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POSSIBLE IMPACTS OF COVID-19 PANDEMIC ON DOMESTIC WASTEWATER CHARACTERISTICS IN KUWAIT

Mohd Elmuntasir AHMED[1*], Adel AL-HADDAD[2], Ali BUALBANAT[3]

[1, 2]Water Research Center, Kuwait Institute for Scientific Research, P.O. Box 24885, 13109 Safat, Kuwait
[3]Ministry of Public Works, P.O. Box 8, 13001 Safat, Kuwait

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Highlights

- Assessment of the daily flow rates and concentrations of raw wastewater from the largest catchment in Kuwait City was conducted for the records of the period from 2015 to 2020.
- The aim is to investigate how the characteristics of wastewater has been altered by the COVID-19 pandemic.
- While population decreased, the average wastewater flow rates in 2020 is 8.8% higher than 2015–2019 average.
- BOD, O&G, NH_4-N, NO_3-N, NO_2-N, alk., TKN, and T.C. concentrations were found to have significant differences between 2020 and 2015–2019.
- An increase in the frequency of COD/BOD ratio > 3, TP in the range 6.5 to 8.5, TKN in the range 40 to 50 was observed in 2020 compared to 2015–2019.

Abstract. The wastewater quality alterations due to the use of cleaning agents, sanitisers, and disinfectants, in addition to the accompanying use of water during COVID-19 have potential impacts on wastewater treatment operations. How the characteristics of wastewater could be altered by the COVID-19 pandemic was the concern of this investigation. Daily records of the Ardiya catchment in Kuwait City were examined for the period 2015–2020. Perhaps due to the excessive use of water during 2020 (446 compared to the five-year average of 436 l/c.d) and the corresponding wastewater generation increase (253 compared to the five-year average of 239 l/c.d), the effect of chemical usage on the wastewater quality has dampened. Nonetheless, an increase in the frequency of COD/BOD ratio > 3, TP in the range 6.5 to 8.5, TKN in the range 40 to 50 were observed in 2020, which was not observed during 2015–2019. These COVID-19 related alterations are important to take into consideration in wastewater treatment operations to achieve wastewater treatment targets.

Keywords: wastewater, characterisation, flowrate, COVID-19, pandemic, pollution.

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Introduction

Worldwide ramifications and impacts of COVID-19 have since been more severe than the first reported case in Wuhan, China in December 2019. Evidently, some of the major impacts of COVID-19 have been on the water sector, wastewater, and aquatic systems (Lodder & de Roda Husman, 2020; Mallapaty, 2020; Hellmer et al., 2020; Blanco et al., 2019; Kitajima et al., 2020; Naddeo & Liu, 2020; Randazzo et al., 2020; Kumar et al., 2020; Balboa et al., 2020), presence and spread of COVID-19 through water and wastewater (Choudri & Charabi, 2019; Naddeo & Liu, 2020; Quilliam et al., 2020; Liu et al., 2020; Santarpia et al., 2020; Long et al., 2020), vulnerability of water and wastewater sector operators, and methods of detection and treatment in water and wastewater (Ahmed et al., 2020; Medema et al., 2020; Wu et al., 2020; Nemudryi et al., 2020; Peccia et al., 2020; Wurtzer et al., 2020; Usman et al., 2020; Haramoto et al., 2020; Zhang et al., 2020a; Bar Or et al., 2020; Kumar et al., 2020; Randazzo et al., 2020; Balboa et al., 2020; Kocamemi et al., 2020). Little attention has been paid to how the COVID-19 pandemic control

*Corresponding author. E-mail: *miahmed@kisr.edu.kw*

measures impacted the wastewater quality, which is an important factor to take into account to achieve wastewater treatment objectives.

Since the outbreak of COVID-19 and as a result of the WHO recommendation for disinfecting hands and surfaces in order to limit the spread of the virus, the use of various cleaning agents has increased. Therefore, COVID-19 pandemic control measures can affect the quality of wastewater in a given community, which is a challenge for decision-makers to adopt proper strategies by monitoring the wastewater (Mousazadeh et al., 2021). Additionally, there are potential impacts of this wastewater characteristics alteration on wastewater treatment operations. Wastewater treatment efficiency relies to a great extent on raw wastewater quality. One crucial and urgent means to achieve good operation, maintenance, and effluent quality in wastewater treatment operations is to look into variation in wastewater quality parameters (Pirsaheb et al., 2014). A number of external variables, such as season, flow, and consumer behavior could influence wastewater characteristics (Raptopoulou et al., 2016). These characteristics may have been greatly altered by the COVID-19 pandemic, for reason of changes in human water use and wastewater production behavior, imposed by the restrictive measures to control the spread of COVID-19. Accordingly, it would be of utmost importance to know how wastewater parameters have been impacted by the COVID-19 pandemic and to examine their patterns during the period of the pandemic. For example, if higher nutrient concentrations were observed in the influent of a wastewater treatment plant; subsequently, this plant would be overloaded; and thus, appropriate (temporary) changes in the operating conditions would be needed. In addition, by obtaining such knowledge, a specific protocol could be developed to mitigate the effect of the COVID-19 pandemic on wastewater treatment operations (Anayah et al., 2021). The concern has been that concentrations of chemicals could reach inhibitory levels and further alter the wastewater, significantly rendering them challenging to treat or would even cause malfunctions in wastewater treatment plants (WWTPs).

Indisputably, sanitising, disinfecting, and cleaning chemicals could also augment the degree of contamination in wastewater. Additionally, consumer habits during the COVID-19 pandemic, such as frequent washing of hands and clothing could produce wastewater contaminated with surfactants, thereby reducing water quality; therefore, wastewater treatment could become even more challenging. At the same time, wastewater containing soaps and detergents and is directly discharged into freshwater bodies without any treatment could have harmful effects on health and the environment (Lechuga et al., 2016; Pattusamy et al., 2013).

Correspondingly, excessive use of disinfectants, such as sodium hypochlorite that is used as a disinfectant against SARS-COV-2, has harmful consequences on wastewater treatment systems. The residual chlorine reacts with organic matter, mainly with the humic and fulvic acids and leads to the formation of trihalomethane compounds. Since these compounds have mutagenic and/or carcinogenic activity in aquatic organisms (Emmanuel et al., 2004), they become harmful to humans and marine ecosystems (Hamed et al., 2017) Likewise, chlorine and quaternary ammonium compounds in wastewater promote resistance to antibiotics (Bernstein & Cottingham, 2015; Mulder et al., 2018), which could even generate a more serious health problem than what has currently been caused by SARS-CoV-2 coronavirus.

Cleaning agents containing quaternary ammonium compounds can react with the chloramines, during chlorine disinfection, to produce carcinogenic byproducts such as nitrosamine (Hora et al., 2020; Campbell & Wang, 2020). According to Young (2001), problems occur infrequently when the chemical agents are used sparingly and are discharged to the treatment works at continuous, but low concentrations. However, large amounts of chemical agents can be discharged at one time during weekly cleaning-in-place and disinfecting operations. The resulting slug dose can interfere with the normal performance of the treatment plant and cause violations of discharge permits for COD, BOD, ammonia, or phosphorus. In extreme cases, process failure can occur (Young, 2001).

Most of the disinfectants used in medical centers are sodium hypochlorite-based (Environmental Services and Regulation, 2015; Fukuzaki, 2006; Rutala & Weber, 1997). During the COVID-19 pandemic, heavy usage of these disinfectant products has become almost of a practice and a habit in households. In effect, the percentage of waste that would contain traces of sodium hypochlorite is expected to build up during the pandemic (Paleologos et al., 2021). A high dose of chlorine is routinely applied to disinfect hospital and municipal wastewaters to ensure the inactivation of the virus. Subsequent water rinsing or natural precipitation then flushes high concentrations of chlorine residues into the environment, including soils, surface water, shallow groundwater, and stormwater drains (Chu et al., 2020).

