frontiers | Frontiers in Environmental Engineering

TYPE Original Research
PUBLISHED 16 November 2023
DOI 10.3389/fenve.2023.1270854

Impact of Corona virus pandemic on wastewater characteristics, treatment, and water reuse in a municipal plant

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RECEIVED 01 August 2023
ACCEPTED 24 October 2023
PUBLISHED 16 November 2023

CITATION
Hamoda MF and AL Rashidi NS (2023), Impact of Corona virus pandemic on wastewater characteristics, treatment, and water reuse in a municipal plant. *Front. Environ. Eng.* 2:1270854.
doi: 10.3389/fenve.2023.1270854

The COVID-19 pandemic is considered one of the most significant threats to health. The effect of the pandemic on performance of wastewater treatment plants has not received much attention in the literature. This study assessed the impact of Coronavirus pandemic on the wastewater quantity, characteristics, treatment processes, and water reuse in Kuwait. It focused on three municipal wastewater treatment plants (WWTPs) with different design capacities, namely Sulaibiya (600,000 m^3/d), Kabd (180,000 m^3/d), and Umm Al-Hayman (27,000 m^3/d), all using tertiary treatment. Daily data records were obtained on influent and effluent over the years 2018–2020 (before and during the pandemic). In addition, influent and effluent samples were collected from the Sulaibiya and Kabd plants for laboratory analysis to determine the effect of increase in the use of home disinfectants. The results indicate an increase (<50%) in the average daily flow rates received in WWTPs during the 2020 home quarantine lockdowns. Statistical analysis showed stability of the Sulaibiya in BOD_5, COD, and TSS removal efficiency while a decrease in the Kabd and UAH plants removal efficiency was observed during the pandemic. During the lockdown period, GC-MS analysis showed a high probability of chloroxylenol (>90), one of the main components of Dettol disinfectant, existing in the raw wastewater samples while the GC-FID analysis indicated the presence of (PAH) as emerging contaminants, at higher concentrations in the influent and effluent samples. The pandemic adversely affected wastewater treatment plant performance and excessive use of Dettol disinfectant by homes resulted in the presence of objectionable organic pollutants in the tertiary-treated effluent which would impair water reuse. Reverse osmosis process used in Sulaibiya plant proved to be effective in removing residual organics and improving effluent quality for reuse during the pandemic.

KEYWORDS
Corona pandemic lockdowns, home disinfectants, statistical analysis, wastewater characteristics, water reuse

Introduction

Wastewater treatment and reuse bring many economic, health, and environmental benefits, the most important of which is reducing the demand for freshwater by using treated effluent as an additional source of water while protecting the environment. In order to avoid risks and impacts on public health and the environment, wastewater must be treated with the best techniques before it is disposed of into water courses, reused for irrigation or other purposes, or used for drinking (Akpor and Muchie, 2011; Hamoda, 2013; Zhang et al., 2020;

Wu, 2020). In the Gulf Corporation Council (GCC) countries, about 2.853 billion m^3/year of wastewaters are produced and 70% of it is tertiary-treated for possible reuse in irrigation (Aleisa and Zubari, 2017). The state of Kuwait is one of the leading countries in sanitation. It is ranked first in the Arab world in terms of treating almost 100% of municipal wastewater generated daily, according to the joint WHO/UNICEF monitoring program (Organisation mondiale de la santé & UNICEF, 2017). In the last 30 years, Kuwait completed the construction and operation of six WWTPs: Riqqa, Umm Al-Hayman (UAH), Sulaibiya, Kabd, Wafra, and Khiran., all of which use tertiary treatment. Significantly, Kuwait operates the largest WWTP using RO worldwide; namely the "Sulaibiya water reclamation plant" which uses the reverse osmosis (RO) process, as quaternary treatment stage, to produce treated water that satisfies the quality standards of potable water. The treated effluents from all these WWTPs are primarily reused in irrigation.

The severe, acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) was discovered for the first time at the end of 2019 in Wuhan, China after several viral pneumonia cases were recorded. With its rapid spread, it caused a new global pandemic. Recent studies have proved the appearance of the virus in the stool of infected patients (Wang et al., 2020; Zhang et al., 2020; Kam et al., 2020; The COVID-19 Investigation Team, 2020; Chen et al., 2020). Therefore, there is a possibility of transmitting Coronavirus disease through stool and urine. Moreover, the virus has been identified in wastewater in many countries worldwide (Ahmed et al., 2020; Zhang et al., 2020; Langone et al., 2020; Rimoldi et al., 2020; Bandala et al., 2021; Pasalari et al., 2023). Many countries have confirmed that the emergence of the Coronavirus in wastewater is an evidence of the importance of using wastewater for epidemiological investigation (WBE) as an alternative to the traditional monitoring approach (Bivins et al., 2020; Polo et al., 2020). However, there is a lack of studies and research showing the impact of the Coronavirus pandemic on WWTPs and treatment process performance. Meanwhile, Kitajima, et al. (2020) reviewed the current knowledge related to the potential of wastewater surveillance to understand the epidemiology of COVID-19, and showed that there is an urgent need for further research to establish methodologies for wastewater surveillance and understand the implications of the presence of SARS-CoV-2 in wastewater. It is necessary, therefore, to shed light on the impact of this pandemic on the performance of WWTPs.

