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Detection of SARS-CoV-2 in Wastewater: Implications for Public Health and Climate Resilience

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Abstract

SARS-CoV-2, the virus responsible for COVID-19, can be traced through feces and urine, making wastewater a valuable resource for controlling its spread. This study aimed to detect SARS-CoV-2 in wastewater from three decentralized treatment plants in Puerto Rico and assess its implications for public health. During monitoring from December to January 2024, high concentrations of SARS-CoV-2 were observed, primarily in December, with an increase in January at the Río Grande and Humacao wastewater treatment plants (WWTPs). These data align with the positivity rates for SARS-CoV-2 reported in Puerto Rico for these communities from October 2023 to January 2024. A Pearson correlation analysis examined the relationship between temperature and SARS-CoV-2 concentration in wastewater, indicating a slight correlation that suggests high temperatures above 30˚C may modestly affect the persistence of the virus in sewage. Understanding these variables is crucial, especially as temperatures rise and contribute to extreme heat. By analyzing the concentration of the virus in sewage, we can predict infection rates in the population and gain insights into the virus's behavior and its resistance to environmental factors. This research underscores the importance of wastewater-based epidemiology (WBE) as an early detection method and its role in sustainable public health strategies. The emphasis is on effective wastewater management to mitigate the impact of COVID-19 and future pandemics in the context of climate change.

Keywords

Wastewater, SARS-CoV-2, Climate Change, Virus

1. Introduction

Climate change is projected to spread thousands of new viruses and strains across animal species by 2070, thereby increasing the risk of infectious diseases transferring from animals to humans [1]. In addition to these growing threats, climate change affects respiratory infectious diseases caused by SARS-CoV-2 [2]. This is a new virus identified as the cause of COVID-19. Several studies about coronavirus have shown that the SARS-CoV virus can be tracked through feces and urine [3]. The SARS epidemic of 2003 had potential links to wastewater, as an outbreak at a high-rise housing estate in Hong Kong involving over 300 people was connected to a faulty wastewater system [4]. The fact that SARS can replicate in the enteric tract raises the possibility of it being an enteric pathogen, with the incidence of diarrhea ranging from 8% to 73% in infected people [5]. SARS has been shown to survive at alkaline pH and room temperature.

Many researchers are studying the coronavirus and its behavior before and after the pandemic. In a compilation of previous studies, the following has been found: a) Coronavirus represented the second most abundant group of human pathogenic viruses in biosolid samples after Parechovirus [6]; b) Studies revealed that RNA of SARS-CoV was found in the sewage before and after disinfection from hospitals [7]; c) Studies in wastewater treatment plant of U.S detected Coronavirus in 83% of wastewater samples, Coronavirus HKU1 was the second most prevalent RNA virus and Coronavirus showed a higher relative abundance in influent samples compared to effluent ones [8]. The importance and utility of wastewater for monitoring viruses like these became evident during the COVID-19 pandemic, where government authorities could determine if there were positive cases of COVID-19 in specific areas. This strategy was only present during the emergence of the pandemic. The presence of viruses and persistence in wastewater is a good area of study for evaluating and suggesting new materials that help remove and destroy all viral particles with possible viability. This contributes to the introduction of pathogenic viruses into the waterways, which then reach the drinking water treatment plants [9]. Therefore, this represents an emerging public health issue, and it is necessary to determine if these pathogens are being disseminated into the environment through sanitary discharges and if they are reaching water bodies and treatment plants. To tackle this challenge, we propose the following objectives. Our goal is to detect pathogenic viruses, such as COVID-19, in wastewater as a source of information on human health, and establish a new strategy that can be used for monitoring, epidemiological studies, and evaluation of the efficiency of wastewater treatment to inactivate pathogenic viruses and promote better conditions to reuse the water.

2. Methods

2.1. Study Zone

Puerto Rico is an island located in the Caribbean. The study zone consists of three decentralized Waste Water Treatment Plants (WWTP), which means systems that are not connected to Puerto Rico Aqueducts and Sewer Authority (Non-PRASA). Criteria included: location in the same geographic area, East of Puerto Rico, with similar qualities; providing infrastructure to collect used water to communities of residential zones, and or touristic with amenities such as hotels, restaurants, and schools. According to the data reported by the Department of Health in Puerto Rico, the regions with infected people are in the metropolitan area. This data was used to determine the regional treatment plants for sampling collection. The treatment plants selected to be east of the island were Coco Beach Utilities, Punta Picuas WWTP, and Palmas del Mar Utility Corp. The first two are located in the municipality of Rio Grande, and the last one is in the municipality of Humacao. Figure 1 shows the locations of the areas in which they provide wastewater collection and treatment services.

