



COVID-19 Lockdown Disruptions on Water Resources, Wastewater, and Agriculture in India

M. Balamurugan¹, K. S. Kasiviswanathan^{2*}, Idhayachandhiran Ilampooranan² and B.-S. Soundharajan³

¹ Department of Civil and Environmental Engineering, National University of Singapore, Singapore, Singapore, ² Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee, India, ³ Department of Civil Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India

The COVID-19 pandemic has disrupted daily activities across multiple sectors globally. The extent of its impact on the global economy and its key sectors, especially water, wastewater, and associated sectors such as agriculture, is still unclear. In this paper, the preliminary impacts of COVID-19 on water resources of India, especially on the river water quality, water usage in domestic and commercial sectors, wastewater treatment sector, and agriculture sector, are discussed. The limitations in the functioning of the existing system and management of water resources are identified. The need for improvements to strengthen the water resources monitoring and developing process-based models are highlighted. This paper also discusses the need for further investigation to identify the extent of impact and contributing factors to improve our understanding of the natural system for preparing, monitoring, and implementing the policies to manage the water resources during any pandemic/epidemics in the future.

Keywords: agriculture, water resources, pandemic, COVID-19, epidemics

RIVER WATER QUALITY

In India, more than 38,000 million liters of untreated sewage are discharged daily into the rivers due to the limited sewage treatment capacity, which can treat only 38% of the sewage generated (CPCB, 2015). On top of this, industrial effluents add further pollution to the rivers. In the river Ganga, industrial effluents alone account for about 12% of the total volume of effluents. Many industries in India, ranging from large to small scale were closed from March 22, 2020, to September 30, 2020, due to nationwide lockdown imposed for COVID-19. During this period, the water quality and quantity in many rivers have consequently improved in a short span of time, especially in river Ganga (a significant perennial river in the northern part of India), which runs 2,575 km covering a broad spectrum of landmass (Jain, 2015; Dutta et al., 2020; Shukla et al., 2021). In river Ganga, the dissolved oxygen levels have increased, biological oxygen demand, and nitrate concentration have decreased which leads to improvement in the overall water quality in just 2-months lockdown period (Dutta et al., 2020). The analysis of water samples collected across different sites ranging from the upper, middle, and lower reaches of Ganga revealed a significant improvement in the water quality mainly due to the shutdown of major industries and agricultural activities. Further, Dutta et al. (2020) reported that as compared to previous years, 60% excess rainfall (i.e., above the historical annual average rainfall recorded) contributed to an increase in the discharge, leading to the increased flow volume in the river. It may be noted that in the above study (i.e.,

OPEN ACCESS

Edited by:

Praveen Kumar,
University of Illinois at
Urbana-Champaign, United States

Reviewed by:

Praveen Kumar,
University of Illinois at
Urbana-Champaign, United States
Harrie-Jan Hendricks Franssen,
Helmholtz-Verband Deutscher
Forschungszentren (HZ), Germany

*Correspondence:

K. S. Kasiviswanathan
k.kasiviswanathan@vr.iitr.ac.in

Specialty section:

This article was submitted to
Water and Built Environment,
a section of the journal
Frontiers in Water

Received: 07 September 2020

Accepted: 26 February 2021

Published: 29 March 2021

Citation:

Balamurugan M, Kasiviswanathan KS,
Ilampooranan I and Soundharajan B-S
(2021) COVID-19 Lockdown
Disruptions on Water Resources,
Wastewater, and Agriculture in India.
Front. Water 3:603531.
doi: 10.3389/frwa.2021.603531

Dutta et al., 2020) relative differences between various water quality parameters of pre- and post-lockdown periods were compared; however, it does not accommodate comprehensive analysis and detailed modeling exercise. Nevertheless, such analyses can be extended to other major rivers of India. Similarly, the Krishna and Cauvery rivers and their tributaries in Karnataka (in the central and southern part of India) also regained their decades-old status in terms of water quality (KSPCB, 2020). The lockdown has also breathed life into polluted creeks and rivers in the Mumbai region as industrial effluents, and other waste inflow has reduced around 50%, as reported by national dailies (Smart water magazine, 2020). In contrast, the rivers that have more urban catchment areas, such as Yamuna River in Delhi, reported no major decline in water quality since domestic sewage makes up about 80% of the pollution, while the rest is from the industries (India Water Portal, 2020). This highlights that the closure of industries in Delhi did not improve the pollution levels in the Yamuna river significantly. It also raises the concern on the level of treatment required for industrial effluents and domestic wastewater before discharging it into the receiving rivers. While the river water quality has improved in the rural stretches of few Indian rivers, the impact of lockdown on other rivers is largely unknown due to lack of information/monitoring, thus, detailed quantitative analyses are not possible. Thus, there is an urgent need for: (i) improving the existing river water quality monitoring system toward finer resolution spatio-temporal data at the national scale and (ii) modeling studies of different complexities, to understand the overall impact of lockdown on water quality in Indian rivers.

