Theme 8

AUGMENTATION OF GROUNDWATER RESOURCES

EVALUATING POND RECHARGE PONTENTIAL IN THE RAMGANGA BASIN WITH DATA DRIVEN MODELING APPROCHES

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Managed Aquifer Recharge (MAR) stands out as an environmentally friendly approach. MAR involves the deliberate infiltration of surface water into aquifers to replenish groundwater reserves, and it has shown great potential in mitigating water scarcity. Therefore, the primary objective of the study is to fill the knowledge gap in pond recharge estimation by creating a comprehensive prediction model tailored to the unique hydrological and climatic conditions of the Ramganga Basin. While most ponds in the area are not currently utilized as MAR systems, this study provides a systematic framework for evaluating their suitability for MAR deployment. By combining statistical and machine learning approaches, it is aimed to establish a predictive methodology that can support policymakers and resource managers in implementing efficient groundwater management strategies. To achieve this, study undertook extensive data collection and validation efforts. Data from 7,443 ponds across the RGB were compiled using multiple sources, including field visits, government registers and remote sensing techniques. These datasets provided critical information on pond characteristics, including location, size, and recharge capacity. The field visits were particularly instrumental in validating the data obtained from government records and remote sensing. For example, while government records often provided outdated or incomplete information, the field visits ensured the accuracy and reliability of the dataset by cross-verifying pond locations using GPS applications. Additionally, remote sensing techniques helped to identify and map ponds that were not listed in official records, thus enhancing the comprehensiveness of dataset.

To validate the recharge prediction model, 23 monitoring stations were installed in the Moradabad zone of the Ramganga Basin. These stations were strategically located to collect data on recharge rates, water levels, and other hydrological parameters. This real-time data was critical for training and testing the prediction model, ensuring its accuracy and applicability across diverse conditions within the basin. The collected data also facilitated an in-depth analysis of recharge patterns and their dependence on various parameters. The study identified 10 key parameters influencing pond recharge: slope, topographic wetness index (TWI), normalized difference vegetation index (NDVI), demographic population, aridity index, turbidity index, groundwater level, curve number, infiltration rate, and precipitation. These parameters were selected based on their relevance to hydrological processes and their ability to capture the spatial and temporal variability of recharge dynamics. By integrating these parameters into the prediction model, it aimed to develop a holistic understanding of the factors driving pond recharge and their relative importance in determining recharge potential. The analysis utilized a combination of statistical and machine learning techniques to develop the prediction model. Among the machine learning models tested, the Gradient

Boost model emerged as the most reliable and accurate for identifying high-potential recharge zones within the basin. The model achieved an impressive area under the curve (AUC) score of 0.92, indicating its high discriminative power in distinguishing between areas with varying recharge potentials. Additionally, the model demonstrated strong performance in forecasting recharge rates, achieving a correlation coefficient (R) of 0.83. It also minimized key error metrics such as the root mean square error (RMSE) and mean absolute error (MAE), further validating its robustness. When compared to traditional statistical models, machine learning models consistently outperformed in terms of accuracy, flexibility, and predictive capability. The Gradient Boost model, in particular, excelled in capturing the complex, non-linear relationships between the recharge parameters and the observed recharge rates. This underscores the potential of machine learning techniques to revolutionize groundwater management by providing more precise and actionable insights. Using the validated model, analyses was extended to predict recharge potential across the entire Ramganga Basin. This basin-wide assessment was crucial, as the 23 monitoring stations provided only localized data, which, while valuable, was insufficient for comprehensive basin-scale analysis. By leveraging the model's predictive capability, identified high-potential recharge zones that could be prioritized for MAR implementation. These zones represent areas where targeted interventions, such as pond restoration or construction, could yield significant benefits in terms of groundwater recharge.

The implications of the findings are far-reaching. By promoting the use of ponds as MAR systems, the proposed approach has the potential to enhance groundwater storage, reduce water stress, and improve the resilience of water resources in the Ramganga Basin. Moreover, the model provides a scalable framework that can be adapted to other regions facing similar challenges. The integration of machine learning techniques with traditional hydrological analysis represents a significant advancement in groundwater management, enabling more efficient and data-driven decision-making. The environmental and socio-economic benefits of pond-based MAR systems cannot be overstated. In addition to augmenting groundwater resources, these systems can help mitigate the adverse impacts of climate change, such as droughts and erratic rainfall patterns. They also offer a cost-effective solution for rural water management, particularly in regions with limited access to alternative water sources. By revitalizing traditional water management practices and integrating them with modern technological approaches, our study demonstrates the potential of ponds to play a pivotal role in sustainable water management. In conclusion, this research addresses a critical gap in the field of groundwater management by developing a robust prediction model for pond recharge estimation in the Ramganga Basin. Through extensive data collection, validation, and analysis, we have demonstrated the feasibility and effectiveness of using ponds as MAR systems. The Gradient Boost model, with its superior performance metrics, provides a reliable tool for identifying high-potential recharge zones and forecasting recharge rates. By enabling more efficient groundwater management, this study offers valuable insights for resource managers and policymakers worldwide. The proposed approach not only enhances the understanding of recharge dynamics but also contributes to the development of sustainable solutions for addressing water scarcity and groundwater depletion. As the global water crisis intensifies, the need for innovative and region-specific strategies like ours becomes increasingly urgent, highlighting the importance of continued research and investment in this critical area.

Keyword: *Pond recharge, managed aquifer recharge, machine learning models, recharge*

GROUNDWATER RECHARGE POTENTIAL OF VILLAGE PONDS IN LUDHIANA DISTRICT OF INDIAN PUNJAB, INDIA

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A study was conducted during 2021–22 to estimate the potential groundwater recharge from the village ponds in a Ludhiana district of Punjab. One of the most dependable sources of water to meet the rising demands of diverse consumer sectors worldwide is groundwater. But the resources sustainability has been seriously threatened by the irrational and indiscriminate exploitation of groundwater without much regard for its depletion. The water table is dropping alarmingly fast in the state of Punjab, where more than 90% of the land is irrigated, at a pace of 55 cm/yr in 2017. This ongoing decrease in the water table necessitates the rapid and efficient development of artificial groundwater recharge and use of available surface water sources for the groundwater recharge. Keeping this in view the study was planned to assess groundwater recharge potential of village ponds using geospatial techniques. To achieve the objectives of the study, Sentinel 2 images of Ludhiana district was downloaded for the March 2021. In order to cover whole Ludhiana district, three tiles (imageries) having ID L1C_T43REQ_AO20909, L1C_T43RFQ_AO20866 and L1C_T43REP_AO29746 were downloaded and used for the analysis. The area of interest was extracted after doing all the operations in Arc GIS. Three spectral indices namely normalized difference water index (NDWI), modified normalized difference water index (MNDWI) and normalized difference pond index (NDPI) were used to identify and demarcate the area of village ponds in each village of the district. The efficiency of these indices were compared with the manually digitized area of the village pond for the accuracy assessment. NDWI could identify about 370 village ponds, MNDWI could identify and extract about 1263 village ponds and to further extract the village ponds, NDPI was used and NDPI could extract about 1410 village ponds whereas manually about 1513 village ponds could be demarcated. During the study, ground truthing of some the pond was also done to support the archived results. The number of ponds and area resulted from the manual digitization was considered as the reference to determine the accuracy of the spectral indices. For accuracy assessment, one village pond from each block of Ludhiana district was selected and then extents of areas for all the selected ponds were compared between manual digitization and three indices. A total of 13 representative village ponds from all 13 blocks of the district were selected during ground truthing. The efficiency of area demarcation was calculated on the basis of manually digitized pond area and area identified using the particular spectral index. NDPI was found to be a superior index than NDWI and MNDWI for identifying the number and area of the village pond through comparison of spectral indices. Manual digitization is very time consuming and cumbersome process so NDPI can be used with an overall efficiency of 90-95% in identifying the number of village ponds and overall efficiency of 65-70% in demarcating area of village ponds. Five village ponds were selected from the district and infiltration study was conducted at the bottom of these ponds during the month of April 2022. The soils samples of the pond bottom at different depths viz. 1-25, 25-50, 50-75 and 75-100 cm were collected and

textural analysis was done using hygrometer. After analysing the percentage fractions of sand, silt and clay for different depths by using soil textural triangle, it was found that the upper layer upto 50 cm was having higher clay percentage due to continuous ponding of these ponds and settlement of the finer particles. This leads to formation of partially impervious layer at the pond bottom. The infiltration rate without disturbing the dried pond bottom and after removing the top 50-60 cm of layers of soil was determined using double ring infiltrometer. During the field study, the infiltration rate of the disturbed bottom of village ponds found higher infiltration rate as compared to undisturbed bottom of those ponds. Therefore, to maximize the pond's capability for recharge, the bottom soil layer should be removed so that entry of water into the ground takes place. After improving infiltration rate, about 60% recharge can be enhanced through village ponds over undisturbed pond bottom. This helped to analyse the rate of change of infiltration of the village pond bottom. Further, the water quality from some the village ponds was also assessed. The water quality parameters such as pH, EC, TS, turbidity, BOD, COD, e-coli were analysed. The majority of the village ponds water quality was determined to be within allowable limits for irrigation, while for some of the ponds, it was above permissible values. So the water should be treated before use for irrigation. While estimating the volume of these village ponds, the average depth of 2 m was considered for the volume estimation of the village ponds and using NDPI, the volume of 873.8 ha-m was estimated. Considering the daily infiltration rate from the pond, annually about 301.9 ha-m of water can be recharged after removal the bottom layer. If the bottom layer is kept undisturbed, then the recharge rate of 181.3 ha-m would be achieved in village pond.

Keywords: *Spectral indices, GIS, village pond, recharge potential, spectral indices*

INTEGRATING HYDROGEOLOGY AND GEOSPATIAL TECHNIQUES FOR GROUNDWATER POTENTIAL MAPPING IN THE SIRHIND CANAL TRACT, PUNJAB, INDIA

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Groundwater depletion is a global concern, necessitating concerted efforts for judicious management, enhancement and development. Groundwater, which, has occupied a commanding position in India's food security and agriculture in the modern years, but a rapid decline in the groundwater table of India has resulted in unmanaged extension. The condition is no better in Punjab. Punjab, a north western State in India has also been witnessing an average annual decline of 53 cm/year which is mainly due to high agricultural consumption and an increase in the domestic water requirement. Despite the critical importance of groundwater resources in sustaining various sectors, including agriculture, industry, and domestic needs in Punjab, a limited number of studies have focused on identifying potential groundwater recharge zones. This scarcity of research is particularly concerning given the heavy reliance on groundwater as the primary source of water supply in the region. The present study therefore aims to address this knowledge deficiency by conducting a comprehensive analysis to delineate and prioritize these recharge zones in the Sirhind canal tract which occupies significant areas in the central and south-eastern region of Punjab, India by leveraging geospatial technology and the Rockworks software. A comprehensive set of 13 thematic layers, such as geology, soil, land use/land cover and drainage density, lineament density, geomorphology, annual rainfall, slope, groundwater level, lithology, specific yield, depth of first aquifer and hydraulic conductivity were meticulously prepared and integrated using a multi-criterion decision-making (MCDM) approach. The remote sensing data for the Sirhind canal tract underwent pre-processing and analysis using ArcGIS 10.2 software, while the Rockworks software was used to develop the subsurface lithology and stratigraphy map of the aquifer zone for Sirhind Canal Tract. The weighted overlay analysis was employed to assign ranks to each parameter, with normalized weights determined through the analytic hierarchy process (AHP) technique. The AHP process involved four groups: AHP1, AHP2, AHP3, and Groundwater Recharge Potential Zones (GRPZ). AHP1 involved the thematic layers of land use/land cover, soil, and rainfall. AHP2 encompassed geomorphology, lineament density, geology, drainage density, and slope. AHP3 included the layers of hydraulic conductivity, specific yield, water table, depth of the first aquifer, and lithology. Afterward, the AHP was applied to AHP3, AHP2, and AHP1 in order to define the GRPZ. Pairwise matrices and normalized pairwise matrices were generated for each group, considering their relative impact on groundwater occurrence, insights from relevant literature, and expert evaluations. The subclasses within each thematic layer were also reclassified in the GIS platform to assign weights ranging from 0 to 9, reflecting their perceived impact on groundwater development. The sensitivity of the results to the removal of one or more layers was analyzed using the map removal sensitivity analysis. The groundwater potential zone map for the *Sirhind canal tract* was then created by integrating the thematic layers using the weighted overlay analysis technique within a GIS platform. The resulting groundwater potential zone map was classified into five categories: very low, low, medium, high, and very high zones. The groundwater potential zones were further cross validated with the results of the pumping test data of observation well of the CGWB. The study's outcomes indicated that 5.01% (1269.09 km^2), 15.38% (3896.47 km^2), 16.43% (4163.23 km^2), 31.05% (7867.71 km^2), and 32.13% (8140.17 km^2) of the study area (25336.67 km^2) were classified as very low, low, medium, high, and very high potential recharge zones, respectively. Very high and high groundwater potential zones are confined generally to central parts of the study area i.e. Ludhiana, Jagraon, Malerkotla, Barnala, Sangrur, Mansa, Talwandi Sabo and some portion of Moga, Faridkot, Rampura Phul, Sunam, Samana, Nabha, Patiala, Rajpura, Sirhind, Samrala and Rupnagar. The moderate groundwater potential zones occur generally in the valleys and areas of high drainage density that are Nakodar, Zira, Firozpur, Moga, Faridkot, Muktsar, Bathinda, Talwandi Sabo, Mansa, Sunam, Samana, Rampuraphul, Patiala, Khanna, Samrala, Sirhind, Nabha and Malerkotla. Notably, low potential zones were identified in the foothills of Shivalik and the southwest region, whereas high recharge potential zones were concentrated in the central plains of the study area. The low and very low groundwater potential zones occur in the steep slope, high drainage density. Sensitivity analysis revealed that among all the thematic maps, the identification of potential recharge zones was most influenced by several factors, including groundwater level, depth of the first aquifer, soil characteristics, geomorphology, rainfall patterns, land use and land cover, lineament density, hydraulic conductivity, geology, and specific yield. The validity of the findings was further confirmed through the analysis of yield data obtained from existing observation wells. The results affirmed that areas with higher yield categories (ranging from 16 to 55 l/s) corresponded to excellent groundwater potential zones, whereas regions with lower yields (ranging from 8.1 to 13 l/s) were associated with poor groundwater potential zones. This differentiation underscores the diversity in recharge capabilities across the region.

