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Research Article

Impact of COVID-19 Nationwide Lockdowns and Unlock Phases in India on River Water Quality of Upper Part of the Ganga River

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Abstract

The river water quality index (RWQI) of the upper Ganga canal has been computed to assess the effect of lockdown and unlock phases lead down by COVID-19 in India. Geospatial distribution of RWQI from January 2019 to December 2021 in the study area revealed significant impacts of lockdown on water quality. However, unlock phases (post lockdown) have deteriorated water quality since August 2020 and reached to actual conditions of the river by August 2021. To evaluate the lockdown as a management strategy to clean the river, other factors were reviewed including rainfall data, migration, and other activities. The results revealed that all the monitoring stations have improved water quality index ranging from 3 to 45 between March to June 2020. The River Ganga at Haridwar showed a two-fold improvement in the water quality index making it the highest positive impact of the lockdown, and at Rishikesh, the water quality index showed the least changes. The average decrease in RWQI has been observed to be 13 units in the year 2020 as compared to 2019 between March to June. In October 2020, RWQI has been observed to be higher as compared to the years 2019 and 2021. This is possibly due to a shift in rainfall patterns and other factors such as evapotranspiration, precipitation, and atmospheric temperature involved in river water quality control. Up to 60% reduction in average total coliforms and fecal coliforms has been observed due to the nationwide lockdown and a shift in human behavior towards cleaner and sustainable approaches.

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Introduction

Globally, impulsive reduction in anthropogenic activities driven by widespread lockdowns has been witnessed due to the COVID-19 pandemic and it has affected every part of the environmental compartment [1–7]. In addition, it has influenced changes in environmental and hygiene practices to enhance the well-being of society [8–12]. To contain the spread of the COVID-19 pandemic, a complete and extensive lockdown was implemented in India from March 24, 2020, to May 31, 2020, in four phases followed by the twenty-two unlocking phases starting from June 1, 2020, to March 31, 2022. Almost all institutions, industrial establishments, hospitality, and transport including air, road, rail, and waterways were suspended except for essential services during the lockdown. However, unlock phases guided some relaxation in industrial activities to avoid negative economic impact.

This pandemic-induced nationwide lockdown had a significant impact on environmental compartments including air, water, and soil. Up to a 34% decrease in the suspended particulate matter has been reported in Vembanad Lake due to the nationwide lockdown [13]. Similarly, up to 44% reduction in air pollutants has

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been observed under the COVID-19 lockdown in India [14]. The lowest concentrations of NO_2, PM_{10}, and $PM_{2.5}$ were observed during the first phase of the lockdown in Delhi, India [15]. However, the second surge of COVID-19 has improved air quality lesser than first lockdown in Delhi, India possibly due to the vaccination drive and less fear of COVID-19, and partial relaxation in activities of industrial to reduce the socio-economic impact as observed in the first lockdown [16–17]. Moreover, the concentration of aerosol over the Indo-Gangetic Plains has been reported to be the lowest in the last 20 years during the lockdown [18]. The atmospheric concentration of CO_2 and CH_4 has dramatically declined over the Yangtze River Delta of China during the COVID-19 lockdown [19]. At the same time, atmospheric secondary aerosols were raised unexpectedly due to more burning of biomass in Hangzhou, China during the COVID-19 lockdown [20].

On another hand, municipal solid waste generation has been remarkably reduced during the nationwide lockdown and/or due to a shift in consumer demand and behavioral change towards sustainable consumption of resources [12, 21]. As per the Central Pollution Control Board (CPCB), Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India, Ganga's water conditions are more conducive for aquatic life since it carries more dissolved oxygen and fewer nitrates, BOD, and total coliforms during lockdown [14, 18]. However, the water quality of the river after unlocking phases has not been well documented in the literature.

The physical-chemical and biological parameters as individual parameters are difficult to follow and cannot describe the overall quality of water resources. However, a water quality index (WQI) approach based on multivariate concerning suitable standards has been often used to describe the quality of water resources including rivers, ponds, lakes, coastal water, and groundwater, and used for their management [22–31]. Assessment of water quality based on WQI facilitates water management authorities to take a quick decision as it converts multiple complex datasets into a single unit less number [32, 33]. WQI has been widely accepted and used tools to assess water quality, although it has many limitations such as uncertainty, ambiguity, and eclipsing due to the selection of algorithm, weightage, and standards. This is possible with the use of optimized advanced machine learning and algorithm which provide uncertainty-free WQI [34–37].

Ganga water is extensively used for drinking purposes without conventional treatment with a disinfection process (Class A water defined by CPCB, Govt. of India). So it is crucial to assess the water quality based on class-A water standards in addition to BIS standards of drinking water. In the current study, the river water quality index (RWQI) has been calculated based on weighted arithmetic and a multivariate analysis approach to understand overall water quality. To investigate the impact of nationwide lockdowns and unlock phases in the upper Ganga canal due to the COVID-19 pandemic, the geospatial distribution of RWQI from January 2019 to December 2021 was studied. In addition, factors including rainfall, migration, and human activities were reviewed to speculate on the possible use of lockdown as a pollution management strategy.

Materials and methods

1) Study area

The Ganga River has been declared the national river of India in 2008 since it is the longest river (2,525 km) in India and it has been regarded as one of the holiest, sacred and cultural rivers of the world. As per the Ganga Basin Report, 2014 (version 2.0) Central Water Commission, Ministry of Water Resources and National Remote Sensing Centre, ISRO, Department of Space, Govt. of India, it originates as Bhagirathi from the Gangotri Glaciers in the Himalayas at an elevation of ~7,010 m in Uttarakhand and flows east through the Gangetic Plains of Northern India including Uttarakhand, Uttar Pradesh, Bihar, Jharkhand and West Bengal State of India [38]. The river extant in Uttarakhand has some of the most culturally significant places such as Rishikesh and Haridwar where a large number of people take holy dips into the Ganga. The study area chosen for the current study is prone to soil erosion since it has mainly silty loams and brown soil with steep slopes in undulating terrain [38]. May month is the hottest month in most of the study areas. A total of 11 river water sampling stations were chosen for the current study (Figure 1). The study area receives wide pollutants from developmental and tourist activities including untreated sewage discharge, partially treated industrial effluent, and wastewater from commercial complexes [39–41]. At the same time, point sources of pollutants in the study area have not been well defined [42].

