ASSESSING THE IMPACT OF COVID-19 ON LONG ISLAND'S GROUNDWATER SYSTEM: A FIVE-YEAR (2018-2023) ANALYSIS OF MONITORING STATIONS IN NASSAU AND SUFFOLK COUNTIES

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Abstract

The groundwater system of Long Island with respect to Nassau and Suffolk counties have been studied to understand its dynamics of managing groundwater supply. Two years ago, a study (Buchbinder et. al, 2021) was conducted to better understand how COVID-19 may have affected groundwater levels and subsequent water usage in Hempstead, Long Island; specifically with regards to the stay-at-home order. It was found that groundwater level dropped and interpreted with a hypothesis that perhaps water consumption increased with the stay-at-home order. As we move into a post-COVID world with more people than ever working from home or within a hybrid manner, it begs the question of how this is affecting Long Island's groundwater levels with comparison to how it was performing at the beginning of the COVID-19 pandemic. We used the R programming language to access and analyze data from 12 monitoring stations, of the original dataset of approximately 56 active groundwater USGS monitoring stations, from the most populated regions of Nassau and Suffolk counties. Furthermore, we found a correlation to population size and density amongst wells which in theory elucidate the influence of COVID-19 on Long Island's groundwater supply before, during, and after its effects. Here, we further develop the research in the previously mentioned study by looking at the last five years of groundwater data (2018-2023). This study could be used to expand the existing knowledge in groundwater management during pandemics and especially inform future decisions regarding Long Island's water supply.

Introduction

Over time, Long Island has been studied extensively throughout the years in terms of hydrology (e.g. Veatch et. al, 1906, McClymonds & Franke, 1972; Chu, 2006) due to its dynamic groundwater system that also relies on other sources of water supply for Nassau and Suffolk counties (i.e. Miller & Frederick, 1969 concerning precipitation inflow) which can yield a myriad of applied uses. However, in recent years due to the worldwide COVID-19 pandemic, this raises the question of how to better manage the water supply in respect to highly dense and highly populated areas (Bogler et. al, 2020; Huo et. al, 2020; Kalbusch et. al, 2020; Bhat et. al, 2021; Campos et. al, 2021; Sayeed et. al, 2021; Bera et. al, 2022). It has been observed that water supplies in areas such as these are prone to different levels of usage compared to the pre-pandemic living environment, making the study of pandemic-era water supplies paramount to maintaining a sustainable environment during turbulent times (e.g. La Rosa et. al, 2020; Campos et. al, 2021; Bera et. al, 2022; Khlystova et. al, 2022). The higher demand in supplies due to a pandemic having strong influence over resources ergo has a stronger influence on the use of these vital, finite resources in which humans require in order to survive within densely populated areas. This is especially the case for Long Island, as the closer to Kings County you travel from Suffolk County; the more dense the population becomes. This is the scope of our study herein, to investigate Long Island groundwater management influenced by a pandemic.

Here, considering that groundwater supply in terms of hydrology is the most important supply of water for Long Island and for a majority of the world (see Thakur et. al, 2020 & Santarosa et. al, 2021 for more information), we assessed the monitoring data of wells being monitored by the United States of Geological Survey (USGS) for the groundwater levels of Nassau and Suffolk Counties over a temporal period concerning pre-COVID time, during COVID time, and post-COVID time. This is due to the fact that during 2020 a lockdown order was put in place from various nations (e.g. Gualtieri et. al, 2020) which also included the United States of America at the time. Due to the situation of the COVID-19 pandemic, an increased water use may have caused a drop in groundwater levels based on the occurrence of a stay-at-home order. Eventually this lockdown was lifted, but our lives have not returned to what was once considered normal before the pandemic: a survey of 30,000 Americans estimates four times as many jobs will be offered remotely from now on compared to pre-pandemic numbers (Barrero et. al, 2021). An investigation is required to assess how groundwater levels have fluctuated during this time.