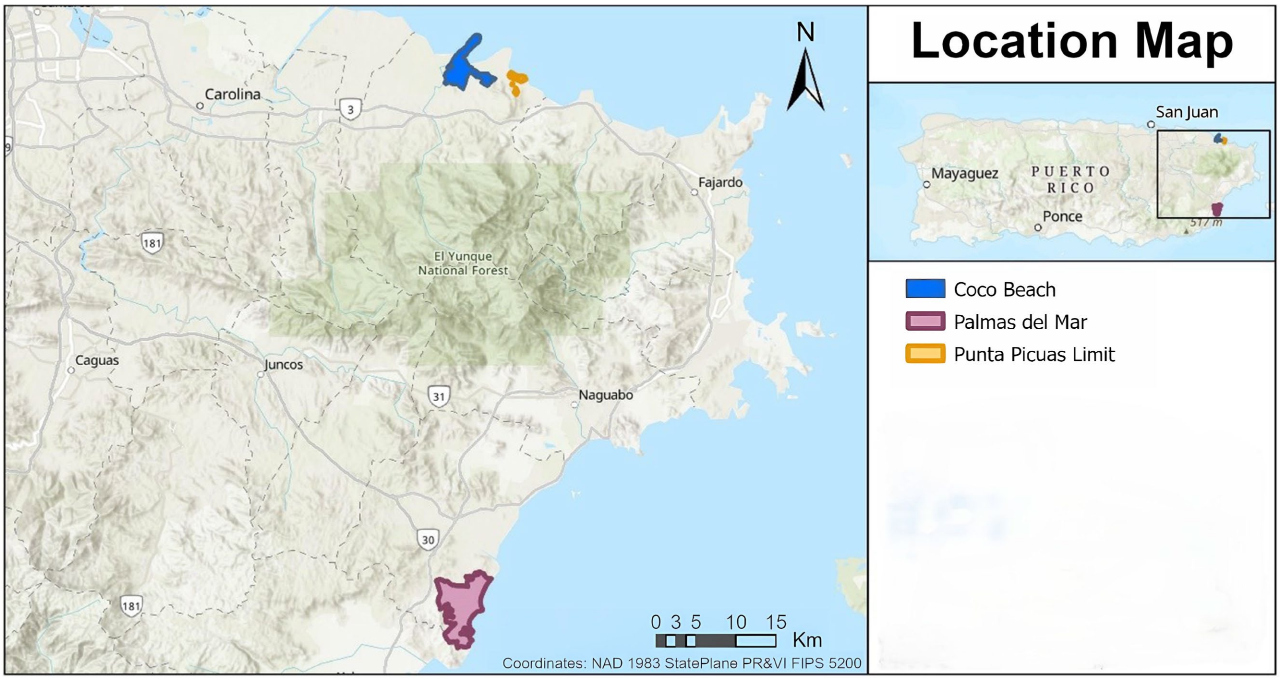

Figure 1. Location map of the study area of the WWTP. (Base map data from Esri (2020), using ArcGIS Pro 3.2.1. Source: GIS. PR. GOV.)

2.2. Study Areas Characteristics

Coco Beach and Punta Picuas are located in a municipality on the Rio Espiritu Santo Natural Reserve. To the north is the Atlantic Ocean. Coco Beach Resort has an elevation from 1 meter above sea level (masl) in most of the area, up to 70 masl in the west. Punta Picuas WWTP is located at 1 masl, the service beach area goes from 1 to 4 masl, and the second service area goes from 5 to 60 masl. Palmas del Mar Resort is located in the southeast of Puerto Rico and borders the Caribbean Sea; its elevation ranges from 1 to 70 masl. Figure 2 includes the three locations with the topographic contours.

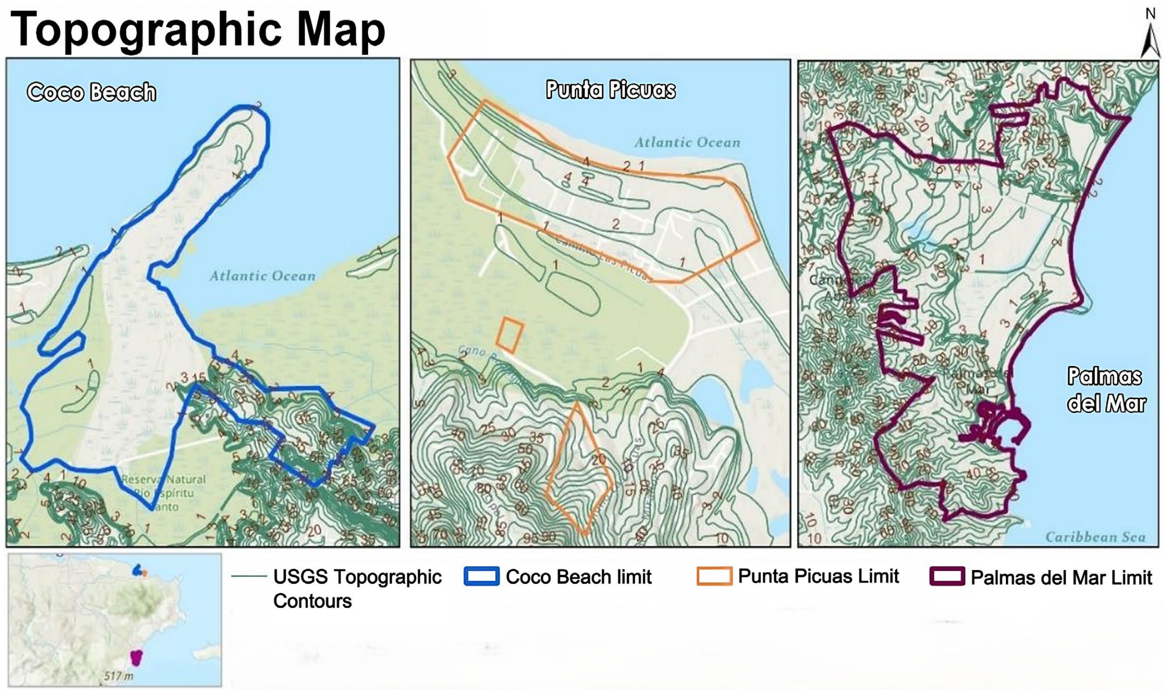

Figure 2. Topographic map of each location of the study areas. (Base map data from Esri (2020), using ArcGIS Pro 3.2.1. Source: GIS. PR. GOV.)

2.3. Sampling Plan

The sampling plan was coordinated with the WWTP operators, and samples were taken at the same selected points each time. Weather conditions were taken into consideration on non-rain dates. For each monitoring, the following plan is carried out as shown in Table 1 and Figure 3:

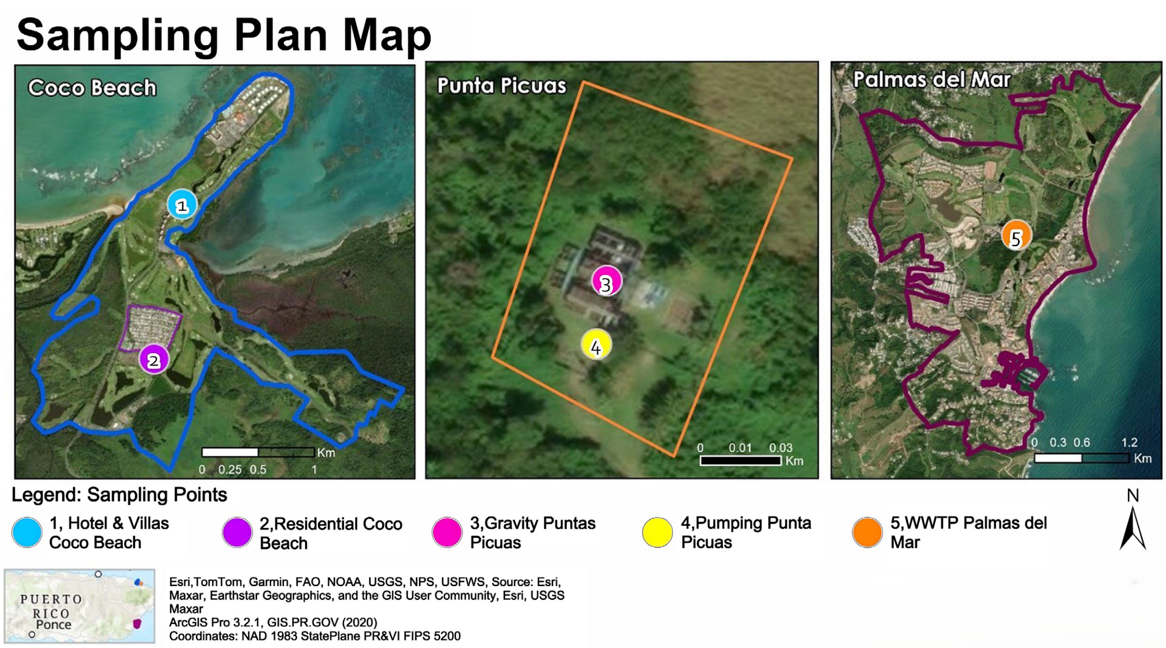

Figure 3. The sampling plan map illustrates the sampling points at the three different locations as described above.

Table 1. Wastewater sampling plan.

Punta Picuas	Coco Beach	Palmas del Mar
3 raw samples at intake by gravity from Hillside Village.	3 raw samples at intake Pump Station 1 of the hotel and villas zone.	3 raw samples at intake at the main treatment tank.
3 raw samples at intake by pumping from residential walkups located in the coastal area.	3 raw samples at intake Pump Station 2 of residential zone.	

2.3.1. Decentralized WWTP at Punta Picuas

Punta Picuas WWTP is located in a rural area in Rio Grande municipality. It borders the West with Río Espiritu Santo Natural Reserve and to the north with the coastal area and the Atlantic Ocean. It is a private, decentralized solution to provide sanitary sewage service of used water treatment to the community of Punta Picuas, which consists of approximately 1300 multi-family unit walkups in the coastal area and others in the mountain area adjacent to the plant (see Figure 4).

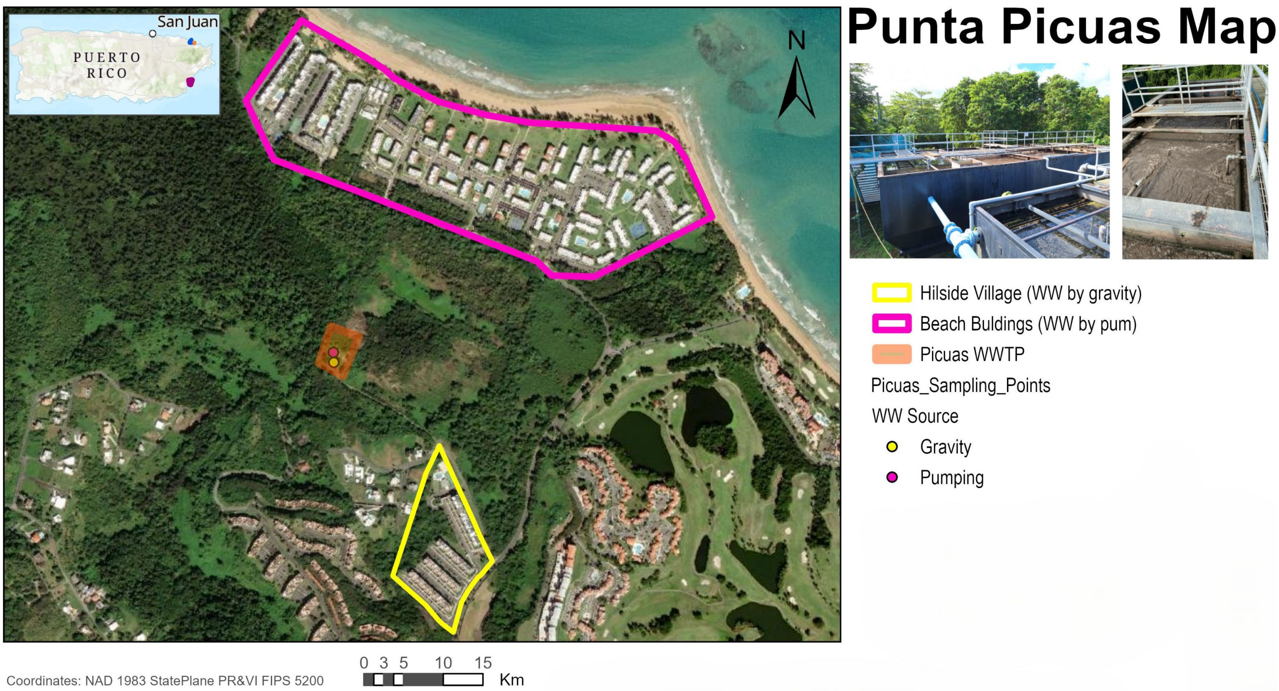

Figure 4. Punta Picuas WWTP location map and community service areas. (Base map data from Esri (2020), using ArcGIS Pro 3.2.1. Source: GIS. PR. GOV.)

The population in this area is approximately 10% full-time residents and 90% fluctuating because most of these homes are second homes, that is, they are used on weekends, holidays, and vacations. The WWTP has a designed capacity to treat 315,000 GPD of wastewater, consisting of 3 modules. It does not operate at full capacity. In peak seasons, the range is 150,000 to 180,000 GPD; the rest of the time, its time is less than 100,000 GPD. Treatment Plant gets intake from a gravity source of 1/3 of the residences of Hillside Village and by a pumping flow of 2/3 of the 7 complexes of walk-up residences located in the coastal zone.

2.3.2. Decentralized WWTP at Coco Beach

Coco Beach WWTP is located in a rural area at Punta Miquillo in the Rio Grande municipality. It borders the Rio Espiritu Santo Natural Reserve to the north, with the coastal area and the Atlantic Ocean. It is a private, decentralized solution to provide sanitary sewage service of used water treatment to the community of Coco Beach (see **Figure 5**). It has two pump stations, one of which provides service to the residential zone of 320 residences, and the second one collects used water from one condo Hotel with 132 apartments, one hotel with 482 rooms, 5 villas, one clubhouse, and 5 restaurants.