Only recently, the real-time monitoring of water quality data for the river Ganga has been initiated (Dutta et al., 2020), however, such a strong database of water quality information does not exist for other Indian rivers. The Central Pollution Control Board of India publishes water quality data of major rivers, mostly on an annual basis. However, to come up with accurate estimates on improvements/reduction in river water quality during and after any consequential events, we need to strengthen the water quality monitoring across all the rivers following the example of river Ganga. It may be achieved through frequent water sampling along with satellite-based water quality monitoring that complements the ground-based monitoring system (Novoa et al., 2012; NASA, 2017; Avdan et al., 2019; Batur and Maktav, 2019). A strengthened monitoring system and its high-resolution data (e.g., daily or weekly) at the national scale will help toward detailed analyses on the water quality status due to anthropogenic activities. Such high-resolution temporal data will also help toward conducting detailed modeling studies at multiple scales across the nation from minor to major water bodies. Further, we can correlate the results from the detailed analyses on: (i) domestic and industrial water consumption pattern; (ii) discharge of pollutant loads from industries and domestic sewage of cities/towns; (iii) agricultural practices; (iv) to identify the hotspots; and (v) seasonal pattern and corresponding driving factors across the nation. Perhaps, such analyses and estimates will further improve our understanding of water resources management and river rejuvenation in the long run. For example, in the case of river rejuvenation, where the Indian

government has made an enormous amount of investment, it is crucial to closely monitor the water quantity, water quality, and biodiversity of all critical river stretches, particularly upstream and downstream of major cities and industrial establishments. This lockdown could be used as an opportunity to improve our understanding of river rejuvenation and manage the water resources effectively. However, such analyses should focus on local/regional scale studies, including simulation and modeling exercises for scientifically investigating the time required for each river to get back to background levels in terms of water quality as reported in Rajaram and Das (2008) (e.g., pre-industrialization and urbanization). Therefore, the data collected during the COVID-19 lockdown period might serve as baseline data, which would help perform various analyses to understand the pre-, during-, and post COVID-19 impacts. Further, studies are needed that use physics-based distributed hydrological models to assess the total pollutant load and identify their exact sources. Despite the non-availability of finer-resolution spatio-temporal water quality data, empirical and statistical water quality models could be applied to meet the data requirements. Further, remote sensing data could also be used as a tool for collecting water quality data to complement ground-based real-time data. Such approaches will enhance our understanding of the impact of lockdown on water quality.

DOMESTIC AND COMMERCIAL WATER SECTOR

Similar to the river water quality, domestic and commercial water sectors were also disrupted during the lockdown due to COVID-19. The lockdown has increased the domestic water demand and decreased the non-domestic (i.e., commercial, industrial, and institutional) demand. The net effect of these changes varies from place to place, depending on the relative proportion of domestic and non-domestic water usage across the major economic sectors (Cooley et al., 2020). Many municipalities have seen a sharp increase in domestic water consumption of (e.g., Kozhikode -Kerala; Ahmedabad—Gujarat) up to 25% (The Times of India, 2020a). However, few places reported a decrease in water consumption due to reduced commercial activities (e.g., Udupi—Karnataka) during the lockdown (Daijiworld, 2020). Since personal hygiene is one of the most important measures to prevent infection with the COVID-19 virus (WHO, 2020), the demand for water has increased under the “living with COVID-19” condition (Sivakumar, 2021). The future water demand, mainly for domestic consumption, would be based on how a majority of the population prefer to work in post-COVID-19 periods as there is evidence for increased demand for packaged and or bottled water consumption in global cities (Bloomberg, 2020; Food Water Watch, 2020; IWA, 2020). The majority of Indian cities face similar issues as they lack uninterrupted water supply from the respective municipal corporations even before COVID-19 impact. Usually, the water supply in these Indian cities is only ~2–3 h on average per day (Hughes et al., 2017). As compared to the service benchmark of 135 liters per capita per day (lpcd), only 69 lpcd on average has been recorded in

most of the Indian cities (Hughes et al., 2017; TERI, 2018; The Diplomat, 2020). These scenarios may further worsen in summer due to sourcing issues such as limited water storage capacities. Lack of water supply has already created work from home culture, mainly in the Information Technology (IT) sector. For example, one of the India's big IT companies has announced that 75% of its half-million employees would work from home in the post-COVID-19 period (Business today, 2020). Similarly, other service oriented industrial sectors are also considering to move into work from home options (Bangalore Mirror, 2020; The Times of India, 2020b). While a significant amount of water could potentially be saved in these commercial sectors and diverted to domestic use, the waste generation at commercial hubs would also be substantially reduced, thereby decreasing the burden of disposing off the wastes safely. For example, the city of Chennai transports at least 30 million liters per day of water to the commercial IT sector (Packialakshmi et al., 2011), and this quantity may potentially be diverted to domestic usage, perhaps to meet the increase in per capita requirement.

