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Original Article

Predictions of Groundwater Variations Using Regression Analysis in Delhi

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Abstract - *This study aims to predict groundwater variations in the Delhi region that are experiencing severe challenges due to rapid urbanization and over-extraction. Groundwater resources are essential for the water supply of cities' agriculture and industries, yet they are under significant pressure. By applying regression analysis, we analyzed groundwater level data from 2001 to 2020 to forecast trends up to 2040. The study results indicate a steady decline in groundwater levels, with predictions showing a drop from 13.22 meters in 2021 to 33.33 meters by 2040. This research is significant as it not only provides a quantitative assessment of groundwater depletion but also highlights the urgent need for sustainable management practices. The novelty of the study lies in its amalgamation of historical data, with predictive modeling offering a compressive approach to understanding groundwater dynamics in urban areas. The study findings have wider implications for policymakers and urban planners in developing long-term strategies for water security.*

Keywords - *Coefficient of determination (R^2), Ground water, Prediction, P-value (Probability value), Regression analysis.*

1. Introduction

Delhi, one of India's most populous metropolitan cities, is facing significant difficulties in sustaining its groundwater levels. The deteriorating quality of surface water further exacerbates the city's increasing dependence on groundwater. The deteriorating quality of surface water further exacerbates the city's increasing dependence on groundwater. There are a lot of studies that look at groundwater trends and predictive modelling, but there is still a big need for region-specific research that combines past data with predictions for the future in a way that makes sense. Previous studies have mostly focused on either temporal trends or predictive modelling. The excessive extraction of groundwater resources has led to a significant decrease in the groundwater table, sacrificing the city's water security. This work seeks to fill a significant gap by conducting a thorough statistical analysis of groundwater variations in Delhi from 2001 to 2020 and projecting future trends up to 2040. Utilizing regression analysis and the Statistical Package for the Social Sciences (SPSS) tool used for future forecasting trends in water declining up to 2040, the groundwater level data was examined to deliver a quantitative evaluation of groundwater depletion and the critical necessity for sustainable management.

The city's escalating reliance on groundwater is compounded by diminished precipitation levels and the deteriorating quality of surface water, thereby making aquifers indispensable for potable water irrigation and industrial activities [1]. As one of the most populous metropolitan areas in India, Delhi's water infrastructure heavily depends on a trifecta of surface water sources, namely the Yamuna River, Upper Ganga Canal, and Munak Canal, which collectively satiate approximately 90% of the city's water requirements. However, these sources are increasingly insufficient to meet the burgeoning demand, leading to an unsustainable rate of groundwater extraction, particularly in regions where surface water provision is either deficient or altogether unavailable [2].

Further excessive groundwater extraction and climate changes can lead to a decline in groundwater levels [3-7]. Studies have noted a decline in the groundwater levels in India [8-10], which is the result of temperature changes and shifting weather patterns that significantly influence the intensity and volume of rainfall, which directly affects groundwater resources. These resources are replenished through surface and subsurface water infiltration into the earth's depths. Therefore, variations in rainfall intensity and volume directly impact groundwater levels. Given the critical role groundwater plays in water supply and the growing challenges posed by global warming, it is essential to project how climate change will affect groundwater level fluctuations. This can be accomplished through the use of software and numerical modeling techniques to investigate these impacts [11]. The over-exploitation of groundwater resources has precipitated a precipitous decline in the groundwater table, threatening the city's water security. India, as the world's largest consumer of groundwater, relies on this critical resource for more than 60% of its irrigated agriculture and 85% of its drinking water supply. However, with 29% of the nation's groundwater blocks classified as overexploited-a condition exacerbated by the ramifications of climate change-this reliance is fraught with unsustainable risk (Person, 2012). However, extensive studies have examined groundwater trends and predictive modeling [12-17]. A significant lacuna persists in region-specific research that concurrently integrates historical data with future projections in a cohesive analytical framework. Prior investigations have predominantly concentrated on either temporal trends or predictive modeling in isolation, thus lacking a comprehensive approach that amalgamates both dimensions [18]. To address this critical gap, this study undertakes a rigorous statistical analysis of groundwater fluctuations in Delhi from 2001 to 2020 and extends the analysis to forecast future trends up to 2040.