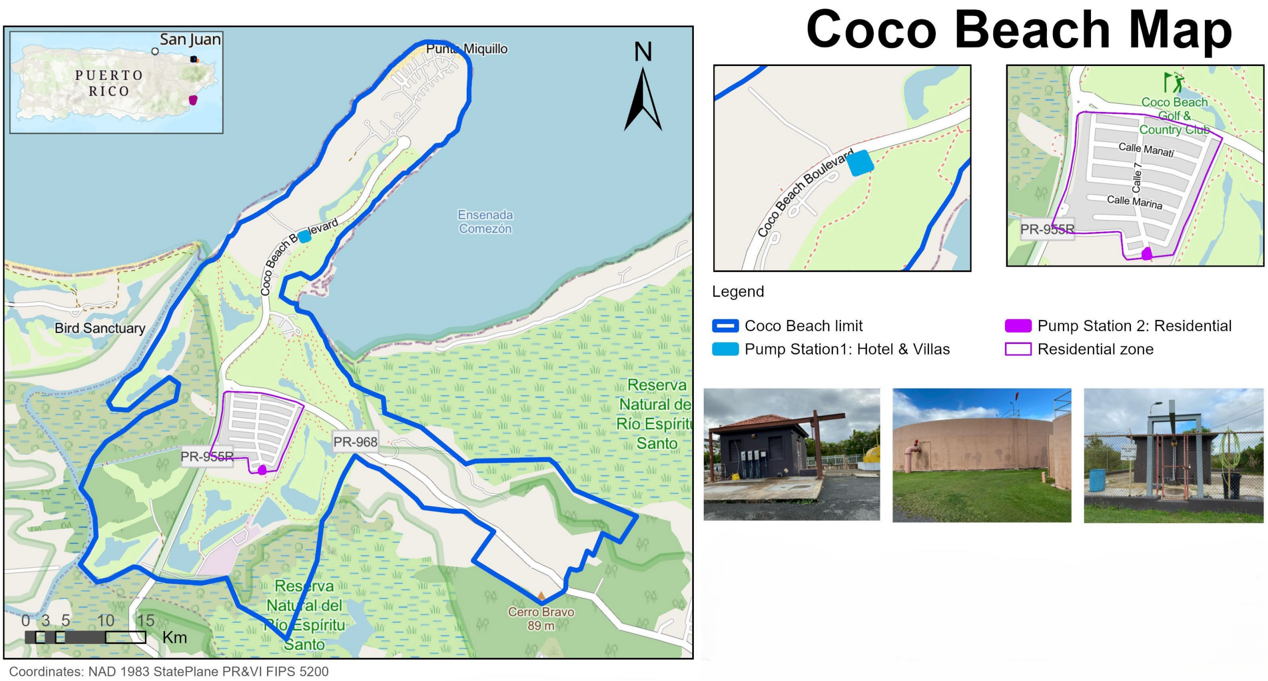

Figure 5. Coco Beach WWTP location map and the communities' service areas. (Base map data from Esri (2020), using ArcGIS Pro 3.2.1. Source: GIS. PR. GOV.)

The WWTP has been designed the capacity to treat 1 million GPD of wastewater. It does not operate at full capacity. It has a golf course that is irrigated with treated water from the plant.

2.3.3. Decentralized WWTP at Palmas del Mar

Palmas del Mar Vacation-Residential Complex has an area of approximately 2800 acres located in Buena Vista and Candelero Abajo neighborhoods of Humacao and Guayanes ward in Yabucoa. The WWTP is part of a Franchised entity operated by Palmas del Mar Utility Corp. (PDMU) to provide sanitary sewage service and treatment of wastewater to the Master planned community of Palmas del Mar (PDM). The WWTP has a permit capacity to treat 1.2 million GPD of wastewater. Being a residential-touristic property, during holiday seasons, the treated water volume range can be registered between 475,000 and 550,000 GPD on average. It serves approximately 3500 clients, among whom are 1 school (350 students), 1

Hotel (106 rooms), 1 Time-Share complex (110 villas with 3 rooms and 16 with 2 rooms), 1 marina (106 slips, AVG 60 boats in season), 18 restaurants, 1 Tennis Center, 1 Golf Club, and 1 equestrian center (see Figure 6).

