INVESTIGATING THE IMPACT OF COVID-19 ON GROUNDWATER SUPPLY: A STUDY OF MANUFACTURING SITES AND SOCIOECONOMIC FACTORS

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Abstract

The population on Long Island, NY is dependent on groundwater supply for daily use, and the recent years of the covid-19 pandemic have undoubtedly changed the operations of daily living for everyone including groundwater usage. In the height of the pandemic, most citizens were forced to stay home out of the need for public health safety. While we did look into the residential aspect of water usage, we also looked at the amount of manufacturing sites across Long Island, and hypothesized that there would be a positive correlation between the manufacturing activity and groundwater level. As people were spending more time in the house, we also hypothesized that the amount of groundwater used would be reflected in the groundwater level fluctuations, and it would have a positive correlation with the mean income level across different areas. To investigate our hypotheses, we were able to collect the groundwater data from 58 USGS (United States Geological Survey) groundwater monitoring stations located on Long Island. Using ArcGIS software and R programming language, we collected and processed the mean income, employment rate, family household, and married households from the US Census Bureau. Converting that data into polygon shapefiles, map layers for the towns on Long Island were paired to the data variables from the Census Bureau. A spatial correlation by using GIS (Geographical Information Systems) methods of clipping the population and income polygons with groundwater trend levels was performed. A moving average of a window of 730 days and three iterations (k=3) was applied in groundwater level USGS data using the Kolmogorov-Zurbenko (KZ) filter incorporated in the kza package in R. Trend and slope was determined by applying a linear regression on each interval (pre-, covid, post-), on the groundwater level data that were previously averaged using the KZ moving average filter. A fit line was obtained, and the associated slope or trend was determined. As a result, we found no significant linear trends that correlate groundwater supply rates with mean income, employment rates, family or married households. However, we found an inverse relationship between the number of manufacturing sites and groundwater slope trends during the time of the pandemic.

Introduction

The population of Long Island in New York is dependent on groundwater as its freshwater source, resulting in groundwater consumption correlating directly with groundwater levels. As groundwater levels are decreasing around the country it's important to determine which areas consume what amount of water in order to plan for the future.

There are four aquifers that provide groundwater to strategically placed water towers across Long Island. These are the Upper Glacial, Magothy, Raritan Clay, and Lloyd Aquifers (Long Island Commission for Aquifer Protection, 2019). Of the four, the Upper Glacial and Magothy provide the most groundwater, with 279 wells (Glacial) and 347 wells (Magothy) respectively. The Lloyd Aquifer is home to the oldest water of the four, dating back several thousand and so it is very rare that water is drawn from its 3 wells. Similarly the Raritan Clay Aquifer mostly acts as a layer between the Magothy and Lloyd aquifers, only having 3 wells similar to the Lloyd Aquifer. In 2022 the concern of saltwater intrusion became more prominent along the coastal areas of the Island resulting in the shutting down of numerous wells. In this study, we are investigating trends of groundwater levels that can be correlated using variables such as population and socioeconomic factors. We used groundwater level fluctuations as a proxy to correlate water usage with demographic data in Long Island, NY.

In March 2020, the United States, along with the rest of the world went into a quarantine due to the covid-19 pandemic, which lasted over a year. This period of time affected the lives of workers, students, and the environment. As people were staying home instead of being at an office or a school, the amount of water used in homes should've increased during the quarantine time. A recent 2022 study (Nemati & Tran 2022) has shown that due to covid, water usage has gone up significantly, due to changes in hygiene practices in direct correlation to the pandemic and the instituted stay at home orders. The CDC, as during previous pandemics, released evidence showing that washing hands more often would be one way to combat the spread of disease. It was also encouraged for people to wash everything that entered their homes, including groceries. Due to this, water consumption in residential homes should show a significant increase and groundwater trends should directly reflect the amount of water used in a given area. We therefore hypothesize that a positive correlation between the amount of groundwater used and the average income level in a given area may be present. We also predict a significant correlation between groundwater usage and manufacturing within the long island area. This paper investigates groundwater trends across the spatial distribution of manufacturing activity, mean income levels, employment rate, family and married households in different towns (Figure 1) in Long Island before, during and after the pandemic.

