

# Effect of Seasonal Variations and Impact Assessment of COVID-19 Lockdown on Water Quality Status of Hindon River, Ghaziabad

N. Verma<sup>a</sup>, A. Kumar<sup>a</sup>, and N. Singh<sup>a,\*</sup>

<sup>a</sup> *Department of Biotechnology, Mewar Institute of Management, Vasundhara, Ghaziabad, UP 201012 India*

*\*e-mail: neetu.avni@gmail.com*

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**Abstract**—Coronavirus disease 2019 (COVID-19) ascertained as a global pandemic that hit most countries during the first quarter (FQ) of 2020, and lockdown (LKD) has been enforced at different levels to cope with the situation, and most of the industrial and commercial activities were halted during this period. Hence, the present study has been introduced to assess the impact of the COVID-19 LKD coupled with seasonal variations (SVs) on the water quality status of the Hindon River (HR), Ghaziabad (GZB). The report includes secondary data analysis of different water quality parameters (WQPs), viz., dissolved oxygen (DO), biochemical oxygen demand (BOD), fecal coliform (FC), and total coliform (TC). BOD and DO are the preliminary indicators of organic load, and analysis of FC and TC determines the overall pathogen load in water bodies. The effect of seasonal variations, i.e., pre-monsoon (PRM), monsoon (MS), and post-monsoon (POM) at sampling locations designated by the monitoring body at HR (GZB stretch), viz., Mohan Nagar road bridge (MNRB), Karheda village (KV), and Chijarsi bridge (CB) was investigated for 2019 to 2021. DO level was comparatively higher during 2020 at sampling stations (SLSs) MNRB and KV. BOD reductions were ~17–40% during the LKD phase at SLSs KV and CB compared to PRD and PLD. The SVs significantly influence the DO and BOD at all the SLSs. The water samples during the PRM of 2020 showed lower BOD levels compared to 2019 and 2021 at all the SLSs. FC/TC ratio was highest at the LKD phase at all the SLSs. The coliform load was greater at SLS CB than at MNRB and KV. A strong positive correlation was obtained between TC-BOD and FC-BOD at the LKD phase during all the SVs. Based on the WQPs analysis, CB was found to be the most contaminated sampling location. Despite higher coliform loads, the LKD phase experienced overall improvements in DO and BOD levels.

**Keywords:** COVID-19, lockdown, Hindon River, physicochemical indices, and coliform

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## INTRODUCTION

Among the Human coronaviruses, SARS-CoV-2 is the seventh on the list [5] after MERS-CoV, HCoV HKU1, HCoV NL63, SARS-CoV, OC43, and 229E [16]. COVID-19 is caused by severe acute respiratory syndrome coronavirus 2 (SARS CoV-2) affecting over 220 countries and territories around the world [28]. The first case of this global pandemic was reported in Wuhan (China) in late December 2019 [54]. Currently, the worldwide cases of COVID-19 are headed above 650 million, including 6.6 million deaths [26]. The USA, Brazil, and India are reported to have major fatalities [26]. Human health and environmental and socio-economic life have also been affected globally [15, 52]. Talking about the environmental aspects, Soni [52] mentioned reports on the impact of COVID-19 on the atmosphere from Spain [8], Western Europe [37], Brazil [41], India [4], and other states. Most of the reviewed work showed significant improvements in different air quality parameters. Sci-

entists also worked on assessing the impact of COVID-19 on water quality [4, 15, 31, 62].

As per WHO [59], half of the global population in 2025 will reside in water-stressed areas; thus, strategies promoting recovery of water, energy, or nutrients from wastewater are of key importance. From past research, it has been realized that for successful planning and execution of water bodies; rejuvenation programs, hydro-geochemical investigations, and assessment of various environmental factors on water quality are essential.

Taking account of water requirement estimates by the National Commission on Integrated Water Resource Development (NCIWRD), Uttar Pradesh (UP) has higher projected requirements between 2025–2050 compared to the other states and Union territories of India. Higher estimated values of net water requirement in UP state alone will be 102.5 km<sup>3</sup> compared to the overall requirement of 627 km<sup>3</sup> in the country [25] (Fig. 1a). In India, the HR is an important source of water in western UP. The HR originates

from the lower Shivalik range in Saharanpur (SHP) district (Uttar Pradesh). It crosses Muzaffarnagar (MZF), Shamli (SH), Meerut (MRT), Baghpat (BPT), Ghaziabad (GZB), and Gautambudh Nagar (GBN) district before meeting the Yamuna River Delhi (downstream) [58]. It receives wastewater from industrial units, domestic discharge, and agriculture activities, with higher effluent volumes from the catchment areas of the GZB district as compared to MZF, SH, MRT, BPT, and GBN [1, 58]. The overall catchment area of HR is reported to have 453 industries recognized as water polluting; of them, nearly 78% are located in GZB. Out of 674.033 MLD of total discharge (industrial and sewage) in the River, 399.693 MLD is contributed from GZB only [58] (Fig. 1b). The GZB district has witnessed a significant increase in environmental contaminants as a consequence of anthropogenic actions engaged in various industrial as well as agricultural activities [1]. Industrial discharge from GZB mainly derives from textile units, followed by other industries such as slaughterhouses, tanneries, pulp & paper, etc. [58]. A total of 9 drains (D1: Jawli, D2: Karedha, D3: Hindon Vihar, D4: Meerut Road Kaila Bhatta, D5: Arthala, D6: Indirapuram, D7: Pratap Vihar, D8: Dasna, and D9: Sahibabad) receive industrial (IF) and domestic effluent (DF) in GZB as per the UPPCB action plan-2019 [58]. D1 and D5 drains receive IF; D3 and D7 receive DF; D6 receive mixed effluents; D8, D4, D2, D8, and D9 receive both IF and DF (Fig. 2). The LKD phase restrains industrial activities, transportation, social events, and other similar occasions at large [15]. Literature survey encounters studies performed on different water bodies in India, which supports improvements in water quality during the LKD period [15]. Hence, the present study aimed to examine the impact of the COVID-19 LKD on the water quality status of the HR (GZB), with respect to the WQPs (DO, BOD, TC, and FC) reported on the UPPCB web portal. The effect of seasonal variations, i.e., PRM, MS, and POM during 2019–2021, on WQPs was also investigated. It is anticipated that the LKD phase will significantly influence the physicochemical and biological profile of the HR water.

## MATERIAL AND METHODS

This section includes an introduction of the study site, acquisition of secondary data, overview of the study design, and methodology adopted.

### *Study Area*

HR has around 7000 km<sup>2</sup> of basin area and lies between 28°30'27" to 30°15'22" N latitudes and 77°20'18" to 77°50'16" E longitudes. Currently, the River gets most of the water from domestic and industrial discharges [58]. Figure 2 shows the HR catch-

ment area falls in UP (India), and the location of drains (D1 to D9) opens into it at the GZB stretch.

