Theme 7

ADVANCED TECHNIQUES FOR GROUNDWATER EXPLORATION AND ASSESSMENT

INTERPRETATION AND INTERPOLATION OF ELECTRICAL RESISTIVITY DATA USING INVERSE PLOT METHOD: CASE STUDY OF GROUND WATER EXPLORATION IN HARD ROCK AREAS OF RAJASTHAN, INDIA

Govind Singh Bhardwaj*

Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India
**Corresponding author e-mail: bhardwaj_gs@rediffmail.com*

Geophysical exploration techniques play a vital role in probing and understanding the nature of the subsurface rock strata, especially in groundwater and subsurface strata conditions. There is demand of the time to have inputs of cost-effective easy access technology for explorations in finding groundwater sources for industrial, irrigation and domestic supply, which is to fulfill the day today needs of the society. The geophysical techniques like electrical resistivity scanning find its wide application in ground water exploration irrespective of several ambiguities. It has proven its cost effectiveness in terms of production optimization. Resistivity meter model SSR MP ATS microprocessor-based instrument is used for data collection, inbuilt capacity to store 100 scan data with average depth 250 m. It is compatible with PC, where RES software installed. Data transferred possible only by establishing connection between instrument and PC. Beauty of the instrument is there one cannot manipulate or change the data obtained and saved. These data directly uploaded in the software for further analysis and simulation. Interpolation and interpretation done by review of geology of the area and experience, as well as feedback of earlier drilled bore wells at suggested sites. Multi-metal antenna also used for contact tracing of saturated and unsaturated strata in the area of interest and tracing the underground water flow channel.

The interpretation involves processing of data, where parameters obtained about depth-wise strata layer thickness and inference drawn for the subsurface rock formations, leads to find out the water saturation status, using geological background knowledge with the preliminary reconnaissance using geologic observation tools. Electrode spacing decreased or increased depending upon values of variables of ascending and descending depths slice of the litho log obtained directly in the display of the instrument. For finding layers, the quantitative approach of inversion technique, elaborates relationship of measured with the actual appropriation. This is carried out using combination of techniques with inverse plot and the microprocessor based electrical resistivity measurement instrument and simulation with 2D software. The emphases on applied aspects are dealt with the resource identification, quantification of the subsurface deposits by CPQ indexing. The Schlumberger configuration considered for field operation. The field equation directly to get the resistivity and thickness of the subsurface layers from the field data is considered as "Inverse slope method" for the study. This methodology has proved to be suitable for varied geological set up, field areas scanning and found practical utility in locating potential bore wells, which is mainly, based on major six variables, amongst Rho, Strip and R play its immense role.

The field operations carried out in most of the cases, where failure bore wells drilled are present. We collected subsurface data, interpretation done using software and interpolated to find out the groundwater bearing strata in terms of its saturation potential and availability are compiled in this study. Typical groundwater scarcity area of Jawai Dam surroundings area in

Pali districts of Rajasthan, in western India, is famous for its wild life shelter and it is a unique tourist's destination to visit leopard residing in the well jointed open joints/ sheets of granite hills formed millions of years ago by lava, which is truly speaking is home/ shelter house to leopards, sloth bears, wolves, chinkara, and crocodiles. It is also nature's beauty to see many migratory birds during winter. To solve the potable water requirement of the local and tourists during summers, geophysical scanning was carried out and successful bore wells located. Tehsil Mavli in Udaipur belongs the annual average rainfall in 604 mm, with an average of 30 rainy days per year is groundwater scarcity zone, surface water bodies almost vanished, all open wells are dry in majority, except few. The area categorized as groundwater dark zone, even than water availability problem solved viz. located sites and potential bore well drilled.

Similarly, success arrived in several groundwater scarcity areas of Nathdwara area district Rajsamand, Badgaon and Girwa area district Udaipur, Gulabpura area Bhilwara, Padanga in Naguar. Ranabeda, nadol area Pali, Nenva area Bundi, and Aditya Cement Works Sawa-Shambhupura Chittorgarh, etc. Groundwater flow direction, venation mapping, subsurface layered profiling of strata, obtained as a final success and systematics, where inventory has been prepared, which elaborates the potentially proven controls of groundwater localizations i.e., Intrusive contacts with the host, concealed open joints, quartz veins contacts with the country rock, rift and graben, interlayered sheets, weathered horizon, micro lineament, etc. Objectively, it is realized to popularize less expensive techniques to avoid dry bore well and help society in finding potential bore well/open well for getting groundwater to fulfill their demands. Focus has been laid on selected area for varied lithological set up so that this could clearly become understandable to all. Present study deals with the 95% accuracy in exploring the subsurface and it has proven the application of geophysical electrical scanning of several areas of hard rocks, and their quantitative and qualitative assessment resulted in potential yield bore wells. The success stories of finding groundwater in acute dry areas, to meet out irrigation, industrial water supply and domestic water supply encourage us to recommend this cheap and easily available technique. In this technique, the problem of longitudinal conductance never arises and sandwiched saturated groundwater strata easily identified, by basic field curve plotted directly.

Keywords: *Geo-electrical resistivity, hard rock, inverse plot, groundwater, Rho, strip, groundwater scarcity, controls of groundwater localization, flow direction*

GRACE SATELLITE DATA AND OBSERVED WELL LEVELS REVEAL THE RELATION BETWEEN SPECIFIC YIELD AND GROUNDWATER DEPTH

Maya Raghunath Suryawanshi[1*], K. Satish Kumar[1], Chethan V.A.[1], Balaram Shaw[1], Vandana S.[1], Aayushi Kochar[1] and Bramha Dutt Vishwakarma[1,2]

[1]Interdisciplinary Centre for Water Research, Indian Institute of Science, Bengaluru (Karnataka), India
[2]Centre for Earth Sciences, Indian Institute of Science, Bengaluru (Karnataka), India
[*]Corresponding author e-mail: maya2509.surya@gmail.com

The specific yield (S_y) is defined as the ratio of the volume of water that saturated rock or soil yields by gravity to the total volume of the rock or soil. It serves as a crucial indicator of the amount of water stored and available in unconfined aquifers. The S_y values are influenced by several key factors such as grain size, shape, initial depth of the water table upon saturation, and rate of water table changes. In land surface models (LSMs), S_y plays a critical role in simulating groundwater dynamics. However, most of the LSMs assume a constant S_y value for the calculations. For instance, the CLM and Noah-MP models commonly uses S_y value of 0.2; VIC and MATSIRO-GW models utilize empirical S_y values of 0.15 or 0.08, respectively. Using a single fixed S_y value can oversimplify groundwater recharge estimations and lead to highly uncertain groundwater estimates. Therefore, there is a need to characterize the spatial and temporal variations in S_y values and investigate the underlying reasons. This knowledge will enhance model performance, thereby improving predictions of groundwater and water availability across diverse hydrological settings at regional and global scale. Various field methods such as pumping and slug tests are used to estimate S_y, but these tests assume steady-state conditions and may overlook complex aquifer heterogeneity. Additionally, they are costly and are not repeated often. Laboratory experiments provide detailed insights into porosity and permeability, essential for S_y calculations, yet they may not fully replicate field conditions. Geophysical methods such as electrical resistivity imaging (ERI) and ground penetrating radar (GPR) offer valuable spatial information on subsurface properties related to S_y but are indirect and require calibration with ground truth data. All these methods collectively provide a comprehensive toolbox for estimating S_y, yet they require careful consideration of aquifer heterogeneity, spatial and temporal variability and uncertainties in data collection and interpretation. Hence, novel methods to estimate S_y are needed.

The Gravity Recovery and Climate Experiment (GRACE) satellite data along with available well data is used to estimate $S_{y.}$ Typically, S_y are used to scale well data to equivalent water height (EWH) and compare with estimates from GRACE data. However, the problem would be posed in an inverse sense and estimate S_y from observations. This study used the monthly GRACE and GRACE-FO Level 3 mascon solutions (JPL RL06.1_v03). The monthly soil moisture data was obtained from the Climate Change Service (C3S) volumetric surface soil moisture (C3SVSSM) COMBINED produce v202212. The Central Groundwater Board (CGWB) provides the groundwater levels (GWLs), which are accessible for four months in a year (January, March, August and November). The S_y is defined as the ratio of change in groundwater storage anomalies (GWSA) to the GWL changes for a given mascon. The change is defined with respect to minimum and maximum values observed each year. The S_y calculated is represented as ‘observation based S_y’. The GWSA were obtained from GRACE Total Water Storage Anomalies (TWSA), which is a combination of all forms of water storages such as surface water, soil moisture and groundwater, etc. Thus, to isolate GWSA,

soil moisture storage anomalies (SMSA) are removed from TWSA. Next, as GWLs are available for four months (January, March, August, November) in a year. Our analysis is limited to only these four months. Further, uncertainty analysis was carried out using error propagation formulae.

Over the entire country, the yearly observation-based S_y values were calculated at the mascon scale (about 3°x3°). For 20 mascons out of 52, S_y values were not calculated due to lack of GWL data. For most of the mascons, the observation-based S_y values match well with the reference S_y. However, our method marginally overestimates S_y values compared to the reference for few mascons (from 40 to 52). The uncertainty assessment was performed through error propagation and the values are within the range when compared to the reference uncertainty. Out of 32, the uncertainty of three mascons (41, 45, 48) are exceeding the reference uncertainty. Further, we studied the variation of S_y with average GWL. Existing literature reports an inverse relationship between S_y and GWL. Similar behavior was observed in most of the mascons. For instance, in mascons 24, S_y decreased with increase in GWLs (m below ground level) and vice versa. However, for a few mascons (22, 26, 33, 34, 41) the inverse relationship between S_y and GWL did not hold good. It is evident from the scatter plot that S_y is decreasing with increasing GWL. A general pattern is hard to extract from the data as the scatter is large and averaging is needed. Thus, to obtain empirical relation between both quantities dynamic size data binning was performed to obtain representative points for a range of groundwater level values. Then, an exponential function was fitted using regression to establish a mathematical relationship between S_y and average GWLs.

In the present study, we estimate S_y using GRACE TWSA and GWLs for whole India. The observation based S_y values performed well when compared with reference S_y in most of the mascons. The S_y values varied through time, and this motivated us to look into factors driving changes in S_y values. We have found that groundwater level has an inverse relation to S_y, in other words, the deeper the groundwater level, the smaller the S_y. The inverse relationship between S_y and GWLs is formalised into an empirical equation derived using available data from GRACE satellites and CGWB dug well data. GRACE satellite data can be employed along with well data for estimating S_y at various spatial and temporal scales. The proposed method can be applicable across diverse hydrological settings at regional and global scale.

Keywords: *Specific yield, GRACE, total water storage anomalies, mascon, groundwater levels, aquifer*

DEDUCING GROUNDWATER POTENTIAL ZONES IN THE WAINGANGA RIVER BASIN, CENTRAL INDIA USING AHP AND GEOSPATIAL TECHNIQUES

A.R. Kharve[1, 2]*, N.C. Mondal[1,2]*, I.C. Das[3] and V. Ajaykumar[1]

[1]CSIR-National Geophysical Research Institute, Hyderabad, India
[2]Academy of Scientific & Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh, India
[3]Geosciences Group, National Remote Sensing Centre, Hyderabad, India
[*]Corresponding author e-mail: arkharve2106@gmail.com, ncmngri@gmail.com

Groundwater plays a crucial role as a resource for humans, meeting the needs of households, agriculture, industry, etc. Due to its hidden nature, preliminary exploration and identifying the groundwater potential are crucial for effective management and development. Availability of groundwater and its quality are affected by many natural and anthropogenic factors like changes in land use, varied climatic condition, geological and geomorphological conditions and over-exploitation of groundwater. Over-exploitation of groundwater without a thorough understanding of its potential can lead to significant water shortages and resource depletion. To effectively assess groundwater resources, mapping groundwater potential zones (GWPZs) is vital. The latest innovations in remote sensing (RS) and GIS, now provides rapid and precise solutions for determining GWPZs. The objective of this study was to develop a map of GWPZs for the Wainganga River basin in Central India (area ~51,384 km²) using a combination of remote sensing (RS), Analytical Hierarchical Process (AHP), multi-criteria decision-making (MCDM), and GIS techniques and to validate the results using well-specific yields and groundwater level fluctuations.

This study models GWPZs using RS, GIS, and AHP techniques. Nine layers such as geology, geomorphology, LULC, soil, drainage density, lineament density, slope, rainfall, and TWI were converted to raster format, resampled to 30×30 m and reclassified. A weighted overlay approach was used in ArcGIS 10.7 to evaluate the groundwater potential index (GWPI), with weights and ranks assigned based on literature and expert input. Sensitivity analysis was carried out by omitting individual layers to assess their impact on the GWPZs. The data sets used in this study includes SRTM-DEM from USGS (30×30 m), LULC from ESRI Sentinel - 2 (10×10 m), rainfall data from IMD (0.25°×0.25°), soil map from FAO (1:5,000,000), geology and geomorphology from the Bhukosh portal (1:50K), lineaments (1:250,000), and slope, drainage, and TWI derived from DEM (30×30 m). Groundwater level data was sourced from the Indian Water Resources Information System.

The demarcation of GWPZs was done through the application of AHP and GIS techniques. The GWPI values varied from 2.79 to 7.53, dividing the basin into five zones: very poor (8.28%), poor (21.63%), moderate (30.21%), good (28.21%), and very good (11.67%). Occurrence of very high potentiality in the southwest parts of the area was majorly attributed to the geology, high lineament density, and LULC. In the central part, the lithology played a vital role as this area covered by alluvium and sandstones. Also, geomorphologically, it was covered by alluvial plain. The very poor to poor zones occurred in the central eastern part, which resulted due to presence of highly dissected plateaus with higher degree of slope and complex geology. Validation of the potential map against the in-situ groundwater level fluctuations and well-specific yields has revealed a strong correlation (R=0.93). It was observed that exclusion of slope resulted in maximum increase in area of very poor potential

zone by 21.77 % and while omission of LULC showed reduction in very poor zone by 9.08 %. In the poor zone, maximum decrease of 7.11 % showed by exclusion of LULC layer. In good potential area, maximum decrease of 9.77 % resulted due to exclusion of slope layer. In very good zone, the maximum area reduction was of 24.77 and 24.51 % after removing of slope and drainage density respectively. While geology (16.20 %), geomorphology (9.78 %), and LULC (12.01 %) have shown significant increase in the area of very good potential zones. The GWPZs are classified into five categories: very good, good, moderate, poor, and very poor. The southern region of the basin shows higher potential, with good and very good zones, while the northern and eastern regions are marked by poor and very poor potential zones. The deduced potential map was validated by comparing it with groundwater level fluctuations and well-specific yields, showing a high degree of correlation. Zones with good and very good potential are identified as the most favourable for groundwater exploration, while poor and very poor zones are the least favourable. Sensitivity analysis reveals significant changes in the very good potential zones when individual thematic layers are omitted. In complex geological setting of the Wainganga River basin, these identified GWPZs are crucial for understanding recharge capacity and optimal groundwater resource utilization.

Keywords: *Groundwater, remote sensing, GIS, AHP, exploration, sustainability, Wainganga River basin, India*

FIELD EXPERIMENT FOR SUSTAINABLE GROUNDWATER MANAGEMENT: EVALUATING DISCHARGE MEASUREMENT METHODS AND AQUIFER CHARACTERISTICS IN ALLUVIAL AQUIFERS OF NORTH-WESTERN INDIA

Ayush Kesharwani*, Priyanka and Vidya Nand Negi

Central Ground Water Board, India
**Corresponding author e-mail: ayush.1996-cgwb@gov.in*

In hydrogeological studies, understanding aquifer characteristics and the behaviour of groundwater flow is essential for sustainable groundwater management. One of the fundamental aspects of this process involves accurately measuring the discharge rate of exploratory pumping wells, as it provides critical data on aquifer parameters such as Transmissivity (T) (m^2/day), Hydraulic conductivity (K) (m/day), and Storativity (S). Variability in discharge measurements can lead to different interpretations of aquifer properties, impacting the assessment and planning of groundwater resources. Field experiments comparing different discharge measurement methods can offer valuable insights into the reliability and precision of each method, as well as their influence on the derived aquifer parameters. This study evaluates the accuracy and precision of four discharge measurement methods namely V-notch Weir, Orifice Flow Measurement (Manometric Head), Volumetric, and Ultrasonic Flow Meter during pumping tests conducted via an 8-inch diameter exploratory well in the alluvial aquifer of Northwestern India. Two pump configurations (a high-capacity vertical turbine (VT) pump and a lower-capacity submersible pump) were used to test each method under varying discharge conditions. The primary objective was to identify the most reliable discharge measurement method by determining the accuracy and precision of each method and to provide insights about how different pumping configurations influence the estimation of T. The experiment involved conducting step-drawdown tests at three incremental discharge rates for each pump configuration. This testing approach allowed for the assessment of different discharge measurement methods under varying pumping conditions. The methodology consisted of three main components viz., discharge measurement method, pumping configuration and data analysis.