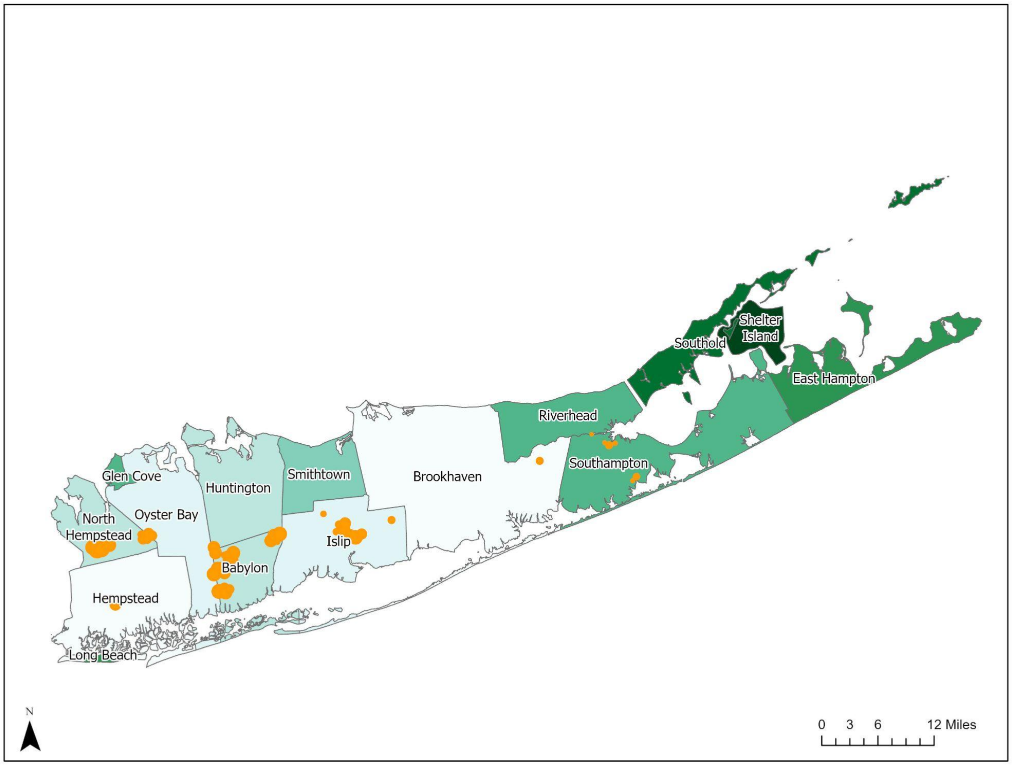

Figure 1. A GIS map of Long Island showing town location (green shaded polygons) and manufacturing sites (orange polygons). The area and amount of manufacturers on the Island is shown on this map. The sites projected have 50 or more manufacturers.

Methods

In order to analyze the groundwater consumption between low-income and high-income residents on Long Island, we conducted a spatial correlation by using Geographical Information Systems (GIS) methods of clipping the population and income polygons with groundwater trend levels. GIS application took place in ArcMap and R programming language. In Rstudio, we used the following packages sf, cartography, mapsf, celestial, leaflet for spatial processing of the data (e.g. clipping polygons etc), kza for moving average, dplyr for data manipulation, lubridate for date format and data structure conversions, BBmisc for standardization of the data (Wickham 2023; Bischl et al., 2022; Cheng et al., 2022; Giraud et al., 2022; Close et al., 2020; Robotham, 2018). Demographic data were retrieved from the US Census Bureau which provides income averages across Long Island along with population and employment rates. Groundwater level data were downloaded for 58 monitoring stations by the United States Geological Survey (USGS). After the data was collected, it was put into an ArcGIS file and Rstudio. Using shapefiles from New York Clearinghouse, Long Island towns were selected and made into its own layer. Then, the census data was joined with Long Island towns layer. This was done in order to show demographic data like median income and employment rate. Next, the New York Shore and Counties line shapefile was added to the map.The Long Island towns land shoreline layer were clipped together. This was done to make the town borders fit within the land area. From there, ground water station locations were downloaded from the USGS and then added to the map. We did the same research for locating areas in which people with higher income reside.

