High-Frequency of Groundwater Level Fluctuations, Underground Erosion, Potential Sinkhole Occurrences Across Long Island, NY

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Abstract

Sinkhole formations pose significant hazards to infrastructure and safety, with Long Island, NY experiencing a recent surge in such occurrences. This paper investigates the potential correlation between high-frequency groundwater level (GWL) fluctuations and accelerated underground erosion, leading to sinkhole formation. Utilizing statistical analyses of GWL data from USGS monitoring stations, we identify locations exhibiting various GWL fluctuations across Long Island. While the results do not indicate a strong correlation between high-frequency GWL fluctuations and sinkhole occurrences on an individual basis, regions characterized by predominantly high-frequency GWL oscillations tend to have a higher incidence of sinkhole formations. This study provides insights into the factors contributing to sinkhole occurrences on Long Island and underscores the importance of further research in understanding and predicting such phenomena related to oncoming warmer temperatures and underground water mobility upon intensive climate change.

Introduction

Groundwater is defined as water which is located underground in between sediment particles and the zones of porous sediments are called aquifers. Subsequently, most of Long Island’s freshwater supply comes from pumping these underground aquifers. The groundwater level (GWL) fluctuations occur naturally due to various factors including seasonal changes, precipitation levels, and also human activity (Tamiru et al. 2018).

Underground erosion occurs when groundwater is able to break down sediment particles, which creates fractures and leads to further erosion. When there is an abundance of underground erosion, fractures will expand until the groundwater reaches a non-porous layer of sediments. Sinkholes form where the sediment layers below the surface undergo chemical weathering, or dissolution, due to groundwater movement from surface water or precipitation. (Matthew, 2018). Typically, rocks such as limestone are naturally dissolved by underground water circulation. Eventually, the surface above the underground eroded area becomes destabilized and collapses inwards, creating a sinkhole.

New York’s Long Island landscape was formed from the outwash of glacial sediments, specifically quartz, clay, silt, sand and gravel deposits. The Upper Glacial Aquifer on Long Island is the closest aquifer to the surface and is composed of porous sands and pebble sediments. (Monti, J. et al. 2006) The water table is found within the top of the Upper Glacial Aquifer (Figure 1).

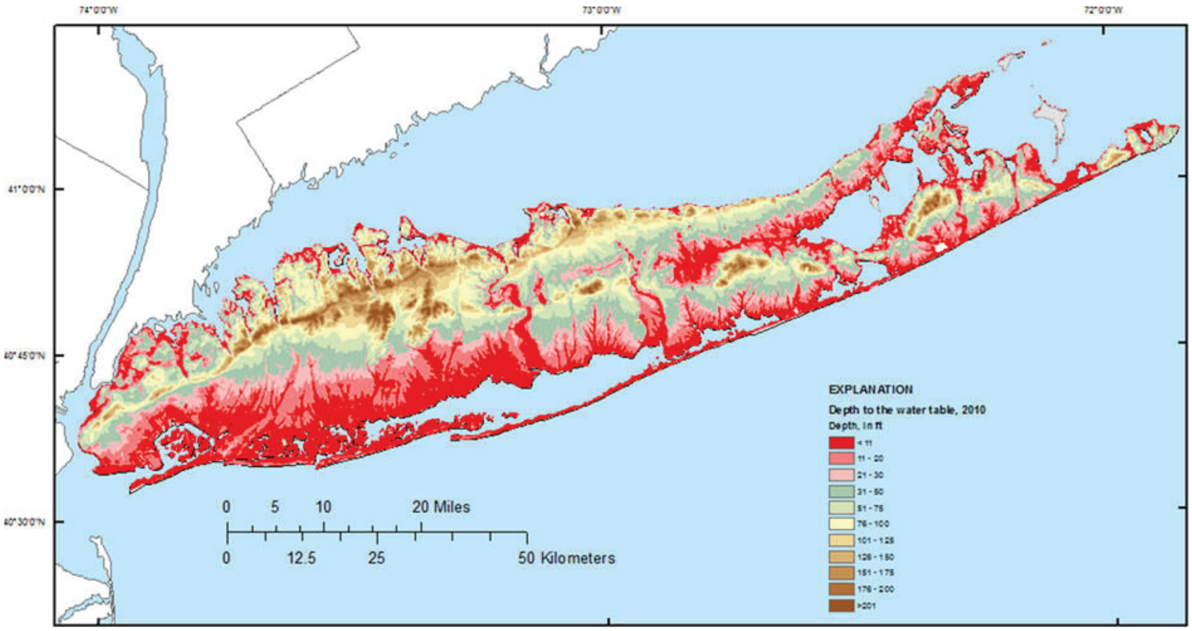

Figure 1. USGS map of the depth to the water table in feet on Long Island, NY 2010 (Como et al. 2013).