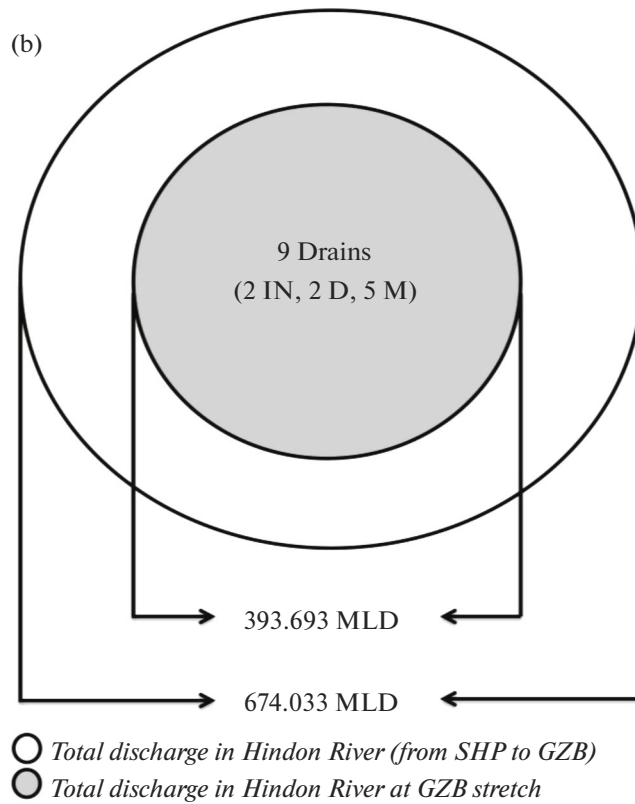
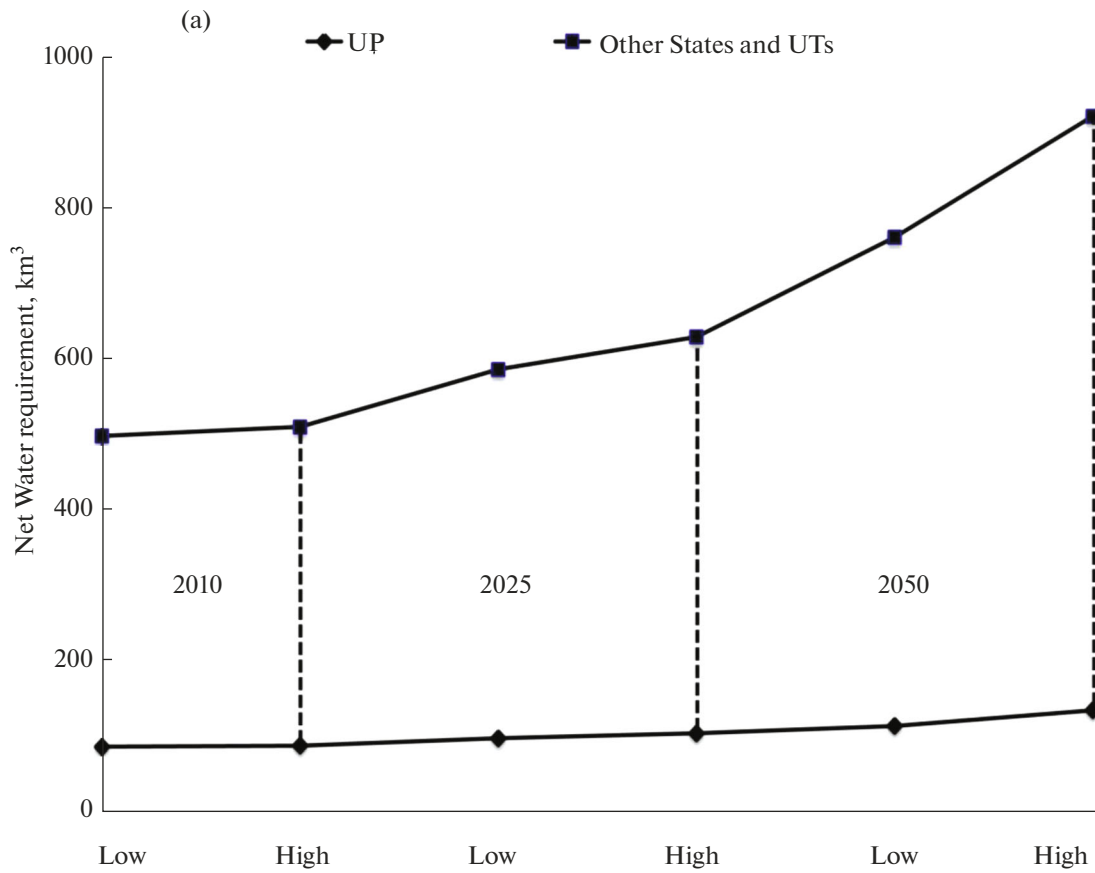
Seeing the past three years' trend (2018–2020) in rainfall and temperature variation in the GZB district, the observed values for rainfall were highest in the month of July–August and ranged from 157.5 to 385.2 mm, the maximum and minimum average temperatures were in the months of May–June (40–42°C) and January (17–20°C) respectively (Fig. 3) [29]. Overall, the district receives its highest rainfall during the monsoon season, and the months of May–June experienced maximum temperature, while January was the coldest month.

### *Data Acquisition*

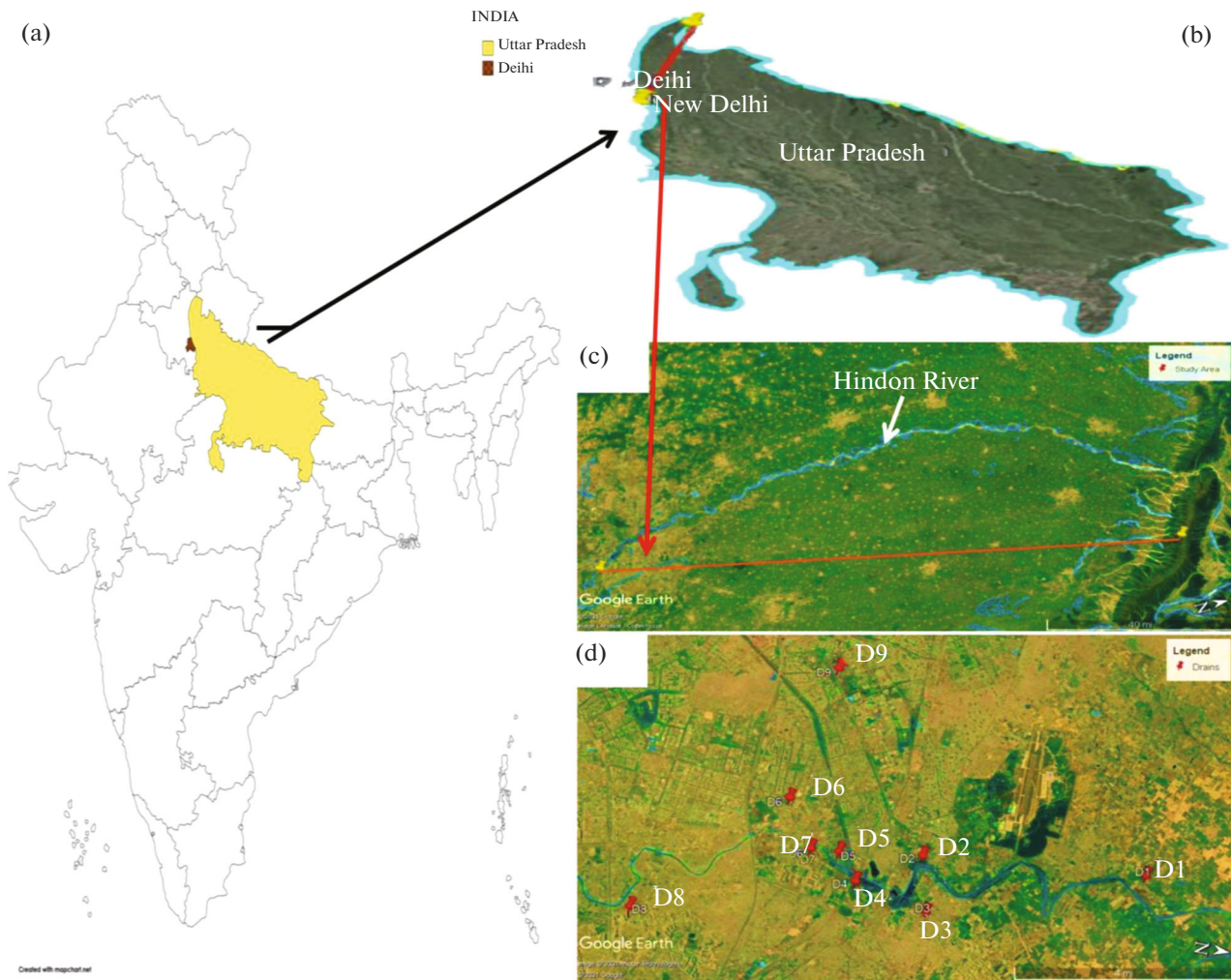
The major objective of the present study is to perform a comparative assessment of the variations in different WQPs of the HR (GZB) during the LKD phase. For a comprehensive evaluation, the study period was defined as pre-lockdown (PRD), lockdown (LKD), and post-lockdown (PLD) phases. The month of February and March were included in the PRD phase. The LKD has been imposed from 25.03.2020 in India; however, due to the data availability on a monthly basis and the majority of the days in March fall before LKD, this month was considered under the PRD phase. The River water's physicochemical properties are a key determinant of accessing its eco-hydrological health [13]. The study includes all four WQPs (DO, BOD, TC, and FC), publically available on the web portal of the UP state pollution control board for each month. The sampling locations designated by the monitoring body at HR (GZB stretch) were MNRB, KV, and CB.