This study addresses a critical research gap by integrating historical data with future projections in a cohesive analytical framework to predict groundwater levels in Delhi. Previous studies either focused on temporal trends or predictive modelling. The proposed research combines both dimensions to provide a comprehensive understanding of groundwater fluctuations and future trends. This study supports groundwater depletion trends from previous research. In existing research, authors emphasize the effectiveness of techniques and the impact of climate change on groundwater depletion. Global studies [3] have recognized groundwater depletion as a global issue, similar to Delhi's tendencies. Delhi's yearly groundwater withdrawal is 183 million m^3 higher than the amount that can be replaced because of overexploitation [19]. The total amount of groundwater in Delhi's South West area has dropped quickly. By 2022, sources are expected to drop from 481 million m^3 to 176 million m^3 [20].

In this study, regression analysis is employed to elucidate the temporal evolution of groundwater levels, with time (represented by the year) as the independent variable and groundwater levels as the dependent variable. The study leverages key statistical measures, including the coefficient of determination (R^2) and p-value, to ascertain the robustness and significance of the predictive models.

2. Literature Review

Enhancing the literature study will facilitate a more comprehensive grasp of the topic, addressing the essential requirement for sustainable groundwater management techniques. This study results from around the world, such as [21], highlighted groundwater loss as a worldwide issue and water stress caused by climate change and human activities. The study analyses [22] the Boussinesq equation analytically to anticipate water table fluctuations from variables in time recharge, pumping, and leakage. Although not specifically for Delhi's groundwater table variations, the method can be used in comparable situations. Sustainable groundwater management requires accurate water table predictions, which may be adapted to Delhi by including local recharge and withdrawal data in the model. The paper by [23] does not discuss Delhi groundwater table variation or predict its future. Uttarakhand India case study is used to create a Generalized Regression Neural Network (GRNN) model to estimate groundwater variation using GRACE, satellite data, and hydro-meteorological data. A summary of the various study methods that have been used in the past, including time series analysis regression models and hydrological modelling. Recognition of research gaps in the existing literature and recommendations for prospective research domains. This study gives important information about how groundwater levels changed in Delhi from 2001-2020 and makes predictions for the year 2040.

Comparing Delhi's groundwater trends with similar metropolitan areas in India and around the world can enhance discussions on groundwater depletion and identify more effective strategies for Delhi's management. Groundwater levels in Chennai, India, have dropped significantly because of over-extraction and rapid urbanization. To resolve this, the city has made it a requirement for buildings to collect rainwater and is working to restore natural sources of water to help recharge groundwater. In the United States, Los Angeles is running out of groundwater because of long droughts and high demand, which is similar to what is happening in Delhi. Beijing City in China is losing a lot of groundwater because of high demand from farms and factories, and the amount of this water is steadily decreasing. The Murray Darling Basin in Australia is also seeing a drop in groundwater levels caused by natural and human activities, just like Delhi. To fix this, the area has put in place integrated water resource management practices such as close supervision, community involvement and spending money on irrigation systems that use less water. The study shows that different approaches are used to deal with groundwater loss in different cities. These include strict rules, water-saving technologies projects to artificially recharge groundwater, and public education programs.

In the context of managing groundwater resources, new advances in numerical simulation, hydrogeophysical survey technology, artificial intelligence and new research on predictive modeling, integrating these technologies into pattern-oriented approaches and predictive modeling have also been reported.

The study employed algorithms that were developed by [24] to examine the effect of climate change on groundwater levels in Mashhad, Iran. It has been shown that this method is useful in identifying existing trends and giving indications of what will happen in the future in other areas. In another work, [25] combined ARIMA modeling with GARCH modelling to forecast the changes in groundwater level within inter-year periods. This statistical usage enables us to forecast and explain short-term events and changes that occur naturally. In arid regions wherein groundwater is an important resource, Numerical Simulation Models (NSMs) are also important in strategic planning for the optimal development and management of groundwater resources [26]. Drylands are estimated to cover around one-third of the earth's surface; hence, understanding subsurface variation is of great interest to global societies; according to [27], out of the applied methodologies for predicting groundwater quality, ML stands as important in developing management strategies. [28] developed prediction models with a greater resolution to model India's groundwater consumption. From these models, the groundwater dynamics over time and space to satellite images are depicted.

3. Climate Change Impact on Delhi Precipitation

As indicated in the work of [29], this chapter outlines how climate change affects groundwater levels and the dynamics active in this phenomenon, namely anthropogenic and climatic factors. It emphasizes that urbanization and climate change may decrease groundwater levels by up to 77 mm by 2030, and thus, the need to manage water resources sustainably is imperative. The chapter invokes relevant research to interrogate these dynamics.