The distinction between high- and low-income areas was determined on the basis of the mean income of county residents and employment rate. We also looked at data for family households and married households. After we gathered all necessary information, we used data from the USGS groundwater sites to see if there is a correlation in consumption between the two living areas, high and low income, during the covid-19 pandemic times. In order to avoid seasonal discrepancies, this study was completed over three different time periods of moving average groundwater level data. The first was *pre-covid (from 2018 to 2020-03-01)*, the next was *covid (2020-03-01 to 2021-06-01)*, and the third period was *post-covid (2021-06-01 to 2023-02-01).*

With the R programming language, we were able to sufficiently analyze the USGS groundwater data from the 58 sites across Long Island. A moving average of a window of 730 days and three iterations (k=3) was applied in groundwater level USGS time series data from all 58 stations using the kza package in R (Close et al., 2020) to remove seasonality and annual cycles, and study the trend. Trend was determined by applying a linear regression on each interval (pre-, covid, post-), on the groundwater level data that were previously averaged using the KZ moving average filter. A fit line was obtained, and the associated slope or trend was determined considering the p-values. We were able to create GIS maps of the Long Island population in relation to groundwater trends with R Leaflet and ArcGIS Pro as well as maps of mean income and manufacturing. To calculate the manufacturing groundwater use, the number of manufacturers in Long Island was counted and the groundwater slope was determined for each station from the 58 active stations of Long Island. The interpreted trend of the groundwater level was determined by differencing the previous day after the application of the KZ filter and was considered as the recharge rate.

Results

Based on the statistical analysis conducted, it was found no significant correlation between groundwater usage pre-covid, during covid and post-covid with mean income, employment rate, married households, or family households, on Long Island, NY (see Figures 3 and 4). 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 (rejecting the null hypothesis). However, we were able to identify an inverse relationship between the amount of manufacturing sites and groundwater slope rate (see Table 1 and Figure 2). Figure 5 in comparison to Figures 6 and 7 show that pre, during and post covid there were noticeable differences in groundwater recharge. Before covid groundwater recharge was highest in the Oyster Bay, Hempstead and Huntington areas where population ranged from 500,000 to 700,000. There was also a midline in Brookhaven where population ranged in the 500 thousands. Looking at Figure 8, we can see that during covid recharge rates rose in the less populated areas such as Southhold, East Hampton and Shelter Island, while also growing slightly in the previously mentioned areas Oyster Bay, Hempstead and Huntington.

Table 1. Amount of manufacturing sites per town in Long Island, groundwater slope maximum and the minimum, and the difference between max. and min. values of groundwater level trends at different covid time intervals.

	manufactoring count	slope (max)	slope (min)	difference
Oyster Bay	low	0.0060	0.0015	0.0045
Hempstead	low	0.0040	0	0.0040
North Hempstead	mid	0.0050	0.0020	0.0030
Babylon	high	0.0020	0.0005	0.0015
Islip	high	0.0010	0	0.0010