Khan et al. [31] mentioned DO, BOD, and TC as crucial parameters for the water quality assessment of freshwater bodies. DO is the total amount of gaseous oxygen dissolved in water [14]. It affects flora and faunal life in aquatic ecosystems and is considered one of the key parameters in assessing water quality [19]. Nearly a minimum DO of 4 mg L<sup>-1</sup> is required to sustain life forms [45]. BOD represents the amount of DO required by aerobic microbes to oxidize organic (Carbonaceous) and inorganic (ammonia) matter completely [14, 22]. BOD values above 5 mg L<sup>-1</sup> are considered undesirable [14], and BOD/COD ratio below 0.3 indicates the presence of a large organic load in waterbodies [22]. FCs indicates contamination of domestic sewage in water bodies.

The correlation coefficient (*r*) was calculated using a Microsoft Excel spreadsheet, where the *r*-value near +1 and -1 indicates strong positive and negative correlations, respectively [32]. A linear regression equation for '*r*' is provided below [10]:



**Fig. 1.** (a) Net water requirement estimates in different states and UTs of India [25]; (b) Total effluent discharge at HR [58] (IN = industrial, D = domestic, and M = mixed).



**Fig. 2.** Map: (a) highlights UP and Delhi region [27]; (b) indicates HR in UP; (c) HR catchment area; (d) location of major drains discharged wastewater into HR (GZB) [58].

$$r = \frac{\sum_{i=1}^n x_i y_i - \frac{\sum_{i=1}^n x_i \sum_{i=1}^n y_i}{n}}{\sqrt{\left[ \sum_{i=1}^n x_i^2 - \frac{\left( \sum_{i=1}^n x_i \right)^2}{n} \right] \left[ \sum_{i=1}^n y_i^2 - \frac{\left( \sum_{i=1}^n y_i \right)^2}{n} \right]}}$$

Linear regression was computed from the equation  $Y = a + bX + \epsilon$ , where 'a' is the constant, b represents the slope of the regression line,  $\epsilon$  is the error term, Y and X are the values of dependent and independent variables respectively [53]. It helps to predict the association between the two variables and serves as an indirect route for quick monitoring of parameters [48].

## RESULTS AND DISCUSSION

### *Effect of Seasonal Variation*

The relevance of PRM, MS, and POM has been taken into consideration to study their impact on DO, BOD, TC, and FC. DO and BOD are the primary determinants of organic load in water bodies. DO depends upon the undergoing chemical, physical and biochemical activities in water bodies and is reported to have poor solubility in water [45]. As shown in Fig. 4a, higher values of DO were observed during POM compared to PRM and MS at SLS-MNRB during 2019 and 2020. A similar trend of reduced DO during MS was noticed at SLS-KV in 2019. Bora and Goswami [14], in their study on the Kolong River, Assam (India), also reported minimum DO during MS, with higher values during PRM followed by POM. In a similar investigation on water quality anal-

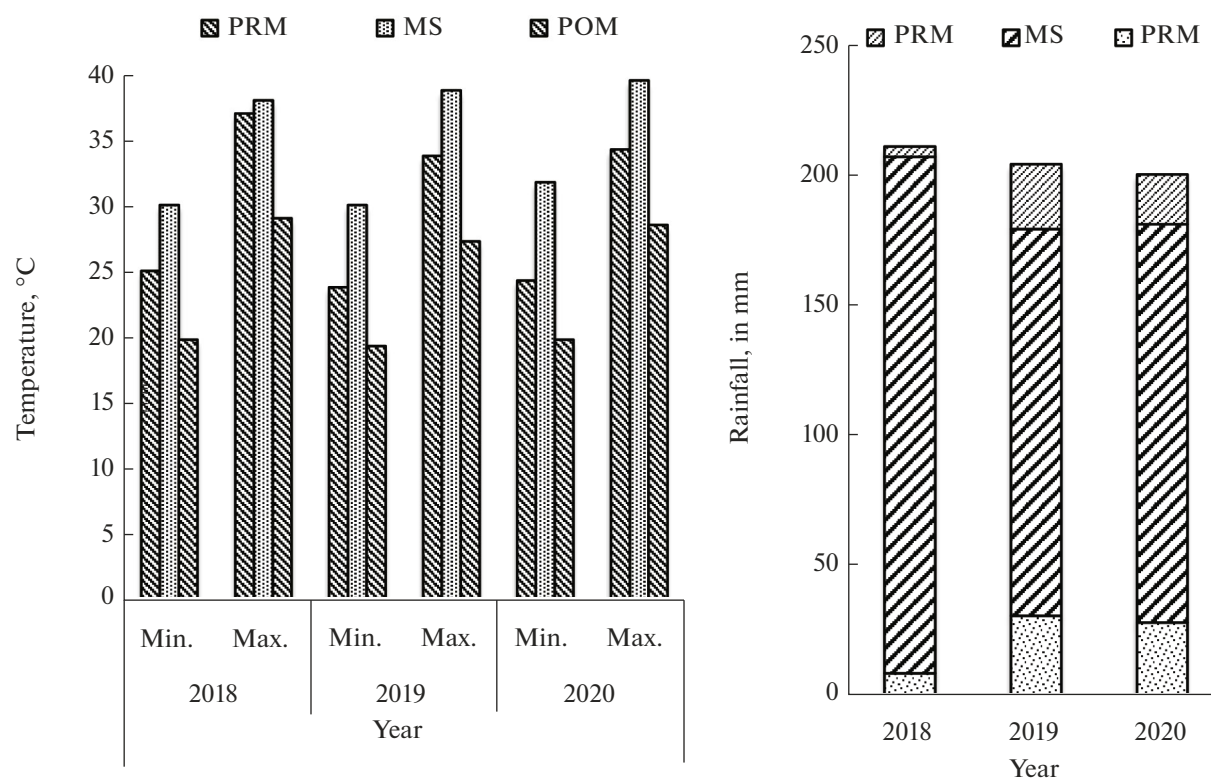


Fig. 3. Variation in: (a) temperature and (b) rainfall during PRM, MS, and POM seasons in the GZB district (Min: minimum, and Max: maximum).

ysis of Ichamati River, West Bengal (India) by Mondal et al. [38], average DO values ( $\text{mg L}^{-1}$ ) from nine SLSs were 5.597, 6.095, and 6.360 during MS, PRM, and POM respectively. The DO value at SLS-CB was nil ( $0 \text{ mg L}^{-1}$ ) in both years, which could be due to the stagnancy of water, thereby may reduce the self-assimilation capacity of the Riverine ecosystems [14]. The other contributing factors could be untreated sewage discharge, agricultural run-offs, inevitable habits of dumping wastes directly into water-bodies precisely by the small groups inhabiting the basin area, etc. [14]. If we compare with 2019, an overall improvement in DO levels was witnessed in 2020 at MNRB and KV. Nevertheless, the DO values were below the standard limits at all the SLSs [19]. The source of DO in water bodies majorly derives from the phytoplanktonic and aquatic plant's photosynthesis ( $5\text{--}20 \text{ mg L}^{-1}$  per day) [39]. Low DO can affect bacterial actions, thus limiting the metabolic conversions of certain organic compounds [56]. Such reductions also impact the survival capabilities of aquatic organisms [45] and indicate potential levels of contaminants in water bodies [14]. The solubility of DO is inversely proportional to the water temperature [56]. The POM period was considered from October to January, and these months have witnessed winters in the GZB district. The higher DO values during POM could be attributed to the decrease-

ing temperature (winters). Sheldon et al. [50] also reported an increment in DO during winters compared to summers.

