URBAN GROUNDWATER DYNAMICS: A CASE STUDY OF A NEIGHBOURHOOD IN VISAKHAPATNAM CITY

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Abstract

This study examines the complex dynamics of groundwater management in the rapidly urbanising MVP Colony of Visakhapatnam, India. In spite of the region's substantial yearly precipitation and favourable geographical characteristics, there is a discernible decline in groundwater levels. The study utilises data gathered between the years 2001 and 2022, encompassing records of precipitation and measurements of groundwater table levels. By utilising Karl Pearson's coefficient, an examination revealed a modest inverse association between the annual precipitation and the depth of the groundwater table. This suggests that factors other than rainfall play a role in influencing the levels of groundwater. The findings of a household questionnaire survey indicate that the insufficiency of maintenance practises pertaining to rainwater harvesting (RWH) systems, coupled with rapid urbanisation, emerged as significant factors contributing to the depletion. The initial interventions implemented by the government to promote rainwater harvesting (RWH) demonstrated short-term enhancements. However, the effectiveness of these measures was hindered by challenges related to maintenance and increased urban growth, thereby negating the positive outcomes achieved. This study shows the importance of adopting regulations for the harvesting of rainwater, providing community education, regulating groundwater extraction, taking into consideration the aspects that go into urban design. These solutions, when combined, make it easier to promote sustainable groundwater management, which in turn helps to ensure that sufficient amounts of this resource will continue to be accessible to both current and future generations, despite the fact that urbanisation and climate change are both on the rise.

Keywords: Groundwater depletion, Population growth, Precipitation, Rainwater harvesting, Urbanization, Water Scarcity.

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INTRODUCTION

Cities have existed for several hundred years. These densely populated areas resulted in the development of diverse roles and the distribution of labour among the population. The term "urbanisation" refers to the process through which a greater proportion of the world's population now lives in urban regions, which occurred concurrently with the expansion of the number of urban centres (Neiderud, 2015). The onset of the Industrial Revolution signified a notable increase in patterns of urbanisation. The advent of this technological transition resulted in the concentration of large numbers of workers and their families inside urban areas, ultimately leading to a predominantly urban-based contemporary lifestyle for a significant proportion of the world's population. Throughout the course of the 20th century and into the 21st century, the gradual advancement of the economy and the subsequent increase in population led to the development of megalopolises. These megalopolises are characterised by their extensive urban conglomerates that spread over significant geographical areas (Henning Nuissl., 2019)

In emerging economies, the development of urban centres and their accompanying infrastructure has led to a significant migration of individuals from rural areas. Throughout history, a significant number of these settlements were strategically situated in close proximity to natural water bodies such as rivers and lakes, resulting in the development of enduring and settled populations (Neiderud, 2015). Three fundamental infrastructural amenities for urban areas encompass potable water provision, solid waste management, and wastewater collection systems. Large metropolitan areas often face groundwater depletion due to excessive extraction, necessitating the import of water for both residential and industrial purposes from adjacent catchment areas (Paulami sahu., 2023).

The importance of groundwater for the urban inhabitants in developing nations cannot be overstated. The water table is the theoretical elevation of groundwater in an open well/ tube well, where it is located within the pore spaces of the saturated zone and unaffected by external pressures. The vertical measurement from the surface of the Earth to the water table is commonly referred to as the water level (Paulami sahu., 2023). Globally, groundwater meets about half of domestic water needs (Aadhityaa Mohanavelu, 2020)

Urban areas must provide water to meet the diverse requirements of individual, communal, industrial, and commercial consumers (Hemant Balwant Wakode, 2018). Financial and geographical constraints play a pivotal role in influencing urban water scarcity. Urban centres, hampered by a lack of synergy among key stakeholders and restricted financial resources, find challenges in implementing expansive water supply projects. Given these challenges, groundwater often emerges as a feasible alternative, prompting residents in these cities to rely on ground water-wells to meet some or all of their water needs. This inclination towards groundwater utilization is increasingly evident in burgeoning cities worldwide, attributable to factors such as rapid population growth, swift urban expansion, elevated per-capita water consumption, high local temperatures, and diminished reliance on surface water sources due to contamination concerns (Aadhityaa Mohanavelu, 2020)

