Investigating Rainfall Impact on Groundwater Depth through Statistical Analysis

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Abstract

Groundwater is an extremely valuable resource, especially in agriculture. It is one of the main sources of water for irrigation. In arid areas where surface water is scarce, groundwater is the only source of water for growing crops. However, in recent years, groundwater use has continually increased to the point where it is now being used faster than it can replenish, especially in certain parts of the United States. The purpose of this study is to determine the effect of rainfall level on water depth below the surface. Rainfall data in Union County, New Jersey, from 2000 to 2022, and water depth levels below the surface from 2001 and 2022 were used. Then, data and graphs were aligned using Python to explore possible correlation. The results show that there is a healthy correlation between precipitation and water level below the surface.

Introduction

Water is the most precious component of life. It is a valuable and limited resource that sustains civilization. Water, which moves via rivers and streams, is kept in lakes, reservoirs, and ponds and held in groundwater aquifers. The two primary water sources utilized to meet global water demands for residential, agricultural, industrial, navigational, and recreational purposes are surface water and groundwater. Managing this resource is fundamentally important to the development of a nation. About 75% of the Earth's atmosphere is shielded by water in liquid and solid forms. The International Maize and Wheat Improvement Centre's annual report from 2015 (CIMMYT, 2015) states that 2.5 percent of the world's water supply is freshwater and 97.5 percent is saltwater supplies. Groundwater makes up around 30.1% of the world's freshwater supply, or less than 1% of total water supply on earth, and it is essential to human life and economic development (UNWWD, 2006). Despite its significance, understanding the dynamics of groundwater in relation to rainfall remains a complex and underexplored area, especially in the context of changing global climate patterns and increasing water demand.

Since the mid-20th century, the world has witnessed a more than fourfold increase in water demand, leading to substantial stress on water resources. According to the United Nations Environmental Program (UNEP), nearly a third of the global population now lives in regions experiencing moderate to severe water stress. In North America, the situation is equally critical, with diverse water availability and usage patterns across the region. For instance, in Canada, a large portion of the population has limited access to the country's abundant water resources due to geographical and infrastructural factors. Areas like Florida, San Antonio, and Albuquerque in the United States heavily depend on groundwater for their water supply.

The scarcity is further compounded by inadequate water management practices, urban development, and land use changes that affect recharge zones and groundwater levels. Urban expansion, for example, has led to decreased infiltration in places like Chicago, while in regions like the Oak Ridges Moraine in Ontario, efforts are ongoing to protect vital aquifers from urban development. Despite the known importance of groundwater as a critical resource for agriculture, drinking water, and ecological balance, there is a lack of comprehensive understanding regarding how variations in rainfall patterns directly impact groundwater levels. This gap in knowledge is particularly crucial in the context of changing global climate patterns, which are altering precipitation dynamics and thus potentially affecting groundwater recharge rates and sustainability.

Existing studies have provided insights into this relationship, but they often lack regional specificity or do not consider the complexities introduced by factors such as soil type, land use, and human activities. This research aims to examine the complex relationship between rainfall and groundwater levels, focusing on Union County, New Jersey. By examining this correlation, the study seeks to contribute to more effective water management strategies at the local county level, ensuring the sustainable use of this crucial resource amidst growing environmental and societal challenges.

Model Development and Approach

Historical data for the monthly average rainfall (in) from October 2000 to September 2022 in Union County, New Jersey, was taken from the USGS. Then, historical data for the daily water level depth below the land surface (ft) from October 2000 to September 2022 in Union County was taken from USGS. Using Python, both of these data sets were graphed on a time series graph; then, Pearson's linear correlation test determined if there was a correlation between rainfall and water level. The p-value of the test was calculated to see how significant the resulting correlation value was.

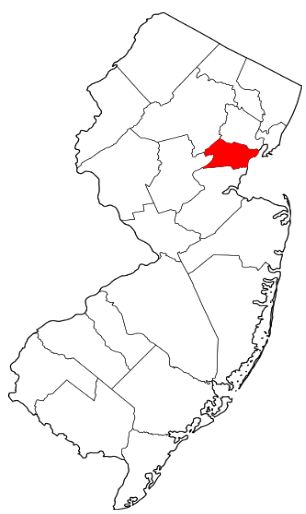

Figure 1: Location of Union County in New Jersey state

Depth of water below surface in Union County

Figure 2 shows the daily mean depth of water below the land surface (in ft.) between 6th October 2000 and 6th October 2022 in Union County, NJ. The mean water level below the surface was observed to be 6.445 ± 0.89 ft. The minimum depth was observed to be 4.61 ft, whereas the maximum water depth was observed to be 9.46 ft. The data were distributed normally (Figure 3)