As compared to the year 2019, the sampling year 2020 showed overall improvement in BOD levels at all the stations (except at KV during POM) (Fig. 4b). An increase in BOD values followed the trend  $\text{PRM} < \text{MS} < \text{POM}$  during 2020 at all the SLSs. However, 2019 showed a mixed trend in BOD levels. At MNRB, lower BOD was observed during MS. Bora and Goswami [14] also found lower BOD during MS, followed by PRM and POM. Though the BOD levels were above the standard limits [14], the average BOD values during PRM, MS, and POM of 2019 and 2020 at all the SLSs were less than  $\sim 58.00 \text{ mg L}^{-1}$ . In general, the  $\text{BOD}_5$  (at  $20^\circ\text{C}$ ) of untreated DWW ranges from 110 (low) to 400 (high)  $\text{mg L}^{-1}$  [22]. This indicates that the proportion of effluent has been pre-treated before discharge into the water body. As per the UPPCB [58] report, out of the total sewage discharged by the nine drains (D1 to D9) in HR (GZB district),  $\sim 48.8\%$  was treated.

From Fig. 4c, it has been observed that the maximum TC count was during POM at MNRB and CB, while at KV, the values were higher during the MS season. A similar trend was followed in the case of FC, except at MNRB. However, the FC/TC ratio ranges

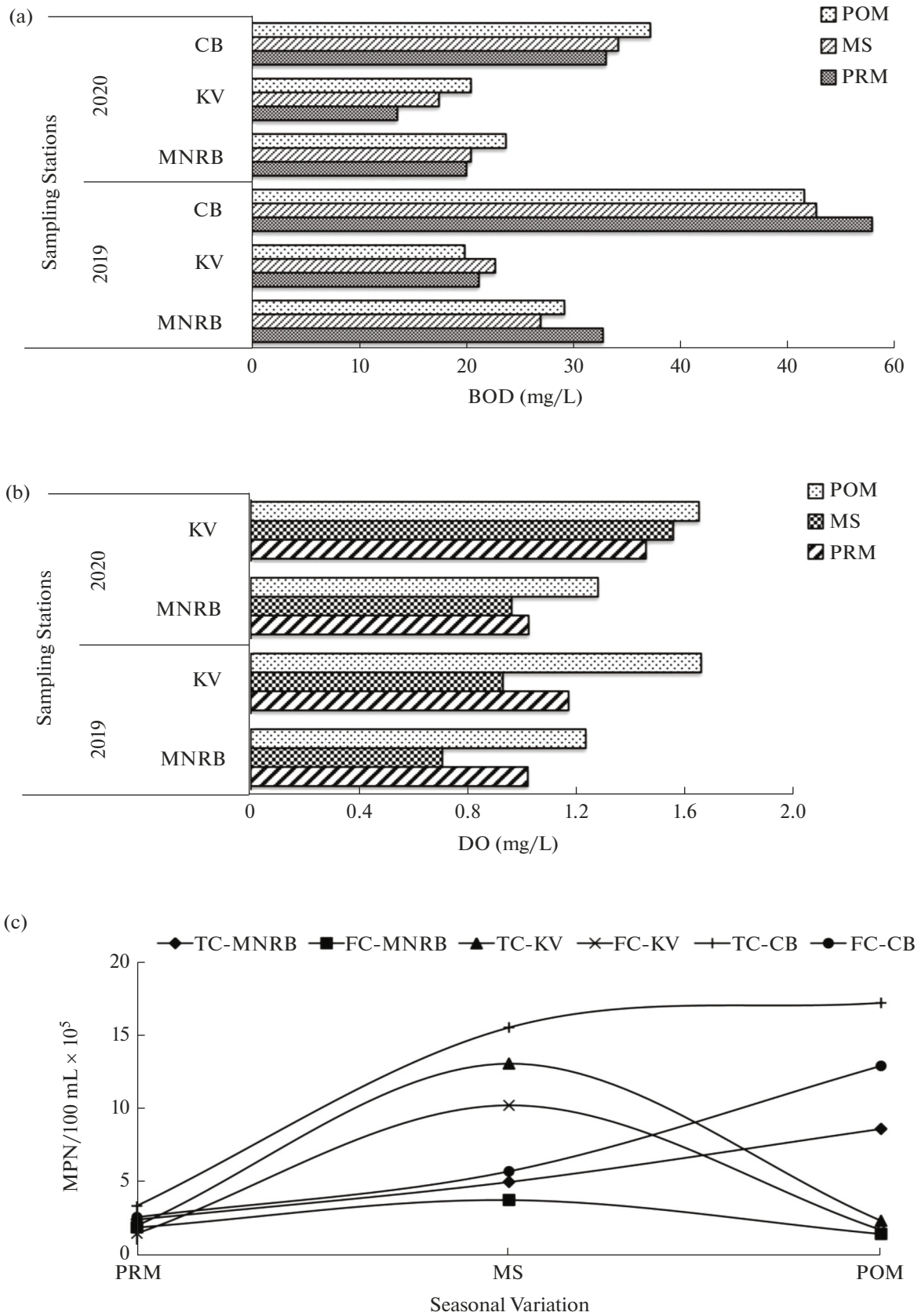


Fig. 4. Variation in: (a) DO, (b) BOD, and (c) TC and FC during POM, MS, and PRM (Note: At the SLS-CB, the DO was nil).

from ~0.74–0.79 in the SLSs during PRM, MS, and POM, except for POM and MS at MNRB and CB, respectively. Overall, the TC load was highest at the SLS-CB. The maximum FC count was at CB, followed by KV (~10<sup>6</sup> per mL) during POM and MS, respectively. This could be due to the discharge of partially or untreated domestic sewage [49]. TC and FC load in DWW ranges from 10<sup>5</sup>–10<sup>6</sup> and 10<sup>4</sup>–10<sup>5</sup> (per mL), respectively [22, 46]. Domestic wastewater (DWW), in common, comprised of greywater (water from domestic activities such as bathing, washing, food preparation, etc.), human fecal matter, and urine [22]. It also contains pathogenic microbes sourced from fecal matter excreted by symptomatic and asymptomatic individuals [22]. Thus, hydro-biological monitoring is an important aspect, precisely, for screening pathogens prone to fecal-oral transmissions. Water quality indices showed comparatively more improvement at the sampling station KV, for which the dearth of urban colonization can be one of the likelihoods [14]. Such investigations can provide vital information on undergoing physio-chemical and hydro-biological changes in the water bodies.

#### *Effect of Lockdown Phase*

Figure 5a demonstrates the variation in DO during PRD, LKD, and PLD. At the SLSs MNRB and KV, the trend in DO was PRD > PLD > LKD. However, the average DO at CB was 0.85 mg L<sup>-1</sup> during LKD and nil for PRD and PLD phases. Khan et al. [31] found an overall reduction of 18.20 and 18.10% in DO during LKD and PLD, respectively. Compared to 2019, the DO was higher during 2020 at MNRB (~9%) and KV (~19%). Though the DO values were below the standard limits at all the SLSs, an improvement was observed at MNRB and KV during 2020. At the SLSs KV and CB, lower BOD levels (~17–40%) have been witnessed during LKD compared to PRD and PLD (Fig. 5b). Contrary to this, at MNRB, ~3.5% higher BOD was observed during LKD than PLD, though a ~13% reduction in BOD value was seen in LKD over PRD. These observations suggest that the LKD phase has restricted anthropogenic activities, which potentially recuperated again during PLD. Khan et al. [31] also made similar findings, with a 7.09 and 19.44% reduction in BOD during LKD and PLD, respectively. Thus, considering BOD as another important WQP, an overall improvement was observed during the LKD phase. As compared to 2019, 2020 has witnessed improvements in BOD levels (~19, ~35.5, and ~28% at KV, CB, and MNRB, respectively).

