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# Recharge Response Mapping of Urban Aquifer – A Regional Case Study in Chennai City

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## ABSTRACT

Safeguarding and preserving groundwater is a significant challenge for the Earth. Over the years, due to urbanization, there has been a tremendous increase in the exploitation of groundwater resources. Aquifers are being overexploited, and to ensure sustainable water use, appropriate planning and management of water resources are required. Artificial Groundwater Recharge from rainwater, i.e., Rainwater Harvesting (RWH), is an important water management technique. It would provide more information regarding the RWH situation. The objective of the research was to develop a methodology for evaluating the effect of RWH on the urban aquifer in Chennai, considering recharge response mapping. RWH mapping is performed using cross-correlation and GIS. The estimation of the cross-correlation coefficients for the observation wells is noteworthy, with due regard to determining the depth of the corresponding rainfall and water table across varying possible time lags. The correlation coefficients are determined with respect to the recharge response zones in the entire region, which are classified as high, moderate, low, and poor. In most places in the coastal watershed, RWH responses are good, while in dense urban and suburban areas, responses are moderate to poor. This methodology will be adaptable to any aquifer in developing countries. Overall, the study emphasizes the importance of implementing temporal and spatial models in groundwater and urban water resource management. By emphasizing the potential and limitations of recharge response mapping using cross-correlation, the present work establishes a foundation for more inclusive studies that could significantly support effective and sustainable groundwater resource management.

***Keywords****: Rainwater Harvesting, Groundwater, Recharge Response mapping, Urban aquifer, GIS*

## 1. INTRODUCTION

Groundwater, which is present at subsurface levels, is said to be stored in the pore spaces and fractures present underneath the Earth's surface. The establishment of the SDGs has emphasised the policy to confirm: "Ensure availability and sustainable management of water and sanitation for all." To sustain freshwater ecosystems, it is necessary to improve their recharge potential [1,2]. Aquifers are under increased pressure due to extensive Land Use Land Cover (LULC) changes, climate change, and over-exploitation of groundwater [3,4]. A proper understanding of groundwater dynamics and recharge potential is necessary to support sustainable groundwater management [5]. Depleted groundwater aquifers must be artificially recharged to improve groundwater conditions. Artificial recharge (AR) techniques utilising

rainwater, referred to as 'Rainwater Harvesting', involve tapping rainwater where it falls and has been utilised in numerous tropical countries in recent times [6,7].

A variety of techniques are used in both rural and urban areas worldwide to assess the groundwater potential [8]. To evaluate the impact of RWH on groundwater potential, a comprehensive methodology must be developed. The Ground Water Resource Estimation Committee (GWREC 2009), a group of experts, has formulated guidelines for recharge estimation using a water-balance approach. Essentially, the methodology employs a lumped-parameter approach [9].

Groundwater recharge may be examined using methods such as the Water table fluctuation (WTF) methodology, Darcian method, Water budget technique, Soil water balance methodology based on rainfall infiltration factor, and Tracer techniques [10]. To better manage groundwater, the WTF methodology is adopted for recharge assessment studies [11]. Whereas the Water balance method is adopted for rainfall assessment, base flow techniques are used for subsurface flow estimation, and Transfer Function Noise (TFN) models are used for recharge estimation [12,13]. Rainfall has an immediate impact on groundwater levels, especially during the monsoon season, when groundwater depletion is minimal [14].

The main aim of this study is to develop a methodology to assess the impact of rainwater harvesting on urban aquifer recharge in Chennai using cross-correlation analysis integrated with GIS. The objectives of the study are to establish the relationship between rainfall and groundwater-level fluctuation patterns over time, to identify recharge response zones, and to create spatial recharge response maps. An unsaturated zone can be defined by an increase in water levels at a specific region. There must be a relationship between rainfall and rising water levels in each area. The water-level rise and rainfall may not align (simple correlation) properly, as there is a time lag due to the travel time of recharged water to influence the water table in the aquifer. So, if a few steps lag the water level data, the match with rainfall may be better. Therefore, employing the cross-correlation technique to generate recharge-response zonation maps was one of the specific goals.

This study presents a systematic approach to investigate the effectiveness of RWH on urban aquifer recharge in Chennai using a cross-correlation analysis technique integrated with GIS. It basically identifies the temporal lag responses between rainfall and groundwater levels to delineate the aquifer recharge response zones. The research provides a spatial framework for sustainable groundwater management, thereby supporting effective artificial recharge planning in an urban environment.

The present work comprises five parts. Section 1 covers the background, need for study, and objectives. The review of the relevant studies is discussed in Section 2. The study area, methods adopted in the study, and methodology of the current work are presented in Section 3. The results and discussion have been provided in Section 4. The conclusions are presented in the last section.

## 2. LITERATURE REVIEW

The current section seeks to identify works on RWH, groundwater recharge, GIS-based assessment, and time-series/cross-correlation analyses within the relevant research domains. [15] carried out a city-wide estimation of groundwater recharge using temporal and spatial

measurements of groundwater levels, which extends the importance of RWH schemes in aquifer recharge in urban areas.

GIS-based recharge potential studies at the watershed scale demonstrated the influence of slope, soil, LULC, and drainage. Delineating groundwater recharge zones in identifying recharge hotspots is important for better artificial recharge planning [16,17,18]. [19] provided a comprehensive review of global water harvesting and groundwater recharge practices, highlighting the importance of integrating RWH with groundwater management strategies. Urban groundwater recharge reviews highlight how RWH, AR, and Geospatial analysis are central to sustainable water management under urbanization pressures. Engineered and nature-based recharge approaches underscore the practical diversity of recharge measures [20]. It emphasizes the broader applicability of RWH in urban water security frameworks, including conceptual indicators and policy implications [21,22]. [23] assessed managed aquifer recharge via rooftop RWH in peri-urban Ghana, demonstrating significant groundwater level increases in wells due to AR. [24] employed historical groundwater data and cross-correlation analysis to characterize recharge events, illustrating the utility of temporal correlation techniques for recharge assessment. [25,26] investigated how rainfall influences, distribution and extreme events affect recharge dynamics to understand the aquifer responses.

These studies reveal that RWH contributes significantly to urban aquifer recharge and groundwater sustainability when combined with GIS-based delineation of recharge potential zones. Spatio-temporal analysis methods are increasingly used to quantify rainfall-groundwater relationships, offering insight into lag times and recharge dynamics that can improve planning and management. These studies emphasise the integration of remote sensing, geospatial analysis, multi-criteria decision support, and temporal data analysis to optimize artificial recharge interventions and to support sustainable groundwater resource management.