Keywords: *AHP, groundwater potential, remote sensing, sensitivity analysis, groundwater recharge*

POTENTIAL AND CHALLENGES OF RIVERBANK FILTRATION IN NORTH AND NORTHEAST INDIA

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India has experienced commendable growth in agricultural production and food security since the Green Revolution in the 1960s, however this has also resulted in it becoming the world's largest groundwater (GW) abstracter at an estimated 251 km^3 per year, of which 89% is used for irrigation (UN, 2022). With simultaneous increasing urbanization and economic growth, the water demand of the domestic and industrial sectors is also expected to increase rapidly, such that sustainability of water sources is important for achieving future cross-sectoral water security. India leads globally in installed capacity for managing aquifer recharge. While MAR is considered a crucial strategy to address GW over-exploitation in India, a comparatively low portion of drinking water is intentionally produced by the natural water treatment technique of riverbank filtration (RBF, a technique of MAR), especially from the Indus–Ganges–Brahmaputra (IGB) basin alluvial aquifer that taken together, is one of the largest GW reservoirs on Earth. RBF serves as an ecosystem service for human health because it effectively removes contaminants, especially pathogens, other particles and organic micropollutants (OMP). Although in Europe new RBF site developments are rare due to decreasing water demand, there is a renaissance of RBF technology in China, Middle East and North Africa, Vietnam, and other countries. On the other hand, in the north Indian state of Punjab, where agriculture is the mainstay of the economy, the establishment of RBF systems has been recommended as a safe long-term solution for rural water supply. With the aim to further investigate RBF as a conjunctive SW–GW management strategy for drinking water production in the IGB Basin, this study evaluated a few sites for RBF in the states of Uttar Pradesh, Uttarakhand, Punjab and Assam.

Geohydraulic and water quality investigations were conducted on a production well for RBF in Agra waterworks (Jeoni Mandi) by the extremely polluted Yamuna River, at rural water supply schemes (RWS) along polluted stretches of the Sutlej and Ghagger rivers in Punjab and for a few RWS along tributaries of the Brahmaputra River in Assam. Additionally, occasional water quality monitoring was conducted for the existing and well-documented RBF site of Haridwar (Uttarakhand) by the Ganga River to re-evaluate its purification capacity. Water samples were analyzed for ions, heavy metals, dissolved organic carbon (DOC), OMP and bacteriological indicators between October 2021 and March 2024. Information on system-design and capacity was also collected from operators of the water supply schemes.

The main advantage of RBF in Agra is the high attenuation of OMP and that no bacteriological indicators were found in the production well despite high impact of partially to untreated wastewater on the Yamuna River (> 2.4×10^8 MPN/100 mL) and even with a moderate portion of bank filtrate (>50%) in the abstracted water from the well. High mean attenuation of 70% was observed for DOC and also for sulfamethoxazole (~100%). Other OMP like naproxen, triclosan, diclofenac, atrazine, atenolol and diuron also showed good removal during RBF. The production well abstracts around 70 to 84 m^3/day and supplements the capacity of the conventional waterworks. Tankers are filled directly at the well with the abstracted water. The water is subsequently distributed by the tankers to areas in the city that are not supplied through pipelines from the waterworks. Based on feedback from the waterworks, the consumers appear to be very satisfied with the water quality (based on the consumer's organoleptic assessment of taste, colour and odor) and there is a high acceptance for the well water even if it is supplied by tankers.

In Punjab, 11 OMP were analyzed with concentrations of over 100 ng/l in river water, for example up to 459 ng/l ibuprofen or a maximum of 1,934 ng/l for caffeine. Only five OMP were found in the well water and in lower concentrations of <100 ng/L (ibuprofen, bisphenol A, caffeine, atrazine and carbamazepine). Atrazine and carbamazepine were found in river and well water in even lower concentrations (<50 ng/L) and showed little to no removal as compared to a very good removal for triclosan, chlorpyrifos, naproxen and diuron. Due to the poor elimination of atrazine and carbamazepine during subsurface passage, these compounds indicate a river-aquifer connection and potentially a certain portion of bank filtrate. Fluoride, arsenic and other trace metals (Cd, Co, Cu, Ni, Pb) in well water were below the limits of the Indian Drinking Water Standard. In Assam, OMP were detected at much lower concentrations (<100 ng/L) in river and well water. Fe, Mn and trace metals As, Cd, Cr, Cu, Pb and Zn were within the acceptable limits of the Indian Drinking Water Standard in the production wells in Agra and Guwahati. The hydraulic connection between the river and aquifer is the most essential criteria for RBF and this is necessary to establish for potential new sites in the IGB basin in order to plausibly determine the portions of bank filtrate and GW in the abstracted well water and consequent removal rates of contaminants. This is also beneficial, if RBF is proposed as a strategy to address overexploitation of GW resources, which is an additional motivation of using RBF in China and Vietnam. Unlike in Haridwar, where the alluvial aquifer is in direct connection with the Ganga River as indicated from borehole profiles, such that the RBF wells abstract a high portion of bank filtrate, at some other sites such as in Agra, the river-aquifer connection is challenging due complex subsurface lithology. At such sites, geohydraulic investigations should be supplemented with stable isotope and OMP investigations, such as for carbamazepine that is considered to be chemically and microbially relatively stable. Overall, there is a high potential to include RBF as water management measure in river basin plans in the IGB basin.

Keywords: *Drinking water, conjunctive water management, organic micropollutants, pathogens, river basin plans*

IDENTIFICATION OF FEASIBLE SITES FOR THE CONSTRUCTION OF SUBSURFACE DYKES (SSD) IN THE DROUGHT PRONE AREAS OF PALAKKAD DISTRICT, KERALA: APPLICATION OF GEOPHYSICAL TECHNIQUES

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Subsurface Dykes (SSD) are water conservation structures, is built across a stream or valley to establish an underground reservoir and to recharge groundwater. The best sites for construction of SSD’s are those where the soil consists of sand and gravel with rock and an impermeable layer at a few meters depth. In many regions, frequent droughts create critical water shortages. Subsurface dykes (SSDs) can be a game-changer, storing rainwater underground to combat these challenges. A subsurface dyke is a subsurface barrier or hidden check dam that spans a stream or river. It slows down the system's natural subsurface/groundwater flow and reserves water below the surface to satisfy demand when it's needed. A groundwater dam's primary function is to stop the base flow, which also serves to keep the sub-basin's groundwater level stable.

The study identified suitable locations for constructing SSD’s in drought-prone areas of Palakkad district, Kerala applying geophysical techniques (ERT & VES) and AHP Analysis. Palakkad is the land of Palmyrahs and Paddy fields. There is considerable change in the land use and cropping pattern in the district for the last five years. The district receives maximum rainfall during the south west monsoon followed by the north east monsoon. The other months receive considerably less rainfall. The annual rainfall varies from 1883 to 3267 mm based on long term normal. The district receives on average 2362 mm of rainfall annually. Major rainfall is received during June to September in the southwest monsoon (71%). The northeast monsoon contributes about 18%. The western part of the district around Pattambi receives the maximum rainfall whereas in the rain shadow area of Chittur in the eastern part receives the minimum rainfall. Due to low income from paddy and coconut, farmers are changing the cropping pattern to cash crops like sugarcane, vegetables and flower cultivation. Over dependence on groundwater for domestic, irrigation and industrial purposes in the district has led to the lowering of water table and water scarcity especially along the eastern parts. In most of the areas especially in the eastern part of the district decline of water levels necessitates deepening of existing dug wells and putting deep bore wells thereby increasing cost of pumping and quality deterioration. To stop further groundwater depletion and contamination and to ensure the long-term sustainability of the state's groundwater resources, scientific management of these resources is essential. The factors viz., geological formations, land elevation, and ground water flow patterns was analyzed to pinpoint the most effective spots. This information will be crucial for water management organizations and local communities to strategically implement SSD’s and improve access to groundwater during droughts. The results of the study show the suitability of the sites for the construction of subsurface dyke in drought prone regions of Palakkad district based on the geology, geomorphology, lineaments and depth to the bedrock Chittur, Pattambi and Thrithala blocks.

To identify the places of SSD in this study, the AHP approach in ArcGIS was used. To confirm the location identified as feasible for SSD, geophysical techniques were used - vertical electrical sounding (VES) was conducted using the Aquameter CRM AUTO-C and electrical resistivity tomography (ERT) using ABEM Terrameter LSv2 multi-electrode system. ERT was carried out using two multi-core cables each having 21 electrodes. Spacing between two electrodes is 2.5 m. Spread length for this ERT unit was 100 m. In the present study 2D electrical resistivity tomography carried out applying GRP, Wenner and Scclumberger methods (ABEM Terrameter LSv2) to determine the subsurface lithological profile in the valleys for the feasibility for construction of subsurface dyke.AHP Analysis was employed in the three severely drought prone administrative blocks in the Palakkad district - Chittur, Pattambi, Thrithala Blocks which are coming under critical and semi critical category as per CGWB groundwater resources assessment (2022). Analytical hierarchy process is a structured decision-making process that involves using expert knowledge to determine the rank and weights by constructing an eigenvalue pair wise comparison matrix. This method is best-suited for decision-making in a problem involving several parameters influencing the result. The methodology of the study involved collecting and preparing all the eight thematic layers using ArcGIS software. The geo-referenced maps were assigned weights computed by the analytical hierarchy process. Google spreadsheets were utilized to compute the average and weightage, while Microsoft Word was utilized to create the table and assign ranks.

In Pattambi block the ERT profiles (GRP and Wenner) in the surveyed location showed a saturated surface layer up to 6 meters from 2 meter below ground level. The massive bed rock was identified at 6 meters below ground level. A narrow subsurface valley was clearly indicated by the 2D Inverse models. In the Thrithala block, the surveyed location showed a saturated layer from 1-4 m bgl. The bed rock was found approximately at 6 meters bgl. Various lithological layers in the valley region were clearly identified from the 2D Inverse model. The location surveyed in the Chittur block showed an ideal condition for construction of SSD with depth to bed rock approximately 2-3 mbgl. The study concluded that SSD was suitable for construction in these locations having depth to massive rock was less than 6m bgl. It was possible to store and recharge large volume of groundwater in the upstream watershed areas affected by water scarcity in the summer months in these areas.