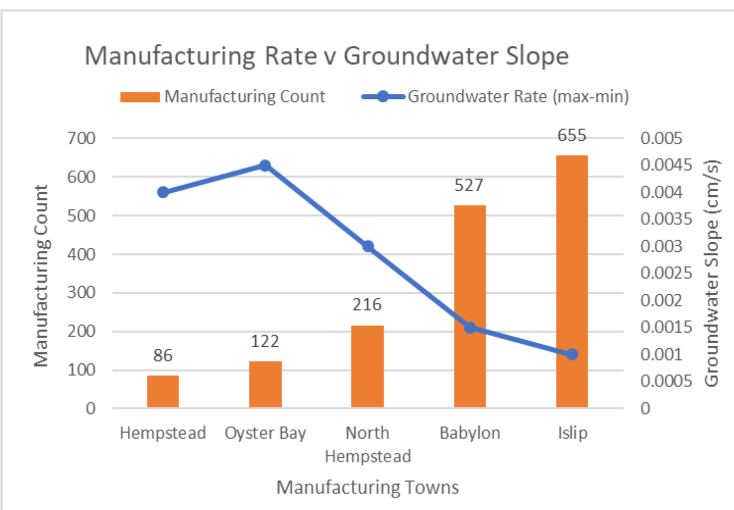

Figure 2. A graph showing the number of manufacturing sites, towns on Long Island, groundwater slope, and the rate of groundwater. We observe an inverse relationship between variables.