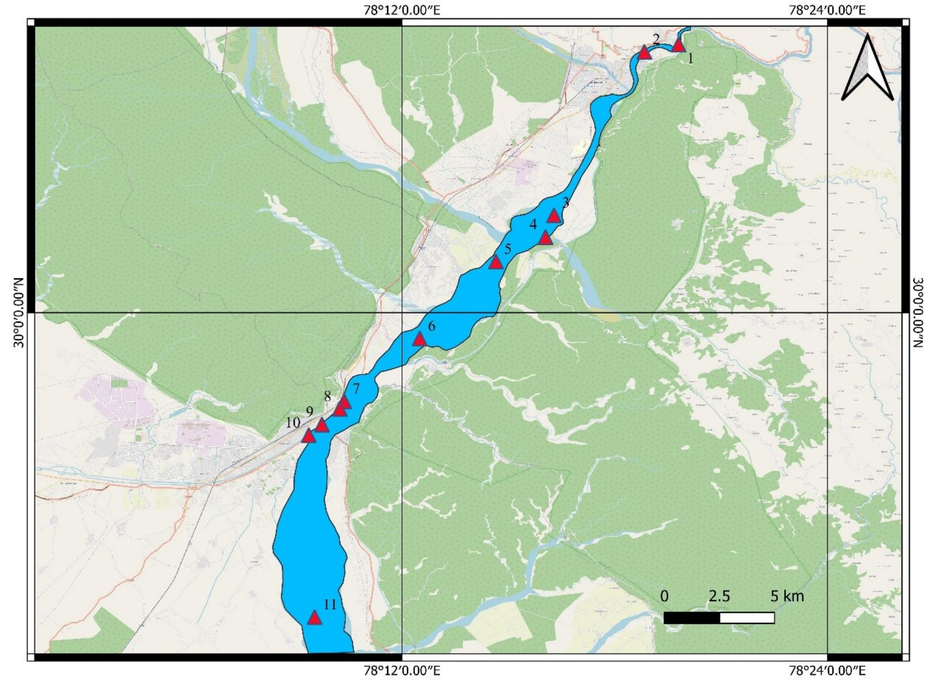

Figure 1 Spatial variation map of water sampling stations of upper Ganga Canals of river Ganga in the study area.

2) River water quality index

RWQI was calculated using multivariate analysis methods using BIS standards of drinking water [43] and standards of class A water intended for drinking purposes after disinfection without conventional treatment as per CPCB [44] by assigning a weightage (W_i) of each selected parameter according to its relative environmental significance and impact on human health (Table 1). Physical-chemical and biological parameters of Ganga's water and its associated upper canal reported by the Uttarakhand Pollution Control Board (UKPCB) were used to describe the impact of the lockdown phases and unlock phases implemented in India. Standards of BOD, DO, and total coliforms of class A water intended for drinking purposes after disinfection without conventional treatment defined by the CPCB, MoEF&CC, Government of India [44] has been considered to compute RWQI.

A maximum of 5 weightage was assigned to the DO due to their high concern in water quality assessment and its environmental significance. Calcium, magnesium, and alkalinity were given 2 weightage as it has a lesser concern in the water quality assessment due to their high positive impact on human health. Chloride, total hardness, BOD, and total coliform were assigned a weightage of 3 based on their environmental significance on water quality. However, pH and TDS were assigned 4 weightages since it plays a vital role in biological activities under natural conditions which are considered to be a key factor to estimate the self-cleaning potential of the river (Table 1). RWQI were computed using the following Eq. 1.

$$RWQI = \sum SI_i \quad \text{(Eq. 1)}$$

In Eq. 1, SI_i is the sub-index of ith parameters. Sub-index of each parameter was computed using the following Eq. 2.

$$SI_i = W_r \times \frac{C_i}{S_i} \times 100 \quad \text{(Eq. 2)}$$

In Eq. 2, SI_i is the sub-index of ith parameters, W_r is the relative weight of respective parameters, C_i is the concentration of ith parameters and S_i is the standards of ith parameters according to BIS 10500 2012 [43] and standards of class A water intended for drinking purpose after disinfection without conventional treatment as per CPCB [44].

To calculate the $SI_{i\ pH,\ DO}$ for the pH and DO, the following Eq. 3 was employed.

$$SI_{i\ pH,DO} = W_r \times \frac{(C_i - V_i)}{(S_i - V_i)} \times 100 \quad \text{(Eq. 3)}$$

In Eq. 3, Vi is the ideal value of pH and DO. The ideal value of 7 and 14.6, respectively for pH and DO were deducted from the measured values in the samples [45]. The relative weight (W_r) is computed from the following Eq. 4.

$$Wr = \left[\frac{Wi}{\sum_{i-1}^{n} Wi}\right] \times 0.95 \quad \text{(Eq. 4)}$$

In Eq. 4, W_r is the calculated relative weightage, W_i is the weightage of each parameter and n is the number of parameters.

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As per the literature [46–49], the categorization of RWQI rating values were classified into five groups namely “excellent” (<50), “good” (50–100), “poor” (100 –200), “very poor” (200–300), “unfit for drinking” (>300).

3) Spatial variation of RWQI

The values of RWQI were interpolated for the rest of the study areas with the inverse distance weightage (IDW) method by using QGIS 3.14 for its spatial variation in 2019, 2020, and 2021. IDW interpolation method generated predicted values of RWQI at each point calculated on the basis of weighted average of the closest sampling points. The weights are calculated through the inverse of the distance from sampling stations to the location of the point of projection. The IDW interpolated RWQI were finally used to generate ranked river water quality maps of every months starting from January 2019 to December 2021 to understand the impact of COVID-19 pandemic.

Results and discussion

1) RWQI of Ganga’s water

A statistical overview of selected water quality indicators showed a significant statistical difference in water quality variables in the years 2019, 2020, and 2021 (Figure 2). This is possibly due to the restrictions imposed during the period of the COVID-19 pandemic. It can be noted that more outliers and extremes are towards the upper whisker for all the indicators except pH (Figure 2). This clearly indicates that the water quality indicators are right-skewed and do not follow a normal distribution pattern. It can be further noted that the pattern of box plots are variables including median values, length of the box, and distribution density over assessment years for all the water quality indicators except COD (Figure 2c). In addition, a standard for COD has not been included in BIS for drinking water as well as in CPCB guidelines for class A water. Therefore, it has been omitted from the RWQI calculation in the present study.

The monthly RWQI of 2019, 2020, and 2021 comparison of the upper canal of Ganga facilitated the computation of the potential impact of nationwide lockdown and associated reduction in anthropogenic pressure on river water. The maximum change in average RWQI (15 units) has been observed in May and June months (Figure 3). More than 80% of the sampling stations showed a maximum reduction in June month of 2020. However, the rest of the sampling stations showed a maximum reduction in May month of 2020. The results of RWQI revealed that the lockdowns have enhanced the overall water quality in most of the study areas. Each of the sampling stations has improved RWQI ranging from 3 to 45 between March to June 2020. Except at the sampling station located after the confluence of river Song near Satyanarayan temple, Raiwala, Dehradun has started deteriorating since June 2020, it showed a negative change in RWQI. The River Ganga at Haridwar (sampling stations 3 to 5) showed a two-fold improvement in the water quality index making it the highest positive impact of the lockdown, and at Rishikesh, the water quality index showed the least changes. The current finding of improved water quality is consistent with the literature [50]. Improved water quality of the river has shown a significant positive impact on aquatic animals and many animals have returned to their natural habitat [50]. However, unlock phases (post lockdown) have deteriorated water quality since August 2020 and reached to actual conditions of the river by August 2021. In October 2021, RWQI has been observed to be higher as compared to the years 2019 and 2020. This is possibly due to a shift in rainfall patterns and other factors involved in river water quality control. These results are in contrast to the literature where strategic lockdowns have been suggested as an option for sustainable environmental management [50].