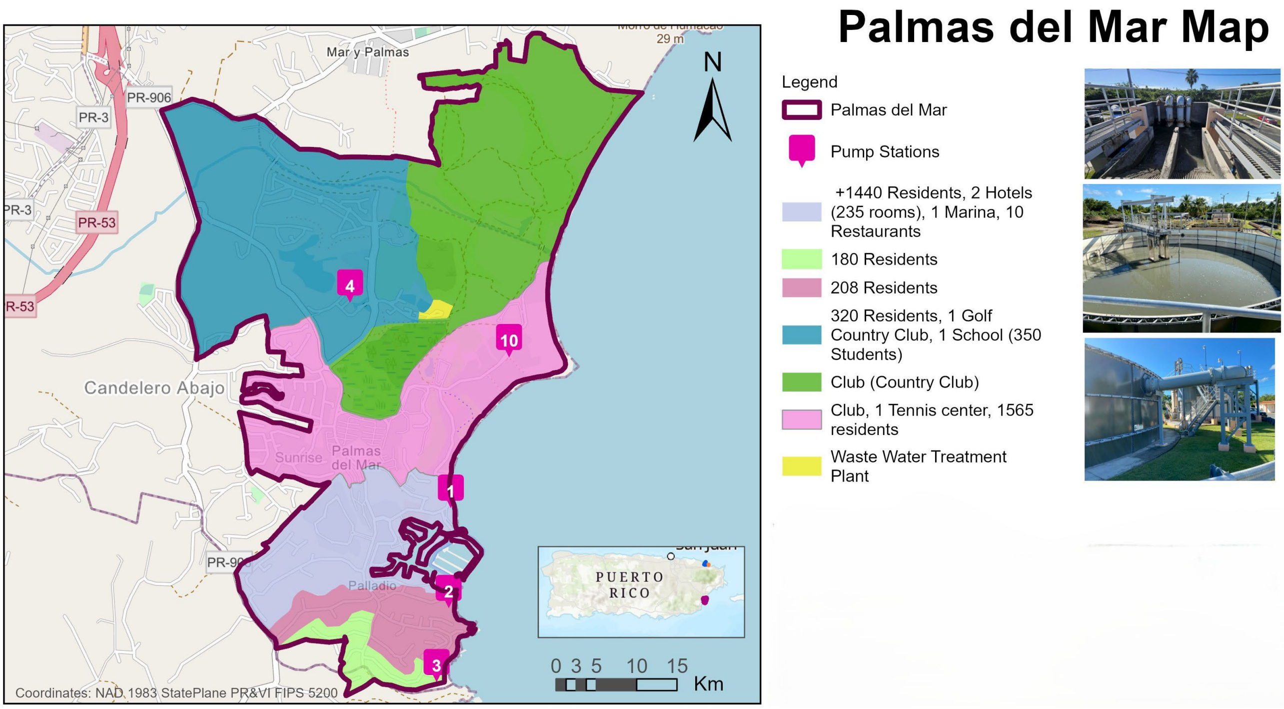

Figure 6. Palmas del Mar WWTP location map and community service areas. (Base map data from Esri (2020), using ArcGIS Pro 3.2.1. Source: GIS. PR. GOV.)

2.4. COVID-19 Sampling Methodology

Samples were collected in the treatment plants with a long-handled ladle, transferred to sterile bottles, and transported in a cooler to maintain the temperature at 4˚C or less until shipment for testing. The samples were packaged and shipped in a box with ice to Biobot Analytical Laboratories in Massachusetts using an overnight delivery service.

Detection of SARS-CoV-2

The U.S. Centers for Disease Control and Prevention has developed an RT-qPCR assay for SARS-CoV-2 detection. RT-qPCR is used to measure the amount of a specific RNA by monitoring the amplification reaction using fluorescence and detecting the gene expression of the particular virus.

This molecular method will be used to detect the initial presence or absence of the virus in the wastewater of the selected Puerto Rico treatment plants. All the samples were analyzed by Biobot Analytical. These results are expressed in units of genome copies per liter of wastewater. For clarity, we refer to this value as the crude concentration of a wastewater sample. The RNA copies/L of SARS-CoV-2 detected in the wastewater of municipalities were evaluated by estimating for each positive sample, assuming a normal distribution of the minimum and maximum values obtained. Many factors can affect the fecal and urine mass in a person, but studies have estimated both fecal solids (29 g/person/day) and urine solids (58 - 64 g/person/day) for individuals. These values are useful for estimating possible asymptomatic individuals in municipalities through wastewater samples. The number of infected individuals in a given 24-hour period (*Jt*) can be estimated using the mass rate of virus copies present in wastewater and the mass rate for shedding of the virus using the following equation:

$$Jt = \frac{Q \times V}{A \times B}$$

where Q is the average flow rate at the WWTP (L per day) for 24 hours, V is the virus copies per L, A is the rate of feces production per person (g per day), and B is the maximum rate at which the virus is shed (RNA copies/g feces/day) [10].

3. Results & Discussion

The United States Centers for Disease Control and Prevention (CDC) established four levels for classifying the level of community transmission based on positivity, based on 7 days as follows: low (less than 5.00%), moderate (5.00% - 7.99%), substantial (8.00% - 9.99%) and high (more than 10.00%) [11]. According to the results of the Puerto Rico Health Department (see **Figure 7**), a high positivity status was reflected, where the indicator was estimated at 11.02%. The maximum positivity value reached was 23.01% for December 28, 2023, which presents a high community transmission level for the sampling dates carried out in the treatment plants.

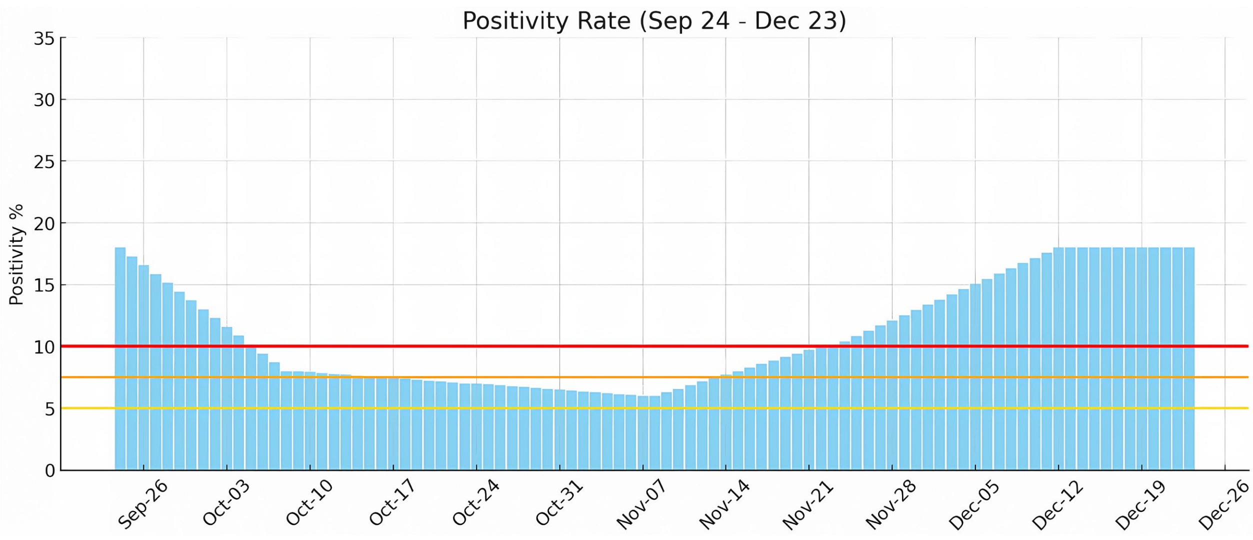

Figure 7. Positivity of COVID-19 in Puerto Rico from October to January 2024.