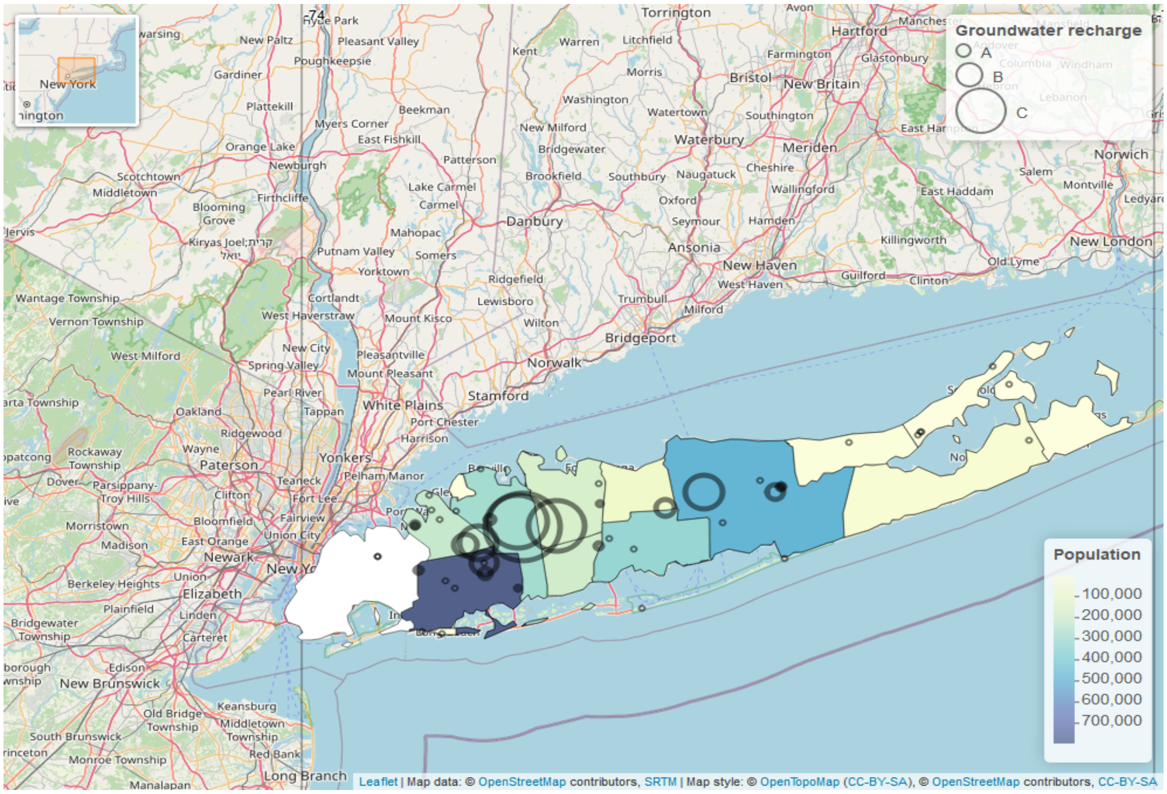

Figure 1 (above). GIS map of 56 USGS active monitoring stations of groundwater wells on Long Island, NY (pre-COVID-19 Pandemic) from Queens to Suffolk Counties which have freely accessible data per respective accession number on their website. All active well locations taken originally from Buchbinder et. al, 2021's dataset. Generated from the USGS website via resources from the R/Leaflet package. Wells plotted on map with colored areas representative of township population across Nassau and Suffolk (excluding Kings and Queens Counties which is the white region). The circles overlying well location areas represent low- (A), medium- (B), and high-recharge (C) rates as a result of the long-term trends of groundwater level during the pre-COVID time interval of 2018-2020.

Methodology

Practically all of the work for this study was conducted in RStudio using the R-programming language, as it is quite versatile concerning large data processing and visualization of the data. In RStudio, we used the following packages: sf, cartography, mapsf, celestial, leaflet for spatial processing of the data (e.g. clipping polygons and other applications); kza for the application of the Kolmogorov-Zurbenko moving average; dplyr for data manipulation; lubridate for date format and data structure conversions, BBmisc for standardization of the data (Grolemund & Wickham, 2011; Robotham, 2018; Close et al., 2020; Bischl et al., 2022; Cheng et al., 2022; Giraud et al., 2022; Wickham 2023).