Keywords: *Subsurface Dykes (SSD), AHP tools and ERT profiling techniques, critical and semi-critical blocks, Palakkad District, Kerala*

AUGMENTATION OF GROUNDWATER RESOURCES THROUGH TECHNICAL SURVEYS AND COMMUNITY BASED GROUNDWATER MANAGEMENT INITIATIVES TO BRING THE AREA OVER EXPLOTED TO SEMI CRITICAL ZONE IN BULDHANA DISTRICT, MAHARASHTRA, INDIA

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Groundwater availability for drinking water is directly linked to the overall groundwater usage in agriculture. It also depends upon its management by the farmers, industries and urban users. Developmental processes both in rural and urban areas start and end with the availability of water of desired quantity and quality. The demand of freshwater reserves has increased largely during last three decades. Geometric growth of population has led to greater pressure on domestic, industrial water supplies and on producing sufficient food grain, which requires more and more water. Inefficient irrigation practices compound the problem of freshwater availability. The available quantity of fresh water is further reduced due to contamination of water resources caused by the discharge of untreated/partially treated wastewater and industrial effluents as well as excessive use of fertilizers and pesticides for irrigated agriculture. The state of Maharashtra covers 9.37% of India’s total geographical area, but shares only 1.43% of the total surface water potential and 3.17% of the total groundwater potential. In Maharashtra, groundwater is the main source of water supply for drinking and domestic uses in rural area. Approximately, 80% of the state drinking water and about 51% of its irrigation needs are met through groundwater resources. Recurring droughts in the state of Maharashtra aggravated the already stressed water resources. Even in the assured rainfall zone, some areas have reached over-exploited stage of groundwater development. In the last few decades, the farmers to have private irrigation sources has led to mushrooming wells/bore wells/tube wells resulting in large declines in groundwater levels. Resulting 73 watersheds are become over exploited, 3 are become critical and 119 water sheds are become semi-critical in the Maharashtra state. Therefore, an immediate attention is taken as far as management of water resources is concerned as Aquifer delineation.

Aquifers are basic units for understanding groundwater and attempting the sustainable management of groundwater resources. Understanding aquifers also includes precisely locating their natural recharge and discharge areas through surface infiltration into shallow, unconfined aquifers. The aquifer based participatory groundwater management project has been implemented in over-exploited mini-watershed of PT-11 (2,3,4,5,6/8) in Jalgaon Jamod tehsil, Buldhana district. Hence, the first step was to construct a disaggregated picture by carefully mapping the aquifers across different hydrogeological settings and understanding their storage and transmission characteristics. Aquifer boundaries are clearly demarcated through groundwater technical surveys of hydro-geological, geo-physical and geo-chemical. The groundwater management with community participation has been attempted through a systematic implementation of supply and demand side interventions formulated with the help of community-based Groundwater Management Action Plan (GWMAP). The supply side interventions envisaged implementation of groundwater recharge structures. Whereas the demand side interventions encompassed various community awareness programs on groundwater conservation, adopting water saving techniques and self-regulatory measures. Substantial part of demand management component has been dovetailed with Agriculture Department and various other government line departments which collectively brought the required demand side management in the project areas.

Water harvesting structures play a major role in groundwater recharge of shallow aquifers. It facilitates augmentation and helps in retaining the water column in wells for longer period of time. The supply side interventions of the GWMAP implemented in the project area comprised of total 537 recharge structures having substantial number of direct groundwater recharge structures such as 273 recharge shafts and trench and 264 gabion bandhara. Operation and maintenance of recharge structures must be done by Groundwater management action plan and village community, preferably through beneficiary groups. A significant positive impact in gross groundwater recharge is seen as it has been increased from 1562.20 Ham in 2014-15 to 2371.70 Ham during 2019-20. An increased net groundwater availability by 809.68 Ham is found to be beneficial in restoring recharge-discharge balance. During year 2014-15, the net groundwater recharge was 1562 Ham and groundwater draft computed was 1614 Ham. The stage of groundwater development which had gone high upto 103% before the project initiation has now been reduced to 76.97 % transforming the aquifer from over-exploited state to safe zone. The aquifer which was groundwater deficient has now retained groundwater balance of 443.91 Ham ascribed to successful implementation of the GWMAP. The stage of groundwater development decreased by 26.03% after the project implementation. Pre and post-monsoon groundwater levels are raised by 2.70 m and 3.28 m, respectively. The saturation has helped in sustaining the groundwater availability round the year. It has helped in bringing the area from over-exploited to semi-critical zone and release the restrictions imposed on groundwater development to a certain extent in the area, hence PT-11 (2,3,4,5,6/8) mini-watershed shows very good performance category. It is evident that the supply side interventions have elevated groundwater recharge and the demand side interventions with the help of community participation like adoption of micro-irrigation practices have gradually decreased groundwater withdrawal.

A positive attitude of farmers developed regarding conservation of groundwater resources for agriculture purpose. Village community is aware and involved in optimized use of groundwater resources. Farmers adopting water saving techniques for irrigation purposes and Micro-irrigated area increased from 0.00 ha to 233.71 ha. The cumulative effect of demand management and raised awareness resulted in increase in cultivable area. After completion of supply and demand side interventions in year 2019-2020, all Twenty-two villages show normalised Groundwater Drought and vegetation cover increase. The project has also shown moderate impact on groundwater quality as about 50% samples have shown excellent to good groundwater quality index, yet, analytes like Nitrogen, show increased concentration.

Keywords: *Augmentation of groundwater, unconfined aquifer, over-exploited and semi-critical watersheds, groundwater technical surveys, recharge structures, micro-irrigation, groundwater drought*

ARTIFICAL RECHARGE TO GROUNDWATER LEVEL DECLINING AREA USING CANAL WATER OF BHANDARA DISTRICT, MAHARSHTRA, INDIA

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Artificial recharge is the process of adding water directly to the aquifer for replenishing the groundwater levels. Development of groundwater resources for irrigation and rural drinking water supply during last few decades have resulted in declining groundwater levels. Due to erratic and scanty rainfall, these aquifers are not replenished. In Mahabharata State eastern most part area of Pauni and Lakhandur taluka of Bhandara district is drained by Wainganga and Chulband rivers is known as Chauras belt (shape of area is square) lies between latitude 20° 40': 20° 55' and Longitude 79° 35': 79° 55', is famous for perennial paddy cultivation and facing problem of progressive water level decline. The area falls in the Survey of India Toposheets No-55 P 9, 10, 13 and 14, forms part of the Wainganga sub-basin and included in Groundwater surveys and development agency watershed WGC-6 and WG 11 and has an aerial extent of 285.33 sq km is under command of right bank canal of the project. Normal rainfall of taluka Pauni is 1274.4 mm and 30 years rainfall shows highest rainfall 2139.1 mm in year 1994 and lowest rainfall 661.7 mm in year 2004. The entire area of Chauras Belt is covered by 30 m thick alluvium, which consists of silt, medium to coarse grained sand, rounded to sub rounded pebbles and boulders which is main aquifer of the area. The alluvium is underline by older metamorphic rocks. The main crop of area is paddy. The water requirement of paddy is very high about 44.21cubic-meters/day (m^3/d). Over exploitation of the groundwater is roughly through 7149 irrigation dug wells and dug cum bore wells having average depth of 25m to 28m (well depth 18m and in well bore 10m) in the local alluvial belt has resulted in an alarming depletion in both post and pre monsoon water levels and in turn the aquifer is partially saturated even after monsoon season. Over-exploitation of groundwater in this belt has resulted in gradual depletion of water level in the area day by day by 11.75 m (7.5 M to 19.25 M) in last two decades. Wainganga River was the primary source of groundwater recharged to sand and gravel aquifers in the Chauras area. History reveals that after the construction of Gose.kh dam on Wainganga River, this buried channel is hydrologically disconnected from Wainganga River which has stopped groundwater recharge to aquifer of Chauras area which is one of the causes of water level depletion in the area.

To overcome this problem Groundwater surveys and development agency delineate aquifers and buried channel of Waingangariver which is hydrologically disconnected from Wainganga River in Construction wall of Gosi kh major irrigation project, and also calculated the acceptance capacity of aquifer was finding out by conducting slug test in study area. The test plays a vital role in designing a model of artificial recharge. The quantity of water that is accepted per unit time and per unit area of aquifer is calculated by slug test and recommended an innovative artificial recharge model of dug well recharge. To delineate the aquifer periodic motioning of groundwater level through 25 observation wells stations, 7 piezometers with digital water level recorder and 325 irrigation well inventories of groundwater extraction structures were carried out in grid pattern of 65 villages on 1:50,000 scale. For construction of artificial recharge structure demarcate the suitable zone for

artificial recharge to groundwater with area and depth in command area of Gosi Khurd left bank canal. As hungry sandy aquifer is available and surface water available through canal considering this field conditions an innovative model of dug well recharge has been recommended in which the surface water (Canal) is filtered through one filter trench and two filter well and then crystal clear water is recharged through recharge well of depth 16 m with filter media. Groundwater surveys and development agency completed the structure for artificial recharge to groundwater by using surplus surface water available in Gosi kh dam. Overall more than hundred projects of such techniques have been constructed to recharge hungry zone of the aquifer, as the water acceptance rate of the aquifer is very high i.e. 4225 Liters per hour. The major outcomes of the study are construction of artificial recharge structure left bank canal command of Gosi Kh, major irrigation project. Outcomes of this study can be replicated in other areas situated in similar hydrological and hydro-geological set up i.e., area of Tapi Purna alluvium of Maharashtra and other states of India.

Keywords*: Artificial recharge, alluvium, aquifer, chauras, overexploitation, decline water level. watersheds, groundwater technical surveys, recharge structures, micro-irrigation, groundwater drought*

SUSTAINING GROUNDWATER RESOURCE THROUGH SOCIO-HYDROGEOLOGICAL APPROACH: A COMPREHENSIVE STUDY IN A CLUSTER OF OVEREXPLOITED VILLAGES IN AMRAVATI DISTRICT, MAHARASHTRA

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While Groundwater spurred the Green Revolution that made India a food secure nation, the widespread extraction of groundwater has led to its alarming decline. Being the most dependent source of water for most of India's people providing the bulk of water for farming and domestic use, availability of groundwater is at risk. As mammoth revenue is invested in implementing water conservation practices and most of the area uses traditional irrigation techniques that stress the availability of water. Thus, there is a necessity to study interaction of water and human systems to address these crises. The government of India is undertaking several steps to manage groundwater and it includes the flagship program named as 'Atal Bhujal Yojana' (Atal Jal). The major objective of the scheme is to improve the management of groundwater resources in selected water-stressed areas in identified states through community-led sustainable groundwater management practices. This program will foster community led groundwater management and behavioral change with a fundamental focus on groundwater management. Present study focusses on a cluster of five over exploited villages from Warud taluka (Block) of Amravati district of Maharashtra state. In this area orange cultivation is a prime perennial horticulture crop which requires irrigation cycles throughout the year. Warud and Morshi blocks of the Amravati district are known for the orange cultivation since last so many decades. In the absence of surface water irrigation projects in the area, the crop is mainly groundwater dependent and hence led to the groundwater over-extraction. Well density has already crossed the safe limit, groundwater levels show long term predominant declining trend, shallow or un-confined aquifer is almost dried up, because of which dug wells are replaced by borewells, and depth of bore wells and their failure percentage is increasing day by day. Due to over extraction and aforesaid problems, Central Groundwater Authority had banned the drilling of new borewells in these two blocks during 2005.

In order to address such groundwater issues over a pan India level through community partnership the Atal Bhujal Yojana is launched in 2020. The area under discussion is a part of the scheme area in Amravati district. In accordance with the scheme objective socio-hydro geological approach is adopted, which includes village level awareness of stakeholders especially farmers through meetings and IEC tools, earmarking of groundwater monitoring stations(observation wells) and measurement of groundwater levels and rainfall by the community, field survey with them for geo-tagging the existing water conservation structures and identifying the sites for new ones, surface geological survey and well inventory in presence of them, data collection of existing cropping pattern and irrigation practices as adopted by farmers, water quality testing. Based on all the data and surveyed information water budgeting and water security plans have been prepared and updated through community consultation and discussions. This led to build the confidence among the

community to manage the groundwater resource at the village level. As the confidence built up among the community, volunteers came forward and took the charge of groundwater management, implementation of measures suggested in water security plan as well as motivated the other people for crop water management practices. It will help in building a comprehensive database that incorporates ground water data availability and quality, as well as its demand on the resource base.

This improved the quality of groundwater monitoring network and the assessment and utilization of monitoring data. With the continued collective efforts of volunteers, community and Government machinery, a visible impact can be seen in the field in the form of crop water management practices, increased water balance and arrest in rate of decline in groundwater level. Supply and demand side management is achieved through convergence of ongoing schemes and with the help of public participation. Forty-five percent farmers have been shifted from high water to low water consuming crops. Area under micro irrigation (drip and sprinkler) has been increased by twenty-five percent. Also, area under Broad Bed Furrow (BBF), mulching (plastic and organic), shed-net, poly-house have been increased during last four years through community participation. More importantly behavioral change and increased capacity of the community to handle the resource management is leading towards the sustainability of resource. Volunteers and village people are monitoring the charts of groundwater level, daily rainfall pattern and supervising the execution of water conservation and artificial groundwater recharge measures, being undertaken in the area through incentive and convergence funds. The present study highlights the success of community-led groundwater management that to in the over-exploited area, whereby an aspiration can be taken for sustainable groundwater management. As groundwater resource is at the discretion of the community, a strong community led groundwater management and public governance can only be the solution for sustainable groundwater management. This requires a fundamental handholding between Government machinery, NGOs and the Community.

