Prediction of Groundwater Depth Using Average Rainfall-Groundwater Correlations in Kolkata, India

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Abstract

Purpose Access to groundwater is important for community livelihoods, especially in key areas of Kolkata, India. Recognizing the central role of water in human life, this research plays an important role in providing useful information to address upcoming challenges. This research aims to create a correlation model between average rainfall and groundwater depth, and revolutionize groundwater exploration and forecasting. Methods: The initiative leverages data on groundwater depth and average rainfall provided by the State Water Investigation Directorate (SWID) and the India Meteorological Department (IMD), respectively. Using different linear regression methods, the correlation was established and illustrated using different types of methods for proof. Data analysis techniques that help create attractive visual representations of data are conducted. Linear correlation analysis was used to study the influence of past rainfall and historical groundwater depth tables to measure groundwater depth. Results: This process will result in a proper correlation model between groundwater and rainfall for a span of 10 years. From the analysis of the correlation model, the future data may be calculated. Conclusion: The proposed relationships will apply this to predict groundwater depth tables for better planning and management of groundwater resources in the study area.

Keywords Groundwater response · Linear regression · Correlations · Data analysis · Prediction

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1 Introduction

Surface and groundwater play indispensable roles in supporting life on Earth. Groundwater, a fundamental component of the hydrological cycle, significantly impacts the ecological dynamics of wetlands and rivers, significantly contributing to their flow. Groundwater resides in underground layers known as aquifers, which consist of permeable rock capable of storing and yielding substantial water volumes. Replenishment of groundwater occurs through various natural processes such as rainfall, snow melt, and percolation from lakes and rivers [1].

Groundwater constitutes approximately 30% of the world's readily accessible freshwater, serving as the principal and favored source of potable water in both rural and urban regions. In rural India, it satisfies 50% of agricultural water requirements and accounts for 80% of the nation's total drinking water consumption [2]. An estimated 2.5 billion individuals rely on groundwater resources to fulfill their daily needs.

India uses the most groundwater worldwide, according to the UNU-EHS World Water Development Report [3]. Rapid industrialization, population increase, and intensified agriculture have overexploited freshwater supplies, lowering groundwater levels. Many Indian districts face groundwater scarcity, losing 122–190 billion cubic meters of agricultural water (CGWB) [4, 5]. Rapid urban expansion reduces rainwater infiltration, limiting groundwater recharge, especially in summer. Sustainable groundwater management requires addressing groundwater level changes, especially due to natural factors like rainfall. In the water cycle, rainfall is the main source of groundwater recharge. Due to repeated monsoon failures, more Kolkata residents have turned to groundwater, causing issues, especially for farmers. The rising population and unsustainable groundwater extraction and mismanagement put great pressure on these water supplies, causing groundwater levels to plummet. According to a senior official in the State Department of Irrigation and Waterways, groundwater levels in the KMC region are falling one foot each year.

According to an article published in Telegraph India by Pradip K. Sikdar and Sumanta Banerjee, the lead scientists of the study, due to over-extraction of groundwater in the past two and a half decades, the groundwater in south-central Kolkata has diminished by 266 km^2, leading to the degradation of freshwater into blended and brackish water" [6]. Until the late 1990s, the entire water supply of the area relied solely on groundwater resources. However, with the increasing population and rising water demands over the years, the water supply dynamics have undergone significant changes. As a consequence of over-extraction, 75% of Kolkata's groundwater is now brackish. Certain hydrochemical conditions observed by the Kolkata Municipal Corporation (KMC) reveal that in certain areas, fresh groundwater is overlaid by brackish water [7]. Although the quantity of potable water has increased significantly at major water treatment plants, waste remains a major concern, as reported by the water supply department. Moving forward, it is imperative to recognize the importance of safeguarding groundwater for a sustainable future. Emphasizing the crucial role of predicting future water levels adds another layer of significance to this commitment.

2 Materials and Methods

2.1 Study Area

Here, we focus on the Kolkata Municipal Corporation (206.08 sq. Kms), Fig. 1, as our study area within the state of West Bengal [8]. Kolkata is situated on the eastern bank of the River Ganga, with coordinates at 88º 30'E–22º 33' N. The city's altitude is approximately 9 m, standing 6.4 m above sea level. In the summer season, temperatures range from 24º to 41 ºC, while in winter, they average between 8º and 24 ºC. Humidity levels during summer range from 85 to 65%. The dry season (November–March) witnesses an average rainfall of 130 mm–150 mm, while in the wet season (April–September), it increases to 1400 mm–1500 mm. The area lies on the Ganga Delta and is part of the Indo-Gangetic plain, characterized by highly alluvial soil [9]. Due to the geological development of the KMC area through silt deposition from the Ganga, the soil beneath is predominantly turbulent in nature.

