AN APPROACH TO STUDY THE COVID-19 STAY-AT-HOME EFFECT ON WATER CONSUMPTION IN LONG ISLAND, NY USING TIME SERIES ANALYSIS OF GROUNDWATER LEVELS

Buchbinder, B.[1], Phan, E.[1], Renner, F.[1], Liebowitz, A.[1], Achek, M.[1], Marsellos, A.E.[1], Tsakiri, K.G.[2]
[1]*Dept. Geology, Environment and Sustainability, Hofstra University, NY, USA,*
[2]*Department of Information Systems, Analytics, and Supply Chain Management, Rider University, NJ, USA*

Abstract

While COVID-19 has had positive impacts on ecosystems across the globe, it has also had drawbacks in other environmental and resource management aspects. This study investigates groundwater levels' trends as a proxy of water consumption after the stay-at-home orders imposed by the COVID-19 pandemic. Statistical analyses were conducted on the groundwater levels near the most populated city of Long Island, which is Hempstead, NY, to investigate any possible overpumping caused by identifying groundwater decline. Excess of supply may deplete water resources, especially during times that citizens remain or work at home for longer durations. Using an R programming language, 56 active USGS groundwater monitoring stations were accessed, and data was downloaded across Long Island, NY. 238,000 groundwater level records were processed from 2000 to now from all stations in Long Island, NY. Groundwater time series data were filtered using a low-pass filter (KZ - Kolmogorov Zurbenko) to create long-term trends to recognize groundwater data behavior prior to and during the pandemic. It was hypothesized that water consumption would increase, which may yield a decrease in groundwater levels from March 2020 to March 2021 because Long Island relies on aquifers for its primary water supply (Masterson, 2021). The data collected in this study suggests that the lockdown imposed by the COVID-19 pandemic affected groundwater levels prominently through both short-term and longer-term analyses.

Introduction

This study investigated the impact of the COVID-19 pandemic on groundwater levels on Long Island, NY. The study was expected to result in observable downward trends in groundwater levels, due to increased residential use as quarantine/ lockdown was instated. This was investigated using R programming language to retrieve data from USGS stations across Long Island (LI) and to conduct statistical analyses.

Studies performed on the impacts of COVID-19 on environmental factors, such as air and water pollution, have been increasingly common (Bhat et al., 2021; Gualtieri et al., 2020; Ming, 2020); however, studies similar to this one have been performed significantly more sparingly, in only a few nations around the world. Nations, such as India and Brazil. China, Italy, France, Spain, and the U.S. have investigated how sharp reductions have occurred in their emissions of carbon and air, water, and sound pollution. While water has been studied for quality, the quantity of water being used during the COVID-19 pandemic, especially given that the main prevention of spreading the disease is frequent handwashing and cleaning, has been overlooked.

One of these studies set in Joinville, Southern Brazil, analyzed water consumption data from February 2019 through April 2020, looking at the short-term changes in direct response to the COVID-19 pandemic (Kalbusch, 2021). The study assessed water consumption on commercial, industrial, public, residential, and on an overall scale for the region. The results indicated that while commercial, industrial, and public water consumption dropped dramatically, the residential rates rose notably. Interestingly, the region's overall water consumption dropped because the drop in the other categories overwhelmed the increase in residential consumption. This stressed the importance of access to clean water for both using and drinking and the need for planning and policy to distribute it responsibly and wisely.

In Bangladesh, concerns for water usage also rose in light of the COVID-19 pandemic. As handwashing is crucial to preventing spreading the disease, the water supply in Bangladesh is overdrawn and wasted at concerning rates (Sayeed et al., 2021). Data collected by web-based surveys and questionnaires indicated that residents frequently left the tap running while scrubbing hands: of the 1,980 participants, 1,134 participants (57.27%) left the water running to scrub their hands. This was from the 1,134 participants, each wasted approximately 12.79 times more water per day than they had before frequent hand washing protocols.