Keywords: *Sustainable groundwater management, socio-hydrogeological survey, water conservation measures, artificial groundwater recharge, NGOs, IEC, Water security plans*

QUANTIFYING RAINWATER HARVESTING POTENTIAL ACROSS VARIOUS TOPOGRAPHIES: A TEN-SITE STUDY FOR FIVE STATES IN INDIA

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In regions with fluctuating water availability, comprehending rainwater harvesting potential across diverse soil characteristics is critical for sustainable water resource management. This study systematically evaluates the rainwater harvesting (RWH) potential across ten distinct sites in India, spanning the states of Uttar Pradesh, Rajasthan, Maharashtra, Madhya Pradesh, and Telangana. The study aims to quantify rainwater harvesting (RWH) potential, with a focus on how local environmental and anthropogenic factors, such as soil characteristics, rainfall patterns, and land use, influence the effectiveness of rainwater harvesting techniques. Utilizing a comprehensive 30-year dataset of average rainfall, detailed soil analyses, and land use classifications, this study estimates runoff volumes. The rationale behind this approach lies in the significant variability in rainfall patterns and soil characteristics across India. By assessing runoff volumes for both annual and seasonal periods, especially focusing on the monsoon season (June to September), the study highlights how regional differences impact the efficiency of RWH systems.

The gridded rainfall data for the area was obtained from the India Meteorological Department (IMD), Pune. Long series of gridded (0.25^{o} x 0.25^{o}) daily rainfall records of 122 years from 1901 to 2022 from the IMD are used in the analyses. In order to ascertain the certainty of rainfall that may occur, the probability analysis of the rainfall data for the period from 1901 to 2022 is also carried out for different probability levels. Lower probability indicates less assurance to the occurrence of rainfall, while higher probability indicates that rainfall has more chance to occur. For doing the analysis, average daily rainfall data has been converted to the average monthly data. The monthly rainfall data has thereafter been analyzed for different probability levels. The rainfall distribution at various probabilities with desired assurance can be used for planning water usages and manage the water resources during low rainfall years. Normal rainfall for the period 1993-2022 (30 years) is used to estimate RWH potential. The annual average normal rainfall for the locations varies as: 0.809 m for Edullapur, Thupakulapalli Medak; 1.139 m for Atkuru-2, Krishna; 0.704 m for Warud, Aurangabad; 0.744 m for Nayakpura, and Nirawali Gwalior; 0.681 m for Sodawash, and Karoda, Alwar; 0.775 m for Teharki, Atmadnagar, and Alipur, Meerut; and 0.930 m for Dudhli Bukhara Aht, Saharanpur. Further, it was found that the percent soil moisture content of the various locations varied from 3.12 % (Medak) to 20.67 % (Dudhli Bukhara Aht, Saharanpur). On the other hand, the bulk density of the various soils ranged between 1.17 g/cm^3 (sodawash, Rajasthan) to 1.72 g/cm^3 (Dudhli, Saharanpur). The soil texture at the various locations varies from silt loam to highly graveled loam.

Key findings from this study revealed estimated annual runoff potential for different station varies from 2,39,578.05 m^3 at Nayakpura, Gwalior to 6,26,446.99 m^3 at Atkuru, Krishna. Site wise the runoff volume was found as: Edullapur, Medak 511666.80 m^3; Thupakulapalli, Medak 461917.80 m^3; Atkuru-2, Krishna 626446.99 m^3; Warud, Aurangabad 395750.34 m^3;

Nayakpura, Gwalior 239578.05 m^3; Nirawali, Gwalior 278233.78 m^3; Sodawash, Alwar 368756.25 m^3; Karoda, Alwar 401544.86 m^3; Teharki, Meerut 310883.63 m^3; Atmadnagar Alipur, Meerut 294369.61 m^3; Dudhli Bukhara Aht, Saharanpur 502432.83 m^3. Similarly, estimated runoff potential for monsoon months (JJAS) for different station varies from 2,09,374.17 m^3 at Nayakpura, Gwalior to 4,31,773.46 m^3 at Atkuru.

The implications of these findings are to emphasize the necessity of site-specific RWH strategies tailored to local soil characteristics, topography, and rainfall distribution. For example, regions with high runoff potential, such as Edullapur, can benefit from enhanced RWH systems, such as larger catchment areas and more efficient water storage infrastructure, to maximize water capture. Moreover, integrating RWH systems into regional water management policies offers significant economic and environmental benefits. In water-stressed regions, RWH systems can alleviate pressure on conventional water sources like wells and rivers, ensuring a more sustainable supply of water for agricultural and domestic use. From an economic standpoint, the initial investment in RWH infrastructure can provide high returns in the form of reduced water scarcity and improved agricultural productivity, especially in arid regions like in Alwar Rajasthan where water scarcity is a major challenge. This research provides a scientific basis for optimizing RWH practices in semi-arid and water-stressed regions. By correlating soil properties, land use patterns, and rainfall data, the study offers actionable insights for policymakers, NGOs, and local communities to enhance water conservation efforts. Furthermore, integrating climate change projections into RWH modeling could help predict future runoff patterns and assist in designing more adaptive systems. In conclusion, the variability in RWH potential across the ten studied sites underscores the importance of localized interventions in water resource management. By aligning RWH techniques with the unique hydrological and geological contexts of each region, stakeholders can achieve sustainable water conservation and support the livelihoods of community's dependent on these critical resources. As RWH continues to gain recognition as a key strategy for sustainable water management, this study sets the stage for more comprehensive approaches that integrate regional differences in rainfall, soil characteristics, and land use into water conservation planning.

Keywords: *Rainwater harvesting, runoff potential, infiltration capacity, Medak, Alwar, Edullapur, Sodawash*

DELINEATING GROUNDWATER LEVEL IMPACT FROM RAINWATER HARVESTING RECHARGE WELLS ACROSS DIVERSE INDIAN GEOGRAPHIES: IMPLICATIONS FOR SUSTAINABLE MANAGEMENT

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Groundwater depletion is an escalating issue in India, driven by increasing water demands, unsustainable extraction practices, and climate variability. The problem is particularly acute in semi-arid and over-exploited regions, where groundwater serves as the primary source of water for agricultural, domestic, and industrial use. This study evaluates the performance of ten rainwater harvesting (RWH) recharge wells distributed across five Indian states—Telangana, Maharashtra, Madhya Pradesh, Rajasthan and Uttar Pradesh—highlighting their role in augmenting groundwater levels and promoting sustainable water management practices. The analysis focuses on site-specific soil properties, groundwater level analysis, and rainfall patterns, which collectively influence the efficiency of recharge wells in replenishing aquifers. The study utilized a robust methodology, incorporating both field and laboratory analyses to capture the diverse hydrological and geological characteristics of the study locations. Soil texture and bulk density analysis were conducted to classify the soils and evaluate their infiltration capacity. Infiltration tests using a double-ring infiltrometer measured the rate at which water percolates through the soil, a critical parameter for estimating recharge efficiency. Rainfall pattern analysis was performed for the monsoon season (June to September, JJAS), as well as on an annual scale, to account for seasonal and inter-annual variability in water availability. Groundwater level analysis spanned three years (2021–2023), with pre- and post-monsoon readings collected to assess the impact of recharge wells on water levels.

Results revealed significant variability in soil infiltration rates across the ten sites, ranging from 1.553 cm/hr at Sodawash village, Alwar, Rajasthan, to 6.809 cm/hr at Nirawali village, Gwalior, Madhya Pradesh. These variations are attributable to differences in soil texture, with sandy soils exhibiting higher infiltration rates compared to clay-rich soils. For example, the sandy loam soil in Nirawali facilitated faster water absorption, enhancing the recharge efficiency of wells in the area. Conversely, the clay-rich soil at Sodawash restricted infiltration, limiting the effectiveness of recharge structures. This underscores the importance of tailoring RWH interventions to local soil characteristics to maximize their impact. Seasonal groundwater level analysis highlighted substantial recharge effects at several locations. For example, groundwater levels in Edullapur village, Medak, Telangana, demonstrated a marked improvement, rising from 17.5–15.1 m below ground level (bgl) during the pre-monsoon season of 2022 to 10.3–7.87 m bgl by the pre-monsoon season of 2023. Similarly, other sites, such as Nirawali, Gwalior, and Jalgaon, Maharashtra, also showed significant gains in groundwater levels following the implementation of recharge wells. These findings illustrate the capacity of recharge wells to mitigate seasonal declines in groundwater levels, particularly in regions with pronounced monsoonal rainfall. The rainfall pattern analysis provided critical insights into the role of monsoonal variability in recharge well performance. The study sites experienced diverse rainfall distributions, ranging from moderate rainfall in Rajasthan to higher precipitation levels in Telangana. Sites with

consistent monsoon rainfall, such as Edullapur and Nirawali, exhibited higher recharge rates, whereas regions with erratic or lower rainfall patterns, such as Sodawash, demonstrated less pronounced effects. This emphasizes the need for integrated water management strategies that consider both recharge infrastructure and supplemental measures, such as soil conservation techniques, to enhance water retention in low-rainfall areas. A detailed cost-benefit analysis of the recharge wells revealed their high efficiency and cost-effectiveness as interventions for groundwater management. Recharge wells, with their relatively low construction and maintenance costs, yielded significant returns on investment in terms of improved water availability, reduced dependency on external water sources, and enhanced agricultural productivity. For instance, in Medak, the availability of groundwater for irrigation increased significantly, reducing the vulnerability of local farmers to water shortages during the dry season. These economic benefits underscore the potential of recharge wells to serve as a scalable solution for water-scarce regions across India. Despite their effectiveness, the study also highlights challenges associated with implementing recharge wells. Site selection, informed by comprehensive hydrological assessments, is critical to ensuring optimal performance. Additionally, the long-term sustainability of recharge wells requires regular maintenance, such as clearing sediment accumulation, which can obstruct infiltration. Policy frameworks must support these efforts by promoting community participation, capacity-building programs, and financial incentives for adopting RWH technologies. The findings from this study have significant implications for groundwater resource management in India. By demonstrating the effectiveness of recharge wells in diverse topographies, the research provides a blueprint for scaling up RWH initiatives to address groundwater depletion at a national level. Integrating recharge wells into broader water management frameworks could play a transformative role in achieving sustainable groundwater resources. Furthermore, this study underscores the importance of continued research and monitoring to refine RWH strategies. Future studies could focus on incorporating advanced hydrological modeling to predict the long-term impacts of recharge wells under different climatic and land-use scenarios. In conclusion, the variability in soil properties, rainfall patterns, and groundwater dynamics across the ten study sites highlights the need for localized RWH interventions tailored to regional conditions. Recharge wells have proven to be highly effective, cost-efficient solutions for mitigating groundwater depletion and supporting sustainable water use in India. By aligning recharge well implementation with comprehensive water resource management plans, stakeholders can address the growing challenges of water scarcity and ensure the long-term availability of this critical resource for future generations.