All these effects would significantly influence the demand and supply patterns of water and corresponding policy to cater to the need for domestic and commercial sectors during the post-COVID-19 periods, at least in the near future. However, the lack of data on the water use of different domestic and commercial sectors to conduct detailed quantitative analyses remain a challenging task in India. It is evident that there is a significant change in water-use patterns in domestic and commercial sectors during the lockdown period. However, the following questions still need to be addressed: (i) how has the change in water-use pattern been realized in different urban regions with varying population density and industrial/commercial activities across the country?; (ii) what was resilience of municipalities in handling the sudden shift in water-demand pattern during the lockdown?; (iii) what was demand-supply gap during the lockdown, and water sourcing issues during peak summer?, and (iv) how will the change in water-use pattern last even after the unlock and set a new normal?

Despite the lack of data, alternate ways of addressing these problems need to be developed using secondary or surrogate data. For example, (i) a shift in domestic water consumption pattern may take into account the population migration scenarios before and during the lockdown, and (ii) demarcating the serviced and non-serviced areas and overlaying with the population migration patterns. The assessment of change in water consumption patterns is crucial for policy and decision-makers to manage the urban water requirement during any future pandemic situations to support appropriate action and to maintain various water utilities.

Recent sensor-based techniques for replacing the traditional water meter can be used to monitor the water usage in the domestic and commercial sectors. Toward such a goal, Kalbusch et al. (2020) analyzed the water consumption data of the city of Joinville in Brazil using various statistical methods such as the Shapiro–Wilk normality test (Ghasemi and Zahediasl, 2012), and a non-parametric paired Wilcoxon test (Tian et al., 2019). The results revealed that there is more water consumption in residential buildings compared to industrial and public buildings

before and after the lockdown periods. Such research studies that closely monitor different economic segments (i.e., high, middle, and low income) in the urban settlements for the possible changes in supply-demand patterns during the post-COVID-19 period will provide additional insights. Thus, creating a comprehensive database for domestic and commercial water use with improved monitoring devices, various machine learning algorithms (Kasiviswanathan et al., 2016; Sun and Scanlon, 2019) and empirical models (Huang et al., 1998) can be exploited to extract the useful information for managing the urban water requirement.

WASTEWATER SECTOR

The COVID-19 virus is enveloped with a fragile external membrane that are less stable and more sensitive to oxidants (Lapolla et al., 2020; Quilliam et al., 2020). Hence, this type of virus might quickly be inactive compared to other viruses that enable water-based transmission (Kataki et al., 2020). The degree to which the coronavirus persist and potentially remain infectious in wastewater is dependent on a number of factors such as resident duration of water, type of treatment, and prevailing environmental conditions (Ahmed et al., 2020; Boneh, 2020). However, the World Health Organization (WHO) has confirmed that the human coronavirus might survive only 2 days in dechlorinated water and hospital wastewater (i.e., Temperature $\sim 20^{\circ}\text{C}$). Monitoring the community sewage for the presence of virus had played an important role in determining the total cases (both symptomatic and asymptomatic cases) in the past (Bogler et al., 2020; STOTEN, 2020). Effective surveillance will be helpful in identifying the infection hotspots at the sewer shed level. While sampling at a finer resolution and covering a larger geographical extent is challenging even in the high-resources setting, it is quite difficult in developing nations like India, where the majority of the population is not connected with wastewater treatment plants (WWTPs) rather they are using septic systems and/or open drains. In India, around 70% of sewage generated in urban areas is discharged directly into the nearby streams or water bodies without treatment. The remaining treated sewage water, and final bio-solids of WWTPs are used in the irrigation field to improve soil fertility (Núñez-Delgado, 2020). While the paradigm of this wastewater based COVID-19 monitoring is difficult to understand even in the high-resource settings, it is further complicated in lower-resource settings like India and other developing nations, thus, it will be difficult to conduct any quantitative analysis based on the available data/information.

For this purpose, Wastewater Based Epidemiology (WBE) has increasingly been employed as a complementary monitoring mechanism to identify the population-wide infection for early warning, which indicates the virus spread in the communities (STOTEN, 2020). In the WBE surveillance approach, the wastewater samples are collected from WWTPs to identify the presence of detectable viral RNA, which could be correlated with the total number of infected cases/infection increase/decrease rate (Sims and Kasprzyk-Hordern, 2020). Therefore, allocating more resources toward WWTPs and ensuring suitable treatment

technologies to trace the viruses are crucial to handle future pandemic situations (Bogler et al., 2020). In the near future, wastewater monitoring needs to be improved to collect real-time comprehensive and objective data to detect emergence and re-emergence of new and old diseases, respectively, the threat of imported pathogens, and the existence of multidrug or pan-drug resistant organisms (Sims and Kasprzyk-Hordern, 2020) that provide better flexibility to monitor diseases through scalable and cost-effective techniques under a low resource setting.