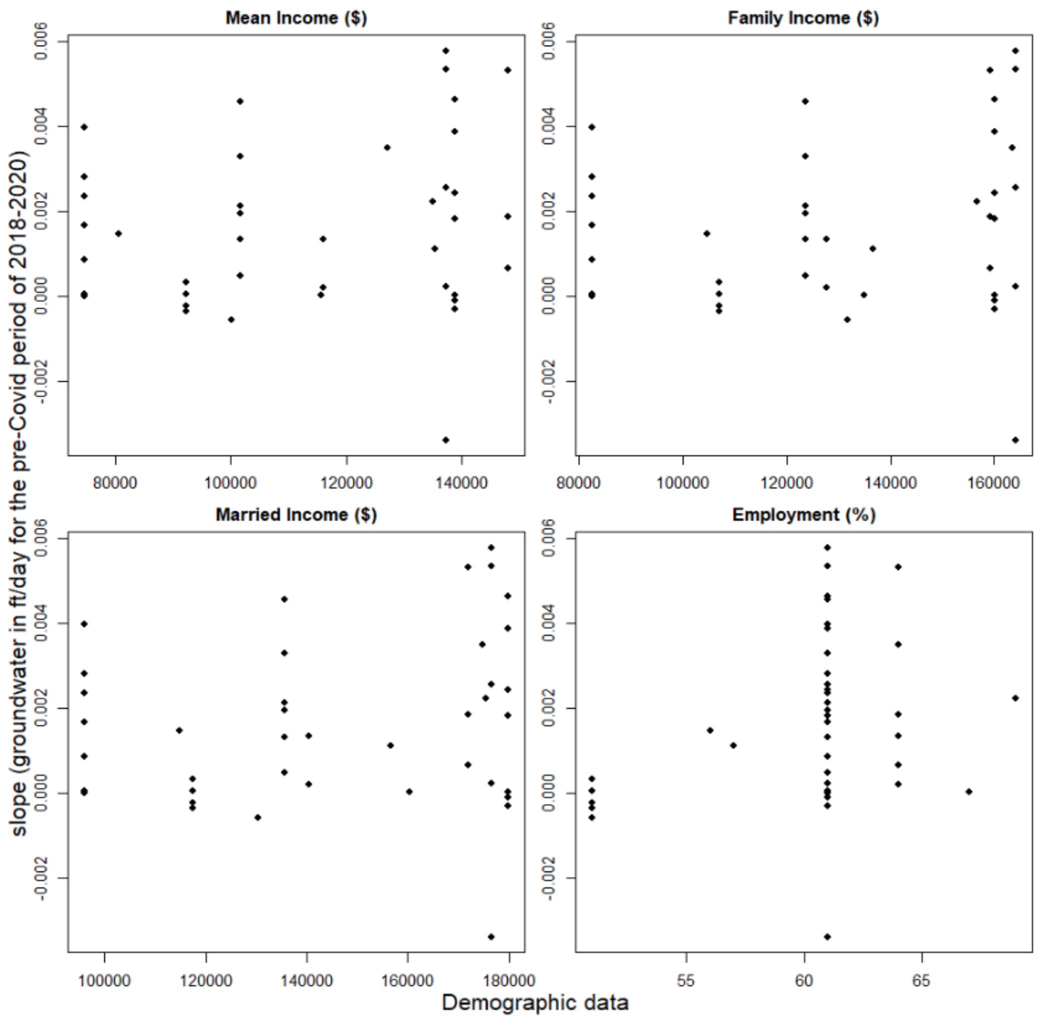

Figure 3. From left to right – Scatterplots showing trends of groundwater levels (slope) for each of the 58 USGS wells for the pre-covid period of 2018-2020 vs. mean income, vs. family homes, vs. married households, and vs. employment rate accordingly. There are no significant linear trends that correlate groundwater level trends (interpreted as a proxy for water usage) with these variables.