Keywords: *Rainwater harvesting, soil infiltration rates, groundwater level, recharge wells, recharge efficiency*

GROUNDWATER RECHARGE ZONING AND ARTIFICIAL RECHARGE SITE IDENTIFICATION IN CHOHAL AND DAMSAL COMMAND AREAS, HOSHIARPUR, PUNJAB USING GEOSPATIAL TECHNIQUES

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This study offers a comprehensive geospatial analysis of groundwater recharge potential within the command areas of the Chohal and Damsal reservoirs, situated in the Shivalik foothills of North-West India, specifically in Hoshiarpur district, Punjab. As the demand for groundwater continues to increase, especially in areas with limited water availability, such studies are crucial for informed resource management. This study focuses on identifying potential zones for artificial recharge within these reservoir command areas, which consist of predominantly 3rd- and 4th-order streams and span diverse landscapes. By identifying the areas suitable for groundwater recharge, this research aims to support sustainable water management practices within the Shivalik foothills. The command areas of the Chohal and Damsal reservoirs are characterized by an average elevation of approximately 296 m above sea level. These regions consist of a variety of land uses, including water bodies (the reservoirs), forests, agricultural land, and built-up areas. The presence of these different land uses plays a significant role in influencing the region's groundwater recharge potential, as factors such as land cover, soil type, and slope gradient impact water infiltration rates. The Shivalik foothills, particularly in Punjab, are known for their undulating terrain and periodic monsoon rains, which contribute to both surface runoff and potential recharge of groundwater aquifers. Therefore, managing these resources effectively is essential for local agriculture, biodiversity, and water security. The primary objectives of this study are twofold. First, it seeks to delineate the command areas of the Chohal and Damsal reservoirs. This process involves mapping the catchment and command areas associated with each reservoir, paying special attention to the contributing stream orders and drainage network. Defining these areas provides a clearer understanding of where water naturally accumulates and flows, allowing for a more targeted approach to groundwater recharge. The second objective is to identify suitable zones within these command areas that have high potential for artificial groundwater recharge. Given the increasing stress on groundwater resources, identifying recharge-prone areas enables effective intervention and ensures that recharge efforts are concentrated in the most beneficial areas. Methodologically, this study employs advanced geospatial techniques, which are particularly useful for natural resource management and hydrological studies. Using geographic information system (GIS) tools, the researchers were able to delineate the command areas associated with each reservoir and analyze various geospatial parameters that impact groundwater recharge potential. The GIS-based approach provides a spatially accurate, data-driven analysis, enabling a systematic assessment of recharge potential based on critical factors such as land use, stream order, slope, and topography. These factors were integrated within a geospatial framework to create recharge potential maps that depict suitable areas for groundwater recharge interventions. The study first delineates the command areas of the Chohal and Damsal reservoirs by defining the stream orders and establishing a 500-m stream threshold. Stream order is an essential parameter in hydrology, as it indicates the size and flow capacity of a stream segment, which affects surface runoff and water infiltration. By focusing on 3rd and 4th order streams, the study ensures that the assessment

captures areas with significant water flow, which are more likely to contribute to recharge. Additionally, the command area delineation takes into account the natural boundaries of these catchment areas, where surface water from precipitation or runoff accumulates and flows into the reservoirs. Following the delineation of the command areas, the study applies geospatial analysis to assess recharge potential. Data on land use, soil characteristics, stream order, topography, and slope gradient were incorporated to identify the zones within these command areas that are most conducive to groundwater recharge. The use of GIS allows for the integration of multiple datasets and the generation of recharge potential maps, which highlight areas that could be prioritized for artificial recharge projects. For instance, areas with gentle slopes and permeable soils were deemed more favorable for recharge, as they allow water to infiltrate rather than flow away as surface runoff. The results of this analysis highlight a substantial recharge potential within the command areas of both reservoirs. Specifically, the Chohal Dam's command area was found to have 70.6% of its area classified as good or very good for groundwater recharge. This indicates that over two-thirds of the area has favorable conditions for recharge, making it a prime candidate for intervention strategies aimed at increasing groundwater levels. Similarly, the command area of the Damsal Dam exhibits a balanced recharge potential, with 69.6% of the area categorized as good or very good for recharge. These figures underscore the potential for implementing focused groundwater recharge projects within the identified zones, which could help mitigate the effects of water scarcity and groundwater depletion. In terms of practical applications, the study’s findings provide valuable insights for water resource managers, policymakers, and local authorities responsible for sustainable water management in the region. The high recharge potential in both command areas suggests that targeted recharge interventions could yield significant benefits. For instance, constructing check dams, percolation tanks, or infiltration wells in these high-potential areas could enhance water percolation into the ground, thereby replenishing local aquifers. Furthermore, integrating these interventions with existing land use practices, such as agroforestry or conservation agriculture, could further support sustainable water resource management and improve agricultural productivity. The study concludes that implementing focused recharge strategies in the identified zones has the potential to significantly enhance groundwater sustainability in the Shivalik foothills. Given the dependency of the local population on groundwater for agricultural and domestic purposes, enhancing recharge is a crucial step towards ensuring long-term water availability. Additionally, the recharge potential maps developed through this study serve as a valuable tool for guiding future groundwater management initiatives, enabling stakeholders to allocate resources and plan interventions more effectively.

Keywords: *Groundwater Recharge, Geospatial Assessment, Dam reservoirs, Command Area, Sustainable Water Management*

ARTIFICIAL RECHARGE OF GROUNDWATER: PROCESSES AND ITS IMPACT IN INDIA

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Groundwater is a replenishable resource, and hence, its availability has often been taken for granted. The limitation of surface water resources and increased agriculture, industry, and domestic use have put the onus on groundwater. Artificial recharge of groundwater is one of the processes to replenish the underground aquifers through accumulating rainwater or using surface water directly or indirectly. However, these recharges are facing significant challenges such as changing rainfall patterns, heterogeneous and complex sub-surface flow, uncertain bio-geophysical processes, and the population is increasing so urbanization reduces the infiltration. For urbanization "progress cannot be stopped; it can only be channelled". Hence to increase the potential of recharge, analysis of methods of artificial recharge is required for particular climatic and geological regions in India. Each type of artificial recharge structure has both upside and downside consequences, which determine whether it will effectively meet the required water resources. In India, there is a varied climate, geology, and topography setup and hence there is a need for various data to understand the artificial recharge system. Artificial recharge is to replenish the groundwater resources through human intervention and rainwater harvesting (RWH) is to collect rainwater for direct use or recharge of groundwater. Managed aquifer recharge (MAR) system is one of the processes to increase the potential of groundwater charge. This paper reviews different methods, their utilization, and their influence on groundwater levels. For a long time, the artificial recharge system has been carried out but as over-exploitation has increased day by day and the resources are finite, there is a need for thorough study. One of the biggest challenges for future investigation is to include advanced MAR systems, machine learning, and GIS for artificial groundwater recharge. Future work should also investigate the role of climate change affecting the recharge system. The primary objective of this paper is to understand the extent and suitability of artificial recharge according to the geological and climatic regions and elaborating on different processes with advantages and disadvantages.

This research methodology involves various techniques of groundwater recharge systems in India. The groundwater level data and other information related to the recharge system are collected from CGWB and state groundwater departments. Due to the decrease in the natural recharge of groundwater, there is a need to increase the potential of artificial recharge by using conventional methods with numerical modeling and managed aquifer recharge systems. There are several methods used for the artificial recharge of groundwater such as percolation tanks, check dams, recharge wells, recharge pits, flooded recharge areas, infiltration galleries, artificial recharge using treated wastewater, and RWH. Several conditions must be considered for artificial recharge to understand its extent and impact like hydrogeological characteristics, water availability, and its quality, environmental and climatic conditions, soil and topography, and understanding of the extent of the aquifer.

The upside and downside of each method are described in the water budget sheet. Feasibility, impact, and challenges are tabulated. Infiltration is one of the best methods to replenish the groundwater that is affected by land use and land cover, soil type and texture, soil moisture content, vegetation, rainfall intensity, temperature, and topography. At some places it is not feasible to construct recharge through infiltration then other structures must be accounted for recharge. Recharge wells can be horizontal or vertical mainly very useful for deep confined aquifers that have restricted natural recharge. Surface spreading methods are one of the best methods to recharge groundwater. Surface water or rainwater has been stored in ponds and basins and percolated to recharge groundwater. This method is widely used and beneficial to conserve the soil, and surface and replenish the groundwater. The induced infiltration method is very useful for coastal regions where fresh water is vulnerable due to saline water intrusion. The geology of the area and lithology are some of the most important parameters to understand which type of structure should be assigned.

This study has conducted a thorough analysis to understand the artificial groundwater recharge system of India. For this purpose, groundwater level data and its fluctuation and groundwater recharge potential index data (wherever present) of different regions of India have been used. Analyzing different data sets from every region of India yields invaluable insight into both artificial recharge and the key factors that influence it. Notably, the outcome of this study indicates the significance of a few fundamental factors in determining the potential recharge system. Explicitly rainfall pattern, geomorphology and lithology, water level, and its fluctuations. Different regions have different specific important factors that influence greatly the recharge system. The contrary importance of other factors is not negligible but according to the different basins. But progressively there is delineation in proper replenishment of groundwater through artificial groundwater recharge indicating a subtle understanding of meteorological and hydrogeological factors at play. Hence this rigorous study not only indicates potential methods for recharge of particular regions but also reduces the chance of failure of structures.

Keywords: *Infiltration, artificial recharge, rainfall patterns, managed aquifer recharge, groundwater recharge potential index*

MAPPING OF VULNERABLE AREA OF DRINKING WATER IN MAHARASHTRA

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Groundwater availability and rainfall impacts vulnerability of drinking water sources to water shortage. This study highlights the key factors for vulnerability of drinking water sources and its security from precipitation, runoff and groundwater prospects of aquifer. The aim of mapping is to build up a common database for various allied departments involved in prediction, planning, estimation and implementation of Drinking Water Scarcity mitigation programme. The Database needs to be brought to minimum common requirements and must be uniform. The main aim is to find out the actual causes for repeated drinking water scarcity in a particular area thereby marking the most scarcity prone areas and least vulnerable areas. This study aims at guiding researchers and water managers in considering the climate-related threats. It highlights how climate change increases the seasonal risks of water supply insecurity in Maharashtra, thereby increasing socioeconomic risks. Groundwater availability for drinking water affects socio-economic status of human being. The precipitation, runoff and groundwater prospectus of aquifer plays an important role in drinking water availability at local scale. Drinking water sources are especially vulnerable and needs to be protected in order to maximise its benefits and minimise drinking water related risks. This study focuses on drinking water vulnerability and its mapping. Different departments of Maharashtra Government are engaged in mitigation of water scarcity by implementing water conservation activities and drinking water scarcity mitigation. Groundwater availability and the factors which impact it, are considered to map the vulnerability areas of drinking water. This helps to provide accurate results for planning and mitigation for drinking water scarcity, so that proper and adequate drinking water may be provided to the end users during the stressed period. Vulnerability of drinking water depends on precipitation, runoff and groundwater prospectus of aquifer. To study the precipitation, rate the Taluka level normal rainfall is considered and rainfall data for last 10 years have been collected and analysed. The available groundwater assessment data of CGWB with taluka and watershed boundaries and static water level data for observation wells have been considered. The slope map of state is classified into different class according to slope percentage to differentiate runoff. Drainage map of state is classified according to the order of drainage to assess the vulnerability of the area for drinking water availability as it directly impacts the runoff and recharge by precipitation. The groundwater prospect map has been used for studying the aquifer characteristics. The total dataset used include rainfall, static water level, groundwater prospect, slope, ordered drainage and groundwater assessment. The thematic map was generated by using the above factors and used for over lay to map the vulnerable areas of drinking water. The areas identified in the thematic map has been classified into four classes i.e., no vulnerable area, mild vulnerable area, moderate vulnerable area and sever vulnerable area. This study is helpful to users who are working on planning and implementation of drinking water scarcity mitigation program.

Keywords: *Vulnerability, groundwater prospects, groundwater assessment, precipitation*

IDENTIFICATION OF CAUSE FOR WATER LEVEL DEPLETION IN COAL MINE AREA OF NAGPUR DISTRICT, INDIA

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The Nagpur district is well known for its coal reserves. Large scale coal mining is carried out in various parts of the district. Coal mines are located in Saoner, Parseoni, Kamptee and Umred talukas. At present, there are 14 (38.90%) underground and 22 (61.1%) open cast mines. The present study is mainly concerned with groundwater depletion in coal mines area (i.e, Bhanegaon and Singhori of Saoner taluka), which falls in Survey of India Topo sheet number 55 O/3. The study area covers around 10249 ha, which includes mining area of 773.46 ha. Buffer zone of 5 km has been taken from centre of Bhanegaon and Singhori mines for the present study covering 21 villages. The exploratory wells are pumped at optimum sustainable yield of 2100 litres per hour (LPH). The wells are pumped continuously. Therefore, main objective of study is to assess the current quantity and quality of groundwater withdrawal from coal mining area in time and space on groundwater regime area of 10429 ha within a buffer of 5 km around the mines. Study also aimed to investigate the changes in the land use pattern and impacts on groundwater due to mining activities in the project area. In addition, the study aimed at recommending the method for artificial recharge to groundwater in affected area by using dewatered mine water during production of coal considering water quality standards and for domestic purpose in vicinity of mines.

