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Water quality index of Yamuna River in Delhi region due to community lockdown amid COVID-19 pandemic

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ABSTRACT

COVID-19 pandemic has created a panic situation to the whole world because of its rapid contagious expansion in human beings. Social lockdown has been imposed throughout world including India to decrease the number of infections in public as no vaccine is available for its cure (at that time). During lockdown, the water quality of river *Yamuna* got improved as the entire commercial premises and industries were shut down. This paper presents the improvement of *Yamuna* river water quality in terms of DO, BOD, COD, pH, conductivity and suspended solids during first phase of lockdown (3 weeks) started from March 24th 2020 to April 14th, 2020 on the basis of data available on the website of CPCB, India. pH values were examined in the range from 7.1 to 8.7 (pre-lockdown) and it was decreased in a range of 7.2 -7.8 (post-lockdown). Similarly, 57% conductivity reduction in river water and 34% TSS reduction in drain water were recorded in post-lockdown time. On an average of 62% BOD and 60% COD load of river *Yamuna* has been reduced in just three weeks of lockdown time period.

Key words : *Yamuna River, BOD, Water quality index, COVID-19, Pre-lockdown, Post-lockdown*

Introduction

Among imperative natural resources, water is kept at second position next to the air for all the living organisms of the earth. It has also considered as a precious gift of nature for everyone and usable water should be transparent, hygienic as well as fragrance-free for human applications (Paul, 2017; Srivastav *et. al.,* 2021; Sarah *et al*., 2019; Chauhan *et al.,* 2019). According to Shrestha *et al.,* (2017), freshwater on the earth is only 3% and rest 97% is salt water present in oceans plus seas. Among the surface fresh water reservoirs of India, *Ganga* river basin (along with its tributaries) can be said as a life line of the country because of its crucial role in its culture as well as economy (Paul and Sinha, 2013; Singh *et al*., 2020b; Patel *et al.,* 2021). It has around 861,404 km^2 of vast catchment area (Rahaman, 2009). In any river system, tributaries are the major contributor freshwater stream and in Ganga river basin, glaciers of Himalayan range and seasonal rains are the major water sources (Vass *et al*., 2010). There are many tributaries of the river Ganga including *Yamuna, Ramganga, Ghaghara, Gandak, Kosi, Mahananda, Damodar, Kali, Gomati, Rind, Chambal, Ken, Tamsa, Betwa, Son* rivers etcfrom different sections of the country (Singh and Singh, 2007; Trivedy, 2010).

Out of these tributaries, *Yamuna* is an important sub-river basin of the Gangatic catchment areas as it serves for 366,223 km^2 areas (~42.5%) of total Gangatic river basin area (861,404 km^2). Moreover, 10.7% of Indian land areas also depend on the water of *Yamuna* river for various purposes (CPCB, 2006; Yadav and Khandegar, 2019). Around the world, river water quality is being depleted day by day due to anthropogenic pollution. Likewise, 70% river water in India is also claimed as polluted in various studies due to the mixing of untreated wastewaters (Singh and Singh, 2007) from the poor sewerage systems of urban areas (~84-92%) and industrial discharges (~8-16%) (Joshi *et al*., 2009; Sinha *et al*., 2016). Apart from these, minor contribution of river pollution has also observed from the agricultural run-off and some natural activities (Lokhande *et al*., 2011). Both, directly and indirectly, river pollution affects the livelihood of human beings and health of aquatic organisms (especially fishes), wild animals and human beings as the pollutants are reaching inside the body through food chain (Trivedy *et al*., 1990; Dubey *et al*., 2012; Medeiros *et al*., 2012; Paul, 2017; Singh *et al*., 2020a), because in the river water diverse types of pollutants have been observed like unstable chemicals, organic complexes, heavy meals, nutrients, particulates or colloidal particles, parasites, bacteria, fungi and viruses (Paul, 2017). Therefore, presence of these pollutants should be monitored in the environment has become in order to protect human wellbeing (Singh *et al*., 2020b).