Figure 2. A Google Earth map showing the locations of sinkhole formations from 2013-2023 on Long Island, NY. Location data was sourced from local news reports.

Several local news outlets have recorded multiple sinkhole occurrences on Long Island in the past 10 years, most reports within the last year (Figure 2). Some of these formations were recorded to be as much as 20 ft deep (Table 1). Sinkholes often cause the destruction of highways, roads, public and privately owned properties, and are hazardous to be around. As such, the cost of repairing damages from sinkhole formations is very high.

Table 1. Sinkhole formations on Long Island 2013-2023 and their respective locations and depths.

Sinkhole	Longitude	Latitude	Year	Depth (ft)
1) Huntington Station	-73.411268°	40.853503°	2023	6
2) Bay Ridge	-74.018219°	40.633155°	2024	20
3) Islip	-73.235022°	40.740219°	2014	12
4) Elmont	-73.712909°	40.700940°	2023	9
5) West Hempstead	-73.650142°	40.704847°	2023	6
6) Baldwin	-73.610711°	40.671756°	2023	n/a
7) Oceanside	-73.633872°	40.645077°	2023	20
8) Lido Beach	-73.629828°	40.587992°	2023	20

Not a lot of previous research has been conducted on the occurrences of sinkholes on Long Island specifically. Most of the sediment on Long Island is mostly Cretaceous sands, gravels and clay (Cohen, 2014). Usually, sinkholes are associated with karst topography and soluble rock types such as limestone or marble. Previous research focusing on GWL oscillations to identify underground erosion and sinkhole formations has also not been widely studied. A study done in 1997 concluded that groundwater oscillations are one of the main causes of sinkholes in karst (Roje-Bonacci, 1997) but this study does not investigate observations of high GWL oscillations promoting underground erosion.

In this investigation, we introduce a new hypothesis stating that groundwater stations exhibiting high frequencies of GWL oscillations is an identifier of accelerated underground erosion, and thus an area prone to occurrences of sinkhole formations across Long Island, New York.

Methods

To analyze groundwater level (GWL) oscillation frequencies, we utilized advanced statistical analysis techniques using the R programming language. The GWL data from the United States Geological Survey (USGS) was downloaded from 58 USGS monitoring stations at various distances from the previous sinkhole occurrences across Long Island, New York (Figure 3). A map showing the locations of sinkhole occurrences on Long Island, New York during the past 10 years was created in Google Earth Pro by using local news reports/sightings of sinkholes to specify location (Figure 2).

A moving average is a statistical calculation which creates a series of averages within different subsets of a whole dataset. This calculation is used to smooth short-term fluctuations and highlight long-term data trends. We also subtracted the moving average from the raw GWL dataset, specifically using a window of 27 days applied three times (27, 3) to filter out moon-tide related cycles and other noise, and focus on short-term data trends.

The Kolmogorov-Zurbenko (KZ) filter, known as the running mean filter, is a smoothing statistical technique that filters time-series data. It is particularly useful for smoothing noise from data while simultaneously preserving the tails of data distributions. We used the KZ filter from the kza package in R (Close et al. 2020) to remove noise and smooth our GWL data without altering the original dataset. This also allowed a more precise analysis of the high-frequency GWL oscillations.