Thomas (1954) found that detergents may have an impact on biochemical oxygen demand (BOD) and on total suspended solids (TSS), causing significant alteration of the distribution of organic load on various treatment stages in a plant, modification of wastewater treatability, and introduction of special operational problems. Ayden et al. (2020) did a comparative analysis between two wastewater treatment plants, one in Sakarya, Turkey region (where highest number of COVID-19 cases were reported) and another in Lüleburgaz (an area that is less affected), on changes in the influent and effluent quality in wastewater treatment plants. They found that while the two plants have almost the same daily flow rate, neither of the plants' flow rates changed during the coronavirus pandemic. Conversely, the Lüleburgaz plant showed an increase in chemical oxygen demand (COD) effluent during the lockdown.

Bodík et al. (2008) investigated the use of a group of cleaning chemicals and disinfectants. The results indicated an excessive effect of disinfectants containing sodium hypochlorite on wastewater treatment, and its use should be considered in households with domestic WWTP in order to prevent the failure in wastewater treatment. According to Bodík et al. (2008), disinfectants based on sodium hypochlorite have inhibitory effects, and the COD removal was the most influenced while disinfectants based on other biocides have the same effects, nonetheless, to a lesser degree as confirmed by Ignatius and Craig (2004). In the same vein, Trevors (1993) found that excessive use of household disinfectants and chemicals can seriously hinder septic tank treatment and produce effluent that is too strong for the leaching bed or treatment unit to handle, considering that these systems are microbial in nature.

In the interim, the change in the lifestyle and human behavior caused by COVID-19 may have an impact on water consumption, wastewater generation, and wastewater quality. As demonstrated in a study by Alygizakis et al. (2021), an increase in wastewater concentrations of surfactants (+196%), biocides (+152%), cationic quaternary ammonium surfactants (+331%) was observed. These changes were attributed to the COVID-19 pandemic use of cleaning chemicals and introduction of social-restriction measures (Alygizakis et al., 2021; Teymoorian et al., 2021).

These changes in water-behavioral-responses are caused by the lockdowns, limited working hours, excessive use of water for cleaning, disinfecting, and other purposes imposed by the new lifestyle intruded by COVID-19, the excessive cleaning, and disinfecting agents (Elsaid et al., 2021).

The reviewed literature demonstrates that an impact on the wastewater characteristics is highly possible during 2020 but its magnitude, significance and manifestation due to the COVID-19 pandemic control measures needs further investigation. Therefore, it would be advantageous and of utmost importance to understand how the wastewater characteristics have changed during 2020 and whether the change is significant.

Hence, the aim of this paper is to examine the largest wastewater catchment in Kuwait wastewater monitoring data to explore the impact of COVID-19. It is hypothesised that the excessive use of cleaning chemicals and the associated water use during the COVID-19 pandemic have altered the wastewater characteristics (quality and quantity). Essentially, how does COVID-19 influence the flows and the quality of the generated wastewater? Relative to wastewater treatment operations, this is crucial, as they are usually designed, by and large, based on these two variables. This study is of significance, and results will be most helpful, since the COVID-19-induced behavioral changes may continue for a longer period, and the probability that pandemics and endemics of similar nature may likely occur in the future.

1. Methodology

Ardiya catchment in Kuwait City, Kuwait (Figure 1) is supplied with potable water from desalination plants as the case in most of gulf countries (Ministry of Electricity and Water, 2021). Data records for Ardiya catchment for the period 2015–2020 were obtained from the Ministry of Public Works (MPW) of Kuwait. The records consisted of the daily flow and concentrations of selected 22 wastewater quality parameters. The records during this period were complete on daily bases for flow and concentrations. In addition to flow rates, concentrations data obtained from MPW records included 22 parameters which are temperature, pH, conductivity, TSS, volatile suspended solids (VSS), total dissolved solids (TDS), COD, BOD, oil and grease (O&G), ammonia nitrogen ($N\text{-}NH_4^+$), organic nitrogen (N-org), nitrate-nitrogen ($N\text{-}NO_3$), nitrite nitrogen ($N\text{-}NO_2$), total phosphorous (P-total), total phosphate (PO_4-total), alkalinity ($CaCO_3$), free chlorine (Cl^-), sulfate (SO_4), total sulfides (H_2S), total Kjeldahl nitrogen (TKN), settleable solids (SS), and total coliform (TC). Measurement at MPW laboratories (9001:2015) were carried out according to American Public Health Association (2014).

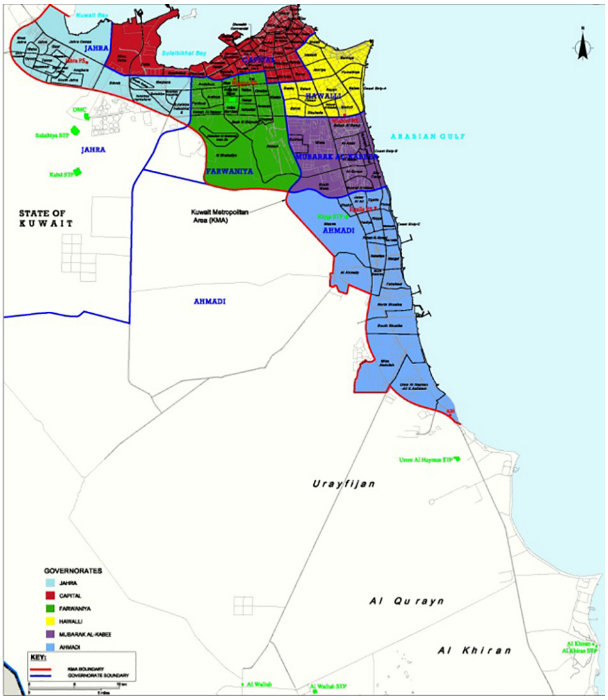

Figure 1. Map of Kuwait City (Ardiay catchment includes areas in green, red and yellow)

1.1. Statistical analysis of flow rates and concentrations

Assessment of the flow rates and concentrations of raw wastewaters was conducted for the records of the period from 2015 to 2020. Analysis was first carried out using the common statistical measures to determine the location (mean, median) and variability (standard deviation and coefficient of variation) of the data sets. The statistical analysis was conducted using Excel (2016). Since these statistical measures were based on the assumption that the distributions were normal, coefficients of skewness and kurtosis were also calculated to quantify the nature of the distributions. The coefficient of skewness is a measure of the symmetry of the data around the mean, and the coefficient of kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution (Jammalamadaka et al., 2021). The skewness coefficient of a normal distribution is zero, while its kurtosis coefficient is 3 (Bono et al., 2020). In addition to the analytical method, graphical analysis was also carried out to determine the nature of the distributions visually.

1.2. The pandemic effect

The mean monthly concentration (Curtis et al., 2020) for each year was calculated by weighing the individual concentrations over the entire month (Equation (1)).

Weighted monthly concentration =

$$= \sum_{i=1}^{n} \left[\left(C_d \times Q_d \right) \right]_i / Q_m \quad i = 1, 2, \ldots n, \qquad (1)$$

where C_d is the daily concentration, Q_d is the daily flow, Q_m is the monthly flow, and n is the number of days in a month.

A 95% confidence interval for the weighted wastewater quality parameters was calculated for each month of the six years (2015–2020). For each month, the parameters which were higher or lower than the 95% confidence interval were identified for each month. These parameters were identified for the year 2020 and were considered to be extremes to be further analysed in comparison to previous years. Z-test and Kruskal-Wallis post hoc (Singh et al., 2021) were used in SPSS® software to compare groups. Additionally, the frequency curves (Pareto diagrams (Follmann et al., 2020)) for identified parameters were generated to infer upon the frequency changes to these parameters during 2020.

2. Results

Ardiya wastewater catchment is the largest in Kuwait as it accounts approximately for half the population of the country with an approximate area of 200 km^2 (Figure 1). Although the catchment is a mixed residential and commercial use, the wastewater considered here is only from domestic sources. The domestic wastewater is collected at Ardiya pumping station and then sent to the largest wastewater treatment plant in Kuwait which is Al-Sulaibiyah wastewater treatment plant to be treated up to tertiary level in addition to reverse osmosis and ultrafiltration stage.

