causing serious impact on the river organisms (Sharma *et al*., 2000) [25]. For the middle Ganga basins, the water quality is seen in the Class D category for almost all stages through different years. Thus, the water could be used for the propagation of Wildlife and fisheries but was found unsuitable for drinking and bathing purposes. A distinct fall in BOD was noticed 2019 onwards, in MG1 and MG2 also, attributed to measures taken by the regulating agencies, including identification of highly polluting industries and tapping of some highly polluting drains that were discharging the wastes into the river, especially the Sisamau drain of untreated municipal sewage (183.3 MLD) by the CPCB under the NMCG initiatives, which significantly reduced pollution in Kanpur downstream.

During the COVID-19 pandemic, the Government of India took a policy decision to impose complete lockdown to prevent /contain the spread of the corona virus SARS 2 in the country, and there were two lockdowns: Nationwide lockdown in four phases during the 1st wave (March 2020-May 2020) and state-wise lockdown during 2nd wave (April 2021- June 2021) when there was complete closure of industries and commercial establishments along with restriction on major transportation facilities. During the first lockdown there were several media reports (India Times, 2020; Hindustan Times, 2020) that suggested that the water quality of rivers including Ganga was showing a remarkable recovery. During the peak of the lockdown, there were reports of 50% decline in overall water pollution. However, the Report of CPCB (2020) reveals that there was a minor decline in BOD in post-lockdown -I period (2020) in MG1 and hardly any significant drop in the BOD of MG2 or UG, when compared to the mean BOD in these stretches in pre-lockdown phase (Fig. 3). Another Report of study conducted in March-April, 2021 (just before imposition of Lockdown-II) by CPCB also indicates BOD values almost similar to pre-lockdown values of 2019 (Fig 3). Though the dissolved oxygen (DO) content showed improvement due to lockdown, but the BOD didn't, indicating thereby little decline in organic load. This is because, industrial activities were stopped but sewage was being generated continuously and the STPs were not properly operated during the lockdown, which kept on adding organic load. A study conducted by Dutta *et al*. (2020) [5] in the middle and lower

Ganga basin, specifically during this period also indicates similar results with no major fall in BOD in most of the monitoring stations despite nationwide lockdown.

Ganga water quality was also assessed adopting satellite-based approach by Muduli *et al*. (2021) [13] using Sentinel-2 data on Chlorophyll a, chromophoric dissolved organic matter (CDOM) and total suspended matter (TSM) serving as proxy for water quality to record the changes due to the nation-wide pandemic lockdown for seven selected locations spread across the entire stretch of the Ganga, while actual field studies were not possible due to lockdown. The satellite data has also shown that due to the lockdown, there was no discharge of industrial effluent, urban runoff, pilgrimage or tourism-related wastes, which helped in improving the water quality to some extent only in some regions like Haridwar. However, organic pollution of the river did not show any significant reduction. These studies show that while industrial wastewaters are often labelled as the major pollution sources for river waters, it is the municipal sewage that is a more significant contributor of organic pollution of the river.

Faecal coliform is an index of contamination of the water with sewage. Changes in faecal coliform (FC) bacteria (MPN/100 ml) over the study period in response to various policy interventions are shown in Fig. 3. There are discernible variations in FC counts in different stretches of Ganga and also across time.