A recent study by Raza et al., 2023 proved that the COVID-19 pandemic significantly impacts water quality, the environment, land pollution, the sanitation system, and human lives differently, but did not show how the performance of WWTPs is affected by the virus pandemic. Pasalari et al. (2023) conducted a study on a large WWTP in Teran, Iran, and showed that modeling-based approaches have a potential role to play in reducing the impact of the ongoing COVID-19 outbreak. Previous studies have focused on discovering the presence of Corona virus in domestic wastewater, but more studies are much needed to examine the impact of the COVID-19 pandemic on wastewater treatment and treated effluent quality for reuse. Therefore, this study was conducted to assess the impact of the Coronavirus pandemic on wastewater quantities, characteristics, and treatment processes. The performance of three main WWTPs in Kuwait, namely Sulaibiya, Kabd, and Umm Al-Hayman (UAH), with different daily capacities (large, medium, small, respectively), was evaluated for 3 years 2018, 2019 and 2020 (before and through the pandemic). Complete daily measurements of quantitative data from the studied wastewater treatment plants were obtained from the Ministry of Public Works in Kuwait. Statistical analyses were performed on flowrate and main water quality parameters, such as chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solids (TSS), oil and grease (O&G), and turbidity. Furthermore, to find out the effect of the home quarantine lockdown periods and the increase in use of household disinfectants on wastewater, influent and effluent samples were collected from the studied plants for more extensive chemical laboratory analysis.

Materials and methods

Wastewater treatment plants

The Sulaibiya WWTP was commissioned in 2005 as the first build, operate, and transfer (BOT) project, comprising four treatment stages for wastewater reclamation. The plant serves the governorates of Al-Asimah and Hawalli in the State of Kuwait and is the largest wastewater treatment and water reclamation facility in the country. It applies screening, grit chambers and gravity sedimentation in the primary-treatment stage; the activated sludge biological process and secondary sedimentation for the secondary-treatment stage; the ultrafiltration (UF) membrane process, UV and chlorination for the tertiary-treatment stage; and the reverse osmosis (RO) membrane process for the quaternary-treatment stage (Hamoda et al., 2015a; Hamoda et al., 2015b). The design flowrate of the Sulaibiya WWTP is 600,000 m^3/d. Approximately 64% of the country's domestic wastewater is treated in this plant (Al-Jarallah, 2013).

The Kabd WWTP was commissioned in 2012 with a design capacity of 180,000 m^3/d and peaks of up to 270,000 m^3/d. The plant receives the domestic wastewater from the Al-Jahra pumping station (JPS) through 2 pipelines, each serving a wide area of Kuwait. The Umm Al-Hayman (UAH) WWTP is located in the south of Kuwait near the coast, where the plant receives sewage from the central pumping station in the area and from a sewage pit that receives wastewater transported by trucks from rural areas (Aleisa et al., 2011). The plant was commissioned in 2001 with a design capacity of 27,000 m^3/d. Both plants comprise primary, secondary (Activated Sludge), and tertiary (granular media filtration) treatment stages (Al-Jarallah, 2013; Hamoda, 2013; Hamoda et al., 2015a; Hamoda et al., 2015b).

Influent and effluent samples for water quality analysis

The samples were collected from two fixed sites one in the inlet (influent) to the plant and the second was in the outlet (effluent) of the plant. The samples were taken at a fixed time of the day (in the morning). All routine analysis (e.g. COD, BOD, TSS . . . .etc.) were conducted on the samples in the laboratory of each concerned WWTP, as specified by the Ministry of Public Works in Kuwait. The samples used for analysis of specific organic matter (emerging contaminants) were transferred immediately to the National Unit for Environmental Research and Services (NUERS) lab at Kuwait University for advanced chemical analysis (e.g. GC-MS, GC-FID). Details are shown below.

Routine physical and chemical analyses included chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solids (TSS), dissolved oxygen (DO), pH, Oil&Grease, and turbidity. These analyses were conducted, onsite in the analytical laboratory facilities of each concerned WWTP, on daily samples collected from the influent and effluents of each WWTP using standard procedures (APHA, 2005). Triplicate samples were analyzed in each case and an average value of the results obtained was reported for each parameter.

Residual organic analysis

All analyses of residual organics were performed following the standard procedures outlined by Baird et al. (2017). The procedures used in the GC-MS method are US-EPA 8270D (Rev.4, Feb. 2007) for analysis and US-EPA and 3510C (UPDATE III, JUNE 1997) for extraction. Moreover, US-EPA 8015C (Rev.3, Feb. 2007) for analysis and US-EPA 3510C (Update III, June 1997) for extraction are used in the GC-FID method. Wastewater samples were collected from the WWTP in washed glass bottles, put in an ice box, and transferred immediately to the National Unit for Environmental Research and Services (NUERS) laboratory at Kuwait University, where the required analyses were performed at once.

GC-MS

The GC-MS is an analytical method that combines two techniques (1) gas chromatography and (2) mass spectrometry. The GC-MS system is easy to use and provides environmental monitoring that is less costly to conduct (Togola and Budzinski, 2008). The GC-MS was used to identify the different organic substances within the test sample. The GC-MS analyses were performed using a 7890A Gas chromatograph from Agilent Technologies. A DB-5MS with 30 m length, diameter 0.25 mm, and 0.25 μm film thickness was the capillary column used. After extraction, samples were injected (1 μL) into the GC in splitless mode at 250°C. The carrier gas was helium set at constant flow mode (0.6 mL/min).

GC-FID

Almost all carbon-containing compounds can be detected using GC-FID. Therefore, FID (Flame Ionization Detector) by measuring the amount of carbon in the sample is considered a detector for organic compounds in GC. Several studies have been conducted in which GC-FID detects some organic compounds (Wu et al., 2002; Rezaee et al., 2006; Styarini et al., 2013).

A KNFP00236 Thermo Finnigan with Trace Gas Chromatograph was used for GC-FID analyses. A DB-5MS with 30 m length, diameter 0.25 mm, and 0.25 μm film thickness was the capillary column used. In splitless mode at 250°C, samples were injected into GC after extraction. The carrier gas was helium set at constant flow mode (0.6 mL/min). Nitrogen was the auxiliary gas used.