Table 1 List of water parameters considered to compute RWQI, their Indian standards of drinking water (BIS 10500: 2012), or class A water intended for drinking purposes after disinfection (CPCB) along with assigned weightage and relative weightage

Water parameters	Indian standards (BIS 10500 2012) or Class ‘A’ standards	Weightage (W_i)	Relative weightage (W_r)
pH	6.5-8.5(8.5)	4	0.123
DO (mg L^{-1})	6 (Class A)	5	0.153
BOD (mg L^{-1})	2 (Class A)	3	0.092
Total coliform (MPN/100 mL)	50 (Class A)	3	0.092
Calcium as Ca (mg L^{-1})	75	2	0.061
Hardness as $CaCO_3$ (mg L^{-1})	200	3	0.092
Magnesium as Mg (mg L^{-1})	30	2	0.061
Chlorides (mg L^{-1})	250	3	0.092
Alkalinity as $CaCO_3$ (mg L^{-1})	200	2	0.061
Total dissolved solids (mg L^{-1})	500	4	0.123

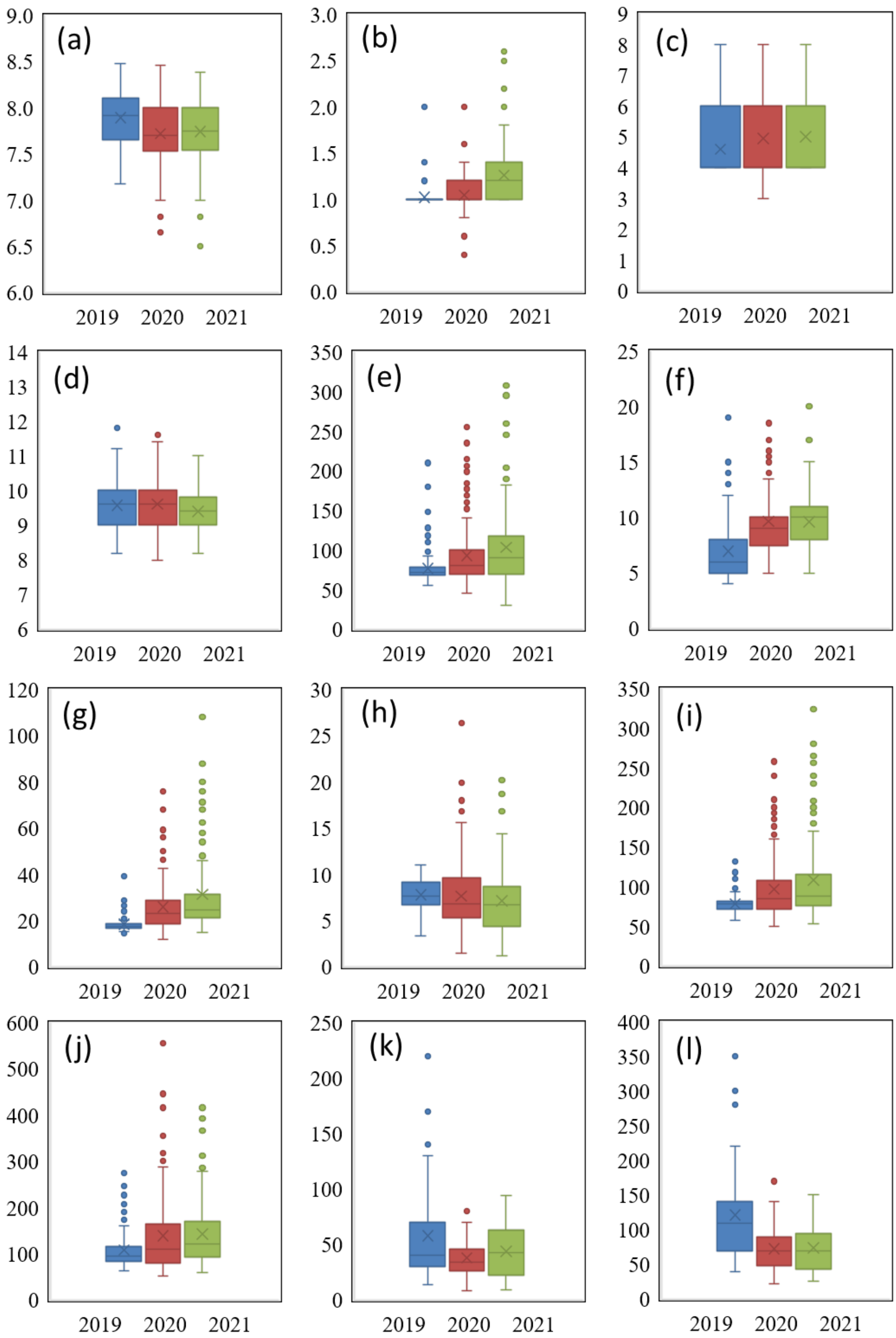

Figure 2 Whisker plot analysis of water quality indicators (a) pH, (b) BOD, (c) COD, (d) DO, (e) alkalinity, (f) chloride, (g) calcium, (h) magnesium, (i) hardness, (j) TDS, (k) fecal coliforms, and (l) total coliforms, showing outlier attributes of the upper canal of the Ganga River in the years 2019, 2020, and 2021.

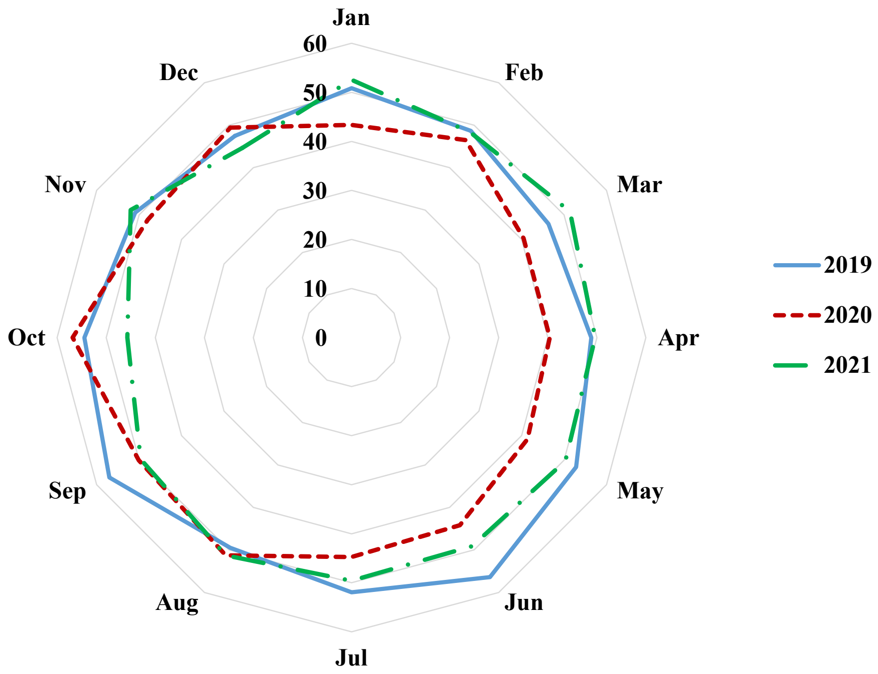

Figure 3 Annual variation of average RWQI of the upper canal of the Ganga River from January 2019 to December 2021.