Across the bank of river *Yamuna*, many industrials units (359 in number) are existed along with Delhi, Agra, Faridabad and Mathura cities and their plenty of untreated wastewaters are getting discharged in the river course (Mishra, 2010). Near *Palla* village, the huge amount of Yamuna river water is locked to supply drinking water for the citizens of Delhi.In Yamuna river, total 23 major drains are the significant contributor of water pollution in the riverat different locations. Between *Wazirabad* downstream to *Okhla* upstream, wastewaters of 16 drains are coming into the river course and rests are around *Okhla* barrage, *Agra* and *Gurgaon* canals. Only five drain's wastewater have the facility to reach up to various STPsfor treatment purpose. On an average, total estimated (till year 2019) flows of these 23 drains are 3026.24 million liters per day and total addition of organic load is ~264.31 tons per day (CPCB 2020). 86% of total wastewater (hydraulic load) and 75% of organic matter addition is carried out by drains like *Najafgarh*, *Delhi Gate*, *Sen nursinghome*, *Barapulla*, *Tughlakabad* and *Shahdara.* Figure 1 shows the proportions of BOD contribution by ten major drains of the Delhi city.

From Figure 1, it can be seen that ten major drains are the main contributors of organic load to the *Yamuna* river i.e. 95.76% of total 264.31 TPD of BOD, rest 4.24% BOD is being added by other drains (13 drains). Out of these ten, only *Najafgarh* and *Shahdara* drains are responsible for more than 73% organic materials addition into the river and around 22% BOD is being contributed by eight drains. According to a report of Central Pollution Control Board (CPCB 2020), the significant sources of Yamuna river water pollution are; disposal of untreated wastewaters of residential colonies and factories, mass bathing (religious dip), cultural practices, garments cleaning, idols drowning, agricultural run-off, solids waste materials etc. As per the reports of Central Pollution Control Board (CPCB) of India, 60% untreated sewage is being discharged at many points of Delhi into *Yamuna* river and the treated water volume is only 40% (CPCB 2005; 2013; Lamba *et al*., 2020). Because of these activities, the ecological condition of *Yamuna* river had become almost dead due to the addition of heavy organic load along with other pollutants.

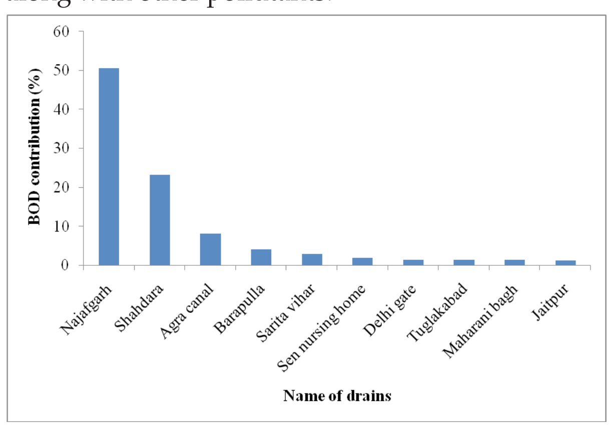

Fig. 1. BOD contribution (%) in *Yamuna* by 10 major drains of Delhi (Source: CPCB 2020)

COVID-19 (Coronavirus disease) is a pandemic as declared by WHO on March 11, 2020. Within very short time span, it has created global human health crisis in more than 210 countries as it was firstly reported in Wuhan (China) during December 2019 (CDC 2020; WHO 2020). Afterwards, it has become devastating in the developed countries such as Italy, Spain, USA, France, Switzerland along with China itself (Paital *et al.,* 2020). Similarly, first case of COVID-19 infection was observed in a student of Indian state, i.e. Kerala on January 30, 2020 who came from Wuhan (China) (ICMR 2020; Bhatnagar *et al*., 2020). A new strain of Coronavirus is responsible for the huge pulmonary infections among human beings and till now, no any effective medicines are available (FDA 2020; Paital *et al.,* 2020). As it is a kind of communicable disease which causes infections among the healthy people by physical touch with low immunity, so in order to prevent from further expansion ofthe viral infection, social lockdown has been imposed in almost every affected country. During, this social lockdown, only emergency services were allowed such as eatables and medical services under strict instructions of Government authorities (Paital *et al*., 2020). Following the experience of the world and high transmission rate of COVID-19, the Government of India has also imposed nationwide lockdown initially for three weeks starting from March 24th2020 to April 14th, 2020. During the first phase of lockdown, all types of public transportations (airways, roadways, railways, metro etc), industries, commercial firms, schools, colleges and universities along with the offices (private and government) have been completely closed. This lock was further extended up to May 3rd, 2020 and so on with some relaxations due to increasing infection rate of the COVID-19.