Discharge measurements were carried out using four distinct methods over one-hour intervals at three step-drawdown levels. The V-notch weir method involved recording the water height passing through a 90° V-notch plate to calculate discharge based on the height-discharge relationship. The orifice flow method was used for manometric head measurements across a circular orifice with standard equations to determine flow. The volumetric method collected water in a known-volume container and measured the time to fill it, providing a direct volume-per-time discharge. Lastly, a non-intrusive ultrasonic flow meter measured flow velocity in a closed conduit to calculate discharge. Two pumping configurations were employed to explore the impact of pump capacity on discharge measurements and aquifer parameter estimation. A vertical turbine pump, with high capacity, imposed significant stress on the aquifer, enabling greater discharge measurements and substantial drawdown. In contrast, a low-capacity submersible pump produced smaller drawdowns, which could lead to an overestimation of T due to higher discharge-to-drawdown ratios and reduced stress on the aquifer.

Data analysis involved both qualitative and quantitative approaches to evaluate the precision and accuracy of discharge measurement methods. Qualitative analysis such as box-and-whisker plots was used to visually assess data spread, favouring methods with points clustered near the overall mean for accuracy. Quantitative analysis included constructing accuracy vs. precision graphs, where mean square error (MSE) quantified accuracy and standard deviation represented precision. Methods exhibiting high accuracy with moderate-to-high precision were deemed reliable for discharge measurement. Following the identification of the most reliable discharge measurement method, aquifer performance tests were conducted using both pump configurations to estimate aquifer transmissivity. Discharge measurements were taken with the selected reliable method, allowing for a comparison of transmissivity values from each pump setup. This comparison helped determine which pump setup yielded transmissivity values most closely aligned with field observations, providing insights into the impact of pumping configuration on aquifer parameter estimation. The comparative analysis of discharge measurement methods across both pump configurations, provided insights into the precision, accuracy and reliability of each method.

The performance of discharge measurement methods revealed that certain techniques consistently outperformed others when applied under their specific operational assumptions. Among these, the 90° V-notch Weir method exhibited the highest accuracy and moderate-to-high precision across both vertical turbine (VT) and submersible pump setups. Its data showed minimal variability and aligned closely with expected flow rates, establishing it as the most reliable method in this study. A comparative ranking of reliability placed the methods as V-notch > volumetric > ultrasonic flow meter (UFM) > manometric head. Significant variability in T estimates was observed between the VT and submersible pump configurations. The VT pump, with its higher discharge capacity and induced drawdown, produced transmissivity values that closely matched field observations, demonstrating its effectiveness for accurately estimating aquifer parameters under stressed conditions. Conversely, the submersible pump, with its lower discharge rate and reduced drawdown, tended to overestimate transmissivity. This overestimation was likely due to the reduced stress on the aquifer, resulting in higher T values that did not accurately represent true aquifer conditions. These results underscore the importance of selecting appropriate discharge measurement methods and pump configurations for accurate aquifer parameter assessment. This field experiment highlights the critical role of selecting appropriate discharge measurement methods and pumping configurations for accurate aquifer transmissivity estimation. Among the methods tested, the V-notch Weir proved most reliable due to its high accuracy and moderate-to-high precision, making it well-suited for transmissivity assessment aligned with specific discharge-to-drawdown dynamics. The VT pump configuration, capable of inducing higher aquifer stress, yielded transmissivity values closely matching field observations, while the submersible pump tended to overestimate transmissivity due to its lower discharge and limited drawdown. These findings highlight the importance of discharge measurement method and pump dating configuration selection in achieving accurate aquifer characterization, offering valuable guidance for sustainable groundwater management.

Keywords: *Transmissivity, discharge measurement, pumping configuration, aquifer pumping test, precision & accuracy, alluvial aquifer*

ELECTRICAL RESISTIVITY AND VLF-EM METHODS FOR GROUNDWATER MAPPING IN DROUGHT-PRONE BASALTIC TERRAINS OF NORTH MAHARASHTRA, INDIA

Anupama Patil and Kadari Srinivasrao*

[1]Groundwater Surveys and Development Agency, Government of Maharashtra, India
[*]Corresponding author e-mail: srinivasarao.kadari@gmail.com

The primary objective of this study is to identify groundwater occurrences in the drought-affected basaltic terrain in North Maharashtra, using an integrated geophysical approach. Water resources in the region exhibit significant temporal and spatial variability. Although the state does not face an overall water shortage, certain locations remain chronically water-stressed due to regional water demands increasing at more than twice the rate of population growth over the past three years. Village administration plays a pivotal role in ensuring sustainable and safe drinking water through the implementation of piped water supply systems for households. Persistent water scarcity restricts access to safe drinking water and hampers basic hygiene practices in homes, schools, and healthcare facilities, exacerbating socio-economic challenges in these regions.

The study area, Rajapur Village, is situated in Yeola sub-division of Nashik District, Maharashtra. The district's climate is generally pleasant, characterized by dryness throughout the year except during the southwest monsoon season. The winter season extends from December to mid-February, followed by the summer season lasting until May. The district experiences significant variability in annual rainfall, ranging from approximately 500 mm to 3400 mm. Analysis of negative departures from normal annual rainfall indicates that about 75% of the district, located east of the Western Ghats including Sinnar, Niphad, Surgana, Kalvan, Satana, Chandwad, Yeola talukas, and parts of Dindori, Peint, and Malegaon sub-divisions can be classified as drought-prone. The average annual rainfall during 2002–2011 ranged from 476.7 mm in Devali to 3508 mm in Igatpuri. In Rajapur, water scarcity is a persistent challenge. The Village administration supplies water once every 15 days through tankers, which are increasingly costly as daily demand grows even in less populous communities. Villagers must transport water approximately 3 km daily from the government headquarters using bicycles, motorbikes, and carts. To alleviate the shortage, the Village administration excavated a new open well, 60 ft deep, located downstream of the Wadpati percolation tank, about 3 km from Govthan. Despite these efforts, the new source often fails to provide water reliably, with interruptions occurring at least once every two days. This underscores the need for a sustainable and comprehensive solution to address water scarcity in the region.

Geophysical investigations were conducted in the vicinity of a drinking water source well, with a depth of 20 m. The primary objective of the survey was to delineate fractures, joints, and groundwater-bearing zones near the source well using Very Low Frequency (VLF) electromagnetic and Vertical Electrical Sounding (VES) resistivity methods. Six VLF profiles (2010E, 2020E, 2030E, 2040E, 2050E, and 2060E) were acquired, each extending 300 m in length with measurements recorded at 10 m intervals. The VLF data were processed and interpreted using RAMAG software. Multi pseudo-depth sections revealed two sets of medium to good conductive geological bodies (depicted in yellow, light pink, and dark pink shades), which were interconnected. Profiles four, five, and six indicated feeble current

densities exceeding 20%, corroborated by VES data. The VES data, interpreted using IPI2WIN software, employed a three-layer resistivity model (ρ1, ρ2, ρ3) to match measured curves with theoretical master curves as described by Orellana and Mooney (1966). Three VES surveys were conducted with electrode separations (AB/2) ranging from 100 to 120 m. Among these, groundwater potential zones were identified at two VES locations. The qualitative analysis categorized geo-electric layer patterns into AA curves (ρ1 < ρ2 < ρ3 < ρ4) and HA curves (ρ1 > ρ2 < ρ3 < ρ4).

The VES data revealed five to six geo-electric layers with resistivity values ranging from 13.50 Ω-m to 82.20 Ω-m, averaging 40.75 Ω-m. The primary aquifer was identified within the fourth to sixth layers, comprising weathered, vesicular, fractured, or jointed zeolitic basalt. The saturated potential zone depth ranged from 4.23 to 34.01 m (average 19.12 m), with a thickness of 3.32 to 29.78 m (average 16.55 m). The conductive anomalous zones corresponded to fractured lineaments-oriented northeast-southwest. A significant fracture, located 38 m southeast of the source well, was determined to have a width of approximately 38 m. The multi pseudo-depth section indicated that the source well was constructed on a high-resistivity geological body (negative anomaly), interpreted as a groundwater barrier, likely an underground compact rock structure. Notably, a fracture was located 30–40 m east of the well, highlighting a shallow groundwater potential zone in this region. Based on the findings, the Bore Blast Technique (BBT) was employed to enhance connectivity between the southeastern fracture zone and the source well. A total of 20 boreholes, each 20–30 m deep, were drilled in three parallel lines and simultaneously blasted. Following the blast, muddy water with bubbles emerged from the well, accompanied by a significant rise in the water level. This intervention successfully reduced the project's expenditure by minimizing the number of required boreholes. Within 24 hrs, the source well was replenished with water, enabling the Village administration to lift water, fill overhead tanks, and supply it to villagers daily. This reduced reliance on costly water tankers, ensuring that the community did not face drinking water shortages even during the summer. The integrated geophysical approach provided a comprehensive understanding of surface and subsurface structures and groundwater potential in the study area. The outcomes facilitated sustainable water resource development, significantly benefiting the local community.

Keywords: *Geophysical investigations, groundwater exploration, pseudo-depth sections, electrical resistivity, bore blast technique*

GROUNDWATER POTENTIAL ZONES USING AHP TECHNIQUE FOR THIRUVANANTHAPURAM DISTRICT, KERALA, INDIA

Pavithra S.L.* **and Yateesh Ketholia**

Indian Institute of Remote Sensing, Dehradun, India
**Corresponding author e-mail: pavithrasivakumar2001@gmail.com*

Groundwater represents an essential natural resource that plays a crucial role in sustaining human health, fostering economic development, and maintaining ecological diversity. This study undertakes a detailed assessment of groundwater potential zones specifically located in the Thiruvananthapuram district of Kerala, employing advanced methodologies including the Analytical Hierarchy Process (AHP) and Geographic Information Systems (GIS). By integrating these powerful tools, the study aims to effectively evaluate and map the status of groundwater resources, which are paramount for sustaining local populations and ecosystems. The AHP methodology, recognized for its structured approach to decision-making, was applied here to prioritize various factors that influence groundwater availability. In this analysis, thirteen thematic layers have been meticulously chosen and integrated, each reflecting critical aspects of the environment that impact groundwater recharge potential. The layers include lithology, which assesses different rock formations and their capacities for water retention; geomorphology, which examines the effects of landscape features on hydrological pathways; and lineament density, which explores the occurrence of fractures and faults that facilitate the movement of groundwater. Furthermore, drainage density was analyzed to understand the distribution patterns of surface water, which can significantly influence groundwater replenishment. In addition to these, slope characteristics were scrutinized to appreciate how the angles of terrain can affect both infiltration rates and the efficiency of runoff. The study also considers surface curvature and roughness, which provide vital insights into the dynamics of water flow across landscapes. The integration of land use/land cover (LULC) is particularly critical, revealing how human activities impact recharge processes in various regions. Soil characteristics were evaluated to determine their capacities for water retention and permeability, which directly affect groundwater availability. The study utilizes the topographic position index (TPI) to assess the positioning of the landscape in relation to potential recharge areas. The topographic wetness index (TWI) was employed to predict zones where water tends to accumulate, influencing both surface and groundwater systems. Furthermore, the normalized difference water index (NDWI) was calculated to assess the extent and health of water bodies within the region, while rainfall data is integrated to characterize regional precipitation patterns, which are vital for understanding groundwater replenishment. The application of AHP in this study facilitates a thorough and systematic approach to weight assignment based on expert judgment, ensuring a detailed evaluation of how each factor contributes to groundwater potential. The integration of GIS enhances this analysis by enabling detailed spatial mapping and visualization across Thiruvananthapuram district, revealing profound variations in groundwater potential influenced by geographic and environmental factors. For instance, areas characterized by active fluvial deposits have been identified as having very high recharge potential, particularly when these deposits are found in conjunction with lower drainage density and enhanced lineament density that allows for efficient groundwater movement. Conversely, regions that feature gentle slopes and rich forest coverage display increased capacities for groundwater recharge, serving as natural buffers and facilitators for sustainable water flow.

In stark contrast, urbanized areas exhibit a significant decline in groundwater potential due to extensive land use modifications, prompting concerns over resource management. Based on these assessments, groundwater potential zones have been classified into five comprehensive categories: very low (indicating unfavorable conditions for recharge), low (showing limited but recoverable potential), moderate (supporting localized recharge efforts), high (demonstrating good potential for active recharge), and very high (representing optimal conditions for substantial recharge). The results obtained from this detailed evaluation underscore a critical finding, groundwater systems are particularly vulnerable to climate variability, which necessitates the adoption of adaptive management strategies tailored to the specific conditions of the region. High-potential areas generally contain optimal combinations of geological, hydrological, and topographical characteristics, while zones with reduced potential are often linked to urbanization trends and adverse natural conditions. This disparity emphasizes the pressing need for sustainable groundwater management practices, particularly protective measures in high-potential zones, along with rehabilitation strategies aimed at areas with diminished groundwater resources. The insights derived from this comprehensive study offer significant implications for local and regional water resource management strategies. The effectiveness of GIS-based analysis in assessing groundwater potential zones is demonstrated vividly through this research, showcasing how a multi-layered approach can reveal the intricate interactions that affect groundwater recharge and availability. Moreover, the study emphasizes the importance of tackling over-exploitation risks and adapting to the challenges posed by climate change, thereby contributing considerably to informed and evidence-based decision-making aimed at sustainable water management practices in Thiruvananthapuram. Additionally, the adaptability of the methodology utilized in this study provides a robust framework that can be replicated for similar assessments in varied geographical contexts, thereby broadening the relevance of the findings across different regions. Considering escalating climate variability and pressures from human exploitation, there is an increasing necessity for careful planning and the implementation of effective conservation measures to ensure the long-term availability and quality of this indispensable resource for generations to come. Ultimately, this study serves to establish a foundational understanding for developing and executing effective groundwater management strategies within the Thiruvananthapuram district. It highlights the critical balance that must be maintained between resource utilization and conservation efforts. By providing actionable recommendations and insights, the study aims not only to inform local stakeholders but also to contribute to broader discussions concerning sustainable resource management amidst ongoing environmental challenges. This collective approach is essential for recognizing, preserving, and enhancing groundwater resources as integral components of the health and sustainability of both human communities and natural ecosystems alike.

Keywords: *Groundwater potential, AHP, GIS, water resource management*

ASSESSMENT OF DYNAMIC AND STATIC GROUND WATER RESOURCES THROUGH AQUIFER MAPPING IN SIDDHARTNAGAR DISTRICT, UTTAR PRADESH, INDIA

Sujatro Ray Chowdhuri[1*], Madhukar Singh[2], Ebadur Rahman[3], Sandeep Kumar Swaroop[3], S.N. Dwivedi[1] and Shive Prakash Rai[4]

[1]Central Ground Water Board, Faridabad, Haryana, India
[2]Central Ground Water Board, State Unit Office, New Delhi, India
[3]Central Ground Water Board, Northern Region, Lucknow, Uttar Pradesh, India
[4]Department of Geology, Banaras Hindu University, Uttar Pradesh, India
[*]Corresponding author e-mail: sujatro.rc-cgwb@gov.in

Ground water, the most preferred common pool resource is under increasing stress due indiscriminate abstraction for agricultural, industrial, and domestic usage. The unregulated exploitation of ground water resources often results in environmental, social and economic stress. Ground water extraction exceeding the natural recharge, results in depletion of ground water levels, predominantly in shallow aquifers. Over-extraction from shallow alluvium aquifers has resulted in declining water levels, and as consequent, the deeper aquifers are being exploited in many areas. The impact of the stress imposed on the shallow aquifer may also be felt in the deeper aquifer depending upon the nature of hydraulic connection between the aquifers. Rapid urbanization, population growth, and agricultural and industrial demands have led to excessive groundwater extraction in India, particularly in Uttar Pradesh, which accounts for nearly 20% of the country's groundwater use. There is, thus, a need to study the nature of inter-aquifer interaction and to assess the actual quantum of ground water resources available in different aquifers for holistic management of ground water resources. Scientific estimation of the groundwater resources depends upon the disposition of the aquifers and its hydraulic properties. With the objective of enhancing groundwater resource management, Central Ground Water Board under Ministry of Jal Shakti, Government of India has launched the National Aquifer Mapping and Management (NAQUIM) program to map the Country's aquifers in 1:50,000 scale with basic aim to delineate existing aquifer systems, assess their potential and characterise individual aquifers properties in quantitative and qualitative terms. The output of NAQUIM studies, i.e., the aquifer geometry of the multilayered alluvium aquifers and its hydraulic properties has been utilized for Siddharthnagar District of Uttar Pradesh for estimation of the dynamic and static in storage ground water resources down to depth 300 m.