2) Spatial variation of RWQI

The spatial variation of RWQI over the last three years (2019-2021) showed a significant distinction (Figure 4). RWQI of 60 to 90% of the study area was observed to be under 50 in the year 2020 except in October 2020. It can be noted that in October 2020, only 8.3% of rainfall was received as compared to normal rainfall in the above Ramganga Confluence sub-basin of the Ganga basin (Figure 5). However, pre-lockdown and unlock years were observed to be less than 50% of the study area with <50 RWQI.

The Ganga River at Haridwar (sampling station 3 to 5) were found to be the highest RWQI in all the monitored years. The gradual increase in RWQI has been observed as the river passes through the urban area of Haridwar (up to sampling station 5) followed by decreasing trend. This is possibly due to the highest number of pilgrims activities in Haridwar as compared to all other study areas. The decrease in RWQI is possibly due to the physical-chemical and biological remediation of pollutants in the river ecosystem. These results indicated the potential of the Ganga River in pollution load handling and self-cleaning properties. Further increase in RWQI is possibly due to further discharge of untreated sewage and solid waste disposal in unmanageable quantities.

Based on the above analyses, it can be predicted that the maximum discharge and disposal of solid waste is carried out between sampling stations S3 to S5 and S8 to S10. The reduction of RWQI in downstream of Haridwar might be possible due to high vegetation on the bank of the river which provides suitable conditions for remediation of several pollutants. The processes such as Phytodegradation, phytosequestration, rhizodegradation, phytohydraulics, phytoextraction, and phytovolatilization play a vital role in the remediation of pollutants on the bank of rivers due to high vegetation in rural areas [51]. These results are consistent with literature that suggest the river is a plug-flow bioreactor with high self-purification potential [52].

3) Impact of lockdown and unlock phases on environmental contamination

A significant change in total coliforms and fecal coliforms in the entire monitoring area has been observed throughout the years 2020 and 2021 as compared to the year 2019 (Figure 6). Total coliforms and fecal coliforms are key biological indicators of total environmental contamination and fecal contamination, respectively in water resources [53]. The highest values of total coliforms were reported in May and June 2019 in the last three years (Figure 6a). However, the lowest values of total coliforms were reported from April to June 2020 (lockdown phase). The average total coliform has decreased by more than 39% in the year 2020 as compared to the year 2019. However, it has increased in the year 2021 by 20% as compared to the year 2020 till June and followed by a 19% decrease till December 2021. This is possibly due to the restrictions imposed during the third wave of COVID-19. A similar trend has been reported in the case of fecal coliform, suggesting a decrease in fecal contamination during the lockdown and a further increase during the unlocking phases. The highest values of fecal coliform have been reported in June 2019. The average coliform has decreased by more than 59% in June 2020 as compared to June 2019 followed by an increase in the year 2021 during unlocking phases up to 75% as compared to the year 2020 (Figure 6b). The reduction percentage of total coliforms and fecal coliforms has declined since June 2020 and reached 4% and -3%, respectively in December 2020 as compared to December 2019.