First phase of social lockdown was very much inflexible as only food supply and medicinal shops were open. Due to heavy shutdown of factories, discharge of wastewater was significantlyreduced in quantity wise. Because of lockdown, around the globe, environmental pollution got reduced by natural purification processes as reported in many studies (Tobías *et al*., 2020). Similarly, level of *Yamuna* river water pollution around the Delhi city also got lowered due the effects of lockdown amid COVID-19 as reported by CPCB (CPCB 2020). In present paper, the publically available data were adopted from the report of CPCB that was collected and measured during first phase of Indian social lockdown. All the interpretations have done on the basis of data available on the online portal of the CPCB, India only.

Methodology

Central Pollution Control Board (CPCB) of India is a government authorized organization and is responsible for the monitoring, analysis, standardization of surface water quality data at country level. In north India, *Yamuna* is a major tributary of *Ganga*river and around the capital city of Delhi, it covers an area of ~22 kilometers between *Wazirabad* and *Kalindi Kunj* (Lamba *et al*., 2020). The sample collection by CPCB officials were carried out in two phases before and after the declaration of social lockdown by Government of India. The dates of river and drain water sampling during pre-lockdown and post-lockdown were March 04, 2020 and April 06, 2020, respectively. At three points of Yamuna river, water samples were collected and analysed for pH, conductivity (suspended solids in case of drain samples), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) in the laboratory of CPCB itselfat Delhi. The names of sampling locations were *Palla, Nizamuddin* bridge and *Okhla* barrage upstream, respectively. At Palla village, Yamuna river enters to the Delhi city (river entry point), and *Nizamuddin* bridge point is a location where the wastewaters of 14 drains mixed with the river water, whereas, *Okhla* barrage upstream is a point of the river which comes after the release of wastewaters of 16 drains. As depicted in Fig. 1, two drains (*Najafgarh and Shahdara*) are contributing significant pollution load in *Yamuna* river water i.e. ~73% organic load of total BOD. Because of this reason, the water samples of these two drains were also collected and analysed as per the standard protocols (CPCB 2020).

Results and Discussion

In India, due to rapid transmission of COVID-19 infections, lockdown was imposed by the Central government in many phases. As mentioned in the earlier section, first phase of social lockdown was very strict as no movement of public allowed. Because of this reason, commercial institutions (including offices and hotels etc) and industries were shut down completely. Therefore, the rate of wastewater generation (residential and manufacturing units) was significantly reduced from the every part of the country including Delhi. Thus, wastewater quantity discharge in *Yamuna* river was also decreased and improvement in the river water quality was observed. Before lockdown, in normal days, ~35.9 MLD wastewater was generated by the industries located in Delhi and this burden of wastewater became zero due to complete closing of the industries (CPCB 2020).

pH variation of *Yamuna* river water during pre and post-lockdown period

pH of water is an important chemical parameter which determines the acidity or alkalinity level of it. It is also very important for the survival of aquatic organisms present in the river.

Highly acidic range of pH (5.5 to 6.0) was found to be dangerous for river aquatic life and enhance the death rate among them (Myllynen *et al*., 1997). Moreover, it gives an idea for the river water treatment for drinking purpose (Rahmanian *et al*., 2015). For drinking purpose, WHO has specified guideline for water pH ranged from 6.5 to 8.5 (WHO 2011). Figure 2 shows the pH variation in river water observed during the previous year (2019) and pre and post lockdown phases.