In the study of [30] climate change, global warming and altered precipitation affect groundwater, consistent with the need for sustainable management. The study by [31] deals with the effects of climate change on groundwater recharge, and the results show that temperature and rainfall patterns have significant effects on recharge. More insights into climate and hydrological modelling are discussed in this paper, which focuses mainly on the southwest monsoon and its contributions to Delhi's total annual precipitation. Also, recall the work done by [32] regarding monsoons, which indicates that much of the rainfall is concentrated during this season. This chapter attempts to determine to what extent climate change variables such as temperature and precipitation affect groundwater levels.

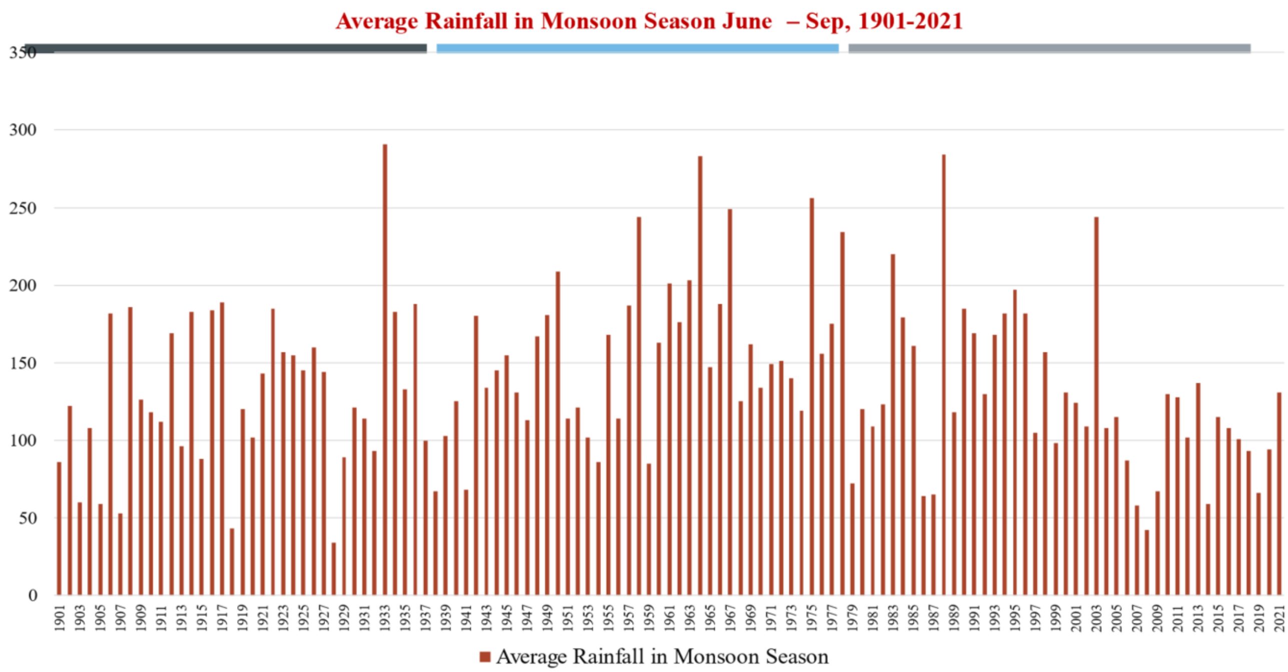

Fig. 1 Historical data of average rainfall of the monsoon season from 1901-2021 in Delhi city

As climatic anomalies have shaped torrential amounts across areas, it is easily visible in Figure 1. These waterfall supplies will have adverse impacts on agriculture, ecosystems, and even biodiversity. Below, a plume is presented, beginning with an analysis of NASA's website for the past one century of rainfall data. With the global climate change, this illustration shows the alterations of the rainfall patterns. Collaborative initiatives can only lead to stronger ecosystems, which in turn will create a Parker that is safe for the future generation. This section discusses the impact of the socio-economics of the population and groundwater use and recommends changes to help improve management strategies with protection measures in residential, commercial and industrial sectors.

The addition of these technologies is effective through the use of water-free technologies. Take, for instance, the growing population in the worst case, and the accumulation of a given area's aquifer is wrapped up in the given climatic conditions. To meet these conditions, strict laws are enforced promoting the use of efficient equipment.