A GIS-based study is conducted to analyze field-based pre-monsoon and post-monsoon piezometric level data spanning the previous 20 years [10], aiming to evaluate groundwater level practices in Kolkata. The analysis employs the inverse distance weighting technique within GIS. Results indicate that the city's water level typically ranges between 10 and 20 ms below ground level (mbgl); over the past decade, there has been a decline of up to 5.5 m [10, 11]. Certain locations show delays in pre-monsoon and post-monsoon levels, suggesting significant abstraction and fluctuations in recharge (Table 1).

Fig. 1 Kolkata municipal corporation area map

Table 1 For groundwater depth data

Year	First half of the year (Jan–Jun)	Final half of the year (Jul–Dec)
2014	17.6	15.79
2015	16.03	15.85
2016	16.22	14.84
2017	15.91	15.86
2018	17.36	16.53
2019	17.87	16.94
2020	16.94	16.23
2021	18.01	15.11
2022	16.72	16.84

2.2 *General Model Development*

The State Water Investigative Directorate and IMD-Kolkata provided half-yearly groundwater depth and rainfall data tables for Kolkata Municipal Corporation's region to develop a correlation model from 2014 to 2022. Table 2 displays average rainfall data variation over time, while Table 1 shows groundwater depths. Using linear regression, a general correlation model between groundwater depth and rainfall will be created [12].

Here to generate the linear relational equation, the Groundwater Depth is taken as the dependent variable whereas Average Rainfall is an independent variable. So, the generated linear regression equation is following, groundwater

$$depth(y) = a + b * Rainfall(x)$$

For the detailed calculation for this equation and to determine the value of these constants a and b, the curve fitting method is used.

Table 2 For average rainfall data

Year	First half of the year (Jan–Jun)	Final half of the year (Jul–Dec)
2014	2.12	5.56
2015	2.65	7.48
2016	2.08	7.12
2017	2.35	8.08
2018	3.31	4.72
2019	2.59	7.41
2020	4.95	5.75
2021	4.62	8.81
2022	2.21	5.01

1. Identification of the parameters;
2. Development of the model;
3. Evaluation of the developed model.

2.3 Linear Regression Model

In this analysis, the groundwater depth model is developed using the data of average rainfall, considering the antecedent rainfall and groundwater depth table [13, 14]. The steps to develop this model are the following:Please note that the first paragraph of a sec-tion or subsection is not indented. The first paragraphs that follows a table, figure, equa-tion etc. does not have an indent, either.

Identification of the parameters:

The controlling parameters to develop the correlation analysis are taken from the antecedent rainfall table and groundwater depth table. The rainfall data is taken as an independent variable which influences the value of groundwater data that is the dependent one.

Development of the model:

The linear regression model with respect to the controlling parameters is demonstrated as a simple linear equation:

$$y = a + bx$$

where y is a dependent variable, x is an independent variable and the constants are *a* and *b*. Here *y* is groundwater depth and *x* is average Rainfall data.

Evaluation of the developed model:

The developed model which is based on Linear Regression to find the correlation between Groundwater (y) and Rainfall (x) is following:

$$y = na + bx \tag{1}$$

Here n defines the number of data in the dataset and the constants are a and b. To evaluate a and b another equation has been generated by multiplying x with both sides of the equation.

$$xy = ax + bx2 \tag{2}$$

In the process of curve fitting Eqs. (3) and (4) are generated by summation of Eqs. (1) and (2) respectively.

$$\sum y = na + b \sum x \tag{3}$$

$$\sum xy = a \sum x + b \sum x^2 \tag{4}$$

Putting the value of $\sum x$, $\sum y$, $\sum xy$ and $\sum x^2$ from the dataset in the Eqs. (3) and (4), the values of a and b have been determined as 17.5 and −0.2 respectively. Replacing these values with the constants a and b in the standard equation the correlation between Groundwater depth and Rainfall has been established. The final equation is following:

$$Groundwaterdepth \ = \ 17.5{-}0.2 * Rainfall$$

Putting the value of Rainfall from the given dataset in the equation Groundwater depth can be determined. From the main equation, the creation of the Groundwater depth table and Time has been formed. From the following table, the graph of Groundwater depth vs. time has been plotted as follows in Fig. 2.