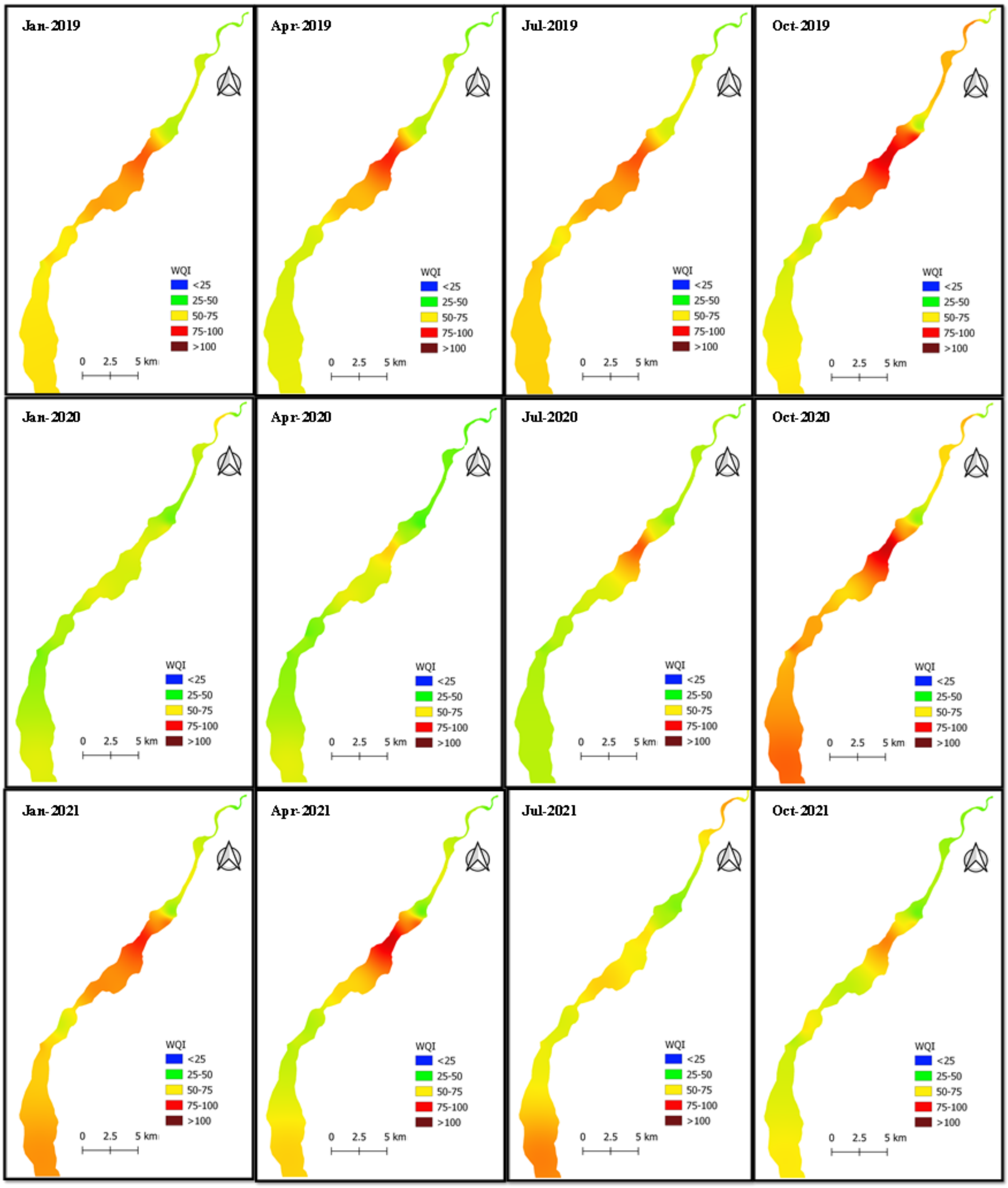

Figure 4 Spatial variation map of RWQI of upper Ganga Canal from January 2019 to December 2021 at three months of interval.

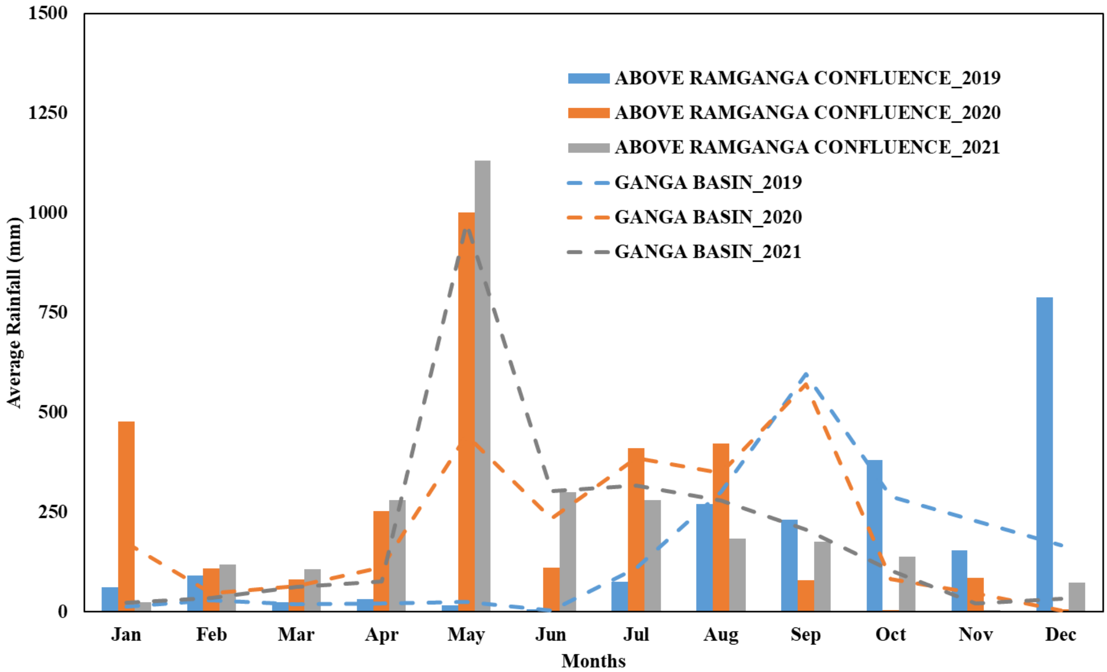

Figure 5 The average monthly rainfall of above Ramganga Confluence sub-basin of Ganga Basin along with average monthly rainfall of Ganga basis from January 2019 to December 2021 as per India Water Resources Information System (India-WRIS).

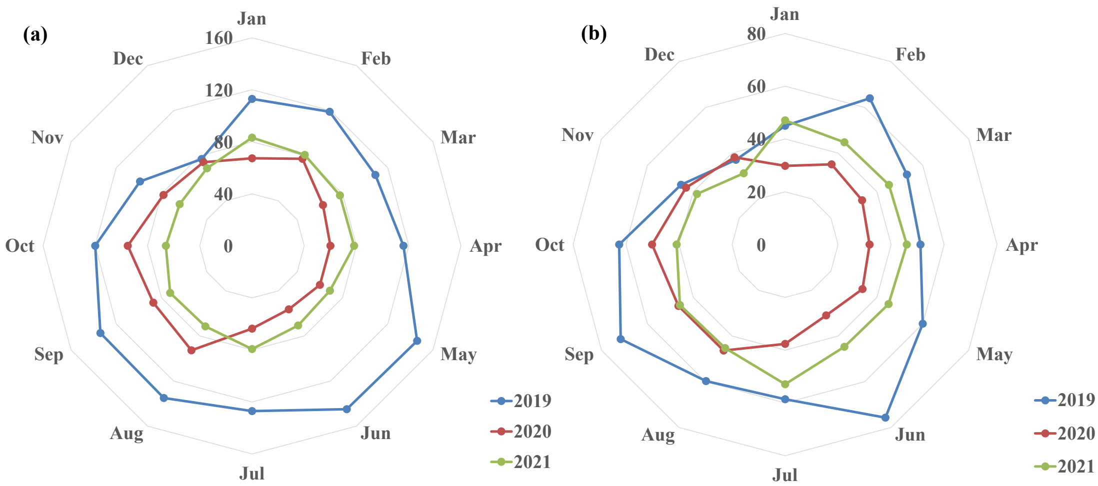

Figure 6 Monthly change in (a) total coliforms (an indicator of environmental contamination) and (b) fecal coliforms (an indicator of fecal contamination) in the years 2019, 2020, and 2021.

The maximum reduction of these indicators has been noted in the year 2020 (lockdown phases) as compared to 2019 followed by an increase in 2021 (unlock phases), although discharge from domestic sewerage has not reduced during these days. This is possibly due to the contribution of pollutants from other sources than domestic discharge such as industrial effluent, transport, and people dips. These observations indicated an impact of lockdown and unlock phases due to a shift in human behavior towards the use and disposal of waste resulting in sustainable and cleaner development even after the lifting of the lockdown.

In addition to anthropogenic factors, natural processes such as changes in precipitation, erosion, and weathering of the earth's crust play a vital role in river water quality and quantity [54]. The rainfall pattern has significantly changed in the last three years in the above Ramganga Confluence sub-basin of Ganga Basin (Figure 5). It can be noted that maximum rainfall has been observed in May 2021 followed by May 2020. However, lesser environmental contaminants and fecal contaminations were reported in June 2020. These observations suggested the involvement of natural processes in river water quality in addition to anthropogenic impact. Similar findings were reported in case of air pollutants using AQI approach from pandemic hotspots including China, Japan, the Republic of Korea, and India [55].