Table 1 gives the catchment population (Public Authority for Civil Information, 2021), average water consumption (Ministry of Electricity and Water, 2021), and average wastewater production per capita calculated from Ardiya catchment data. It is important to note that the water consumption and wastewater production vary by month depending on the population dynamics (Kuwait population is nearly 70% expats and during the summer months' travel is very significant), climate conditions among others. Table 1 indicates there is a slight increase in water use between 2015 and 2020, negligible water use and a slight increase in wastewater production. During 2020 the population decreased due to the travel ban because of the COVID-19 pandemic resulting in a slight increase in water use and accompanying wastewater production.

2.1. Wastewater flow data

The summary statistics for individual years (2015–2020) and for the five (2015–2019) and six years (2015–2020) averages, revealed that the five and six years' averages follow a normal distribution as indicated by the kurtosis and skewness coefficient values of (3.24, –0.07) and (3.10, 0.02), respectively. None of the individual years showed to be close to normal with the exception of year 2019 flow (kurtosis and skewness of 2.53 and,0.09, respectively) which could be assumed to be normally distributed. The fact that the six years' averages are normally distributed demonstrated that the period considered may be said to be representative of the true population.

The relatively high value of kurtosis coefficient for 2020 (16.13) compared to year 2018 (2.53) indicated more flat distribution (Jammalamadaka et al., 2021). This, in turn, would indicate that the wastewater generation was more stable during this year, conceivably, due to lack of mobility owing to lockdowns imposed by the COVID-19 pandemic. This was clear from the larger standard deviation, variance, and mean confidence level of 2018. For the 2020, mean, median, and maximum were the highest among all years. Also, 2020 had the highest skewness among all years, as could be seen that this could have been largely due to the lockdown period.

Also, statistical analysis of annual data revealed high variability of daily wastewater flow rates (494,712, 589,106, 541,909, 47197 m^3/d for minimum, maximum, average, and standard deviation, respectively) with the average per

Table 1. Data for Ardiya Catchment

Parameter	Units	2015	2016	2017	2018	2019	2020
Population	Million	1.94	1.99	2.00	2.04	2.1	2.05
Water consumption	l/c.d	441.35	444.54	443.63	431.34	419.51	445.90
Wastewater production	l/c.d	215.41	244.74	242.43	245.22	245.84	252.62

capita daily flow increasing annually since 2015 (Table 1). However, the annual increase in average per capita daily flow was highest in 2016, after which the per capita consumption remained fairly stable and a highest occurred in 2020. A z-test of 2020 daily wastewater flow compared to 2015–2019 average daily flow (541,909 m^3/d) yielded ($P < 0.01$). This, when combined with the decrease in population during 2020 (Table 1), would indicate that the year 2020 average daily flow increase (8.80%) was significantly higher than the previous five years.

It is to be mentioned that due to mass transmission of SARS-CoV-2, globally, governments of most of the countries were seen to be establishing a large number of quarantine centers, screening centers, isolation wards for keeping the infected (Kataki et al., 2021). Additionally, significant numbers of testing and sample collection facilities are being established within a very short time dedicated to COVID-19 related testing. This could imply that substantial quantities of wastewater would be generated from such facilities (Kataki et al., 2021). According to a recent study in India, during this pandemic, around 20–40 L of water per person are being used every day, which is five times higher than the average, which would lead to a 25% increase in water demand and wastewater generation (Rohila, 2020). Another study (Yazdian & Jashmidi, 2021), confirmed a 20% increase in wastewater treatment plant inflows in Iran and this increase was accompanied by a decrease in BOD and COD concentrations (dampening effect).

The annual flow data for 2015–2020 broken by month are shown in Figure 2. It can be seen that there has been an annual increase inflow, with the highest flow attained in 2020. Figure 2 reflects on the monthly increase, which confirms the annual increase in wastewater flow data on a monthly basis. However, the monthly flow increments (Figure 3) have been shown to vary between increasing and decreasing by month since 2017. The year 2020 had the largest monthly increments over the past four years with no decrease in any month. This increase could reflect the increase in water usage (Colella et al., 2021) during

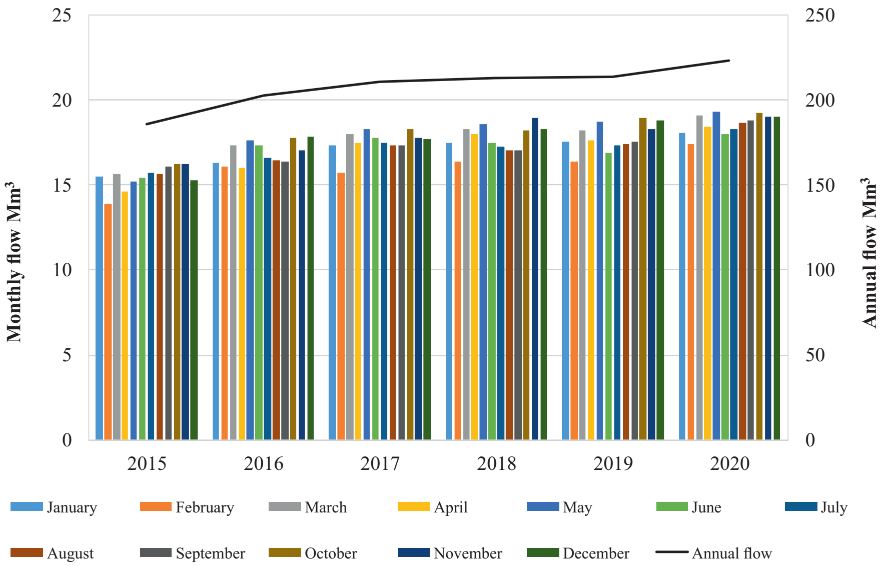

Figure 2. Annual flow data and monthly breakdown for 2015–2020

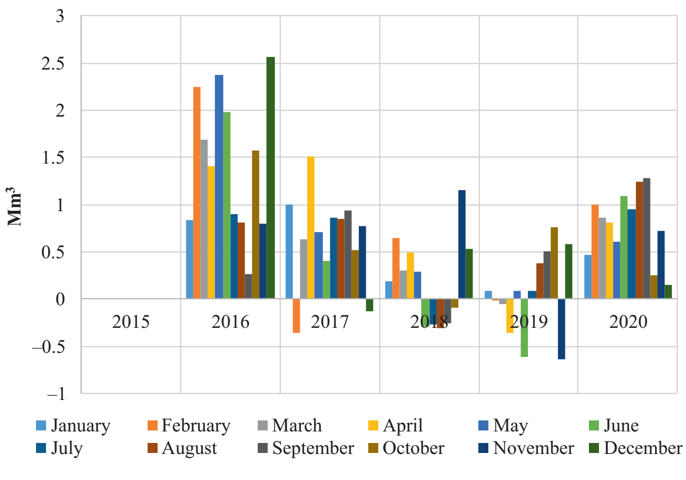

Figure 3. Monthly flow increments for 2015–2020, taking 2015 as a base year

2020 due to COVID-19 pandemic, and also feasibly, due to increase in water consumption for cleaning and disinfecting purposes, as well as other activities, such as swimming, etc. This was particularly correct for all the months. The year 2020 was higher in flow as well as average monthly flow increments, as depicted in Figures 4 and 5. Figures 4 and 5 show that while the monthly flow ratio increased by a ratio of 1 to 1.12, the monthly increments reach up to 5.40 times. This increase in water consumption and, consequently wastewater generation, has been confirmed by Rohila (2020) and Kataki et al. (2021).

2.2. Wastewater quality data

The American Water Works Association (AWWA) conducted a survey on AWWA members about the expected challenges in business operations in wastewater sector caused by the pandemic. Absenteeism/continuity of operations and impacts on-field operations were found to be the top challenges in this sector (American Water Works Association, 2020). The control of COVID-19 virus and the appropriate management of wastewater have been especially challenging for temporarily established COVID-19 dedicated centers, where toilets are connected directly to the municipal sewage network, as there is no residence time, and disinfectants addition to the wastewater is not easy (Xu, 2020). Further, as there is inflation in water consumption owing to increase in consciousness toward cleanliness, this would add to additional generation of wastewater from all sectors (Kataki et al., 2021).