For the analysis used in this study, a moving average function was heavily utilized in a range of window sizes to articulate trends of the groundwater data. The moving average function in R Studio is designed to average a specific window of data from the overall data to clarify trend(s) that occur within those frames and eliminate irregular frequencies over the entire time series dataset. The short-term data's kz analysis produced groundwater levels trend over a shorter period of time: the past year, in direct relation to COVID 19. The long-term data displayed data from the year 2000 and on to reference how the pandemic over the last year deviated from the past trends.

This study investigates the groundwater levels and the changes in social patterns during the COVID 19 pandemic, which may have affected the use of water on Long Island (Fig. 1). As assessments of how groundwater fluctuated over time were performed through R using data from USGS stations around LI, the expected results would show a decrease in groundwater levels as more water was drawn from them.

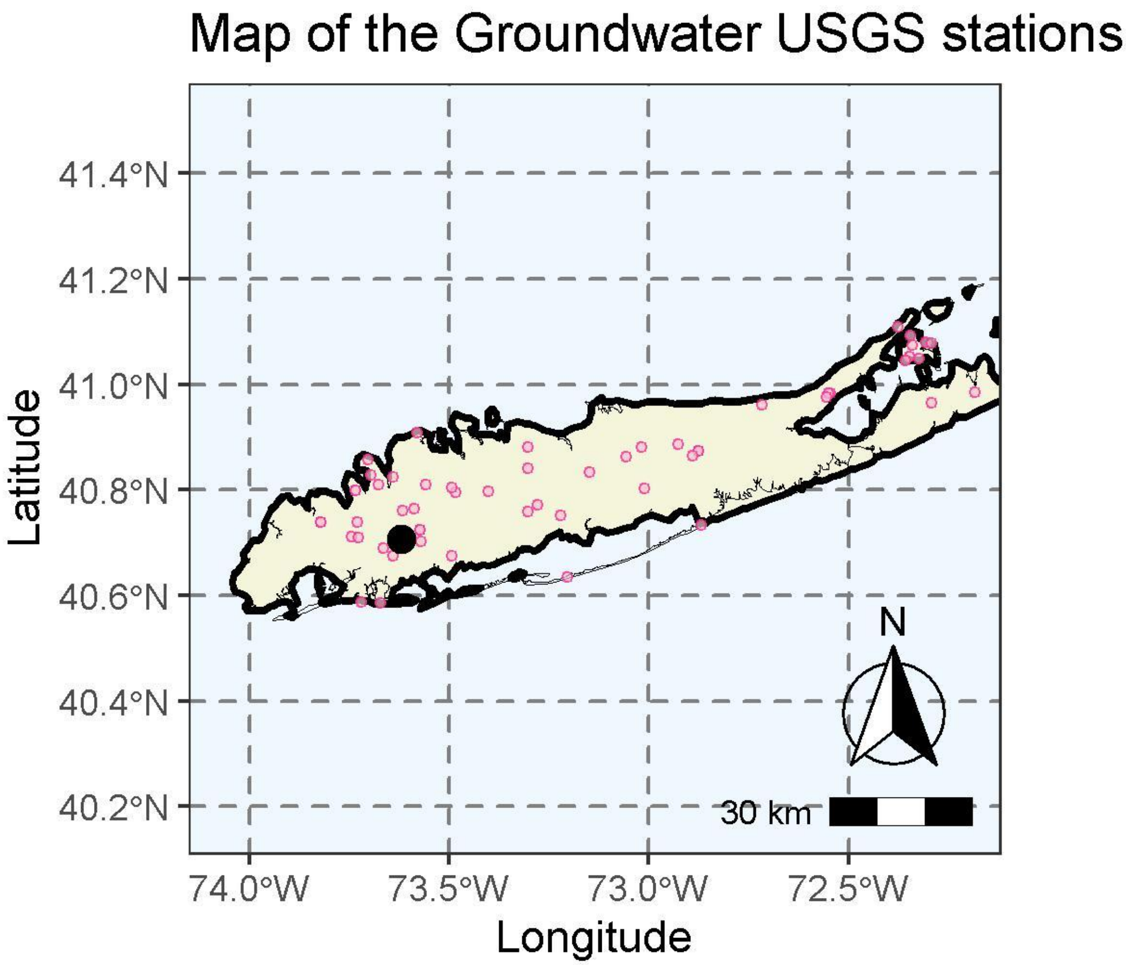

Figure 1: *Map of the USGS stations monitoring groundwater levels (shown by pink dots) processed in this study, including the stations surrounding Hempstead on the map of Long Island (shown by the black dot).*