4) Impact of lockdown and post-lockdown phases on Ganga's water

The water quality of the Ganga River has deteriorated in the last few decades due to more urban exposure, industrial effluent discharge, and change in land use land cover [14, 56]. A significant change in the water quality of river Ganga under lockdown and post-lockdown is imaginable since more than 80% of total pollutants are due to domestic sewage discharge and the rest are contributed by industrial activities [57]. The water quality of the Ganga river is expressively dependent on anthropogenic activities in addition to geomorphological functions since more than 97 towns, 29 cities, and many villages are located on the bank of the river [18]. Similar observations have been reported from China, Turkey, and India where river water quality has improved in lockdowns and returned to the actual conditions after the lifting of lockdowns [58–60].

The water quality of a river ecosystem is often directly linked with human health, ecological health, and biodiversity of flora and fauna. About 30% of total environmental pollutants including river pollutants are directly exposed to human beings [61–62]. Several natural and anthropogenic activities such as urbanization, industrialization, hydropower projects, untreated wastewater discharge, rainfall, surface runoff, lack of awareness, and seasonal variations are concomitant with river water quality [63–65]. Residential mobility also plays a vital role in the water quality of rivers. During the first lockdown, residential mobility increased by more than 31% in India because of the temporary movement of people towards their permanent residences [66]. In addition, the quality of water also depends on its origin and change in climate [67,68]. For the last 100 years, river ecosystems are one of the most exploited and vulnerable environmental compartments of the aquatic biomes [67, 69–70]. The decline in biodiversity is one of the major threats to the hydrological and biological sustainability of aquatic biomes. This is true for the Ganga River which flows through multiple urban areas in the central part of India with high self-cleaning potential. Similar to other rivers, it plays a significant role in assimilating or carrying off municipal and industrial effluent, runoff from agricultural fields, manure discharges, roadways, and street pollutants [71]. The flow rate of rivers is dependent on many factors including pumped inflow and outflow, precipitation, surface runoff, and groundwater recharge [72]. The amount of pollutants in the river is highly dynamic and varies seasonally with flow rates.

On another hand, the river act as a natural plug flow bioreactor for the remediation of various pollutant discharged into it [73]. Biological activities play a major role in the degradation, transformation into non-toxic, and transport of pollutants in the natural ecosystem [61,74–77]. In addition to biological activities, physical-chemical processes can play a vital role in the environmental fate of pollutants in river ecosystems [78]. However, the extent of remediation depends on various factors and limits the self-purification process. At the same time, not all man-made pollutants are degradable under natural decomposition in river ecosystems such as plastics. The self-cleaning properties of the river are a function of time. Therefore, if the rate of introduction of pollutants into the river is faster than the rate of its natural decomposition, the pollutants get piled up and the result is detrimental. As per the observed results, it is evident that the water quality of the Ganga River is the cumulative result of natural processes and human interference with the river ecosystem.

Conclusion

The ranked river water quality maps generated of the study area has provided excellent tools to understand dynamics of river water quality of upper Ganga Canal. Based on the investigation, a substantial improvement in the Ganga water during lockdown phases imposed in India has been observed. However, post-lockdown phases have deteriorated the water quality and reached similar conditions as pre-lockdown years. The observation of results were not only due to changes in the mobility of people but also due to changes in the rainfall pattern. Most of the variation in the water quality of the Ganga River was due to natural phenomena and human interference in the river ecosystems. Based on the current investigation, the use of lockdown as a remedial measure for pollution handling is not effective since after lockdown the conditions are resumed to their original. Further assessment to find-out point pollution inventory of the study area could facilitate the river management strategies to maintain the water quality of the Ganga.

Declaration of competing interest

The authors declared that they have no conflicts of interest in this work.

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References

[1] He, G., Pan, Y., Tanaka, T., The short-term impacts of COVID-19 lockdown on urban air pollution in China. Nature Sustainability, 2020, 3, 1005–1011.

[2] Nanda, D., Mishra, D.R., Swain, D., COVID-19 lockdowns induced land surface temperature variability in mega urban agglomerations in India. Environmental Science: Processes & Impacts, 2021, 144–159.

[3] Rume, T., Islam, S.M.D.U., Environmental effects of COVID-19 pandemic and potential strategies of sustainability. Heliyon, 2020, 6, e04965.

[4] Nigam, R., Pandya, K., Luis, A.J., Sengupta, R., Kotha, M., Positive effects of COVID-19 lockdown on air quality of industrial cities (Ankleshwar and Vapi) of Western India. Scientific Reports, 2021, 11, 1–12.

[5] Chakraborty, B., Bera, B., Adhikary, P.P., Bhattacharjee, S., Roy, S., Saha, S., ..., Shit, P.K. Positive effects of COVID-19 lockdown on river water quality: evidence from River Damodar, India. Scientific Reports 2021, 11, 1–16.

[6] Braga, F., Ciani, D., Colella, S., Organelli, Pitarch, J., Brando, V.E., ..., Falcini, F. COVID-19 lockdown effects on a coastal marine environment: Disentangling perception versus reality. Science of the Total Environment 2022, 817, 153002.

[7] Lv, Y., Tian, H., Luo, L., Liu, S., Bai, Z., Zhao, H., ..., Yang, J. Understanding and revealing the intrinsic impacts of the COVID-19 lockdown on air quality and public health in North China using machine learning. Science of the Total Environment 2023, 857, 159339.

[8] Zhang, X., Maggioni, V., Houser, P., Xue, Y., Mei, Y., The impact of weather condition and social activity on COVID-19 transmission in the United States. Journal of Environmental Management 2022, 302, 114085.

[9] Zhang, W., Li, S., Gao, Y., Liu, W., Jiao, Y., Zeng, C., ..., Wang, T. Travel changes and equitable access to urban parks in the post COVID-19 pandemic period: Evidence from Wuhan, China. Journal of Environmental Management 2022, 304, 114217.

[10] Jia, X., Shahzad, K., Kleme , J.J., Jia, X., Changes in water use and wastewater generation influenced by the COVID-19 pandemic: A case study of China. Journal of Environmental Management, 2022, 314, 115024.

[11] Martey, E., Etwire, P.M., Adzawla, W., Atakora, W., Bindraban, P.S., Perceptions of COVID-19 shocks and adoption of sustainable agricultural practices in Ghana. Journal of Environmental Management, 2022, 320, 115810.

[12] Stutz, B., Buyken, A.E., Schadow, A.M., Jankovic, N., Alexy, U., Krueger, B. Associations of chronotype and social jetlag with eating jetlag and their changes among German students during the first COVID-19 lockdown. The Chronotype and Nutrition study. Appetite, 2023, 180, 106333.

[13] Yunus, A.P., Masago, Y., Hijioka, Y., COVID-19 and surface water quality: Improved lake water quality during the lockdown. Science of the Total Environment, 2020, 731, 139012.