Still, it is uncertain to predict the influence of the LKD phase in achieving these figures, as apart from anthropogenic activities, several environmental and seasonal variations can also have significant impacts. The idea of following temperature and precipitation data relies on the close association between the hydro-

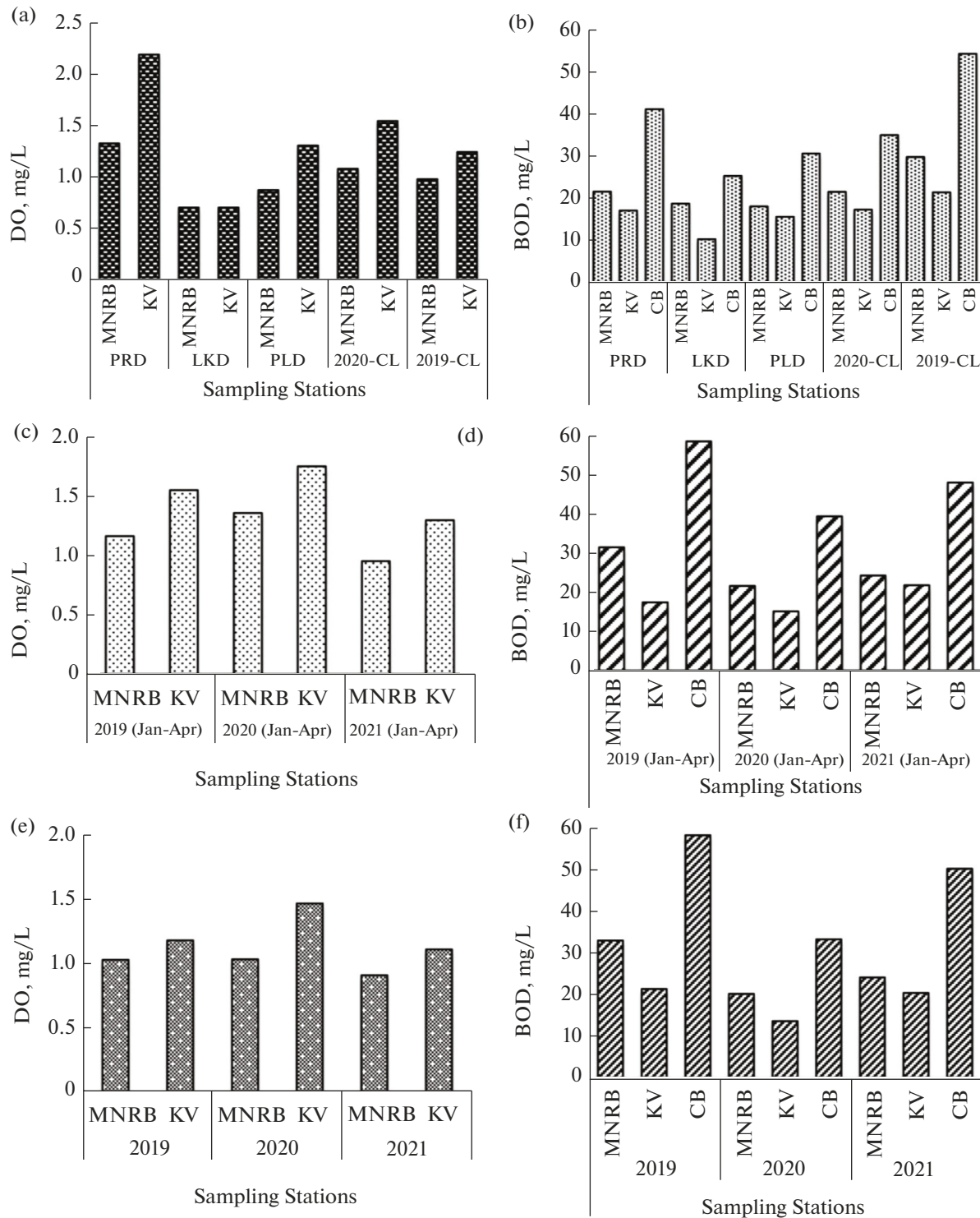
sphere and the components of an atmosphere [62]. Temperature is critical for water quality analysis [38]. The average temperature during PRD (24°C) was lower than LKD (37°C) and PLD (39°C) phases (Fig. 6a). LKD also experienced low rainfall comparatively (Fig 6b). The solubility of DO decreased with an increase in temperature [7]; thus, low temperature could be one of the possibilities for improving DO during the PRD phase (including months of low temperature, i.e., February and March). In addition, low rainfall (dry) periods are also reported to have reduced DO levels in water bodies due to decreasing water flow [38].

WQPs during the first quarter (FQ) of 2019, 2020, and 2021 were also analyzed. The purpose behind tracking FQs was comparative assessment with the latest available data (i.e., January–April 2021), the scope of inter-periodic deviations, and exploring the past three-year trends of variation in these parameters, which also includes LKD period (i.e., 25 March to 30 April 2020). It was noticed that the 2020 FQ has higher DO (Fig. 5c) and lower BOD values (Fig. 5d) compared to the 2019 and 2021 FQs. During the FQ of 2020, the average DO at CB was 0.43 mg L<sup>-1</sup>, which was nil during the 2019 and 2021 FQs. At the SLS-MNRB, 14.34 and 29.78% higher DO were observed during the FQ of 2020 compared with the FQ of 2019 and 2021, respectively. A similar trend was witnessed at the sampling station KV with higher DO values during FQ of 2020 (11.40% higher than FQ of 2019 and 25.93% higher than FQ of 2021). BOD shares an inverse relationship with DO [11], and in 2020 FQ, the BOD levels showed an improving trend at all three SLSs.

About two-thirds of LKD duration (i.e., 25 March to 31 May 2020) falls in the PRM period; hence variations in WQPs during PRM in the past three years have also been explored. PRM of 2020 noticed higher DO at MNRB and KV (Fig. 5e) and lower BOD (Fig. 5f) at all the SLSs, compared to 2019 and 2021. Improvements in DO levels were more pronounced during the transition from 2020 to 2021 compared to 2019 to 2020. Taking the view of temporal assessments, Yunus et al. [62], through Landsat-8 OLI data analysis, observed a decrease in suspended particulate matter (SPM) during the LKD (31 March 2020 and 16 April 2021) in Vembanad Lake, Kerala (India). Aman et al. [4] also made similar observations while analyzing SPM data of the Sabarmati River at the Ahmedabad section. These interpretations further designate the influence of the LKD phase on restricting anthropogenic actions, leading to improvements in WQPs such as DO and BOD.

#### *Analysis of FC/TC*

Coliforms are Gram-negative, rod-shaped, non-sporulating, aerobic, or facultative anaerobic bacteria [17]. They belong to the Enterobacteriaceae family,



**Fig. 5.** Variation in: (a) DO and (b) BOD levels during PLD, LKD, PRD, 2019–CL, and 2020–CL; (c) DO and (d) BOD levels during the FQ of 2019–2021; (e) DO and (f) BOD levels during PRM season of 2019–2021 (Note: At the SLS-CB, the DO was nil; CL = complete year, i.e., January to December).

representing 10% of intestinal microflora [43]. This group includes *Enterobacter*, *Escherichia*, *Citrobacter*, and *Klebsiella* genus [17]. Coliforms are found in soil, vegetation, and aquatic bodies and are abundant in the

fecal matter of warm-blooded animals [44]. The coliform bacteria in drinking water indicate the risk of water-borne diseases [44]. Fecal-derived organic load partially affects the BOD levels in water bodies [23].