As part of NAQUIM studies, extensive hydrogeological data collection was carried out in the study area, including 62 Vertical Electrical Soundings (VES), construction of 12 aquifer-specific exploratory and observation wells, water level and piezometric head measurements of various aquifers, 12 pumping tests, and sampling of water quality specific to each aquifer. A multilayered three-tiered aquifer system upto depth 300 m has been established using the VES data, lithological log and geophysical log of the exploratory wells. The aquifer system has been characterized by unconfined (Aquifer-IA) aquifers at shallow depths followed by semiconfined (Aquifer-IB) to confined aquifers (Aquifer-II&III) separated by impermeable clay layers at greater depths. Long duration pumping test of 1000 minutes each has been conducted in 12 exploratory wells and aquifer parameters like Transmissivity (T) and

Storativity (S) have been estimated using mathematical models from Jacob 1946, Theis 1935, and Agarwal 1980. Piezometric head of deeper aquifers and water level of lower aquifers were recorded at regular intervals at these locations. Ultimately, the Dynamic (DGWR) and Static Ground Water Resources (SGWR) of the multilayered three-tiered aquifer system upto depth 300 m has been estimated using the aquifer geometry, hydraulic properties of the aquifers and piezometric head of the aquifers in accordance with the methodology prescribed by the Ground Water Resource Estimation Committee (GEC-2015).

The value of the DGWR of Aquifer I has been considered from National Compilation on Dynamic Ground Water Resources of India, 2022 report and the SGWR upto the depth of 50 m using equation [($SGWR_{upto\ 50m} = (50-D_{PRE}) \times A \times Sy \times$ Aquifer %), Where, D_{PRE}= Depth to water level in Pre-monsoon, A= Area of aquifer, Sy= Specific yield of the aquifer and Aquifer%= ratio of cumulative thickness of granular zones and total aquifer thickness]. For estimating SGWR below 50 m depth down to the bottom of Aquifer I, block-wise average Storativity value has been utilized. The SGWR of Aquifer I below 50 m depth has been assessed using equation [($SGWR_{below50m} = (D_{AqI}-50) \times A \times S$), Where, D_{AqI}= Depth to bottom of Aquifer I, S= Storativity of the aquifer]. For estimation of SGWR of confined aquifers i.e., Aquifer II and Aquifer III, average piezometric head and depth up to top of the confined aquifer has been considered. This has been calculated by using the equation [($SGWR_{Aquifer\ II\ \&\ III} = A \times S \times \Delta h = SA(h_{PRE}-h_0)$), where, A= Areal extent of confined aquifer, h_{PRE}= Piezometric head, h_0= depth up to top of the confined aquifer].

Total ground water resources down to depth of 300 m has been estimated as 5.16 billion meter^3 (bcm), of which 0.87 bcm (17%) is DGWR and 4.29 bcm (83%) is SGWR. The distribution of the total resource in three aquifers are 4.92 bcm (95%), 0.21 bcm (4%) and 0.03 bcm (1%), respectively. Groundwater resource assessment down to 300 m reveals that about 95% of resources are in unconfined to semi-confined aquifers, with only 5% in deeper confined aquifers. Unconfined aquifers, which are easier to recharge and sustain, are predominantly utilized for various purposes. Confined aquifers, though under high pressure, contain less water due to reduced porosity at greater depths. For sustainable management, extraction from deeper aquifers should be limited to essential drinking water needs only and the cumulative ground water extraction from all the aquifers should not exceed the annual replenishment in shallow aquifer.

Keywords: *Ground water resource, aquifer mapping, NAQUIM*

MONITORING GROUNDWATER FLUCTUATIONS IN AGROCLIMATIC ZONES OF INDIA USING GRACE SATELLITE DATA AND PRECIPITATION CORRELATION ANALYSIS

Sukant Jain*, Richa Pandey and Mantsha

National Institute of Hydrology, Roorkee, India
**Corresponding author e-mail: sukantjain1@gmail.com*

Groundwater is a vital resource for India, serving as the primary source of water for irrigation, domestic use, and industry. This dependency on groundwater is critical in the dry months of the year. However, rapid industrialization, urbanization, and intensification of agriculture have led to alarming groundwater depletion rates, particularly in regions of northern India. Understanding the fluctuations in groundwater storage and its controlling factors is essential for sustainable management of water resources and for crafting informed groundwater policies. This study aims to monitor groundwater fluctuations across the country by analyzing trends in Terrestrial Water Storage Anomalies (TWSA) over 14 distinct agroclimatic zones of India using data from the Gravity Recovery and Climate Experiment (GRACE) satellite mission. By combining GRACE data with satellite-based precipitation data from the Global Precipitation Measurement (GPM) mission, this study evaluates both the climatic and anthropogenic factors influencing groundwater storage across these zones. The findings offer valuable insights into how groundwater levels are affected by precipitation patterns as well as human activities, providing a foundation for formulating region-specific groundwater management strategies.

This study focuses on the analysis of monthly TWSA data derived from GRACE for the period from 2002 to 2023 across 14 agroclimatic zones of India. TWSA data is a critical measure of changes in terrestrial water storage, encompassing variations in surface water, soil moisture, and groundwater levels. The study area includes diverse agroclimatic zones, including the Trans-Gangetic Plain, Lower Gangetic Plain, Western Himalayan Region and Central Plateau. This zoning is essential for understanding region-specific patterns and enabling tailored management practices. Monthly TWSA values were calculated for each agroclimatic zone, and the trend analysis was conducted using the Mann-Kendall (MK) test, for identifying monotonic trends in environmental data series. The MK test yields the z-score, a standardized statistic that indicates the direction and strength of the trend: positive z-values suggest an increasing trend, whereas negative values indicate a declining trend. In addition to GRACE TWSA data, satellite-based monthly precipitation data from the GPM mission was also obtained for each zone. Correlation analysis was performed between precipitation & TWSA values to identify the influence of rainfall on TWS. A one-month lag was considered in the correlation analysis to account for the delayed effect of precipitation on groundwater recharge processes. This approach helped to distinguish zones where groundwater fluctuations are influenced more by climatic variables from those where human activities are the predominant factor. In this study, GRACE data was not processed to isolate the groundwater storage component. Instead, we directly correlated monthly GRACE TWSA values with rainfall data, enabling us to identify areas where TWSA is in decline but shows a poor correlation with rainfall. This approach suggests that declining trends in GRACE data in these regions are predominantly driven by groundwater depletion, as other variables within TWS typically exhibit strong monthly correlations with rainfall.

The analysis of TWSA trends reveals significant variability in TWS patterns, highlighting both climatic and anthropogenic influences. The test analysis shows a noticeable declining trend in eight out of the 14 zones, predominantly in northern India. Among these, the Trans-Gangetic Plain zone, which spans Punjab, Haryana, Delhi, and parts of Rajasthan, displays the most substantial storage depletion, with a z-score of up to -19, signifying a strongly negative trend. The total water storage decline in this region is particularly alarming, with a cumulative loss of 5213 cm and a maximum annual loss of 73.89 cm in TWS. This extensive depletion is indicative of any continuous climatic extremes or severe over-extraction, likely driven by intensive irrigation practices and high water demands from expanding urban and industrial sectors. Conversely, zones without significant declines in TWSA generally correspond to regions where groundwater storage is more closely associated with rainfall patterns. Correlation analysis between monthly TWSA and GPM precipitation data supports this observation, with R^2 values reaching up to 0.7 in zones where TWSA shows no decline. This positive correlation, particularly with a one-month lag, suggests that in these zones, precipitation is a primary contributor to groundwater recharge and variability. In zones with declining trends, however, the correlation between TWSA and precipitation is markedly lower, indicating that rainfall alone does not account for TWS fluctuations. These results imply that in areas with weak TWSA precipitation correlations, anthropogenic activities such as unsustainable groundwater extraction for irrigation and industrial use are likely the primary drivers of groundwater depletion. For instance, the Trans-Gangetic Plain region exhibits poor correlation between TWSA and precipitation data, reflecting the region's heavy dependence on groundwater for agricultural production and indicating a diminished role of natural recharge processes in replenishing groundwater storage.

This study highlights the significant role of remote sensing in monitoring groundwater fluctuations in India. The findings underscore the potential of GRACE data for tracking trends in TWS and differentiating between climate-induced and anthropogenic factors influencing groundwater levels. By correlating GRACE-based TWSA with satellite-derived precipitation data, this study offers a nuanced understanding of the spatial and temporal variations in groundwater storage. The results indicate a critical need for region-specific groundwater management strategies. In zones where groundwater storage is closely tied to rainfall, water conservation and recharge-enhancement techniques aligned with seasonal precipitation patterns could be effective. In contrast, in areas with severe depletion and weak precipitation correlation, stricter regulations on groundwater use and adoption of sustainable irrigation practices are essential to mitigate further decline. Specifically, the Trans-Gangetic Plain and other northern regions with declining trends require urgent intervention to balance agricultural productivity with sustainable water use practices. The socio-economic implications of these findings are substantial, as groundwater scarcity in highly populated and agriculturally intensive regions could impact food security and economic stability. The outcome of this serves as a critical step towards understanding the complex interplay between climate, human activity, and groundwater trends, offering valuable insights for policy formulation and conservation efforts. By informing both policymakers and stakeholders, this study supports efforts to ensure the long-term sustainability of groundwater resources, contributing to India’s water security in the face of mounting environmental and anthropogenic pressures.

Keywords: *Groundwater storage, GRACE, GPM, MK test, remote sensing*

GEOPHYSICAL RESISTIVITY SURVEY (VES) FOR SELECTION OF ARTIFICIAL RECHARGE OF APPROPRIATE ARTIFICIAL RECHARGE FOR AUGMENTATION OF GROUND WATER RESOURCES IN PAITHANKHEDA VILLAGE, MAHARASHTRA, INDIA

Irshad Shaikh*, Parkash Shelar, Vijaytha Solanki, Aruna Kharat and Sharad Gaikwad

Groundwater Surveys and Development Agency, Chhatrapati Sambhajinagar, Maharashtra, India
**Corresponding author e-mail: irshad.geophy@gmail.com*

Geophysical exploration techniques play a vital role in probing and understanding the nature of the subsurface rock strata. Groundwater in hard rock like Deccan basalts of Maharashtra, occurs mainly in weathered, fractures, faults, and joints. The electrical resistivity method is the most suitable method among all other geophysical methods for the prospecting of groundwater resources. The main reason is the notable contrast between the resistivity of the water-saturated formation and the formation vadose zone of the area. The electrical resistivity methods, using the instrument named ABEM Tetrameter–SAS 300 and Aquameter CRM 20 (4 W), a microprocessor-based instrument used for data collection by which Aquameter's intelligent microprocessor technology employs ingenious methods for extracting subsurface information. It is a popular instrument, because of its single-button operation, deep penetration, and accurate and reliable results, even in adverse field conditions. The instrument has a facility to measure self-potential (SP) which is useful in mineral prospecting and environmental studies. It also has an inbuilt capacity to store more than 100 scans with an average depth of up to 300 m. The method for investigation is vertical electrical sounding (VES) by Schlumberger configuration. At different parts of the study area, soundings at different lithological layers beneath the ground were probed to understand the thickness and surface geological formation by checking with apparent resistivity of each litho-layer and its capacity to bear water capacity of a particular rock. Appropriate no of soundings is done at the project location for getting litho-logical characteristics variation with depth. The obtained readings in the field are plotted in the b-logarithmic graph sheet and the geoelectric field curve was interpreted and correlated with standard two layer's master curves by partial curve matching techniques to ascertain the water-bearing strata beneath the earth. The same was also cross-checked with the computer software IPI2WIN and Computer Software IX1D and the geological condition of the selected Project area. In the present study, the data generated while conducting electrical resistivity surveys through Vertical Electrical Sounding (VES) in Paithan Kheda village in Maharashtra State were analyzed at 22 sites in different locations along with geological and hydro-geological information. The objectives were to understand the nature and extent of the aquifer, to find out the location and thickness of unsaturated zones, and to evaluate the extent of appropriate artificial recharge structures at suitable locations across the village. Interpretation of the top-sounding curves indicates the presence of three to four subsurface geo-electric layers across the study area. The topsoil layer has a range of resistivity values of 2 to 30 ohm-m and lithology comprises of clay with kankar, and lateritic sand. This is followed by the weather and jointed basalt layers with resistivity values of 100 ohm-m. The 300 ohm-m could be identified below the depth of 45 m. At some places, doleritic dykes were also observed with resistivity values > 300 ohm-m. The VES data when correlated with the available lithology data indicates a prominent water-bearing zone between 30 and 45 m below ground level (mbgl). The underlying hard and compact basalt has very little possibility of groundwater occurrence. The top unsaturated and unconfined granular zone up to a depth of 30 m could therefore be easily recharged artificially through rainwater harvesting measures thereby augmenting the groundwater resources of the existing aquifers. Site-specific artificial recharge measures from counter bonding, gully plugs, check dams, and percolation tanks. Recharge shafts and subsurface dekes have been identified across the village for effective recharge of the aquifer especially in its northeastern and southern block regions. Considering the deteriorating groundwater situation, these initiatives would be significant in catering to the needs of future generations. It is the most common, time-saving, and easy-to-operate method for groundwater exploration.

Keywords: *Rainwater harvesting, artificial recharge, VES, lithology, morar shales, Schlumberger configuration*

IDENTIFYING GROUNDWATER POTENTIAL ZONES IN DELHI NCR USING INTEGRATED REMOTE SENSING, GIS AND AHP APPROACHES

Jatin Chaudhary[1], S.M. Pingale[2]* and Deepak Khare[1]

[1]Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India
[2]National Institute of Hydrology, Roorkee, India
**Corresponding author e-mail: pingalesm.nihr@gov.in*

The Delhi and nearby NCR regions have been facing the problem of groundwater scarcity which could be due to an increase in population, global warming that leads to a rise in temperature, and urbanization. To meet the rising demands, we need the groundwater. Climate changes like long dry periods and irregular rainfall have given us even more challenges to look out for better management of the groundwater. To address the issue regarding groundwater scarcity, we first need to identify the groundwater potential zones in NCR and nearby regions. Especially in the regions like NCR where the resources are very limited, we must use very accurate and systemic methods to ensure water availability in the future. To identify the groundwater potential zones, we have used a combination of tools like remote sensing (RS), GIS and the analytic hierarchy process (AHP) to analyse various factors affecting groundwater. For analysis, we have included geological features, land use, slope, drainage density, soil type, and fractures in the ground (lineaments). The study area was chosen based on a mix of urban, semi-urban, and rural areas. The thematic layers have been used that represent the factors that influence groundwater availability. The factors include lithology, slope, drainage network density, soil texture, land use/land cover, and lineament density. The thematic layers were converted into raster format for spatial analysis using GIS. We have used high-resolution datasets for lineament density and lithology to enhance the precision and granularity of the hydrological parameter representation. Using AHP, the weights were assigned to each layer based on their relative impact on the availability of groundwater. We have used a pairwise comparison matrix to quantify the relationships between layers and normalized the weights to ensure reliability and consistency. This organized weighting process helped in identifying the most critical factors that influence groundwater recharge and extraction. Furthermore, the thematic layers were overlaid using the weighted sum approach in the GIS to generate the GWPZ map. Study areas were categorized into four zones: based on good, moderate, poor, and very poor, based on the suitability of groundwater recharge and extraction activities of the map. For validation of the GWPZ map, we have used the observational well data collected across the study area. The strong correlation between the delineated zones and observed groundwater levels confirms the robustness of the adopted methodology. The findings indicated that a significant portion of the study area falls within good and moderate GWPZs. This underscores the effectiveness of the integrated RS-GIS-AHP approach that helps in the accurate identification of zones with high groundwater potential. This study emphasizes the importance of leveraging advanced datasets and innovative methodologies in groundwater studies. The permeability as a weighted factor was incorporated to address spatial variability in subsurface hydraulic conductivity, further improving the delineation of suitable areas for groundwater recharge. Also, the integration of lineament density data offered valuable insights into subsurface water flow pathways, that enhanced the precision of the GWPZ map. The spatial analysis based on GIS has ensured that the thematic layers were effectively combined and has facilitated data-driven decision-making for sustainable groundwater management. The results of this study hold significant implications for regions facing high water demand and resource constraints. The framework for GWPZ mapping has provided a replicable model that policymakers, urban planners, and resource managers can use to prioritize areas for conservation and recharge initiatives. This study also shows the importance of high-resolution datasets and sophisticated weighting methodologies to improve the accuracy and predictive capability of GWPZ maps. The developed methodology has enhanced the reliability of GWPZ assessments, offering important and actionable insights for sustainable development. The findings ensure long-term water resource management in urban and semi-urban settings, particularly in rapidly developing regions like NCR that rely highly on the refined spatial representation of hydrological parameters. By addressing key challenges associated with groundwater scarcity, the findings give insights into ensuring water security and supporting the broader goals of sustainable urban growth. In conclusion, this study introduces an innovative and comprehensive methodology for delineating the GWPZs in NCR and surrounding areas. The usage of advanced datasets along with traditional factors, enables a more detailed and nuanced knowledge of groundwater dynamics. The generated GWPZ maps are a valuable tool for handling groundwater scarcity to promote sustainable growth and development. This adaptable methodology can be extended to similar regions worldwide, which offers a significant contribution to groundwater management and spatial hydrology. This study serves as a typical example for the importance of embracing cutting-edge technologies and interdisciplinary approaches to addressing critical water resource challenges in a rapidly evolving global environment.