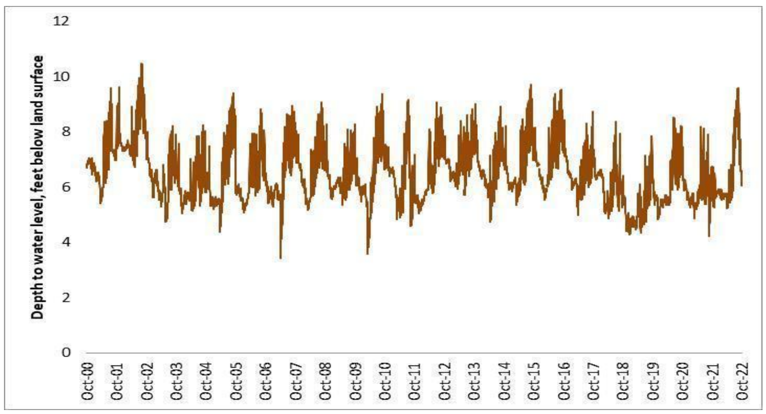

Figure 2: Daily depth of water level below land surface (ft) since October 2000 to October 2022

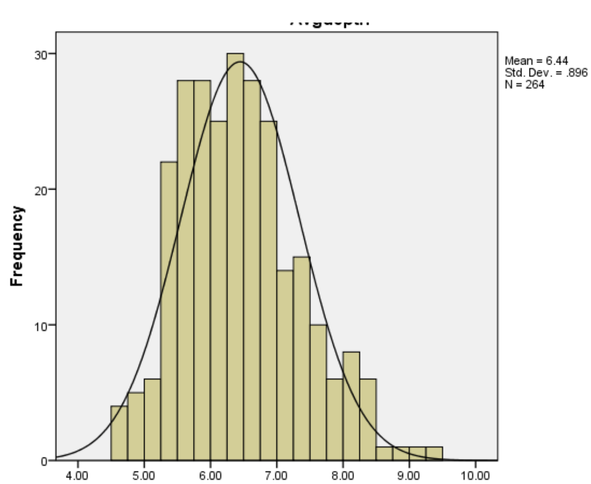

Figure 3: Normal distribution of water depth (monthly) in the Union County

Rainfall in Union County

Figures 4,5 shows the monthly rainfall (in inches) from October 2000 and September 2022 in Union County, NJ. The mean rainfall was observed to be 4.077 ± 2.17 inches. The minimum rainfall was observed to be 0.69 in, whereas the maximum rainfall was observed to be 18.18. The data were distributed normally except for outliers in 2005 and 2011 (Figure 5)