According to the report from the Department of Health of Puerto Rico, the cases reported by hospitals and care centers show that the cases remained stable during December 2023. Then they increased in January 2024 until February 4, 2024. **Figure 8** shows the presence of the SARS-COV-2 virus in wastewater. Coco

Beach samples show an increase in the detection of copies of the virus in hotel areas (points in color red) as opposed to the residential area (points in color blue). This is due to the greater number of people in that area and tourists. In the case of the Picuas WWTP, the highest number of viral infections was found by pumping the flow of 2/3 of the complex of 7 walk-up residences located in the coastal area (points in color red) vs samples by gravity (point in color blue). At the Palmas del Mar WWTP, the data show a decrease in viral presence starting in January, and the pattern in the other treatment plants is consistent. The results show the trends of SARS-CoV-2 effective concentrations in each wastewater treatment plant (WWTP) located in Rio Grande and Humacao.

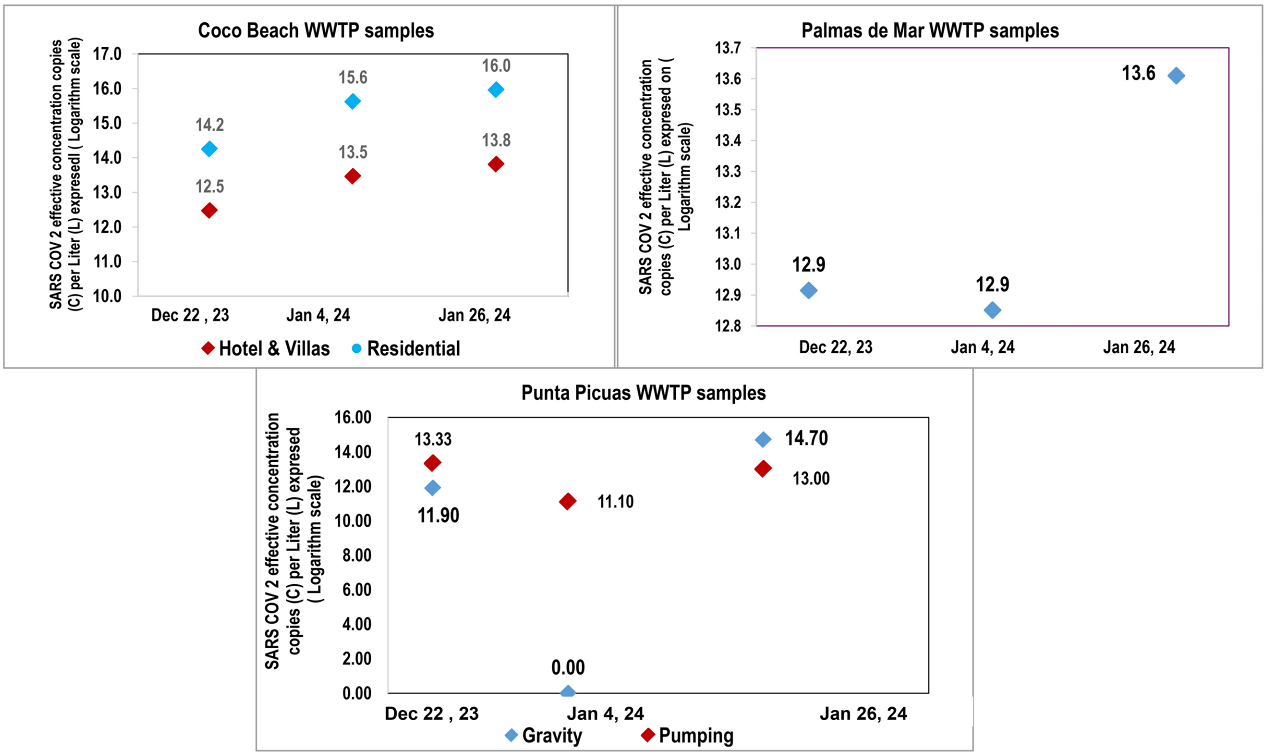

Figure 8. Effective concentration of SARS-CoV-2 copies per liter of wastewater treatment plants (hotel areas represented by points in red instead of the residential area in blue). In Picuas WWTP residences area, by pumping flow is represented for points in color red vs samples by gravity in the color blue.

During December to January 2024, we observed high concentrations of SARS-CoV-2, primarily in December, at the Rio Grande, and Humacao wastewater treatment plants (WWTP). These decentralized water treatment plants serve communities of 3600 people, and the capacity is 1.2 million gallons per day (MGD). Figure 9 data shows an increase in SARS-CoV-2 effective concentration in the colder months starting in December 2023 and January 2024, and then a decrease in the warm seasons. Puerto Rico was at a high transmission level for the period from December to January 27, 2024, with a reported case rate of 148.27 cases of COVID-19 for each 100,000 inhabitants, reflecting the continued impact of this virus on the island [12].