## 3. METHODS

### 3.1 Study Area

Northeastern Tamil Nadu is home to Chennai, India's fourth major metropolis, its geographical coordinates are 13º 04′ N latitude and 80º 17′ E longitude. Chennai covers an area of 174 $Km^2$[9].

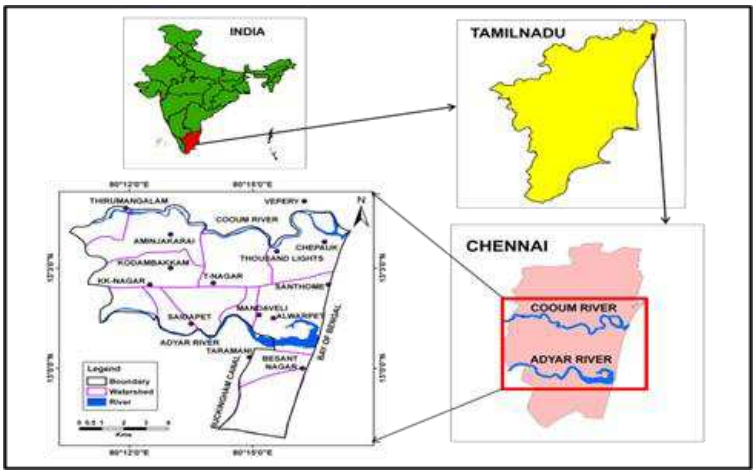



Figure 1. Study Area Location

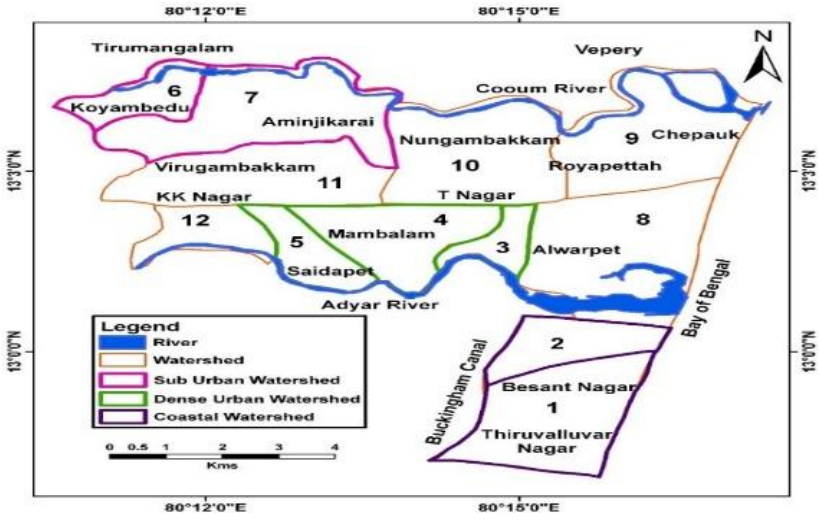



Figure 2. Hydrological Watershed Distribution in Chennai

The Cooum and Adyar rivers flow through Chennai city (Figure 1). Study area is spread over 75.45 km$^2$, consisting of 12 sub-watersheds. The classification of the study area occurs into three distinct watershed groups based on the density of population and soil condition viz. a. Coastal urban b. Dense urban and c. Less dense sub-urban watersheds as shown in Figure 2. This categorization is useful to compare the relative performance of RWH in various regions.

### 3.2 Data Collection

Secondary data are collected from India Meteorological Department (IMD) records, Central Groundwater Board (CGWB) records, Tamilnadu Water Supply and Drainage Board (TWAD), and Metro water publications and internet sites. For continuous monitoring of water levels throughout the study area, 19 observation wells maintained by CGWB are considered for the study. For analysis, daily rainfall data from the Nungambakkam rain gauge station placed in study area is collected for the period 2010 to 2023. To ensure continuous and reliable monitoring of groundwater fluctuations across the study area, data from 19 observation wells maintained by the Central Ground Water Board (CGWB) were utilized. These wells are strategically distributed and provide long-term groundwater level records, enabling accurate assessment of spatial and temporal variations in the water table. The use of CGWB observation wells enhances the credibility and consistency of groundwater analysis throughout the study period.

### 3.3 Methodology

Delineation of recharged response zones is vital in groundwater resource studies. Hydrogeological, geophysical, and geomorphological maps are utilised to prepare AR zones. The potential areas for AR were identified by integrating different thematic maps in GIS. For the identification of the possible sites for AR, many researchers followed the various tools available in GIS. A model was developed by [27] using the Soil Conservation Service Curve Number (SCS-CN), and Remote Sensing Data integrated with GIS; the potential zones for AR were identified. Using Shuttle Radar Topography Mission (SRTM) data, [28] modified the study and identified recharge areas using the above-mentioned product and applied the MCDM (Multiple Criteria Decision Making) technique with GIS, whereas [29] used Digital Elevation Model (DEM) data and GIS. With the combination of several thematic layers such as soil, slope, land use, geomorphology, drainage coverage, and contour density into a Geospatial environment, the possible zones were determined by assigning weights. Suitable sites were identified, and potential zone mapping using GIS was carried out by [30,31]. A criteria

decision analysis approach was used to find appropriate locations for RWH facilities (like contour bunds, check dams, as well as farm ponds) to satisfy irrigation demand. By utilising RS and GIS approaches, the best site, or AR, was found.

The model included several factors, including LULC, slope, stream order, soil aspect, hydrology, and other parameters [32,33]. [34] examined various recharge estimation techniques, including a recession curve displacement approach, graphical separation, hydrograph analyses, WTF, the online GIS-based automated hydrological analysis tool and empirical formulas. [7] demonstrated that, in comparison to other traditional methods, the utilization of GIS, remote sensing, as well as Multiple Criteria Decision Analysis (MCDA) technologies is promising and effectively identifies the appropriate places for groundwater recharging. GIS-based Analytic Hierarchy Process (AHP) techniques were applied by many researchers [35,36,37] using a variety of decision-making techniques, for example the AHP, Fuzzy Logic (FL), as well as Frequency Ratio (FR), to define Artificial Groundwater Recharge Zones (AGRZs). [38,39,40] also adopted statistical analysis methods, model studies, and AHP for the identification of possible zones for AR.