A simpler answer to the increasing reliance on Delhi's ground surge is a development strategy integrating effective laws and a clear understanding of the econometrics of law. This encompasses licensing along with punitive measures for illegal withdrawal of wells, which include monitoring, promotion of water-saving technologies, and capping extraction activities in sensitive areas.

3.1. Study Area

Delhi, the capital of India, is a large metropolitan area in the northern region of the country, covering 1,484 square kilometers. Its location is between 28°24'15" and 28°53'00" north latitudes and 76°50'24" and 77°20'30" east longitudes as per Survey of India Toposheet Nos. 53D and 53H.

The National Capital Territory of Delhi is surrounded by two states: Haryana to the north, west, and south, and Uttar Pradesh to the east across the Yamuna.

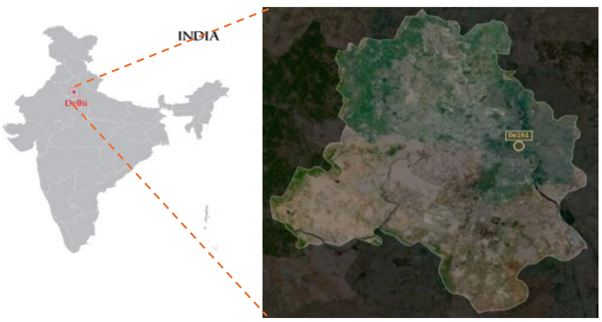

Fig. 2 Geographical location of delhi

The National Capital Territory (NCT) of Delhi has witnessed significant fluctuations in groundwater levels over the past two decades. These changes are driven by rapid urbanization, population growth, over-extraction, and decreased rainfall.

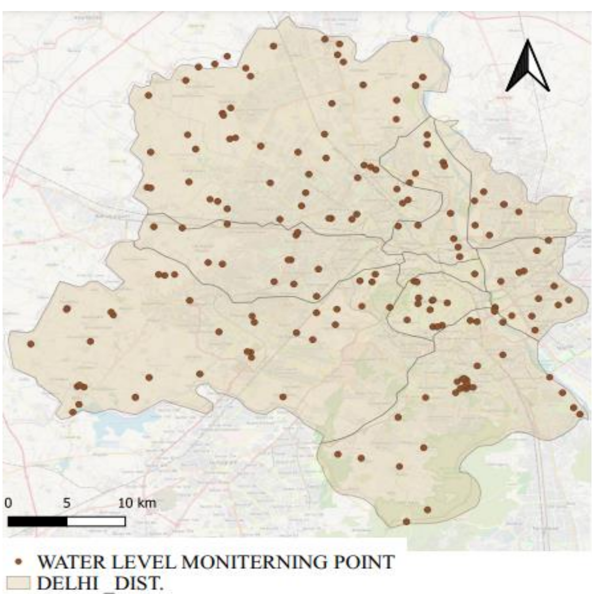

Fig. 3 Shows the water level monitoring points of Delhi

The exponential increase in population and urbanization has intensified water abstraction, exacerbating groundwater depletion. Studies have shown in Figure 3 that the number of water level monitoring points.

Monitoring well, points in Delhi decreased from 125 in 2012 to 82 in recent years, indicating a severe decline in groundwater levels due to lower rainfall in the season and high population growth [33].

3.2. Data Collection

This groundwater level data was collected from the Central Groundwater Board (CGWB) state unit office RK Puram New Delhi. There are well-monitoring points that are observed at the water table level, pre-monsoon or post-monsoon, which provide accurate data. This is the most common method of piezometer use to determine the depth and volume of groundwater. Some potential biases in the data set, such as limited coverage in remote or less developed areas, can be the reason for uneven spatial representation. Another is variability in measurement techniques or observer bias in manual readings.

Descriptive Statistics, including mean, median, standard deviation, minimum, maximum, and range, were computed to provide preliminary insights into the core tendencies and variability of groundwater levels during the two-decade span 2001-2020. The dataset included annual measurements of groundwater depths (in meters below ground level) from various monitoring wells distributed across the Delhi region.

This approach ensured that the study captured the broad spatial variability inherent in the groundwater levels across different urban and peri-urban areas. Collected data is organized in a tabular format with years and corresponding groundwater levels shown in Table 1 (Source: Central Groundwater Board (CGWB), Delhi).