When beginning this study, a large portion of the code was adapted from a prior study (i.e. Buchbinder et al, 2021) concerning COVID-19's impact on groundwater levels before and during the lockdown via mathematical and statistical means. Our study via this methodology built upon these findings done two years prior, recovering new and unique results herein to add onto other previous studies (Schubert et. al, 2004; Stumm et. al, 2004; Chu, 2006; Misut & Voss, 2007; Kalbusch et. al, 2020; Bhat et. al, 2021) by providing new data amongst past hydrological surveys and time-series analyses. This is for further analysis on the impact of the stay-at-home order done at the very beginning of COVID-19, which has been hypothesized herein to have had a lasting effect on Long Island's groundwater levels. We attempt to prove this hypothesis by looking at groundwater levels 2 years before the pandemic (2018-03-01 to 2020-03-01), during the pandemic (2020-03-01 to 2021-06-01), and approximately 2 years after the lockdown (2021-06-01 to 2023-03-01) for recovering significant trends; both in the raw and center-moving average water level data of the wells from selected areas across Nassau and Suffolk counties via the R-programming language. Some statisticians in the past have expressed doubt over center-moving averages before, hence herein we decided to apply the Kolmogorov-Zubenko (KZ) filter equation using the "kza" package in R (Close et al., 2020), that can provide to us a clear interpretation of physical processes via the center-moving averages we utilize within this study (Yang & Zurbenko, 2010; Marsellos et. al, 2020). Overall, the KZ filter is the best choice for this time-series analysis for various reasons including, but not limited to, the capability of handling missing data based on available data and the underlying model, along with producing more accurate variables as it is based on the Kalman filter, which is a more advanced filtering technique compared to simple moving average filters, it can handle non-stationary data and it does not create non available values (NA) caused by the moving average window effect (e.g. Zurbenko, 1986; 1991; Tsakiri & Zurbenko, 2010).

Groundwater level data from before the pandemic was included in order to fully understand the significance of COVID-19's impact in a contextual perspective, even after the lockdown order was lifted to ensure that enough data could be siphoned from a temporal best reflective of the pandemic's net effect on Nassau and Suffolk counties' groundwater levels. Using this information, R was used to analyze the data and produce graphs, GIS maps (Geographical Information Systems), and figures. To make the maps included in the results section, all of the necessary shapefiles were downloaded from the NYC GIS Clearinghouse and the groundwater data was downloaded from the United States Geological Survey (NYS Office of Information Technology Services, 2020-2022). A spatial join was performed to include only Long Island's data and later on to isolate stations from the highly-populated areas of Suffolk and Nassau Counties. The maps were generated using resources from R/Leaflet (Cheng & Xie, 2022).

Figure 2 (right). KZ-Filter equation utilized for the moving average adapted from Zurbenko (1986). Concerning variables; m = time-frame of the moving average (window) equivalent to 2 k + 1; k = component of the moving-average "window"; j = location in the time series; Xt = time series; Yt = dependent variable (groundwater table level).

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

Accessible, public data from the USGS (United States Geological Survey) website was directly accessible through R-code (United States Geological Survey, 2023), however the most recent data for many if not all of these wells are not approved by the USGS and some wells do not have a lot or sometimes any pre-COVID-19 data. We compensated for this by utilizing a wide (730 days) center-moving average window via the KZ-filter formula (Figure 2) mentioned here earlier, with the raw data generated as graphs in R-code as mentioned prior. The objective nature of our interests were focused on those townships under Nassau and Suffolk counties that serve large-population areas. The well data that was collected was cleaned from 56 wells down to 12 via filtering manually by keyword in R, so that maps could be made directly in R without any confusing or extraneous information. The selected locations with respect to wells in this study include the following towns: Brookhaven, Hempstead, Huntington, Islip, Long Beach, and North Hempstead. Wells were identified using a GIS-clipping methodology in R based on location and population served in order to ensure that the results would be significant and relevant, as this would result in some of the highest water supply use across Nassau and Suffolk counties (Giraud, 2016, 2017; Pebesma, 2018; Robotham, 2018; Giraud, 2022). Any water data from Queens and Kings Counties was not included despite being located on Long Island because the vast majority of water consumption in those areas is from New York City's water supply, not Long Island's groundwater system (Misut & Voss, 2007). We investigated the trends, determined by applying a linear regression on each interval of the groundwater level data that were previously averaged using the KZ moving average filter; these fit lines were obtained and the associated slope/trend was determined. A fit line was obtained, and the associated slope or trend was determined considering the p-values to reject the null hypothesis that there is no linear trend. We ensured relative to the well that we selected our wells based on the correlation of high density with high population consensus (Uttara et al., 2021).