Notable adaptations to the groundwater system involve alterations in the level of the water table, considerable changes in the permeability field due to development and the installation of utility services, and adjustments to groundwater recharge. The phenomenon of urbanisation leads to a reduction in the process of groundwater recharge, primarily due to the concurrent increase in impermeable surfaces. The continuous extraction of groundwater has the capacity to cause a decline in water tables, resulting in negative outcomes such as the entry of saltwater, land subsidence, and the deterioration of ecosystems that depend on groundwater, such as springs (Sharp, 2010)

Water scarcity is a multifaceted issue influenced by numerous sources; however, a prominent underlying reason can be attributed to the phenomenon of rapid population expansion. With the growth of the population, there will be a corresponding rise in the proportion of those lacking access to potable water. The regions currently afflicted by the most severe instances of water stress are also witnessing the most pronounced rates of population expansion (Deborah.Bensen, 2022). India holds the distinction of being the greatest consumer of groundwater globally. The utilisation of approximately 230 cubic kilometres of groundwater annually accounts for more than 25% of the worldwide aggregate. Aquifers in densely inhabited and economically prosperous regions are experiencing depletion. The phenomenon of climate change is anticipated to exacerbate the already existing pressures on groundwater resources. (Janakiraman, 2022).

STUDY AREA

Geographical and Climatic Overview:

Located in the northern coastal region of Andhra Pradesh, Visakhapatnam district is nestled between the Eastern Ghats and the Bay of Bengal. The region's climate is characterized as tropical sub-humid, featuring moderate to severe summers and notable seasonal precipitation (Rajasekhar Mopuri, 2020). The district receives an average annual rainfall of approximately 1,116 mm. Precipitation is minimal in January, while October is the most precipitation-heavy month, averaging 207.5 mm. In terms of groundwater resources, the district's aquifers are primarily divided into two categories: hard rock formations, such as Khond alites, charnockites, and granitic gneisses, and softer sedimentary formations like sandstones and alluvium (vidyadhar, 2013).

MVP Colony – A Focal Point of the study

The study narrows its focus to MVP Colony within Visakhapatnam city, covering an area of about 2.67 square kilometres. This colony houses approximately 78,000 inhabitants (MVP Colony, 2020).

MVP Colony, a prominent sector within Visakhapatnam, has been facing significant concerns regarding groundwater depletion. This situation has been shaped by a confluence of factors such as rapid urbanization, population growth, and changing climatic conditions. The expansion of area in the MVP colony, characterized by an influx of concrete structures, diminishes the ground's natural ability to recharge aquifers. This is due to the reduction of permeable surfaces that allow rainwater to seep into the ground. With MVP Colony's growing population, there's an escalated demand for water, leading to over-exploitation of available groundwater resources. This demand often translates to deeper borewells and over-extraction. The adoption of rainwater harvesting remains inconsistent across the colony. Erratic rainfall patterns and occasional drought conditions impact the natural replenishment of groundwater. A few years of deficient rainfall can significantly strain the groundwater levels, making recovery challenging. Being a coastal city, Visakhapatnam, and by extension MVP Colony is just abutting the Bay of Bengal, the study area is vulnerable to saline water intrusion, especially if groundwater is over-extracted. This reduces the potability and usability of the water, making it unsuitable for most domestic and agricultural purposes. A general lack of awareness about the consequences of over-extraction, combined with limited community engagement in conservation efforts, exacerbates the depletion problem. Given the vital importance of groundwater as a primary resource for both domestic and commercial activities in MVP Colony, there's a pressing need to investigate its dynamics. This understanding will pave the way for sustainable water management practices and inform decision-making processes at both community and administrative levels (P.Satyanarayana, 2013).

MATERIALS AND METHODS

Data Collection on Groundwater and Rainfall:

Groundwater table data for Visakhapatnam from 2001 to 2022 was obtained from the Ground Water Department of Visakhapatnam. Simultaneously, monthly rainfall records for the identical time frame were sourced from the official website of the India Water Resources Information System. The collated data provided the foundation for examining the correlation between yearly rainfall and groundwater levels.

Preliminary Survey and Questionnaire Refinement:

Initially, a preliminary survey was carried out in the study area utilizing a draft questionnaire to assess the real-world conditions. Feedback from this initial phase led to the refinement of the questionnaire, which was then employed in a comprehensive study of 250 randomly selected households. Information was collected directly from the inhabitants of these selected dwellings, irrespective of whether they lived in individual houses or apartment complexes.