3 Result Analysis

This phase is essential in the process of converting raw data into insights that hold significance. It empowers researchers to derive valuable conclusions, adding depth to our understanding of the groundwater system under scrutiny. There have been notable changes observed in the occurrences of intense monsoon rainfall spells. The monsoon rainfall showed increasing trends. Pre-monsoon and post-monsoon rainfall showed a decreasing trend. Like less rain fell in the months of Dec, Jan, and Feb (denoted as "12," "1," and "2") of every year. Due to the pumping of groundwater for various reasons during a dry spell, the groundwater level displayed a falling pattern that continued until the next monsoon season. Major variations in groundwater levels could also result from the regular monsoonal rainstorms that occur between June and December.

3.1 Groundwater Level Fluctuations

A dry month can be defined as having no precipitation, whereas a wet day has more precipitation than a particular threshold, depending on the climate of a particular month and groundwater fluctuations can be linked using both deterministic and probabilistic approaches [15]. Examining the data corresponding to June, July, and August (Denoted as "6," "7," and "8"), a conspicuous indication emerges of a substantial rise in rainfall levels during this period. Notably, in Fig. 3 the month "July" consistently exhibits significantly higher rainfall levels, overall displaying the trends of monsoon. However, there is a dip in rainfall between 2020 and 2021. This study gives us a better understanding of how the groundwater system works, helping

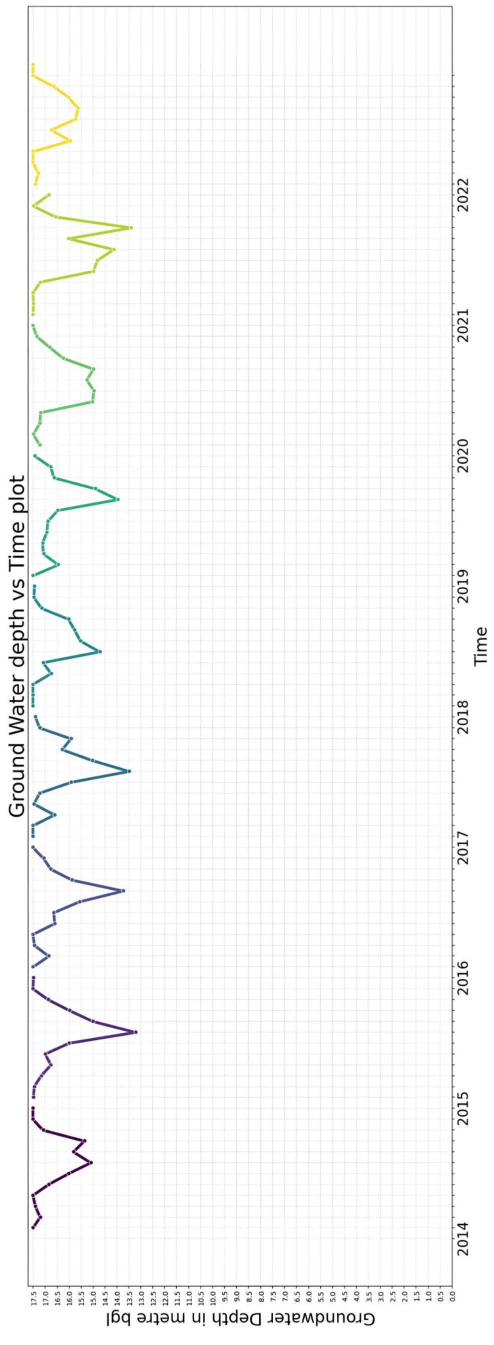

Fig. 2 This plot shows the variation of groundwater depth with respect to Time in the region of Kolkata Municipal Corporation

us see the bigger picture and more complete conclusions. The groundwater level responds quickly to changes in rainfall. Imagine rain as a recharge for the underground water tank. When it rains, water seeps into the ground, quickly filling up the tank (groundwater).