Results

In total, three maps were generated to show groundwater levels on Long Island, NY over the three temporal periods we are studying with respect to the water supply; we also generated a "reference point" where it shows the 56 active groundwater monitoring stations (Figure 1). In the map where groundwater level trends showed recharge before COVID-19 (Figure 3), the fastest recharge was a well in Huntington. On the "During COVID-19" map (Figure 4), this same well has decreased in recharge. In the last map (Figure 5), "Post COVID-19", this well is in the A category, as its recharge has slowed significantly. Not all of the progressions shown are as clear or as linear as this one, which is why it was chosen as an example. Moreover, it is evident that the water supply recharge from pre-COVID-19 time to during-COVID-19 time (Figure 3) had a significant shift from Eastern Nassau/Suffolk to Westernmost Nassau (Figure 4). Concerning the main spatial trends elucidated visually via the maps we generated herein, from during-COVID-19 time and post-COVID-19 time, this trend of higher water recharge in Westernmost Nassau continues (Figures 4 and 5) whilst Suffolk County during post-COVID-19 time has higher recharge; a contrast from during-COVID-19 time where higher recharge was present in Nassau County instead of Suffolk County. Overall, there is a gradual trend where Suffolk County recharges groundwater at a higher rate across pre-COVID, during-COVID, and post-COVID time (Figures 3, 4, and 5).

When observing the trends from the 12 wells we analyzed herein concerning the extraction of raw data, creating a KZ-filtered moving-center average of the groundwater level via the time-series analysis equation (Figure 2), and visualization into line graphs (Figure 6); certain trends per well were elucidated. Concerning Nassau Wells (that is Hempstead, Long Beach, and North Hempstead), they're mostly showing an overall trend which declines by 2022-2023. Hempstead had a normal fluctuation in the pre-COVID-19 period and during-COVID-19 period, however never recovered; this is also the case for Long Beach. However, North Hempstead has a continuous upward trend that eventually becomes almost fully horizontal with almost no change in groundwater levels when comparing the raw data from post-COVID and during-COVID time. Concerning Suffolk Wells (that is Brookhaven, Huntington/South Huntington, and Islip), akin to the selected Nassau Wells analyzed, the wells overall had a decline in the groundwater levels. The Huntington and Islip wells show declining trends with no rebound to pre-COVID groundwater levels circa 2022-2023; however Brookhaven has a similar overall trend akin to North Hempstead, albeit with no return to previous groundwater levels whilst on a decline overall concerning the raw data. Brookhaven is also similar to North Hempstead in regards to the moving-center average where it becomes nearly horizontal. P-values were always less than our threshold set (0.05), indicating that the predictor's changes are related to over the respective time intervals. Moreover, slopes per interval were determined and provided P-values that were always less than 0.05 indicating that predictor's changes are related to changes in the response variable; ergo we reject our null hypothesis.