Statistical analysis of data

Statistical analyses were performed on data using the SPSS software package (version 24). These included descriptive statistics, regression analysis, and analysis of variance (ANOVA) tests.

Results and discussion

Daily influent wastewater flow

To evaluate the plant performance, the measurement of influent wastewater flow rate is fundamental, as the increase in the wastewater flow rates to the plant influences the concentrations of water quality parameters. Thus, there is often a relationship between physicochemical parameters and flow rate. In general, wastewater flow rates depend on population and human activities. Therefore, to reach its goal in this study, it was necessary to focus on the periods of partial and total curfews (lockdowns) imposed by the state as precautionary restrictions to confront the spread of Coronavirus since the beginning of the crisis. Figure 1 presents the home quarantine time periods imposed by Kuwait's Council of Ministers.

Sulaibiya WWTP influent flow

Data on the average daily flow rates to the Sulaibiya WWTP indicate a high increase in flow rates for the years.

2019 and 2020 compared to 2018, due to the rise in the plant's operational capacity from 425,000 m^3/d to 600,000 m^3/d at the beginning of May 2019, by connecting the sewerage collection system of newly developed residential areas (Figure 2). In comparison, the relative increase in the average daily flow rates for 2020 compared to 2019 was relatively small.

Kabd WWTP influent flow

There has been a noticeable increase in the wastewater flow rate to the Kabd WWTP during the study years (Figure 3). The flow rates are often relatively lower during the summer vacation period, which occurs in May, June, July, and August (summer months), due to the tendency of most of the population to travel outside the country for vacation. Conversely, as shown in Figure 3, the average flow rate during those months for the year 2020 was the highest compared to the years 2018 and 2019 for the same period because of the preventive measures that the government applied in the country, including the ban on travel abroad and enforcement of home quarantine. Notably, the average daily flow during the total curfew in the country in May 2020 is relatively higher (180,609 m^3/d) than the rest of the partial home quarantine months for the year 2020.

Um Al-Hayman (UAH)WWTP influent flow

The data indicates some discrepancy in the wastewater flow rates to the UAH plant during the 3 years of study (Figure 4). Since 2018,

FIGURE 1
The home quarantine timeline imposed by Kuwait's Council of Ministers during the Coronavirus crisis.

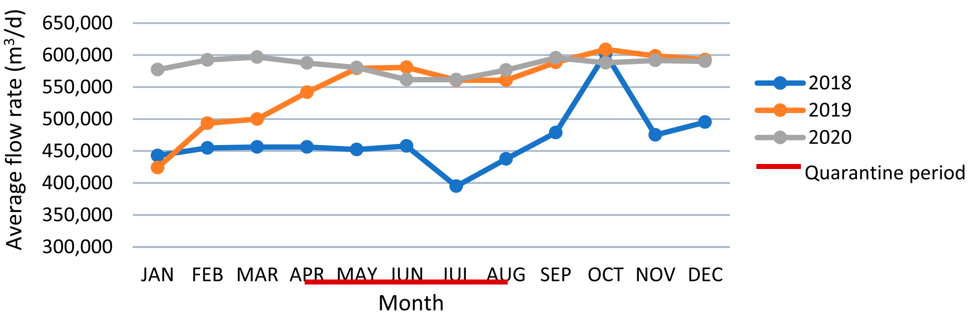


FIGURE 2
Average daily flow to Sulaibiya WWTP for the years 2018, 2019 and 2020.

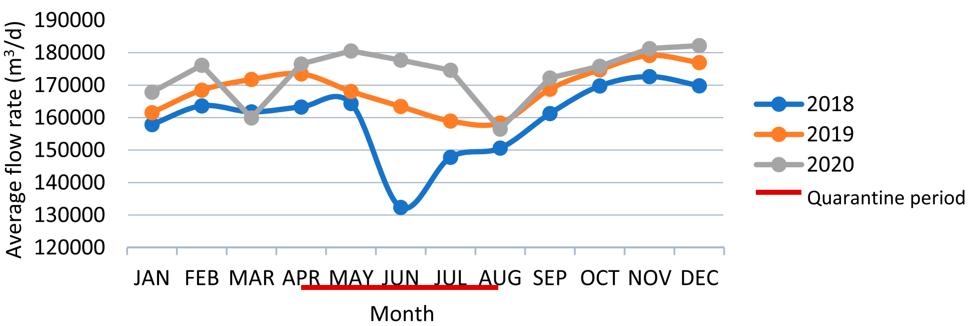


FIGURE 3
Average daily flow to Kabd WWTP for the years 2018, 2019 and 2020.

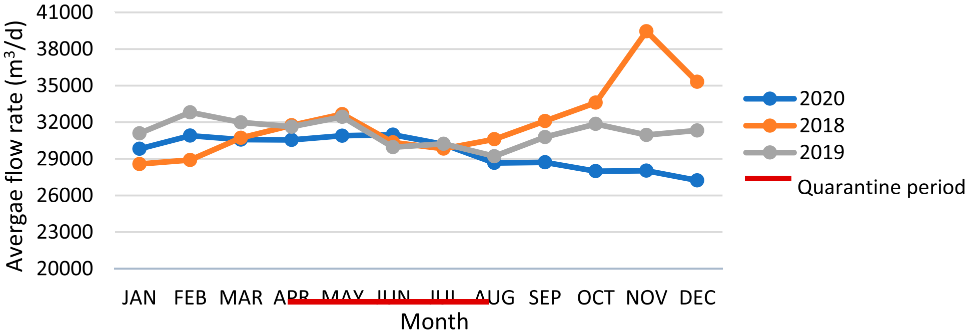


FIGURE 4
Average daily flow to Umm Al-Hayman WWTP for the years 2018, 2019 and 2020.

there has been a relative increase in the average flow rate to the plant. Conversely, there was a decrease in the average flow rate between 2019 and 2020. It is worth noting that the average flow rate to the WWTP during the home quarantine months of the year 2020 was the highest compared to the rest of months, except for February of the same year. Crucially, the average daily flow to the UAH plant during the 3 years of study frequently exceeded the plant's design capacity (27,000 m^3/d). It is to be noted that, unlike the other two plants considered in this study, the area served by the UAH plant is a strictly designated residential area with no commercial or industrial activities allowed, thus most residents stay at home and do not have to move for work in other areas during the lockdown periods.