A periodogram time-series analysis (TSA) is a statistical tool used to identify the dominant frequencies in a dataset. It can be helpful in situations when trying to identify dominant cyclical patterns within a noisy dataset. We used this analysis technique in R to identify the high-frequency GWL oscillation from the USGS groundwater stations on Long Island by plotting $\frac{1}{frequency}$ to show periods. The maximum period of GWL fluctuations observed on each of the USGS stations was detected. Projection of the maximum periods at all monitoring stations created a GIS map (Figure 3) with red being the wells showing high-frequency fluctuations and blue dots for those of low-frequency groundwater level fluctuations. The GIS map was composed in R utilizing the packages sf (Pebesma & Bivand, 2023) and ggspatial (Dunnington, 2023) to input and process shapefiles, ggplot2 (Wickham, 2016) to plot the GIS map, and celestial (Robotham, 2018) to retrieve latitude and longitude of the stations.

Results:

Based on the media reports and news about sinkhole occurrences, we have gathered a list of recent sinkholes (Table 1) that occurred mostly at the southern Long Island with few exceptions. Time series analysis of the groundwater stations has detected high-frequency (red dots) and low-frequency (blue dots) GWL oscillations across Long Island (Figure 3). We observe a moderate spatial correlation between stations showing high-frequency GWL oscillations and the occurrence of sinkhole formations mapped in Figure 2 and 3.