From Figure 2, it is visible that in year 2019 pH values at all the sampling locations were observed in the range from 7.1-8.7. Moreover, in the year 2020 (March 04, 2020) before imposing lockdown, almost same pH values were recorded for all the same locations. However, significant decreases in pH values were noticed in the post duration of lockdown (April 06, 2020) as the pH values ranged in between 7.2 – 7.8 for all the above river water sampling locations. At *Palla* sampling point of river, the pH was drastically changed from 8.7 (2019 and pre-lockdown period) to 7.8 (post-lockdown). Significant pH variations show the level of improvement in river water quality in terms of decreasing basic characteristics of water. pH values of river water could be affected by the change in temperature, alteration in atmospheric composition and presence and absence of living organisms (Bahadur and Chandra, 1996; Adebowale *et al*., 2008). Atmospheric variation is possible due improvement in the air quality of Delhi as no emission was taking place during lockdown. However, continuous discharges of the pollutants into the river water have direct influence on the significant pH variation (Gangwar *et al*., 2012). According to USEPA (2014), an ideal range of pH for the discharge of wastewater should be in between 6.0-9.0.

Variations in dissolved oxygen (DO) in river *Yamuna* during pre and post-lockdown period

Photosynthesis and atmospheric diffusion are the major sources of dissolved oxygen in any surface water reservoir and this is a basis of all aquatic lives present in it. DO values determine the water quality condition in terms of the decomposition of organic matter is taken place by whether aerobic or anaerobic organisms (Sawyer *et al.* 2003). Because of these important reason, DO in Yamuna river water was determined during pre and post-lockdown phases at *Palla*, *Nizamuddin* and *Okhla* U/s sampling points. At *Palla* sampling point, level of DO in the *Yamuna* river water was determined as 8.2 mg/L in 2019 and

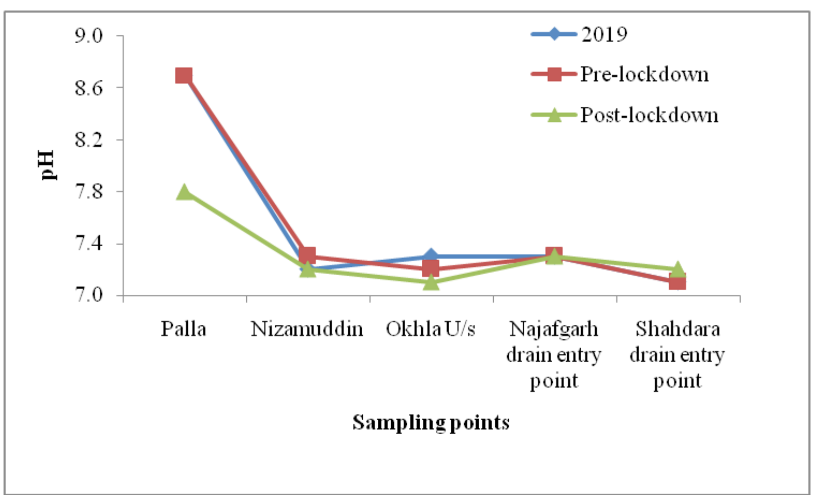

Fig. 2. pH variation of Yamuna river water in 2019, pre and post lockdown phase

during post-lockdown it was 8.3 mg/l (April 2020). Based on the DO measurement, the river water falls under the category of class-A (if DO is greater than 6 mg/l) as defined by CPCB, India in designated best use classification (JICA 2005). At *Nizamuddin* and *Okhla* U/s sites, levels of DO were observed as only 2.4 mg/l and 1.2 mg/l, respectively during post-lockdown phase. There was no DO level was detected at these two sites during pre-lockdown analysis. Therefore, little improvements in DO were observed in the river water at *Nizamuddin* and *Okhla* U/s sites. However, river water of these two sites can be used for irrigation and industrial cooling purpose only as per the definition of CPCB, India for designated best use because at both the sites water falls in the Class-E (JICA 2005).