Statistics for the six-year wastewater quality data revealed that, unlike the normal distribution of flow (0.02 and 3.10 for skewness and kurtosis, respectively), the concentrations of wastewater did not seem to follow a normal distribution nor their logarithmic or weighted value transformations (Table 2). The skewness and kurtosis coefficients for all wastewater quality parameters clearly demonstrated that the data are not normally distributed (Table 2), which is standard and customary. In fact, wastewater data are usually not normally distributed (Metcalf & Eddy, 2014). Statistical analysis also reflects high variability of these data as indicated by the sample mean and variance for each wastewater quality parameter (Table 2).

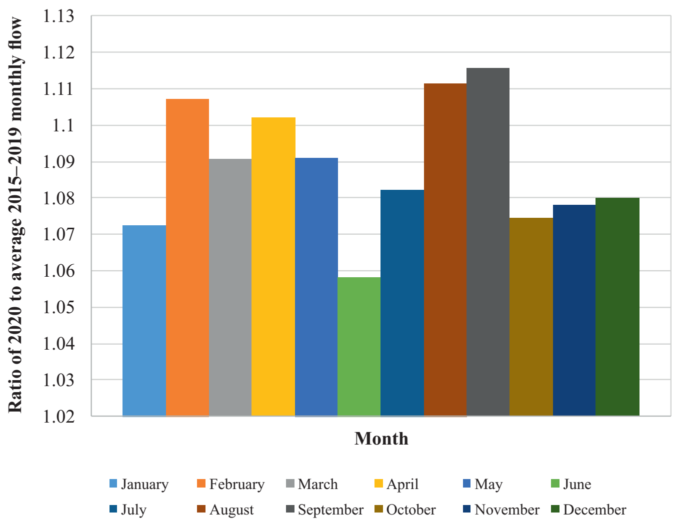

Figure 4. Ratio of year 2020 to average 2015–2019 monthly flow

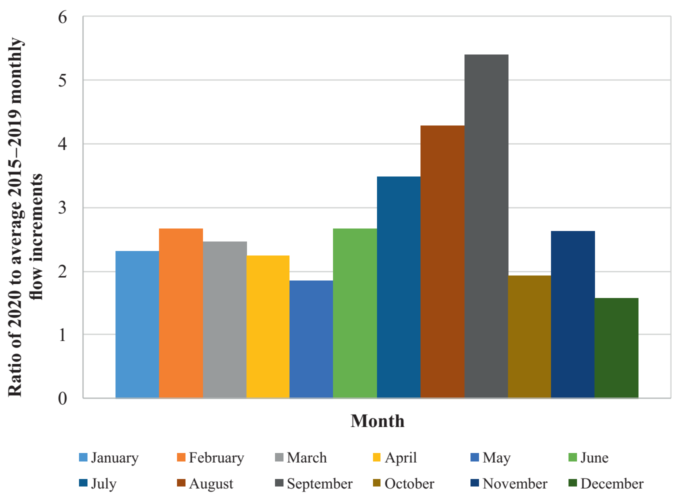

Figure 5. Ratio of year 2020 versus average 2015–2019 monthly flow increments

Therefore, the analysis would be qualitative and quantitative for certain parameters.

The weighted average concentrations (Eq. (1)) could account for consumer behavior upon water use change and therefore better reflect the variation of the load changes than using average concentration (Curtis et al., 2020). The weighted concentrations of 22 wastewater parameters were calculated, and the analysis revealed a clear variation of annual weighted averages of all parameters with some years above, and some have been shown to be lower than the five-year weighted average (Table 3). Out of these wastewater parameters' changes, BOD, O&G, NH_4-N, NO_3-N, NO_2-N, alk., TKN, and TC, were found to have significant differences between 2020 and 2015–2019 monthly weighted averages using Kruskal-Wallis post hoc test for 2020, 2015–2019, and 2015–2020 monthly weighted averages and the p values were 0.00, 0.04, 0.01, 0, 0.00, 0.01, 0.03, and 0.05, respectively. The reduction in BOD is certainly due to the increase in water consumption as discussed previously and COD/BOD ratio has increase to 2.31 in 2020, while the 2015–2019 monthly weighted average was 2.16, indicating 7.13% increase. The increase in organics and nitrogen could be attributed to an increase in surfactants, biocides, and cationic quaternary ammonium surfactants, as observed by Alygizakis et al. (2021). Since these changes are significant they may trigger operational changes in wastewater treatment plants. However, these overall averages could not precisely reflect the significance of the impacts of the pandemic since monthly variations are also important. Monthly variations are clearly reflective of many parameters including lockdown measures and these will be further discussed.

To further investigate whether the 2020 and 5-yr average variations were unique to the year 2020 and not just an annual variation, the weighted monthly averages of 2020 were compared to the 5-yr weighted monthly average using the 95% confidence data. Parameters which have shown extremes (above or below 95% confidence means) have been identified and tabulated by month. Table 4 presents the extreme of the 22 parameters by the month of each year. Parameters that have shown extremes (either high (h) or low (l)) compared to the 95% confidence data in 2020 and have not shown similar behavior in previous years were considered to be unique to the year 2020; and hence, could be further considered to be associated with the COVID-19 pandemic.

Table 2. Mean, variance, skewness, and kurtosis of wastewater quality data (2015–2020)

Parameter	Unit	Actual Values				Weighted Values		Logarithmic values	
		Mean	Var.	Kur.	Skew.	Kur.	Skew.	Kur.	Skew.
Temp.	[°C]	28.7	11.28	0.03	–0.61	–1.07	0.27	–0.15	–0.65
pH	[–]	6.92	0.02	1.32	0.26	0.15	–0.01	1.68	0.31
Conductivity	[µs/cm]	1423.17	140530.50	8.58	2.3	3.02	0.53	7.45	2.20
TSS	[mg/l]	188.35	4998.85	12.02	2.36	8.18	1.80	12.30	2.43
VSS	[mg/l]	156.86	3294.40	12.39	2.34	10.07	1.84	12.51	2.39
TDS	[mg/l]	821.19	50471.10	7.31	2.07	2.60	0.44	6.37	2.00
COD	[mg/l]	436.01	10840.01	21.09	2.32	3.97	0.93	22.29	2.45
BOD	[mg/l]	202.56	2882.78	6.9	1.27	1.41	0.46	7.06	1.29
Grease & Oil	[mg/l]	40.7	261.43	158.98	7.22	141.68	9.78	1.44	0.87
N-NH_4	[mg/l]	29.63	14.12	1.46	0.48	0.49	–0.06	1.31	0.19
N-org	[mg/l]	8.67	7.19	0.79	0.29	0.12	0.044	0.81	0.30
N-NO_3	[mg/l]	0.41	0.14	201.51	8.86	1.64	1.28	215.36	9.6
N-NO_2	[mg/l]	0.02	0.03	1204.14	32.37	28.34	4.46	1004.90	29.59
P-total	[mg/l]	5.54	2.43	27.71	4.09	3.06	1.31	29.39	4.38
PO_4-total	[mg/l]	16.92	21.97	27.98	4.03	3.00	1.29	29.84	4.32
alkalinity ($CaCO_3$)	[mg/l]	192.24	515.95	1.56	0.08	1.00	–0.24	2.07	–0.07
Cl^-	[mg/l]	260.40	13162.84	9.68	2.43	1.63	0.42	8.46	2.33
SO_4	[mg/l]	130.16	910.29	0.07	0.31	0.71	0.61	–0.01	0.25
Sulfides-total (H_2S)	[mg/l]	4.25	17.00	10.77	2.44	1.94	1.26	12.73	2.69
TKN	[mg/l]	38.13	14.3	1.33	0.04	2.27	–0.58	0.64	0.09
Settleable solids	[ml/l]	2.25	2.28	27.75	3.12	0.31	0.50	27.10	3.21
Total Coliform	[CFU/100 ml]	4.8E+12	3.22E+24	42.85	3.18	–0.39	0.43	51.16	3.77