The type of soil and human activities, like construction, can either speed up or slow down this process. In Fig. 4 we observe the Groundwater trend categorized by rainy months like June, July, and August. This visual representation helps us get a clearer grasp of how the groundwater changes during these key months. Subsequent para-graphs, however, are indented.

3.2 Correlation

The graph in Fig. 5 depicting the correlation between Groundwater levels and Average Rainfall reveals a consistent upward trend for both lines during the monsoon season. However, in the post-monsoon, as well as during the summer and winter seasons, discernible variations become prominently evident in the graph. These fluctuations indicate the Average Rainfall and Groundwater's different seasonal changes.

3.3 Heatmap Analysis

The heatmap in Fig. 6 vividly reveals the connection between groundwater levels and average rainfall across the studied regions [16]. Darker areas on the heatmap suggest a stronger positive correlation, indicating that higher groundwater levels coincide with increased average rainfall. Conversely, lighter areas suggest a weaker or negative correlation. The visualization gives a clear picture of how groundwater and rainfall work together.

3.4 Regression Performed

The average groundwater level during the monsoonal period was observed to be **11.0437037 MBGL**. The substantial increase in groundwater recharge, attributed to heavy rainfall during this season, significantly contributes to the considerable rise in groundwater levels. During the non-monsoon seasons, when rainfall is limited in various areas of the KMC, cultivated lands primarily rely on groundwater sources for irrigation. Consequently, during this period, the groundwater levels are observed to be low. Increased precipitation generally raises the groundwater, while excessive extraction leads to a decline. Variations in rainfall cause the groundwater level to vary rapidly. In Fig. 7 we examined the connection between Average Rainfall and Groundwater using Linear Regression [17, 18]. The R2 score (*used to evaluate the*

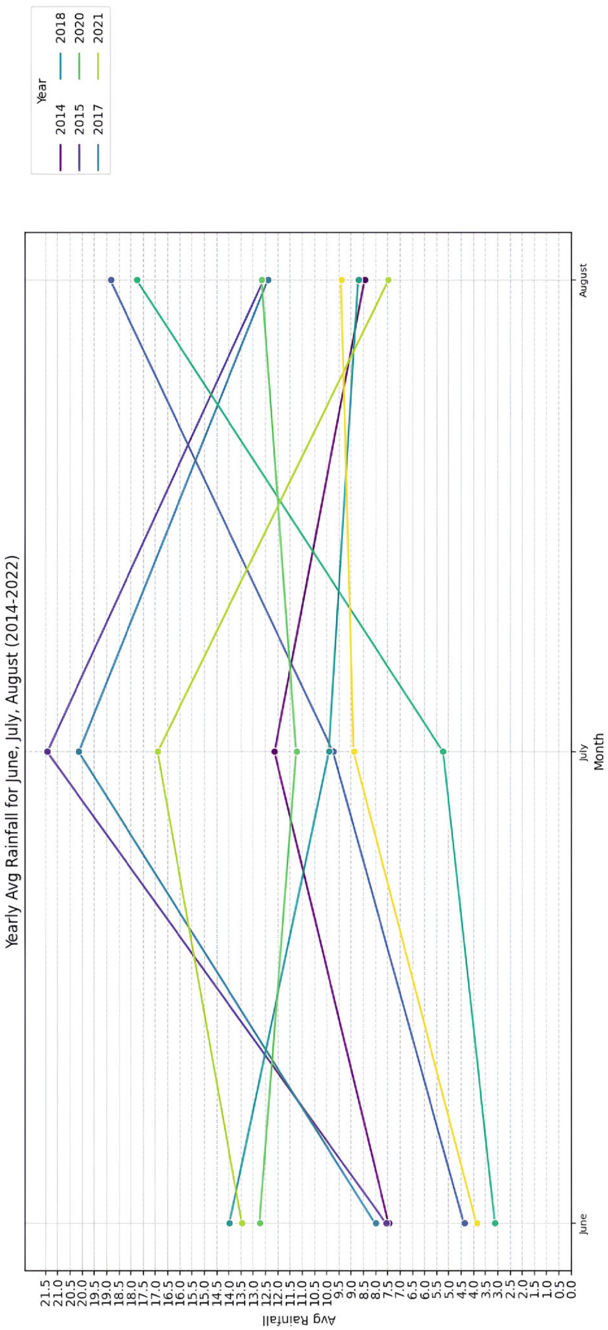

Fig. 3 Yearly "average rainfall" for June, July, and August (2014–2022)

