Exploring Climate Change Effects on Sinkhole Formation: Long-Term Temperature Analysis in Long Island, NY (1948-2024)

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Abstract

In recent years, there has been an overall increase in sinkhole occurrences in Long Island, NY. Sinkholes typically form when water erodes detrital or evaporite rock beneath the Earth's surface, creating a cavity that eventually collapses. Increased underground water mobility may lead to accelerated sinkhole development, especially upon more frequent warming temperatures due to climate change. We have analyzed historical atmospheric temperature data in Long Island, NY, spanning 76 years (1948-2024) by applying the Kolmogorov-Zurbenko (KZ) filter to investigate the number of prolonged freezing and thawing events per year. We have utilized R language coding (Rstudio) to account for the number of times that the temperature fluctuated at two specific temperature intervals of freezing (-4 to 1°C) and thawing (4 to 10°C). We have found that the number of prolonged thawing events has increased while the number of freezing times has decreased, leading to an increase in water mobility and, ultimately, the exacerbation of underground erosion. Understanding the relationship between temperature changes and water mobility is crucial for assessing the potential impacts of climate change on sinkhole dynamics and for implementing effective mitigation strategies in vulnerable regions of Long Island.

Introduction

The present study investigates the mechanisms of sinkhole formation in Long Island's unique geological setting, which consists primarily of loosely consolidated glacial till. Many scientists have studied climate change over the past few decades, surveying temperature extremes, weather changes, ice core data, etc. While climate change is supported by the vast majority of the scientific community already, its connection to certain geohazards is not. Some of the most commonly studied correlations to climate change are that of hurricanes, volcanic activity, floods, and heat waves as seen by the map provided by (Extreme weather and climate change. Center for Climate and Energy Solutions, (2024),Earthjustice. (2024) the top four years in terms of extreme weather (Tropical storms, Droughts, Severe Storms, etc.) are 2020-2023 which is indicative of climate change. One specific hazard that is undermined within most online databases when discussing climate change is sinkholes, especially in the Eastern United States, as they occur less frequently than in other parts of the country, thus it is not considered as much.

Long Island's surface is mostly composed of loose glacial sediments like sand, clay, and gravel. This separates it from New York City and other parts of New York (Cohen 2014). Long Island has experienced a slight increase in sinkhole frequency over recent years; there are about nine documented events on the official New York NBC database within the last ten years (2013-2023) (NBCNY 2024). While this number seems low, the frequency of sinkholes before this decade is much less. This is understood due to the lack of reports online about any sinkhole occurrences in the past. Within the last ten years, sinkhole reports have been more frequent, and there is limited research on the correlation between climate change/rising temperatures and water mobility that affects sinkholes. The goal of this study is to support the idea that increased temperature fluctuations due to climate change correspond to water mobility as freeze-thaw melting increases, resulting in more erosion and sinkholes on Long Island.

The prevalence of sinkholes relates to climate change since the decreases in freeze-thaw action correspond to increases in temperature values. The lack of freeze-thaw events bridges the connection between climate change and underground water mobility since it is understood that there is more water flow when there is less ice. Sinkholes are a geohazard caused by unsteady grounds and sediment. If there is more water mobility, there is more erosion, leading to those causes. Other factors that play into this are saline concentrations; if they are high, which they are on Long Island, clay particles become flocculated, making them less steady (Palomino and Santamarina, 2005; Lyu et al., 2020). In addition to salinity, researchers consider thermal conductivity to be a factor in freeze-thaw cycles, since ice melting increases in winters. Thirdly, the apparent thermal conductivity of soils increases with increased concentrations of NaCl in a soil solution (Noborio & McInnes 1993). This fact is relevant because it means thermal conductivity is generally higher when there is more NaCl in soil. Further supporting that Long Island soil gets warm easily. In another study, it was found that "thermal conductivity increases linearly with density [of NaCl] from 0.2 to 1 W/(m*K) for densities from 1.1 to 2.3 g/cm^3" (Stacy et al. 2014). This also suggests that Long Island soil may weaken due to increased temperatures, since increased salinity is directly proportional to increased thermal conductivity. Increased thermal conductivity heightens the impacts that climate change has on freeze-thaw fluctuations and the melting that comes from that (Lyu et. al. 2020). This all supports how global heating is increasing water mobility, thus eroding the depths of Long Island, causing more sinkholes to occur in recent years. This research aims to investigate the number of freeze and thaw times per year over the past 76 years and apply it to our data. This offers a proxy for underground erosion and subsequent sinkhole occurrences, which will be analyzed in our results.