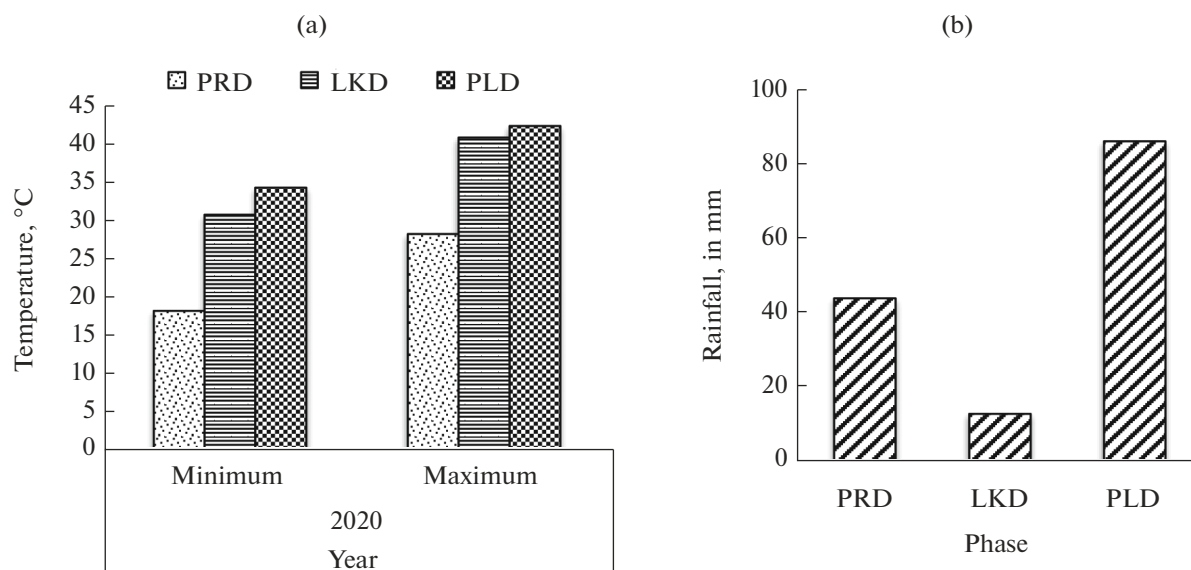


Fig. 6. Variation in: (a) temperature and (b) rainfall during PLD, LKD, and PRD phases.

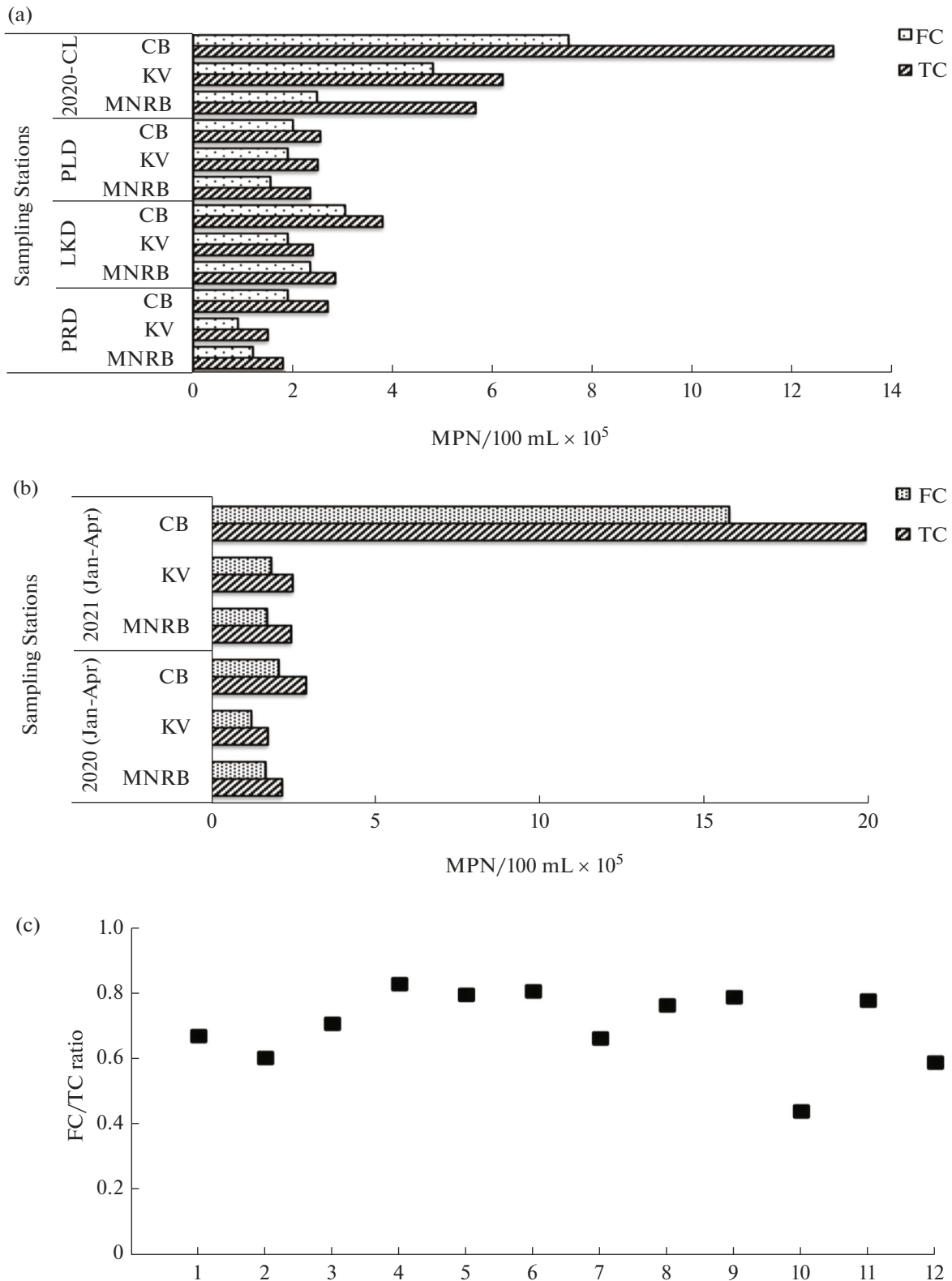
Therefore, to a certain extent, analyzing coliform load (TC and FC) can help to predict the “quantum of domestic sewage” in wastewater. This will facilitate further assessment to predict the extent of treatment received by the wastewater before discharging into the water bodies. The effect of seasonal variation and the impact of LKD phase on TC and FC count in HR (GZB) have been discussed in this section.

At the SLSs MNRB and CB, coliform counts were higher during the LKD phase (Fig. 7a). 36.84 and 28.95% higher TC in LKD compared to the PRD phase was noticed at MNRB and CB, respectively. Similarly, 17.54 and 32.89% higher TC count was observed at MNRB and CB, respectively, during LKD, compared to the PLD phase. At MNRB and CB, the increase in FC count ranges from 34.04–48.94% during LKD as compared to the other two phases and follows the trend PRD < LKD > PLD. TC (37.50%) and FC (52.63%) counts were relatively higher during LKD over the PRD phase, though a slight reduction (4%) in TC count was seen in LKD when compared to PLD at SLS-KV. On comparing the FQs of 2020 and 2021, coliform counts were increased in 2021 at all the SLSs with higher values at SLS-CB (Fig. 7b). Mentioning here, SLS-CB during FQ-2021 has witnessed 85.30 and 86.71% higher TC and FC respectively than FQ-2020. It could be due to the higher sewage inflow [23]. Comparatively, the increment in coliform counts during FQ-2021 was relatively low at MNRB, over the other two SLSs. Overall observations marked SLS-CB as more contaminated in terms of coliform counts than the MNRB and KV. The higher TC indicates a significant influence of anthropogenic activities on water quality [31]. Urban colonization near riverside is also a contributing factor [23]. FC indicates domestic sewage load in the water

bodies. FC/TC ratio was analyzed using a scatter plot (Fig. 7c), and it was observed that the FC/TC ranges from ~0.66 to ~0.82, ~0.60 to ~0.79, and ~0.70 to ~0.82 at SLSs MNRB, KV, and CB respectively during PRD, LKD, and PLD phases. SLS-KV in 2020 has a higher FC/TC ratio, followed by CB and MNRB. FC/TC ratio was higher during LKD than the other two phases at all the SLSs, indicating higher fecal coliform loads during LKD.