Variation in oxygen demand of river *Yamuna* during pre and post-lockdown period

Biochemical oxygen demand (BOD) determines the quality of surface water which is the quantity of oxygen required by decomposers (bacteria, fungi etc) to decompose the organic materials present in water (Sawyer *et al*., 2003; Gangwar *et al*., 2012). Therefore, it is among the most important quality parameter of any surface water reservoir as well as help in the designing of water treatment facility (Gangwasr *et al*., 2012). Figure 3 shows the level of BOD of Yamuna river water observed during the previous year (2019) and pre and post lockdown phases.

From Figure 3, it can be seen that in year 2019, BOD levels were varied from 8.8, 18 and 19 mg/l at *Palla*, *Nizamuddin* and *Okhla* upstream sampling points of the *Yamuna*river, respectively. However, BOD values of drains were found to be very high as 90 mg/L for *Najafgarh* and 128 mg/l in *Shahdara*. In March 2020 (also pre-lockdown time), the BOD of the levels of BOD at *Nizamuddin* and *Okhla* U/s rose up to 57 and 27 mg/l, respectively. As per the observation in March 2020, an increase of more than 300% BOD was noted at *Nizamuddin*, whereas an increase of more than 166% noted at *Okhla* U/s as compared to the BOD levels of year 2019. Interestingly, during post-lockdown phase (April 2020), drastic decreases were observed in the levels of BOD as 75% at *Palla*, ~90% at *Nizamuddin* and 77% at *Okhla U/s* as compared to March 2020. However, the 38% (*Najafgarh)* and 30% (*Shahdara*) BOD values were decreased in the drain's water sample. As per the analyses of CPCB, quantity of domestic wastewater discharge of Delhi was not supposed to decrease; only decrease was expected in the quantity of industrial effluents during lockdown. Despite of this expectation, the levels of BOD were normally found to be decrease at all the locations of river water sampling points as well as in both the drains (CPCB 2020). According to the designated best use classification of BOD by CPCB, India, only at *Palla* sampling location, river water was found in the categories of Class-A, B, C and D (being less than 3 mg/l during post-lockdown) and it can be used as drinking water (only after water treatment followed by disinfection)

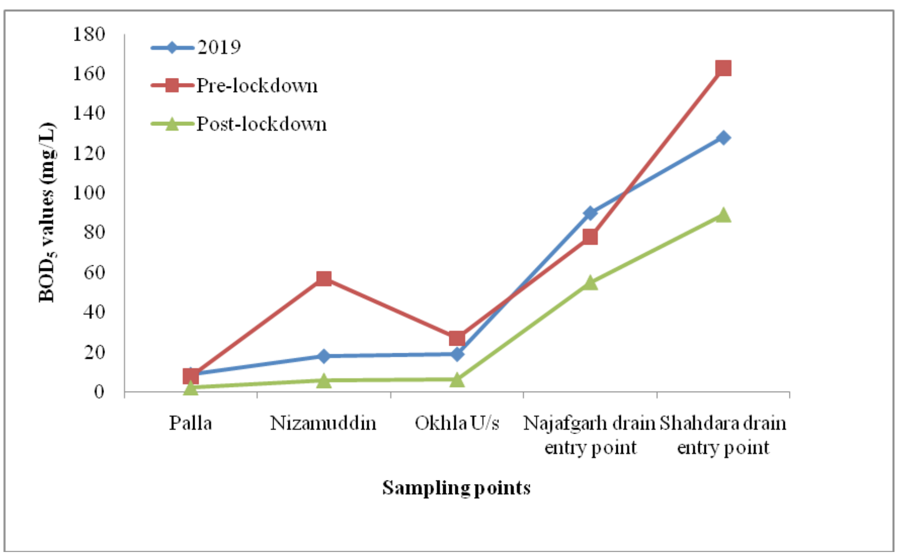

Fig. 3. BOD variation in *Yamuna* river water observed during the previous year (2019) and pre and post lockdown phases

and aquaculture purposes (JICA 2005).