Since most of the methods are time-consuming, the cross-correlation methodology is used to analyze the recharge response of unconfined aquifers for the various rainfall events. Based on variations in the coefficient of correlation, the entire region is divided into several zones of response. The cross-correlation method is utilized by several investigators [41,42] for the identification of the groundwater recharge potential zones. A combination of GIS and cross correlation gives a spatial distribution of recharge response, known as Recharge Response mapping**.** Daily rainfall data (p), gathered from IMD for the entire study period along with monthly groundwater level data (d) of observation well from CGWB are used in this analysis. From the daily rainfall data, monthly rainfall and the average/mean rainfall for the entire season are calculated. In the same way, average/mean groundwater level for the entire period is calculated. Using this, the deviation from the mean as well as the standard deviation of monthly rainfall data and monthly groundwater level data can be calculated. Cross-correlation coefficient (r) among p and d is calculated using Equation (1).

$$r = \frac{PD}{n\sigma_p\sigma_d} \qquad \text{----------Equation 1}$$

Where

$D$ = Deviation of groundwater level from the mean
$P$ = Deviation of rainfall from the mean p (=p – $p^{'}$),
$d$ (= $d$–$d'$),
$\sigma_d$ = Standard deviation of $d$-series
$\sigma_p$ = Standard deviation of p-series and
$n$ is the number of rainfall-related depth-to-water level datasets.

A detailed methodology has been framed to prepare the recharge response zonation maps using cross correlation technique in a GIS environment is shown in Figure 3. There are temporal and regional variations in the correlation coefficient between these two factors. Rainfall during the north-east and south-west monsoon seasons causes a notable increase in water level. The water table's reaction to the rainfall events is delayed by one or two months when plotting water-level hydrographs with rainfall data. With a time-lag of 0, 1, 2, 3, and 4 months, an effort is thus made to connect the water-level variation from June to December. Cross-correlation coefficient values for various possible time lags are estimated and the graphs are plotted. From this, interpretation can be made by selecting the higher cross correlation coefficient which demonstrates the recharge response pattern and the time response of recharge. Using the maximum cross-correlation coefficient values of different wells and their location in the GIS

environment, a recharge response map is prepared. A greater correlation coefficient indicates a high response to groundwater recharge. Lesser values imply moderate, less, and poor response zones. The results are spatially represented in a GIS environment.

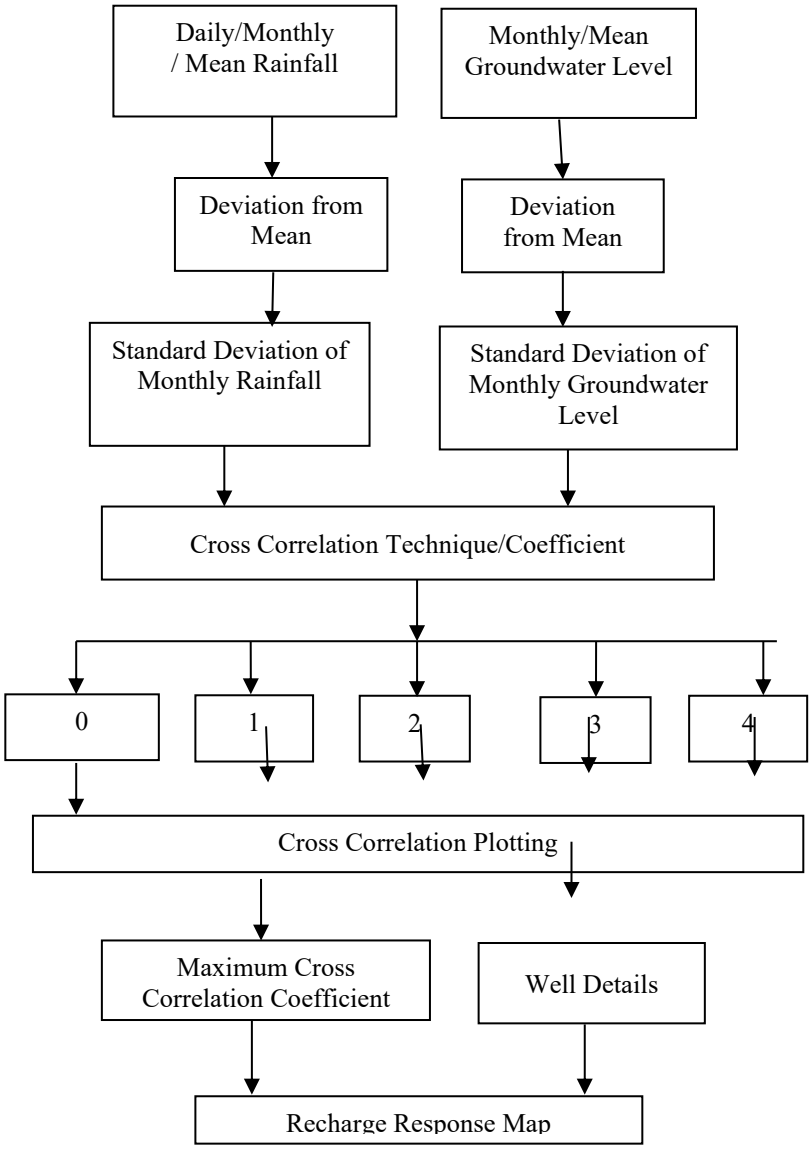



Figure 3. Flow chart for recharge response mapping

## 4. RESULTS

Significant groundwater potential improvement will be obtained if more rainwater penetrates the stratum and reaches the aquifer. To enhance the recharge, the structures should be provided at appropriate locations. This can be achieved by knowing the response of topography towards groundwater recharge, which will be known by delineating the recharge response zones. The recharge response coefficient is calculated from the cross-correlation technique. Attempts are made to account for spatial variability of rainfall by including IMD data from Meenambakkam station. But it could not be used as its influential Thiessen polygon accounts for only 4 % of the entire study area. Additionally, 19 observation wells provide monthly groundwater level data for cross correlation analysis. Following one or two months of rainfall, there is a correlation between the study area's unconfined aquifer's water level and rainfall response.

Using the formula for different potential time lags, the cross-correlation coefficients among the water table depth and related rainfall are computed for each of the 19 wells. The following Table.1 demonstrates the cross-correlation coefficient values from June to December (Southwest and Northeast monsoons) with corresponding time lags.