Comprehensive Household Survey in MVP Colony:

Subsequently, a meticulously designed household survey was developed, with data gathered from households in MVP colony. This encompassed information on the number of households with tube wells, their depths, the households dependent on groundwater, and the availability of rainwater harvesting facilities. The aim is to understand the intricate links between three key factors: rainfall patterns, dependence on groundwater, and the potential for groundwater overuse and exploitation.

Using Karl Pearson's Coefficient Technique to Study the Correlation between Annual Rainfall and Groundwater Table Depth. Karl Pearson's coefficient of correlation, commonly referred to as Pearson's r, is a statistical measure that provides the strength and direction of the linear relationship between two quantitative variables. In the context of the MVP Colony's groundwater study, this technique can be instrumental in determining how annual rainfall influences the depth of the groundwater table.

RESULTS

Interpreting the Relationship Between Annual Rainfall and Groundwater Table Depth Using Karl Pearson's Coefficient

Data Collection

- Rainfall Data: Acquire annual rainfall data, ideally spanning several years to get a robust dataset.

Groundwater Table Depth: Measure the groundwater table depth at regular intervals throughout the same years.

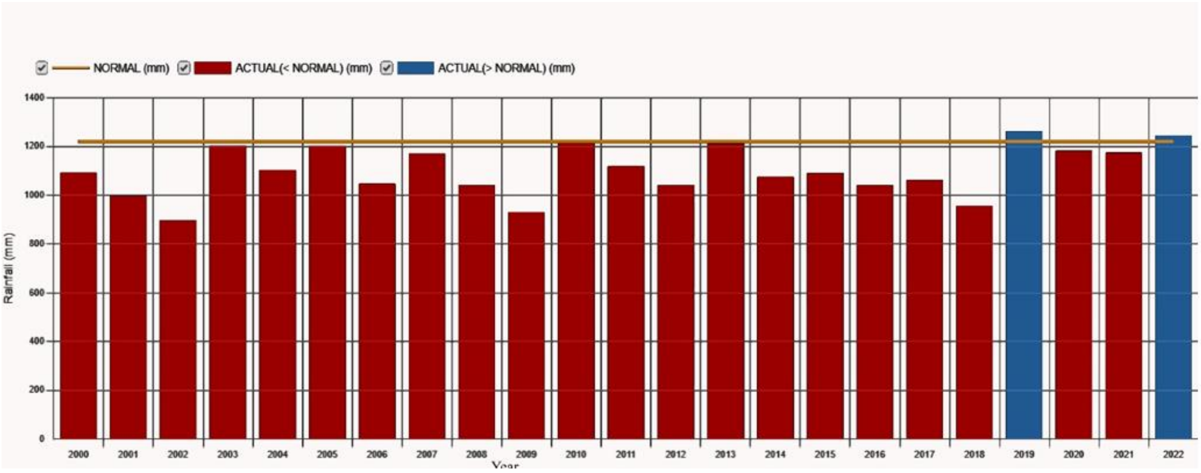

Fig 1: Annual Rainfall Data (2000-2022)
Source: (APWRIMS, 2023)