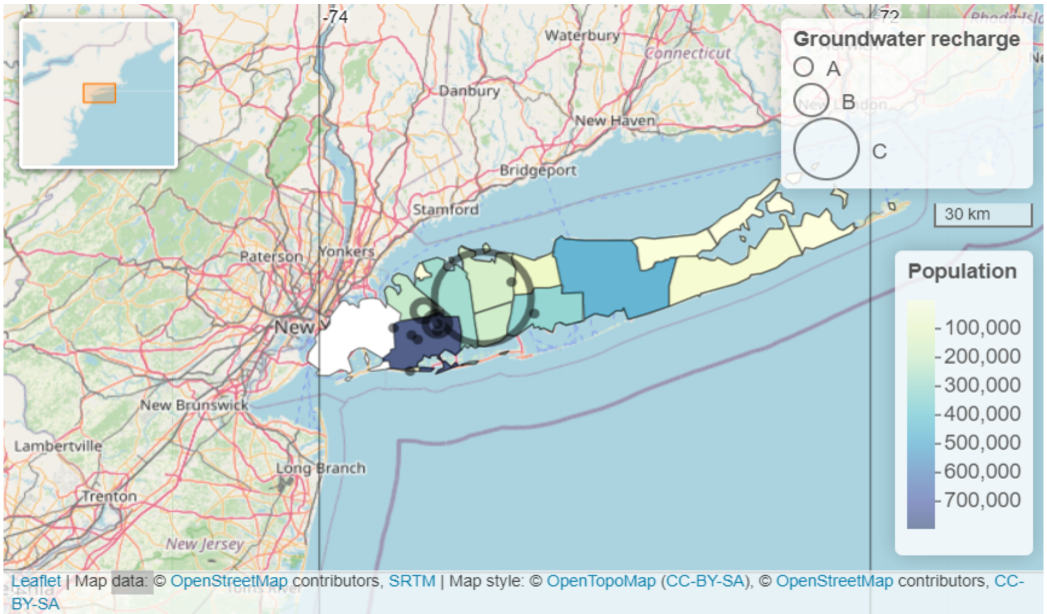

Figure 3 (above). GIS map showing groundwater recharge before COVID-19 on Long Island, NY. Groundwater level data retrieved from USGS from March 2018 through March 2020. GIS generated using Leaflet package, and RStudio. Wells plotted on map with colored areas representative of township population across Nassau and Suffolk counties (excluding Kings and Queens Counties) which mirror density likely as well the greater the population becomes. The circles overlying well location areas represent low recharge (A), medium recharge (B), and high recharge (C) as a result of the long-term trends of groundwater level.

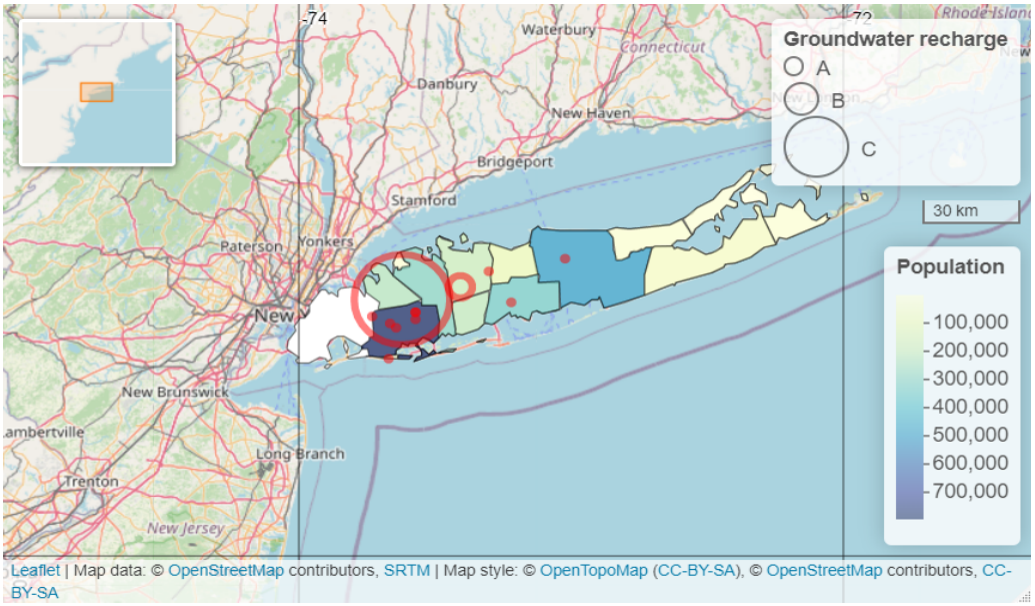

Figure 4 (above). GIS map showing groundwater recharge during COVID-19 on Long Island, NY. Data from March 2020 through September 2021. All active well locations taken from the USGS website. The GIS map was generated from the USGS via resources from Leaflet, OpenStreetMap, and RStudio. Wells plotted on the map with colored polygon areas representative of township population across Nassau and Suffolk (excluding Kings and Queens Counties) which mirrors density likely as well the greater the population becomes. The circles overlying well location areas represent low recharge (A), medium recharge (B), and high recharge (C) as a result of the long-term trends of groundwater level.