Keywords: *Groundwater Potential Zones, GIS, AHP, lithology, lineament density, LULC*

INTEGRATING REMOTE SENSING, GIS AND MACHINE LEARNING TECHNIQUES FOR ASSESSING GROUNDWATER AVAILABILITY

Ashish Dobhal*, Rajeev Ranjan and A.K. Keshari

Department of Civil Engineering, Indian Institute of Technology Delhi, India
**Corresponding author e-mail: ashishdobhal18@gmail.com*

Groundwater is a critical resource for meeting freshwater demands in a region. In recent years, its significance has grown considerably due to increasing threat of climate change to global water supplies, especially for arid and semi-arid regions where water is already in scarce and groundwater level is at a decreasing trend. Globally, agriculture is the largest consumer of groundwater, followed by domestic use and the industrial sector. Groundwater offers a distinct advantage over surface water as it can be accessed on demand. The growing water demand driven by population growth is often addressed by increased exploitation of groundwater resources. Urbanization has elevated this challenge by reducing groundwater recharge through enhanced surface runoff, increased evaporation, and the expansion of impervious surfaces, leading to decreased infiltration. This study is aimed to assess the groundwater availability for the National Capital Territory (NCT) of Delhi. Currently, the city is facing significant challenges regarding its water resources, with limited availability of surface water for drinking and extensive dependence on groundwater to meet industrial, agricultural, and domestic demands. The large-scale extraction of groundwater has disrupted the balance between supply and demand, raising critical concerns about both the quantity and quality of the groundwater. Overexploitation and pollution of groundwater are among the pressing issues, and Delhi has been classified as an overexploited region in terms of groundwater availability. To ensure the sustainable management and utilization of groundwater resources, it is essential to comprehensively evaluate the hydrogeological conditions, along with the driving forces, demand, current scenario, impacts, and responses affecting the groundwater.

The commonly employed methods for investigating groundwater availability include hydrogeological and geophysical testing at the field level, which offer detailed insights into the subsurface hydrogeological characteristics but are often expensive and time-intensive. To address these limitations, the objective of this study is to present an integrated approach combining remote sensing (RS), GIS and machine learning (ML) to assess groundwater availability and identify critical zones that warrant greater attention for effective groundwater resource management in a region. For assessing the groundwater availability of a specific region, acquiring accurate inventory data also remains a challenge due to the dependence of groundwater yield on multiple factors. Thus, in the present study, hydrological and physiographical factors that influence groundwater availability predominantly were analyzed and used as input to the developed ML model. These factors include pervious and impervious surface characteristics, geomorphological characteristics, soil characteristics, and seasonal rainfall patterns of the region. The geomorphology map was obtained from the Geological Survey of India and digitized using ArcGIS. Soil maps were obtained from the National Bureau of Soil Survey and Land Use Planning and converted into digital format. India Meteorological Department (IMD) gridded rainfall dataset was used to obtain the rainfall pattern. Surface water bodies were delineated from high-resolution satellite data of Landsat 9, and LULC maps were created using supervised classification with a maximum likelihood classifier. Images were geometrically rectified to a common projection (Universal

Transverse Mercator and datum WGS84) and resampled using the nearest-neighbour algorithm in ERDAS Imagine software. The classification accuracy was assessed through a confusion matrix comparing classified pixels with reference data. The proposed methodology utilizes random forest (RF), an ensemble decision tree-based supervised machine learning model, to assess groundwater availability. Groundwater depth and pumping datasets were used for training (70%) and validation (30%) of the supervised-based learning. The model uses a collection of independent individual classification and regression tree (CART) classifiers. RF model was chosen due to its robustness and efficiency in remote sensing applications. It uses the Bootstrap aggregation algorithm for creating multiple models from a single training dataset by estimating the statistical quantities from the samples, such as mean, standard deviation, etc., and the final response is estimated based on all the involved outputs from the decision trees. The accuracy of the developed model was analyzed through the receiver operating characteristic (ROC) curve analysis. It is the area under the ROC curve (AUC) that estimates the overall model accuracy and is widely used to analyze the performance of machine learning models. ROC-AUC value ranges from ranges from 0 (poor) to 1 (good), and 0.5 signifies randomness. Further, a sensitivity analysis was carried out to identify the critical factors that influence groundwater resources significantly and assess the impact of variable uncertainties in the final output. The present study utilizes the Geemap module of the cloud-based computing platform Google Earth Engine in Python for the RF model development and performance analysis to assess groundwater availability in the study area. The thematic maps and spatial analysis of various input parameters and the final output have been carried out using ArcGIS 10.5 geospatial tool.

The study reveals that about 10% of the study area exhibits poor groundwater availability and 13% excellent groundwater availability. The area under the ROC curve for RF also indicates good predictive accuracy of the model. The availability of groundwater is observed across all the geological formations in the Delhi region, with its occurrence primarily influenced by hydrogeomorphic units such as the rocky ridges, pediments, alluvial uplands, and floodplains. The alluvial floodplain of the Yamuna River is found as the most proficient zone for subsurface freshwater resources in the region. Significant groundwater level depressions are observed in the southeastern part of Delhi, enclosed on three sides by the Delhi Ridge. Similar depressions are also observed in the southwest district on both sides of the Najafgarh drain. These depressions strongly influence the dynamics of groundwater flow in the region. The study reveals that the rapid population growth, urbanization, and the transformation of pervious to impervious surfaces have significantly impacted groundwater availability in the region. The developed methodology in the present study is scalable, and the findings would be useful for sustainable groundwater management, basin management strategies, agricultural planning, and managing groundwater resources under climate change.

Keywords: *Groundwater, GIS, remote sensing, machine learning, random forest*

NATIONAL AQUIFER MAPPING AND MANAGEMENT (NAQUIM) PROGRAMME: A PAN INDIA INITIATIVE TO MAP AND MANAGE AQUIFERS

Rachna Bhatti* **and G. Praveen Kumar**

Central Ground Water Board, Faridabad, India
**Corresponding author e-mail: rbhattihp@gmail.com*

Groundwater is found within aquifers, which are geological formations capable of storing and transmitting water, typically composed of porous or fractured rocks, or loose materials. In India, groundwater has become a critical resource, fulfilling a significant portion of the nation's requirements for drinking water and irrigation; specifically, it accounts for 80% of the drinking water in rural areas, 50% in urban settings, and two-thirds of the water used for irrigation purposes. The focus has shifted from merely developing groundwater resources to effectively managing them. A fundamental aspect of groundwater management involves aquifer mapping, which serves as the foundational step in the design, planning, and execution of management strategies. This process is essential due to the intricate nature of groundwater systems and the varied conditions influenced by factors such as hydrogeology, social dynamics, economic considerations, and ecological impacts. By implementing aquifer mapping, there is potential for enhanced governance and improved management frameworks for groundwater resources. Aquifer mapping in various hydrogeological settings will provide an accurate and thorough micro-level picture of ground water in India, allowing for the development and execution of effective ground water management plans at the right scale for this shared resource. As a result, many areas of rural India as well as urban India will experience increased irrigation facilities, drinking water security, and sustainable water resource development. Additionally, it will lead to improved groundwater management in places that are susceptible. The Central Ground Water Board is implementing the National Project on Aquifer Management (NAQUIM) under the "Ground Water Management and Regulation" scheme during the XII plan period in order to address the current and upcoming challenges facing the nation's ground water sector. The major objectives are (i) delineation of aquifer disposition in 3-dimension along with their characterization on 1:50,000 scale in identified priority areas; (ii) quantification of ground water availability and assessment of its quality to formulate Aquifer Management Plans, and (iii) facilitating sustainable management of ground water resources at appropriate scales through participatory approach with active involvement of stake holders. Out of 32.8 lakh km^2 of the total geographical area of the country, nearly 25 lakh km^2 of mappable area was identified and has been covered under the NAQUIM program up to 2023. The methodology includes compilation, generation, and integration of existing and new data, thematic map preparation, and formulation of a Management Plan with pinpointing the demonstrative artificial recharge structures. The NAQUIM outputs include information about the lateral and vertical extents of aquifers, groundwater levels, groundwater quality, and status of groundwater resources, along with management plans that include supply- and demand-side interventions. NAQUIM reports are being disseminated to policymakers, state governments, and other stakeholders and are being used to mitigate groundwater issues, with special emphasis on drinking water and groundwater regulation to ensure the sustainability of India's groundwater resources. Based on the ideas of participatory groundwater management, NAQUIM produced a toolkit for groundwater management. Additionally, the management plans are valuable resource for developing appropriate climate change adaptation plans.

Keywords: *Groundwater, aquifer, NAQUIM, artificial recharge, supply and demand side interventions, source sustainability*

GEOSPATIAL ANALYSIS FOR GROUNDWATER RESOURCE ASSESSMENT: A CASE STUDY OF KIRTI NAGAR BLOCK, TEHRI GARHWAL, UTTARAKHAND, INDIA

Bhawna Siwach* and Mohan Singh Panwar

Department of Geography, School of Earth Science, H.N.B. Garhwal University, Srinagar, Uttarakhand, India

**Corresponding author e-mail: siwachbhawna99@gmail.com*

Groundwater is a vital resource for sustaining livelihoods, particularly in mountainous regions such as Uttarakhand, where surface water availability is both seasonal and limited. The state heavily relies on natural springs and groundwater resources to meet the water demands of its population. However, increasing water demand, coupled with climatic variations and the challenging topography of the region, has made sustainable water resource management a pressing concern. The Kirti Nagar block in Tehri Garhwal, Uttarakhand, exemplifies these challenges due to its rugged terrain, variable rainfall, and limited surface water sources. This study addresses these challenges by focusing on the delineation of groundwater potential zones (GWPZs) in the Kirti Nagar block using geospatial techniques and validating these zones through the spatial distribution of natural springs. Springs are an essential source of water in this region, making their preservation and sustainable management critical for the local communities. A systematic and Integrated approach was adopted to delineate GWPZs, leveraging advanced geospatial tools such as remote sensing, GIS and Analytical Hierarchy Process (AHP). The methodology involved generating multiple thematic layers, including slope, lithology, land use/land cover (LULC), soil type, rainfall, drainage density, and lineament density. These layers were derived using satellite imagery, field surveys, and secondary datasets. The AHP method was employed to assign weights to each parameter based on its relative importance to groundwater recharge, determined through expert opinion and pairwise comparisons. This multi-criterion decision-making technique is well-suited for groundwater studies as it enables the integration of diverse factors influencing recharge potential. The weighted overlay analysis in GIS was then applied to integrate the thematic layers and generate a comprehensive groundwater potential map.

The generated map classified the Kirti Nagar block into five distinct categories of groundwater potential: very high, high, moderate, low, and very low. Validation was a critical step in this process, conducted by overlaying the spatial distribution of natural springs on the generated GWPZ map. Field validation and hydrogeological observations further substantiated the reliability of the findings. The analysis identified areas with flat to gentle slopes, high lineament density, and favorable lithological conditions as having higher groundwater potential. Conversely, regions characterized by steep slopes and rocky terrain exhibited significantly lower potential. In the northern part of the Kirti Nagar block, characterized by alluvial deposits and dense vegetation, groundwater potential was found to be very high to high. These areas are favorable for groundwater recharge due to their flat terrain and permeable lithology, which enhance infiltration. In contrast, the southern and western regions, dominated by steep slopes and rocky formations, exhibited low to very low groundwater potential. The steep slopes in these areas promote surface runoff rather than infiltration, thereby limiting groundwater recharge. The validation process indicated a strong correlation between the high-potential zones delineated on the map and the actual locations of

natural springs in the region. This correlation reinforces the accuracy and reliability of the adopted methodology. Springs were predominantly located in areas classified as very high to high potential zones, suggesting that the factors influencing groundwater recharge, such as lineament density and favorable lithology, also govern spring distribution. Drainage density emerged as a critical factor influencing groundwater potential in the study area. Areas with lower drainage density demonstrated higher groundwater recharge potential, as reduced surface drainage encourages water infiltration into the subsurface. Similarly, lineaments, which are fractures or faults in the rock, were found to play a significant role in groundwater movement. These features act as conduits, facilitating the flow and storage of groundwater. The inclusion of rainfall data provided valuable insights into the spatial variability of recharge potential across the study area. Regions with higher rainfall exhibited greater recharge potential, aligning well with field observations and hydrogeological conditions. This study highlights the efficacy of geospatial techniques in delineating groundwater potential zones in mountainous regions with complex hydrogeological settings. The integration of AHP and GIS ensures a reliable and cost-effective approach for groundwater exploration. By combining scientific methods with local knowledge, the study offers practical solutions to address water scarcity challenges in the Kirti Nagar block.

The findings provide valuable insights for policymakers, planners, and local authorities to develop sustainable groundwater management strategies. The identification of high-potential zones can guide targeted groundwater exploration and the implementation of recharge structures such as check dams and percolation ponds. Additionally, conserving natural springs, which are intrinsically linked to groundwater systems, is essential for maintaining the water security of local communities. This study also emphasizes the importance of adopting a holistic approach to water resource management, considering both surface and subsurface water systems. By integrating multiple criteria and leveraging advanced geospatial tools, the methodology ensures a comprehensive understanding of the factors influencing groundwater potential. The results demonstrate that areas with flat terrain, dense vegetation, and permeable lithology are most suitable for groundwater recharge, whereas steep and rocky regions are less favorable. Moreover, the study underscores the role of lineaments and drainage density in influencing groundwater movement and storage. These insights can inform the design of site-specific interventions to enhance groundwater recharge in low-potential areas. For instance, constructing recharge pits along lineaments or reducing surface runoff in steep terrains can improve water infiltration. The Integration of rainfall data adds another dimension to understanding groundwater dynamics in the region. By correlating rainfall patterns with recharge potential, the study provides a basis for predicting the impact of climate variability on groundwater resources. This is particularly relevant for Uttarakhand, where monsoon rains are critical for replenishing water sources. In conclusion, this study demonstrates the potential of geospatial techniques in addressing the challenges of groundwater resource management in mountainous regions like the Kirti Nagar block. The delineation of GWPZs provides a scientific basis for sustainable water management and the conservation of natural springs. By combining modern technology with traditional knowledge, this approach offers a pathway to ensure water security for communities in Uttarakhand. The findings can serve as a model for similar studies in other mountainous regions, contributing to the broader goal of sustainable water resource management in the face of increasing demand and climate change.