Various historical baseline databases like demographic details, rainfall for last 52 years (1971- 2022) were collected from IMD. For static water levels, reconnaissance and detailed surveys in all 21 villages and existing open cast coal mine have been carried out. The well inventories of 123 irrigation wells were carried out to know the present condition of groundwater occurrence. Total 8 tube wells cum piezometers were drilled for knowing the subsurface geology and occurrence of groundwater in the study area. A few traverses for knowing the information regarding surface geology of the study area were taken and a geological map was produced. For assessing dewatering, data for mine was collected from the coal mining company and as well as from CGWB. For land use comparison between the land use pattern in 2008, before inception of mine (2016) and current land use (2022) for the study area was generated using GIS software. The soil type data was collected from various government organizations like WCL, CMPDI, GSI, CGWB, Pollution Control Board, DGM, MRSAC and Local Gram panchayat and in house data of GSDA. Generation of ground water scenario and its uses was done by ground water estimation. Present groundwater usage by all end users was collected and the comparison between the historical and present-day groundwater estimation of study area was performed. Dewatering in the mine for winning ore material is a very common phenomenon and it involves large quantity of pumping of ground water and its discharge into nearby streams. A comprehensive study has been carried out to understand the actual process and its implication over groundwater regime. The draft calculation is performed for 2015-16 and 2022-23 on the basis of water table fluctuation observed during the particular year. The results obtained indicate that in land use in the mining area has increased while agricultural area has decreased in the year 2022 as compared to the land use pattern of years 2008 and 2015 The water table fluctuation of year 2015-16

was 5.2 m and for 2022-23 it was 7 m, respectively. Normal Monsoon recharge for 2015-16 and 2022-23 was 1812.20 ham and 2525.44 ham, respectively. It could be observed that normal recharge to groundwater has increased by 713.24 ham i.e. the increase of 28.24% when compared to 2015-16. Net groundwater availability after removing base flow is found to be 1821.92 ham during 2015-16 and 2530.97 ham during 2022-23, which indicates that there is remarkable increase in groundwater recharge during the current year. The gross groundwater draft (Agricultural + Domestic + Mining) for 2015-16 is 1653.89 ham and for 2022-23 it is 2630.05 ham. The stage of ground water development for study area was 92.12% during 2015-16 and 191.18% during 2022-23. The study area was having groundwater balance of 168.03 ham in 2015-16 and -99.08 ham in 2022-23. Thus, according to GEC 2015 guide lines, the area could be categorized into overexploited category. But, as the study area is a part of five watersheds, therefore, on large scale, it is occurring as safe with respect to groundwater development. Based on above groundwater estimation, it can be concluded that the stage of groundwater extraction prior to inception of mine in 2015 was at 90.78 %, which has shown an exponential growth to 103.91% after 8 years of the start of the coal mining in the year 2023.

Keywords: *Groundwater draft, groundwater withdraw, fluctuation, land use, coal mining, geology, GIS, dewatering*

AN ARTIFICIAL RECHARGE IN THE DECCAN BASALTIC TERRAIN: A CASE STUDY OF THE EXPLOITED DEO MINI-WATERSHED, AMRAVATI DISTRICT, MAHARASHTRA, INDIA

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The utilization of a dug well for artificial recharge is a simple and economical approach. However, inconsistent precipitation and varied hydrogeological conditions result in an unequal distribution of water resources, particularly in hard rock regions. Therefore, an investigation of the Deo mini-watershed was conducted utilizing remote sensing and GIS tools to develop artificial recharge strategies. Field observations suggest that a significant proportion of surplus water is present in certain areas, particularly adjacent to the main channel of the Deo mini-watershed, which can be designated for artificial recharge structures. Artificial recharge of groundwater through dug wells is one of the most effective groundwater recharge techniques for controlling groundwater level depletion, resource augmentation, and well sustainability, in addition to groundwater problem mitigation. To recharge existing dug wells with rain, run-off from agricultural fields are diverted towards was in order to enhance the groundwater levels in the affected areas. The Artificial Recharge of groundwater, using Dug wells recharge techniques will be useful to control over-exploitation of groundwater resources, as well as to ensure sustainable water resource management and assured irrigation facilities in the affected areas. It helps to reduce surface runoff, increase water availability for irrigation, the industrial and residential sectors, improve drainage, revive springs, and improve groundwater. Artificial recharge groundwater through dug well flooding techniques is a great way of increasing the water table and raising groundwater availability. Among many other things, this method is generally used when a deep confined aquifer is present, but in present case, this method is found suitable to recharge the shallow dug wells, tapping unconfined aquifer. Dug wells of the area are deep or have a large average diameter. The recharge work was done in a systematic manner and was able to provide irrigation for an additional piece of land. The benefit of well recharging is that the farmers only have to invest a small amount of money once, but they can enjoy the profits for a long time. In this method, existing dug wells can be utilized as a recharge structure, when surplus surface water is available during monsoon season, which can be subsequently used during summer season. Thus, existing dug wells can be used for artificial recharge of ground water which can provide source water sustainably. In the Alluvial area, percolation tanks and recharge wells are most suitable structures. Also One direct artificial recharge technique is dug well flooding, which involves pumping water into dug wells to replenish desaturated unconfined aquifers. This method can greatly raise groundwater levels in the Deo mini-watershed and along its stream basins, making it very beneficial there. Water seeps through the ground and replenishes the underlying aquifer by flooding wells. This technique can significantly improve water availability in de-saturated zones by replenishing groundwater when used extensively or in succession. This approach is best in places where the conditions are suitable for these kinds of water management techniques.

Keywords: *Artificial recharge, watershed management, groundwater, deccan basalt*

IMPACT OF WATER CONSERVATION MEASURES THROUGH CHECK DAMS ON WATER RESOURCES IN SEMI-ARID REGIONS: A CASE STUDY FROM ANANTAPUR, ANDHRA PRADESH, INDIA

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Water is an engine that drives all developmental activities in a village. The presence of good quantity and quality water provides basis for good agriculture, health, livelihood, livestock, ecology and environment among others in a village. On the other hands water scarcity in any village leads pushes it to poverty in all these fields. Groundwater is main source of irrigation in India contributing up to 87% for agriculture and 85% for rural drinking water supplies. India has 35 million people without access to safe water from its total population of 1.42 billion. According to a new report by UNICEF and the World Health Organization, some 2.2 billion people around the world do not have safely managed drinking water services, 4.2 billion people do not have safely managed sanitation services, and 3 billion lack basic handwashing facilities. One of the main causes of all these problems is water scarcity and in particular absence of safe drinking water. Anantapur (called Sri Satya Sai district formed on 4 April 2022 from parts of erstwhile Anantapur district of Andhra Pradesh) falls under semi-arid climatic zone in South India with hot and dry conditions for most of the year. It also falls under rain shadow regions of western ghats getting low and limited rainfall. Anantapur gets pre-monsoon showers from March, mainly through north-easterly winds blowing in from Kerala whereas monsoon arrives here in September and lasts until early November. Located in South-Western corner of Andhra Pradesh in South India, Anantapur district receives the least rainfall in the state of Andhra Pradesh, and the rainfall is second lowest in India, after Jaisalmer in Rajasthan. The average annual rainfall in the district is 535 mm/year. The agriculture in most of the area is primarily rainfed due to limited surface and groundwater resources that can support irrigation. The untimely rains frequently lead to crop failure or very poor crop yield making farmers life very difficult. Under these circumstances, many people migrate to nearby cities in search of labour work. The groundwater depletion is an escalating issue in India, driven by rising water demands and unsustainable extraction practices further intensifying with increasing impact of the climate change. This study evaluates the impact of construction of check dams on local water resources in water scarce villages of Anantapur.

The project encompasses groundwater level monitoring, rainfall pattern analysis, changes in cropping pattern and water tanker supply in the village. The groundwater levels were monitored on monthly basis in mostly abandoned wells or agricultural wells using Digital Water Level Indicator device. While monitoring agricultural wells, a precaution was taken to inform the farmers in advance 24-48 hours to ensure that there is no pumping from the bore wells which were monitored as it could affect the levels and one may not get the true water levels due to effect of pumping. The methodologies included groundwater level comparisons during pre-monsoon and post-monsoon seasons during 2018 and 2019. The seasonal groundwater level monitoring highlighted a substantial impact of groundwater recharging on local water resources due to construction of three check dams across Chitravathi river (a tributary of Pennar river) in the villages of Kodur and Morasalapalle gram panchayats in

Chilamathur Mandal of Anantapur, Andhra Pradesh. One check dam of 65 m length and two check dams of 30 m each were constructed at strategic locations in the villages of Kodur-Subbaraopeta, Mudapally-Timadipally and Madhurepally-Kandurparthi and could hold water in the stream ranging from 300 - 800 metres upstream side. The water runoff during heavy rainy days that used to rapidly flow out untapped from these villages was arrested through these check dams, build using stone masonry structures with spillover for safe passage of excess water to downstream side. Two-three sluice gates were also provided at suitable heights to control the flow of water from upstream side of the check dams. The checks dams were able to hold a substantial quantity of water providing sufficient time for water percolation into the ground. It resulted in significant enriching of groundwater resources and considerably improving the groundwater levels. It also provided surface water storage in upstream side of the check dams for most month of the year. The stored rainwater is being used by villagers for bathing, cloth washing, cattle etc and acting as a source of continuous recharging of groundwater resources of the region. The continuous water level monitoring data of 24 months (between January 2018-December 2019) shows a significant rise in water levels from 87.25 m - 77.05 m below ground level (bgl) in the pre-monsoon seasons of 2018-19 to 90.25 m - 70.59 m bgl during post -monsoon seasons of 2018-19. Most of the farmers reported that the yield of their bore wells considerably improved along with rejuvenation of few dry/low yielding borewells also. Several water tankers operating in the village for drinking water and critical irrigation in agriculture fields running earlier are no more in demand. These findings underscore that construction of check dams across rivers and seasonal nallahs provide huge opportunity for construction of groundwater recharging structures such as check dams and can make a significant impact on local water resources by augmenting the water levels and increasing the availability of water for drinking, irrigation, livestock etc. The construction cost of such check dams is little higher but at the same time their return on investment is also very high recovering the investment cost with 3-5 years only due to its multidimensional positive impact on people’s lives, agriculture, livestock, livelihoods, ecology and environment among many others. The project also highlighted the importance of collaborative efforts of Public-Private-People partnership in transforming the villages economy through well designed and properly implemented water conservation measures emphasizing on community engagement, training and empowerment for a long-lasting impact. Thus, it can be concluded that the construction of check dams along the rivers, local streams and other strategic locations in the villages under suitably favourable conditions can be a game changing intervention for augmenting local water resources and checking the declining groundwater levels for achieving sustainable groundwater management in India.

***Keywords**: Semi-arid zone, check dam, groundwater recharging, water levels, groundwater management*

ASSESSING GROUNDWATER RECHARGE AND SUSTAINABLE EXTRACTION RATES FOR WATER RESOURCE MANAGEMENT

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Groundwater is a vital resource for Bengaluru International Airport Limited (BIAL) in its effort to meet current and future water demands. BIAL aims to become self-sustainable in water usage by augmenting rainfall as a source of groundwater recharge. Understanding the groundwater flow patterns, drainage, and spatial variations in groundwater levels is essential for optimizing water resources within the BIAL premises, particularly given its location near several large lakes. These lakes are influenced by surface water runoff and, to some extent, groundwater inflows, both of which play a role in their overall water balance. Thus, assessing how BIAL's water resources interact with the surrounding hydrological features is crucial for planning sustainable groundwater extraction. This study focuses on the assessment of potential for groundwater extraction without the use of managed aquifer recharge (MAR). The main objective of the study is to estimate the recharge and sustainable groundwater extraction rates under the natural conditions.

In order to estimate the recharge rate to groundwater in the BIAL land area, the data of temporal groundwater levels monitored by BIAL since 2016 for open wells of BIAL (W1-AS; W2-AS; W3-LS; W4-LS; W5-LS & W6-AS) were analysed. The groundwater levels were available for period from September 2016 (i.e. post monsoon period onwards) till September 2018. The analysis shows that the monthly standard deviation of the wells is about 1 to 1.5m. The water levels in these open wells are relatively shallow as the groundwater is present in the weathered zone. These open wells existed prior to the BIAL and were part of the agricultural land use in those times. However, the groundwater use from these wells for agriculture or other activities was stopped after the land was acquired by BIAL, and hence, the groundwater levels might have risen to the upper weathered zone in the BIAL land area. In order to simulate the groundwater levels, monthly rainfall data were gathered from KSNDMC for the Anneswara station near BIAL.

The study used a lumped 1D groundwater model AMBHAS developed by IISc team which is based on a simple model for water table fluctuations in response to precipitation. The groundwater levels were simulated using the AMBHAS-1D model and a comparison of the model simulations was done with the actual data. The mean annual recharge for these three years (2016 to 2018) was 57 mm and the mean annual rainfall recharge factor is estimated to be ~7.5% of the mean annual rainfall. Since the rainfall varied considerably in these three years, the annual recharge also exhibits large variation (coefficient of variation of annual recharge ~50%). Since the rainfall stations are not within the BIAL premises, in order to analyze the sensitivity of the nearby rainfall station, data from another station Kannamangala, which is also close to BIAL was considered. The rainfall at this station was marginally different for each year from the Anneswara station. The simulations once again showed a good comparison with the observed levels and the mean annual recharge was estimated as 58 mm, which resulted in an annual rainfall recharge factor of about 8% which is very close to that obtained from the data of Anneswara station. This suggests that about 1.6 MLD (land area of 1622 ha and safe utilizable rate as 60% of mean annual recharge) of groundwater can be safely extracted from the resource available in the shallow upper weathered zone within the BIAL land area based on the current recharge conditions. By promoting water harvesting and enhancing the groundwater recharge practices in the BIAL property, the safely utilizable groundwater resource can be further augmented.