Table 3. Weighted 2020 and previous 5-yr wastewater parameters

Parameter	Unit	2020	5-yr	% Increase	% Decrease
Temp.	[°C]	28.46	28.76		1.03
pH	[–]	6.96	6.92	0.67	
Conductivity	[µs/cm]	1372.98	1424.02		3.58
TSS	[mg/l]	174.31	191.68		9.06
VSS	[mg/l]	144.47	159.69		9.53
TDS	[mg/l]	807.74	818.24		1.28
COD	[mg/l]	419.71	440.24		4.66
BOD	[mg/l]	181.69	206.31		11.93
Grease & Oil	[mg/l]	45.48	39.94	13.88	
$N\text{-}NH_4$	[mg/l]	32.37	29.10	11.21	
N-org	[mg/l]	8.24	8.72		5.49
$N\text{-}NO_3$	[mg/l]	0.16	0.46		65.74
$N\text{-}NO_2$	[mg/l]	0.01	0.02		59.00
P-total	[mg/l]	5.86	5.48	7.05	
PO_4-total	[mg/l]	17.90	16.73	7.04	
Alkalinity ($CaCO_3$)	[mg/l]	207.56	189.55	9.50	
Cl^-	[mg/l]	234.79	262.57		10.58
SO_4	[mg/l]	126.85	130.06		2.47
Sulfides-total (H_2S)	[mg/l]	4.82	4.17	15.70	
TKN	[mg/l]	39.84	37.78	5.45	
Settleable solids	[ml/l]	2.35	2.25	4.26	
Total Coliform	[CFU/100 ml]	4.06E+12	4.88E+12		16.75

The extreme parameters are listed by month in Table 5, together with the timeline of the government's response and measures taken to reduce transmission of COVID-19 pandemic.

While a correlation between parameters exhibiting extremes during 2020 and the lockdown phases could not be further examined given the secondary data, there is a variation of these parameters between the different lockdown phases (Table 5). This variation could be attributed to many factors including population mobility, working hours, type of facilities operating during lockdown, state of alert due to COVID-19 cases, and change of water-related social behavior, among others.

Temperature and pH were not among the parameters exhibiting extremes during 2020. However, it was detected that the average monthly wastewater temperature was below 27 ºC in November through February and more than 27 ºC for the rest of the year, with an annual mean of 28.7±0.14 ºC. This was no exception in 2020; however, the temperature was lower than 27 ºC in March of 2015 and 2016. Survival of viruses in the environment depends on several factors and is boosted with viral aggregation and negatively affected with temperature increase, presence of sunlight, presence of indigenous microbial population; whereas, the effects of organic matters and humidity are contradictory (Pinon & Vialette, 2018). Temperature has been documented to reduce survival and transmission of COVID-19 through water and wastewater (Zhang et al., 2020b; Geller et al., 2012; Wang et al., 2005). Longer retention of SARS-CoVs infectivity has been observed at lower temperatures, for example, 14 d at 4 °C versus two days at 25 °C in wastewater (Geller et al., 2012). This would imply that in cold seasons and temperate-climate zones, the environmental survival of SARS-CoV-2 may be increased (Bogler et al., 2020).

According to Lai et al. (2005), the pH of feces was reported to have an impact on SARS-CoV-1 survival, ranging from three hours in slightly acidic feces of a newborn to four days in diarrheal feces of an adult with a pH of up to 9. To the contrary, SARS-CoV-2 in suspension did not show substantial reduction in infective titer after 60 min over a wide range of pH (3–10) (Chin et al., 2020). Therefore, in the observed pH where the pH overall average is 6.91±0.01, the survival of COVID-19 virus is not expected to be affected.

Previous work highlighted that a free chlorine residual in the range of 0.2–0.5 mg l–1 for municipal wastewater is sufficient to disinfect the SARS virus readily (Wang et al., 2005). Although García-Ávila et al. (2020) have reported an increase in chlorine use during the COVID-19 pandemic, however, no extremes have been observed in the chlorine parameter during 2020.

Table 4. Extreme parameters for weighted average monthly wastewater quality data 2015–2020

Month	Days	Temp.	pH	Con-ducti-vity	TSS	VSS	TDS	COD	BOD	Grease & oil	N-NH_4	N-org	N-NO_3	N-NO_2	P-total	PO_4-total	Alka-linity ($CaCO_3$)	Cl^-	SO_4	Sulfi-des-total (H_2S)	TKN	Sett-leable solids	Total Coli-form
Unit		[°C]	[–]	[μs/cm]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[ml/l]	[CFU/ 100 ml]
Jan	20	–	–	–	H	H	–	–	–	–	H	–	–	–	H	H	H	–	L	–	H	H	–
	19	H	–	–	L	L	–	–	–	H	–	–	–	–	–	–	–	L	H	–	–	–	L
	18	–	–	–	–	–	–	–	L	–	–	L	–	–	–	–	–	–	L	–	–	–	–
	17	–	H	–	–	–	–	H	H	–	–	–	–	H	–	–	–	–	–	–	–	–	–
	16	L	L	–	–	–	–	L	–	L	L	–	H	H	–	–	L	–	–	H	L	–	H
	15	–	–	H	–	–	H	–	–	–	–	H	H	H	–	–	–	H	–	L	–	–	–
Feb	20	–	–	–	H	H	–	–	–	–	H	L	–	–	H	H	H	–	–	H	–	H	–
	19	H	L	–	L	L	–	L	L	–	–	–	–	–	–	–	–	L	H	–	L	L	L
	18	–	–	–	–	–	–	–	–	–	–	L	–	–	–	–	–	–	–	–	H	–	H
	17	L	H	–	–	H	–	H	H	–	–	H	–	–	–	–	–	–	–	–	–	–	–
	16	–	–	–	–	–	–	–	–	–	–	–	H	H	–	–	L	–	–	–	–	–	H
	15	–	–	H	–	–	H	–	–	L	–	–	–	–	–	–	–	H	–	–	–	–	–
Mar	20	–	–	–	–	–	–	–	–	H	–	–	L	–	–	–	–	–	–	H	–	–	L
	19	–	H	–	–	–	–	–	–	L	–	H	–	H	L	L	L	–	–	–	–	L	–
	18	–	–	–	H	H	–	H	H	–	–	–	–	–	H	–	–	–	–	–	–	H	–
	17	–	H	–	–	–	–	–	–	–	–	–	–	H	–	–	H	–	–	–	–	–	–
	16	–	–	–	–	–	–	L	–	–	–	–	H	–	–		–	–	–	–	–	–	H
	15	L	–	H	–	–	H	–	–	–	L	–	–	–	H	H	–	H	H	–	–	–	–
Apr	20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	19	–	–	–	–	L	–	–	L	–	–	L	–	–	L	L	–	–	–	–	L	L	L
	18	–	–	–	H	H	–	H	H	–	–	–	–	–	H	H	–	–	L	–	–	H	–
	17	H	–	–	–	–	–	–	–	–	–	–	–	–	–	–	H	–	–	–	–	H	–
	16	–	L	–	–	–	–	–	–	L	–	–	–	–	–	–	–	–	H	–	–	–	–
	15	–	L	H	–	–	H	–	–	–	L	–	H	H	H	H	L	H	–	–	–	–	–
May	20	–	–	L	L	L	L	–	L	–	L	H	L	–	L	L	L	L	–	L	–	–	–
	19	H	L	–	–	–	–	–	L	H	H	H	H	L	–	–	–	–	L	H	–	–	L
	18	–	H	–	–	–	–	–	–	–	H	–	–	–	–	H	–	–	–	–	H	H	–
	17	–	–	–	–	H	–	H	–	–	–	–	–	H	–	–	H	–	–	–	–	H	–
	16	–	–	–	–	–	–	L	–	–	–	H	–	–	–	–	–	–	–	–	–	–	H
	15	–	–	H	–	–	H	–	H	–	–	L	H	–	H	H	–	H	H	–	–	–	–