Keywords: *Groundwater, geospatial techniques, springs, sustainable water management*

ESTIMATION OF AQUIFER HYDRAULIC CHARACTERISTICS USING DAR-ZARROUK PARAMETERS: A CASE STUDY OF LOHAGHAT BLOCK, CHAMPAWAT DISTRICT, UTTARAKHAND, INDIA

Somvir Singh*

Central Ground Water Board, Mid-Eastern Region, Dak Bungalow Chauraha, Patna, Bihar, India
**Corresponding author e-mail: somvir81-cgwb@gov.in*

Groundwater is a critical source of potable water for domestic, industrial, and agricultural uses. However, it is increasingly under threat due to over-exploitation driven by urbanization, industrial activities, and agricultural demands. This degradation has had severe, long-term impacts on both human populations and ecosystems. The Vertical Electrical Sounding (VES) is a widely used geophysical method based on measuring the potential difference between one pair of electrodes while transmitting direct current through other pair and offer valuable insights into the depth, thickness, and lateral extent of aquifer systems in the piedmont zone. For this study, resistivity soundings were conducted using the Schlumberger electrode configuration with a maximum current electrode separation (AB/2) of 470 m. The apparent resistivity values derived from the formula were plotted on a bi-logarithmic graph against the half-current electrode separation. From these plots, qualitative deductions were made regarding the resistivity of the top layer, the depth of each layer, and the signature of the curves. Initial quantitative interpretations were conducted using the partial curve matching technique, wherein the field curves were matched segment by segment with appropriate master and auxiliary curves. These methods are crucial for identifying groundwater potential zones and managing water resources effectively. While traditional hydraulic characterization involves pumping tests to determine parameters such as hydraulic conductivity, transmissivity, porosity, and specific yield, geo-electric parameters can provide alternative estimates in the absence of pumping test data. The Schlumberger array is particularly effective for subsurface investigations due to its high signal-to-noise ratio, good resolution of horizontal layers, and sensitivity to depth. This study aimed to characterize the geo-electrical properties of shallow aquifers and estimate their hydraulic parameters using surface geophysics, and calculate their protective capacity in Lohaghat block of Champawat district, Uttarakhand.

The Lohaghat block, located in the Kumaon Division of the Champawat district and covers about 216 km² area. The climate is relatively temperate and humid compared to adjacent regions. The diurnal temperature range is significant, with the hottest months being May and June, though temperatures are generally not excessively comfortable and heavily relies on groundwater for drinking and agricultural purposes. Groundwater in this area primarily originates from localized aquifers within favorable geo-hydrological conditions such as river valleys and fractured rock formations. Physiographic factors, including gently sloping areas and broad valleys, also influence groundwater emergence. The study area exhibits a complex geological framework characterized by a diverse array of rock types, influenced by intermittent tectonic disturbances associated with various orogenic cycles. The aquifer behavior in this region is complex, influenced by alluvial sediments from surrounding mountain ranges and the Doon Gravels along the Sarda River. Despite this complexity, delineating aquifers remains challenging due to the reliance on surface features rather than

subsurface characteristics. Effective groundwater management necessitates thoroughly understanding the area's geological, geomorphological, and hydrological conditions.

The interpretation of the Vertical Electrical Sounding (VES) data was conducted using IX1Dv3.1 software, employing a layered resistivity model ($\rho1$, $\rho2$, $\rho3$) to match measured curves with a set of theoretically calculated master curves, as described by Orellana and Mooney (1966). This study conducted twenty VES with electrode separations (AB/2) varying between 100 and 470 m, and out of 20 VES locations, the groundwater potential zones occur in 12 VES locations in the study area. Qualitative assessment identified four primary geo-electric layer patterns: HK curves ($\rho1 > \rho2 < \rho3 > \rho4$) and KH curves ($\rho1 < \rho2 > \rho3 < \rho4$). The VES data revealed seven to eight geo- electric layers, with resistivity ranging from 13.24 Ω-m to 170.59 Ω-m, and an average resistivity of 83.66 Ω-m. The principal aquifer was located within the fourth to seventh geo- electric layers, consisting of weathered or fractured phyllites, granite, quartzite, and sand. The aquifer depth varied from 17.24 to 91.15 m with an average value of 53.88 m and its thickness ranged from 14.59 to 69.56 m (average 28.17 m) Hydraulic characteristics derived from the geo- electric data indicated a porosity range of 33.31% to 56.14% with an average of 45.40%, protective capacities from 0.12 to 1.9 mhos with an average value of 0.55 mhos, and transverse resistance between 344.03 and 8272.25 Ωm^2 with an average of 2476.63 Ωm. Whereas, Transmissivity values ranged from 67.61 to 902.54 m^2/day with an average value of 268.77 m^2/day, transverse resistivities from 4.72 Ω-m to 208.53 Ω-m with an average value of 61.21 Ω-m, longitudinal resistivities from 37.11 Ω-m to 521.63 Ω-m with an average value of 165.25 Ω-m, and anisotropy values from 0.27 to 1.35 with an average value of 0.64. Hydraulic conductivity varied between 3.20 and 34.72 m/day with an average of 10.45 m/day. These parameters were used to estimate hydraulic conductivity and transmissivity. Dar-Zarrouk parameters including aquifer thickness, resistivity, hydraulic conductivity, transmissivity, longitudinal conductance, transverse resistance, and anisotropy were utilized to assess groundwater potential, classifying the area into moderate and good productivity zones. This study demonstrates the efficacy of surface geophysical methods in estimating aquifer hydraulic characteristics where pumping test data are not available.

Keywords: *Electrical method, Dar-Zarrouk parameters, Hydraulic parameters, Longitudinal resistivity, Transverse resistivity, Anisotropy*

MAPPING AQUIFER POTENTIAL: A HYDROGEOLOGICAL INVESTIGATION OF THE LUNI RIVER BASIN, RAJASTHAN, INDIA

Pintu Kumar Gupta[1*], L. Surinaidu[1], Nitesh Patidar[1], Ajit Kumar Behera[1], Satendra Kumar[1] and Sudesh Kumar Chaudhary[2]

[1]*National Institute of Hydrology, Roorkee, India*
[2]*North-Western Regional Centre, Jodhpur (Rajasthan), National Institute of Hydrology, India*
[*]*Corresponding author e-mail: guptapintu.nihr@gov.in*

The Luni River Basin in Rajasthan, India, faces critical groundwater challenges due to over-extraction, limited recharge, and climatic variability. This study investigates key aquifer parameters transmissivity and storativity revealing significant spatial variations influenced by geological heterogeneity. The hydrogeological investigation of the Basin underscores the significant impact of geological heterogeneity and human activities on groundwater dynamics. This study identified wide spatial variations in aquifer properties, emphasizing the need for region-specific management strategies. By combining field investigations and historical data, the research provides a robust framework for understanding aquifer behavior in arid and semi-arid regions. The Luni River Basin, encompassing the arid and semi-arid regions of Rajasthan, India, is crucial for sustaining agricultural livelihoods and local ecosystems. Assessing aquifer parameters like transmissivity, storativity, and hydraulic conductivity is crucial for understanding groundwater dynamics in the Luni Basin. However, a notable gap in comprehensive studies evaluating these parameters leads to a limited understanding of the basin's hydrogeological dynamics. This research aims to accurately characterize aquifer parameters by conducting comprehensive pumping tests, facilitating better water resource management. However, unsustainable groundwater extraction practices, coupled with limited recharge rates and climatic variability, have led to declining groundwater levels and quality. This poses significant challenges for water resource management and sustainability in the region. Existing research in the Luni River Basin has primarily focused on groundwater assessment, hydrogeological mapping, and water quality analysis. However, there is a gap in comprehensive spatio-temporal analyses that examine long-term trends and variations in groundwater levels across different spatial scales within the basin. There is a need to investigate spatial variations in groundwater levels across different hydrogeological units, land use types, and administrative boundaries within the Luni River Basin. With climate variability exacerbating the issue, understanding the hydrogeological dynamics of the basin is critical for sustainable water management. This study aims to estimate key aquifer parameters-transmissivity, storativity, and hydraulic conductivity-through comprehensive field investigations and laboratory experiments. The outcomes will facilitate the development of better water resource management strategies tailored to the basin's unique geological and climatic conditions. The Luni River Basin originates near Ajmer, Rajasthan, and flows through seven districts, covering a stretch of 495 km before terminating in the Rann of Kutch, Gujarat. Characterized by extreme climatic conditions, the region experiences annual rainfall averaging 464 mm (2000–2022 IMD data). The basin's geology includes diverse formations like alluvial plains, dunes, and sedimentary rocks, impacting groundwater availability and movement. Groundwater extraction supports agriculture, but overuse, coupled with low recharge rates, has intensified water scarcity. To achieve the study objectives, a multi-phased methodology was adopted: Geological data was analysed to select pumping test locations across diverse hydro-geological settings. Constant-rate and step-drawdown methods were employed to determine aquifer properties for the time-drawdown data obtained from the CGWB. Using Jacob's straight-line, curve fitting method and Theis's recovery methods, data was analysed to estimate transmissivity, storativity, and hydraulic conductivity. Two exploratory wells will be drilled in confined and unconfined aquifers, and sediment samples will be collected for lithological profiling and laboratory experiments. The data from field tests and historical trends were synthesized to identify patterns and drivers of groundwater fluctuations. The study from the data collected revealed significant spatial variations in aquifer properties across the Luni River Basin, attributed to geological heterogeneity and land use practices. Transmissivity values showed a wide range, from as low as 4.42 m^2/day (Amritpura, Ajmer) to 792.11 m^2/day (Gangasara, Barmer). High transmissivity values in areas like Barmer indicate more permeable aquifers, likely due to quaternary deposits. Low values in regions like Ajmer suggest restricted groundwater movement, possibly influenced by compacted sedimentary formations. Storativity values ranged from 3.81×10^{-4} to 1.02×10^{-3}, with variations linked to aquifer confinement levels and geological settings. Observation wells in confined aquifers exhibited lower storativity, indicating limited storage potential. Specific capacity was highest in exploratory wells at Balotra and Barmer, confirming the presence of productive aquifers in these regions. Quaternary formations displayed better aquifer properties, such as high transmissivity and storativity, supporting enhanced groundwater extraction. Jurassic and Palaeocene formations had limited permeability, reducing groundwater potential. The hydro-geological investigation in the Luni River Basin highlights the critical role of geological heterogeneity and human activities in shaping groundwater dynamics. The study's findings emphasize the need for region-specific groundwater management strategies, including recharge enhancement and regulation of extraction practices. High-transmissivity regions can be targeted for managed aquifer recharge (MAR) initiatives. Low-transmissivity areas require controlled groundwater extraction and alternative water sources to prevent aquifer depletion. By integrating field, lab, and historical data, this research offers a comprehensive framework for understanding aquifer behavior in arid and semi-arid regions, providing a valuable basis for policy formulation and sustainable water resource management in the Luni River Basin.

Keywords: *Luni river basin, pumping test, transmissivity, storativity, geology*

SATELLITE-BASED APPROACH TO ESTIMATE THE GROUNDWATER STORAGE CHANGES AND LAND DEFORMATION FOR JODHPUR CITY

Surender Pal, L. Surinaidu* and Anupma Sharma

National Institute of Hydrology, Roorkee, India
**Corresponding author e-mail: lsn.nihr@gov.in*

The Sentinel-1 satellite provides high-resolution radar data for precise land deformation monitoring using InSAR, detecting subtle ground movements such as subsidence. Launched on 3 April 2014, this polar-orbiting satellite operates in a sun-synchronous orbit and offers frequent revisits, ensuring regular and accurate surface displacement measurements and giving high temporal resolution images. InSAR techniques analyse phase differences between SAR images captured at different times to detect changes in the Earth's surface. DInSAR, an advanced form of InSAR, is particularly effective for monitoring land subsidence, environmental changes, and geohazards. It processes sequential interferograms to estimate cumulative displacement over time and is well-suited for tracking surface deformation in stable regions. On the other hand, the GRACE satellite monitors changes in total water storage (TWS) across large regions, capturing variations in groundwater mass by measuring subtle shifts in Earth's gravity field. GRACE's data helps identify groundwater depletion or accumulation over time, providing valuable insights into long-term groundwater trends and anomalies on a regional scale.

The present study focuses on Jodhpur in western Rajasthan, India. This region is characterized by its arid climate conditions and unique geomorphology that comprises dunes, rocky outcrops and alluvial plains that make it significant reliance on groundwater resources. The study combines Sentinel-1's DInSAR technique with GRACE data to analyse surface deformation caused by groundwater extraction. The study used 30 Single Look Complex (SLC) images from 1 January 2017 to 31 December 2024, processed with the Sentinel Application Platform (SNAP) software. SLC data, retaining phase information and amplitude, are indispensable for interferometry. The DInSAR technique successfully detected subsidence and uplift in the region with surface deformation. Key methodologies of DInSAR include pre-processing, which is (a) orbit file correction, which is updated precise orbit information that improves geolocation accuracy. (b) Coregistration: Aligning master and slave images at the sub-pixel level using Enhanced Spectral Diversity (ESD) ensures phase consistency. (c) Interferogram Generation: Subtraction of flat-earth and topographic phases to produce differential interferograms. Post-Processing: (a) Debursting: Seamline removal creates a continuous interferogram. (b) Phase Filtering: Goldstein filtering enhances fringe visibility and reduces noise. (c) Phase Unwrapping: Ambiguities are resolved in interferogram using SNAPHU (Statistical-Cost Network Flow Algorithm for Phase Unwrapping). (d) Geocoding: The unwrapped phase is georeferenced using SRTM 1 arcsec DEM for spatial accuracy. (e) Validation: Ground-truth data from GPS measurements and groundwater level studies are used for accuracy assessment.

The preliminary results from the present study, compared GRACE'S TWS data with DInSAR surface deformation. TWS data indicate distinct seasonal and long-term annual trends in water storage variations. The results reveal changes in hydrological dynamics in Northern and Central part of Jodhpur. For example, during pre-monsoon of year 2023 in northern Jodhpur, average TWS was recorded at -201.73 mm, showing water storage depletion, possibly due to high groundwater extraction during summer. The post-monsoon period partially recovered, with an average TWS of -156.72 mm. The overall year in northern Jodhpur showed a marginal decline in water storage, with a net change of -2.73 mm from January to December. On the other side, Central Jodhpur displayed comparatively better hydrological condition throughout the year, with an average TWS of -133.02 mm and a significant recovery in post-monsoon with an average TWS of -62.49 mm; overall +77.11 net change from January to December, highlighting effective monsoon recharge. The Sentinel 1 SAR study shows that the subsidence of 10-20 mm per in the areas of sandy and sediment-filled zones that may be due to intensive groundwater pumping. However, Jodhpur's rocky basement may limit subsidence in some areas. On the other hand, upliftment is negligible (<5 mm/year), mainly in areas of low groundwater extraction, rates make upliftment relatively rare. The reasonable consistency of both Sentinel 1 SAR data and GRACE'S TWS is observed. The in-situ groundwater level data provided by Central Ground Water Board's (CGWB) having good seasonal correlation with GRACE data. The joint inversion of Sentinel 1 higher resolution data with GRACE data may enhance hydrological monitoring that can allow more accurate and detailed analysing the spatial and temporal fluctuations of water storage patterns across the region. Groundwater level (GWL) data is point-based data of well observation that will supplement the regional trends observed in Sentinel 1 and GRACE, allowing for a more complete examination of groundwater dynamics. Integrating these InSAR and GWL measurements will provide great insight into groundwater sustainability and sufficient detailed information about land deformation.

This analysis underscores the applicability of DInSAR techniques in land deformation studies for urban and arid regions. The availability of Sentinel-1 SAR data and SNAP software presents a strong avenue through which trends may be detected and analysed. However, for future studies, advanced techniques such as StaMPS PSI (Persistent Scatterer Interferometry) and SBAS (Small Baseline Subsets) should be employed to analyse long-term deformation trends with better resolution. Expanding the study area to include the entire Luni River Basin and analysing Sentinel-1 could provide a comprehensive understanding of regional deformation trends and improve monitoring surface deformation linked to groundwater depletion. Additionally, the effects of anthropogenic activities such as industrial expansion and urbanization can be quantified more precisely. In conclusion, Sentinel 1 high-resolution SAR data and Grace's TWS data with groundwater level change data give a valuable approach to land deformation analysis. The study also shows the challenges in combining SAR and TWS data, but it can be overcome by extending the dataset's timeframe of Sentinel 1 and interpolation for TWS data. This study outcome will serve as a baseline for assessing subsidence in urban and agricultural zones, aiding better infrastructure planning and management.