Table 1. Cross correlation values for sample wells with a different time lag

| Sl. No. | Well locations | Zero-month lag | One month lag | Two months lag | Three months lag | Four months lag |
|---|---|---|---|---|---|---|
| 1 | T. Nagar | 0.14 | 0.27 | 0.35 | 0.31 | 0.28 |
| 2 | Besant Nagar | 0.05 | 0.53 | 0.38 | 0.32 | 0.19 |
| 3 | Aminjakarai | 0.14 | 0.37 | 0.44 | 0.35 | 0.24 |
| 4 | Tirumangalam | 0.17 | 0.36 | 0.48 | 0.28 | 0.15 |
| 5 | Anna Nagar west | 0.03 | 0.29 | 0.34 | 0.24 | 0.13 |
| 6 | Koyembedu | 0.13 | 0.31 | 0.32 | 0.20 | 0.07 |
| 7 | Arumbakkam | 0.11 | 0.30 | 0.38 | 0.26 | 0.12 |
| 8 | Chinmaya Nagar | 0.00 | 0.25 | 0.22 | 0.14 | 0.05 |
| 9 | Virugambakkam | 0.09 | 0.43 | 0.38 | 0.30 | 0.15 |
| 10 | KK-Nagar | 0.15 | 0.44 | 0.43 | 0.32 | 0.19 |
| 11 | Mambalam | 0.13 | 0.35 | 0.43 | 0.27 | 0.13 |
| 12 | Saidapet | 0.12 | 0.48 | 0.42 | 0.33 | 0.21 |
| 13 | Nungambakkam | 0.13 | 0.45 | 0.44 | 0.33 | 0.18 |
| 14 | Royapettah | 0.18 | 0.51 | 0.39 | 0.43 | 0.25 |
| 15 | Alwarpet | 0.25 | 0.52 | 0.41 | 0.24 | 0.11 |
| 16 | Chepauk | 0.23 | 0.48 | 0.36 | 0.18 | 0.03 |
| 17 | Chetpat | 0.14 | 0.33 | 0.32 | 0.30 | 0.26 |
| 18 | Vepery | 0.15 | 0.40 | 0.37 | 0.20 | 0.10 |
| 19 | Thiruvalluvar Nagar | 0.14 | 0.51 | 0.47 | 0.37 | 0.20 |

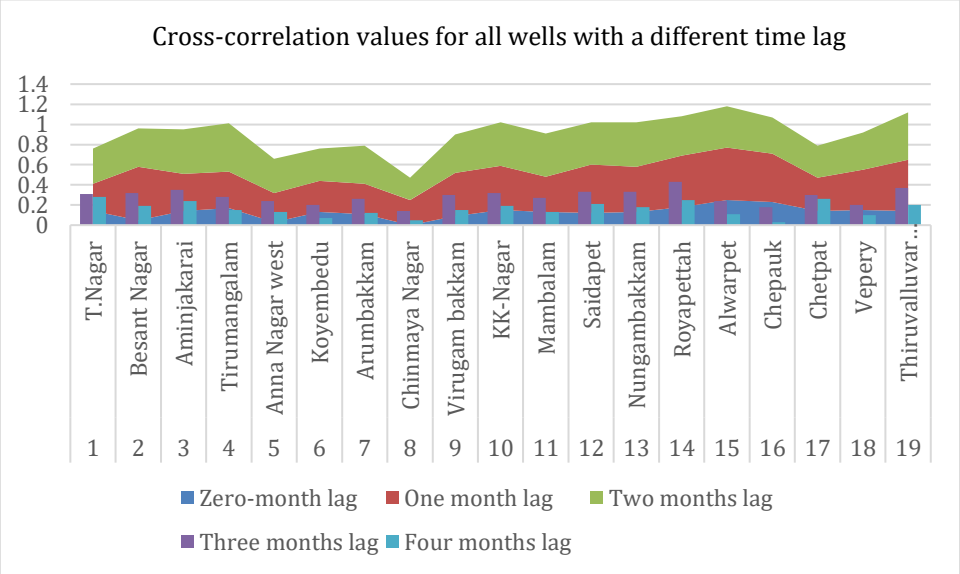



Figure 4. Cross correlation values sample wells with a different time lag

Cross correlation values between all wells at different time lags also assist in understanding the coherence of well signals over time, as shown in Figure 4. One signal being shifted relative to another, the correlation at each lag indicates whether the wells have delayed or fore-shifted responses to the same guiding factors (such as pumping, recharge, or geological connections). High positive correlations at one lag identify a strong relationship with a delay in time, while low or negative values designate weak or opposing relationships. This analysis supports the identification of hydraulic connections, aquifer response times, and the effects of well interaction. Figure 4 shows the cross-correlation values of sample wells for different time lags (from 0 to 4 months).

At zero-month lag, the correlations between most wells are relatively low, which infers a less intense immediate response. At the lags of one month and two months, the values of correlation are generally higher, which means that some wells respond to driving factors (e.g., rainfall or pumping) following a time lag. Three- and four-month lags exhibit comparatively stronger correlations in many wells (for example, Besant Nagar, Virugambakkam, Royapettah and Thiruvallur), pointing towards increased delayed connectivity or aquifer responses with the passage of time. The trend highlights that successful responses are rarely instantaneous but often have time-dependent relationships, advantageous in understanding aquifer recharge dynamics and groundwater flow patterns.

Table 2. Estimated Distribution Parameters for different time lag

| **Estimated Distribution Parameters** | | | | | |
|---|---|---|---|---|---|
| Description | | Zero-month lag | One month lag | Two months lag | Three months lag |
| Normal Distribution | Location | 0.1305 | 0.3989 | 0.3858 | 0.2826 |
| | Scale | 0.06014 | 0.09213 | 0.06149 | 0.07125 |
| | | | | | |