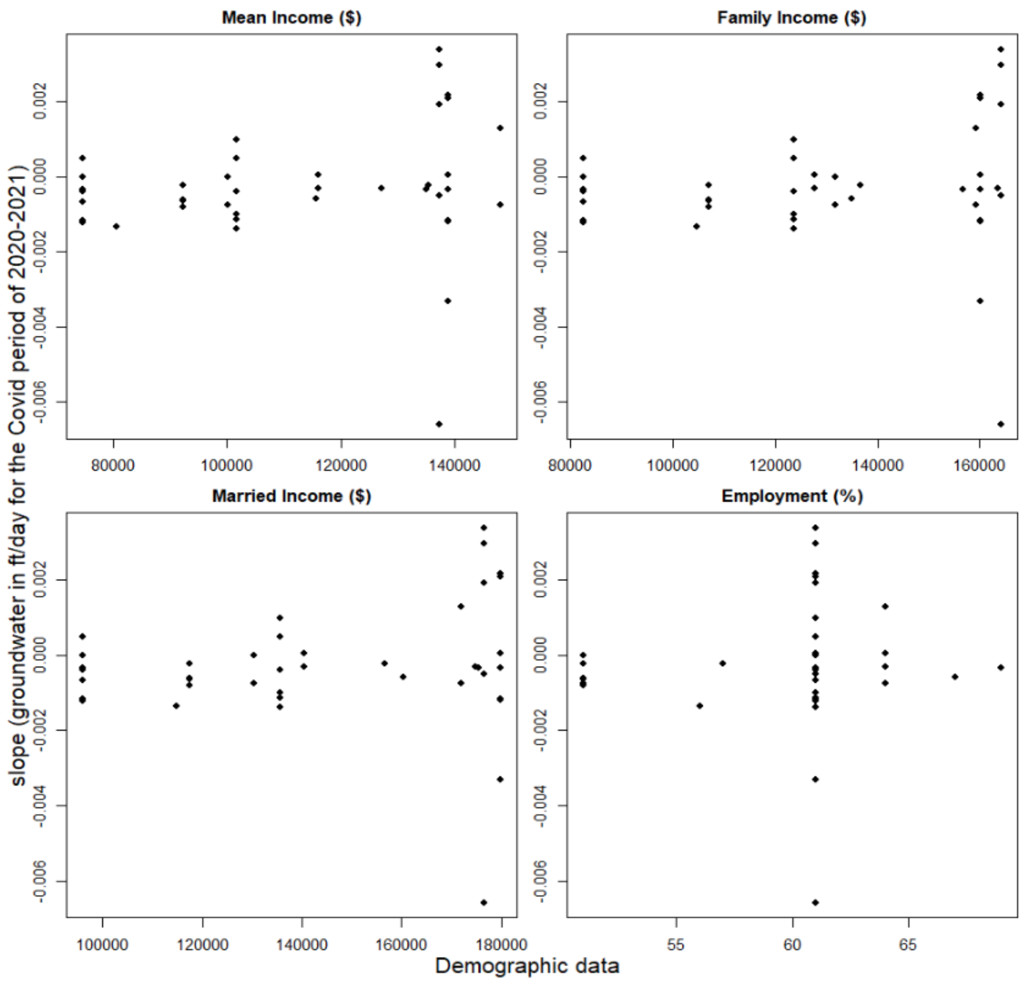

Figure 4. From left to right – Scatterplots showing groundwater level trends (slope) for the covid period of 2020-2021 vs. mean income, vs. family homes, vs. married households, and vs. employment rate, accordingly. There are no significant linear trends that correlate groundwater level trends (interpreted as a proxy for water usage) with these variables.

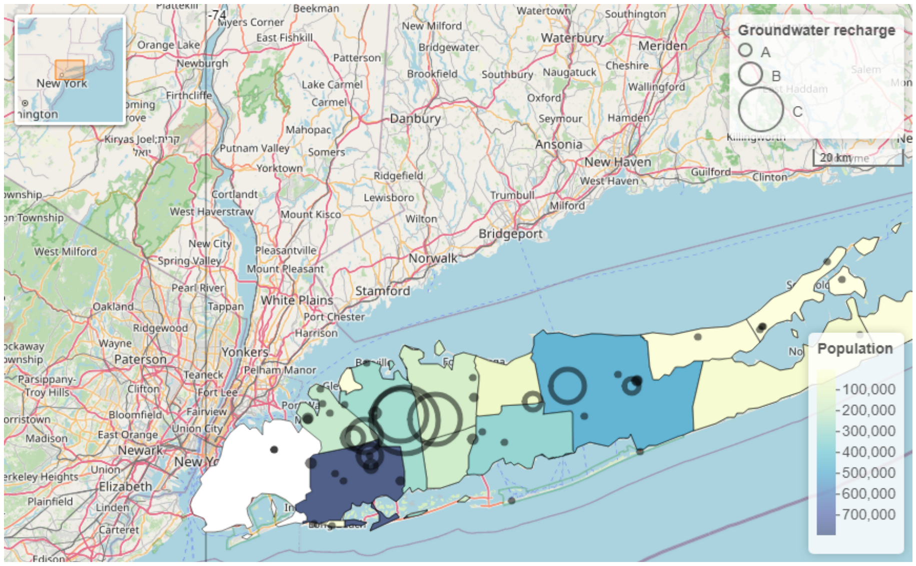

Figure 5. A GIS map of Long Island, NY during pre-covid times showing population and groundwater level trends (interpreted as recharge rate) . Larger circles indicate a higher slope of groundwater recharge.