Variation in chemical oxygen demand values of river *Yamuna* during pre and post-lockdown period

Chemical oxygen demand (COD) determines the quality of industrial wastewater which is the quantity of oxygen required for the breakdown of the organic materials with the help of any strong oxidising agent (for example, $K_2CR_2O_7$) (Sawyer *et al.*, 2003; Gangwar *et al.*, 2012). Along with COD, several types of pollutants may be present in the industrial wastewater discharge and the higher values of COD of any discharge may have greater contribution in the recipient water reservoir like rivers as surface water reservoirs are the easy places for the of dumping of industrial as well as domestic wastewaters (Gangwar *et al.*, 2012). Therefore, it is also one of the most important water quality parameter for the designing of industrial wastewater treatment system (Sawyer *et al.*, 2003). Figure 4 shows the levels of COD of Yamuna river water observed during the previous year (2019) and pre and post lockdown phases.

As depicted in Figure 4, levels of COD were recorded at *Palla* sampling points of the *Yamuna* river as 26 mg/l in year 2019, 28 mg/l in pre-lockdown phase (March 2020) and 6 mg/l in post-lockdown phase (April 2020). It is clear that within one year of duration the level of COD got increased 2 mg/l, whereas within one month (March 2020 to April 2020), it got reduced up to 6 mg/l. Total reduction in COD level was recorded at *Palla* around 78% within the duration lockdown even less than one month. At *Nizamuddin* site, levels of COD were observed as 71 mg/l, 90 mg/l and 16 mg/l during 2019, pre-lockdown and post-lockdown phases, respectively. It appears that more than 127% COD was increased within one year. However, the drastic reduction in COD value was noticed after lockdown i.e. around 82% as compared to the value of before lockdown and 77% reduced than the levels of 2019. At *Okhla* U/s river water sampling point, COD values were determined as 67 mg/l in 2019, 95 mg/l in March 2020 (pre-lockdown) and only 18 mg/l in April 2020 (post-lockdown). Total reduction of COD levels were recorded as >73% in the comparison of 2019 and >81% during post-lockdown (April 2020). It is noteworthy that reduction ranged from 73%-81% was achieved within less than only one month. Comparatively, the level of COD was increased more than 141%. Similarly, significant decreases were noticed in the COD values of drain waters as 45% and 33% in the *Najafgarh* and *Shahdara*, respectively as compared to pre-lockdown value. Chaudhary and Walker (2019) reported poor Ganga river water quality in terms of elevated levels of pH, conductivity, BOD and COD due to the mixing of unprocessed wastewaters of the municipality and factories.

Conductivity variation of *Yamuna* river water during pre and post-lockdown period

Conductivity can be referred as the capability of carrying current of any solution due to presence of cations (for example, calcium, magnesium, sodium etc) and anions (for example, sulphate chloride etc) in it (Sawyer v 2003; Rahmanian *et al.*, 2015). However, concentration of sodium cation is abundantly

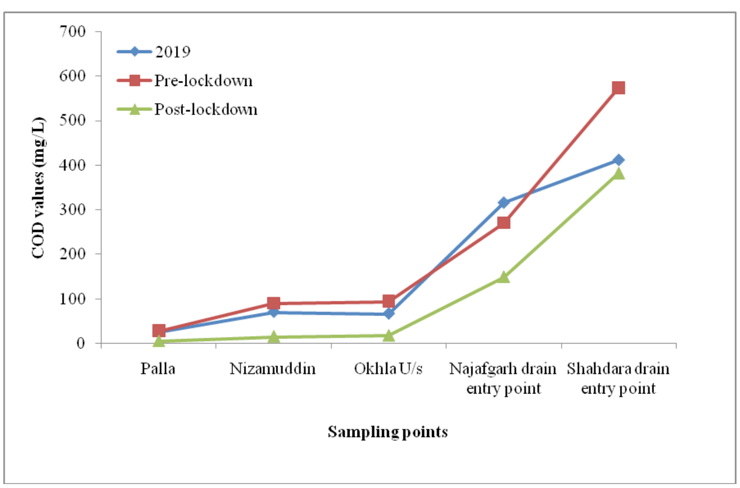

Fig. 4. COD variation in *Yamuna* river water observed during the previous year (2019) and pre and post lockdown phases

present in a solution having high electrical conductivity (Ali *et al*., 2012). Conductivity measurement is essential to know the amount of required chemical during the water treatment (Muhammad *et al*., 2011; Ali *et al*., 2012; Khan *et al*., 2013). Hence, its measurement is important and to be determined in water. Values of conductivity got reduced from 668 µS/cm to 273 µS/cm at *Palla*, from 1369 µS/cm to 460 µS/cm at *Nizamuddin*, and 861 µS/cm to 488 µS/cm at *Okhla* U/s water sampling points of *Yamuna* river as shown in Figure 5.