A critical aspect of this study is that not all recharge is recoverable. While the recharge within BIAL's domain is estimated to be 58 mm annually, the amount available for reuse is limited. It is essential to account for groundwater discharge during MAR planning, as a portion of the recharged water will laterally flow out of the area, making it unavailable for future use. The future scope of this research, therefore, involves advancing the use of groundwater modeling to incorporate additional observed data and refine estimates of groundwater discharge. Understanding discharge rates is critical for calculating how much of the recharged water can be safely extracted. These insights will support the design of a more sustainable water extraction strategy that integrates managed aquifer recharge practices, allowing BIAL to optimize its groundwater resources while minimizing the risks such as waterlogging or excessive depletion.

Keywords: *Groundwater modelling, groundwater extraction, groundwater recharge, aquifer management, AMBHAS-1 D model, sustainability*

GROUNDWATER POTENTIAL ZONATION MAPPING USING TOPSIS, VIKOR, FUZZY AHP AND EDAS: A CASE STUDY OF THE SHARAVATI RIVER BASIN, KARNATAKA, INDIA

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Groundwater is a critical resource, especially for agricultural activities, which account for approximately 60% of its usage in India. However, excessive groundwater exploitation has led to significant depletion of its levels. The Sharavati River Basin, known for its diverse topography, flora, fauna, and favourable monsoonal climate supporting diverse agriculture, has recently faced rapid developmental pressures. This study aims to assess the groundwater potential zones and develop management strategies for the Sharavati River Basin in Karnataka, India. The study employs advanced modelling techniques, including TOPSIS, VIKOR, Fuzzy AHP, and EDAS, to map and evaluate the groundwater potential zones within the watershed, which spans approximately 2,800 km^2, with a major portion located in the Western Ghats. This region experiences substantial annual rainfall but uneven seasonal distribution, leading to groundwater scarcity problems due to increased anthropogenic activities, such as agriculture, deforestation, and urbanization. Groundwater potential mapping is crucial to understanding how various natural and human factors, including geology, drainage patterns, slope, land use, geomorphology, precipitation, and topographical wetness index, contribute to groundwater scarcity in this area. The study employs multiple models to increase the accuracy and reliability of groundwater potential mapping. The results can be further discussed and presented to policymakers and research organizations to inform and guide significant steps toward sustainable groundwater management and minimizing its overuse.

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with a 30x30 meter resolution has been acquired from the United States Geological Survey (USGS) database. Land use and land cover data have been sourced from the Environmental Systems Research Institute (ESRI) website, while soil data have been obtained from the Food and Agriculture Organization (FAO) database. Precipitation data has been retrieved from the Indian Meteorological Department (IMD) portal, and groundwater data has been collected from both the Central Ground Water Board (CGWB) and the Water Resources Information System (WRIS) of India. Various thematic layers were prepared. The researchers employed Fuzzy AHP to assign weights to the natural and human factors that impact groundwater potential. This method utilizes expert opinions to address decision-making uncertainties by comparing the relevant factors. The groundwater potential zones were ranked using two innovative approaches; TOPSIS and VIKOR. The TOPSIS model ranks areas based on their proximity to the ideal solution, while the VIKOR method focuses on finding a balanced compromise. Employing both techniques together provides a more accurate representation of groundwater potential in different areas. The research also employed the EDAS method to identify groundwater potential zones by measuring each area's deviation from the average. This approach offers a balanced perspective and helps to avoid extreme or ideal solutions, leading to a more meaningful classification of groundwater potential zones. The findings will be validated through a comparative analysis with ground truth data obtained from adjacent

wells and hydrological measurements of the water table. Additionally, the application of Receiver Operating Characteristic curves will provide a detailed evaluation of the precision of each of these models.

The comprehensive analysis of the Sharavati River Basin has yielded substantial insights into the region's groundwater potential. The findings indicate that areas with high groundwater potential are primarily characterized by gentle slopes, elevated drainage densities, lineament densities, suitable land cover types, and porous soil conditions, which collectively facilitate groundwater recharge and storage. In contrast, regions with low groundwater potential are predominantly situated in steep topographical areas with low permeability and less favourable land use practices, exacerbating water scarcity issues. The synergistic application of the four modelling techniques employed in this study has resulted in a nuanced understanding of groundwater potential dynamics within the Sharavati River Basin. The TOPSIS and VIKOR methods produced comparable rankings across most of the analysed areas, reinforcing the validity of the results. Additionally, the EDAS model provided a balanced and integrative perspective, highlighting the importance of multiple factors influencing groundwater availability. Furthermore, the Fuzzy AHP method significantly improved the weighting accuracy assigned to each factor, refining the overall assessment of groundwater potential. This multifaceted approach underscores the value of integrating various modelling techniques to comprehensively evaluate groundwater resources, ultimately paving the way for more effective management strategies.

This study conclusively demonstrates that integrating multiple analytical models and techniques, including TOPSIS, VIKOR, Fuzzy AHP, and EDAS, constitutes a robust methodology for mapping groundwater potential zones in regions of the Sharavati River Basin. The findings underscore the efficiency of employing a multi-method approach to yield precise and actionable insights into groundwater availability. The findings from this study offer valuable insights that can inform decision-making processes related to groundwater extraction, recharge, and conservation efforts, particularly within the ecologically sensitive Western Ghats region. By synthesizing data from diverse modelling frameworks, this study offers a comprehensive analysis that is instrumental in identifying areas suitable for sustainable groundwater management practices. The results are relevant to policymakers, urban planners, and other stakeholders. This study emphasizes the importance of continued research in this domain. Future investigations could build upon the methodologies employed in this study by systematically monitoring temporal changes in groundwater levels, thereby enabling a more dynamic understanding of groundwater availability. Incorporating considerations related to climate change, such as variations in precipitation patterns, temperature fluctuations, and extreme weather events, will be essential for developing predictive models that can reliably forecast future groundwater availability. This comprehensive approach will contribute to the existing knowledge base and provide valuable insights for effective groundwater management in the face of evolving environmental challenges.

Keywords: *Topis, Vikor, Edas, Fuzzy Ahp, Sharavati river, Modelling*

SPATIAL ANALYSIS OF GROUNDWATER POTENTIAL ZONES IN DHASAN BASIN OF BUNDELKHAND REGION, MADHYA PRADESH

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Groundwater is an indispensable natural resource that plays a critical role in meeting the water demands of urban and rural populations. Its reliability, cleanliness, and ease of extraction make it essential for agriculture, drinking, and industrial applications. Globally, groundwater supports 80% of rural and 50% of urban households for domestic purposes. Despite its significance, groundwater availability is threatened by issues such as over-extraction, limited recharge, and challenging hydrogeological conditions, especially in drought-prone regions. The Bundelkhand region, of Madhya Pradesh includes the Dhasan River Basin, exemplifies these challenges due to its hard rock terrain and erratic rainfall. To tackle these issues, modern techniques such as Remote Sensing (RS) and Geographic Information Systems (GIS) are essential for delineating groundwater potential zones and devising sustainable management strategies. The Dhasan Basin, a sub-basin of the Yamuna River in Madhya Pradesh, consists of approximately 890 km² area in central India, located between latitudes 23.50°N and 24.80°N and longitudes 78.36°E and 79.60°E. Geologically, the basin is complicated, with strata from the Bundelkhand Craton, Bijawar Group, Vindhyan Supergroup, and Deccan Trap. These formations, which include rocks such as granitoids, Banded Iron Formations (BIFs), sandstones, and basalts, have poor porosity and permeability, limiting groundwater recharging. As a result, water is mostly available through shallow dug wells and rainfall capturing, which is usually concentrated in fractured or jointed zones. Given these limitations, a systematic assessment of groundwater potential is critical for long-term resource management in the basin. To address the region's groundwater challenges, this study utilizes an RS & GIS based approach integrated with the Multi-Influence Factor (MIF) technique. The methodology incorporates various biophysical and environmental parameters to effectively delineate the groundwater potential zones. Eight key thematic layers drainage density, geology, lineament density, land use/land cover (LULC), elevation, rainfall, slope, and soil were developed using satellite imagery, topographic maps, and field data. Each parameter was weighted based on its significance in influencing groundwater recharge and storage; for instance, lineament density and geology, which significantly impact groundwater movement, were assigned higher weights, while factors like LULC and rainfall were given moderate weights. A weighted overlay technique in GIS synthesized the layers, resulting in a detailed groundwater potential zoning map.

The analysis classified the Dhasan Basin into three groundwater potential zones: Good, Moderate, and Poor. The Good Potential Zone, covering 7.39% of the total area, consists of regions with high lineament density, alluvial deposits, and favourable slopes, which promote effective infiltration and storage. The Moderate Potential Zone, constituting 76.50% of the study area, encompasses regions with fractured rocks, moderate rainfall, and adequate drainage density, making them moderately suitable for groundwater development. However, sustainable extraction and recharge measures are crucial to ensuring long-term water availability. The Poor Potential Zone, accounting for 16.10% of the basin, is characterized by hard rock formations, steep slopes, and low porosity, which limit groundwater recharge and extraction. For these areas, alternative water management strategies, such as rainwater harvesting or surface water storage, are recommended to mitigate water scarcity. The spatial distribution of groundwater potential zones reflects the influence of geological formations, surface features, and environmental factors on groundwater availability. The predominance of the moderate zone highlights the potential for targeted recharge interventions, such as constructing check dams, percolation tanks, and contour bunds. These measures can significantly enhance groundwater storage and mitigate water scarcity in the basin. Moreover, the study emphasizes the importance of integrating hydrogeological, environmental, and socio-economic considerations to develop a comprehensive water management framework for the region. The study underscores the utility of geospatial techniques in groundwater potential assessment. By leveraging RS and GIS technologies alongside the MIF approach, the research provides a robust, spatially explicit framework for identifying groundwater potential zones. This methodology is particularly beneficial for data-scarce regions like the Dhasan Basin, where traditional hydrogeological surveys may be limited by time and resources. Furthermore, the approach demonstrates the potential for replicability in similar regions facing groundwater challenges, offering a scalable solution for water resource management. The findings of this study have significant implications for water resource planning and management in the Dhasan Basin. Decision-makers can utilize the groundwater potential map to prioritize areas for recharge interventions, sustainable extraction practices, and agricultural planning. By identifying zones with higher groundwater availability, the study supports informed decision-making to ensure equitable and sustainable water distribution. Additionally, the methodology can guide policymakers in addressing water scarcity through strategic investments in groundwater infrastructure and conservation measures.

In conclusion, groundwater is a vital resource for the Dhasan Basin, which faces significant challenges due to its hard rock terrain and limited recharge. This study, employing RS-GIS and the MIF technique, successfully delineates groundwater potential zones, providing actionable insights for sustainable water resource management. The classification of the basin into Good, Moderate, and Poor zones highlights the need for targeted interventions to address groundwater scarcity. The research demonstrates the effectiveness of geospatial techniques in providing reliable, cost-effective solutions for groundwater management in arid and semi-arid regions. Future studies could incorporate additional factors, such as groundwater quality and socio-economic data, to enhance the comprehensiveness and applicability of groundwater potential assessments in similar contexts.

Keywords: *Groundwater, Yamuna River, Dhasan Basin, GIS, multi-influence factor, sustainable management, water resource planning*

GEOSPATIAL AND HYDROGEOLOGICAL PERSPECTIVE ON GROUNDWATER DEPLETION TRENDS AND RECHARGE STRATEGIES IN AN AGRICULTURE DOMINATED WATERSHED FOR FUTURE WATER SECURITY

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Groundwater is a vital source of freshwater, supplying approximately 30% of global needs and playing a critical role in agriculture, domestic use, and industrial processes. However, increasing population, rapid industrialization, climate variability, and prolonged droughts have significantly elevated groundwater demand, often surpassing natural replenishment rates. Overextraction is particularly prevalent in arid and semi-arid regions where surface water availability is limited. India, as the world's largest consumer of groundwater, withdraws more than the U.S. and China combined, supporting over 1.3 billion people. Despite large-scale surface water projects, groundwater remains the principal irrigation source, especially in regions characterized by erratic rainfall patterns and shifting cropping systems. Remote sensing studies indicate rapid depletion of groundwater resources across various regions in India. The spatial variability of groundwater availability is influenced by multiple factors, including land use, soil characteristics, geological formations, and consumption rates. Climate uncertainties further underscore the necessity for continuous groundwater monitoring to facilitate sustainable management. However, limited data constrains research on groundwater exploitation under climate change. Trend analysis techniques provide critical insights into groundwater behavior, aiding in irrigation management and forecasting future water levels. Several statistical methods have been widely utilized globally to evaluate groundwater fluctuations in India.