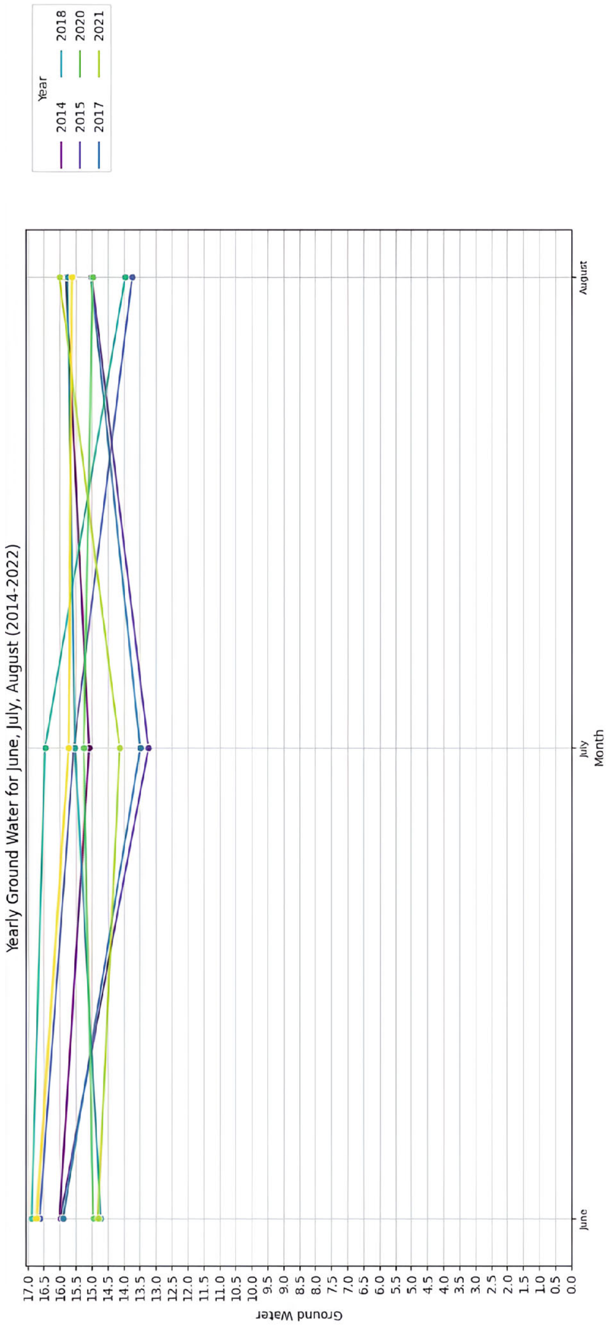

Fig. 4 Yearly "groundwater" for June, July, August (2014–2022)

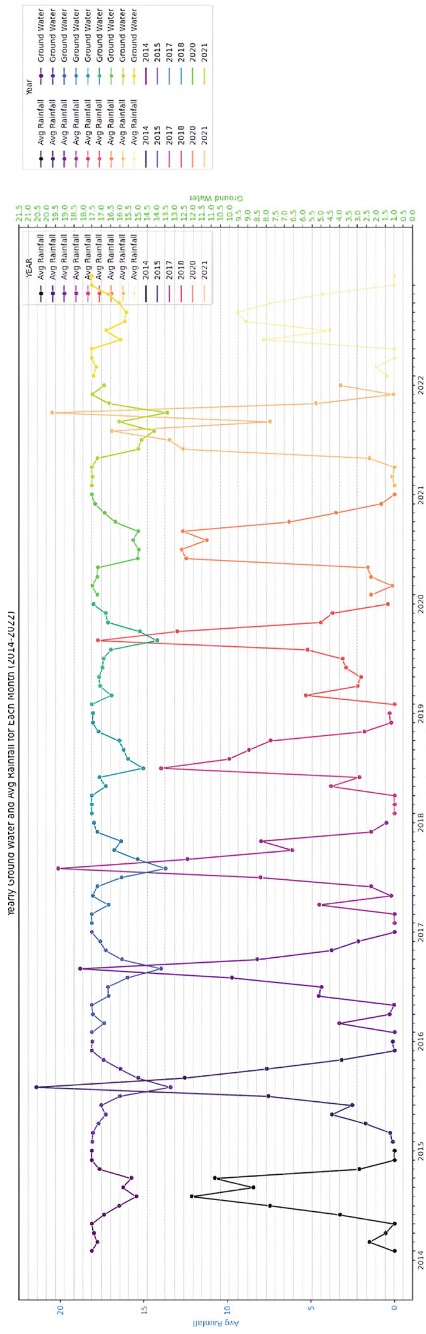

Fig. 5 Correlation between groundwater and average rainfall levels Average rainfall