On an average, more than 57% of total conductivity has been reduced in the river water in the interval of pre-lockdown and post-lockdown phases due to the closure of industries. Three major contributors of electrical conductivity have been identified in water as industries, agricultural runoff and change land patterns (Scatena, 2000; Jindal and Sharma 2011). In Delhi city, industries could be a major reason of the addition of cations and anions as later two reasons are minimal with respect to first one. Moreover, higher level of conductivity can cause corrosion in industrial units, scale formation in domestic electric devices etc (Rahmanian *et al.,* 2015). According to USEPA (2004), for agricultural activities and industrial applications, electrical conductivity has recognised as a vital parameter for water quality.

Total suspended solid variation during pre and post-lockdown period in drain watersamples

Total suspended solids were also determined in the water samples of the drains as *Najafgarh* and *Shahdara*. In the water of *Najafgarh* drain TSS level was 200 mg/l, 152 mg/l and 106 mg/l in year 2019, pre-lockdown, and post-lockdown time periods, respectively. The reduction in TSS was observed as 30% in the lockdown period only. Similarly, *Shahdara* drain in 2019 the TSS value was 380 mg/l, which was increased up to 464 mg/l till pre-lockdown time (March 2020) and reduced up to 305 mg/l during post lockdown (April 2020). Hence, more than 34% TSS reduction was occurred due to the effects of lockdown in *Shahdara* drain water samples.

Comparison of water quality index (WQI) of Yamuna river at *Palla, Nizamuddin* and *Okhla* locations during pre and post-lockdown

Water quality index can be used a trustworthy method of evaluating pollution levels in the water (both surface and groundwater) (Dore, 2015). WQI calculations are based on the consideration of multiple water quality parameters which facilitates the understanding of water quality of a particular area/source among common public. In terms of river water quality, WQI measurement helps the people or water treatment authorities to identify the less polluted area to reduce the cost of water treatment along with human health protection (Hellawell, 2012). Moreover, it will good for the cattle health and other uses of water too as Singh *et al*., (2020) calculated water quality index for Kali river stretch of

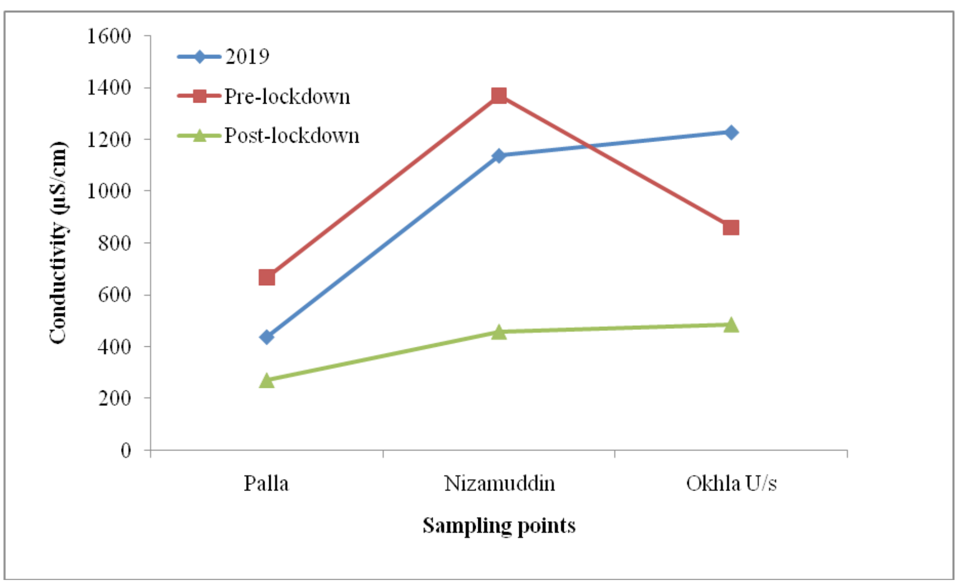

Fig. 5. Change in conductivity in *Yamuna* river water in 2019, pre and post lockdown phase

India for the similar objectives.