This study investigates Depth to Groundwater Level (DGWL) trends using data from 57 groundwater monitoring stations over a 24-year period (1996–2019) for pre-monsoon (May) and post-monsoon (November) seasons. Data were sourced from the India-Water Resources Information System (India-WRIS) portal, ensuring the inclusion of only complete time-series datasets. A robust pre-processing approach was employed to construct temporal series, enabling spatial variation analysis through station-wise averaging and spatial mapping. Trend analysis was performed using the Mann-Kendall (MK) test to detect statistical trends and Sen’s Slope estimator to quantify the magnitude of changes over time. To classify wells based on DGWL fluctuations, Hierarchical Cluster Analysis (HCA) was implemented using Python’s SciPy library. The agglomerative clustering technique grouped stations based on similarities in groundwater level variations, with results visualized as a dendrogram. Innovation Trend Analysis (ITA) was employed to categorize trends into monotonic, non-monotonic, or no-trend patterns by dividing the dataset into two halves and plotting their inter-relationship. The parametric Standard Groundwater Level Index (SGWLI) was applied for comparative trend evaluation. The non-parametric MK test identified groundwater trends, where positive and negative ZMK values indicated increasing and decreasing trends, respectively. Sen’s Slope estimator quantified the rate of change, and SDWLI was used to

assess seasonal groundwater level deviations across monitoring stations. Spatial groundwater variations were analyzed using the IDW interpolation method, generating DGWL maps for selected years (1996, 2000, 2005, 2009, 2015 & 2019) for pre- and post-monsoon seasons. Missing values were estimated based on weighted distances from surrounding measurements, providing a comprehensive temporal & spatial understanding of groundwater dynamics.

Rainfall infiltration was identified as a major determinant of groundwater availability, with higher rainfall contributing to groundwater recharge and lower rainfall exacerbating depletion. HCA classified the wells into three distinct clusters based on DGWL fluctuations: Cluster 1 (17 wells), Cluster 2 (35 wells), and Cluster 3 (5 wells), with most wells in Clusters 2 and 3 concentrated in the Rewa and Satna districts. The groundwater levels exhibited a significant decline, raising sustainability concerns. ITA revealed that 58% of wells experienced an increasing DGWL trend during the pre-monsoon season, while 70% showed a similar trend in the post-monsoon season. Conversely, 21% and 12% of wells exhibited decreasing trends in the pre- and post-monsoon seasons, respectively. The ITA results indicated a general trend of groundwater depletion between 1996 and 2019, with an average decline of 0.09 m/year in the pre-monsoon & 0.08 m/year in the post-monsoon season. The MK test and Sen's Slope method identified 19 wells with a significant increase in DGWL and one well with a declining trend in the pre-monsoon season, whereas 15 wells exhibited an increasing trend and one well showed a decreasing trend in the post-monsoon season. Sen's Slope values ranged from -0.27 m/year to 0.69 m/year (pre-monsoon) and -0.27 m/year to 0.39 m/year (post-monsoon) indicating substantial groundwater depletion in specific regions. DGWL maps from 1996 to 2019 demonstrated a decline in groundwater levels at rates of 6.1 cm/year (pre-monsoon) & 7.4 cm/year (post-monsoon). The worst-affected areas included the Satna, Rewa & Prayagraj districts, where excessive groundwater extraction for agriculture was identified as a primary driver of depletion. To counteract groundwater loss, this study proposed artificial recharge structures such as check dams, percolation tanks and Nala bunds. GIS-based site selection for these structures was conducted considering topography, soil characteristics and drainage patterns to maximize recharge efficiency. Effective groundwater management is essential in this predominantly agricultural basin, where 70% of land use is dedicated to farming. This study integrates multiple statistical & geospatial analyses to provide a holistic understanding of groundwater dynamics. The findings indicate substantial groundwater depletion, particularly in the central basin, attributed to high population density and extensive agricultural water use. Clusters 1 & 2 showed decreasing groundwater trends at rates of 18 cm/year and 4 cm/year, respectively, while Clusters 3 & 4 exhibited increasing trends of -8 cm/year and 31 cm/year. ITA results confirmed that 58% of wells experienced an increasing DGWL trend in the pre-monsoon season & 70% in the post-monsoon season, while 21% and 12% of wells exhibited declining trends, respectively. Urgent groundwater conservation measures are required to ensure sustainable water availability. Policy recommendations include adopting modern irrigation techniques, expanding rainwater harvesting initiatives, implementing groundwater extraction regulations, and promoting sustainable land-use practices. These measures are crucial for mitigating depletion and enhancing groundwater security in agriculture-dependent regions. The findings of this study provide valuable insights into long-term groundwater management strategies, informing policy decisions and guiding future research on groundwater sustainability.

Keywords: *Groundwater recharge, hydrogeology, water security, trend analysis*

ASSESSMENT OF RAINWATER HARVESTING SYSTEM TO COMBAT WATER SCARCITY AND RECHARGE OF AQUIFERS IN GUWAHATI CITY, ASSAM, INDIA

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Water is life. But access to safe drinking water, which is a basic human right, has been significantly threatened due to mismanagement of water resources, climate change, landuse landcover changes, increased urbanization, industrialization, population explosion to name a few. As per predictions, by 2025, the number of people suffering from water scarcity will reach three billion. In such circumstances, rainwater harvesting (RWH) emerges as an appropriate solution for India. The use of rainwater for harvesting dates back to several thousand years back when humans first learnt farming. Rainwater harvesting practice is perhaps the most urgent need of the hour especially in urban areas where water resources are fast depleting due to increased population explosion and unrestricted exploitation. Rainwater harvesting in response to climate extremes enhances the resilience of human society not just ecologically but also financially. It is one of the concepts that can be implemented to meet the water shortage problem as it is a part of sustainable architecture and it brings a lot of advantages, not just to the users but also to the environment and government machinery.

Guwahati City, the gateway to the north-eastern part of India suffers from looming water crises more recently. As per reports of the Central Groundwater Board (CGWB), groundwater extraction in the city has touched 75%, thus, making it fall under the semi critical stage. While, the water needs within certain pockets of the city are met by the supply of treated water from Brahmaputra River, yet a major part of the city still relies on groundwater. The present study is an attempt to assess the status of rainwater harvesting system across Guwahati City in Assam. Further, the paper discusses the potential rainwater harvesting techniques which can be easily implemented in the households of Guwahati city. This assessment will help local authorities and policy makers to execute Rainwater Harvesting schemes in water shortage areas and thereby facilitating recharge of groundwater. To access the status of rainwater harvesting structures in the city along with collections of available secondary data, a questionnaire survey was conducted. The questionnaire was prepared taking under consideration water demand at household level, the attitude of the people towards water conservation, habits related to water usage, awareness about the water scenario, community attitude and behavior, tariffs related to water. People were interrogated about water efficient buildings, water efficient products and water policies. Based on the survey it was found that the existing water supply across certain pockets of the city is unpredictable. Many localities like Chandmari, Lachit Nagar, Kahilipara, Kalapahar, Rajgarh, Milanpur, Shantipur, Lokhra, GS Road, RG Baruah Road etc. is under the threat of looming water crises. The expansion of the city along with increased urbanization and population growth has facilitated in reduction of the recharge areas across the city. Based on the questionnaire and socio-economic survey conducted across 50 households, it was found that only 5% households had rainwater harvesting structures. These structures again underwent severe wear and tear due to lack of proper operation and maintenance. While, there is a

general lack of awareness on rainwater harvesting systems, the economic status and lack of availability of space in the households also was a key factor that led to these systems being unpopular among the communities. Approximately 55% of the surveyed household lacked appropriate space for installation of harvesting structures. Quality of the harvested rainwater remained a major concern among some of the households. Such concerns typically stemmed out from the utter lack of awareness about rainwater harvesting. Almost 90% of the surveyed households purchased water from tankers during the summer season. While the city received surplus water during monsoon, yet due to a lack of proper water management, most precipitated water gets lost as runoff. Communities thus expressed grievances for the high price they pay to for supply of water at their doorsteps. It was observed that due to irregularities of the public water supply, people have to heavily depend on these water tankers where the cost of 700 litres of potable water is as high as Rupees 250. It is, thus, imperative that efforts for increased awareness are made along with highlighting site-specific structures to facilitate communities to integrate harvesting systems in their households. This is turn will also reduce the recurrent flash flood events that occurs in the city during the monsoon season. Further, awareness on the ecological and financial benefits lured from implementation of rainwater harvestings structures would go a long way in ensuring that communities adopt conservation practices.

Keywords: *Rainwater harvesting, groundwater recharge, water scarcity, awareness*

EFFECTIVE MANAGED AQUIFER RECHARGE: INSIGHTS FROM GUJARAT USING PRECAST MODULAR SYSTEMS AND JOHNSON SCREENS

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Managed Aquifer Recharge (MAR) is a strategic approach aimed at enhancing groundwater resources, particularly critical in regions facing water scarcity. The innovative solutions are essential in case of Gujarat, where diverse topography and climate conditions challenge traditional water management practices. This study explores the integration of precast modular systems and Johnson screens to optimize aquifer recharge processes. Precast modular systems offer flexibility and efficiency in construction, enabling rapid deployment in various terrains. These systems are designed to facilitate effective water infiltration and storage, crucial for replenishing aquifers. Coupled with high-performance Johnson screens, which prevent sediment clogging while maximizing water intake, these technologies ensure sustainable recharge operations. This study highlighted the necessity of utilizing rain quantification systems to monitor and assess rainfall patterns, allowing for informed decision-making regarding recharge activities. By examining case studies from different regions of Gujarat, this research aimed to showcase successful implementations of MAR, demonstrating their impact on groundwater sustainability, agricultural productivity and community resilience. Through this investigation, we tried to underline the importance of innovative engineering solutions in addressing water scarcity challenges and promoting sustainable water management practices in Gujarat and beyond. Gujarat, located in western India, faces significant challenges in water resource management due to its semi-arid climate, variable rainfall patterns and increasing demands from agriculture, industry, and urbanization. The state relies on a combination of surface water from rivers, lakes, and reservoirs, as well as groundwater, which plays a crucial role, particularly in areas where surface water is scarce. MAR has emerged as a viable solution to address these challenges. Furaat Earth Private Limited has developed an innovative precast modular system that incorporates Johnson Screens for high-performance recharge wells. These systems have been designed to effectively channel surface water and harvested rainwater into aquifers, thereby enhancing groundwater levels and quality. Strategically placed near overflowing ponds, urban areas, and water-logged regions, these recharge wells are adaptable to Gujarat's diverse terrain. By capturing excess surface water during rainfall events and directing it into the aquifer, the MAR approach not only helps replenish groundwater supplies but also mitigates issues related to flooding and waterlogging. This initiative aims to foster sustainable water management practices, ensuring a reliable water supply for agricultural, industrial, and domestic use across the state. Key findings from the project revealed hydrological benefits of MAR, improvements in groundwater quality and increased storage capacity, enhanced ecosystem resilience to climate impacts, and the synergy of MAR with rainwater harvesting as a strategy to combat groundwater depletion and over-extraction.

The collaboration between Furaat Earth and Johnson Screens represents a significant advancement in promoting MAR in Gujarat, a region facing acute water scarcity challenges.

This partnership combines Furaat Earth's innovative water management solutions with Johnson Screen's expertise in high-performance well screen technology. In summary, the collaborative efforts benefits: (i) Enhancing Groundwater Sustainability: The primary goal is to improve groundwater levels and quality through efficient recharge systems. By utilizing Johnson Screens, the partnership aims to optimize water flow into aquifers while minimizing sedimentation and clogging (ii) Implementing Innovative Technologies: Furaat Earth's systems for MAR, combined with Johnson Screens, offer a comprehensive approach to aquifer recharge. This includes modular systems that are adaptable to Gujarat's diverse terrains, ensuring effective water infiltration across various environments (iii) Community Engagement and Education: The partnership emphasizes the importance of community involvement in water management. By conducting workshops and awareness programs, Furaat Earth and Johnson Screens aim to educate local communities on the benefits of MAR and sustainable water practices and (iv) Data-Driven Decision Making: Utilizing rain quantification and monitoring systems, the collaboration seeks to collect valuable data on rainfall patterns and groundwater levels. This information will guide recharge efforts and enhance the overall effectiveness of the implemented systems.

This study underscores the need for an integrated water resource management approach that addresses ecological, social, and economic dimensions, with MAR serving as a critical strategy for sustainable groundwater management in Gujarat. Through this partnership, Furaat Earth and Johnson Screens aim to significantly improve the resilience of Gujarat's water resources. By addressing the pressing issues of groundwater depletion and salinity intrusion, the collaboration not only enhances agricultural productivity but also supports local communities in achieving sustainable water management. The initiative reflects a forward-thinking approach to environmental challenges, demonstrating how partnerships between innovative companies can lead to effective solutions for some of the most pressing water-related issues in the region.

Keywords: *MAR, Johnson screens, high-performance recharge wells, precast modular systems, rainwater harvesting, sustainable groundwater management*