Methodology

A series of codes in R programming language at Rstudio, R were developed that allowed for the compiling of results, graphs, maps, and figures. The groundwater data during lockdown was compared to groundwater data ranging back from roughly the year of 2000 (Fig. 2). This provided a baseline of water usage data, which was expected to reveal a drastic change in the amount of water used during the COVID-19 pandemic.

Raw groundwater data from multiple USGS stations on Long Island was downloaded onto R studio using R programming language. Applying the "summarize" function, a summary table was made with the data after it was "cleaned": which eliminated stations without data, stations outside the obtained geographic range, and excessive columns. The remaining summary table contained the stations' number, date, latitude, longitude, and groundwater level measurements. With the data being grouped by station, a series of functions were applied including plotting special figures, such as the lollipop plot through the R package "ggplot2". To perform groundwater data analysis, a moving average function was applied to each groundwater station, and finally the data was standardized to present data at the same scale. The moving average function was a low-pass filter function to allow all the groundwater data been averaged with the kz function using the (kza) package. There were three different window size ws of moving averages and t iterations plotted (ws,t): one with the windows (30,5), which showed short-term trends, with (90,5) as the long-term trends, and the other with the parameters (365,5) for a year-long average. Applying all of these moving averages displayed the groundwater behavior from lockdown (the year of 2020) until the 2000s.

The Kolmogorov-Zurbenko (kz) function was key to this analysis because it has been previously observed that a low signal-to-noise ratio may mask significant trends and in various time scales (Zurbenko and Sowizral, 1999). The low signal-to-noise ratio does not necessarily consist mostly of noise, but components such as other physical phenomena with significant variance and an application of a low-pass filter may eliminate such interferences to reveal the existence of trends over different time scales (Marsellos et al., 2020). The time series decomposition using the Kolmogorov–Zurbenko (KZ) filter provides adequate separation of frequencies in the time series data, and it has been applied in many environmental applications (Eskridge, et al., 1997; Ward, 2007; Tsakiri & Zurbenko, 2011; Tsakiri & Zurbenko, 2013). The KZ filter provides a simple design and allows a physical interpretation of all the components of the time series (Zurbenko, 1986; Wikipedia KZ Filters). The KZ filter has the advantage from other filters to perform with the best and closest results to the optimal mean square of error. Also, it allows effective separation of frequencies for application directly to datasets with missing data (Close & Zurbenko, R-CRAN package "kz").

Kolmogorov-Zurbenko (KZ) low-pass filter

The KZ filter is a low-pass filter, and it has been applied with three repeated iterations (p) of a simple moving average of (m) points. The moving average of the KZ filter is provided by expression (1):

$$\mathrm{Y_t} = \frac{1}{\mathrm{m}} \sum_{\mathrm{j}=-\mathrm{k}}^{\mathrm{k}} (\mathrm{X_{t+j}}) \quad (1)$$

where m = 2 k + 1. The output of the first iteration becomes the input for the second iteration, and so on. The time series is produced by p iterations of the filter described above, and it is denoted by the following expression (2):

$$\mathrm{Y_t} = \mathrm{KZ_{m,p}}(\mathrm{X_t}) \quad (2)$$

The KZ filter has been applied, which allows a physical interpretation of the revealed trends. In addition, the KZ filter provides the minimum square of errors between the components of the time series data (Zurbenko and Sowizral, 1999).