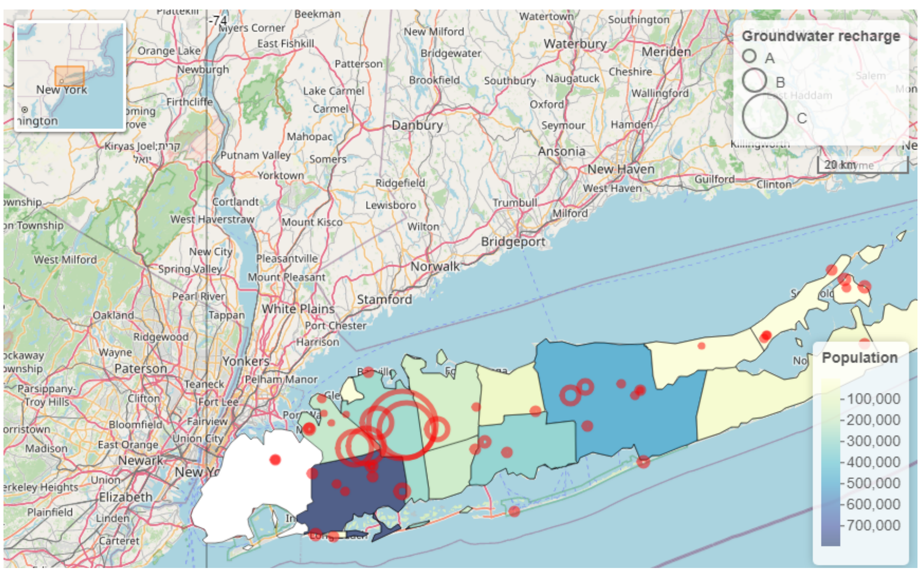

Figure 6. A GIS map of Long Island, NY during covid showing population and groundwater level trends (interpreted as recharge rate). Larger circles indicate a higher slope of groundwater recharge.

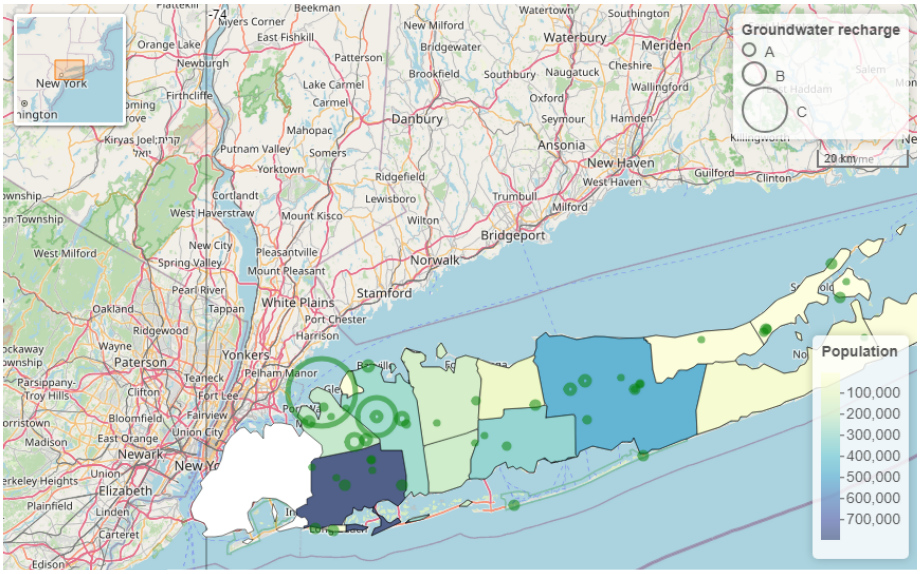

Figure 7. A GIS map of Long Island, NY post-covid showing population and groundwater level trends (interpreted as recharge rate). Larger circles indicate a higher slope of groundwater recharge.

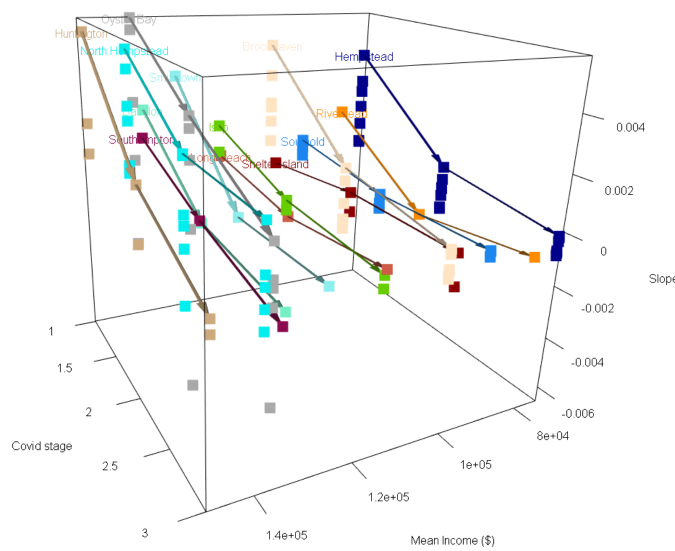

Figure 8. A three-dimensional graph showing towns, mean income, covid stage, and groundwater level trends (slope; determined as differencing with previous day). We observe a slight increase of variation in the data points as mean income increases.