Continued Table 4

Month	Days	Temp.	pH	Con-ducti-vity	TSS	VSS	TDS	COD	BOD	Grease & oil	N-NH$_4$	N-org	N-NO$_3$	N-NO$_2$	P-total	PO$_4^-$-total	Alka-linity (CaCO$_3$)	Cl$^-$	SO$_4$	Sulfi-des-total (H$_2$S)	TKN	Sett-leable solids	Total Coli-form
Unit		[°C]	[–]	[µs/cm]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[ml/l]	[CFU/ 100 ml]
Jun	20	–	–	–	–	–	–	H	–	–	–	–	–	–	H	H	–	–	–	–	–	–	–
	19	H	–	–	L	L	–	–	L	–	–	L	–	–	–	–	–	–	–	H	–	–	–
	18	–	H	–	–	–	–	–	–	–	H	L	–	–	–	–	–	–	–	–	H	–	–
	17	L	L	–	H	H	–	–	–	H	–	–	–	–	–	–	H	–	–	–	–	–	–
	16	–	–	–	–	–	–	L	H	–	L	–	–	–	–	–	–	–	–	–	–	L	H
	15	–	–	H	–	–	H	–	–	L	–	H	H	H	–	–	–	H	H	–	–	–	–
Jul	20	H	H	–	–	–	–	–	–	H	H	–	–	–	H	H	H	–	–	H	H	–	L
	19	–	–	–	L	L	–	–	L	–	–	L	–	–	L	L	–	–	–	–	L	–	–
	18	H	–	–	–	–	–	H	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	17	–	–	–	L	L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	16	L	–	–	H	H	–	–	–	–	–	H	–	H	H	H	–	–	–	–	–	H	H
	15	–	L	H	–	–	H	–	H	–	L	–	H	–	–	–	L	H	H	L	–	L	–
Aug	20	L	–	–	–	–	–	–	–	–	H	–	–	–	–	–	H	–	–	–	H	–	L
	19	–	–	–	–	–	–	–	L	–	–	L	–	–	–	–	–	–	–	–	–	H	–
	18	H	H	H	–	–	–	–	–	–	–	–	–	–	–	–	–	H	–	–	–	–	–
	17	–	–	L	H	H	L	–	–	H	–	–	–	–	H	H	–	–	L	–	–	–	–
	16	–	–	–	–	–	L	–	H	L	–	H	–	H	–	–	L	L	H	L	–	L	–
	15	–	–	–	–	–	–	L	–	–	–	–	H	–	–	–	L	–	–	–	–	L	–
Sep	20	L	–	–	L	L	–	L	L	H	H	–	–	–	–	–	H	–	–	–	H	–	L
	19	–	–	–	H	–	–	H	–	–	–	L	–	–	–	–	–	–	–	–	–	H	–
	18	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	17	–	–	–	–	–	–	–	–	–	–	–	–	H	–	–	–	–	–	H	L	–	–
	16	–	L	L	–	–	–	–	H	L	–	–	–	–	H	H	L	L	H	L	–	–	H
	15	–	–	H	–	–	H	–	–	–	–	–	H	–	–	–	–	H	H	–	–	L	–
Oct	20	L	–	–	L	L	–	–	–	–	H	–	–	–	–	–	H	–	–	–	H	–	–
	19	–	L	–	H	H	–	–	–	H	–	–	–	–	H	H	–	–	–	H	H	H	L
	18	–	–	H	–	–	H	–	–	–	–	–	–	–	–	–	–	H	–	–	–	–	–
	17	–	–	–	–	–	–	L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	16	–	–	L	–	–	L	H	H	L	–	–	–	–	–	–	–	L	H	L	–	–	–
	15	–	–	–	–	–	–	–	–	–	L	H	H	H	–	–	L	–	H	–	–	–	H

End of Table 4

Month	Days	Temp.	pH	Con-ductivity	TSS	VSS	TDS	COD	BOD	Grease & oil	$N\text{-}NH_4$	N-org	$N\text{-}NO_3$	$N\text{-}NO_2$	P-total	PO_4-total	Alkalinity ($CaCO_3$)	Cl^-	SO_4	Sulfides-total (H_2S)	TKN	Settleable solids	Total Coliform
Unit		[°C]	[–]	[µs/cm]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[ml/l]	[CFU/100 ml]
Nov	20	–	–	–	L	L	–	L	L	–	H	–	L	L	L	L	H	–	–	–	H	–	–
	19	–	L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	H	–	–	L
	18	–	–	–	–	–	–	–	–	–	L	–	–	–	–	H	L	–	–	–	L	–	–
	17	–	–	L	H	H	–	–	–	–	–	–	–	–	–	–	L	–	–	–	–	H	–
	16	L	–	–	–	–	–	H	H	–	–	H	–	–	–	–	–	–	–	–	–	H	–
	15	–	–	H	–	–	H	–	–	L	–	–	H	H	–	–	–	H	–	L	–	L	H
Dec	20	–	H	–	–	–	–	–	L	H	–	L	L	–	–	–	–	–	–	–	–	–	L
	19	H	L	L	–	–	–	–	–	–	H	–	–	–	–	–	–	L	–	–	–	–	–
	18	–	–	H	L	–	H	–	–	–	–	–	–	–	–	–	–	–	H	H	–	–	–
	17	–	–	–	H	H	–	H	–	–	–	–	–	–	H	H	–	–	L	–	–	H	–
	16	L	H	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	15	–	–	H	–	–	H	L	–	L	L	H	H	H	–	–	–	H	–	L	–	–	H

Table 5. Summary of 2020 extreme wastewater quality parameters versus COVID-19 response

Month	COVID-19 response timeline	COVID-19 response restrictions	Parameters higher than 95% confidence	Parameters lower than 95% confidence	Remarks
Jan	COVID-19 declared elsewhere	–	TSS, VSS, N-NH_4, TP, PO_4-T, Alk, TKN, SS	SO_4	Low SO_4 and high SO_4 had been observed in 2018 and 2019, respectively. No higher limits were observed in the 6 years
Feb	COVID-19 declared elsewhere COVID-19 detected in Kuwait 24 Feb 2020	–	TSS, VSS, N-NH_4, TP, PO_4-T, Alk., sulfides, SS	N-org	Higher VSS values were also observed in 2017, Low N-org was also observed in 2018
Mar	A public holiday was declared from 12 to 26 March, and extended until May 30	–	O&G, sulfides	NO_3, TC	No low TC was observed in six years No low NO# was observed in six years
Apr	Public holiday	–	–	–	Normal month
May	Public holiday Lockdown phase 1 on 31 May 2020. Lockdown phase 1 on 31 May 2020	The first phase included partial curfew shortened to between (6pm and 6am) coupled with a lockdown on areas with surge in cases Activities to resume in the first phase included home deliveries of restaurants, telecommunication companies, food retailers, companies' transportation of employees, gas stations, private clinics and car workshops	N-org	Cond., TSS, VSS, BOD, N-NH_4, NO_3, TP, PO_4-T, alk., Cl, sulfides	High N-org values were observed in 2016 and 2019 Low BOD was observed in 2019
Jun	Lockdown phase 1 Lockdown phase 2 on 30 June 2020	Phase 2: curfew shortened to between 9pm and 6am. workforces in government and private sectors should be less than 30 percent, in addition to the resumption of work in the construction sector, banking, malls opening for eight hours and according to special instructions; parks and pickups from restaurants	COD, TP, PO_4-T	–	–
Jul	Lockdown phase 2 Lockdown phase 3 on 28 July 2020	Phase 3: end of curfew, Workforces would increase to less than 50%, and visits to social care homes would be allowed, as well as the reopening of hotels, resorts and hotel apartments. Taxis will be allowed to operate with only one passenger, and mosques would be allowed to perform Friday prayers	O&G, N-NH_4, TP, PO_4-T, alk., sulfides, TKN	TC	High TP, PO_4-T were observed in 2016
Aug	Lockdown phase 3 Lockdown phase 4 on 18 August 2020	Phase 4: in addition to phase 3, restaurants would be receiving customers but with restrictions, and public transportation resumed but with distancing	N-NH_4, alk., TKN	TC	–

End of Table 5

Month	COVID-19 response timeline	COVID-19 response restrictions	Parameters higher than 95% confidence	Parameters lower than 95% confidence	Remarks
Sep		–	O&G, N-NH_4, alk., TKN	TSS, VSS, COD, BOD, T.C	–
Oct	Lockdown phase 4	–	N-NH_4, alk., TKN	TSS, VSS	–
Nov	Lockdown phase 4	–	N-NH_4, alk., TKN	TSS, VSS, COD, BOD, N-NO_3, N-NO2, TP, PO_4-T	–
Dec	Lockdown phase 4	–	O&G	BOD, N-org, N-NO_3, TC	–

Conceivably, chlorine concentrations are dampened by the regular use of bleach. Additionally, chlorine will readily react with organic matter in the wastewater, and its compounds have no disinfection effect.