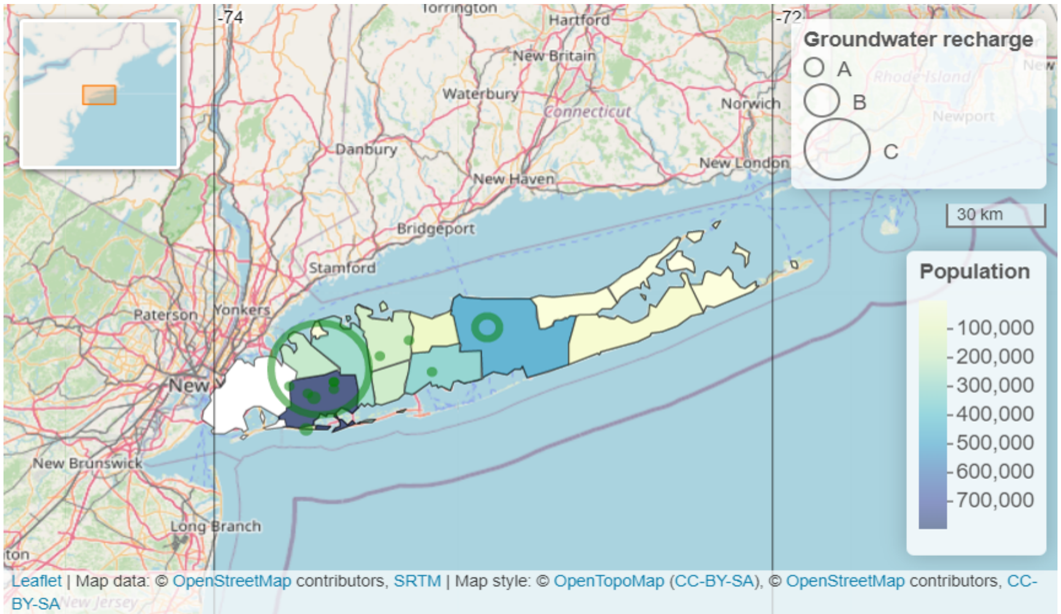

Figure 5 (above). GIS map of groundwater recharge post COVID-19 on Long Island, NY. Data from September 2021 through February 2023. All active well locations taken from USGS. Generated GIS map from the USGS resources using Leaflet, OpenStreetMap, and RStudio. Wells plotted on map with colored areas representative of township population across Nassau and Suffolk (excluding Kings and Queens Counties) which mirrors density likely as well the greater the population becomes. The circles overlying well location areas represent low recharge (A), medium recharge (B), and high recharge (C) as a result of the long-term trends of groundwater level.