Keywords: *SAR, InSAR, DInSAR, GRACE, ground water storage, land deformation*

GEOPHYSICAL INVESTIGATIONS TO QUANTIFY FRESHWATER STORAGE FOR CONJUNCTIVE WATER RESOURCE MANAGEMENT IN IGNP

Survey Daman Sharma*, Nitesh Patidar, M.K. Goel, Anupma Sharma, Gopal Krishan, Surjeet Singh and Sumant Kumar

National Institute of Hydrology, Roorkee, India
**Corresponding author e-mail: surveydaman@gmail.com*

The Indira Gandhi Nahar Pariyojana (IGNP), an important irrigation project in northwestern India, was established to transform arid lands into productive agricultural areas. While the project has achieved significant success in enhancing agricultural output and livelihood opportunities, it has also led to unintended challenges. Issues such as waterlogging, soil salinity, and uneven groundwater distribution have emerged over time, resulting from excessive seepage, inefficient water use, and the region's complex hydrogeology. Waterlogging, particularly in the upper commands, and salinity in the middle and lower commands have undermined agricultural productivity, posing a significant challenge for sustainable water resource management. Addressing these issues necessitates an integrated approach that combines the use of surface water and groundwater, especially by leveraging the freshwater pockets of saline aquifers. This study employed a combination of geophysical and hydrochemical methods to identify and quantify freshwater storage zones in the IGNP command area. Electrical Resistivity Tomography (ERT) was used to delineate subsurface resistivity variations, which help distinguish between freshwater and saline water zones. Freshwater exhibits higher resistivity due to its lower ionic concentration compared to saline water. The ERT survey, conducted at 10 strategic locations involved a Schlumberger electrode configuration with spacing optimized for capturing resistivity profiles up to a depth of 50 m. These locations were chosen based on their hydrogeological importance and their relevance to water resource management.

The ERT findings provided valuable insights into the spatial distribution of freshwater and saline zones across the IGNP area. Results revealed that in the upper commands, including Sardarpura and Masitawali, the shallow zones of high resistivity indicate freshwater accumulation. These zones, often shallower than 20 m, are likely being recharged by canal seepage and rainfall. The lower density of fresh water leads to its retention in the top layers, creating these freshwater pockets. In the middle commands, encompassing areas like Suratgarh and Zorawarpura, the resistivity profiles were dominated by low-resistivity zones, reflecting extensive saline aquifers. However, intermittent localized freshwater pockets were observed at various locations. The lower commands exhibited a mix of resistivity patterns, with some areas showing moderate resistivity values that may correspond to brackish or slightly saline water. To complement the geophysical analysis, water samples were collected from different locations for water quality assessment. The samples were analyzed for parameters such as pH, electrical conductivity (EC), trace metal concentrations, and isotopic composition (δD and $\delta^{18}O$). These hydrochemical parameters provided additional context for interpreting the ERT results and evaluating water suitability for agricultural and domestic purposes. The pH values of the samples ranged from 8.08 to 9.49, indicating slightly alkaline conditions typical of the region. Electrical conductivity values, a direct indicator of salinity, varied significantly across the study area, with values ranging from 750 µS/cm in freshwater zones to over 20 mS/cm in highly saline aquifers. These findings aligned well with the

resistivity patterns observed in the ERT profiles, further corroborating the delineation of freshwater and saline zones.

The trace metal analysis revealed varying concentrations of elements such as arsenic (As), iron (Fe), and manganese (Mn). While arsenic and iron concentrations were generally within permissible limits for irrigation in freshwater zones, elevated levels were detected in some saline areas, emphasizing the need for cautious groundwater use. The isotopic analysis of δD and $\delta^{18}O$ provided critical insights into the recharge mechanisms of the aquifers. The isotopic signatures indicated that groundwater in the upper commands is primarily recharged by canal seepage and rainfall, with minimal evaporation effects. In contrast, the middle commands exhibited isotopic enrichment, consistent with evaporative processes and limited recharge. This distinction highlights the dynamic interaction between surface water and groundwater in the IGNP region and underscores the importance of localized management strategies. The integration of ERT results with hydrochemical data highlights the heterogeneous nature of aquifers in the IGNP area. The identified freshwater zones, particularly in the upper commands, offer significant potential for sustainable groundwater extraction to supplement irrigation and domestic water needs. These zones can support conjunctive water use strategies, wherein surface water and groundwater are managed together to optimize resource availability and minimize adverse impacts such as salinity intrusion. Conversely, the predominance of saline aquifers in the middle commands calls for alternative approaches, such as the use of saline-tolerant crops, aquaculture, or controlled drainage systems, to mitigate the challenges of salinity while utilizing available water resources effectively.

The findings of this study demonstrate the value of combining geophysical and hydrochemical methods to characterize groundwater systems in regions facing complex water resource challenges. By delineating freshwater storage zones and understanding the hydrogeological processes governing groundwater quality, this research provides a foundation for sustainable water resource management in the IGNP command area. The potential for leveraging freshwater pockets within saline aquifers underscores the importance of targeted interventions to enhance water use efficiency and ensure long-term agricultural sustainability.

Keywords: *IGNP, groundwater, conjunctive management, ERT, salinity*

GEOSPATIAL DELINEATION OF GROUNDWATER POTENTIAL ZONES: A MULTI-CRITERIA APPROACH FOR PROBLEMATIC DISTRICTS OF BUNDELKHAND AND KYMORE PLATEAU, INDIA

Ashish Pratap Singh[1], Harshita Rani Ahirwar[2], M.K. Nema[1*] and A.K. Nema[2]

[1]National Institute of Hydrology, Roorkee, India
[2]Banaras Hindu University, Varanasi, India
[*]Corresponding author e-mail: mxnema@gmail.com

The water demand is increasing rapidly with the growing population, urbanization, and industrialization in the whole world. Among the resources of water, groundwater is considerably a highly reliable source of fresh water. Because of various factors like pollution, over-extraction, and climate variability, both the quality and quantity of groundwater supplies are under severe threat. Also, it has become a difficult task to identify and delineate the groundwater potential zones precisely for sustainable water resource management. Madhya Pradesh being one of the important states in India from the point of view of water availability and forest cover, is selected for research. Because of the state's diverse hydrogeological qualities, the groundwater potential in Madhya Pradesh varies noticeably from one location to another. Chhatarpur district (8672 km^2) from Bundelkhand region, Katni (5058 km^2), Panna (7092 km^2), Rewa (6303 km^2), and Satna (7491 km^2) from Kymore Plateau region was selected for the study. The total area is about 34,616 km^2 approximately with elevation ranging from 200 m to 600 m above mean sea level. The soil profile of the study area comprises mainly alluvial and red sandy soil. The average infiltration rate ranges from 2.5 to 5 cm/hr. The land use land cover (LULC) analysis reveals that 25% of the area includes urban and barren land, 30% of the area is forested whereas 45% of the total area is under agriculture. The region lies within the Tons and Ken River basin. It receives around 800-1200 mm annual average rainfall out of which only 10-15% contributes to the recharge of groundwater due to high evaporation rates exceeding 60% of the precipitation. Also, the study area faces a reduction in recharge potential by up to 20% and an increment in surface runoff and sediment load by 15%-20% due to extensive mining activities and extraction of groundwater for irrigation in the area of Panna and Satna districts. In this study, Analytical Hierarchical Process (AHP), Geographic Information System (GIS), and Remote Sensing is used to create Groundwater Potential Zones (GWPZ). The remotely sensed data including elevation, slope, drainage density, geology, rainfall, soil texture, topography, modified normalized difference water index, normalized difference vegetation index, and land use/cover were used to generate thematic layers in the GIS environment. Drainage density was evaluated to assess capability for surface runoff by using SRTM DEM, supported by the geological and soil texture data that aids in establishing subsurface storage and infiltration potential acquired by FAO. Rainfall data were added to incorporate estimations of recharging taken from IMD, while RS indices such as Modified Normalized Difference Water Index and NDVI were utilized to show water presence and vegetation cover, respectively. LULC analysis was done to determine the anthropogenic impacts and natural land use influences on the dynamics of groundwater produced from the Landsat dataset. This integration of multi-criteria elements with GIS and remote sensing techniques will ensure a robust analysis of the groundwater potential zones.

The AHP method was used to assign the weightage and ranking to each affecting element. The thematic layers are then overlayed over each other, Groundwater Potential Index (GWPI)

was calculated by summation of products of the attribute class and its thematic layer weight. This groundwater potential index was subjected to various values that define the classification of different Groundwater Potential Zones. The superimposed maps were categorized into five distinct classes of groundwater potential zones (GPZs): “very low”, “low”, “moderate”, “high”, and “very high” GWPZs. The class title is self-explanatory as “Very High” shows the maximum chances of availability of groundwater in the area whereas “Very Low” shows the least. The classification was done by integrating the main controlling factors including elevation, slope, drainage density, geology, rainfall, soil texture, topography, MNDWI, NDVI, LU/LC, and proximity to water bodies. The generated zonation map showed 12.54% area falling under the high GPZ, which represents the areas of highest recharge and higher availability of groundwater. Conversely, 60.54% of it was in the moderate GPZ, which shows areas characterized by balanced patterns of recharge and extraction. The low GPZ occupied 16.52%, representing zones with limited availability due to adverse geological or hydrological conditions, while the extremely low GPZ accounted for 10.40%, representing critically water-scarce regions. The zonation mapping was validated on the basis of yield data over observed boreholes developed in the study area itself to ensure its accuracy. This validation showed that 78.25% of the bore wells manifested yield as per the projected GPZ classification and confirmed that the model was appropriate. In general, the average yield ranges from 4 to 12 litres per second for the high and moderately classified zones, and that for the low and extremely low yield zones fall below 3 lps in most cases. The results have marked the strength of the methodology in delineating groundwater potential zones and emphasizing its potential to guide effectively groundwater exploration and management strategies. The results are very helpful in not only gaining the groundwater status but also in the management of sources, planning policies, and acknowledging the recharge possibilities in the problematic area in special reference to attaining sustainable development goals. Overall, this research provides a technique to delineate groundwater potentiality, which will be very helpful for managing groundwater resources.

Keywords: *AHP, GIS, groundwater, potential zones, remote sensing*

QUANTIFICATION AND GEOSPATIAL MAPPING OF DUG WELLS IN DISAPPEARING DRY TROPICAL WATERSHEDS

Anshumali*, Rahul Kumar Pandey, Rahul Kumar Gupta, Roja Eliza and Sanchit Kumar

Department of Environmental Science and Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, Jharkhand, India
**Corresponding author e-mail: anshumali@iitism.ac.in*

Since the inception of human civilization, Hand-dug wells have provided water for drinking, bathing and cleaning, irrigation, livelihood, industries. In light of recent global and regional data compilations and analyses, the paramount question is why the shallow and deeper dug well density (DwD) is increasing despite depleting groundwater levels, seasonal and interannual water table fluctuations, high construction and operational costs, stringent regulatory measures, extreme changes in LULC and rainfall, etc. We answered this fundamental question by carrying out the dug well inventory in the “Critically Endangered” 4th order Banki watershed (518.35 km^2) and its sixteen sub-watersheds (varied from 8.43-160.61 km^2) situated in the lower Ganga River basin and supporting livelihoods and ecosystem services to ≥ 0.4 million people residing in the 197 villages of seven administrative blocks. We quantified and analyzed the dug well frequency (DwF), dug well density (DwD), and dug well abundance (DwA) in the well-defined 1 km x 1 km grided watershed and sub-watershed boundaries. The DwF is the number of grids in which a dug well occurs, expressed as a percentage of the total number of grids examined. The DwF indicates the probability of finding the grid(s) with dug well(s), which does not involve counting or measuring the dug well in each grid. Additionally, it provides a probabilistic approach to dug well distribution, allowing for efficient spatial analysis and clear comparisons across sixteen sub-watersheds. The DwD and DwA refer to the number of dug well(s) per unit area, but the DwA is always equal to or greater than the DwD because the DwA considers only those grids in which dug wells are recorded and counted. These intrinsic quantitative parameters were finally evaluated by developing GIS techniques and statistical relationships with agriculture areas, population density, number of households, and drainage order of the Banki watershed and its sixteen sub-watersheds. The overall DwF was 75.97 % in the Banki watershed and varied from 1.18 to 31.20 % in its sixteen sub-watersheds. The DwF was higher in the larger sub-watersheds than in the smaller sub-watersheds and showed a lack of uniformity in the distribution of dug wells. Low DwF indicates that the dug wells in the sub-watersheds are either irregularly distributed or rare in particular grids. The high DwF exhibited by the large sub-watersheds denotes their significant groundwater development owing to the long history of settlements and agricultural practices. The DwD in 591 grids varied from 0 to 52 km^{-2}. However, 142 grids covering 103.76 km^2 showed zero DwD. The DwD were grouped into five classes: 0-10, 11-20, 21-30, 31-40, and > 41. The mean DwD in the Banki watershed (9.32 km^{-2}) is higher than the global (0.7 km^{-2}) and national average (2.51 km^{-2}). The mean DwD varied from 0.05 to 3.11 km^{-2} and was higher in the large sub-watersheds than the small sub-watersheds. The DwD increased with the sub-watershed and agricultural areas and the expansion of settlements (number of households and population density). The DwD further showed an increase with a decrease in the drainage density (Dd), indicating disappearing ephemeral and perennial small streams in the sixteen sub-watersheds pose irreversible tipping points, and local people are overcoming spatiotemporal challenges of water availability by constructing dug wells at different depths in the entire Banki watershed. Introducing DwA in the quantitative assessment deals with increasing footprints

of intensive groundwater exploration on the aquifer vulnerability. Unlike the DwD, the DwA varied from 2.67 to 19.14 km^{-2}. It was higher in the small sub-watersheds than the large sub-watersheds, indicating that the former have well-developed dug well networks. The low DwD and high DwA in small sub-watersheds are responsible for the dynamic groundwater development and shifting toward the aquifer-centric ecosystem services in the disappearing dry tropical sub-watersheds. Moreover, the quantitative assessment of the dug wells offered robust methods of ground truth verification of the increasing poor groundwater potential zones (GWPZ) in the Banki watersheds and its sixteen sub-watersheds. To overcome this pressing global water crisis at the microscale, we must rejuvenate the drainage density in the small watersheds and sub-watersheds. Linking DwF, DwD, and DwA with Dd offers a holistic, empirical, and novel approach to (1) channel the surface runoff and stormwater, (2) offset the difference between DwD and DwA, (3) augment the recharge of the aquifers, (4) buffer the impact of groundwater over-pumping on river-aquifer interactions, (5) slow or reverse the rapid and accelerating groundwater declines without compromising drinking, domestic and agricultural water supply, and (6) effectively implement the groundwater policies and schemes as well as regulatory measures. Our new method of dug well quantification is flexible, scalable, and useful in groundwater management and decision-making without exhaustive secondary data collection. Additionally, our study is the first attempt to quantify hydro-sociology (dug well frequency, density, and abundance) at the local, regional, or global scale. This could become possible when we developed watershed and sub-watershed models of dug well inventory. The irreversible diversions of small watersheds and sub-watersheds in large river basins increased groundwater dependency. The watershed model of quantifying dug wells simplified the intricate relationship between rivers and aquifers and invariably addressed the limitations of random dug well sampling in regional and global data analysis. Therefore, the watershed model of dug well assessment reflects the external state of aquifer systems. As seen in our study, stream shrinkage and loss of landscape connectivity can affect groundwater recharge, highlighting the need for immediate attention to aquifer conservation.

Keywords: *Dug well inventory, GIS, river-aquifer interactions, aquifer conservation, aquifer-centric ecosystem*

ASSESSMENT OF HYDROLOGICAL CHARACTERISTICS OF THE KAMENG RIVER BASIN BASED ON MORPHOMETRIC PARAMETERS USING GEOSPATIAL TECHNOLOGY

Harikrishnan G.[1]* and Rahul Dev Garg[2]

[1]*Defence Geoinformatics Research Establishment, Chandigarh, India*
[2]*Civil Engineering Department, Indian Institute of Technology, Roorkee, India*
[*]*Corresponding author e-mail: harikrishnan_g@ce.iitr.ac.in*

Morphometry is defined as the scientific measurement of the Earth's surface configuration, including the sizes and shapes of various landforms. It is utilised to assess the hydrological and interpret the geologic conditions and morphometric characteristics of various aspects of a catchment, including linear, surface, and relief aspects. Also, drainage morphometry provides a quantitative description of basin geometry better to understand a drainage basin's geological and geomorphic history. This analysis provides valuable insights into the hydrological behaviour of the rocks present within the river basin or watershed. This morphometry is an exploratory tool to obtain quantitative measurements that provide information about certain aspects of a region, including tectonic activity, flood dynamics, surface runoff, and soil erosion and also emphasizes that the geomorphological characteristics of a catchment area significantly influence runoff intensity, which is particularly sensitive to the basin's features. In morphometric studies, drainage basins are typically regarded as distinct physical units. In this study, an investigation was conducted into the characteristics and hydrological behaviour of the Kameng River basin to promote sustainable river resource management. The primary focus on quantitative methods aims to comprehensively identify the area's relief features.