Results

The graphs resulting from the analysis of groundwater data in R are displayed below. The lollipop graph was utilized to assess the range of the data used from around the island and determine what time scale would be accessible. This graph yielded a range of the year 2000 and 2021.

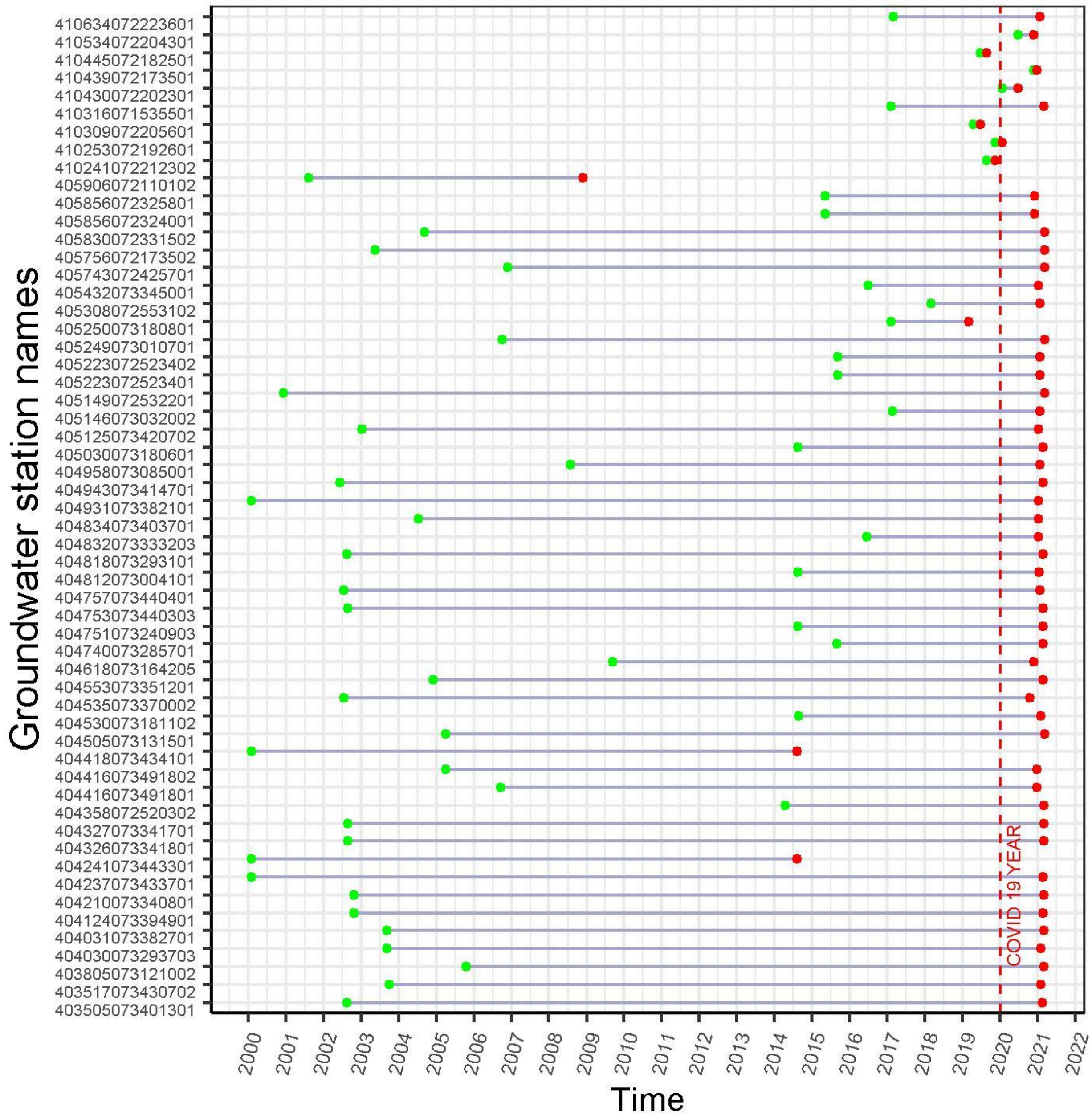

Figure 2: Lollipop diagram of all USGS stations with groundwater levels data displaying the range of dates that groundwater was monitored.