Water quality parameters

Water quality parameters include the physical, chemical, and biological characteristics of wastewater, the most important are those used to characterize the water for reuse in irrigation. Therefore, this study considered five water quality parameters: BOD_5, COD, TSS, O&G, and turbidity, for their importance in this regard.

Influent wastewater quality parameters

After considering the water quality parameters measured in the laboratories of the three plants studied, turbidity data were not available for the raw wastewater influent for all the studied plants. Regarding the data of the Sulaibiya influent BOD_5, COD, TSS, and O&G, there is no apparent increase in flow in 2020, especially in the months of home quarantine (April to August), compared to the years 2018 and 2019. The average influent BOD_5 varied from 130 to 266 mg/L over the study years. In 2018, 2019 and 2020, the average influent COD were in the range of 358–559 mg/L. The average influent TSS values varied from 135 to 256 mg/L through the study years. However, the average O&G of the influent were in the range of 22.84–67.19 mg/L over the study period. On the other hand, the Kabd plant average influent BOD_5 values were in the range of 247–356 mg/L over the study years. Similarly, in the UAH plant, the average influent BOD_5 often ranged between 200 and 350 mg/L. It is noteworthy that higher COD values indicate higher organic pollutants in wastewater. Alternatively, the results about the Kabd influent COD values indicate an increase during the home quarantine period. The highest value was 906 mg/L reached in May 2020, during the country's total lockdown, and exceeded the acceptable limit of 700 mg/L set by Kuwait EPA, while the lowest value in the same month was 648 mg/L, which is also somewhat high. Accordingly, the average influent COD values ranged from 509 to 720 mg/L through the study years. In comparison, the average influent concentration of the COD often ranged between 400 and 700 mg/L at the UAH plants. On the other hand, the Kabd influent TSS and O&G were in the range of 165.19–213.97 mg/L and 30.53–64.7 mg/L over the study years.

Concerning influent BOD_5 values in the UAH WWTP, it was in the range of 116.10–217.17 mg/L in 2019 and 2020. UAH WWTP influent COD results indicate an apparent increase in COD averages during home quarantine months (518.48–570.63 mg/L). In 2019 and 2020, the average influent COD values were in the range of 449.37–570.76 mg/L. Furthermore, the average influent TSS were in the range of 167.33–247.70 mg/L in 2019 and 2020. Meanwhile, the average influent O&G varied from 24.28 to 34.97 mg/L in 2019 and 2020.

For the Sulaibiya, Kabd, and UAH WWTPs, the recorded average influent BOD_5, COD, TSS values wastewater were almost within the range limit established by Kuwait's EPA for the parameter concentrations allowed to be discharged into the sewer network (500, 700, 300 mg/L, respectively), over the study years (before and during Coronavirus pandemic). The increase in COD values of wastewater during the period of the pandemic is presumably due to the excessive use of home disinfectants as chemical substances which are washed out reaching the wastewater drains at home and collected in the wastewater that ultimately received in the WWTPs, thus contributing to the total COD of the wastewater.

Effluent water quality parameters

The quality of wastewater effluent, after treatment, directly impacts the environment and the human being through the way it is disposed or reused. The values of water quality parameters after tertiary or quaternary treatment must be in line with the national and international water quality standards. It is to be noted that the COD and turbidity data for the effluent from the Sulaibiya WWTP were not available. Additionally, the turbidity effluent data for the UAH WWTP and the O&G data for the Kabd WWTP were not available.

A closer look at the effluent data over the study years for each WWTP indicates that quaternary treated water in the Sulaibiya WWTP was not affected by the Corona pandemic. The treated water quality parameters at the Sualibiya WWTP are relatively similar during the three study years, including 2020, precisely the period of partial and total lockdown. The average BOD_5 and TSS of the Sulaibiya WWTP effluent during quarantine months (April to August) ranged from 0.1 to 0.2 mg/L and 0–0.01 mg/L. Meanwhile, the average effluent BOD_5 were $<=$ 0.4 over the study years. At the same time, through the study years; the Sulaibiya average effluent TSS were $<=$ 0.4 mg/L. However, the average secondary COD values ranged between 10 and 50 mg/L, while the average secondary turbidity values varied from 2 to 10 NTU over the 3 years of study. For effluent O&G values, it was zero through the study years.

There is some discrepancy in the values of the tertiary-treated water quality parameters for the Kabd WWTP, especially during partial and complete home quarantine; this implies a defect in the performance efficiency of the Kabd WWTP. The Kabd average effluent BOD_5 during the home quarantine period was in the range of 14.89–18.81 mg/L. However, over the study years, the average BOD_5 were in the range of 6.28–18.82 mg/L. During the home quarantine period, the Kabd average effluent COD was between 41.72 and 82.95 mg/L. Meanwhile, the average COD were varied from 19.20 to 84.58 mg/L during the study years. Therefore, the average effluent COD during the quarantine period was almost double its value reported during the rest of the study months. The apparent increase in the average values during the home quarantine period was for turbidity and TSS values. The Kabd average effluent turbidity was ranged from 26.22 to 68.24 mg/L during the home quarantine months. While the average effluent turbidity varied from 5.09 to 19.64 NTU in 2018 and 2019, and 8.44 to 68.24 NTU in 2020.