While tools like WBE is already reported in the literature (Hart and Halden, 2020; Sims and Kasprzyk-Hordern, 2020) as it has the potential to monitor the progress of disease and act as surveillance systems, the real-time monitoring at a different time and spatial scales is a cumbersome process. Under these limitations, the recent advancements in sensors, Internet of Things (IoT), cloud-based data management, and application of deep learning methods would offer the solutions for effectively monitoring and operating the WWTPs through automated alerts about the potential infectious substances, and provide useful information for decision making (USEPA, 2018; Kando, 2020). Hence, it is the right time for researchers and application developers to start developing efficient technologies/platforms using state-of-the-art sensing, computing, and communication resources. The following questions need to be addressed through future research studies:

- (i) How do we overcome the difficulties in employing environmental surveillance techniques like WBE in a lower-resource setting like India? What type of surrogate datasets and methodologies could be employed?
- (ii) What are the effects of untreated wastewater carrying viral strain on surface and groundwater systems, crop irrigations, and water re-use?
- (iii) Are we equipped with adequate treatment technologies to treat viral strains and future pandemics?

Thus, this pandemic situation could be used as a key to improve the capacity building toward: (i) infrastructure creation (connecting all rural and urban places with STPs and building new STPs); (ii) re-evaluation and enhancement of existing treatment procedures; (iii) real-time data monitoring at finer spatial and temporal scale; and (iv) using state-of-the-art sensing and computing techniques, to manage the future pandemics effectively.

AGRICULTURAL AND FOOD SECTOR

Indian economy is largely driven by the agricultural sector with around 18% of GDP and provides livelihood to 58% of the population. Already Indian farmers face several issues such as monsoon delays or failures, extreme weather conditions, price volatility, and rising debt. In addition, the COVID-19 pandemic has created new challenges that were previously not experienced by the agriculture sector. Due to the COVID-19 lockdown, most of the agricultural activities had been suspended or postponed for at least a couple of months (i.e., from March to

May 2020), which has direct impacts on the water withdrawals for irrigation and crop production (FAO, 2020; WEF, 2020) and allied sectors (IHS Markit, 2020). It is estimated that the reduction in food grain production in India during the lockdown period due to massive reverse migration (i.e., labor shortage) can be as high as 23% (Balwinder-Singh et al., 2020) even after providing relaxation to agricultural activities (i.e., exemption from lockdown restrictions). Reduced agricultural activities and supply chain has declined the vegetables, fruits, and oil supply by 10% in India but, with minimal impact on prices (Mahajan and Tomar, 2020). Due to less agricultural activities, the ministry of water resources in India reported that the average discharge in the Yamuna river for this period has increased from 300 to 3,000 cusecs (Financial Express, 2020). The water storage status of 123 major reservoirs (as on May 06, 2020) was 68.036 billion cubic meters (BCM), which is 159% of the last 10 years' average storage of 41.328 BCM for the same period (CWC, 2020). However, the extent of the decrease in reservoir releases for irrigation is largely unknown. Also, a similar reduction may be possible in groundwater usage since the lockdown because it supports around two-third of irrigated agriculture in India. However, lack of data hinders any quantitative analysis about changes in water withdrawals for agriculture during the lockdown period. Bhakra Beas Management Board (a federal agency in India regulating water supply and power generation in Beas-Satlaj river basins) has advised its stakeholder states to draw more water from its canal network to recharge the groundwater in order to drain the reservoirs (The Tribune, 2020). This could be partly due to reduced irrigation demand as well as increased inflows to the reservoirs. The lockdown has created a huge disturbance among migrant laborers who participate in seasonal harvesting activities. While reduced agricultural activity could significantly affect the overall agricultural production, imposing restrictions on transportation would further disturb the supply chain management. Though policies and regulations that are followed differ from state to state, any imbalance in the agricultural production would impact the demands of other states of the country. If this prolongs after the COVID-19 peak, that will end up in resulting widespread famine and lead to uncertainty in the food security of the country (Stephens et al., 2020). Overall, this will not only impact the country level supply but would also seize the opportunity in the global level trading as India exports a large volume of rice, wheat, meat, milk products, tea, honey, and horticultural products.

Quantifying the exact supply-demand pattern is difficult as many people are involved in the intermediate handling of the agricultural products starting from the farmer's field to consumers. Multiple stakeholders involving long supply chain management are always challenging to handle if any future pandemic situation occurs. Adequate tools should be created for mapping and optimizing the supply chain management for increasing the overall resilience of the system. In addition, we need to create clear mechanisms to assess the short- and long-term consequences of water use in the agricultural sector. As India's 40% food grains are produced by small farmers (owners of <2.5 hectares of land), they should be encouraged for increasing agricultural productivity through

implementation of resilient agricultural practices (Neal, 2020) such as adaptation to climate change, landscape protection and biodiversity maintenance, thereby simplifying the complex supply-demand pattern. Government may encourage private sectors to create more grain storage facilities across the country to handle future pandemic situations. Developing a decision-making support system for planning the irrigation under changing climate should be encouraged. This should also include the tools to perform river basin scale analyses mainly for diversion of unused irrigation water to other sectors.