The spectral analysis graphs, which were run on a 30-, 90-, and 365-day moving average, display the groundwater levels' trends at each station from the Hempstead area. These graphs displayed a general trend of a low groundwater value at the beginning of the data, around 2003, a peak around 2012, and a second drop around 2017 (Fig. 3-6). The graph trend begins to rise again after this, implying a second peak in coming years, but in early 2020 trends begin to fall where the previous 20 years implied a continued rise. This is especially prominent in the 30-day analysis of the data over the year 2020 specifically (Fig. 4).

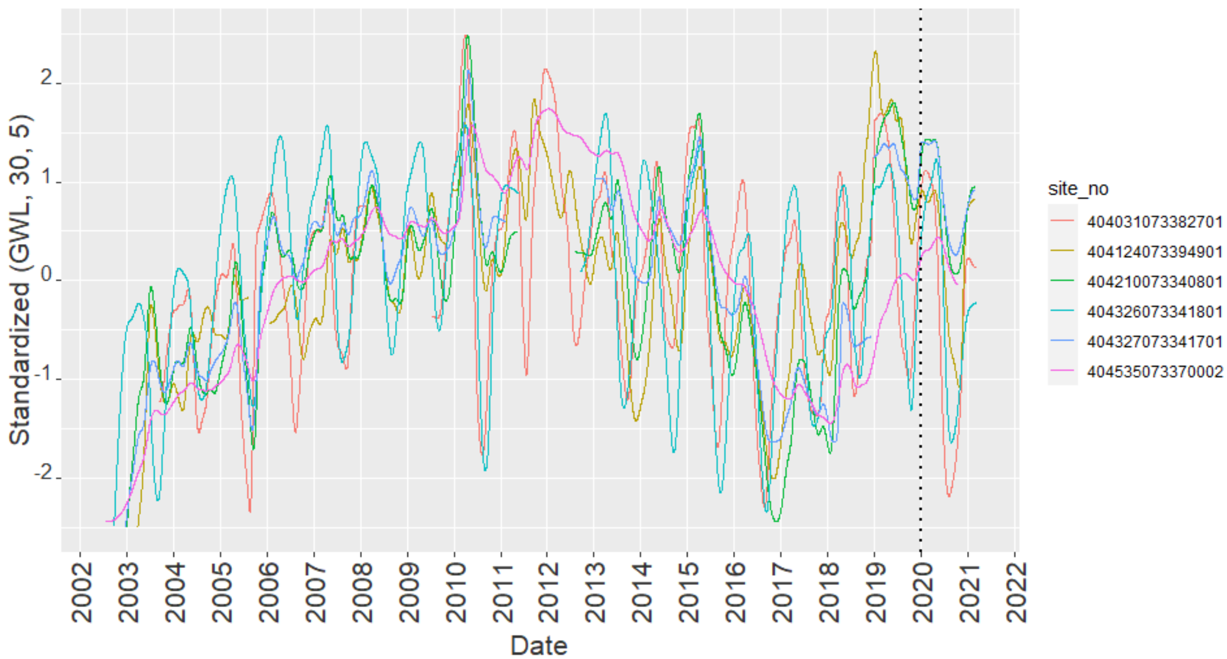

Figure 3: 30-day moving average of groundwater monitoring sites of USGS wells near Hempstead, NY. Data was processed using the "normalize()" function with a "standardize" method: displays standardized values of GWL levels after application of the kz function for a window of 30 days, iterated 5 times.