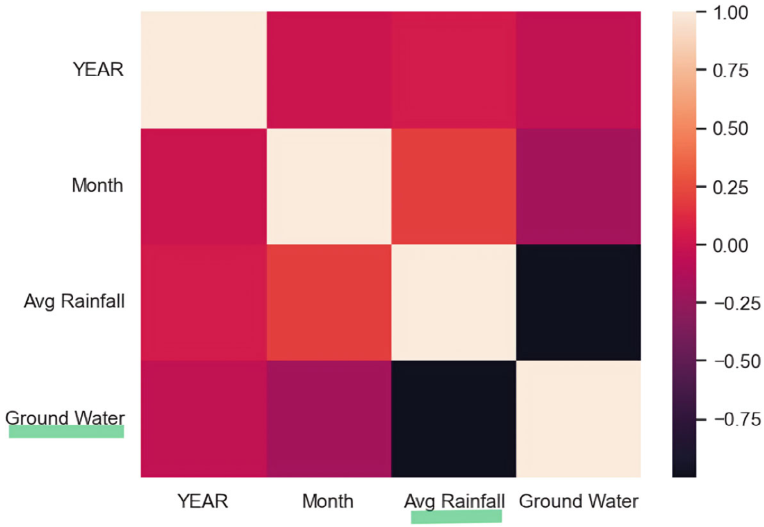

Fig. 6 Heatmap: showing the correlation of groundwater and average rainfall

performance of a linear regression model), indicating their correlation, is remarkably high at 0.999. Also, the scatter plot clearly demonstrates a positive association between groundwater levels and rainfall.

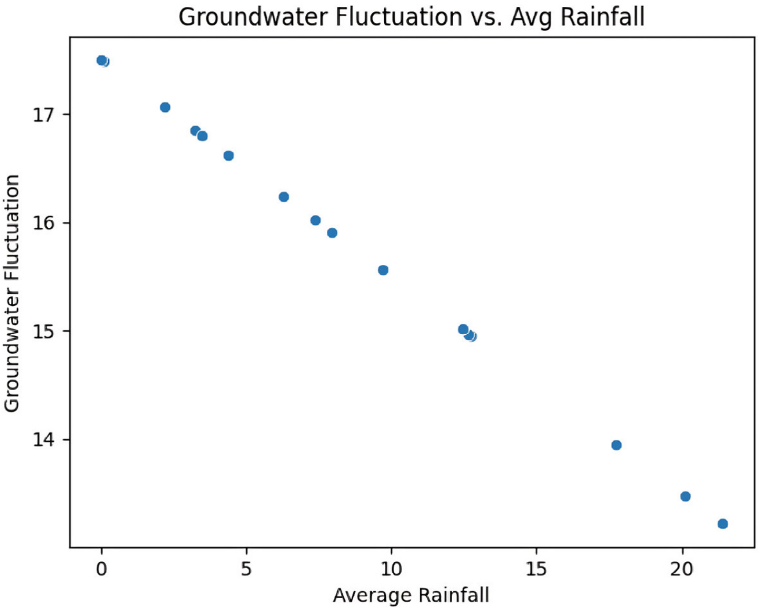

Fig. 7 Linear regression performed between average rainfall and groundwater

4 Conclusion

Groundwater, one of nature's most valuable resources, supplies Kolkata Municipal Corporation with drinkable water. It is useful in urban and rural environments for daily tasks. Additionally, groundwater's effect on natural equilibrium is important. To predict future groundwater levels, this study examines past changes. The goal is to create a groundwater depth prediction dataset by correlating average rainfall and groundwater depth data from 2014 to 2022 in Kolkata Municipal Corporation. The study examines how rainfall affects groundwater levels in the Ganga River watershed. Variations in average rainfall and groundwater depth are observed. Thus, better planning and management of these resources are needed.