Table 1. Average annual water table of Delhi (2001-2020) observed

S. No.	Year	Water Table (meters)
1	2001	9.67
2	2002	12.31
3	2003	13.23
4	2004	12.95
5	2005	15.05
6	2006	18.28
7	2007	16.15
8	2008	15.07
9	2009	15.35
10	2010	14.1
11	2011	13.83
12	2012	14.93
13	2013	13.15
14	2014	12.09
15	2015	12.18
16	2016	12.44
17	2017	13.16
18	2018	13.4
19	2019	12.1
20	2020	13.33

This illustrates the average annual water table of Delhi from 2001 to 2020, showing considerable fluctuations over the two-decade period. In 2001, the water table was at its lowest, recorded at 9.67 meters. This low point might reflect the effects of prolonged droughts, reduced rainfall, or over-extraction of groundwater. By 2002, there was a noticeable decrease to 12.31 meters, suggesting a period of downgrade of water level, potentially due to poor rainfall or increased water extraction practices. The data depicts a complex relationship of factors influencing Delhi's groundwater table.

Periods of significant decreases, such as from 2001 to 2006, likely reflect ineffective "groundwater recharge" efforts and unfavorable rainfall patterns. Conversely, the periods of incline, particularly from 2007 to 2011, could be attributed to decreased water extraction, favorable rainfall, or effective groundwater management. The fluctuations observed from 2012 to 2020 indicate ongoing challenges in maintaining a stable groundwater level. This highlights the need for continuous and adaptive water management strategies to address the varying environmental conditions and human impacts on groundwater resources. The raw data was processed for a preliminary screening to check for inconsistencies or missing values. Given the long-term nature of the study, ensuring data integrity was crucial, and a linear regression model was derived from the processed data using statistical tools.

4. Methodology & Statistical Analysis

The study primarily applied linear regression to analyze and predict groundwater level fluctuations in Delhi from 2001 to 2020, as well as to forecast trends up to 2040 by using SPSS.

Linear regression makes modeling the year-groundwater level relationship simple and interpretable. This makes it easier for decision-makers and even urban designers to follow. Statistical Robustness: A high C of determination (R = 0.96) demonstrates a satisfactory linear correlation between sets of variables, explaining 96% variability of the groundwater level for about a year. This is critical because it demonstrates the desire for change through determination, which is projected to reduce to 33.33 meters by the year 2040. The research employed linear regression analysis on available data on fluctuations in groundwater levels in the Delhi region for the period between 2001 and 2020. It made forecasts up to 2040 using the Statistical Package for the Social Sciences (SPSS) software package. This makes it easier to model the year and groundwater level so that it makes sense to urban planners and decision-makers.

The quantitative research design was, in this case, used together with 2001 to 2020 Groundwater Management in India National Capital Region-level targets places the practice of Extractive Industrial Agriculture in a more precise chronological critical perspective for the better management of natural resources considering trends and patterns of data over time. The use of statistics and computing enables objectivity and potency of the outcomes, hence promoting an evidence-based approach to urban and environmental planning. Regression analysis is a statistical procedure used in conjunction with two or more variables to achieve the desired relationship. In this research, regression analysis is done to explore how the year (independent variable) from 2001 to 2020 affects the groundwater levels (dependent variable) in meters across Delhi within the range of years 2001 and 2020. This section discusses the parameters, formulas and methods used for the regression analysis. To examine the relationship between time (year) and groundwater levels, regression analysis was performed and estimated the parameters β_0 andβ_1 using the least squares method, which minimizes the sum of the squared differences between observed and predicted values.

Linear Regression Equation is defined as:

$$Y=\beta\_0 +\beta\_1 X+\epsilon \quad (1)$$

Where,
Y is the predicted groundwater level
β_0 is the intercept of the regression line
β_1 is the slope of the regression line
X is the year

The Coefficient of Determination (R^2) is defined as

$$R^2=1-SS_{res}/SS_{tot} \quad (2)$$

Where
SS_{res} is the sum of squares of residuals
SS_{tot} is the total sum of squares

The regression statistics provide insights into the relationship between the year and the water table levels shown in Table 2.

Table 2. Regression statistics for water table levels in Delhi (2001-2020)

Statistic	Value
Multiple R	0.926
R Square	0.96
Adjusted R Square	0.98
Count	20

The multiple R-values of 0.926 suggest a very good correlation between the two variables. The coefficient of determination (R^2) was also derived to understand the proportion of variance in groundwater levels that the yearly progression could explain. The R^2 value of 0.96 indicates that 96% of the variability in the water table levels can be explained by the year. This is further supported by the adjusted R square value of 0.98, which adjusts the R square value for the number of predictors in the model and is often used to assess the 'goodness' of fit. The calculated value indicates that the model does fit the data well.