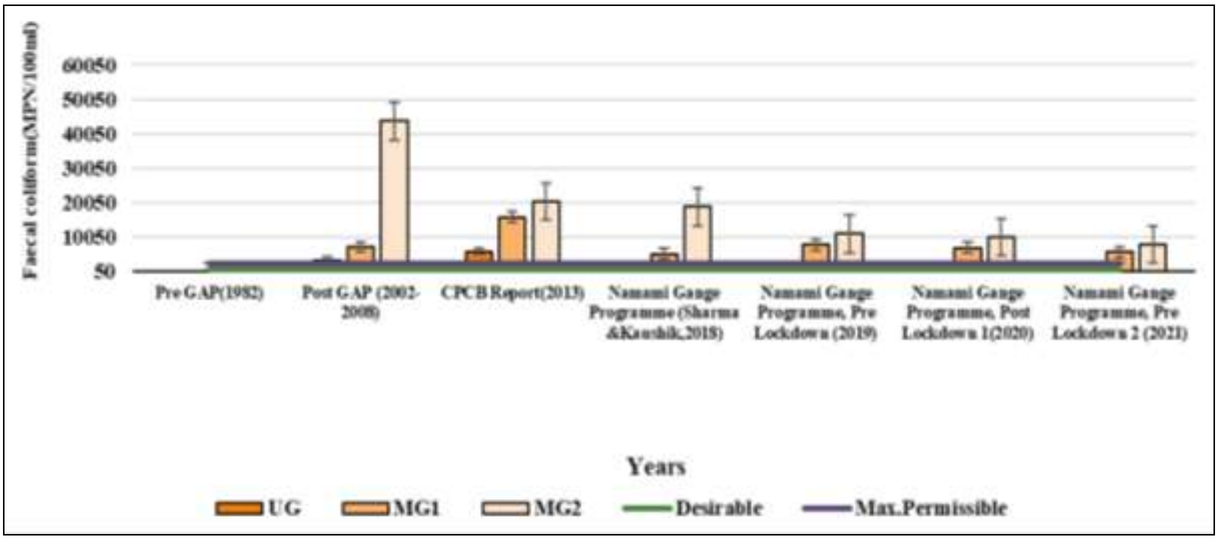

Fig 3: Changes in faecal coliform bacteria count (MPN/100 ml) in river water in Upper and middle Ganga in response to Ganga Action Plan and Namami Gange Programme.

In the pre-GAP phase, MPN of faecal coliform (FC) had not been studied, but in the Post-GAP period, the count was found to be very high (4.36 X 10^4 /100 ml) in MG2 stretch. The number declined thereafter but the count was still very high in MG1 and MG2 in 2013 and 2017-18. In pre-lockdown (2019) period, and even in the post-lockdown -1(2020) and pre-lockdown -2 (2021), the faecal coliform count was high ($1.0x10^4$- $2.5x10^3$) in MG-1 and 2 in the river water. In the UG stretch, the count was lower, but still ranged from $1.2x10^3$ to 5.9X 10^3 up to 2018. A sharp decline was observed 2019 onwards in upper Ganga basin, when the FC counts came down to 14-17/100 ml, which made it come under desirable limits (<50/100 ml). In the middle Ganga basin, however, the counts of FC were much above maximum permissible limits (>2500/100 ml). The coliform counts were also reported to remain high in middle and lower Ganga basins during the pandemic lockdown as reported by Muduli *et al*. (2021) [13] in their satellite-based study. Coliform bacteria present in river waters indicate water contamination with sewage and other pathogenic organisms that are detrimental to human health as they cause many enteric diseases (Scott. *et al*., 2003) [21].

Thus, although DO was found to be good and was found to fall within Class-A (CPCB Designated Best Use Class), and BOD also showed improvement after 2018 making the middle Ganga basins too approaching Class-B criteria, but the FC counts far exceeded the desired limits in MG1 and MG2 all through. Thus, a major challenge is to control the sewage contamination of the river water.

The NMCG has therefore, started mapping population and sewage generation in small towns and villages on the banks of the river, and initiatives have been taken for joining them to sewage connections and STPs with adequate installation capacity to treat all the sewage are being built across the river basin (www.nmcg.nic.in).