Since the announcement of COVID-19 in China, the use of detergents, sanitisers, and disinfectants has surged, and this may have caused an increase in nitrogen and phosphorous compounds depending on the type of detergent or sanitiser. In January and May (Table 5), excessive use of sanitising chemicals could probably be the cause of spike in nitrogen, phosphorous, and TSS (Mousazadeh et al., 2021; Pirsaheb et al., 2014; Raptopoulou et al., 2016; Mulder et al., 2018; Hora et al., 2020; Campbell & Wang, 2020; Paleologos et al., 2021; Thomas, 1954). The public holiday period was accompanied by increased oil and grease (perhaps due to increased cooking at home during March); while the nitrogen and phosphorous returned to normal until the return to work at the end of June 2020. This would indicate a decrease in the use of sanitizing and disinfection chemicals during low mobility phases of lockdown. In July, when partial return of activities was started, there was again a spike in nitrogen, phosphorous, and TSS due to slug of chemicals from the return to work cleaning activities as reported by Alygizakis et al. (2021). Then, (August–December) only an increase in nitrogen compounds was observed during the rest of the year, which could be attributed to regular use of cleaners and sanitisers. The increase in nitrogen compounds was accompanied by an increase in alkalinity, however, it may be said to be trivial. Oil and grease also was observed to be high in September and December, which indicates a change in cooking habits during partial lockdown.

Contrariwise in January and February, where dust storms are common in Kuwait, TSS showed an increase; while in May, when the lockdown was on, it showed an increased water usage accompanied by lower TSS. Also in May, conductivity value was lower than normal, indicating increased water usage. This is also reflected in the reduction of some parameters, such as BOD and COD during May, September, November, and December 2020.

During the few months (March, July, August, September, December), TC was reduced, perhaps due to excessive use of disinfectants, particularly during March and when activities were resumed during phases 2 and 3 of the lockdown. As reported by Ignatius and Craig (2004), the increase in use of disinfectants had little effect on the coliform; however, apparently, the use of disinfectants was remarkably high during these months, and the recovery of coliform was also fast due to decrease in use of disinfectants during some months when new COVID-19 cases were less.

While BOD and COD have shown an increase in June and decrease in May, September, November, and December of 2020, the ratio of COD to BOD had slightly increased, which could be owing to excessive use of sanitisers and disinfectants. This ratio is important in determining the biodegradability of wastewater (Metcalf & Eddy, 2014). Lowering of BOD and COD could be probably an indicator for increase in flow rather than an increase in the population. These are likely to be changes due to the pandemic. The increase in COD has been reported by Ayden et al. (2020) for Lüleburgaz plant in Sakarya, Turkey.

Organic matter at increasing concentration was reported to reduce the survival time of spiked CoVs in various water samples (Bogler et al., 2020) (for example, ten days in lake water versus two days in raw wastewater). This may be due to the presence of antagonist bacteria that can inactivate the viruses via extracellular enzymatic activity (Ye et al., 2016; Casanova et al., 2009; Gundy et al., 2009). Differently, organic matter in the context of wastewater treatment can non-specifically adsorb in the envelope of SARS-CoV virus, protecting it from oxidative damage during chlorination, ultraviolet (UV) radiation, and protozoan, or metazoan predation (Ye et al., 2016; Gundy et al., 2009). Additionally, viruses shed by infected patients are often already associated with organic material (for example, feces and sputum) and are thus protected from some inactivation mechanisms (Ye et al., 2016; Geller et al., 2012).

As evident from Table 5, as the COVID-19 pandemic prolongs the main impacts on wastewater quality are manifested in the higher concentrations of O&G and nitrogen compounds accompanied by dilution of organics, TSS, TC, and TSS. The increase definitely associates with increased use of detergents while the decrease associates with increased use of water. Similar tendencies have been reported by Yazdian and Jamshidi (2021) in the decrease of BOD and COD due to increased water use, increase in nitrogen compounds, and reduction in TSS. The increase in O&G may indicate a change in behavior associated with stay home policies (Anayah et al., 2021). Although these changes may be tolerated by wastewater treatment plants (Yazdian & Jamshidi, 2021) they could trigger the need for operational changes.

Most importantly, Table 5 demonstrates that the pandemic effects on wastewater characteristics are also related to the lockdown phases imposed by the government. During return to normal phases, with lesser restrictions, the impact on wastewater characteristics was more pronounced than strict lockdown phases (Mar–June 2020).

Inclusive, the wastewater quality parameters increasing in 2020 were associated with organics, nitrogen, and phosphorous (in few months). These were further examined by the Pareto frequency curves (Follmann et al., 2020) to infer upon changes of frequencies of occurrence of higher concentration ranges. The frequencies of occurrence provide a good statistical indicator of change of parameters frequencies since averages may not differ significantly (Follmann et al., 2020). Some of the important operating parameters, such as COD/BOD ratio, and nutrients (TP and TN) have been further investigated using Pareto diagrams, as shown in (Figures 6 to 8).

As seen in Figure 6, the COD/BOD ratio for the five-year average was 77% between 1.5 and 2.4 and 23% of the time above that; while for 2020, it stayed roughly the same. The extreme values above 3 in 2020 (increased from 8 to 13% in 2020) would represent a higher percentage than their corresponding values for the five-year average. These extremes could only be explained by a rise in COD for reason of the use of cleaning agents accompanied by BOD reduction due to increased use of water (Yazdian & Jamshidi, 2021). Also, TP in the range 6.5 to 8.5 became more frequent than previous five years (Figure 7). Similarly, an evident increase in the frequency of 40 to 50 range for TKN was observed, which came at the expense of the 30–35 range in the previous five years (Figure 8). The occurrence of higher concentrations of BOD, COD, TP, and TN were distributed throughout 2020 and had no particular pattern relating to lockdown measures and may be triggered by responses to news or propaganda surrounding the pandemic to be further investigated. Nonetheless, these changes to BOD, COD, TP, and TKN are supported by previous literature (Mousazadeh et al., 2021; Pirsaheb et al., 2014; Raptopoulou et al., 2016; Mulder et al., 2018; Hora et al., 2020; Campbell & Wang, 2020; Paleologos et al., 2021; Alygizakis et al., 2021) and would be a challenge to wastewater treatment plants' operators around