Table 3. Descriptive statistics of water table levels in Delhi (2001-2020)

Descriptive Statistic	Value
Mean	13.63871
Standard Error	0.409878
Median	13.28205
Standard Deviation	1.833029
Sample Variance	3.359997
Kurtosis	1.534404
Skewness	0.485473
Range	8.61
Minimum	9.67
Maximum	18.28
Sum	272.7741
Count	20
Largest(1)	18.28
Smallest(1)	9.67
Confidence Level (95.0%)	0.857884

The descriptive statistics were also calculated for the annual groundwater levels. This analysis provided basic metrics such as mean, median, standard deviation, minimum, maximum, and range. These statistics offered initial insights into groundwater levels' central tendencies and variability over the two-decade period. The descriptive statistics of the water table data mention in Table 2 from 2001 to 2020 provide a thorough overview of the central tendencies and dispersion measures of the groundwater levels over 20 years. The descriptive statistic values are shown in Table 3. Groundwater depth-averaged 13.64 meters over these years. Various data points revolve around this average. The mean's standard error of 0.41 meters is small, indicating that it is a reliable estimate of the true average water table level. The median water table is 13.28 meters, close to the mean, indicating a symmetrical distribution with no extreme skewness. The standard deviation of 1.83 meters indicates moderate groundwater level variability, with most values around the mean. The 3.36 sample variance supports this moderate variability. Kurtosis and skewness are measures of the shape and asymmetry of the distribution, respectively. The kurtosis value of 1.53 suggests a distribution that is slightly more peaked than the normal distribution, indicating that there are fewer extreme deviations from the mean.

The skewness value of 0.49 indicates a slight positive skew, meaning that there are a few more high values pulling the distribution to the right. The range of the data is 8.61 meters, calculated from the minimum water table level of 9.67 meters observed in 2001 to the maximum of 18.28 meters observed in 2006. This wide range shows that there have been significant fluctuations in groundwater levels over the years. The total sum of the water table levels over the 20 years is 272.77 meters, and there are 20 observations in total, confirming the completeness and consistency of the data.

4.1. Modelling

Predictive modeling was conducted to forecast future groundwater levels from 2021 to 2040. The forecasting model was developed using linear regression techniques using statistical tools based on the historical data trends observed from 2001 to 2020.