The Kameng River basin, a tributary of Brahmaputra River originates in Tawang district from the glacial lake below snow-capped Gori Chen Mountain on the India-Tibet border. River is situated between the latitudes 26°37'38" and 27°57'33" North and the longitudes 91°58'2" and 93°22'32" East, encompassing an area of approximately 10,786 km^2. The river meanders through the foothills of the Himalayas for approximately 265 km through the Assam and Arunachal Pradesh in India. Many residents depend on fishing and various water-based activities, making it an important source of income for the surrounding communities. This stunning location, which combines a rich heritage, adventure, and natural beauty, holds significant cultural importance. The river flows through the Kameng Valley in Arunachal Pradesh, passing through dense forests, valleys and hills. Kameng River joins the Brahmaputra River at Tezpur, near east Kolia Bhomora Setu bridge in Assam. The Kameng River is the border between East Kameng and West Kameng districts and separates the Sessa and Eaglenest wildlife sanctuaries to the west from the Pakke Tiger Reserve to the east. Near Bhalukpong in Arunachal Pradesh, the river enters the alluvial plains. It initially flows east-southeast, flanked by two boulder ridges, before making a sharp turn to the south and continuing along a relatively straight path until it joins the Brahmaputra River. Image-interpretation techniques were employed to classify the drainage information of the study area. The drainage maps were developed utilizing ALOS PALSAR DEM data at a resolution of 12.5 m. Several parameters were taken into consideration in this study namely 1) Linear Aspects of the Basin: This category includes stream order, stream number, bifurcation ratio, stream length, stream length ratio, and the length of overland flow. 2) Areal Aspects of the Basin: Key factors in this category encompass basin area, perimeter, drainage density, stream

frequency, basin shape, form factor, elongation ratio, circulatory ratio, and drainage texture. 3) Relief Aspects of the Basin: To evaluate the relief characteristics, the analysis included ruggedness, relative relief, relief ratio, gradient ratio, dissection index, and hypsometric. The analysis was conducted within the ArcGIS environment, which facilitated the processing and visualization of these parameters effectively. This study examines the dynamics of morphometric analysis through geospatial technology.

The Kameng River basin demonstrates a diverse drainage pattern that includes dendritic, sub-dendritic, trellis, and rectangular configurations. Additionally, the analysis indicates a notable degree of elongation within the basin. These morphometric characteristics are crucial for understanding the region's hydrological behavior and landscape dynamics, contributing valuable insights for environmental assessment and management efforts. This indicates a robust conformity between the slope factors and the drainage system, strongly influenced by tectonic activity. The analysis of the hypsometric integral and dissection values reveals that the landscape is predominantly in the early youth stage of the erosion cycle. This finding offers a valuable opportunity to deepen our understanding of the natural processes involved in shaping the environment. At this stage, the landscape is marked by sharp relief features, youthful topography, and minimal soil development, highlighting the active role of erosive forces. Recognizing these characteristics can enhance our exploration of how this developmental phase influences ongoing geological and ecological dynamics. A well-established relationship exists between slope angle and drainage structure. The basin's lithological characteristics can be effectively understood by examining texture and drainage density. The geometric layout of the basin enhances our ability to analyse flood dynamics, playing a crucial role in shaping Stream Energy and erosion patterns. This understanding can lead to more effective management strategies for flood risks and sediment control. The unique shape of the basin plays a crucial role in understanding flood dynamics, shaping the flow of streams, and impacting erosion patterns. This configuration not only reveals the secrets of how water moves and behaves during floods but also highlights the powerful forces at work in shaping our landscapes. As a result, these morphological attributes increase flood velocities, enhancing the river's ability to erode and transport sediment. The river is anticipated to be vital in transporting sediment downstream, contributing to current and future geomorphological processes. The river is set to continuously transport sediment downstream, shaping the landscape throughout both the present and future geological eras. This dynamic flow sculpts the earth and tells the story of our ever-changing environment.

Keywords: *Kameng River basin, morphometric parameters, DEM, GIS*

INTEGRATED GEOHYDROLOGICAL, GEOSPATIAL, AND GEOPHYSICAL APPROACHES FOR SUSTAINABLE GROUNDWATER MANAGEMENT IN THE BUNDELKHAND CRATONIC REGION, INDIA

Ravi Shankar Dubey, Pallavi Chattopadhyay* and Praveen Kumar

Department of Earth Sciences, Indian Institute of Technology, Roorkee, India
**Corresponding author e-mail: cpallavi@es.iitr.ac.in*

Groundwater management in semi-arid and arid regions, particularly in hard rock settings, requires innovative and integrative approaches due to the inherent complexity of the geological environment. The Bundelkhand Cratonic region, characterized by limited groundwater availability and challenging hydrogeological conditions, demands precise tools to identify, monitor, and manage water resources effectively. In response to these challenges, this study employed a suite of nine thematic layers lineament density, drainage density, slope, water level, geomorphology, geology, land use/land cover (LULC), rainfall, and soil developed within the ArcGIS environment. These thematic layers were systematically ranked according to their influence on groundwater emergence and mapped using the Analytic Hierarchy Process (AHP) technique, producing a groundwater potential map categorized into very low, low, moderate, good, and very good zones. This integrated geospatial, geohydrological, and geophysical methods approach offers a promising solution for sustainable groundwater management, particularly in data-scarce regions like the Bundelkhand Craton. This study explores an integrated approach for groundwater management in arid hardrock regions, combining Geospatial techniques**,** Electrical Resistivity Tomography (ERT), and Geohydrological methods for sustainable management of groundwater. This research focuses on the comprehensive analysis of hydrological factors controlling the semi-arid and arid regions by developing an integrated approach for effective management in the Jhansi region of the Bundelkhnad cratonic region.

The combination of GIS-based multi-criteria decision analysis (MCDA) through the AHP and geophysical Electrical Resistivity Tomography (ERT) gradient surveys measuremnts is a potential way for groundwater mapping in hard rock regions. Numerous factors, directly and indirectly, affect the behavior of Cratonic aquifers. So, the methodology involves the selection and analysis of thematic layers controlling the cratonic emergence based on the literature survey and advice of hydrological experts such as lineament density, slope, geology, geomorphology, drainage density, water level, rainfall, soil, and LULC. The geology and geomorphological layers were downloaded from the Bhukosh portal. The Digital Elevation Model (DEM) downloaded from USGS SRTM data with a resolution of 30 m was used to create lineament density, drainage density, and slope map. The LULC map was created by training the Sentinal II satellite image samples in a GIS environment using the Random Forest algorithm in ArcGIS software. All the thematic layers were analyzed in a GIS environment with the same resolution. A pairwise comparison matrix was created by allocating weights to various parameters using the AHP methodology. Following the allocation of weights to each parameter and its sub-parameters based on their significance in hard rock hydrology, a potential map is generated by superimposing and integrating all layers on a pixel basis using a weighted overlay approach inside the ArcGIS environment. This methodology is validated with field-based data, including well locations and ERT pseudo-sections, ensuring robustness and reliability. The study used location data of 7 borehole

discharge data collected from the field to validate groundwater potential maps. The relationship between the different thematic layers and the groundwater potential values presents the relative importance of different hydrologic layers in controlling the hard rock aquifers. A hydrogeological field survey was also conducted to assess the geological conditions that lead to the formation of groundwater pathways channeling toward the flow.

The research region is categorized into five distinct groundwater potential zones: very high (8.24%), high (37.63%), moderate (33.62%), low (17.34%), and very low (3.17%). Approximately 80% of the research region is classified within the "moderate" to "very high" potential zones. The 2D ERT gradient survey measurements conducted at eight sites underscore the significance of shallow preferential and saturated zones in the region. A very good correlation between the groundwater potential zones and the ERT, as well as finding well-yield data, yields validation of approximately ~71.5 accuracy of the above findings. The findings also highlight the strong correlation between geological structures like fractures, faults, etc., identified by geospatial, hydrogeological survey, and geoelectrical resistivity methods.

This study demonstrates the effectiveness of combining GIS, geophysical, and geohydrological techniques to generate accurate and comprehensive groundwater potential maps. The use of ERT further enhances this integrated approach, especially in areas with limited data, providing critical insights into groundwater distribution in the arid Bundelkhand Cratonic region. These findings not only advance the understanding of groundwater resources but also offer valuable information for residents and policymakers to devise sustainable management strategies. Looking forward, future research should aim to refine modeling techniques, incorporate additional data, and leverage advanced technologies to address ongoing challenges in groundwater management. Interdisciplinary collaboration and stakeholder engagement will be essential in developing adaptive strategies and informing policies for sustainable groundwater use. This integrated approach offers valuable potential not only for the Bundelkhand Craton but also for other arid regions worldwide, where sustainable groundwater management is crucial for socio-economic development and environmental conservation. Furthermore, fostering interdisciplinary collaboration and stakeholder engagement will play a pivotal role in developing adaptive management strategies and informing policy frameworks for sustainable groundwater use. By embracing these advancements and approaches, future studies can further refine our understanding and management of groundwater resources, ensuring resilience and sustainability in water-stressed environments globally. This integrated approach holds promise not only for the Bundelkhand Craton but also for similar arid regions worldwide, where effective groundwater management is essential for socio-economic development and environmental conservation.

Keywords: *Cratonic region, groundwater potential zone, GIS, AHP, Electrical Resistivity Tomography, sustainable groundwater management*

DEMARCATION AND ASSESSMENT OF INLAND SALINITY/GROUNDWATER QUALITY IN PARTS OF WESTERN DHARWAD CARTON FROM TRANSIENT ELECTROMAGNETIC SOUNDINGS

N. Narsimha Naidu*, Veena R. Achuta and Mayank Dixit

Central Ground Water Board- South West Region, Bengaluru, Karnataka, India
**Corresponding author e-mail: nnnaidu3.kb@nic.in*

Lithology, rock water interaction, and unexploited groundwater over a period of time genesis for the accumulation of salts in groundwater in the subsurface which leads to groundwater quality degradation/Inland salinity. The present study area (Navalgund Taluk, Dharwad district, Karnataka State, India) of 693 km^2 in Western Dharwad craton is an example of an inland salinity problem. Delineation of electrical subsurface resistivity distribution, depth extent of salinity, and identification of freshwater pockets in study area are objective of present research study. A geophysical method, the Transient electromagnetic technique (TEM), has been widely used to find low resistivity zones since it is sensitive to highly conductive zones.

Dharwad craton comprises a predominant suite of TTG (Tonalite-Trondhjemite-Granodiorite) gneisses collectively referred to as peninsular gneisses. The second category of rocks within the Dharwad craton comprises greenstones or schist belts characterized by sedimentary associations. The study area is situated in western Dharwad craton, Karnataka state. It is dominated more or less by Granites and Granitic Gneisses. Schists, Greywackes and Sericite Schists are observed as thin patches in the northeastern part of the study area. High-grade metamorphism is observed in the southern part, while low-grade metamorphism is observed in the northern part. The climate classified as sub-tropical temperate. Normal annual rainfall for the period 1991 to 2020 is 588 mm. The study area forms a more or less vast plain at an average elevation of 564 m.s.l. It comes under the drainage of the Malaprabha river, which is in turn a tributary of the mighty Krishna River. In the southwestern part, Ferruginous cherts and Banded Haematite Quartz bands occur alongside Argillites and Greywackes. The lithology in the study area is indicative of poor groundwater repositories and Granitic Gneiss is the main water-bearing formation. Groundwater occurs within the weathered and fractured Granitic Gneiss under water table and semi-confined conditions. The bore wells were drilled from a minimum depth of 53 mbgl to a maximum of 200 mbgl. The depth of the weathered zone ranges from 5 mbgl to 20 mbgl.

TEM Soundings were conducted with a maximum 40x40m square single-turn Coincident loop, where the transmitter and receiving coils were laid parallel to each other, with an offset distance of 5m. TEMPLOT software is used for data reduction and interpretation of TEM-sounding data. Acquired data. i.e. voltage versus time transformed into conductivity versus depth based on the SPIKER algorithm. A total of 153 TEM (Transient Electromagnetic) soundings were carried out to delineate the depth extent of inland salinity and freshwater pockets in the study area. 40 good quality soundings out of 153 were extracted for depicting 1D, 2D, and 3D distribution of subsurface electrical resistivity.

Pseudosections from TEM data in the study area revealed the presence of subsurface low resistivity zones affected by inland salinity. Resistivity values after pre-processing and processing of TEM data, have been used to identify the depth extent of salinity in the subsurface. Resistivity values in the subsurface are in the range of 2-30 Ω.m and there are exceptional values also present in some locations in the study area. Based on resistivity values, water bearing formations in this area is divided into three zones. 1. Saline zone: <10 Ω.m, 2. brackish zone: 10-20 Ω.m and 3. Freshwater zone: >20 Ω.m. Due to a limited transmitter loop (40*40m size) and instrumental constraints, the depth of investigation is restricted to shallow depths in the range of tens to hundreds of meters. From the acquired data, it is clearly possible to map the salinity extent in depth. At most locations depth of investigation is restricted to saline zone only. It is depicted that the saline zone extends from 5 m to 110 m depth. In the central part of the study area, the depth of salinity is in the range of 75-110m whereas east and western part salinity is observed in the depth range of 50-75m.

The geophysical study has clearly deciphered the extent of inland salinity in aquifers I and II. In the major part of the study area, both the aquifers are affected by salinity in the depth range of 50-140m. Few freshwater pockets have been identified. Additionally, to know the resistivity regime of the aquifers, the Dar-Zarrouk parameter, longitudinal conductance (S), is also performed along with the spatial variation of resistivity from Vertical Electrical Sounding (VES) data. The high resistivity values and low S values, at these locations, are in correspondence with low EC values of groundwater samples of exploratory and key wells. However, investigation of contaminated land and groundwater can be linked to detective solving a mystery. To adequately define the relations between the subsurface resistivity measured by TEM and the change in water quality in depth, additional borehole geophysical data are needed for more detailed qualitative interpretation.

Keywords: *Inland salinity, transient electromagnetic sounding, Navalgund, saline zone, brackish zone*

LITHOLOGICAL MODELING AND DELINEATION OF GROUNDWATER POTENTIAL ZONES FOR GROUNDWATER RESOURCE MANAGEMENT FOR JORHAT AND MAJULI DISTRICTS, ASSAM, INDIA

Bijoy Krishna Chetia*, Jayashri Dutta, Marshal Pegu, Samsul Alam and Rahul Saikia

Jal Jeevan Mission, Assam
**Corresponding author e-mail: bijoykrishnaster@gmail.com*

Groundwater, although is a replenishable source of water, has emerging concerns as its quality is degraded day by day and its quantity is also getting decreased. Groundwater is often considered a safer source of drinking water compared to surface water, as it is typically less vulnerable to contamination. However, geogenic sources can contaminate groundwater as it passes through various rocks, soils, and minerals. In the context of Assam, although the quantity of groundwater is not a big issue, its quality is in alarming situation as it is contaminated with some deadly contaminants like Arsenic and fluoride. The contamination of arsenic in Assam is coming in a big way and it can cause public health hazards and natural misfortune. Till now, the source of these contaminants is believed to be geogenic as the geomorphology and lithology favour the dissolution of the elements. A detailed investigation of the source of these contaminants is essential to protect the aquifers and mitigate further contamination. Although the groundwater of Assam is in a better place than any other state in case of groundwater availability, with increasing population and urbanization, the probability of depletion of groundwater level increases as extraction increases to fulfil the water demand. Therefore, sustainable measures should be taken as necessary steps to prevent the resource. The present study aims to investigate the arsenic contamination in groundwater and examines the role of clay layers in influencing its distribution within the Majuli and Jorhat districts of Assam, India. The subsurface lithology has been classified into four units viz., clay, silt, fine sand and coarse sand. The significance of clay disposition and thickness in the distribution of Arsenic and other contaminants has been analysed. Additionally, this study identifies groundwater potential zones to support sustainable groundwater management. These zones are classified into six categories: very poor, poor, moderate, good, very good, and excellent. The primary data used for this study were lithological data and aquifer depth. These data were collected from the field during drilling through a dedicated mobile application that was developed to collect lithological data. The data were verified and digitized through Rockworks.20 for the 2D and 3D interpretation of the aquifer characteristics and the preparation of the fence diagram to know the aquifer disposition. The secondary data for groundwater quality were collected from literature. The thematic maps were prepared using secondary data from Bhukosh, Alos Palsar, and Google Earth Engine. The maps were prepared using ArcGIS 10.8 software, and overlay analysis was done using the Analytical Hierarchy Process (AHP).