3.2 River water quality (upper and middle Ganga) during various religious mass-bathing events after NMCG interventions

Ganga is viewed as the most sacred and pious river of the country, and several culturally and religiously important events known as' *Mela*s are held regularly on the banks of river Ganga when thousands of people from different regions gather and there is mass-bathing in the holy river. One of the most important mass-bathing events is the Kumbh -*Mela* that occurs every three years. The Ardh Kumbh *Mela* is held at Haridwar and Prayagraj (Allahabad) every six years while the Poorna Kumbh is observed every 12 years at four places Allahabad, Haridwar, Ujjain, and Nashik (Rodda and Ubertini, 2004) [19]. On the completion of 12 Poorna Kumbh *Mela*s, there is 'Maha Kumbh *Mela'*, which is held at Allahabad after every 144 years, with great fervor. Besides this, 'Magh *Mela'*, an annual festival is held on the banks of Ganga during the months of (January/February) that draws a vast crowd of devotees for holy dip in the Ganga. Offerings of flowers, milk, ghee, grains, and coins are made by devotees in the river water during these religious events and besides this, the ashes of mortal remain of people are customarily immersed in the Ganga by the Hindus, a major sect of India, and all such socio-cultural anthropogenic activities are reported to have deteriorated the river water quality (Semwal and Akolkar, 2006; Maharaj, 2012) [20-23, 10].

After the launching of Namami Gange programme under National Mission for Clean Ganga, several measures were taken to prevent pollution and improve the river water quality. Variations in river water quality of upper Ganga (UG) and middle Ganga (MG1, MG2) stretches in terms of mean DO (mg/l), BOD (mg/l), and total coliform bacteria (MPN/100 ml) during major mass-bathing events from 2016-2021, after proper implementation of the Namami Gange programme have been shown in Figs.4-6.

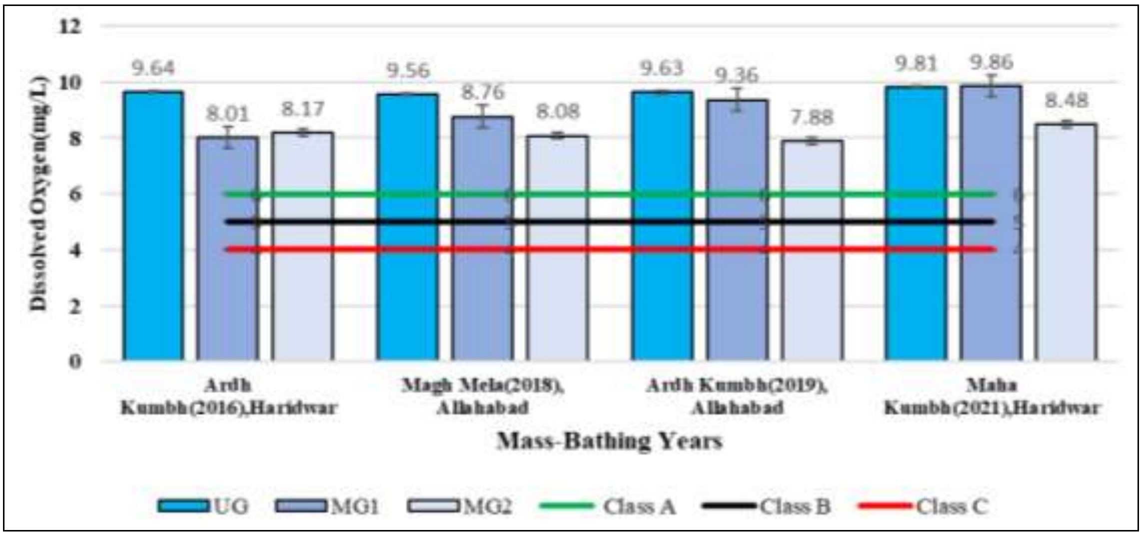

Fig 4: Dissolved oxygen, DO (mg/L) in the river water in upper and middle Ganga during some religious *Melas* involving mass- bathing events (2016-2021)

It may be seen that the mean values of dissolved oxygen in the river water were quite good in the range of 9.56-9.81 mg/L in UG basin and 7.88-8.48 mg/L in MG2, even though the *Mela*s were held at Haridwar (UG basin) and Allahabad (MG2 basin). The DO values of MG1 continued to be high (8.1-9.86 mg/l). This indicates that despite thousands of people assembling and taking mass bathing along with performance of religious rites at specific places on the banks of Ganga, the DO levels remained high falling under class A, which was due to the actions taken by NMCG.