SUSTAINABLE DEVELOPMENT GOALS (SDGs)

The SDGs related to water, such as SDG-06 (Clean Water and Sanitation) with subclasses 6.1 to 6.5, 6A, and 6B is on track to achieve universal and equitable access to safe and affordable drinking water for all by 2030. However, the impact of COVID-19 on the SDG plans is yet to be assessed. On a positive impact, the growing importance of public health due to COVID-19 are urging the government to prioritize the supply of clean water to their citizens. Also, due to the pandemic, there are possibilities for an immediate increase in assistance from international organizations like WHO, UNICEF, UN-Water, and Red Cross and Red Crescent to less developed countries toward better water supplies and access (Cooper, 2020; IMF, 2020). In contrast, the present situation across India has created a huge economic loss and unemployment situation. This may be a threat for non-water-based SDGs such as no poverty (SDG-01), Zero Hunger (SDG-02), public health (SDG-03), and gender equality (SDG-10), and thus, may create an imbalance in government actions on water-related SDGs as well. Before the pandemic, the global water use had increased by a factor of six over the century, and the majority (up to 70%) was used for irrigation, and the remaining 30% was consumed across other sectors such as industry and domestic use (WEF, 2020). However, the recent multi-fold surge in water demand for health and hygiene and the corresponding change in dynamics across sectors are difficult to quantify due to non-availability of data, which calls for intensive data monitoring on sector-specific aspects. Thus, a better way forward in developing countries such as India may be to reallocate their internal resources to increase the priority toward improving the supply of safe water (Thethirdpole, 2020). Also, we need to strengthen government capacities to anticipate and manage unforeseen disruptive events. Considering the above aspects, the possibilities of achieving the SDG goals may be higher. Further, the SDGs targets need to be reassessed on the possible implementation timeframe, which may differ due to COVID-19 disruptions.

SUMMARY AND CONCLUSIONS

The impacts of COVID-19 on water resources and immediately associated sectors in India were discussed based on the: (i) current impacts, (ii) deficiencies that prevent adequate

quantitative assessment, (iii) future needs, guidance, and recommendations, and (iv) what might be achieved if these recommendations are followed. Overall, the discussion highlighted the significant effects of COVID-19 lockdown on the water resources, both in quality and quantity, such as (i) improvements in water quality in some reaches of rivers due to COVID-19 lockdown that prevented industrial effluent discharge, (ii) shift in water demand-supply patterns in domestic and commercial sectors, (iii) disruptions in agricultural activities with minimal impact on prices and changes in agricultural water usage patterns and (iv) need for re-assessment of SDG goals. Also emphasized the need for (i) strengthening the data monitoring process and the creation of sector-specific comprehensive databases, (ii) creation of surrogate data for immediate analyses, (iii) comprehensive modeling frameworks to understand the sources and governing factors, and (iv) re-assessment of SDG goals due to pandemic disruptions. The data measurements and estimations during the lockdown period may serve as reference data for the baseline scenario in water sectors, including water consumption, wastewater discharge, treatment facilities, and groundwater withdrawals, to estimate the future anthropogenic effects in these sectors. Adopting advanced technologies such as remote sensing, the internet of things, and artificial intelligence would improve the management capabilities toward a comprehensive monitoring and modeling system and complement the research activities. Though the discussions on the current issues and the potential for further research outlined in this paper are limited to the Indian context, we believe that these suggestions are applicable to most of the developing countries supported by quantitative analyses with relevant data.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

ACKNOWLEDGMENTS

The authors would like to thank the Editor, Prof Praveen Kumar, and reviewers for providing valuable suggestions that helped to improve the quality of the manuscript significantly. We would like to also acknowledge the Ministry of Human Resources Development, Government of India, for supporting this research work under the Scheme for Promotion of Academic and Research Collaboration (Project Code: SPARC/2018-2019/P1228/SL).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frwa.2021.603531/full#supplementary-material>

Supplementary Figure 1 | Major river basins and cities (discussed in the manuscript).