Discussion

Though we did not find any significant correlation between groundwater usage and income during the covid pandemic, we later investigated to find any links between groundwater usage and manufacturing site location during the stages of the pandemic. Looking at the amount of active industries in the towns on Long Island (Table 1), we observe that there is a high difference in groundwater trends in the towns with a low manufacturing count (Oyster Bay and Hempstead) and a low difference in groundwater slope for towns with higher manufacturing counts. (Babylon and Islip). This tells us that there is no residential correlation in groundwater usage however there is a commercial correlation. In Table 1 and Figure 2, the rate of groundwater level decreases, but the amount of manufacturing sites increases. This means that the towns with higher numbers of manufacturing areas have an inverse relationship with groundwater level trends.

From our statistical analysis graphs in Figure 3 and Figure 4 we observe that there is no significant correlation between groundwater usage and income levels, family households, married households or employment rate across Long Island. There are no visible trend lines that would correlate a positive or negative relationship between income level and groundwater usage.

However, in Figure 5 the map that shows groundwater recharge slope during the pre-covid times, and Figure 7 that shows groundwater recharge in the post-covid times, we see a significant decrease in the recharge slope in the Brookhaven area. This area also has a lower population compared to the areas with very little change in water recharge slopes pre, during and post covid. A smaller recharge slope indicates that less groundwater was being recharged in that area post-covid than during pre-covid (Figure 6). We also observed a slight migration of the groundwater recharge data circles from more eastern locations pre-covid to moving west towards Queens, NY in the post-covid map. Overall, this indicates there was an increase in recharge slope on the west side of Long Island and Queens and a decrease on the eastern side over the course of the pandemic. This may be due to the higher population on the west side of Long Island.

In Figure 4 and Figure 8 there is a slight increase in variation of the data points which are in the higher mean income section compared to the towns with a lower mean income. Over the course of the pandemic period, this graph shows that in higher income towns, the groundwater recharge slope has a higher variance than the groundwater recharge slope in the lower income towns. Ultimately, this means that in higher income areas on Long Island, there was a higher groundwater recharge rate. This also confirms that in lower income areas during each stage of the pandemic, groundwater recharge rate was lower compared to the higher income areas. One explanation could be that lower income areas tend to be more frugal with use of utilities. However, this slight variation is not significant enough to say with certainty that there is a positive correlation between higher income and groundwater usage.

Conclusion

To conclude, our initial hypothesis on the correlations between income level and groundwater usage has resulted in no correlation, which we did not expect as the pandemic had many impacts on social living and environment. Residential activity had no significant effect on groundwater usage during the stages of the covid pandemic. However, the investigations with manufacturing sites on Long Island proved to show otherwise. We found that the number of manufacturing sites and groundwater level trends had an inverse relationship during the stages of the pandemic. The relationship between manufacturing and groundwater trends could be investigated throughout a smaller time scale, monthly for example, to yield more timely results. Investigation across other States in the US could provide more coherent results for such hypotheses. Using these methods to determine the allotment and usage of groundwater depending on resident income gives us an idea of how societal ideology impacts groundwater management. This model can be applied to other States in the US or in another country.

Credit Authorship Contribution Statement

Hope, J: editing, formatting, R coding, writing - Abstract, Introduction, Methodology, Results, Discussion, Conclusion; Morrison-John, M: R coding, formatting, reference citing, writing - Introduction, Methodology; van der Vegt, M.M.: R coding, data analysis, editing, writing - Introduction, Results; Varnum, G: reference citing, mapping, formatting, data curation, data analysis, writing - Introduction, Methodology, Results; Marsellos, A.E.: supervision, R coding, guidance, editing; Tsakiri, K.G. - R coding/providing KZ-Filter code for data processing.

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Appendix

GIS resources:

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