#### Correlation and Regression Analysis

A strong negative correlation was observed among BOD-DO, TC-DO, and FC-DO during PRM, MS, POM, and PRD. BOD decreases with an increase in DO [11]; coliform bacteria show a decreasing trend with an increase in DO. A strong positive correlation was found between TC-BOD and FC-BOD during PRM, MS, POM, LKD, and PRD (Table 1). This could be due to the inverse relationship between DO and BOD; increasing DO levels showed decreased coliform counts. FC-TC shows a strong positive correlation in all the considered periods. The TC count includes FC load; thus, higher TC can be attributed to increased FC. Ghildyal [23] also recorded such observations during the summer and rainy seasons at HR (Meerut). A similar correlation was seen between FC-BOD and TC-BOD except during the PLD phase. A strong positive correlation between FC-BOD and TC-BOD was also seen in the study of Ghildyal [23]. WQPs during the LKD phase showed a mixed trend, with a moderate ( $r = 0.3$ – $0.7$ ) to strong ( $r = 0.7$  to  $1.0$ ) positive correlation [47]. Only during the LKD phase a positive correlation was seen between BOD and DO. Tripathi et al. [57] also reported a strong positive correlation ( $r = 0.943$ ) between BOD and DO in their



**Fig. 7.** TC and FC count in water samples: (a) during PRD, LKD, PLD, and the year 2020; (b) first quarter of 2020–2021; (c) scatter plot showing FC/TC (1 = MNRB-PRD, 2 = KV-PRD, 3 = CB-PRD, 4 = MNRB-LKD, 5 = KV-LKD, 6 = CB-LKD, 7 = MNRB-PLD, 8 = KV-PLD, 9 = CB-PLD, 10 = MNRB-2020, 11 = KV-2020, 12 = CB-2020).

**Table 1.** Correlation coefficient among WQPs

PRD				
parameters	DO	BOD	TC	FC
DO	1			
BOD	-0.975110089	1		
TC	-0.987494848	0.997870828	1	
FC	-0.994572146	0.992887264	0.998538367	1
LKD				
	DO	BOD	TC	FC
DO	1			
BOD	0.827250707	1		
TC	0.572855804	0.962058367	1	
FC	0.921550641	0.980489661	0.996921354	1
PLD				
	DO	BOD	TC	FC
DO	1			
BOD	-0.984817744	1		
TC	-0.421873213	0.572855804	1	
FC	-0.395086524	0.548556999	0.999569368	1
PRM				
	DO	BOD	TC	FC
DO	1			
BOD	-0.999247525	1		
TC	-0.999994259	0.999373219	1	
FC	-0.997250521	0.999374340	0.997495902	1
MS				
	DO	BOD	TC	FC
DO	1			
BOD	-0.975863755	1		
TC	-0.999994259	0.999373219	1	
FC	-0.997250521	0.999374340	0.997495902	1
POM				
	DO	BOD	TC	FC
DO	1			
BOD	-0.999468024	1		
TC	-0.976678454	0.969156437	1	
FC	-0.971871233	0.979035221	0.898639378	1

**Table 2.** Regression equation between parameters showing a strong correlation

S. No.	Parameters	Regression Equation
<b>PRD</b>		
1.	BOD-DO	$BOD = -11.223874 DO + 39.725465$
2.	TC-DO	$TC = -0.556411 DO + 2.655638$
3.	FC-DO	$FC = -0.460487 DO + 1.875941$
4.	TC-BOD	$TC = 0.048848 BOD + 0.70553$
5.	FC-BOD	$FC = 0.039939 BOD + 0.274962$
6.	FC-TC	$FC = 0.820513 TC - 0.307692$
<b>LKD</b>		
1.	TC-DO	$TC = 8.392857 DO - 3.333929$
2.	FC-DO	$FC = 6.607143 DO - 2.566071$
3.	TC-BOD	$TC = 0.091437 BOD + 1.369278$
4.	FC-BOD	$FC = 0.075559 BOD + 1.072014$
5.	FC-TC	$FC = 0.80832 TC - 0.005098$
<b>PLD</b>		
1.	BOD-DO	$BOD = -11.813692 DO + 29.977018$
2.	FC-TC	$FC = 2.269231 TC - 3.780769$
<b>PRM</b>		
1.	BOD-DO	$BOD = -13.281167 DO + 33.228578$
2.	TC-DO	$TC = -0.91565 DO + 3.434104$
3.	FC-DO	$FC = -0.743065 DO + 2.680442$
4.	TC-BOD	$TC = 0.068849 BOD + 1.145316$
5.	FC-BOD	$FC = 0.056026 BOD + 0.819631$
6.	FC-TC	$FC = 0.811711 TC - 0.106911$
<b>MS</b>		
1.	BOD-DO	$BOD = -11.108592 DO + 33.396036$
2.	TC-DO	$TC = -2.461217 DO + 13.279987$
3.	FC-DO	$FC = 2.412113 DO + 4.594512$
4.	TC-BOD	$TC = 0.336367 BOD + 3.115823$
5.	FC-BOD	$FC = -0.140859 BOD + 10.009027$
6.	FC-TC	$FC = 0.338775 TC + 2.81674$
<b>POM</b>		
1.	BOD-DO	$BOD = -10.257627 DO + 37.178111$
2.	TC-DO	$TC = -8.371149 DO + 17.595241$
3.	FC-DO	$FC = -7.303499 DO + 12.544881$
4.	TC-BOD	$TC = 0.809374 BOD - 12.562998$
5.	FC-BOD	$FC = 0.716874 BOD - 14.058397$
6.	FC-TC	$FC = 0.787906 TC - 2.009344$