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$ ----------Equation 2

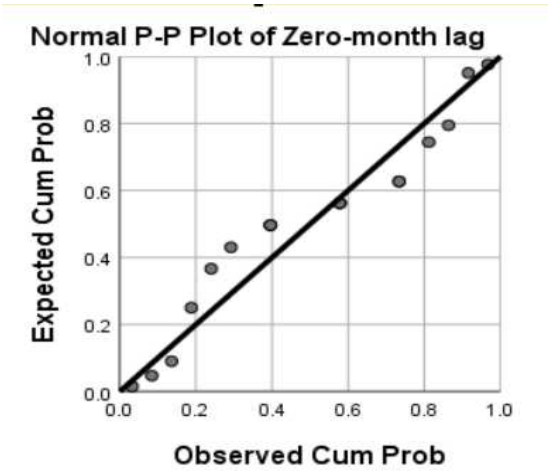
Where

μ =mean of x

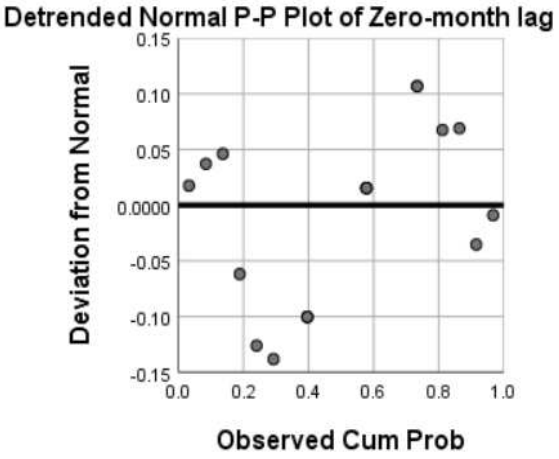
σ=standard deviation of x

π=3.14159

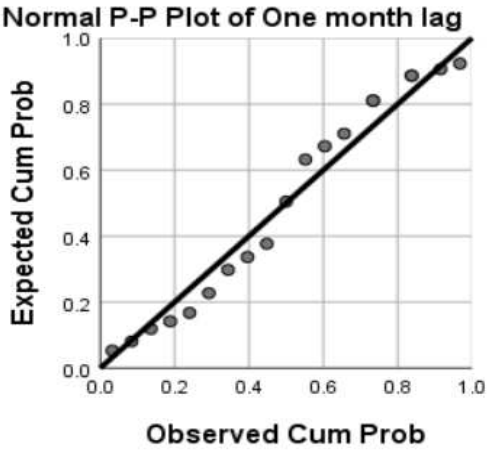
e=2.71828



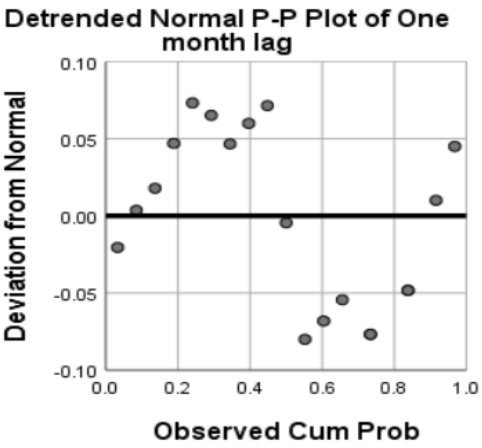

(5a)



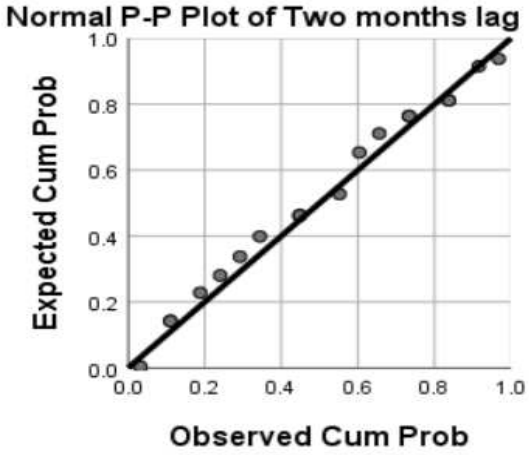

(5b)



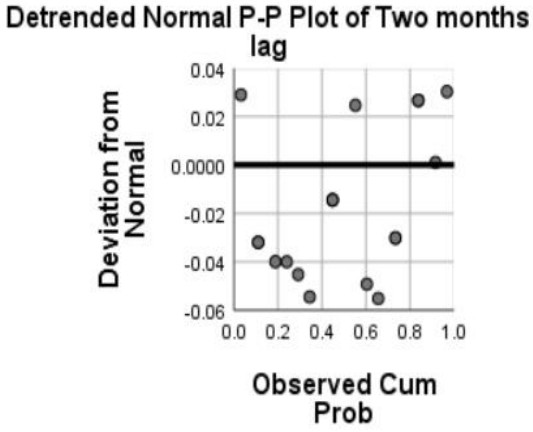

(5c)



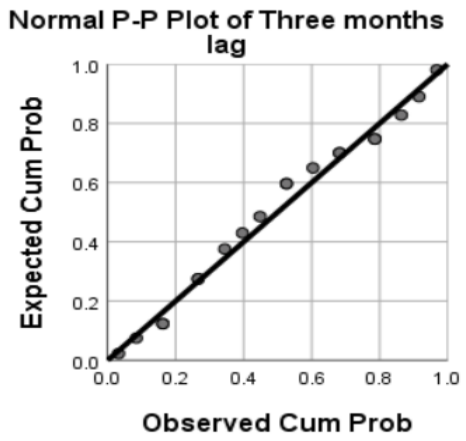

(5d)



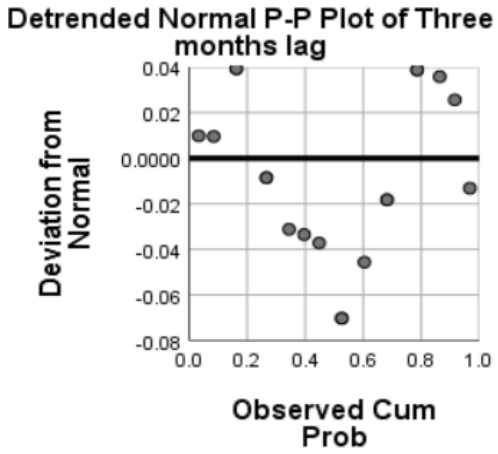

(5e)



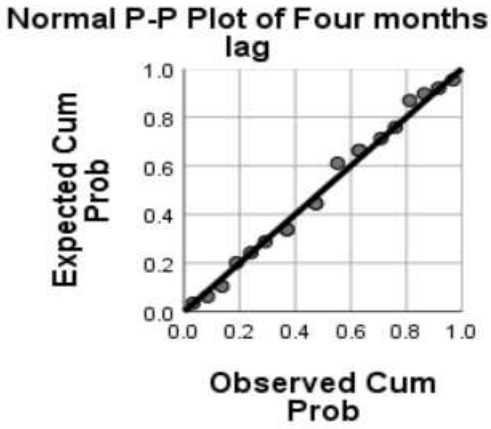

(5f)



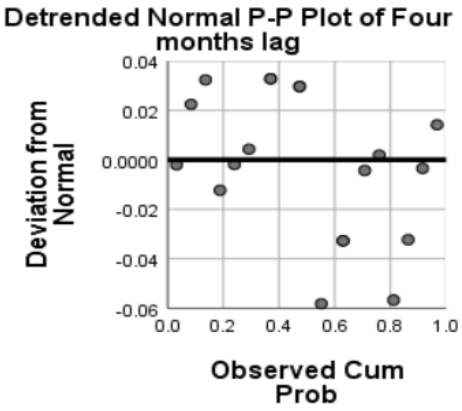

(5g)




(5h)




(5i)




(5j)

Figure 5a-5j. Temporal lag map corresponding to different wells in the selected study area

## 5.DISCUSSIONS

### 5.1 Comparative Analysis of Temporal Lag

Twelve of the nineteen observation wells had a positive response within a month after the rainfall events, and seven wells had a response within a two-month period. Figure 5a-5j shows the temporal lag map corresponding to different wells in the selected study area. The estimated distribution parameters explain how cross-correlation coefficients follow a normal distribution across different temporal lags (Equation 2). The location parameter (mean) achieves its minimum at zero-month lag (0.1305), which denotes a weak immediate correlation, while it is the highest at one-month lag (0.3989), indicating a stronger delayed response. The scale parameter (spread/variability) is found to be lowest at zero-month lag (0.06014) and highest at one-month lag (0.09213), signifying greater variability in the correlation coefficients in considering delayed responses. Overall, the results emphasize how correlations strengthen after a short lag (one month) and then slowly weaken at longer lags, thus capturing the temporal dynamics involved in good connectivity and aquifer responsiveness.