As for the TSS during the home quarantine period, it was between 26.06 and 64.96 mg/L. However, the average TSS was in the range of 7.94–23.52 mg/L in 2018 and 2019, and 8.18–64.97 mg/L in 2020. The BOD_5, COD, and TSS values during the home quarantine period were relatively high compared to those reported in a study conducted in the Kabd WWTP, Kuwait, for 4 years from 2013 to 2016, where the average COD was between 19.9 and 25.5 mg/L. As for the BOD_5, the daily average was between 4 and 5 mg/L, and the average TSS ranged between 4.75 and 5.8 mg/L (Alsulaili et al., 2020). In comparison, the TSS averages in the UAH plant ranged between 1 and 10 mg/L in the effluent. Moreover, the average values of BOD_5 and COD in the plant effluent varied from 1 to 8 mg/L and 8–100 mg/L (Hamoda, 2013). Furthermore, the data show that the average O&G in the secondary effluent from the Kabd plant was between 1 and 4 mg/L during the home quarantine period. Similarly, in the UAH WWTP, the O&G content ranged between 1 and 10 mg/L for the secondary effluent.

At the UAH plant, the results show the stability of the plant's situation during the Coronavirus pandemic. The average effluent BOD_5 in the home quarantine months was in the range of 4–5 mg/L. However, for the available data from the UAH plant, the average effluent BOD_5 content ranged from 3 to 7 mg/L in 2019 and 2020. For the UAH plant average effluent COD was in the range of 25.7–31.0 mg/L during the home quarantine period. However, the average effluent COD was ranged from 21 to 36 mg/L in 2019 and 2020. The apparent slight increase was for both TSS and O&G. Average content of TSS in the UAH effluent increased between the 3 years, and the increase was more noticeable in the year 2020; during the quarantine period, where it was ranged from 4 to 5 mg/L. However, the UAH average TSS of effluent varied from 1 to 6 mg/L in 2019 and 2020. Moderate content of the UAH effluent O&G during the home quarantine months was in the range of 2–3 mg/L. For the effluent O&G values, it was ranged from 1 to 4 mg/L in 2019 and 2020. Nevertheless, in the normal range, the available turbidity data in 2019 varied from 2 to 5 NTU.

There is a clear evidence for an increase in COD, turbidity, and oil & grease concentrations in the wastewater received in the influent of all WWTPs considered in this study apparently due to the excessive use of home disinfectants and hygienic substances used for personal healthcare, especially during the lockdown periods where people stay for much longer times at home. This was reflected in the wastewater effluent (after treatment) produced from such WWTPs, except that produced in the Suilaibia WWTP where the RO process is used as an effluent polishing system, where the RO membranes was capable of removing the residual "trace" organics and produce an effluent suitable for reuse as it satisfies the water quality standards set by the concerned authorities. As such, effluent water quality from the other two WWTPs (Kabd and UAH) would have been impaired the water reuse in irrigation.

Plant efficiency

Removal efficiency

The efficiency of the plant depends on the removal of different pollutants such as organics and solids. In this study, the efficiency of the plant was determined based on removal of main parameters such as COD, BOD_5, TSS, and O&G. The Sulaibiya WWTP has maintained its efficiency during the Corona pandemic. Especially during the period of the home quarantine (lockdown) imposed in Kuwait for the year 2020 to avoid the pandemic. The plant's overall removal efficiency for BOD_5, O&G, and TSS concentrations was >99% based on the wastewater influent and effluent concentrations during the 3 years of study. Similarly, in a study conducted on the Sulaibiya WWTP, for the year (2012), the efficiency of the plant in removing each of BOD_5 and TSS was >99% (Hamoda et al., 2015b).

For the Kabd WWTP as an example, Figure 5 shows that the overall removal efficiency decreased during the home quarantine months in the year 2020. The decrease in removal efficiency during the home quarantine period was more evident in the case of COD and TSS. The plant's average overall removal efficiency for the COD and TSS during 2020 home quarantine months of April, may, June, July and August dropped to 88.29% for COD and to 73.62% for TSS, respectively. The corresponding removal efficiency of BOD_5 decreased to %, 94.67%, during the home quarantine months. In comparison, in a previous study conducted on this plant in the year 2017 (Alsulaili et al., 2020), the average overall plant removal

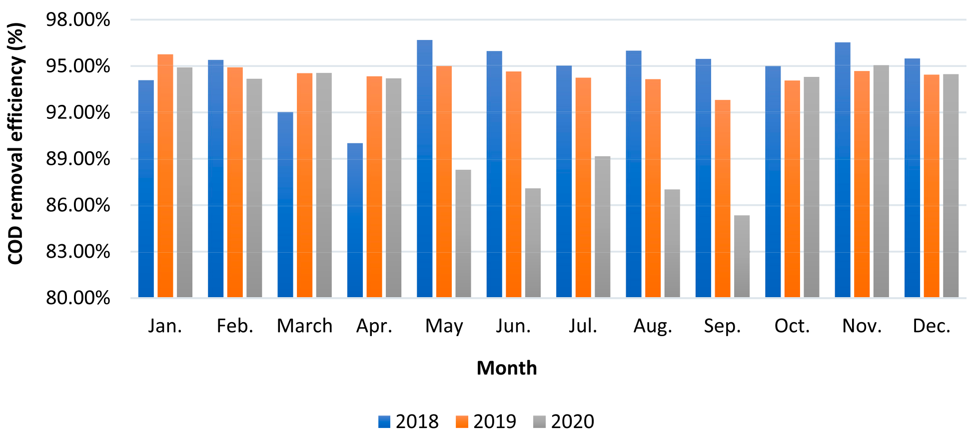


FIGURE 5
Overall COD removal efficiency in Kabd WWTP for the years 2018, 2019, and 2020.

efficiency for BOD_5, COD, and TSS was 98.05%, 96.07%, and 96.55%, respectively. Also, removal efficiency for O&G decreased to 96.94%. Apparently, the home quarantine months witnessed a decrease in the removal rates of the water quality parameters in the Kabd plant.