Before the Ardh Kumbh *Mela* (2016) at Haridwar, the State government of Uttarakhand invested in the building interceptor channels and installation of biodigesters in villages along the riverbanks. These indirect measures helped in preventing the inflow of organic wastes into the river and maintaining the desired dissolved oxygen concentrations in the river in the upper and the middle Ganga basin, which continued even during the Magh *Mela* held at Allahabad in 2018. Policy intervention by the Central Govt. to keep the river Ganga, clean during the festive events by arresting tonnes of garbage and organic wastes during the month-long fairs thus had a significant positive impact on the river water quality. Various floating trash skimmers, de-siltation and dredging equipment helped in cleaning the water. It was noteworthy that during Ardh Kumbh (2019) held at Prayagraj (MG2), the mean dissolved oxygen in the river water still showed high concentration (7.88 mg/l).

Looking into the interventions that helped in preventing the pollution load entering the river during the *Mela*s, it was found that on the bank of the 'Sangam' at the event site, the Jal Board of Prayagraj prevented the discharge from 46 major drains carrying 270 MLD of the waste enter the river. The wastes were treated at 8 regular and two transient Sewage Treatment Plants (STPs) along with engagement of technologies like bioremediation, geo-bag modular STP, and partnerships with the National Environmental Engineering Research Institute (NEERI) that treated the waste to get < 30 Biological Oxygen Demand (BOD) levels. To treat the waste from over 0.122 million provisional toilets made in the Jhansi area as basic amenity for lakhs of devotees and visitors at the Kumbh, the Jal Board established two interim STPs. Along with inaugurating STPs, a permanent sewer line of 8.5 km was laid (Sector-1,2) in the Cantonment zone, where most momentous events occurred. To ensure that the solid debris spawned in the *'Mela'* area does not reach the river, the Prayagraj Municipal Corporation deployed 40 trash compactors to condense the garbage produced and 120 tippers to take the garbage for predisposal to a designated area.

The distinct improvement in DO occur during the most massive bathing event of Maha Kumbh *Mela* that took place at Haridwar in 2021. The values of DO rose considerably for all three basins. It is due to the steps of NMCG, attempting to guarantee clean Ganga water to the pilgrims at this sacred location with no sewage water discharge. All principal and insignificant sources of pollution were blocked under the Namami Gange Programme. Kassawan Nullah, one of the most oversized drains that would severely degrade the river, was tapped and redirected to the STP. The installation of 68 MLD STP at Jagjeetpur, Haridwar (UG) contributed to treating the sewage burden, which normally gets enormously compounded during major festive assemblages like Kumbh. Another 14 MLD STP at Sarai, Haridwar, Uttarakhand under the Mixed Annuity model, added to the extensive campaign of saving and reinvigorating the river. In all three basins, even during the multitude of bathing events, the dissolved oxygen (DO) continued to be > 6 mg/L, which comes under the DO classification of Class -A as per Designated Best Use (DBU) standards designed by CPCB.