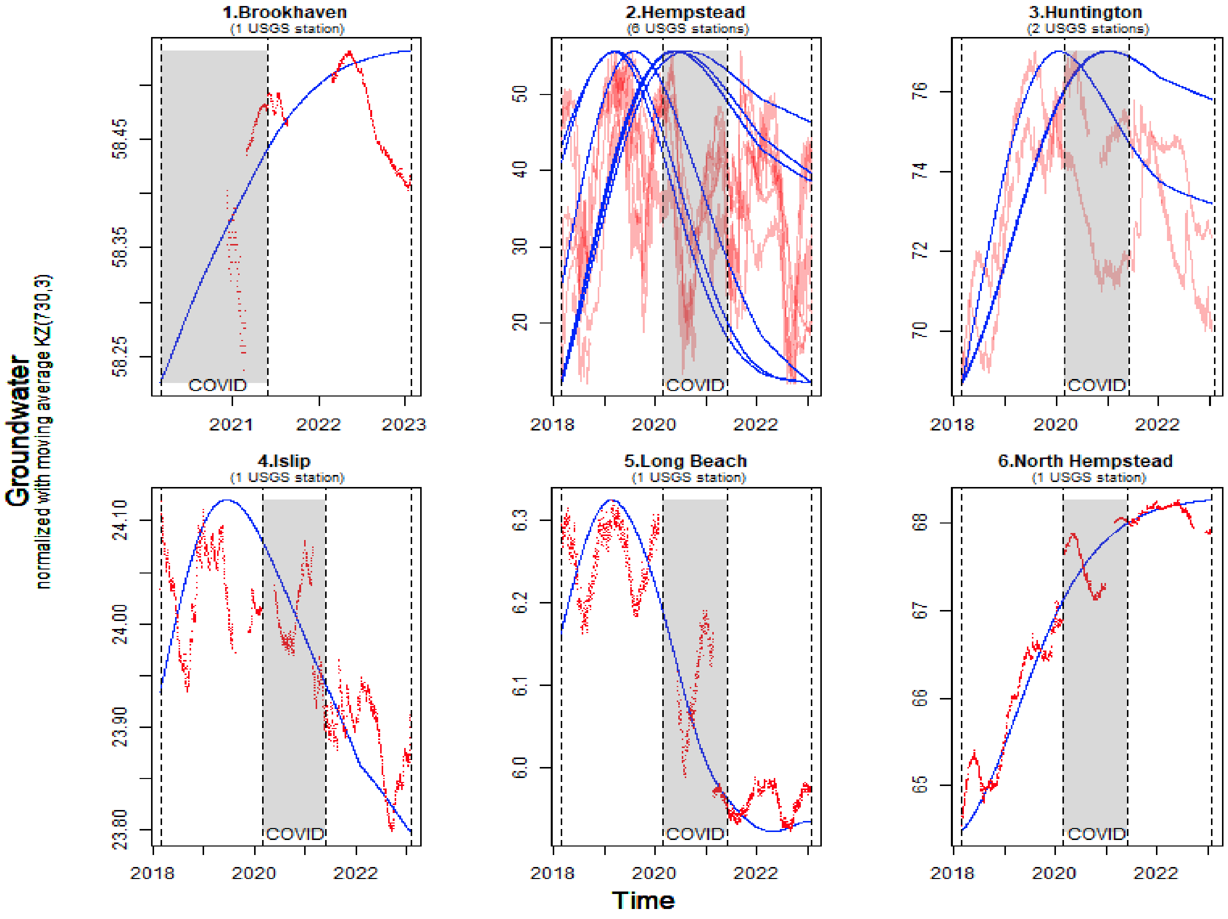

Figure 6 (above). Groundwater level shown by red dotted line; based on the National Geodetic Vertical Datum of 1929, (NGVD 29 in units of feet) versus the studied time intervals related to the pandemic. KZ-filtered groundwater level with kz(730,3) parameters is shown by blue line. The six line graphs of all 12 wells include Hempstead and Huntington/South Huntington towns that contain more than one well. Groundwater level data were retrieved from USGS using Rstudio.

Discussion

Concerning the implications in which our maps elucidate with water supply recharge, it makes logical sense because the more westernward you head as you approach Queens and Kings counties (New York City), the more populated and more dense the area becomes with respect to urbanization efforts which then can be grossly exacerbated by the influence of a pandemic. When COVID-19 began to greatly affect the nation, ergo triggering the lockdown order, the draw on Long Island's groundwater supply increased significantly. As seen in Figure 7, the majority of wells analyzed in this study were found to have higher levels of discharge than recharge after the stay-at-home order despite all twelve wells recharging before COVID-19. However, looking at the groundwater level fluctuations from after COVID-19 (specifically the lockdown order), it is clear that these wells are using more water than is being replenished. Moreover, from Figure 7 mentioned prior, the data when visualized shows an implication of a trend moving downward, as this implies overall that the groundwater supply has become more depleted over time and hasn't replenished, hence the downward trend.

Long Island's groundwater supply is limited by many risks including but not limited to saltwater intrusion, being a coastal landform, so preserving and maintaining water usage levels is of utmost importance. Overconsumption of groundwater could contribute to possible saltwater intrusions, contaminating Long Island's main water source. This, in part, motivated this study, as unanticipated events like a global pandemic and lockdown order pose a risk for the sustainability of important systems like the ability of groundwater levels to naturally recharge fast enough to keep up with consumption. Furthermore, even though the lockdown order is no longer in effect, many people who had to change their behaviors at the beginning of the pandemic have not returned to their previous habits, possibly accounting for the low rates of recharge from areas closer to the city, as people continue to work from home. This is just one way in which COVID-19 continues to impact our lives. More research will need to be conducted to definitively know what the stressors on Long Island's groundwater levels are presently. Studies like this one can be used to help come up with plans to manage our water supply in the future.