REFERENCES

- Ahmed, W., Angel, N., Edson, J., Bibby, K., Bivins, A., O'Brien, J. W., et al. (2020). First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: a proof of concept for the wastewater surveillance of COVID-19 in the community. *Sci. Total Environ.* 728:138764. doi: 10.1016/j.scitotenv.2020.138764
- Avdan, Y. Z., Kaplan, G., Goncu, S., and Avdan, U. (2019). Monitoring the water quality of small water bodies using high-resolution remote sensing data. *ISPRS Int. J. Geo-Inf.* 8, 553. doi: 10.3390/ijgi8120553
- Balwinder-Singh, Shirsath, P. B., Jat, M. L., McDonald, A. J., Srivastava, A. K., Craufurd, P., et al. (2020). Agricultural labor, COVID-19, and potential implications for food security and air quality in the breadbasket of India. *Agric. Syst.* 185, 102954. doi: 10.1016/j.agsy.2020.102954
- Bangalore Mirror (2020). *How COVID-19 Will Change the Workplace*. Available online at: <https://bangaloremirror.indiatimes.com/bangalore/cover-story/how-covid-19-will-change-the-workplace/articleshow/75383072.cms> (accessed May 06, 2020).
- Batur, E., and Maktav, D. (2019). Assessment of Surface water quality by using satellite images fusion based on PCA method in the Lake Gala, Turkey. *IEEE Trans. Geosci. Remote Sens.* 57, 2983–2989. doi: 10.1109/TGRS.2018.2879024
- Bloomberg (2020). *Danone Says Coronavirus Weighs on Bottled Water Sales*. Available online at: <https://www.bloomberg.com/news/articles/2020-02-26/danone-cuts-outlook-as-coronavirus-weighs-on-bottled-water-sales> (accessed May 01, 2020).
- Bogler, A., Packman, A., Furman, A., Gross, A., Kushmaro, A., Ronen, A., et al. (2020). Rethinking wastewater risks and monitoring in light of the COVID-19 pandemic. *Nat. Sustain.* 3, 981–990. doi: 10.1038/s41893-020-00605-2
- Boneh, I. (2020). *COVID-19 and Wastewater Utilities*. Guest Column. Water online. Available online at: <https://www.wateronline.com/doc/covid-and-wastewater-utilities-0001> (accessed May 06, 2020).
- Business today (2020). *Post-COVID, 75% of 4.5 Lakh TCS Employees to Permanently Work from Home by '25 from 20%*. Available online at: <https://www.businesstoday.in/current/corporate/post-coronavirus-75-percent-of-3-5-lakh-tcs-employees-permanently-work-from-home-up-from-20-percent/story/401981.html> (accessed April 28, 2020).
- Cooley, H., Gleick, P. H., Abraham, S., and Cal, W. (2020). *How the Coronavirus Pandemic is Affecting Water Demand Changes in Water Demand*. Available online at: <https://pacinst.org/publication/coronavirus-impacts-on-municipal-water-demand/> (accessed August 15, 2020).
- Cooper, R. (2020). *Water Security Beyond Covid-19*. Brighton: Institute of Development Studies. Available online at: <https://gsdrc.org/publications/water-security-beyond-covid-19/> (accessed June 15, 2020).
- CPCB (2015). *Directions Issued under Section 5 of EPA Act, 1986 Regarding Treatment and Utilization of Sewage for Restoration of Water Quality of River to Metropolitan Cities and States/UT Capitals*. Available online at: <http://www.indiaenvironmentportal.org.in/content/420116/directions-issued-under-section-5-of-epa-act-1986/> (accessed October 19, 2020).
- CWC (2020). *Brief Note on Live Storage Status of 123 Reservoirs in the Country (With Reference to Reservoir Storage Bulletin of 6.5.2020)*, Central Water Commission, India. Available online at: <http://www.cwc.gov.in/sites/default/files/05.03.2020-fb-pdf.pdf> (accessed May 08, 2020).
- Daijiworld (2020). *Baje Dam has Enough Storage, No Water Woes for Udupi*. Available online at: <https://www.daijiworld.com/news/newsDisplay.aspx?newsID=705405> (accessed May 08, 2020).
- Dutta, V., Dubey, D., and Kumar, S. (2020). Cleaning the river ganga: impact of lockdown on water quality and future implications on river rejuvenation strategies. *Sci. Total Environ.* 743:140756. doi: 10.1016/j.scitotenv.2020.140756
- FAO (2020). *Keeping Food and Agricultural Systems Alive - Analyses and Solutions in a Period of Crises - COVID-19 Pandemic*. Available online at: <http://www.fao.org/2019-ncov/analysis/en/> (accessed May 07, 2020).
- Financial Express (2020). *Jal Shakti: Water Availability Good but Difficult for States to Spend on Projects Due to Lockdown; details*. Available online at: <https://www.financialexpress.com/infrastructure/jal-shakti-water-availability-good-but-difficult-for-states-to-spend-on-projects-due-to-lockdown-details/1948971/> (accessed May 08, 2020).