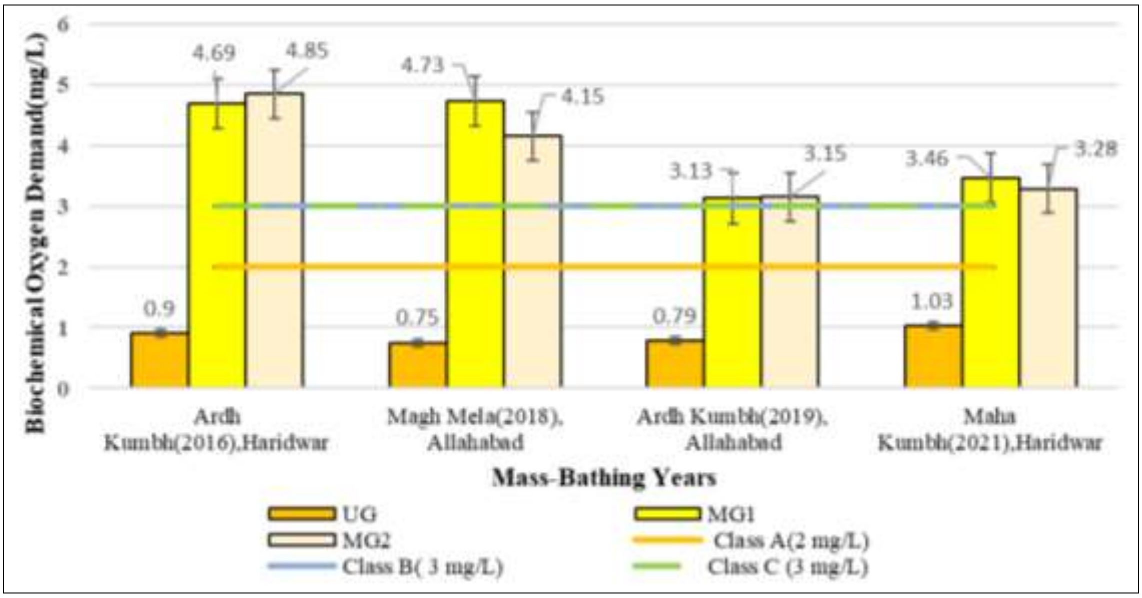

Fig 5: Biochemical Oxygen Demand, BOD (mg/L) of river water in upper and middle Ganga during *Melas* accompanied with mass-bathing events (2016-2021)

BOD of river water during Ardh Kumbh (2016) ranged from 0.9-4.85 mg/L, with the most elevated value in MG02. Despite the *Mela* being held at Haridwar (UG), the BOD in UG stretch was from 0.79-1.03 mg/l, falling in Class -A The mean BOD had a minor decline during Magh *Mela* (2018) period in UG (0.75 mg/L) and MG02 (4.15 mg/L), while BOD in the MG01 stretch did not show any marked change. The BOD in MG01 and MG02 were significantly more than in UG, indicating higher organic pollution load in the middle Ganga stretches, and the values were more than that prescribed for Class-B (BOD 3 mg/l).

A decline in BOD of the river water was discernible in all the stretches after 2018, which may be attributed to strong interventions of NMCG that helped reduce BOD in river water by controlling the infusions of organic contaminants. The BOD in upper Ganga was found to be in Class A. The BOD in MG01 and MG 02 were still found to be 3.1-3.5 mg/l, which is > 3 mg/L, the preferred concentration for Class B (DBU) framed by CPCB, and Primary Water Quality Criteria for outdoor bathing. It may be seen here that although several steps were taken to control organic pollution during the *Melas*, the BOD levels in these stretches indicated that these were still not suitable for bathing though mass bathing events took place. A distinct fall in BOD was, however, witnessed 2019 onwards. Even during Ardh Kumbh (2019), held at Allahabad (MG2), not just in UG basin, but also in MG1 and MG2, which seem to be due to more holistic steps taken by the government. The water quality improved as pollutants were prevented from entering the river. The government added several unique projects, where STPs were established at Haridwar with excellent treatment capability to counter sewage pollution, not only for the current load but also for future. The actions included the interception of most drains and their diversion to STPs.