Methodology

We used Rstudio to acquire and clean data using the reproducible R language packages GSODR (Sparks A., Hengl T., Nelson A., 2024), KZA (Close B., Zurbenko I., Sun M., 2020), and rNOAA (Chamberlain S., Hocking D., 2023) packages which gathered data directly from different weather stations throughout Long Island and the Tristate area. We cleaned the data and interpolated wherever there were small gaps utilizing *imputeTS* package (Moritz S, Bartz-Beielstein T 2017). The relevant data was ultimately derived from two stations, located at John F. Kennedy International Airport. We wrote a script in Rstudio to count the number of times per year the atmospheric temperature entered into two specific intervals. The first, called the freezing, is represented by the interval of -4°C to 1°C, and the thawing interval is represented by 4°C to 10°C. A moving average utilizing the KZ filter with a window of 11 years was applied three times for each temperature interval (Fig. 1) to investigate a possible trend. The KZ filter demonstrates a robust performance in the presence of non-stationary data and outliers; there was no signal loss or tail-clipping like a standard moving average may introduce (Zurbenko, 1986; Tsakiri & Zurbenko, 2011). Its iterative process efficiently addresses the impact of abrupt changes or anomalous data points, ensuring a more stable and reliable output. Consequently, the KZ filter strengthens with few iterations the elimination of short-term noise and avoids over-smoothing potential trends.

Results

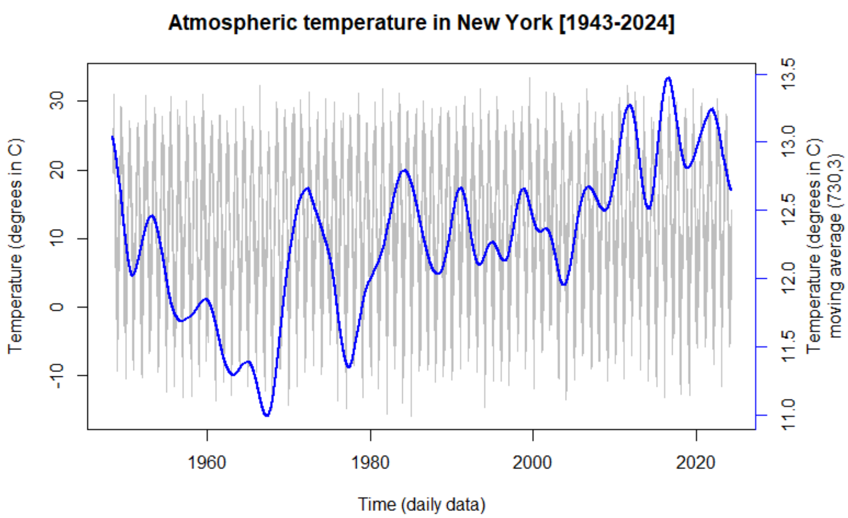

Figure 1: The trend of historical atmospheric temperatures over the past 76 years on Long Island, New York. The graphs portray frequencies of underground temperature values as they occur within the respective temperature ranges (℃). Temperature (℃) averages are represented on the right side axis, aligning with the blue line. The blue line represents the moving average over a window of two years (730 days) applied three times to limit outliers and show more accurate trends.

A negative trend in the total number of times (Figure 1) temperatures crossed the freezing window per year (left) as well as a positive trend in the total number of times temperatures crossed the thawing window per year (right). Figure 2 shows a positive trend in average yearly temperature over the last 74 years.