For the UAH plant, the results indicate that the pandemic had a slight negative effect on the plant removal efficiency. The plant average overall COD and BOD_5 removal efficiency during the home quarantine period decreased to 94.00% for COD and to 96.72%, for BOD_5. As for the corresponding plant removal efficiency during the months of the home quarantine, for each of TSS and O&G, the removal decreased to 97.93%, for TSS, and to 89.57% for O&G. In general, the efficiency of UAH plant removal of pollutants was lower, compared to the larger WWTPs considered in this study.

Regression analysis

By applying linear regression analysis, the relationship between pollutant removal and the studied influent wastewater parameters for each WWTP in this study was analyzed separately. The results indicated no significant effect of the parameters concentration on the efficiency of the parameter removal efficiency, where an R^2 value of less than 0.7 was obtained indicating a weak correlation.

Standard limits for effluent reuse

For the Sulaibiya WWTP effluent data, it is noted that the characteristics of the final treated effluent from the plant satisfied not only the irrigation water quality criteria but also the Kuwait's EPA standards for Unbottled Potable water, during the 3 years of study, including the quarantine period Furthermore, tertiary treated wastewater follows the guidelines of Kuwait's EPA, and the average final effluent for them satisfies the water quality standards for reuse in irrigation. On the contrary, the Kabd WWTP and the UAH plant tertiary-treated effluent characteristics exceeded the Kuwait's EPA guidelines during the 2020 home quarantine period, as the concentrations of some water quality parameters in the final effluent exceeded the water quality standards for reuse in irrigation. For instance, the average daily TSS values exceeded the Kuwait's EPA standard, which is 15 mg/L, and the average daily turbidity values were 68.24 and 57.98 NTU in May 2020 (total lockdown in Kuwait) and June 2020, respectively, which exceeded the EPA standard of 50 NTU. Moreover, BOD_5 values exceeded the EPA standard of 10 mg/L during the home quarantine period.

Statistical analysis of plant performance data

ANOVA test

Two-way ANOVA was conducted to determine if there are significant differences between the observed values for 2020 with both 2019 and 2018, using a model that included the main factors COD, BOD_5, TSS, O&G, and turbidity (only for Kabd WWTP effluent data) at 5% significance level. The results obtained showed that for the influent wastewater and effluent BOD_5 data, the test is statistically significant at the significance level of $\rho = 0.05$ between 2018 and 2020 and between 2019 and 2020, respectively for the Sulaibiya WWTP.

Moreover, for the Kabd WWTP effluent data, the test is statistically significant at a significance level of $\rho = 0.05$ concerning the COD, BOD_5, TSS, and turbidity data between 2018 and 2020, and COD, TSS, and turbidity between 2019 and 2020. Meanwhile, O&G influent data between 2019 and 2020 are statically significant at a level of $\rho = 0.05$. For the UAH WWTP, the test is statistically significant at the significance level of $\rho =$ 0.05 for influent wastewater BOD_5 and O&G data between 2019–2020 and 2018–2020. In addition, for COD and TSS data between 2019 and 2020, TSS and O&G between 2018 and 2020 in the effluent. Nevertheless, the ANOVA for the rest of the studied influent and effluent water quality parameters for each wastewater treatment plant in the study were statistically comparable at a significance level of $\rho = 0.05$. This indicates that there was an evident impact of the Coronavirus period on both the influent and effluent wastewater characteristics at the studied plants.

Analysis of wastewater influent and effluent for residual organic compounds during Covid-19 pandemic (effect of home disinfectants)

This section explains the results obtained by analyzing wastewater influent and effluent samples in the laboratory using advanced analytical techniques to determine the emerging contaminants and examine the effect of home quarantine and increase in the use of home disinfectants on wastewater influent and effluent characteristics. All residual organic analyses were performed following the standard procedures outlined in (Baird et al., 2017).

PH values for the samples

The pH value of the samples is shown in Figure 6. The pH of the influent samples was slightly alkaline, possibly due to excessive use of home disinfectants, but was often within the recommended range of the Kuwait's EPA (6–8). The pH of effluent samples was lower than that of the influent, particularly in Sulaibiya WWTP where the RO process is used in the quaternary stage of treatment.

GC-MS analysis

GC-MS in identification mode

To verify the concentration of 16 polycyclic aromatic hydrocarbon (PAH) compounds specified by the United States Environmental Protection Agency (US-EPA), as emerging contaminants in wastewater, the GC-MS test was conducted in identification mode for the 16 compounds. These compounds are Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, and Benzo(g,h,i) perylene (Lerda, 2011). Some of these compounds exceed the detection level (LOD=42.0 μg/L) in some samples. Table 1 shows GC-MS analysis for the US-EPA 16 PAHs of the Sulaibiya and Kabd influent wastewater, and Sulaibiya and Kabd effluent wastewater samples. The results of GC-MS indicate that the amount of naphthalene exceeded the LOD in the Sulaibiya and Kabd WWTP influent 7th of Nov. 2020 and 12th of Dec. 2020 samples, also in Kabd effluent 7th of Nov. 2020 sample. However, naphthalene was higher in the 7th of Nov. 2020 samples than in the 12th of Dec. 2020 samples for