- Food and Water Watch (2020). *Coronavirus has Brought a Major Warning About Our Water*. Available online at: <https://www.foodandwaterwatch.org/news/coronavirus-has-brought-major-warning-about-our-water> (accessed May 06, 2020).
- Ghasemi, A., and Zahediasl, S. (2012). Normality tests for statistical analysis: a guide for non-statisticians. *Int. J. Endocrinol. Metab.* 10, 486–489. doi: 10.5812/ijem.3505
- Hart, O. E., and Halden, R. U. (2020). Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: feasibility, economy, opportunities and challenges. *Sci. Total Environ.* 730, 138875. doi: 10.1016/j.scitotenv.2020.138875
- Huang, N. E., Shen, Z., Long, S. R., Wu, M. C., Shih, H. H., Zheng, Q., et al. (1998). The empirical mode decomposition and the Hilbert spectrum for nonlinear and nonstationary time series analysis. *Proc. R. Soc. A* 454, 903–995. doi: 10.1098/rspa.1998.0193
- Hughes, S., Chu, E. K., and Mason, S. G. (2017). *Climate Change in Cities: Innovations in Multi-Level Governance*. Springer-Science, 378. doi: 10.1007/978-3-319-65003-6
- IHS Markit (2020). *COVID-19: Effects on the Fertilizer Industry, Agribusiness Analysis and Research Report*. Available online at: <https://ihsmarkit.com/research-analysis/report-covid19-effects-on-the-fertilizer-industry.html> (accessed May 07, 2020).
- IMF (2020). *World Economic Outlook. Chapter 1: The Great Lockdown. International Monetary Fund Report*. Available online at: <https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020> (accessed May 08, 2020).
- India Water Portal (2020). *COVID-19 Lockdown: Health of Ganga and Yamuna Rivers Improves*. Available online at: <https://www.indiawaterportal.org/articles/covid-19-lockdown-health-ganga-and-yamuna-rivers-improves> (accessed April 27, 2020).
- IWA (2020). *COVID-19 and 'Chasing for Water' - Water Access in Poor Urban Spaces*. Available online at: <https://iwa-network.org/covid-19-and-chasing-for-water-water-access-in-poor-urban-spaces> (accessed April 27, 2020).
- Jain, S. K. (2015). *Hydrologic Inputs for Ganga rejuvenation, Presentation at the Future Ganga Workshop*. Available online at: <https://www.ceh.ac.uk/sites/default/files/Future%20Ganga%20Workshop%20-%20Sharad%20Jain%20-%20NIH.pdf> (accessed May 07, 2020).
- Kalbusch, A., Henning, E., Brikalski, M. P., Vieira de Luca, F., and Konrath, A. C. (2020). Impact of coronavirus (COVID-19) spread-prevention actions on urban water consumption. *Resour. Conserv. Recycl.* 163, 105098. doi: 10.1016/j.resconrec.2020.105098
- Kando (2020). *Israeli Firm Using IoT to Halt Looming COVID-19 Wastewater Crisis*. *Environment News*. Available online at: <https://nocamels.com/2020/04/israeli-firm-iot-covid-19-wastewater-crisis/> (accessed May 06, 2020).
- Kasiviswanathan, K. S., Saravanan, S., Balamurugan, M., and Saravanan, K. (2016). Genetic programming based monthly groundwater level forecast models with uncertainty quantification. *Model. Earth Syst. Environ.* 2, 27. doi: 10.1007/s40808-016-0083-0
- Kataki, S., Chatterjee, S., Vairale, M. G., Sharma, S., and Dwivedi, S. K. (2020). Concerns and strategies for wastewater treatment during COVID-19 pandemic to stop plausible transmission. *Resour. Conserv. Recycl.* 164, 105156. doi: 10.1016/j.resconrec.2020.105156
- KSPCB (2020). *Cauvery, Tributaries Look Cleaner as Pandemic Keeps Pollution Away*. Available online at: <https://www.thehindu.com/news/national/karnataka/cauvery-tributaries-in-old-mysuru-region-look-cleaner-as-pandemic-keeps-pollution-away/article31210429.ece> (accessed April 20, 2020).
- Lapolla, P., Lee, R., and Mingoli, A. (2020). Wastewater as a red flag in COVID-19 spread. *Public Health.* 185, 26. doi: 10.1016/j.puhe.2020.05.045
- Mahajan, K., and Tomar, S. (2020). *Here Today, Gone Tomorrow: COVID-19 and Supply Chain Disruption - Working Paper*. Ashoka University.
- NASA (2017). *Satellite Observations of Water Quality for Sustainable Development Goal 6, GEO Week 2017, October 24*. NASA's Applied Remote Sensing Training Program. Available online at: https://arset.gsfc.nasa.gov/sites/default/files/water/GEOWeek17/GEO-24Oct_final.pdf (accessed May 08, 2020).
- Neal, M. J. (2020). COVID-19 and water resources management: reframing our priorities as a water sector. *Water Int.* 45, 435–440. doi: 10.1080/02508060.2020.1773648