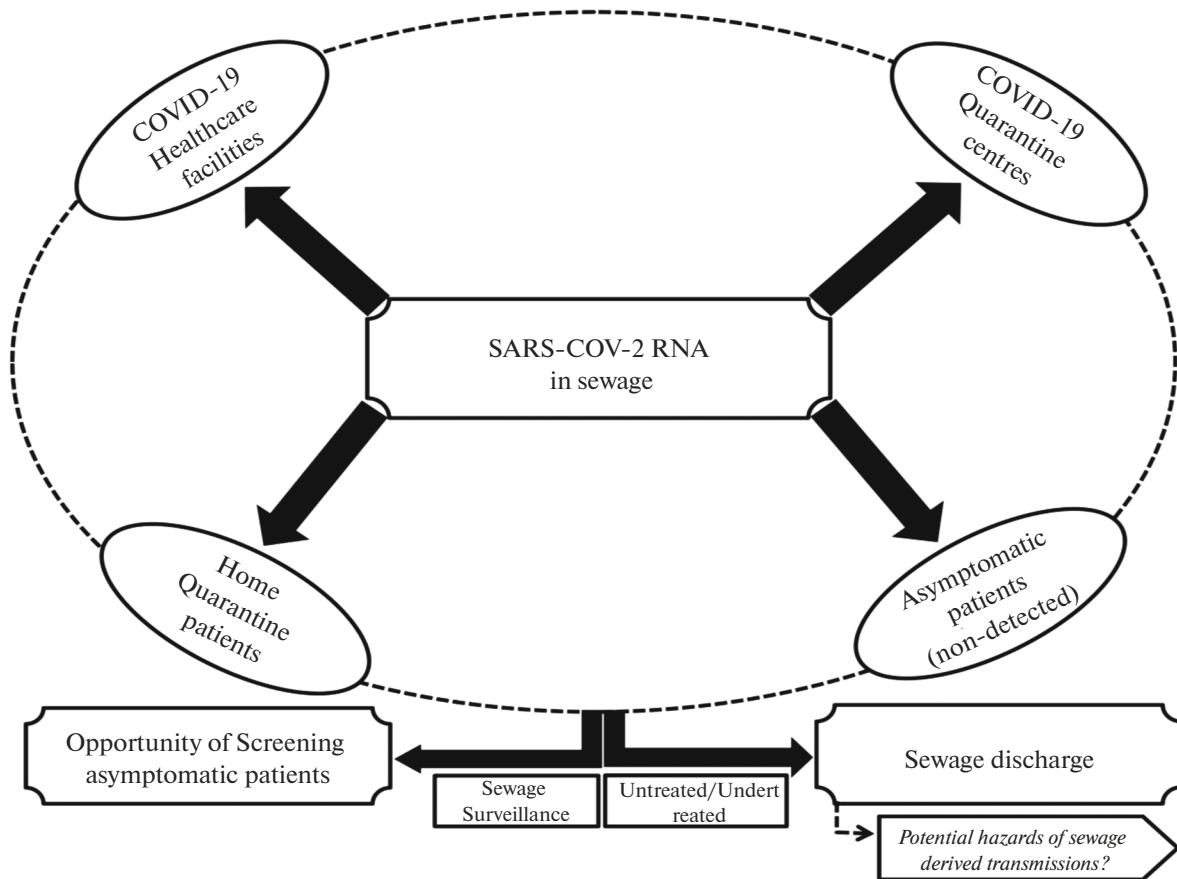


Fig. 8. Potential routes of SARS-CoV-2 RNA in sewage (conceptualized from [31]).

investigation on WQPs of River Ganga at Shringverpur (Allahabad, UP, India). Table 2 displays regression equations between parameters with a strong positive correlation ( $-0.90 \leq r \leq +0.90$ ) [10]. Establishing a relationship between different physicochemical parameters through regression analysis can reduce the number of parameters considered for routine monitoring.

#### Overview of Wastewater-Based Surveillance of COVID-19

Wastewater-based epidemiology (WBE) inculcates studies indicating the presence of pathogens in wastewater [36]. Approximately, 1.8 billion people use fecal-contaminated drinking water sources [12]. The risk of pathogens transfer via the oral-fecal route is documented in the available reports [9]. Foladori et al. [20] reviewed the possible routes of virus entry into the gastrointestinal (GI) tract (such as respiratory secretions swallowing through the upper respiratory tract; residues of APICs-antigen presenting immune cells; replication of the virus in the intestinal cells of humans) and their presence in feces [24, 61].

Few reports have discussed the possibilities of fecal-oral/sewage-derived transmissions of SARS-CoV-2 [9, 12, 18, 20, 24, 55, 61]. As per WHO & UNICEF [60], the risk of spreading SARS-CoV-2 from an infected person's fecal matter appears to be low, and there is no evidence of transmissions through sewerage systems (treated or untreated wastewater). Literature reports the presence of SARS-CoV-2 RNA in the feces of COVID-19-infected patients [12, 15, 18, 20, 55]. Figure 8 shows potential routes of SARS-CoV-2 RNA in sewage water. From the WBE point of view, such investigations can be useful in tracing infections at the community level and become more helpful as this will also include non-detected asymptomatic patients.

In the investigation of Xiao et al. [61], out of the 73 COVID-19 positive hospitalized patients, the feces of 39 were screened positive for SARS-CoV-2 RNA [61]. They found an abundance of ACE-2 in the cilia of glandular epithelia. Kumar et al. [33] cited that 48–67% of COVID-19 infected people were found positive for the presence of SARS-CoV-2 RNA in their stools. Foladori et al. [20] mentioned the estimated viral load between  $5 \times 10^3$  to  $10^{7.6}$  copies/mL (based on the course of infection) in the feces of SARS-CoV-2

patients, which decreases in the range of 2-copies/100 mL to  $3 \times 10^3$  copies/mL upon entering into wastewater treatment plant (WWTP) as a result of dilution (based on pandemic level). In their review, Mandal et al. [36] reported the presence of SARS-CoV-2 RNA in wastewater samples. This will impose an additional challenge, particularly in poor sanitation regions [9, 18]. Chakraborty et al. [15] observed higher SARS-CoV-2 load in the sediment-based concentration of wastewater (sewage treatment plant inlet, sludge, and sewage pumping station), compared to the supernatant, composite, and syringe filter methods. They also suspected higher partitioning of SARS-CoV-2 in a solid phase. The high population density areas are more susceptible to this infection, as evidenced by wastewater-inspired environmental surveillance studies [15]. Li et al. [35] also highlighted the presence of SARS-CoV-2 in various environmental media. According to Ahmed et al. [2], to keep an eye on the city's health (in view of the COVID-19 pandemic) based on wastewater surveillance, it is preferred to monitor the major drains instead of all the wastewater systems. On reviewing the likelihood of fecal-oral transmission of SARS-CoV-2, one possible route mentioned was aerosol formation from the water contaminated with SARS-CoV-2 [40]. Shi et al. [51] also stated such potential routes (aerosolization through indoor drainage systems and toilet flushing). However, intensive studies are required to facilitate a detailed understanding of this area.

SARS-CoV-2 is a lipid-enveloped virus with a fragile outer membrane and is more susceptible to oxidation [21, 30]. Thus the contaminated water, upon passing through the conventional centralized water treatment plants (filtration/disinfection), potentially inactivates the virus [60]. In untreated sewage, it can survive up to several days [12], with longer survival possibilities in low-temperature regions [12, 36] and places of low light [35]. Other factors affecting SARS-CoV-2 survival in wastewater include organic matter load and the presence of antagonistic microbes [40]. Arora et al. [6] detected the SARS-CoV-2 genome in wastewater at a higher ambient temperature of 45°C. Alahdal et al. [3] recorded a relatively low SARS-CoV-2 RNA load in sewage under hot climatic conditions. However, WWTP following standard operations can eliminate or reduce such risks [6, 15, 42, 55]. Non-screening of asymptomatic patients have become a challenge during the pandemic [31]. Researchers recommend investigating the possibility of SARS-CoV-2 transmission through physical contact with contaminated surface waters [50] and its fate in the urban water cycle [40]. Such studies can contribute to screening asymptomatic COVID-19 patients [9, 31, 34, 36, 55] and could be an effective tool for early warning of such epidemics [15, 20, 33, 55]. Investigations leading to community-level screening with higher sensitivity of diagnostics (RT-PCR) from contaminated water samples are recommended, as the possibility of interfer-

ence of physicochemical parameters such as pH, BOD, COD, and TDS with the RT-PCR findings cannot be ignored [6] in wastewater-based surveillance of SARS CoV-2 RNA.

## CONCLUSIONS

The present study will provide valuable insights into the implications of the LKD period and SVs on WQPs of the HR (GZB). The seasonal variations significantly influenced the DO and BOD levels, which were also observed during the LKD phase for a short-term duration. Overall, CB was found to be more contaminated compared to other SLSSs. COVID-19 unearths numerous challenges competing for environmental resilience. Physicochemical and hydrobiological studies on water bodies have potential significance in analyzing the impact of pandemics based on wastewater-based surveillance. DO and BOD showed significant improvements during the LKD phase. A higher FC/TC ratio during the LKD phase showed an increment in coliform load. Such investigations play a crucial role in exploring the short/long-term effects of COVID-19 pandemics on different environmental components. The observed water quality indices necessitated the real-time monitoring of key physicochemical parameters and implementation of effective strategies leading to its reinstatement through sustainable routes and promoting its self-restorative potential.

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## CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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