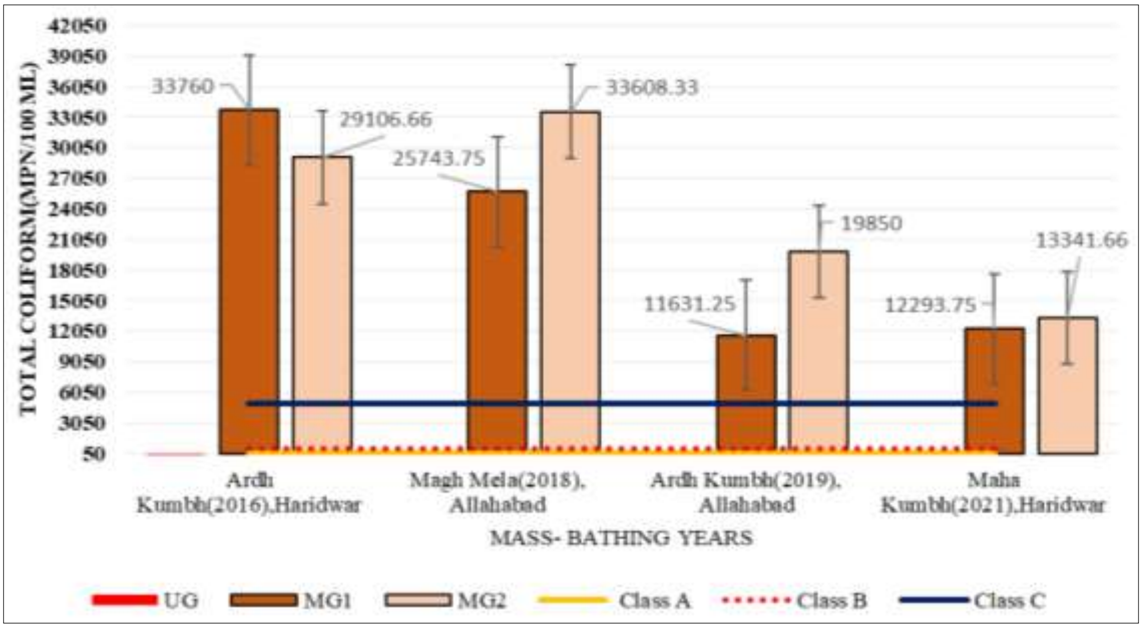

Fig 6: Total coliform bacteria count (MPN/100 ml) of river water in Upper and middle Ganga during mass-bathing *Melas* after NMCG interventions

Unlike that in other monitoring programmes, where total faecal coliform (FC) counts were determined in the river water, in the monitoring schedules of river water quality during various *Melas*, the total coliform (TC) bacteria were reported. The TC included all coliforms entering the water from soil, sewage and animal wastes. The total coliform count in the UG basin remained low (24.5-35.3/100 ml) throughout, indicating maintenance of desired quality even during the ceremonial baths. But during the Ardh Kumbh (2016), the middle Ganga basins exhibited very high values of total coliform (MG1: 3.376X 10^4, MG2: 2.910^4 MPN/100 ml), indicating severe contamination with sewage, animal waste or contamination from nearby areas. This is indicative of the fact that open defecation in many areas of the river basin has still not been eliminated despite best efforts and plans to stop it. It is however, very interesting to record significant decline in the total coliform (TC) count during the Magh *Mela* (2018) at Allahabad (MG1), attributable to the actions under the NMCG as discussed above. In the MG2 stretch, the TC counts were still very high indicating inadequacy of existing STPs and other steps taken. However, from 2019 onwards, as stronger steps were taken as discussed above, the conditions improved. During the Ardh Kumbh (2019) at Allahabad, the numbers of coliform were seen to drop significantly (MG1- 1.16 X 10^4; MG2- 1.98 X 10^4). The NMCG by this time had installed 27500 community toilets along with 5000 pre-fabricated toilets in Allahabad with septic tanks to prevent open defecation particularly along the riverbanks. Another initiative was the installation of 16000 dustbins across Allahabad. Similarly, during the mega event of Maha Kumbh *Mela* held at Haridwar (2021), the coliform counts were almost similar for MG1 and a little less in MG2. Though there was significant fall in TC count, the whole of middle Ganga basin (MG1, MG2) still fell in the water quality Class C. This suggests more stringent measures to be taken to achieve the target of restoring the river water quality in middle river basin by upgrading it to Class-A or Class-B from the present Class-C.