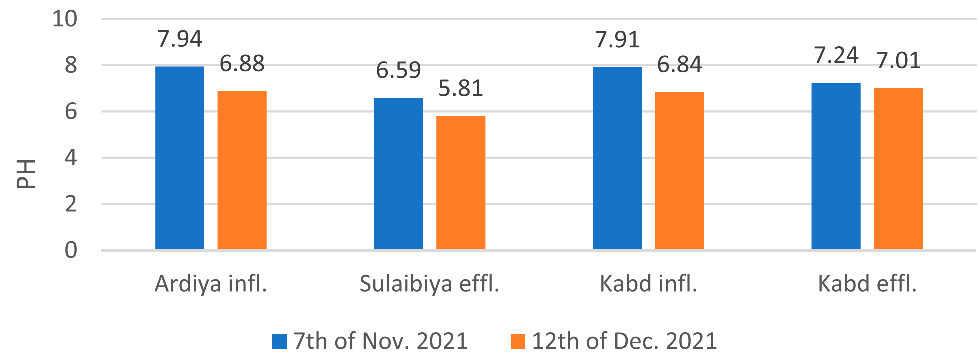
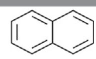
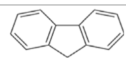
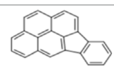
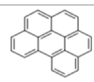
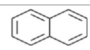
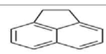
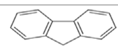
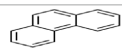
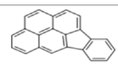
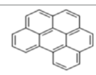
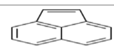
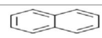
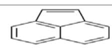


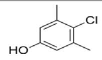
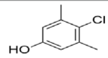
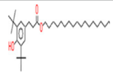
FIGURE 6
The pH values for Sulaibiya and Kabd influent and effluent wastewater samples.

TABLE 1 GC-MS analysis of US EPA 16 polycyclic aromatic hydrocarbon compounds, in Sulaibiya and Kabd influent and effluent samples (Formula, structure, molecular weight, and level of detection).

Sample ID	Compound name	7th of Nov.2020 sample LOD (µg/L)	12th of Dec. 2020 sample LOD (µg/L)	Chemical formula	Chemical structure	MW (g/mol)
Suilabiya Inf.	Naphthalene	401.37	90.44	$C_{10}H_8$		128.17
	Fluorene	53.00	below LOD	$C_{13}H_{10}$		166.22
	Indeno (1,2,3-cd) pyrene	46.92	below LOD	$C_{22}H_{12}$		276.30
	Benzo (g,h,i) peril-ene	53.60	below LOD	$C_{22}H_{12}$		276.33
Kabd infl.	Naphthalene	865.44	82.62	$C_{10}H_8$		128.17
	Acenaphthene	455.09	below LOD	$C_{12}H_{10}$		154.21
	Fluorene	186.48	below LOD	$C_{13}H_{10}$		166.22
	Phenanthrene	114.76	below LOD	$C_{14}H_{10}$		178.23
	Indeno (1,2,3-cd) pyrene	47.45	below LOD	$C_{22}H_{12}$		276.30
	Benzo (g,h,i) peril-ene	70.71	below LOD	$C_{22}H_{12}$		276.33
Sulaibiya effl.	Acenaphthylene	below LOD	102.10	$C_{12}H_8$		152.19
Kabd effl.	Naphthalene	131.53	below LOD	$C_{10}H_8$		128.17
	Acenaphthylene	below LOD	102.10	$C_{12}H_8$		152.19

[a]LOD: 42.0 µg/L, LOQ: 84.0 µg/L.

TABLE 2 GC-MS analysis (In scan mode) of organic compounds in Sulaibiya and Kabd influent and effluent samples (Probability, formula, structure, and molecular weight).

Sample ID	Compound name	7th of Nov. 2020 sample LOD (µg/L)	12th of Dec. 2020 sample LOD (µg/L)	Chemical formula	Chemical structure	MW (g/mol)
Sulaibiya Infl.	Chloroxylenol	90	90.4	C_8H_9ClO		156.61
Kabd infl.	Chloroxylenol	90.4	90.3	C_8H_9ClO		156.61
Sulaibiya effl.	Benzenepropanoic acid, 3,5-bis (1,1 dimethylethyl)-4-hydroxy-, octadecyl ester	93.1	-	$C_{35}H_{62}O_3$		530.68
Kabd effl.	Benzenepropanoic acid, 3,5-bis (1,1 dimethylethyl)-4-hydroxy-, octadecyl ester	93	-	$C_{35}H_{62}O_3$		530.68

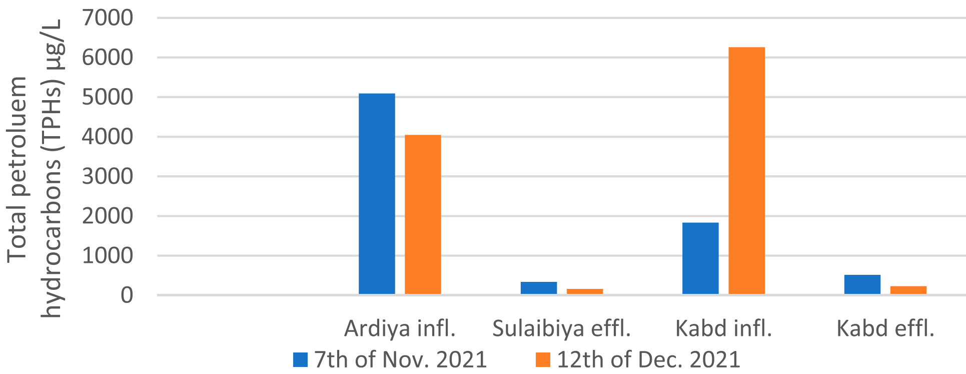


FIGURE 7
GC-FID analysis of total petroleum hydrocarbons (TPHs) in Ardiya and Kabd influent wastewater samples and Sulaibiya and Kabd effluent samples.