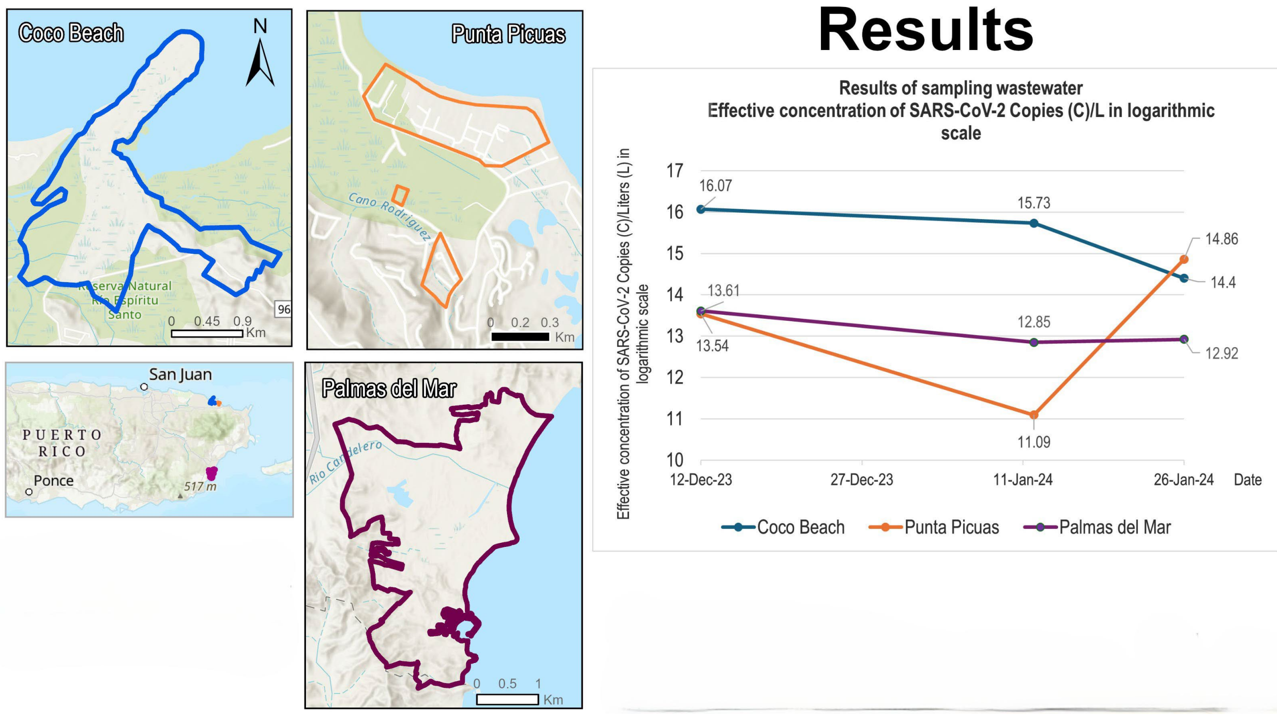

Figure 9. Trend of the effective concentration of SARS-CoV-2 on a logarithmic scale of three treatment plants identified on a geo-spatial map. (Base map data from Esri (2020), using ArcGIS Pro 3.2.1. Source: GIS. PR. GOV.)

Table 2 shows the trend of infections during the sampling dates with an increase. These data coincide with those reported by the Department of Health with SARS-CoV-2 according to the positivity rate during the period from 2023 to January 2024, as shown in Figure 7. In January 2024, Puerto Rico experienced a notable increase in reported cases of COVID-19 compared to previous months. This increase can be attributed to several factors, including higher transmission rates, social interactions, and gatherings during the holiday season that likely contributed to the increase in cases, possible new variants, and changes in public

Table 2. The number of infected individuals in a given 24-hour period (*Jt*) is shown (*Jt*).

Sampling date	WWTP	Flow rate (10^6 L per day)	pH	Temperature	RNA (copies per L) (logarithmic scale)	Estimated infected individuals
22-Dec	Coco Beach		8.9	31	1.9×10^6	3155
4-Jan	Coco Beach	1.9×10^6	7.4	31	9.5×10^6	2088
26-Jan	Coco Beach		7.4	30	6.2×10^6	661
22-Dec	Picuas		8.2	31	7.6×10^6	86
4-Jan	Picuas	6.8×10^5	7.5	29	6.5×10^6	7
26-Jan	Picuas		7.4	29	2.8×10^6	321
22-Dec	Palmas del Mar		7.2	30	8.1×10^6	281
4-Jan	Palmas del Mar	2.0×10^6	7.2	31	3.8×10^6	131
26-Jan	Palmas del Mar		7.8	30	4.0×10^6	140

health measures. To analyze the relationship between temperature and the effective viral concentration found, the Pearson correlation was performed. The correlation between temperature and concentration was 0.2, which demonstrates a weak relationship between these two variables. While SARS-CoV-2 generally degrades more quickly at higher temperatures [13], the weak correlation observed in the Pearson analysis suggests that the temperature's effect on other unmeasured factors, such as the retention time in the sewage system or the chemical composition of the wastewater, likely influences the virus's degradation. These variables are important to analyze at times when the temperature continues to increase and generates extreme conditions [14].

4. Conclusions

The detection of SARS-CoV-2 in wastewater in Puerto Rico has demonstrated significant potential for enhancing public health surveillance and response strategies in the region. This study underscores the feasibility and effectiveness of WBE as a tool for tracking the spread of COVID-19 within communities [15]. By monitoring sewage for the presence of the virus, we can obtain early indicators of infection trends, which are particularly valuable in areas with limited clinical testing resources [16].

Our findings reveal that wastewater analysis can serve as a reliable, non-invasive method to gauge the prevalence of COVID-19 across diverse populations. The ability to detect viral RNA in wastewater samples from different locations provides a comprehensive overview of the infection landscape, allowing health officials to identify and respond to emerging hotspots more swiftly [17]. In low- and middle-income countries, such as Puerto Rico, viral levels in wastewater have been shown to correlate with clinical cases and sometimes precede the increase in notifications by 5 - 7 days, reinforcing the usefulness of WBE as an early warning system [18]. The implementation of this surveillance method in Puerto Rico has already provided critical data that informed public health decisions and interventions. Moving forward, it is imperative to continue refining these techniques, expanding sampling coverage, and integrating WBE data with other epidemiological information. This approach will not only enhance our understanding of COVID-19 transmission but also prepare us for future public health challenges [19].

In conclusion, the successful detection of SARS-CoV-2 in Puerto Rican wastewater highlights the value of WBE in managing and mitigating the impacts of pandemics. By leveraging this innovative surveillance tool, Puerto Rico can strengthen its public health infrastructure, ensuring a more resilient and responsive system to safeguard the health of its communities.

Recommendations for Treatment Plant Operators Detecting COVID-19 in Wastewater: Establish a routine sampling schedule to consistently monitor SARS-CoV-2 levels in wastewater and Increase sampling frequency in response to rising infection rates or outbreaks in the community [20]. Ensure all personnel handling samples follow strict biosafety guidelines, including the use of personal protective equipment, and provide training on proper sample collection, handling, and disposal procedures to minimize the risk of exposure.

Collaborate with local health departments to share data, integrate findings into broader public health surveillance efforts, and utilize data analytics tools to track trends and identify potential hotspots within the community. Evaluate current wastewater treatment processes to ensure they are effective in reducing viral loads. Consider implementing additional disinfection steps, such as ultraviolet treatment or chlorination, to enhance virus removal.