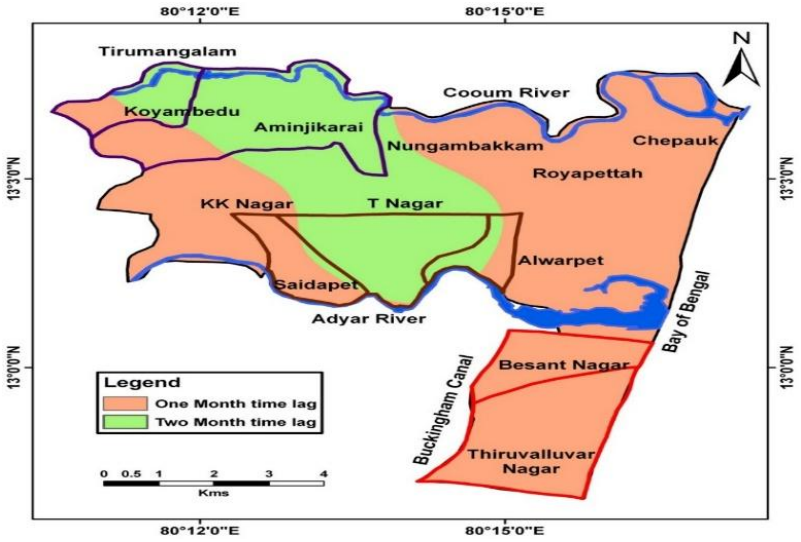



Figure 6. Time lag map

This time lag map shows the response of different watersheds in Chennai to rainfall events (Figure 6). Areas shaded in orange indicate a one-month time lag, while areas in green indicate a two-month time lag in hydrological response. Such analysis helps with flood prediction, water management, and urban planning. Figure 7 shows the plotting of the correlation coefficient values for the sample wells having a one-month time lag and Figure 8 shows the plotting of correlation coefficient values for sample wells having two-month time lag.

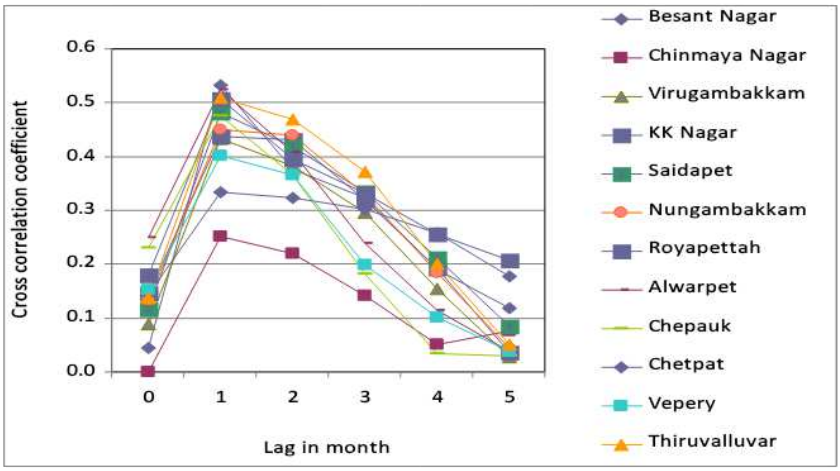



Figure 7. Cross-correlation values for sample wells (1month lag)

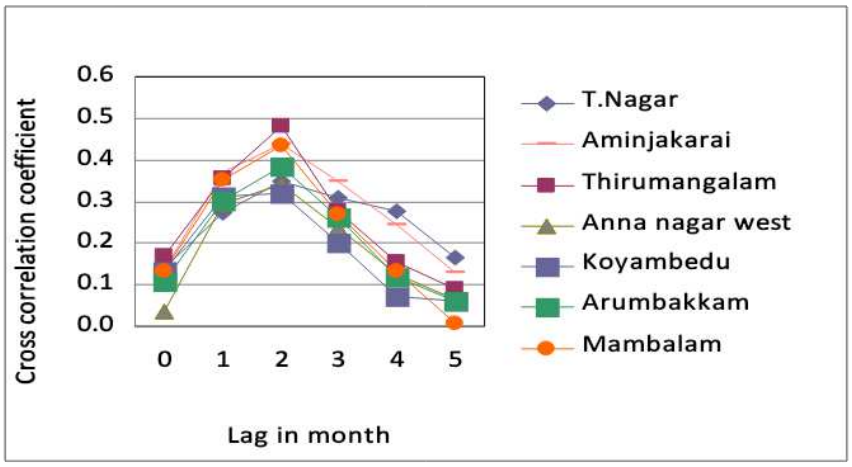



Figure 8. Cross-correlation values for sample wells (2 months lag)

### 5.2 Spatial Analysis of Recharge Response Behavior

These correlation values demonstrate how the unconfined aquifer's recharge response behaved in the research area. To several months in deep water tables beneath sediments/eroded zones including restricted vertical permeability, travel time can differ from several minutes for the shallow water table in permeable formations. Cross correlation coefficient values are employed to qualitatively estimate the recharge response zone. Using the spatial analysis instrument in GIS, the recharge response map is prepared from the cross-correlation coefficient values, and it is shown in Figure 9. Further, the recharge response map is categorized into four zones based on the range of correlation coefficient values such as for high response the value is in the range $r > 0.50$; moderate response for recharge $r = 0.45$ to 0.50; less response for recharge $r = 0.35$ to 0.45 and poor response for recharge $r < 0.35$. High value of correlation coefficient indicates the aquifer response is good for recharge, and a low value indicates that low response to recharge. Sample wells located near coastal watershed show better response, whereas those in the dense urban watershed show moderate to less response for recharge. But wells in the suburban watershed indicate less and poor response.