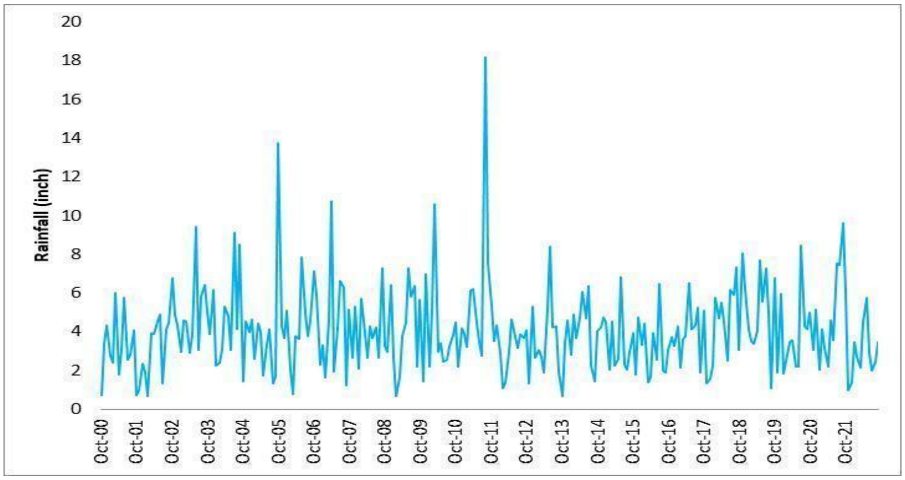

Figure 4: Monthly average rainfall since October 2000 to September 2022

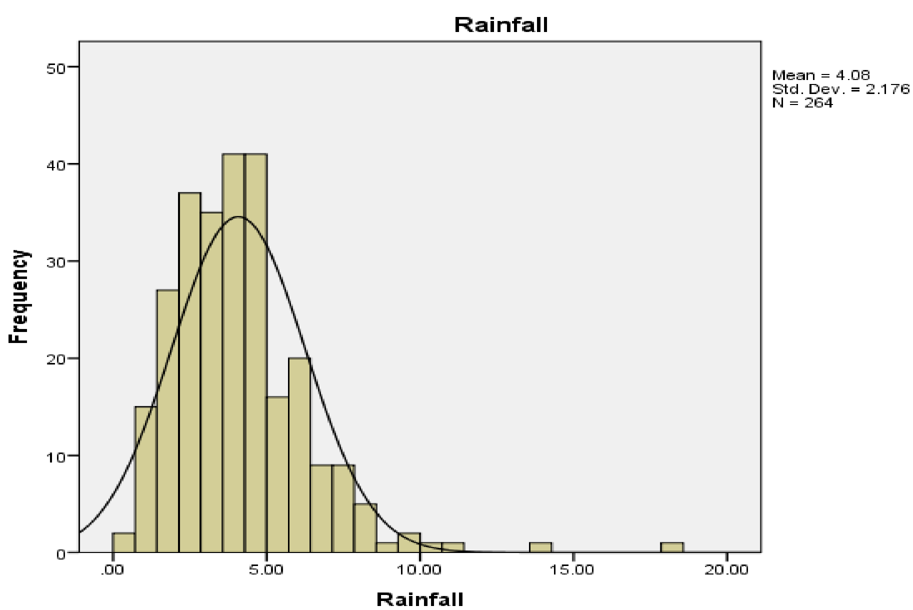

Figure 5: Monthly rainfall (inch) distribution pattern since October 2000 to September 2022

Correlation between average water depth below land surface and rainfall in Union County

Figure 6 shows a graph depicting the association between monthly water depth below the land surface and rainfall between October 2000 and September 2022 in Union County, NJ. A Pearson correlation coefficient was computed to assess the linear relationship between water level (below the surface) and precipitation, and there was a significant negative correlation between the two variables, $r(262) = -0.224$, $p < 0.001$. depicts that with an increase in rainfall, there was a significant decrease in the water level below the land surface.

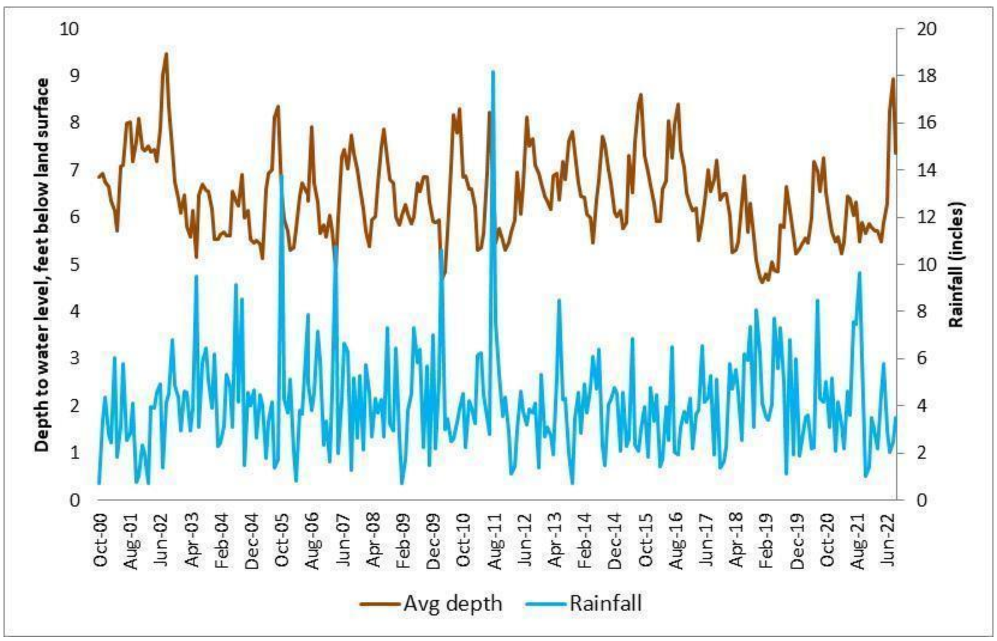

Figure 6: Association between monthly water depth below land surface and rainfall between October 2000 and September 2022 in Union County, NJ.