The State Water Investigate Directorate (SWID) and Indian Meteorological Department (IMD) provided vital rainfall and groundwater depth data. Multiple correlation analyses have determined the relationship between rainfall and groundwater depth, pinpointing critical components. The linear regression approach determines the correlation equation constants through curve fitting, creating the correlation model.

Empirical evidence from antecedent tables supports the association between rainfall and groundwater depth. Groundwater levels vary across Kolkata Municipal Corporation, highlighting the intricacy of hydrological connectivity in the aquifer system and the importance of such data for groundwater management.

Adapted linear regression models for influencing parameters can improve groundwater resource planning and management in the region. These connections can estimate groundwater table depths with reasonable accuracy, improving decision-making.

References

1. Jirasirilak, S., Putthividhya, A., & Phongsinabhichart, C. (2015). GIS-based statistical analyses of rainfall and groundwater depth correlations in Thailand. In *World Environmental and Water Resources Congress 2015*, (pp. 565–575).
2. Sarkar, T., Kannaujiya, S., Taloor, A. K., Ray, P. K. C., & Chauhan, P. (2020). Integrated study of grace data derived inter annual groundwater storage variability over water stressed Indian regions. *Groundwater for Sustainable Development, 10*, Article 100376.
3. Eberle, C., O'Connor, J., Narvaez, L., Mena Benavides, M., & Sebesvari, Z. (2023). Interconnected disaster risks 2023: Risk tipping points.
4. CGWB: Ground water resource assessment. Central Ground Water Board. https://cgwb.gov.in/ground-water-resource-assessment-0
5. Delhi, P. (2022). Rate of depletion in ground water resources. Ministry of Jal Shakti. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1883862
6. Sikdar, P., & Chakraborty, S. (2017). Numerical modelling of groundwater flow to understand the impacts of pumping on arsenic migration in the aquifer of north Bengal plain. *Journal of Earth System Science, 126*, 1–22.
7. Bose, S., Mazumdar, A., & Basu, S. (2020). Review on present situation of groundwater scenario on Kolkata municipal area. In *IOP conference series: earth and environmental science*, (Vol. 505, p. 012022). IOP Publishing.
8. Corporation, K. M. About Kolkata. https://www.kmcgov.in/KMCPortal/jsp/KolkataStatistics.jsp
9. Das, D., & Chattopadhyay, B. (2009). Characterization of soil over Kolkata municipal area. In *Proceedings of the Indian Geotechnical Conference, Guntur, India* (pp. 17–19).
10. John, B., Das, S., & Das, R. (2023). Natural groundwater level fluctuations of Kolkata city based on seasonal field data and population growth using geo-spatial application and characterised statistical techniques. *Environment, Development and Sustainability, 25*(7), 6503–6528.
11. Biswas, K., Chakravarty, D., Mitra, P., & Misra, A. (2019). Estimation of ground deformation using psinsar with l-band alos palsar data: A case study of Kolkata, India. In *IGARSS 2019–2019 IEEE International Geoscience and Remote Sensing Symposium* (pp. 2119–2122). IEEE.
12. Hussain, F., Wu, R.-S., & Shih, D.-S. (2022). Water table response to rainfall and groundwater simulation using physics-based numerical model: Wash123d. *Journal of Hydrology: Regional Studies, 39*, Article 100988.
13. Huang, S. (2023). Linear regression analysis.
14. Majandang, J., & Sarapirome, S. (2013). Groundwater vulnerability assessment and sensitivity analysis in Nong Rua, Khon Kaen, Thailand, using a GIS-based Sintacs model.12 *Environmental Earth Sciences, 68*, 2025–2039.
15. John, B., & Das, S. (2020). Identification of risk zone area of declining piezometric level in the urbanized regions around the city of Kolkata based on ground investigation and GIS techniques. *Groundwater for Sustainable Development, 11*, Article 100354.
16. Gu, Z. (2022). Complex heatmap visualization. Imeta, *1*(3), 43.
17. Natarajan, V. A., Tamizhazhagan, V., Tangudu, N., & Kumar, M. S. (2022). Analysis of groundwater level fluctuations and its association with rainfall using statistical methods. *Journal of Algebraic Statistics, 13*(3), 1895–1904.
18. Schmidt, A. F., & Finan, C. (2018). Linear regression and the normality assumption. *Journal of Clinical Epidemiology, 98*, 146–151.