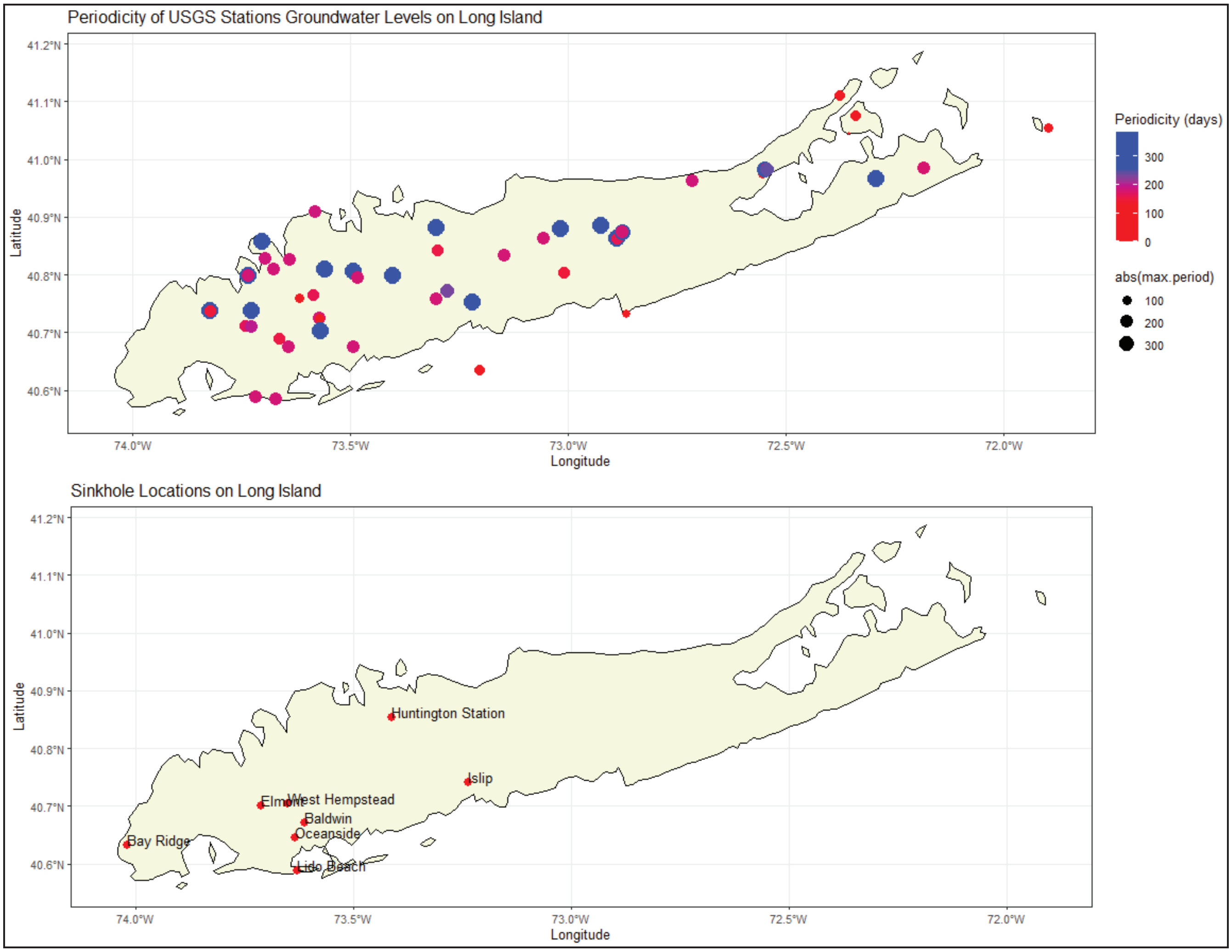

Figure 3. (Top) A GIS map showing the periodicity in days of USGS stations GWL across Long Island, NY. Higher frequency of GWL oscillations indicate lower periodicity (red dots). (Bottom) A map of the sinkhole locations from Table 1 across Long Island, NY.

Discussion

Observing the depth to the water table on Long Island (Figure 1) and the map of sinkhole formations (Figure 2 and 3) we can see that most of the sinkholes that were formed occurred in areas where the depth to the water table was less than 30 ft below the surface. A low depth to water table surface is more likely to be vulnerable to contamination from salt water intrusions or flooding due to high precipitation. Due to these natural factors that influence fluctuations of

GWL, we can relate the occurrences of sinkhole formation to areas where the depth to the water table is shallow on Long Island.

We observe a slight linear pattern among the sinkhole formations mapped in Nassau County between 2013-2023 (Figure 2). The reason for this is not quite clear. When looking for any structural formations which could influence the occurrence of sinkholes like fault lines, none appeared in any previous record. The two moraines on Long Island, Ronkonkoma and Harbor Hill, form east to west across the northern portion of Long Island's landscape, not in the southern part. The pattern of sinkholes occurring in north-south lineation may suggest more anthropogenic influenced formation.

Comparing depth to the water table (Figure 1) and the periodicity of the GWL from the USGS stations (Figure 3) we observed that at lower depths we find lower periodicity of GWL. This would suggest that the higher frequency GWL fluctuations are located at more shallow depths from the surface to the Upper Glacial aquifer. We can also use this relationship to identify a higher rate of underground erosion at these shallow depth, low periodicity stations. These areas should be marked for further study due to any climatic conditions influencing GWL fluctuations to prevent flooding or sinkhole hazards.

Looking at the formation of sinkholes across Long Island and the USGS groundwater stations exhibiting low periodicity of GWL (Figure 3) we observed that the locations of sinkholes from 2013-2023 are slightly related to the locations of low periodicity GWL stations, particularly near the Elmont and West Hempstead sinkholes. This would support our hypothesis that the formation of sinkholes are related to high frequency GWL oscillations. The oscillation describes the number of days in which the GWL fluctuates. A higher periodicity indicates GWL fluctuations are less frequent and more gradual in a given time. A lower periodicity indicates GWL fluctuations are more frequent in a given time. This also indicates a higher frequency of oscillation. From our results, we observed that the occurrence of sinkhole formation across Long Island slightly relates to the location of high frequency GWL oscillations.

Conclusion

Long Island's sinkhole occurrences have not been sufficiently investigated in recent years. The influence of anthropogenic activity on the occurrence of sinkhole formations is still a topic needing further investigations. We can conclude there is a distinct relationship between the depth to the water table and sinkhole formations from 2013-2023 across Long Island with most of the sinkhole formations occuring where water table is closer to the surface that is at the south area of Long Island with few exceptions. We can also conclude that high-frequency oscillations of GWL occur at shallower depths of the water table on Long Island. This supports our hypothesis on identifying accelerated underground erosion. Lastly, we can confirm that the occurrence of sinkhole formations are somewhat related to the USGS groundwater stations exhibiting high frequency GWL oscillations. From our results, we can predict the relative location of future sinkhole formations by looking at the USGS stations showing high frequency GWL oscillations. Future investigations into other areas with sinkhole formations would provide a more coherent result for our hypothesis.

Credit Authorship Contribution Statement:

Hope, J.H: writing – Introduction, Methods, Results, Discussion & Conclusion. Data analysis and R-coding practicing, reference citations, cartography, editing, formatting. Marsellos, A.E: writing – Abstract. Supervision, editing, GIS mapping, R-coding guidance. Tsakiri, K.G: R-code/providing additional insights to KZ filter for data processing.

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