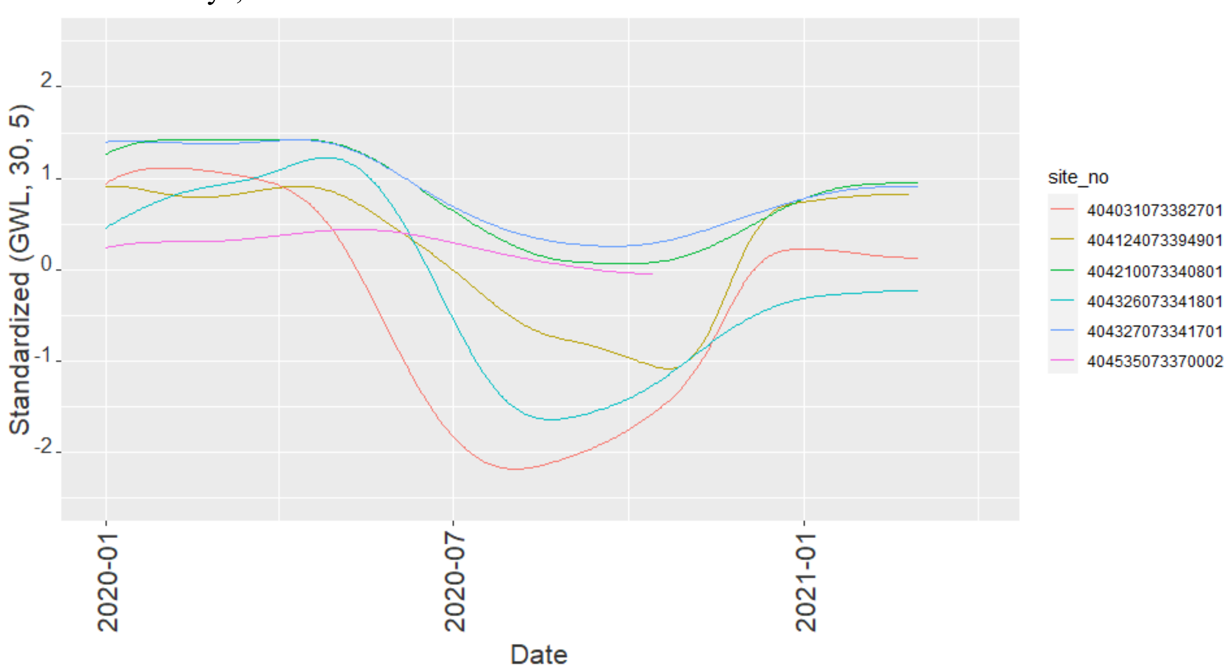

Figure 4: A prominent groundwater level decline during the interval of the stay-at-home orders imposed by the COVID-19 pandemic. Data were standardized using the "normalize()" function

(method: “standardize”) after the application of kz function with a 30-day moving average and an iteration of 5 times on USGS sites near Hempstead, NY from January 2020 to March 2021.