- Novoa, S., Chust, G., Sagarmínaga, Y., Revilla, M., Borja, A., and Franco, J. (2012). Water quality assessment using satellite-derived chlorophyll-a within the European directives, in the southeastern Bay of Biscay. *Mar. Pollut. Bull.* 64, 739–750. doi: 10.1016/j.marpolbul.2012.01.020
- Núñez-Delgado, A. (2020). What do we know about the SARS-CoV-2 coronavirus in the environment? *Sci. Total Environ.* 727, 138647. doi: 10.1016/j.scitotenv.2020.138647
- Packialakshmi, S., Ambujam, N. K., and Nelliya, P. (2011). Groundwater market and its implications on water resources and agriculture in the southern peri-urban interface, Chennai, India. *Environ. Dev. Sustain.* 13, 423–438. doi: 10.1007/s10668-010-9269-1
- Quilliam, R. S., Weidmann, M., Moresco, V., Purshouse, H., O'Hara, Z., and Oliver, D. M. (2020). COVID-19: the environmental implications of shedding SARS-CoV-2 in human faeces. *Environ. Inter.* 140, 105790. doi: 10.1016/j.envint.2020.105790
- Rajaram, T., and Das, A. (2008). Water pollution by industrial effluent in India: discharge scenarios and case for participatory ecosystem specific local regulation. *Futures* 40, 56–69. doi: 10.1016/j.futures.2007.06.002
- Shukla, T., Sen, I. S., Boral, S., and Sharma, S. (2021). A time-series record during COVID-19 lockdown shows the high resilience of dissolved heavy metals in the Ganga River. *Environ. Sci. Technol. Lett.* doi: 10.1021/acs.estlett.0c00982
- Sims, N., and Kasprzyk-Hordern, B. (2020). Future perspectives of wastewater-based epidemiology: monitoring infectious disease spread and resistance to the community level. *Environ. Int.* 139, 105689. doi: 10.1016/j.envint.2020.105689
- Sivakumar, B. (2021). COVID-19 and water. *Stoch Environ Res Risk Assess* 35, 531–534. doi: 10.1007/s00477-020-01837-6
- Smart water magazine (2020). *India's Rivers Benefit from Lockdown*. Available online at: <https://smartwatermagazine.com/news/smart-water-magazine/indias-rivers-benefit-lockdown> (accessed April 29, 2020).
- Stephens, E. C., Martin, G., van Wijk, M., Timsina, J., and Snow, V. (2020). Impacts of COVID-19 on agricultural and food systems worldwide and on progress to the sustainable development goals. *Agric. Syst.* 183, 102873. doi: 10.1016/j.agsy.2020.102873
- STOTEN (2020). *Editors' Choice: FOCUS on Covid-19 Diagnosis by Wastewater-Based Epidemiology: SARS-CoV-2 Concentration and Detection Methods, Biomarkers and Future Perspectives*. Available online at: <https://www.journals.elsevier.com/science-of-the-total-environment/editors-choice/focus-on-covid-19-diagnosis-by-wastewater-based-epidemiology> (accessed November 21, 2020).
- Sun, A. Y., and Scanlon, B. R. (2019). How can Big Data and machine learning benefit environment and water management: a survey of methods, applications, and future directions. *Environ. Res. Lett.* 14, 073001. doi: 10.1088/1748-9326/ab1b7d
- TERI (2018). *India's Rampant Urban Water Issues and Challenges, Study by the Energy and Resources Institute*. Available online at: <https://www.teriin.org/article/indias-rampant-urban-water-issues-and-challenges> (accessed May 06, 2020).
- The Diplomat (2020). *Unraveling Urban India's Water Challenges Amid COVID-19*. Available online at: <https://thediplomat.com/2020/04/unraveling-urban-indias-water-challenges-amid-covid-19/> (accessed April 30, 2020).
- The Times of India (2020a). *Chennai: No Water, Work from Home, IT Firms Tell Staff*. Available online at: <https://timesofindia.indiatimes.com/city/chennai/no-water-work-from-home-it-cos-tell-staff/articleshow/69763283.cms> (accessed April 29, 2020).
- The Times of India (2020b). *Excessive Water Usage During Lockdown a Cause of Worry: KWA*. Available online at: <https://timesofindia.indiatimes.com/city/kozhikode/excessive-water-usage-during-lockdown-a-cause-of-worry-kwa/articleshow/75249147.cms> (accessed May 05, 2020).
- The Tribune (2020). *Expecting Massive Inflows, Bhakra Beas Management Board Advises States to be Proactive*. Available online at: <https://www.tribuneindia.com/news/punjab/expecting-massive-inflows-bhakra-beas-management-board-advises-states-to-be-proactive-80695> (accessed May 06, 2020).
- TheThirdpole. (2020). *Pandemic Effect - Can We Save the SDG on Water and Sanitation?* Available online at: <https://www.thethirdpole.net/2020/04/28/pandemic-effect-can-we-save-the-sdg-on-water-and-sanitation/> (accessed May 01, 2020).
- Tian, F., Lu, Y., Hu, H., Kinzelbach, W., and Sivapalan, M. (2019). Dynamics and driving mechanisms of asymmetric human water consumption during alternating wet and dry periods. *Hydrol. Sci. J.* 64, 507–524. doi: 10.1080/02626667.2019.1588972
- USEPA (2018). *Online Water Quality Monitoring in Distribution Systems for Water Quality Surveillance and Response System*. Technical Report, Office of Water (MC-140) - EPA817-B-18-001-APRIL2018.
- WEF (2020). *Five Lessons for the Future Water*. Available online at: <https://www.weforum.org/agenda/2020/04/covid-19-water-what-can-we-learn/> (accessed May 07, 2020).
- WHO (2020). *Water, Sanitation, Hygiene, and Waste Management for the COVID-19 Virus - Interim Guidance*. Available online at: https://apps.who.int/iris/bitstream/handle/10665/331846/WHO-2019-nCoV-IPC_WASH-2020.3-eng.pdf (accessed October 20, 2020).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2021 Balamurugan, Kasiviswanathan, Ilampooranan and Soundharajan. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.