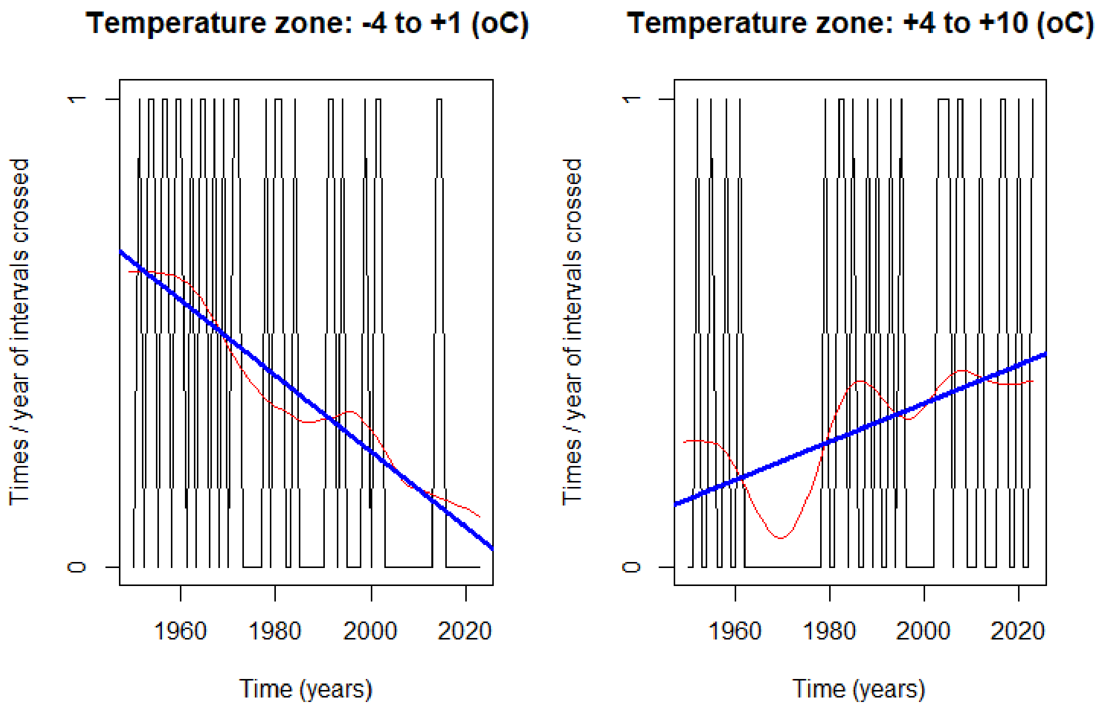

Figure 2: Times per year of intervals crossed at zones of temperature between -4 to +1 ºC and +4 to 10ºC. The blue line follows the trend, analyzing temperature change over that time frame. Red line data excludes the sunspot impact of eleven-year cycle (utilizing a KZ filter with 11 years window applied for an iteration of 3 times), since sunspots are known to affect groundwater temperatures (Tentomas & Marsellos 2022).

Discussion

In conceptualizing this experiment, our aim was to explore a potential correlation between global warming and the occurrence of sinkholes. Specifically, we endeavored to investigate the relationship between the documented increase in global temperature, as elaborated upon in subsequent sections of this paper, and the erosion of glacial sediments precipitated by heightened water mobility and increased rainfall resulting from elevated temperatures. Our data gathering methodology involved using R language (RStudio) to gather historical atmospheric temperature data of daily intervals from selected weather stations operated by NOAA (The National Oceanic and Atmospheric Administration) situated within the immediate tristate area and along Long Island, NY. Subsequently, we compared this data with existing research findings to understand potential correlations between rising global temperatures, amplified water mobility, and the anticipated heightened incidence of sinkholes.

Conclusion

The research we have conducted and the data we have collected both work together to support the concept that increased temperatures due to climate change have a direct impact on sinkhole formations. The way we supported this hypothesis was through research on freeze-thaw, as our data exposed the truth that these freeze-thaw cycles have declined in frequency over time. This suggests that ice is melting and remaining unfrozen underground even in the coldest portion of the year, supporting the development of water mobility within Long Island soil. With the observation of temperatures over the past sixty to eighty years, it is clear that sinkhole formation due to climate change is a recent phenomenon at the northern latitudes that used to experience more prolonged winter times.

Credit Authorship Contribution Statement

Gonzalez,X editing, literature, Rstudio coding, Figure 1, Figure 2, writing- Abstract, Introduction Methodology, Discussion; Hubbs, D: Literature, editing, writing-, Abstract, Introduction Results; Pelletier, A.: references, literature, editing, writing - Introduction, Discussion; Dailey,S.: editing,, writing - introduction, Discussion, Conclusion; Marsellos, A.E.: supervision, Rstudio coding, guidance, editing;

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