Groundwater is contaminated in both the two districts with arsenic according to studies conducted by many researchers. Arsenic contamination occurs in shallow aquifers (above 25m) of the Majuli district, decreasing with increasing depth. The local inhabitants were also affected as arsenic was found in their hair, nails and urine. Likewise, the Titabor area in Jorhat district is also highly contaminated with arsenic in shallow aquifers. The present study indicates that a significant clay cap exists between shallow and deeper aquifers in this region, playing a dual role. It acts as a barrier to prevent arsenic contamination in deeper aquifers while facilitating arsenic concentration in the overlying shallow aquifers. High arsenic load in shallow aquifers may be attributed to the presence of a clay layer underlying the aquifer which potentially may act as a barrier for the underlying aquifer. The clay layer may promote the process of reductive dissolution during organic carbon drawn from the clay layer. There is a clay layer of thickness ranging from 2 m to 46 m which acts as a confining layer between the two aquifers. The expanding nature of clay may also result in the dissemination of arsenic from the pores of the overlying aquifer. The extensive geochemical and hydrogeological study could reveal the provenance of arsenic in the area.

Analysis of the he groundwater potential zones in the area indicates that the highest area is covered by very good potential zone followed by good, excellent, poor, moderate and very poor potential zone. The excellent potential zones are present in the Majuli district. For the sustainable management of the groundwater resource, excellent and very good potential zones can be selected as suitable sites which will be ideal for the implementation of artificial recharge projects. The findings of this research provide valuable insights for planners and policymakers, enabling more informed decisions regarding sustainable groundwater management. The groundwater potential zone was delineated such that the groundwater management plan could be properly planned.

Keywords: *Arsenic contamination, clay capping, groundwater potential zone, lithology, sustainable groundwater management*

AN EXCEL BASED PROGRAMMING APPROACH TO ANALYZE PUMPING TEST DATA FROM LARGE DIAMETER WELL BY PAPADOPULOS-COOPER (1967) METHOD USING DRAWDOWN AND RECOVERY PHASE DATA

Chandrakant P. Bhoyar*

Groundwater Surveys and Development Agency, Nagpur (Maharashtra), India
**Corresponding author e-mail: cpbhoyar_71@yahoo.co.in*

Papadopulos - Cooper (1967) method is popularly used to analyse the pumping test data from large diameter wells. Although method considers confined aquifer in its assumption, but can be applicable for leaky or un-confined aquifer tapped in large diameter shallow dug wells. Here, a small resultant storage coefficient (S) indicates that the aquifer is essentially confined, while a large value indicates that it is leaky or un-confined. The method uses an analytical type-curve fitting approach, which involves the preparation of type curves on logarithmic paper for a family of F ($u_{w,}$ α), versus 1/u_w for different values of 'α' as given in tables presented by Papadopulos and Cooper (1967). The method considers only drawdown phase data for estimation of the aquifer parameters, whereas the drawdown phase data of large diameter wells in hard rock areas usually shows negligible aquifer response indicating that most of the water is pumped from the well storage. Therefore, the recovery phase data is equally important and need to be considered while estimating the aquifer parameters from large diameter well pumping tests. Secondly the method requires long duration pumping test data to get close match, as the form of type curves differs only very slightly when 'α'differs by an order of magnitude. Hence, an error is caused in estimating storativity (S) by this approach, as large diameter wells in hard rock areas cannot sustain long duration pumping due to low permeability of aquifers.

Many researchers have suggested the numerical approach to analyse the pumping and recovery phase data from pumping tests on large diameter wells in hard rock areas. However, an EXCEL based tool is not available for analysis. Hence efforts are made to analyse the large diameter wells pumping test data of drawdown and recovery phases in EXCEL spreadsheet domain by applying the same general flow equation, for drawdown '$\mathbf{s_w}$ 'in a large diameter well. The approximation of Well Function for large diameter well 'F ($u_{w,}$ α)', as developed by Sushil K Singh (2007) is used to get different set of values of F ($u_{w,}$ α) for a given set of 'u_w' and 'α'. An EXCEL spreadsheet is developed for a set of time domain data including time since pumping started (drawdown phase) and time since pump stopped (Recovery or residual drawdown phase) as maintained during field observations. 'Q', r_w and $r_{c,}$ are kept constant and an arbitrary value of 'S' and 'T' are considered initially, to get the corresponding values of 'u_w' and 'α' for each time set. These values of 'u_w' and 'α' are, then used for calculating the value of F($u_{w,}$ α) using approximation formulae. Then, by putting input values drawdown and residual drawdown (s_w) is estimated for each time value. Thus, for each value of time period as maintained in the field observations, 's_w' is calculated based on the input data and a spreadsheet of time and drawdown is developed. Field curve (graph), for time since pump started versus drawdown and residual drawdown is plotted in the same spreadsheet and for the same time set, modelled values of drawdown and residual drawdown are also plotted on the same graph. An EXCEL based programming is adopted to match the modelled drawdown and residual drawdown graph with the observed one, by changing 'T' and 'S' values till the close match is obtained for both the pumping test phases. When the

closed match is obtained between two graphs, the input values of ‘T’ and ‘S’ are considered to be the representative transmissivity (T) and storativity (S) values for the given set aquifer condition.

Drawdown and Recovery phase data from short duration pumping tests conducted on fifty-Seven (57) large diameter wells in hard rock and soft rock areas of Nagpur Region, Maharashtra, including Basalt, Granite and Rhyolite, Granite Gneisses, Schists, Fractured Limestone, Sandstone, Shale and Alluvium aquifers were analyzed by this approach. Of these fifty-seven (57) tests, three (3) are from Alluvium aquifer, fifteen (15) from Basalt aquifer, two (2) from Gondwana Sandstone, five (5) from Penganga Shale and Limestone, four (4) from Granites and Rhyolites, and twenty-eight (28) from Granite Gneisses and Schists. For Alluvium aquifer ‘T’ ranges from 62 to 131 m^2/day and ‘S’ from 0.056 to 0.070, for Basalt aquifer, ‘T’ ranges from 18 to 82 m^2/day and ‘S’ from 0.0083 to 0.021, for sandstone ‘T’ ranges from 17 to 91m^2/day and ‘S’ from 0.001 to 0.01, for shale and limestone aquifers ‘T’ ranges from 24 to 31 m^2/day and ‘S’ from 0.017 to 0.022, for Granites and Rhyolites ‘T’ ranges from 18 to 45 m^2/day and ‘S’ from 0.001 to 0.0227, for metamorphic rocks (Gneisses and Schists) ‘T’ ranges from 14 to 34 m^2/day and ‘S’ from 0.006 to 0.011. The ‘S’ values in the range of 0.001 to 0.009 indicate leaky aquifer condition and values in 0.01 to 0.07 range indicate un-confined aquifer conditions (i.e. S=Sy (Specific Yield). The aquifer parameters (T and Sy), as estimated by the presented approach find best resemblance with local hydrogeological setting and are in close range with the values of ‘Sy’ as recommended by GEC-2015 (National Groundwater Estimation Committee) norms. Thus, the approach as discussed is found to be very useful in analysing the pumping test data from large diameter wells in hard rock areas.

Keywords: *Aquifer, large diameter well, pumping test, drawdown and recovery phases, well function, transmissivity, storativity, specific yield*

DEVELOPMENT OF WEB-BASED BASEFLOW SEPARATION ANALYSIS TOOL

Ravindra Vitthal Kale[1]*, Parivita Sampagaonkar[2], Tanvi Narayankar[2], A.K. Lohani[1], M.K. Goel[1], Sonali Kadam[2]

[1]National Institute of Hydrology, Roorkee, India
[2]Bharati Vidyyapeeth's College of Engineering for Women, Pune, India
**Corresponding author e-mail: ravindrakale2610@gmail.com*

Baseflow separation is a critical process for understanding groundwater contributions to streamflow and spring flow, essential for water resource management and hydrological studies. However, existing methods for baseflow separation are often fragmented across multiple platforms and programming languages, making it difficult for researchers to efficiently analyze datasets. This study introduces a unified web-based tool for baseflow separation that consolidates three established base flow separation methods into a single, user-friendly interface, integrating a Python Flask-based backend and a React-based frontend, enabling hydrologists to easily analyze and visualize hydrological data. The web-based tool developed in a virtual Python environment within VS Code. This analysis tool uses a Python Flask backend with scientific libraries such as Pandas and NumPy for processing hydrological data. Presently, three common baseflow separation methods incorporated are Eckhardt (2005): A recursive digital filter for separating base flow from total flow; Chapman and Maxwell (1996): A modified version of Lyne and Hollick for greater flexibility; and Lyne and Hollick (1979): A linear filter to decompose streamflow into base and quick flow components. The frontend, built with React, enables users to upload hydrological datasets in Excel format, apply the baseflow separation methods and configure analysis parameters, extract periods of recession, delivering comprehensive outputs such as MRC graphs and visualize results through interactive charts, and exhaustive downloadable reports in PDF format, summarizing key statistics and results. The tool also allows users to identify recession periods which provides insight into streamflow dynamics. The results visualized through interactive charts and Master Recession Curve (MRC) graphs plays crucial role in analysing the streamflow recession behaviour over time. The tool was tested on multiple datasets, yielding reliable base flow separation results. Visualizations generated using the Lyne and Hollick, Chapman and Maxwell, and Eckhardt methods were consistent with traditional manual methods. The MRC graphs effectively illustrated streamflow recession patterns, providing insights into the groundwater-surface water interaction. Users were able to adjust analysis parameters, tailoring the tool to specific datasets and hydrological conditions. The PDF reports contained detailed outputs, including base flow indices and recession rates, making it easy for users to share and document their findings. In conclusion it may stated that the developed web-based baseflow separation tool successfully integrates multiple separation methods into a single platform, simplifying the process of analyzing hydrological data. By providing easy-to-use interactive features and generating visualizations, the tool enhances the efficiency of base flow analysis. It is a valuable resource for researchers and water resource managers, offering comprehensive outputs for informed decision-making. Future improvements could include the integration of real-time data or advanced predictive models to further enhance its capabilities in hydrological research and water resource management.

Keywords: *Base Flow Separation, Streamflow, Water Resource, Master Recession Curve*

ANALYSIS OF GROUNDWATER LEVELS AND AQUIFER PARAMETERS IN THE YAMUNA RIVER BASIN FOR SUSTAINABLE GROUNDWATER MANAGEMENT

Rahul Kumar[1], Sumant Kumar[1*], Vinod Kumar[1], Nitesh Patidar[1], Pradeep Kumar[1] and Vidyasagar Jha[2]

[1]National Institute of Hydrology, Roorkee, India
[2]Ministry of Environment, Forest and Climate Change
[*]Corresponding author e-mail: sumantks@gmail.com

Water is vital for ecosystems, socio-economic development, and human survival, with groundwater serving as the primary freshwater source. However, excessive extraction driven by population growth, agriculture, and industrial needs has led to severe depletion and contamination. Globally, agriculture accounts for 42% of groundwater use, followed by households (36%) and industries (27%). In India, 90% of the rural and 30% of the urban population rely on groundwater, with Uttar Pradesh, an agriculturally dominant state, heavily dependent on it for irrigation. Yamuna river basin, which supports both surface and groundwater irrigation, nearly 81% of farmers depend solely on groundwater. The Yamuna River basin in Uttar Pradesh, faces major stress due to extensive agricultural practices and unplanned groundwater abstraction, further aggravating public health and economic concerns. Sustainable management is urgently needed. The study focuses on the Yamuna River Basin in Uttar Pradesh, covering 24 districts, and is divided into three zone. Zone-1 (Saharanpur to Firozabad), zone-2 (Mainpuri to Lalitpur) and zone-3 (Kanpur Nagar to Prayagraj). Each zone presents distinct hydrological challenges, making this zonal classification essential for understanding groundwater dynamics in the region. Uttar Pradesh experiences a subtropical climate with hot summers, a monsoon season from June to September, and cold winters. The majority of rainfall occurs during the monsoon, influencing groundwater recharge. The combination of climatic factors, agricultural practices, industrial demands, and population growth makes this region critical for understanding groundwater sustainability challenges.

The present study evaluates groundwater resources in Uttar Pradesh using data from 151 monitoring wells across three zones and transmissivity data from 24 districts, obtained from the Central Groundwater Board (CGWB). Spanning 24 years (1996–2019), the dataset includes seasonal records for pre-monsoon and post-monsoon periods, providing insights into groundwater dynamics and trends. The inclusion of transmissivity data helps enhances the understanding of groundwater movement and storage capacity. This study highlights the critical role of the Yamuna River in maintaining groundwater levels (GWL), though it faces challenges related to water quantity due to excessive extraction. The Mann–Kendall and Sen's slope tests at 95% of confidence level were applied for analysing groundwater level trend.

In Zone-1 during the post-monsoon season, 47.06% of wells revealed no significant changes in water levels, 41.18% showed a decline, and 11.76% exhibited rising groundwater levels. In Zone-2, 64.29% of wells were stable, 26.19% showed a decline, and 9.52% exhibited rising levels, while in Zone-3, 65.33% of wells remained stable, 25.34% showed a decline, and 7.33% exhibited rising levels. Similarly, during the pre-monsoon season, 50.00% of wells in Zone-1 maintained stability, 47.06% revealed a decline, and 2.94% exhibited rising levels. In

Zone-2, 59.52% of wells remained stable, 35.71% showed a decline, and 4.75% exhibited rising levels, while in Zone-3, 64.00% of wells were stable, 30.67% revealed a decline, and 5.33% exhibited rising groundwater levels. The decline in groundwater levels, observed in 41.18%, 26.19%, and 25.34% of wells in Zones 1, 2, and 3 respectively during the post-monsoon season, as well as in 47.06%, 35.71%, and 30.67% during the pre-monsoon season, highlights insufficient recharge or over-abstraction of groundwater. Zone-1 experiences a greater decline in groundwater levels followed by Zone-2, and Zone-3. This indicates that Zone-1 is the most stressed zone, while Zone-3 is the least concerned. The higher stress in Zone-1 can be attributed to its dependence on the Yamuna River, whereas Zone-2 benefits from both the Yamuna and some additional rivers. In contrast, Zone-3 is recharged by the Yamuna as well as the Ganga River during monsoon season, which significantly supports groundwater replenishment. The GWL trends analysis highlight the sustainable groundwater management to mitigate long-term environmental and socio-economic consequences. During the post-monsoon season, the groundwater level in Zone-1 ranges from 0.01 to 17.39 m below ground level (bgl) with an average depth of 6.14 m bgl, followed by Zone-2, where it ranges from 0.10 to 38.20 m bgl with an average depth of 6.63 m bgl, and Zone-3, where it varies from 0.02 to 30.58 m bgl with an average depth of 6.24 m bgl. Similarly, during the pre-monsoon season, the groundwater level in Zone-1 ranges from 0.13 to 17.55 m bgl with an average depth of 7.13 m bgl, followed by Zone-2, where it ranges from 0.37 to 38.60 m bgl with an average depth of 8.14 m bgl, and Zone-3, where it varies from 0.45 to 33.60 m bgl with an average depth of 8.49 m bgl. The varying geological formations, draft and recharge across the zones can be linked to the transmissivity values, which measure an aquifer's ability to transmit water. Zone-1, with a transmissivity range from 25 to 2500 m^2/day, Zones 2 and 3 have higher transmissivity values of 20 to 5755 m^2/day and 1.5 to 6338 m^2/day, respectively, enabling greater water movement and well yield potential. The GWL is bit shallow in zone1 but showing declining trend in more wells in comparison with zone 2 and zone 3. A conjunctive use may be adopted for sustainable management in Yamuna River basin of Uttar Pradesh.

Keywords: *Yamuna, groundwater level, Uttar Pradesh, trend analysis*