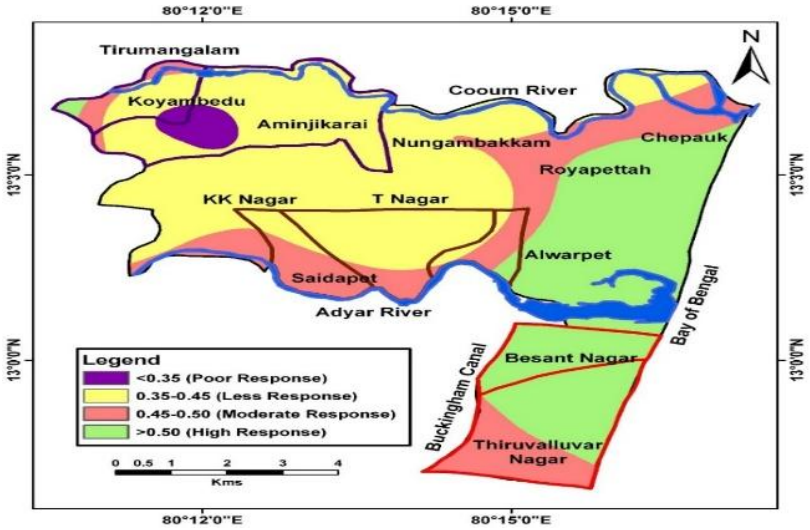



Figure 9. Recharge response map

5.3 Limitation on Recharge Response study

These results reinforce the fact that groundwater recharge in Chennai is significantly affected by temporal lag as well as spatial heterogeneity. A successful incorporation of cross correlation analysis with the capabilities of GIS technology ensures a significant success rate in meeting ever-increasing groundwater management needs in the urban sector. Although it was observed that methodology itself is limited in terms of resolution as well as simplifying assumption, it is nevertheless a viable solution to address the needs of effective artificial recharge planning by conceiving recharge response zones.

## 6. CONCLUSION AND FUTURE WORK

The present study adopted cross-correlation methodologies integrated with GIS to map recharge responses to various rainfall events at different time lags. For a range of potential time lags, the cross-correlation coefficients between the water table depth and matching rainfall were calculated for 19 sample wells. These correlation values show how the unconfined aquifer's recharge response behaved in the selected study area. Twelve of the nineteen sample wells show a significant response at a one-month lag after rainfall, whereas the remaining sample wells show a significant response at a two-month lag. Four recharge response zones were created to categorize the final correlation coefficient values across the entire region. These are: zones of high, moderate, low, and poor responses. For a good response in recharge zones, the maximum correlation coefficient is used, and for a poor response to recharge, the minimum correlation coefficient is used. Most wells in coastal watersheds show a significant response to rainfall events, whereas in dense urban and suburban watersheds, the response is moderate to low.

The significance of the present study extends beyond the geographical area, as several metropolitan cities across the globe are experiencing similar issues, such as increased imperviousness, changes in LULC patterns, climate change, and overexploitation of groundwater. Moreover, the present study can contribute significantly to informed decision-making by identifying potential RWH zones to recharge groundwater and efficiently support its long-term sustainability. It is also significant for addressing the global need for water security by meeting the requirements of SDG 6.

Further research needs to explicitly consider groundwater abstraction and leakage from water supply systems, as well as the role of urban drainage networks, to isolate natural recharge from anthropogenic influences effectively. Long-term monitoring studies of how different RWH and artificial recharge structures perform under real-world conditions, and their efficiency will help validate and refine the outcomes of recharge response mapping.

## CONFLICT OF INTEREST

There is no conflict of interest.

## REFERENCES

[1] Amiri M, Salem A, Ghzal M. Spatial-temporal water balance components estimation using integrated GIS-based Wetspass-M model in Moulouya Basin, Morocco. ISPRS Int J Geo-Inf. 2022;11(2). doi:10.3390/ijgi11020139.

[2] Jin Z, Tang S, Yuan L, Xu Z, Chen D, Liu Z, et al. Areal artificial recharge has changed the interactions between surface water and groundwater. J Hydrol. 2024;637:131318. doi:10.1016/j.jhydrol.2024.131318.

[3] Mishra AK, Upadhyay A, Srivastava A, Rai SC. Probabilistic groundwater recharge zonation in hard rock terrain using geospatial techniques in Veniar watershed, South India. Ecohydrol Hydrobiol. 2020;20(3):456–471. doi:10.1016/j.ecohyd.2019.01.004.

[4] Singh V, Sherring A, Kumar S, Rai P, Kumar V. Assessing the impact of groundwater recharge on underground reservoir replenishment in Eastern Uttar Pradesh, India. Int J Environ Clim Change. 2024;14(7):623–631.

[5] Gong M, Li P, Kong J. Estimation of groundwater recharge and assessment of groundwater quality in the Weining Plain, China. Water. 2025;17(5):704.

[6] Hussain MS, Abd-Elhamid HF, Javadi AA, Sherif MM. Management of seawater intrusion in coastal aquifers: a review. Water. 2019;11(12):2467. doi:10.3390/w11122467.

[7] Kadam AK, Umrikar BN, Sankhua RN. Assessment of recharge potential zones for groundwater development and management using geospatial and MCDA technologies in semiarid region of Western India. SN Appl Sci. 2020;2(2):1–11. doi:10.1007/s42452-020-2079-7.

[8] Khan MS, Duragasi AR, Gumma RK. Delineation of groundwater recharge potential zones using GIS-AHP and AR feasibility assessment in Prakasam district, Andhra Pradesh, India. Arab J Geosci. 2025;18(9):158.

[9] Jebamalar J, Ravikumar G, Meiyappan G. Groundwater storage through rain water harvesting (RWH). Clean Soil Air Water. 2012;40(6):624–629. doi:10.1002/clen.201100517.

[10] Mahmud MNH, Roy D, Paul PLC, Hossain MB, Yesmin MS, Kundu PK, et al. Natural groundwater recharge: a review on the estimation methods. Bangladesh Rice J. 2023;25(2):45–56. doi:10.3329/brj.v25i2.62706.

[11] Addisie MB. Groundwater recharge estimation using water table fluctuation and empirical methods. H2Open J. 2022;5(3):457–468. doi:10.2166/h2oj.2022.026.

[12] Andualem TG, Demeke GG, Ahmed I, Dar MA, Yibeltal M. Groundwater recharge estimation using empirical methods from rainfall and streamflow records. J Hydrol Reg Stud. 2021;37:100917. doi:10.1016/j.ejrh.2021.100917.

[13] Collenteur RA, Bakker M, Klammler G, Birk S. Estimation of groundwater recharge from groundwater levels using nonlinear transfer function noise models and comparison to lysimeter data. Hydrol Earth Syst Sci. 2021;25(5):2931–2949. doi:10.5194/hess-25-2931-2021.

[14] Sasidharan S, Bradford SA. Assessing drywell designs for managed aquifer recharge via canals and repurposed wells. Sci Rep. 2025;15(1):1829.