[14] Arora, S., Bhaukhandi, K.D., Mishra, P.K., Coronavirus lockdown helped the environment to bounce back. Science of the Total Environment, 2020, 742, 140573.

[15] Pandey, M., George, M.P., Gupta, R.K., Gusain, D., Dwivedi, A., Impact of COVID-19 induced lockdown and unlock down phases on the ambient air quality of Delhi, capital city of India. Urban climate, 2021, 39, 100945.

[16] Mahato, S., Pal, S., Revisiting air quality during lockdown persuaded by second surge of COVID-19 of megacity Delhi, India. Urban Climate, 2022, 41, 101082.

[17] Jain, T., Currie, G., Aston, L., COVID and working from home: Long-term impacts and psycho-social determinants. Transportation Research Part A: Policy and Practice, 2022, 156, 52–68.

[18] Dutta, V., Dubey, D., Kumar, S., Cleaning the River Ganga: Impact of lockdown on water quality and future implications on river rejuvenation strategies. Science of the Total Environment, 2020, 743, 140756.

[19] Liang, M., Zhang, Y., Ma, Q., Yu, D., Chen, X., Cohen, J.B. Dramatic decline of observed atmospheric CO_2 and CH_4 during the COVID-19 lockdown over the Yangtze River Delta of China. Journal of Environmental Sciences, 2023, 124, 712–722.

[20] Xu, H., Chen, L., Chen, J., Bao, Z., Wang, C., Gao, X., Cen, K. Unexpected rise of atmospheric secondary aerosols from biomass burning during the COVID-19 lockdown period in

Hangzhou, China. Atmospheric Environment, 2022, 278, 119076.
[21] Kulkarni, B.N., Anantharama, V., Repercussions of COVID-19 pandemic on municipal solid waste management: Challenges and opportunities. Science of the Total Environment, 2020, 743, 140693.
[22] Ghosh, M.K., Ghosh, S., Tiwari, R., A Study of Water quality index assessment of ground water and pond water in Sirsakala Village of Bhilai-3, Chhattisgarh, India. International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development, 2013, 3, 63–74.
[23] Yisa, J., Jimoh, T.O., Oyibo, O.M., Underground water assessment using water quality index. Leonardo Journal of Science, 2012, 33–42.
[24] Saeedi, M., Abessi, O., Sharifi, F., Meraji, H., Development of groundwater quality index. Environmental Monitoring and Assessment, 2010, 163, 327–335.
[25] Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Rajiv Ganthi, R., Chidambaram, S., Anandhan, P., ..., Vasudevan, S. Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. Environmental Monitoring and Assessment, 2010, 171, 595–609.
[26] Kaur, B.J., George, M.P., Mishra, S., Groundwater quality and water quality index of Delhi City, India, 2014, 32, 865–871.
[27] Singh, S., Hussian, A., Water quality index development for groundwater quality assessment of greater Noida sub-basin, Uttar Pradesh, India. Cogent Engineering, 2016, 3, 1–17.
[28] Khosravi, R., Eslami, H., Almodaresi, S.A., Heidari, M., Fallahzadeh, R.A., Taghavi, M. ..., Minaee, R.P. Use of geographic information system and water quality index to assess groundwater quality for drinking purpose in Birjand City, Iran. Desalination and Water Treatment, 2017, 67, 20458.
[29] Banerjee, T., Srivastava, R.K., Application of water quality index for assessment of surface water quality surrounding integrated industrial estate-Pantnagar. Water Science and Technology, 2009, 60, 2041–2053.
[30] Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I., A comprehensive method for improvement of water quality index (WQI) models for coastal water quality assessment. Water Research, 2022, 219.
[31] Uddin, M.G., Nash, S., Mahammad Diganta, M.T., Rahman, A., Olbert, A.I., Robust machine learning algorithms for predicting coastal water quality index. Journal of Environmental Management, 2022, 321, 115923.
[32] Uddin, M.G., Nash, S., Olbert, A.I., A review of water quality index models and their use for assessing surface water quality. Ecological Indicators, 2021, 122, 107218.
[33] Parween, S., Siddique, N.A., Mahammad Diganta, M.T., Olbert, A.I., Uddin, M.G., Assessment of urban river water quality using modified NSF water quality index model at Siliguri city, West Bengal, India. Environmental and Sustainability Indicators, 2022, 16, 100202.
[34] Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I., A novel approach for estimating and predicting uncertainty in water quality index model using machine learning approaches. Water Research, 2023, 229, 119422.
[35] Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I., A sophisticated model for rating water quality. Science of the Total Environment, 2023, 868, 161614.
[36] Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I., Performance analysis of the water quality index model for predicting water state using machine learning techniques. Process Safety and Environmental Protection, 2023, 169, 808–828.
[37] Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I., Assessing optimization techniques for improving water quality model. Journal of Cleaner Production, 2023, 385, 135671.
[38] India-WRIS WebGIS, Ganga Basin report, Central Water Commission, Ministry of Water Resources and National Remote Sensing Centre, ISRO, Department of Space, Govt. of India, 2014.
[39] Matta, G., Kumar, A., Nayak, A., Kumar, P., Appraisal of spatial–temporal variation and pollution source estimation of Ganga River system through pollution indices and environmetrics in Upper Ganga basin. Applied Water Science, 2022, 12, 1–11.
[40] Kumar, A., Taxak, A.K., Mishra, S., Pandey, R., Long term trend analysis and suitability of water quality of River Ganga at Himalayan hills of Uttarakhand, India. Environmental Technology & Innovation, 2021, 22, 101405.
[41] Sharma, M., Kansal, A., Jain, S., Sharma, P., Application of multivariate statistical techniques in determining the spatial temporal water quality

variation of Ganga and Yamuna rivers present in Uttarakhand state, India. Exposure and Health, 2015, 7, 567–581.

[42] Kumar, A., Matta, G., Bhatnagar, S., A coherent approach of water quality indices and multivariate statistical models to estimate the water quality and pollution source apportionment of River Ganga system in Himalayan region, Uttarakhand, India. Environmental Science and Pollution Research, 2021, 28, 42837–42852.

[43] BIS, Indian standard drinking water specification (second revision). Bureau of Indian Standards, 2012, IS 10500, 1–11.

[44] Central Pollution Control Board, Water Quality Criteria, Central Pollution Control Board (CPCB), Ministry of Environment, Forest and Climate Change (MoEF), Goverment of India. Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Goverment of India 2021.

[45] Hameed, A., Alobaidy, M.J., Abid, H.S., Maulood, B.K., Application of water quality index for assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq, 2010, 2010, 792–798.

[46] Chakraborty, B., Roy, S., Bera, A., Adhikary, P.P., Bera, B., Sengupta, D., ..., Shit, P.K. Eco-restoration of river water quality during COVID-19 lockdown in the industrial belt of eastern India. Environmental Science and Pollution Research, 2021, 28, 25514–25528.