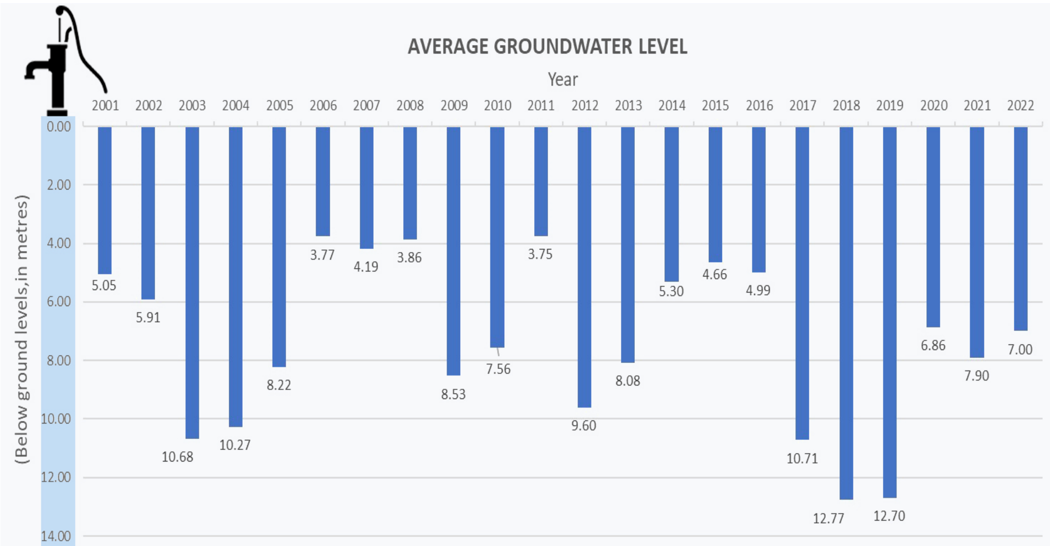

Fig 2: Annual Groundwater Table (in meters) in MVP Colony during (2001-2022)
Source: Ground Water Department, Visakhapatnam

Application of Pearson's Coefficient Formula

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

Where:

x and y are the two variables (in this case, annual rainfall and groundwater table depth, respectively).

n is the number of data points.

Interpretation of the Results:

- r = 1: Perfect positive correlation. This would mean as rainfall increases, the groundwater table depth also increases, which would be a counterintuitive result suggesting other significant influences on the groundwater table.

- r = -1: Perfect negative correlation. This would imply that as rainfall increases, the groundwater table rises (i.e., depth decreases), which is the expected natura result.

- r = 0: No correlation. This would indicate that rainfall does not have a discernible impact on the ground water table depth in the studied area.

Values between 0 and 1 or 0 and -1 indicate varying strengths of positive or negative correlations, respectively.

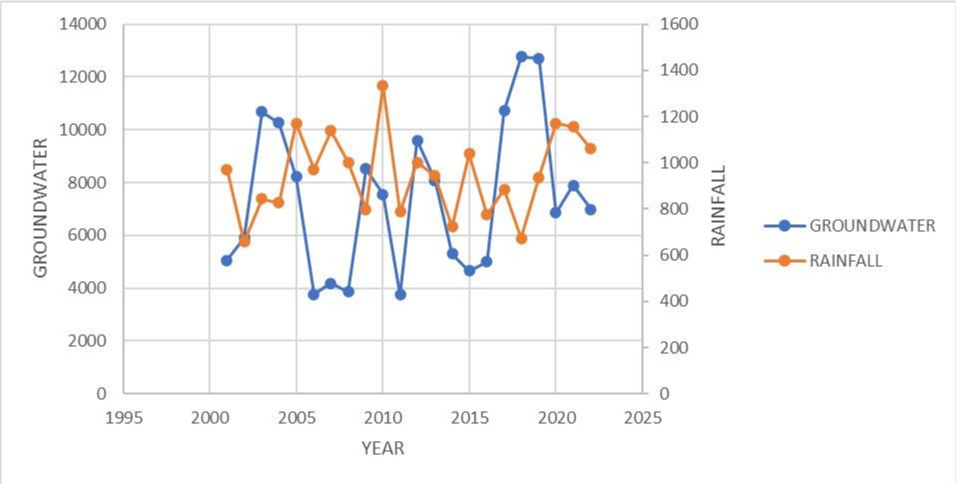

Fig 3: Correlation between Annual Rainfall and Groundwater Table in the study area using Karl Pearson's coefficient technique

Upon applying Karl Pearson's coefficient technique to the collected data, a correlation coefficient (r) value of -0.14911 was determined see Fig.3.

Interpretation:
Correlation Strength: The value of -0.14911, while negative, is closer to 0, indicating a weak negative correlation between annual rainfall and groundwater table depth.

Directional Relationship: The negative sign of the coefficient indicates that with an increase in annual rainfall, there is a decline in the groundwater table depth. However, the strength of this correlation is weak.

Implications:
Groundwater Depletion: Despite the weak correlation, the negative relationship does suggest that other factors are at play which contribute to the declining groundwater table, even when there's an increase in rainfall. A prominent suspect in this scenario is the over-exploitation of groundwater. The overuse of groundwater resources by residents can have a significant impact on the natural recharge rate.

External Influences: The weak correlation hints at other factors, apart from rainfall, that may be influencing the groundwater levels, such as land use changes, urbanization, and ineffective rainwater harvesting systems.

Findings from the ground water table and questionnaire survey
2009 Data- Despite a surge in the monthly mean rainfall surpassing 200mm, the groundwater depth was observed to have plummeted to 10 meters, suggesting other overriding factors impacting the groundwater table.