Results and Discussion

Pearson correlation coefficient was computed to assess the linear relationship between precipitation and water depth below the surface. The resulting value was $R = -0.229$, and the calculated p-value was less than 0.001 ($p = 0.0001714$), which is significant. This correlation indicates that as precipitation increases, the depth of water below the surface decreases, a result that aligns well with expected hydrological behavior.

A significant negative correlation was observed between the water depth below the surface and precipitation, indicating that the water depth is decreasing with precipitation growth. This negative correlation is indicative of a healthy and functioning groundwater recharge system. In ideal scenarios, increased rainfall leads to more water percolating through the soil and replenishing underground aquifers, thereby reducing the depth to groundwater.

Examining the correlation between rainfall and groundwater depth is important for several reasons:

I. *Water Table Recharge:* Rainfall is a primary source of natural recharge for groundwater. By understanding this correlation, we can assess how effectively rainfall contributes to replenishing underground aquifers.
II. *Sustainable Water Management:* Knowledge of how rainfall affects groundwater levels aids in sustainable water management. It helps in predicting the availability of groundwater and planning for periods of scarcity, especially in areas prone to droughts or with limited surface water resources.
III. *Ecological Balance:* Groundwater levels can affect the health of ecosystems, particularly in wetlands. Understanding how rainfall influences groundwater can aid in maintaining ecological balance and biodiversity.
IV. *Agricultural Planning:* Agriculture often depends on groundwater for irrigation. Understanding the relationship between rainfall and groundwater levels can assist farmers in making informed decisions about irrigation practices, crop selection, and planting schedules, ensuring more efficient use of water resources.
V. *Groundwater Quality:* The correlation can also indicate the potential for contamination of groundwater. Heavy rainfall can sometimes lead to increased runoff and infiltration of pollutants into aquifers. Understanding this relationship helps in managing the risks to groundwater quality.
VI. *Flood Management:* In areas where the water table is high, heavy rainfall might not sufficiently infiltrate, leading to surface runoff and potential flooding. Understanding the rainfall-groundwater relationship can help in flood risk management and mitigation planning.
VII. *Climate Change Adaptation:* With changing climate patterns, rainfall distribution and intensity are also changing. Understanding the correlation helps in adapting to these changes, forecasting future water availability, and developing strategies to mitigate the impacts of climate change on water resources.

Future Work

This study lays the groundwork for future research that aims to broaden its geographical scope and incorporate key environmental factors, offering a more comprehensive understanding of groundwater dynamics. Key areas of focus for subsequent studies should include:

I. Geographical Expansion: By extending the research to include a diverse array of counties, particularly those with varying climatic conditions, a more representative range of hydrological behaviors and patterns can be captured. This will shed light on regional differences in groundwater dynamics, providing a more nuanced understanding across different environments.
II. Soil and Topography Analysis: Investigating the impact of different soil types and topographical features on groundwater recharge is essential. These factors, with their distinct permeability and water retention properties, play a crucial role in determining

how rainfall influences groundwater levels. An in-depth study of these aspects will enhance the understanding of the physical processes governing groundwater recharge.

III. Land Use Impact: The influence of human activities on groundwater resources is profound. Urbanization, agriculture, and industrial activities alter natural water courses and affect recharge zones. Future research should delve into how changes in land use patterns affect the interplay between precipitation and groundwater levels, considering both the current state and potential future developments.

IV. Climate Change Projections: In the face of changing global climate patterns, understanding how these shifts impact groundwater systems is imperative. Future studies should focus on forecasting the effects of climate change on precipitation and, consequently, on groundwater resources. This will be crucial for developing strategies aimed at enhancing resilience and adaptive capacity in response to climatic changes.

In conclusion, future research, by encompassing a wider range of counties and incorporating critical factors like soil type, topography, and land use, will significantly enhance the understanding of groundwater recharge processes. This expanded scope will provide invaluable insights for developing adaptable, effective, and sustainable water management strategies in various regions, under the growing challenges of climate change and human impact. Integrating hydrology with geology, urban planning, and environmental science can provide a more holistic understanding of groundwater systems. This interdisciplinary approach is essential for developing effective water management strategies.

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