During mass-bathing events, increase in the biochemical oxygen demand has been reported in rivers of Uttarakhand, India due to inputs of large quantities of wastes in to the waterways containing organic load, bacteria and other nutrients (Kumar *et al*., 2010) [9]. As various preventive steps were taken to check the discharge of organic load in the river water during various mass bathing events during 2019-2021, the BOD did not show any significant increase during the *Melas* when compared with non-event periods. There are several studies showing that Ganga waters have high anti-microbial and self-purifying properties (Singh *et al*. 2011; Bhargava 2013) [21, 2]. Ganga water has a remarkably higher number of bacteriophages in comparison to Yamuna and Narmada Rivers. The number of bacteriophages was reported to be particularly high in the upper Himalayan stretch of Ganga. These results show higher bactericidal capacity of the river Ganga (NEERI 2017) [15]. The low coliform bacteria in upper Ganga throughout could be attributed to this property. This suggests that besides protecting and cleaning the river water, it is very important to restore the ecological balance of the river and provide an enabling environment for endemic biota to thrive in the river that is required for restoring the river health. With this consideration, the Ganga River Basin management Plan (GRBMP, 2015) [7] emphasized on ecological restoration of the river. NMCG Action Plans were based on the GRBMP proposal in which living organisms in the river were also considered important interacting with water and sediments, which help maintain the ecological health of the river. The Namami Gange programme under NMCG has adopted in principle the plan proposed by GRBMP, and therefore it is systematically taking initiatives for restoration of river Ganga considering a holistic ecological approach coupled with technological strategies for pollution prevention and control.

4. Conclusion

With rapid industrialization starting about five decades ago in the major cities in Ganga basin there was a boom in discharge of untreated wastewaters into the river leading to its degradation that necessitated launching of Ganga Action Plan (GAP) in 1986, sponsored by the Union Govt. and later, the Namami Gange programme, under NMCG, in 2015 for Ganga water protection, pollution prevention and river restoration. A critical appraisal of the water quality over four decades in response to the policy interventions, the COVID-19 lockdown, and episodic religious *Melas* involving mass bathing in the river in upper and middle Ganga basin revealed the temporal dynamics of dissolved oxygen, biological oxygen demand and coliform bacterial counts. DO concentrations in the upper as well as middle Ganga stretches improved raising it to DBU Class-A, in response to GAP but the decline in BOD and faecal coliform bacterial count were not significant enough to improve its DBU class. Although GAP had a focus on installation of STPs but failure of this policy programme to achieve the desired standards of BOD and FC reveals inadequacy of GAP, mainly because it hardly considered the overall river health. The NMCG policy is based on the recommendations of Ganga River Basin Management Plan put forth in 2015, which focusses on river health restoration adopting a holistic approach. Therefore, The *Nanami Gange* Programme led to distinct improvement in river water quality (DO, BOD) at most of the sites in studied stretches of the river, falling within the maximum permissible limits. The pandemic lockdown led to improvement in DO level of Ganga waters, which was also accompanied by heavy rains and good flow. The river's self-purification capacity also improved. More fishes and other aquatic fauna were observable. There was a drop in all anthropogenic activities, while there was no reduction in household sewage. Hence, BOD and coliform counts did not fall. However, lockdown was a temporary phenomenon, as once anthropogenic activities resumed, the river started facing the pressures. What is demanded is stringent enforcement of statutes, and cessation of activities is not an enduring solution. If the deterioration of the river continues, it will not only deter the riverine flora and fauna but will hamper the entire ecosystem. Thus, maintaining the water quality within permissible limits through continuous monitoring and surveillance, biomonitoring, identifying the point sources of pollution, tapping of highly polluting drains discharging into the river, proper municipal solid waste management, proper and adequate sewage treatment plants, maintaining sustained ecological flows, enabling suitable environment for the endemic biota, and community awareness have to be all taken up for restoration of riverine quality to continue enjoying the benefits river Ganga.

4.1 Declaration of conflict of interests

The authors declare no conflict of interests or personal relationships that could have appeared to influence the research reported in this paper.

4.2 Credit Authorship Contribution Statement

Prerna Sharma: Writing-original draft, Data curation, Methodology, Software, Formal Analysis, Investigation, Resources.

4.3 Anubha Kaushik: Conceptualization, validation, review and editing, Visualisation, Supervision.

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