State Government's Intervention (2014)- Following the government's push for rainwater harvesting systems in residences in 2014, there was a noticeable improvement in groundwater levels. During the post-monsoon periods of 2014-16, the groundwater depth improved significantly, rising closer to the surface by 2 meters. This indicates the immediate effectiveness of the RWH systems.

Post-2016 Scenario- However, subsequent years saw a regression in groundwater levels. Specifically: In 2017, the groundwater depth ranged between 8m (minimum) and 14m (maximum). In 2018, the depths further varied between 8m and 17m. Interestingly, there appears to be an inconsistency in the provided data for 2018, as two different depth ranges are mentioned.

Factors Impacting Groundwater Levels Post-2016 Maintenance of RWH Systems- The data acquired from the household questionnaire surveys point to inadequate maintenance of the RWH pits as a primary reason for the decline in groundwater levels.

Urbanization and Infrastructure Development: An uptick in concrete surfaces, due to population growth and infrastructure enhancement, has likely inhibited the natural recharge of groundwater, despite the region receiving ample rainfall.

Further, the questionnaire survey data shows 72% of the residences from the survey are dependent on both municipal and groundwater for their daily water requirements. Further, 30% respondents utilize groundwater for 50-75%, and 45% respondents utilize groundwater for 75-100% of their daily water requirements. The survey data shows that few residents in had to reach up to the depth of 400 feet whereas the majority of the residents have tube wells within the range of 100-200 feet deep. The data shows that 85% of the households surveyed have tube wells. Out of which 20% households had to increase the depth of their tube wells than the initial depth in recent years, majorly up to 100-150 feet. Out of the 250 households surveyed, only 42% installed RWH pits. It's noteworthy that among the 20% households that deepened their tube wells, 58% had RWH pits. A concerning revelation from the survey is that none of the RWH pits were being maintained appropriately, indicating a potential loss in the efficiency of these systems.

CONCLUSION AND SUGGESTIONS

The comprehensive study undertaken in the MVP Colony of Visakhapatnam, set against the backdrop of rapid urbanization paints a complex picture of groundwater management. Despite Visakhapatnam's geographical privilege of being nestled between the Eastern Ghats and the Bay of Bengal and receiving substantial rainfall annually, the groundwater levels in MVP Colony are experiencing a downward trend. While there's a weak negative correlation between rainfall and groundwater table depth, suggesting that increased rainfall should naturally lead to higher groundwater levels, the reality is less straightforward. Numerous factors contribute to this anomaly, with the overarching theme being human intervention. Urban sprawl, evidenced by the rapid surge in concrete structures, diminishes the soil's innate capacity to recharge aquifers. The rising population's ever-growing thirst compounds this issue, with the data revealing that a significant proportion of households are heavily reliant on groundwater, sometimes tapping into depths of up to 400 feet. The state government's intervention in 2014, advocating for rainwater harvesting, initially yielded positive results with the groundwater table showing signs of recovery. However, this momentum was short-lived. The subsequent decline in groundwater levels post-2016 can be attributed to the dual culprits of inadequate maintenance of RWH systems and uncontrolled urban infrastructure development. The findings from the household survey, where a significant number of households deepened their tube wells and many RWH pits fell into disrepair due to neglect, reaffirm this observation. In conclusion, rainwater harvesting regulations are essential to sustainable water resource management. We can conserve groundwater by encouraging rainwater harvesting pit adoption and maintaining them through inspections and community engagement. Penalties for non-compliance could improve these regulations. However, genuine transformation takes awareness and knowledge. Community education programmes will help people understand groundwater preservation and rainfall collection. Community participation in monitoring and maintenance projects encourages community accountability.

Extractions must be strictly controlled for prudent groundwater management. Monitoring systems and extraction licences or limitations, especially for deeper tube wells, can reduce depletion. The relationship between urban development and groundwater recharge is important. Permeable surfaces and recharge zones in urban development can improve groundwater replenishment and human expansion. Continuous research and monitoring are essential. The complex relationship between rainfall, groundwater levels, land use changes, urbanisation, and climatic patterns needs ongoing study. Our water conservation efforts are adaptable and effective when policies and methods are updated based on research. Regulation, education, community engagement, and adaptive management will preserve groundwater for future generations.

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