[47] Singh, P.K., Panigrahy, B.P., Verma, P., Kumar, B., *In*: Singh VP, Yadav S, Yadava RN (Eds.), Springer Singapore, Singapore 2018, 429–437.

[48] Vasistha, P., Ganguly, R., Assessment of spatio-temporal variations in lake water body using indexing method. Environmental Science and Pollution Research, 2020, 27, 41856–41875.

[49] Barodawala, S., Parmar, P., Prasad, B., Ground water quality index of growing smart city of vadodara. International Journal of Environmental Sciences & Natural Resources, 2018, 9, 57–62.

[50] Khan, I., Shah, D., Shah, S.S., COVID-19 pandemic and its positive impacts on environment: An updated review. International Journal of Environmental Science and Technology, 2021, 18, 521–530.

[51] Lone, M.I., He, Z., Stoffella, P.J., Yang, X., Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives. Journal of Zhejiang University. Science. B, 2008, 9, 210 – 220.

[52] Vicente, J., Colmenarejo, M.F., Sanchez, E., Rubio, A., Garcнa, M.G., ..., Jimenez, A.M. Evaluation of the water quality in the Guadarrama river at the section of Las Rozas-Madrid, Spain. Water and Environment Journal 2011, 25, 55–66.

[53] Brandt, M.J., Johnson, K.M., Elphinston, A.J., Ratnayaka, D.D., *In*: Brandt MJ, Johnson KM, Elphinston AJ, Ratnayaka DDBT-TWS (Seventh Eds.), Butterworth-Heinemann, Boston 2017, 235–321.

[54] Hamid, A., Bhat, S.U., Jehangir, A., Local determinants influencing stream water quality. Applied Water Science 2019, 10, 24.

[55] Hu, M., Chen, Z., Cui, H., Wang, T., Zhang, C., Yun, K. Air pollution and critical air pollutant assessment during and after COVID-19 lockdowns: Evidence from pandemic hotspots in China, the Republic of Korea, Japan, and India. Atmospheric pollution research, 2021, 12, 316–329.

[56] Srinivas, R., Singh, A.P., Shankar, D., Understanding the threats and challenges concerning Ganges River basin for effective policy recommendations towards sustainable development. Environment, Development and Sustainability, 2020, 22, 3655–3690.

[57] Ghildyal, D., Singh, K.P, Singh, P., Verma, R. Healing of rivers during coronavirus lockdown in India: A statistical approach. International Journal of Lakes and Rivers, 2020, 13, 105–119.

[58] Liu, D., Yang, H., Thompson, J.R., Li, J., Loiselle, S., Duan, H. COVID-19 lockdown improved river water quality in China. Science of the Total Environment, 2022, 802, 149585.

[59] Tokatl , C., Varol, M., Impact of the COVID-19 lockdown period on surface water quality in the Meriз-Ergene River Basin, Northwest Turkey. Environmental Research, 2021, 197, 111051.

[60] Khan, R., Saxena, A., Shukla, S., Sekar, S., Goel, P., Effect of COVID-19 lockdown on the water quality index of River Gomti, India, with potential hazard of faecal-oral transmission. Environmental Science and Pollution Research, 2021, 28, 33021–33029.

[61] Prasad, B., Phthalate pollution: Environmental fate and cumulative human exposure index using the multivariate analysis approach. Environmental Science: Processes and Impacts, 2021, 23, 389–399.

[62] Prasad, B., Prasad, K.S., Dave, H., Das, A., Asodariya, G., Talati, N., ..., Kapse, S. Cumulative human exposure and environmental

occurrence of phthalate esters: A global perspective. Environmental Research 2022, 210, 112987.

[63] Trivedi, R.C., Water quality of the Ganga River – An overview. Aquatic Ecosystem Health & Management, 2010, 13, 347–351.

[64] Chadetrik, R., Arun, L., Prakash, D.R., Assessment of Physico-chemical Parameters of River Yamuna at Agra Region of Uttar Pradesh, India. International Research Journal of Environment Sciences, 2015, 4, 25–32.

[65] Anderson, D., Moggridge, H., Warren, P., Shucksmith, J., The impacts of “run-of-river” hydropower on the physical and ecological condition of rivers. Water and Environment Journal, 2015, 29, 268–276.

[66] Saha, J., Chouhan, P., Lockdown and unlock for the COVID-19 pandemic and associated residential mobility in India. International Journal of Infectious Diseases, 2021, 104, 382–389.

[67] Gregory, K., The human role in changing river channels. Geomorphology, 2006, 79, 172–191.

[68] Arnell, N.W., Halliday, S.J., Battarbee, R.W., Skeffington, R.A., Wade, A.J., The implications of climate change for the water environment in England. Progress in Physical Geography, 2015, 39, 93–120.

[69] Bunn, S.E., Davies, P.M., Biological processes in running waters and their implications for the assessment of ecological integrity. Hydrobiologia, 2000, 422, 61–70.

[70] Aneta Spyra, Justyna Kubicka, M.S., The use of biological indices for the assessment of the river quality (Ruda River, Poland). Ecological Chemistry and Engineering, 2017, 24, 285–298.

[71] Mukherjee, D., Chattopadhyay, M., Lahiri, S.C., Water quality of the River Ganga (The Ganges) and some of its physico-chemical properties. Environmentalist, 1993, 13, 199–210.

[72] Vega, M., Pardo, R., Barrado, E., Deban, L. Assessment of Seasonal and Polluting Effects on the Quality of River Water by Exploratory. Water Research, 1998, 32, 3581–3592.

[73] Silva, D.C.V.R., Queiroz, L.G., Marassi, R.J., Araъjo, C.V.M., Bazzan, T., Cardoso-Silva, S., ..., Pompeo, M.L.M. Predicting zebrafish spatial avoidance triggered by discharges of dairy wastewater: An experimental approach based on self-purification in a model river. Environmental Pollution, 2020, 266, 115325.

[74] Prasad, B., Suresh, S., Biodegradation of Phthalate Esters by Variovorax sp. APCBEE Procedia, 2012, 1, 16–21.

[75] Prasad, B., Suresh, S., Biodegradation of dimethyl phthalate ester using free cells, entrapped cells of Variovorax sp. BS1 and cell free enzyme extracts: A comparative study. International Biodeterioration & Biodegradation, 2015, 97, 179–187.

[76] Prasad, B., Suresh, S., Biodegradation of dimethyl phthalate, diethyl phthalate, dibutyl phthalate and their mixture by Variovorax Sp. International Journal of Environmental Science and Development, 2012, 3, 283–288.

[77] Prasad, B., Biodegradation of ortho-dimethyl phthalate by a binary culture of Variovorax sp. BS1 and Achromobacter denitrificans. International Journal of Environmental Science and Technology, 2017, 14, 2575–2582.

[78] Anawar, H.M., Chowdhury, R., Remediation of polluted river water by biological, chemical, ecological and engineering processes. Sustainability (Switzerland), 2020, 12.