Considering this importance, WQI of Yamuna river has been calculated for all the three areas *Palla, Nizamuddin* and *Okhla* during pre and post-lockdown amid COVID-19 pandemic. WQI calculations have been carried out in present study as reported by Ramakrishnaiah *et al*., (2009) (eq. i).

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \text{ ....(i)}$$

Where, W_i = relative weight, w_i = weight of each parameter, and n = number of parameters. Further, quality rating scale (q_i) was obtained through dividing concentration by its respective standard prescribed by BIS 10500 (2012). The calculated values have been again multiplied by 100 as shown in eq. (ii) Ramakrishnaiah *et al*. (2009):

$$q_i = \frac{C_i}{S_i} \times 100 \text{ ....(ii)}$$

Where, q_i = quality rating, C_i = concentration of each parameter in water sample, and S_i = Indian drinking water standard set by BIS 10500 (2012).

Afterwards, WQI was calculated using following mathematical expressions (eqs. iii and iv) Ramakrishnaiah *et al.* (2009):

$$SI_i = W_i \times q_i \text{................(iii)}$$

$$WQI = \sum SI_i \text{................(iv)}$$

Where, SI_i = subindex of i^{th} parameter, qi = quality rating of i^{th} parameter, and n = number of parameters.

According to Ramakrishnaiah *et al.* (2009), WQI of water can be categorized into different class for further uses as excellent, good, poor, very poor and not suitable potable purpose (see Table 1).

In present study, water quality index was computed for three locations of Yamuna river (i.e. *Palla, Nizamuddin* and *Okhla*) during pre and post-lockdown amid COVID-19 pandemic. The three water quality parameters considered for the calculations of WQI were dissolved oxygen, pH and BOD_5.

Table 1. Water quality classification based on WQI value (Source: Ramakrishnaiah *et al.*, 2009)

S. No.	Values of WQI	Level of water quality
1.	<50	excellent
2.	50-100	good water
3.	100-200	poor water
4.	200-300	very poor water
5.	>300	Water unsuitablefor drinking

Significant improvements were observed in the values of WQI for all the studied locations. For example, during pre-lockdown period the WQI of *Palla, Nizamuddin* and *Okhla* were 227, 982 and 482, respectively. However, during post-lockdown period, these values were only 95.6, 133 and 137, respectively for the same locations. Overall, it can be inferred that the water quality of *Yamuna* river at these three locations were in poor category before lockdown. However, at *Palla* location it was it was significantly improved in post-lockdown time and achieved the category of "good water". These improvements may be attributed to the less discharges of domestic discharge of wastewater from the Delhi.

Conclusion

Based on the findings of CPCB and our analyses, the water quality of *Yamuna* river has found to be significantly improved within three weeks of first phase of lockdown period from March, 2020 to April, 2020. Water samples were collected analysed for DO, BOD, COD, pH, conductivity and suspended solids. Significant improvements were noticed in all the above mentioned water quality parameters. Addition of continuous organic load has been a major constraint for the treatment authorities, however, in this study 62% of BOD reduction has been observed in *Yamuna* river till first phase of post-lockdown period. Further improvement is also expected as the partial lockdown was continued till 31st May, 2020.

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Availability of data and materials

All data used in present manuscript are publically available on the website of Central Pollution Control Board of India.

Competing interests

No funding was received.

Authors' contributions

ALS: Ideation& drafting; R: Help in computations; VKC: Supervision and expert view; NP: Review and editing; RBS: Review and expert opinion; AKB: illustrations of the diagrams.

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