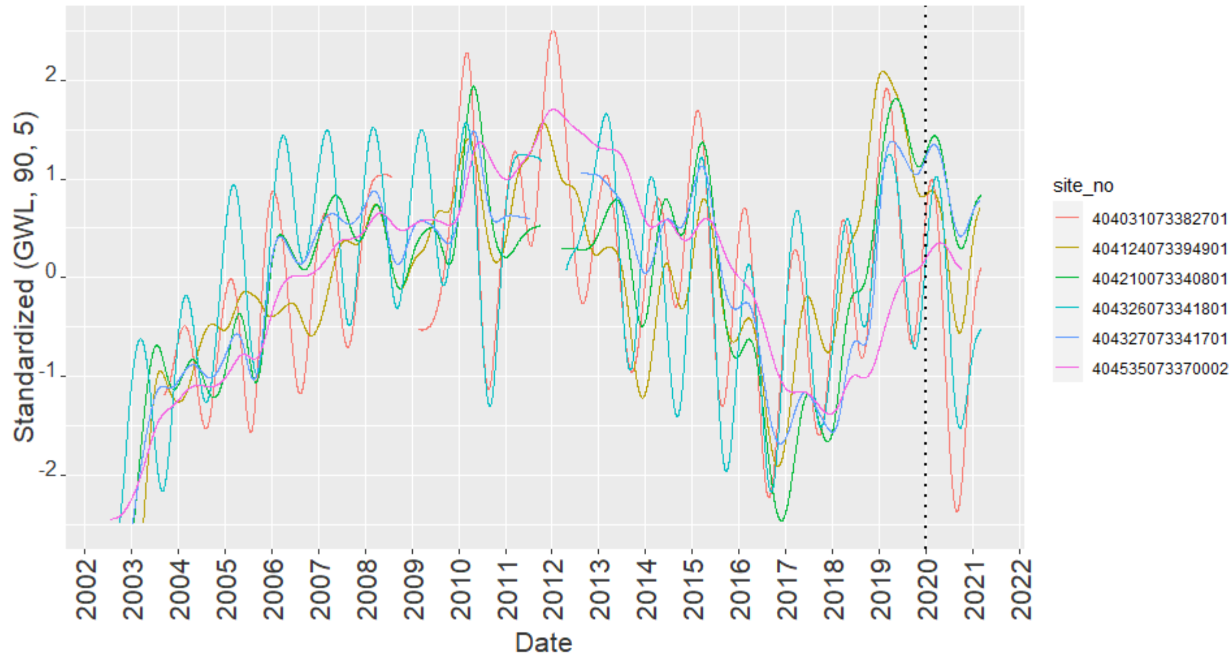

Figure 5: 90-day moving average of groundwater monitoring sites of USGS wells near Hempstead, NY. Data was processed using the "normalize()" function with a “standardize” method: displays standardized values of GWL levels after application of the kz function for a window of 90 days, iterated 5 times.