Sulabiya and Kabd influents. Thus, in the Kabd WWTP, the naphthalene is not completely removed after the tertiary plant treatment. Naphthalene is a volatile organic compound (7th of Nov. 2021 sample (114.76 µg/L). Like most PAHs, phenanthrene has the same uses in dyes, pesticides,etc. (Sahoo et al., 2020). For the influents of Sulaibiya and Kabd plants, the Indeno (1,2,3-cd) pyrene concentrations were (46.92 and 47.45 µg/L, respectively) and Benzo (g,h,i)perylene (53.60 and 70.71 µg/L, respectively) exceeded the LOD slightly in the Sulabiya and Kabd 7th of Nov. 2020 influent wastewater samples. The indeno (1,2,3-cd) pyrene and the Benzo (g,h,i)perylene are aromatic hydrocarbon compounds with limited uses, often like the rest of the PAHs.

GC-MS in scan mode

GC-MS analysis was conducted in a scan mode to identify the organic compounds (including home disinfectants) present in the samples. Higher peaks indicate a high probability of the presence of the compound in the sample. The results presented in Table 2 show the organic compounds that were identified in the samples with different probabilities (above 30%). The presence of the compound Chloroxylenol with a high probability in the Sulaibiya and Kabd wastewater influent samples (7th of Nov. 2020 and 12th of Dec. 2020 samples) indicates presence of Dettol (a commercial home disinfectant) in a high percentage in that samples since it is one of the main compounds in the composition of Dettol (El-Badawy and Eldesoky, 2018). However, it is palm acid and is a significant component of oil extracted from palm trees (Vegetable oil for cooking). One of the compounds that had a high probability of being present in the 7th of Nov. 2021 effluent samples of both the Sulaibiya and Kabd plants is Benzenepropanoic acid, 3,5-bis(1,1 dimethylethyl)-4-hydroxy-, octadecyl ester, which is known as the antioxidant 1076 (Antioxidant 1076 2082-79-3, 2017). It can be applied to many organic substrates and is considered a high-efficiency stabilizer. Additionally, it is a surgically inhibited phenolic antioxidant.

GC-FID analysis

Figure 7 shows the GC-FID analysis of total petroleum hydrocarbons (TPHs) in Ardiya and Kabd influent wastewater samples and Sulaibiya and Kabd effluent samples. It calculated the total area of all the peaks from the C_8-C_{40} range in the given extracts using valley to valley integration. The results indicated that the 7th of Nov. 2021 and 12th of Dec. 2021 samples from the Ardiya PS and the Kabd WWTP for influent wastewater show high organic pollutants exceeding the detection level. As for the Sulaibiya WWTP, the product water has a meager amount of pollutants in the 7th of Nov. 2021 sample and almost no pollutants in the 12th of Dec. 2021 sample (<LOD). Furthermore, Kabd effluent samples indicate many organic pollutions, especially in the 7th of Nov. 2021 sample. Significantly, the Ardiya PS and Kabd raw wastewater were diluted as they contained many organic pollutants.

These analyses showed that emerging contaminants would be present in the effluent to be reused in irrigation, as a results of the excessive use of home disinfectants and personal care chemicals. Thus raises the question of limiting the reuse of the treated effluent during the pandemic, specially at times of lockdowns due to presence of such emerging contaminants.

Conclusion

This study was conducted to assess the impact of the Coronavirus pandemic on the quantities, characteristics, and treatment of wastewater in Kuwait and identify the effect of increased use of home disinfectants, cleaning chemicals, and personal care hygienic chemicals during the period of home quarantine, on effluent characteristics. Three WWTPs of different capacity (large, medium, and small), namely Sulaibiya, Kabd, and UAH were studied. The results obtained clearly indicate that the flow rates of wastewater received at treatment plants experienced an increase (<50%) during the home quarantine period and almost throughout the year 2020, compared to the years preceding the pandemic. The performance and removal efficiency of the large Sulaibiya, advanced WWTP, with an extensive flow rate capacity, showed consistent performance even during the Corona pandemic and the period of home quarantine in Kuwait. The plant achieved up to 99% removal of the BOD_5, COD, and TSS. On the contrary, there was a significant decrease in the removal of pollutants, dawn to 80% removal efficiency, during the home quarantine period in Kabd (medium size) and UAH (small size) WWTPs. The pandemic had a negative effect on removal of pollutants in WWTPs, especially during the home quarantine (lockdown) period. Furthermore, GC-MS and GC-FID organic analysis on influent samples collected from each of the three plants clearly indicate presence of PAH (Polycyclic Aromatic Hydrocarbons) as emerging organic contaminants during the period of Coronavirus apparently due to the excessive use of home disinfectants, cleaning chemicals, and personal care hygienic substances during the pandemic. Such organic contaminants were also present in the effluent from the Kabd and UAH treatment plants but were not detected in the effluent from Sulaibiya plant as it was possibly removed by the advanced membrane processes (reverse osmosis) used in the quaternary treatment stage. Presence of such contaminants in the treated effluents would impair effluent water reuse.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

MH: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing–original draft. NA: Conceptualization, Methodology, Writing–original draft, Investigation, Project administration, Supervision.

Funding

The authors declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors would like to thank the Ministry of Public Works in Kuwait for providing plant data and allowing to take the samples collected for this study. Many thanks to National Unit for Environmental Research and Services (NUERS) lab at Kuwait University (SRUL01/13) for their cooperation and assistance in analyzing the samples by GC-MS and GC-FID techniques.

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.

The author MH declared that they were an editorial board member of Frontiers at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

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