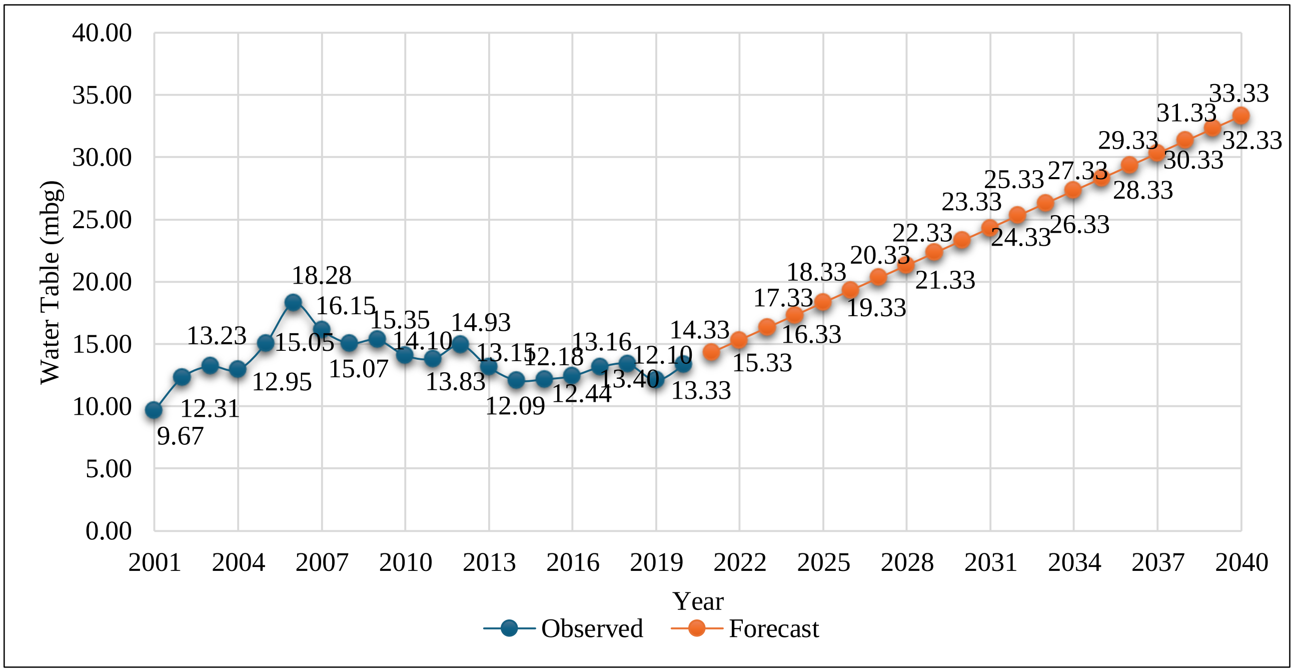

Fig. 4 Forecast of the water table levels in Delhi from 2021 to 2040

This model projected annual declines in groundwater levels, providing a quantitative basis for evaluating potential future scenarios under continuing trends. The forecasting involved extrapolating the regression model to predict future values of groundwater levels for the next 20 years, using the established trend line from the historical data. This step was crucial for understanding the potential impacts of ongoing environmental and anthropogenic pressures on groundwater resources. Figure 4 presents a forecast of the water table levels in Delhi from 2021 to 2040. The X-axis represents the years, while the Y-axis denotes the water table levels in meters below ground level (mbgl). The forecast trendline shows a clear downward trajectory, indicating a gradual decline in the groundwater levels over the forecast period.

In the final years of the forecast period, the water table is projected to decrease further, reaching 30.33 meters in 2037, 31.33 meters in 2038, and 33.33 meters by 2040. This consistent downward trend over the 20-year forecast period highlights the severity of 'groundwater depletion' in Delhi. Figure 4 illustrates a concerning trend of groundwater decline, which, if not addressed, could lead to severe water scarcity issues in the future. This forecast serves as a critical reminder of the urgent need for policies and practices aimed at preserving and replenishing groundwater reserves to ensure long-term water security for Delhi.

4.2. Model Validation Techniques

Model validation is essential to predictive model development. The model performs well on both trained and unseen data. This chapter covers model validation approaches, including cross-validation and comparison of anticipated values with suppressed data. Cross-validation is an approach that allows the evaluation of the predictive performance of a model by partitioning a dataset into subsets and training and testing the model on different subsets at a time.

The most novel includes Cross-K-Fold Validation, Leave-One-Out Cross-Validation, and Cross-Validation stratification, which is computationally intensive but provides fairness and robustness to imbalanced datasets. Certain validation techniques, like cross-validation and holdout tests, enhance the dependability and applicability of the predictive models in unseen data. Given the appropriate metrics and performance indicators, these approaches are in a position to furnish an all-inclusive framework for the evaluation or accuracy of models.

4.3. Limitations and Assumption of Model

This study, while thorough, is not without limitations. The predictive modeling relies on historical data from 2001 to 2020, which may not fully capture future changes in land use climate or policy interventions. The study also focuses on Delhi as a case study. While the findings are significant, they may not directly apply to other regions with different hydrogeological and socioeconomic conditions. Additionally, the scope of the study did not include qualitative assessments of community perceptions or the socioeconomic impacts of groundwater depletion, which could be valuable for informing more targeted policy interventions. The regression model cannot examine community opinions or the socioeconomic effects of groundwater depletion. The complexities of groundwater systems, which are influenced by dynamic interactions among climatic, geological and anthropogenic factors, may be oversimplified by regression models. The dependability of the regression model is dependent on the range of the observed data. When this range is transcended, such as in forecasting future groundwater levels under conditions that are no longer commonplace, erratic predictions can result. The reconstruction of the regression model assumes that the groundwater level will fall or rise in a more or less linear fashion over time, which might not be correct once any water management infrastructure or regulation has been implemented. It also simplifies the analysis, but it may miss some nonlinearities or some abrupt changes that random events, life circumstances, or internal variations in the population might cause. Errors or gaps in data could affect the reliability of the model and the predictions.

4.4. Sustainable Stormwater Management Practice

Delhi's urban sprawl calls for the utilization of novel measures in its groundwater management, advanced technology, and the required policy frameworks. Some of the measures include the use of technology to promote rainwater harvesting in domestic and commercial structures, integration of greywater reuse schemes to address water deficiency problems, and carrying out cost and effectiveness analysis. All these strategies are essential so that there is continuing equilibrium and recharging of the groundwater resources in Delhi.