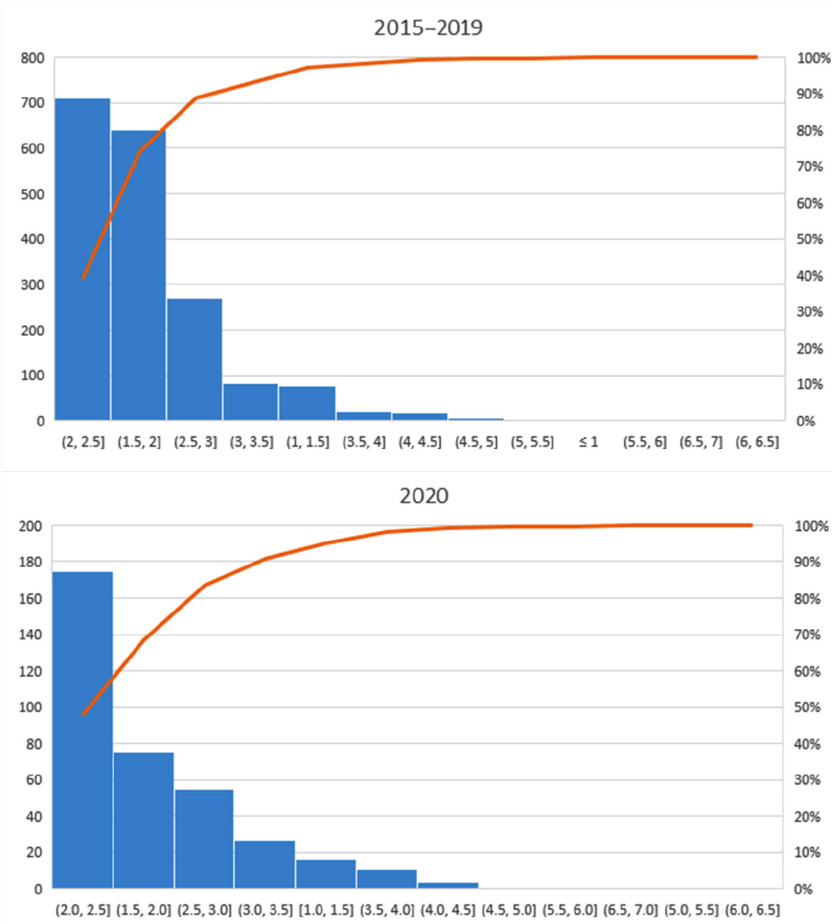

Figure 6. COD/BOD ratio Pareto diagram for 2020 versus 2015–2019

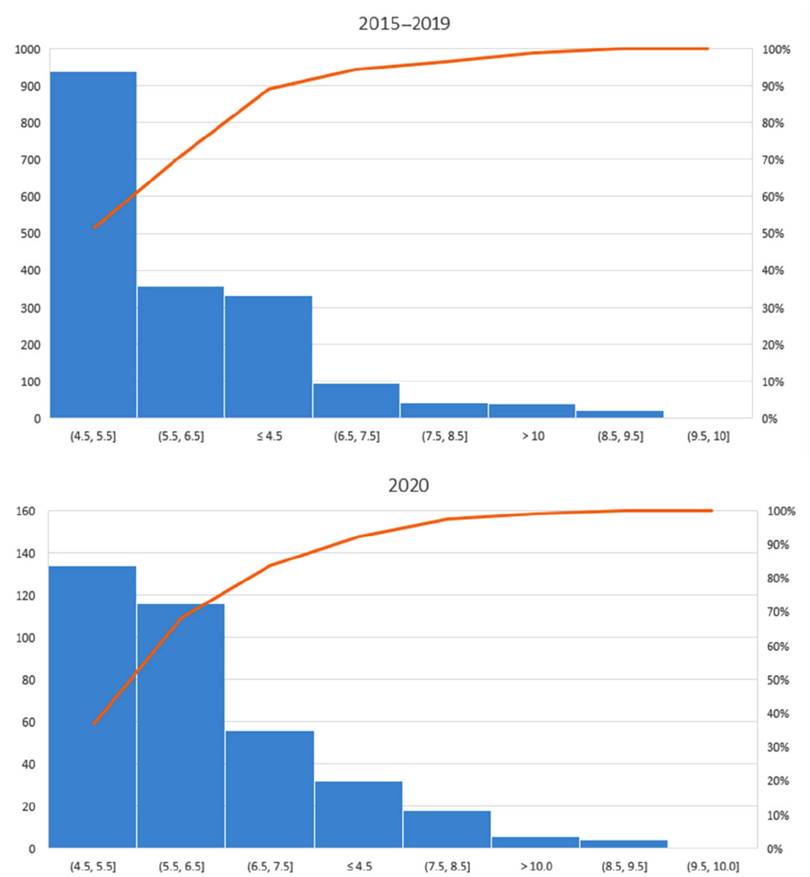

Figure 7. TP Pareto diagram for 2020 versus 2015–2019

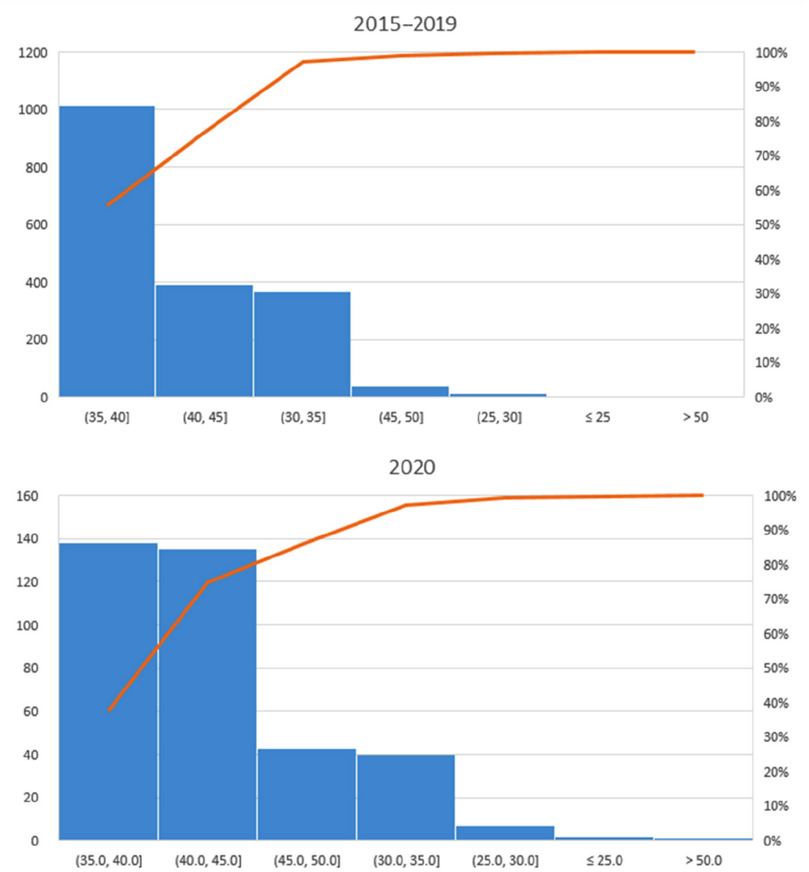

Figure 8. TKN Pareto diagram for 2020 versus 2015–2019

the world and, hence, shall be taken into consideration in wastewater treatment operations. Also, these changes in frequencies of occurrence, coupled with impact of defecting chemicals on the microbial community, may pause serious threat to wastewater treatment outcomes.

In summary, changes to wastewater quality during 2020 were more pronounced than in the previous five years. These changes included an increase in wastewater generation rates, an increase in main wastewater quality parameters such as the organics and total nitrogen, and an increase in the frequency of occurrence of higher values of organics and total nitrogen concentrations. These changes were intruded by the COVID-19 pandemic control measures including mobility restrictions and use of cleaning and disinfection chemicals as confirmed by Alygizakis et al. (2021) and Aydın et al. (2020) among others. The findings of this study brings to the attention that these alterations in wastewater characteristics need to be appropriately addressed in the operation of wastewater treatment facilities. Some of the policies suggested by Yazdian and Jamshidi (2021) may be part of an overall strategy depending on the type of COVID-19 control measures, wastewater generation sources, and water use societal behavior. Additionally, the findings presented a methodology which could be followed to detect, quantify, and assess these changes at different locations.

This study, among others, highlighted the possible impacts of the COVID-19 pandemic on wastewater characteristics in the largest wastewater catchment in Kuwait City. Although significant changes were inferred, the findings highlighted the need for further research to establish appropriate monitoring and response measures to changes in wastewater characteristics during pandemics. It also brought forward the importance of synergizing COVID-19 control measures (including lockdown policies) with wastewater treatment operations.

Conclusions

The main characteristics of the wastewater flow during the six years were examined for a wastewater catchment in Kuwait City, Kuwait. The wastewater flow rates in 2020 appeared to be higher in average in 2020, probably due to excessive water usage for COVID-19 pandemic control. This excessive water usage, and thus, wastewater generation by far, may have dampened the effect of chemical usage on the wastewater quality. However, TKN, TP, TSS, and O&G were among the parameters that have shown extremes during some months in 2020, which were not reported during the previous five years. Additionally, while COD/BOD ratio (3.0–3.5 range) increased from 8 to 13% in 2020, TP in the range 6.5 to 8.5 mg/l became more frequent than previous five years. Similarly, an evident increase in the frequency of 40 to 50 mg/l range for TKN was observed, which came at the expense of the 30–35 mg/l range in the previous five years. It is important to note that wastewater with COD/BOD ratio higher than 2.0 are usually hard to treat.

The alterations to wastewater characteristics during 2020 were found significant and associated with the COVID-19 pandemic control measures. Therefore, a thorough assessment of wastewater treatment facilities is required to ensure optimal operation in response to these alterations in wastewater quality.

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