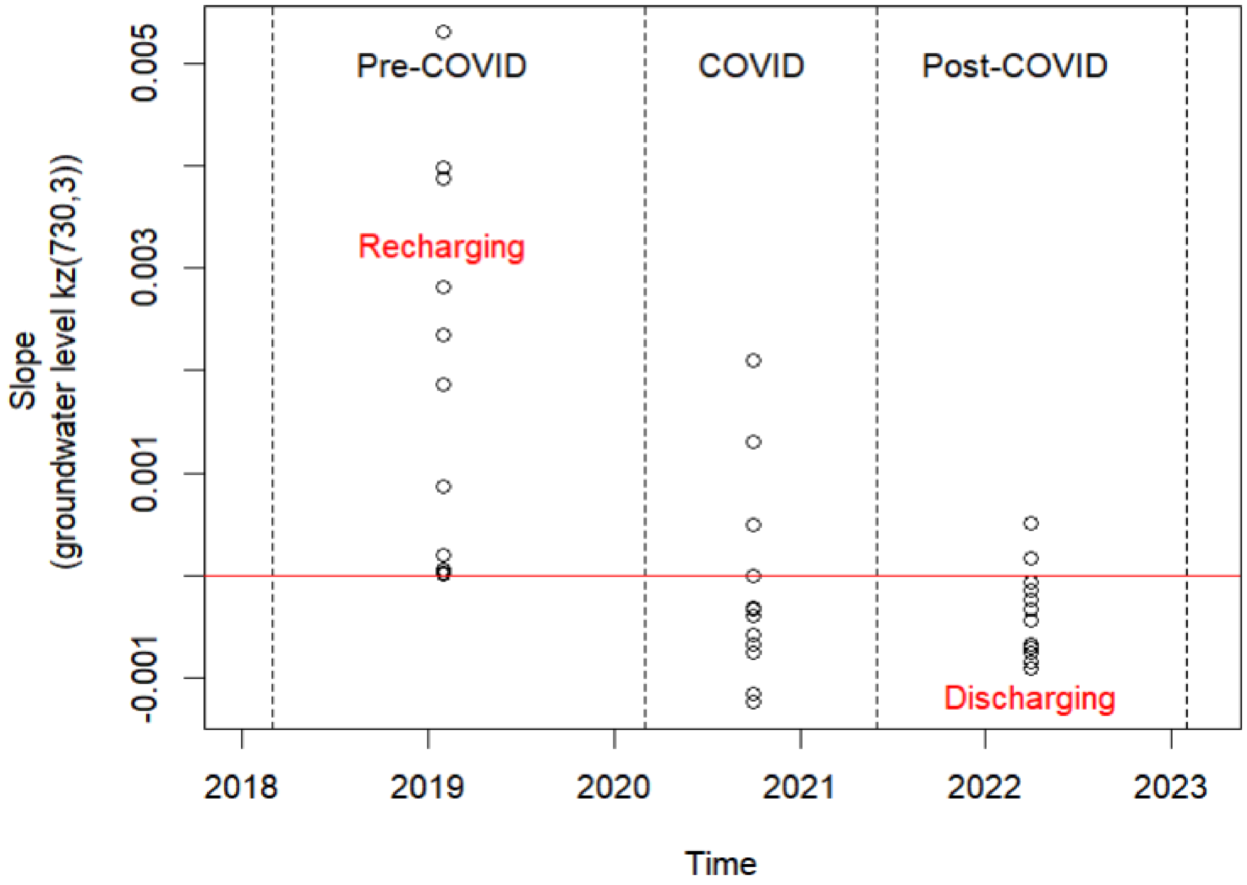

Figure 7 (above). A “scatter-plot” graph/diagram representing the trends of groundwater level (in ft per day) in respect to the three time intervals related to the pandemic from the 12 wells located at the highest populated areas of Nassau and Suffolk counties. The time intervals are Pre-COVID-19 defined here as 2018-2020, COVID-19 as 2020-2021, and Post-COVID-19 as 2021-2023 via the vertical dotted lines in-between the plots. Each individual black circle represents a groundwater-supply well. A threshold that separates the discharging from recharging is reflected by the zero slope of the groundwater level.

Conclusion

GIS maps with groundwater level trends computed using moving average data from the USGS monitoring wells located at the highly populated areas of Nassau and Suffolk counties, may imply water usage fluctuations caused by the residents' behavior change as a result of the pandemic. The pre-COVID GIS map allows us to observe the spatial pattern of higher groundwater level trends closer to central Long Island, while during COVID and post-COVID times those trends migrated closer to New York City. We think that as more people were working from home during the pandemic, they likely delayed the retreat of some wells’ water levels.

Credit Authorship Contribution Statement

Hart, W: editing, formatting, R coding, writing - Abstract, Introduction, Methodology, Results, Discussion; Gogos, K: major R coding, data formatting, data analysis, graphing, mapping; Gallagher, C: data curation, data analysis, editing, writing - Abstract, Introduction, Methodology, Discussion, Conclusion; Kaplan, A: reference citing, mapping, data curation; Marsellos, A.E.: supervision, R coding, guidance, editing. Tsakiri, K.G. - R coding/providing KZ-Filter code for data processing.

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