The groundwater crisis faced by Delhi is likely to take the form of multi-dimensional facets which has to deal with tackling the water crisis in one of the most afflicted areas of the world. The proposal requires the pricing of groundwater to incorporate aspects of demand management and the adoption of community-based methods to ensure stewardship of the resource. Yet, gaps remain in the regulation of irons and the degree of community mobilization, providing a space where these encumbrances could be harnessed to precipitate the practices in Delhi sustainably.

To ensure sustainable groundwater management by 2040, it is crucial to implement comprehensive collaborative and flexible long-term monitoring and data-gathering systems. Key approaches include installing smart meters and sensors strategically using geospatial technologies and GIS to monitor changes in groundwater levels and land subsidence and regularly assessing groundwater data to identify trends and potential issues. Regular public reports on groundwater status can foster trust and encourage stakeholder engagement. Local people and farmers can also help monitor, as seen in North

Gujarat, India, where citizen scientists improved accuracy. To manage groundwater resources efficiently, standardized procedures, collaborative frameworks, and modern technologies should be used. Implementing these recommendations for long-term groundwater sustainability post-2040 requires continuous monitoring of data integration, advanced analytics, policy development, community engagement and ongoing research.

5. Conclusion

This study uses regression analysis to make predictions about future groundwater levels up to 2040 based on changes in Delhi's groundwater levels from 2001 to 2020. The results show that groundwater levels are steadily falling. This is because of fast urbanization, too much pumping and not enough recharge. Predictive modelling shows that the level of groundwater will continue to drop, which makes it even more important to find good ways to handle this resource right away. Implementing sustainable practices, including enhancing urban planning and increasing public awareness, is a critical step in addressing the groundwater crisis and ensuring a secure water future for Delhi. In comparison to prior research, the findings of our study corroborate the broader trend of groundwater depletion observed in other urban areas globally. For instance, the study by [34] on the projected climate-driven changes of water table depth in major global basins similarly highlights the vulnerability of urban aquifers to both climatic and anthropogenic pressures. Similarly, [35, 36] observed in the Murray–Darling Basin that groundwater levels have been declining due to both natural and human-induced factors aligning with the trends identified in Delhi.

Further, our study's findings resonate with those who investigated the influence of urbanization on groundwater chemistry in the Lanzhou Valley Basin in China. They found that urban expansion and associated activities significantly altered groundwater levels and quality, paralleling the impacts of urbanization in Delhi. Groundwater depletion has emerged as a significant issue everywhere, and many [37-39] have stressed the need for improved data analyses to understand the trends in groundwater. This is in line with our regression analysis approach, which seeks to make sense of fluctuations in groundwater levels. Some aspects of this study also point to a dire requirement of present-day Delhi to adopt a paradigm shift in the way groundwater resources are managed. The situation in regard to the provision of water supply is hardly any better, even in the larger `meta" cities, especially those countries which have gone through rapid industrialization.

Theoretically, sustained supersaturation of groundwater is feasible even when there is a rapid population increase, but this is not likely to happen in practice owing to the rapid growth of cities and industrial hubs. Urbanization increases risks that may undermine levels of groundwater. Without achieving these targets, it will be impossible to ensure groundwater security in cities. This underscores the incredible significance of this study in relation to the need for prompt and affirmative action-oriented policies and practices relevant to water supply management. Sustainable practices, including adopting water-efficient technologies and enforcing strict regulations on groundwater extraction, are essential to prevent further environmental degradation. Moreover, initiatives aimed at artificial recharge, such as rainwater harvesting and the construction of recharge wells, should be prioritized to replenish the city's aquifers. Effective groundwater management will not only mitigate the risk of water scarcity but also support Delhi's long-term urban growth and the well-being of its inhabitants. These comparative analyses point out the broader applicability of our findings and the necessity of integrated and region-specific approaches to groundwater management. While our study focuses on Delhi, the patterns observed are reflective of global challenges reinforcing the imperative for targeted interventions in urban water resource management.

5.1. Scope for Further Research

While this study provides a comprehensive analysis of groundwater variations in Delhi, there are several areas where further research is warranted. Future studies could explore the impact of specific urban planning and policies on groundwater levels and assess the effectiveness of different artificial recharge techniques. And investigate the role of climate change in exacerbating groundwater depletion.

Additionally, research that focuses on the social and economic dimensions of groundwater management, such as the cost-benefit analysis of sustainable practices and the role of community engagement, would contribute to a more holistic understanding of the issue.

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