[15] Souissi D, Msaddek MH, Zouhri L, Chenini I, El May M, Dlala M. Mapping groundwater recharge potential zones in arid region using GIS and Landsat approaches, southeast Tunisia. Hydrol Sci J. 2018;63(2):251–268. doi:10.1080/02626667.2017.1414383.

[16] Gururani DM, Kumar Y, Abed SA, Kumar V, Vishwakarma DK, Al-Ansari N, et al. Mapping prospects for artificial groundwater recharge utilizing remote sensing and GIS methods. Water. 2023;15(22). doi:10.3390/w15223904.

[17] Rajasekhar M, Ajaykumar K, Raju GS, Bhagat V. Identification of artificial groundwater recharge zones in semi-arid region of southern India using geospatial and integrated decision-making approaches. Environ Chall. 2021;5:100278. doi:10.1016/j.envc.2021.100278.

[18] Allafta H, Opp C, Patra S. Identification of groundwater potential zones using remote sensing and GIS techniques: a case study of the Shatt Al-Arab Basin. Remote Sens. 2021;13(1):1–28. doi:10.3390/rs13010112.

[19] Arabameri A, Roy J, Saha S, Blaschke T, Ghorbanzadeh O, Bui DT. Application of probabilistic and machine learning models for groundwater potentiality mapping in Damghan sedimentary plain, Iran. Remote Sens. 2019;11(24). doi:10.3390/rs11243015.

[20] Shinde SP, Barai VN, Gavit BK, Kadam SA, Atre AA, Pande CB, et al. Assessment of groundwater potential zone mapping for semi-arid environment areas using AHP and MIF techniques. Environ Sci Eur. 2024;36(1). doi:10.1186/s12302-024-00906-9.

[21] Wang C, Dai F, Liu Y, Wang Y, Li H, Qu W. Shallow groundwater responses to rainfall based on correlation and spectral analyses in the Heilonggang Region, China. Water. 2023;15(6). doi:10.3390/w15061100.

[22] Jebamalar J, Sowmya V, Ravikumar P. City-scale groundwater recharge evaluation using temporal water level data and GIS. J Water Resour Prot. 2020.

[23] Senthilkumar S, Gnanavel S, Kumar D. GIS and remote sensing-based groundwater recharge zone mapping in Tamil Nadu, India. Sustain Environ Res. 2019.

[24] Ramachandran A, Shankar R. GIS-based identification of groundwater recharge zones in Tamil Nadu watersheds. J Hydrol Eng. 2020.

[25] Kumar P, Singh R, Gupta A. Integrated RS/GIS approach for optimal rainwater harvesting site selection. Environ Earth Sci. 2023.

[26] Gebreslassie M, Yakob T, Shemsedrin A. Water harvesting and groundwater recharge: a comprehensive review. 2025.

[27] El Amrani M, Bennouna A. GIS-based AHP/MIF models to identify rainwater harvesting sites and recharge potential zones in Morocco. J Water Land Dev. 2026.

[28] Sharma T, Patel V. Urban groundwater recharge and sustainable water management: a critical review. Water. 2024.

[29] Gupta K. Analysis of groundwater recharge techniques for urban areas. Int J Water Environ Eng. 2025.

[30] Amihere-Ackah E, Boateng S, Adjei K. Managed aquifer recharge via rooftop rainwater harvesting: a case study from Ghana. J Hydro-Environ Res. 2025.

[31] Valois B. Temporal correlation analysis for groundwater recharge characterization. J Water Resour Prot. 2020.

[32] Ren H, Li X, Zhang Y. Impact of rainfall distribution on groundwater recharge dynamics using time series analysis. J Hydrol. 2025.

[33] Liu Q, Huang M, Wu J. Cross-correlation and wavelet analysis of rainfall and groundwater level data. Water Resour Manag. 2025.

[34] Mohan S, Pramada SK. Natural groundwater recharge estimation using multiple methods combined with an experimental study. Water Supply. 2023;23(5):1972–1986. doi:10.2166/ws.2023.090.

[35] Sharma R, Kumar N, Sharma BB. Applications of artificial intelligence in smart agriculture: a review. Lect Notes Electr Eng. 2022;832(4):135–142. doi:10.1007/978-981-16-8248-3_11.

[36] Sheena AD, Ramalingam M, Anuradha B. Groundwater potential evaluation using fuzzy inference system. Desalin Water Treat. 2018;122:268–276. doi:10.5004/dwt.2018.22902.

[37] Chandramohan R, Kanchanabhan TE, Siva Vignesh N. Identification of artificial recharge structures using remote sensing and GIS for arid and semi-arid areas. Nat Environ Pollut Technol. 2019;18(1):183–189.

[38] Pradeepraju PN, Nagaraju D, Sudeep SR. Suitable site selection for artificial recharge structures in Bandalli watershed, Chamarajanagar District, Karnataka, India using remote sensing and GIS techniques. Curr World Environ. 2022;17(3):727–742. doi:10.12944/cwe.17.3.20.

[39] Jean Olivier KK, Brou D, Jules MOM, Georges ES, Frédéric P, Didier G. Estimation of groundwater recharge in the Lobo Catchment (Central-Western Region of Côte d'Ivoire). Hydrology. 2022;9(2):1–18. doi:10.3390/hydrology9020023.

[40] Jayswal PS, Gontia NK, Sondarva KN, Patel VA. Site selection for rainwater harvesting using remote sensing, GIS and AHP. Int J Plant Soil Sci. 2023;35(18):1360–1378. doi:10.9734/ijpss/2023/v35i183403.

[41] Amihere-Ackah P, Monney I, Okyere DC, Adjei KA, Appiah-Adjei EK. Assessing the potential of managed aquifer recharge using rooftop rainwater harvesting with shallow wells in peri-urban communities in Kumasi, Ghana. Discov Water. 2025;5(1). doi:10.1007/s43832-025-00245-7.

[42] Albarakat R, Lakshmi V. Comparison of normalized difference vegetation index derived from Landsat, MODIS, and AVHRR for the Mesopotamian marshes between 2002 and 2018. Remote Sens. 2019;11(10). doi:10.3390/rs11101245.

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**Jebamalar, A:** Study Conceptualization, Investigation, Data curation, writing – original draft, **Revathee, T**: Data collection, Conceptualization, Writing – original draft, Analysis and Interpretation of results. **Anuradha,** B: Analysis and Interpretation of results Supervision, Investigation on challenges and **Packialakshmi, S:** Writing – review and editing, revision in data analysis, and Interpretation of results and Draft manuscript preparation.

## Supplementary Files

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