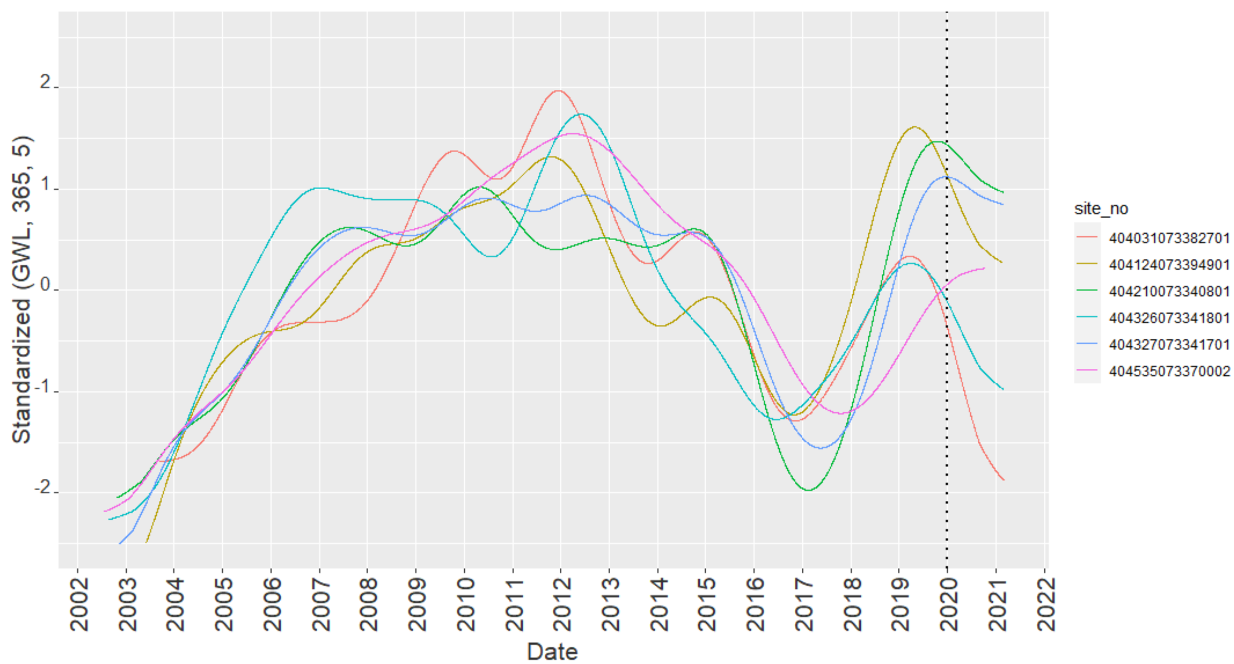

Figure 6: 365-day moving average of groundwater monitoring sites of USGS wells near Hempstead, NY. Data was processed using the "normalize()" function with a “standardize” method: displays standardized values of GWL levels after application of the kz function for a window of 365 days, iterated 5 times.

Discussion

Groundwater on Long Island is a valuable and vulnerable resource, as freshwater from aquifers is the primary source of usable water to Nassau and Suffolk Counties (Monti, 2021). Because Long Island is formed from glacial deposits, the bedrock of the Island is composed of large deposits of sand, gravel and clay, being glacial and fluvial, or deltaic. The resulting structure allows Long Island's water table to exit between 0 and 190 ft below surface level, and be limited by gneiss and schist bedrock approximately 2,700 ft below surface level. Additionally, as a coastal landform, salt water acts as a lateral limit.

Long Island experiences frequent rainfall and snowstorms that recharge groundwater, resulting in a surplus in the groundwater budget of the Island (Fetter, 2014). However, the groundwater overconsumption on Long Island could result in an influx of salt water into the groundwater system, and could contaminate the water supply that the Island relies on. The groundwater supply management during crises such as droughts, or pandemics that could result in higher withdrawals, need to be well planned so that the groundwater is protected and used sustainably as a resource.

Further study would be required to ascertain the levels of groundwater consumption in residential areas instead of water usage in public or industrial facilities. The trends of the groundwater data across both the short-term and long-term assessments indicated a significant drop in groundwater levels in correlation with the events of COVID-19. Unlike those of other studies, the groundwater of both residents and industrial and public facilities on LI rely on the groundwater supply, resulting in the consistent trends found in this study.

This study will act as a precursor for future groundwater data implementation to determine water consumption in regions in and around Long Island in response to the COVID-19 pandemic, which may pose an outlier in groundwater trends years into the future. This downward trend occurred when a 15-year upward trend was expected, and may continue to display as an abnormality in future analyses (Fig 5 & 6).

Conclusion

Water consumption was hypothesized to increase drastically due to the lockdown imposed by the COVID-19 pandemic. Looking at the graphs and analyses that resulted from this study, groundwater levels in each of the moving average windows indicated a downward trend as predicted (Fig. 3-5). In a yearly focused graph of the 30-day moving average, it can be determined that the downward trend starts appearing at the beginning of COVID-19 lockdown and continues down this trend until the end of 2020, which is when lockdown restrictions were mitigated.

The groundwater levels shown in the 30-, 90-, and 365- moving averages may imply an overall consensus of water consumption in Hempstead increasing during the COVID-19 lockdown (Fig. 3, 5 & 6). COVID-19 shows a prominent impact on a long-term and short-term timescale of groundwater level decline, thus far. With this consistently observed downward trend in mind, the hypothesis that water usage would increase drastically throughout the lockdown period from the COVID-19 pandemic is supported and suggests that groundwater was more heavily consumed over the year 2020.

Credit authorship contribution statement

Buchbinder, B: data curation, R coding, writing - Introduction, Methodology, Conclusion, editing; Phan, E.: R coding, data formatting & formal analysis, writing - Introduction, Methodology, Conclusion, Discussion, editing; Renner, F.: writing - Abstract, Introduction, Conclusion, Discussion, editing; Liebowitz, A.: reference citing, editing; Achek, M.: writing - Conclusion, Discussion, editing; Marsellos, A.E.: Supervision, Conceptualization, R coding, editing; Tsakiri, K.G.: R coding, writing - Methodology

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