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Data Availability Statement

All relevant data are included in the paper.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Carlson, C.J., Albery, G.F., Merow, C., Trisos, C.H., Zipfel, C.M., Eskew, E.A., *et al.* (2022) Climate Change Increases Cross-Species Viral Transmission Risk. *Nature*, **607**, 555-562. https://doi.org/10.1038/s41586-022-04788-w

[2] Marazziti, D., Cianconi, P., Mucci, F., Foresi Crowther, L., Chiarantini, I. and Della Vecchia, A. (2021) Climate Change, Environment Pollution, COVID-19 Pandemic and Mental Health. *Science of the Total Environment*, **773**, Article ID: 145182. https://doi.org/10.1016/j.scitotenv.2021.145182

[3] La Rosa, G., Bonadonna, L., Lucentini, L., Kenmoe, S. and Suffredini, E. (2020) Coro-

navirus in Water Environments: Occurrence, Persistence and Concentration Methods—A Scoping Review. *Water Research*, **179**, Article ID: 115899. https://doi.org/10.1016/j.watres.2020.115899

[4] Wang, Y., Wang, Y. and Wang, Y. (2022) A Review of the Environmental Fate and Transport of Microplastics in Soil: Challenges and Perspectives. *Journal of Hazardous Materials*, **424**, Article ID: 127531.

[5] Hung, L.S. (2003) The SARS Epidemic in Hong Kong: What Lessons Have We Learned? *Journal of the Royal Society of Medicine*, **96**, 374-378. https://doi.org/10.1258/jrsm.96.8.374

[6] Bibby, K., Viau, E. and Peccia, J. (2011) Viral Metagenome Analysis to Guide Human Pathogen Monitoring in Environmental Samples. *Letters in Applied Microbiology*, **52**, 386-392. https://doi.org/10.1111/j.1472-765x.2011.03014.x

[7] Wang, X.W., Li, J.S., Guo, T.K., Zhen, B., Kong, Q.X., Yi, B., *et al.* (2005) Excretion and Detection of SARS Coronavirus and Its Nucleic Acid from Digestive System. *World Journal of Gastroenterology*, **11**, 4390-4395.

[8] Bibby, K. and Peccia, J. (2013) Identification of Viral Pathogen Diversity in Sewage Sludge by Metagenome Analysis. *Environmental Science & Technology*, **47**, 1945-1951. https://doi.org/10.1021/es305181x

[9] Corpuz, M.V.A., Buonerba, A., Vigliotta, G., Zarra, T., Ballesteros, F., Campiglia, P., *et al.* (2020) Viruses in Wastewater: Occurrence, Abundance and Detection Methods. *Science of the Total Environment*, **745**, Article ID: 140910. https://doi.org/10.1016/j.scitotenv.2020.140910

[10] McMahan, C.S., Self, S., Rennert, L., Kalbaugh, C., Kriebel, D., Graves, D., *et al.* (2021) COVID-19 Wastewater Epidemiology: A Model to Estimate Infected Populations. *The Lancet Planetary Health*, **5**, e874-e881. https://doi.org/10.1016/s2542-5196(21)00230-8

[11] Centers for Disease Control and Prevention (CDC) (2022) United States COVID 19 County Level of Community Transmission as Originally Posted. https://catalog.data.gov/dataset/united-states-covid-19-county-level-of-community-transmission-as-originally-posted

[12] PR Health Department (2024) Resumen Ejecutivo Situación de la Epidemia del COVID-19 en Puerto Rico. Indicadores para Semana Epidemiológica número 4. https://www.salud.pr.gov/CMS/DOWNLOAD/8524#:~:text=Durante%20la%20semana%20epidemiol%C3%B3gica%20n%C3%BAmero%204%2C%20la%20regi%C3%B3n%20con%20mayor,casos%20por%20cada%20100%2C000%20habitantes

[13] McManus, O., Christiansen, L.E., Nauta, M., Krogsgaard, L.W., Bahrenscheer, N.S., von Kappelgaard, L., *et al.* (2023) Predicting COVID-19 Incidence Using Wastewater Surveillance Data, Denmark, October 2021-June 2022. *Emerging Infectious Diseases*, **29**, 1589-1597. https://doi.org/10.3201/eid2908.221634

[14] Chahal, C., van den Akker, B., Young, F., Franco, C., Blackbeard, J. and Monis, P. (2016) Pathogen and Particle Associations in Wastewater: Significance and Implications for Treatment and Disinfection Processes. *Advances in Applied Microbiology*, **97**, 63-119. https://doi.org/10.1016/bs.aambs.2016.08.001

[15] Patwary, M.M., *et al.* (2022) SARS CoV-2 Wastewater Based Epidemiology in Low and Lower Middle Income Countries: A Systematic Review. EHP Publishing.

[16] Ahmed, W., Angel, N., Edson, J., Bibby, K., Bivins, A., O'Brien, J.W., *et al.* (2020) First Confirmed Detection of SARS-CoV-2 in Untreated Wastewater in Australia: A

Proof of Concept for the Wastewater Surveillance of COVID-19 in the Community. *Science of the Total Environment*, **728**, Article ID: 138764. https://doi.org/10.1016/j.scitotenv.2020.138764

[17] Ocagli, H., Zambito, M., Da Re, F., Groppi, V., Zampini, M., Terrini, A., *et al.* (2025) Wastewater Monitoring during the COVID-19 Pandemic in the Veneto Region, Italy: Longitudinal Observational Study. *JMIR Public Health and Surveillance*, **11**, e58862. https://doi.org/10.2196/58862

[18] Wölfel, R., Corman, V.M., Guggemos, W., Seilmaier, M., Zange, S., Müller, M.A., *et al.* (2020) Virological Assessment of Hospitalized Patients with Covid-2019. *Nature*, **581**, 465-469. https://doi.org/10.1038/s41586-020-2196-x

[19] Filip, R., Gheorghita Puscaselu, R., Anchidin-Norocel, L., Dimian, M. and Savage, W.K. (2022) Global Challenges to Public Health Care Systems during the COVID-19 Pandemic: A Review of Pandemic Measures and Problems. *Journal of Personalized Medicine*, **12**, Article 1295. https://doi.org/10.3390/jpm12081295

[20] Alhama, J., Maestre, J.P., Martín, M.Á. and Michán, C. (2021) Monitoring COVID-19 through SARS-CoV-2 Quantification in Wastewater: Progress, Challenges and Prospects. *Microbial Biotechnology*, **15**, 1719-1728. https://doi.org/10.1111/1751-7915.13989

Highlights

- Decentralized wastewater treatment plants are an effective method for early detection of COVID-19 in communities.
- The highest incidence of COVID-19 was recorded in January 2024.
- Geospatial analysis identifies location areas with higher virus concentrations.
- Environmental factors, such as temperature, influence the persistence of SARS-CoV-2 in wastewater.
- The study contributes to sustainable public health strategies through improved wastewater management.