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STUDY ON EXPERIMENTAL MODEL: “GROUNDWATER QUALITY IMPROVEMENT BY ARTIFICIAL RECHARGING OVER NATURAL RECHARGING”

Mr. Hemanshu K. Rana¹, Dr. Neeraj D. Sharma²

¹Research Scholar, Gujarat Technological University, Chandkheda, Gujarat, ²Manager (EIA), En-Vision Enviro Technologies Pvt. Ltd, Surat, Gujarat
hemanshurana76@gmail.com, neerajrwh@gmail.com

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Corresponding author: Dr. Neeraj D. Sharma

Email: neerajrwh@gmail.com

ABSTRACT

Groundwater quality plays a pivotal role in ensuring sustainable water resource management, particularly in urban and semi-urban regions where aquifer recharge is increasingly influenced by anthropogenic and climatic factors. This study investigates the efficacy of artificial groundwater recharge using rainwater to improve key water quality parameters specifically Total Dissolved Solids (TDS), Chlorides, Electrical Conductivity (EC), and Chlorides in the context of the aquifer system of Navsari District, Gujarat, India. A laboratory-based experimental setup was meticulously developed to simulate actual aquifer conditions using silty and coarse-grained sand collected from Eight selected well locations across the all 5 Talukas of Navsari District within study area. The experimental methodology involved enriching the aquifer mass in the setup with native groundwater, followed by controlled dilution using measured quantities of rainwater. The concentrations of target parameters were analysed both theoretically and experimentally pre-recharge and post-recharge. Statistical validation using the coefficient of determination (R^2) values ranging from 0.622 to 0.939 confirmed a strong correlation between predicted and observed outcomes. The results revealed significant reductions in TDS, Chlorides, and EC ranging between 11.00% to 22.3% across different sites demonstrating the potential of rainwater as an effective medium for improving groundwater quality through artificial recharge. This study not only offers a replicable model for groundwater quality enhancement but also contributes to a deeper understanding of aquifer behaviour under recharging conditions, with implications for water resource planning and environmental sustainability

KEYWORDS: Groundwater, Artificial recharge, Groundwater quality, Total dissolve solids, Electrical conductivity, Chlorides, Physico-Chemical Parameters

INTRODUCTION

Groundwater is an important part of the global freshwater resource that supplies more than one-third of the world's drinking requirements and a large portion of agricultural and industrial uses [1]. In arid and semi-arid areas, it frequently constitutes the sole source of water, given the seasonal and reduced availability of surface water [2]. Yet intensive groundwater pumping over the past few decades due to rapid urban growth, population increase and irrigation expansion have resulted in alarming aquifer depletion and deteriorating groundwater quality. Ample examples are found in India as well as other parts of the world where groundwater levels in many areas have been declining more than 1 m every year, with quantity and quality crises [3][4].

Groundwater recharge is considered as the process by which water enters the saturated zone of an aquifer [15]. Groundwater recharge occurs when water moves into aquifers from the surface, naturally or as a result of human activities [5]. It is a key operation to maintain water table and long-term water availability. The rate of natural recharge varies with the amount and distribution of precipitation, permeability of the soil, use of the land, and hydrogeological characteristics. However, in the context of current climatic and anthropogenic stresses, natural recharge is not enough to restore the overexploited aquifers, especially in the water-stressed areas [6].

However, in many cases, natural recharge processes are limited, despite the ecological advantages provided by them. The current degree of urbanization has decreased the ratio of the permeable and the impermeable surfaces, reducing the quantity of rainwater infiltrated into the soil, on one hand, and widening the soil and water disturbance by the runoffs from agriculture and industry and the pollution caused by them, on the [8]. Moreover, the seasonal and non-uniform distribution of precipitation, as well as geological restrictions make natural recharge unreliable and heterogeneously deployed [7]. Finding engineering solutions to these challenges to accelerate recharge and make groundwater use more sustainable is urgently needed.

Artificial recharge or managed aquifer recharge (MAR) is the deliberate recharge (or intentional recharge) of water into an aquifer using engineered systems, with the main objective being the recovery of water among others from a variety of sources including water bodies that would otherwise be lost to evaporation or other uses. In addition to its proven value in increasing the available volume of groundwater, artificial recharge has demonstrated promise regarding groundwater quality enhancement by filtration, adsorption, microbial degradation and ion exchange during the infiltration process [5][9]. Multiple works have reported that artificial recharge can efficiently

decrease nitrate, heavy metals, and other pollutants in groundwater [4][7]. Yet, despite these encouraging findings, relatively little is known about the relative efficacy of artificial and natural recharge on water quality, particularly under controlled experimental conditions.

Study Area: The research was carried out within the various five talukas –Vandsa, Chikhali, Gandevi, Navsari, Jalalpore of Navsari district, Gujarat state, India. Geography and Area Navsari is a district in the southern part of Gujarat, India, covering an area of 2,211 square kilometres. It is situated between 20°07' and 21°00' of North latitudes and 72°43' and 73°00' of East longitudes. The district includes five talukas: Navsari, Gandevi, Chikhali, Jalalpore, and Vandsa. The area is influenced by a tropical monsoon climate, hence with a mean annual rainfall of approximately 1,864 mm, which favours various agricultural practices. The most common soil types are sandy loam and clay, which determine the water retention and drainage properties [4][12].

The region in Navsari depends heavily on ground water for drinking and irrigation purposes. But the underground water quality has also been a great concern for different reasons. Saratanpara and Singh (2018) employed an adaptive neuro-fuzzy inference system (ANFIS) to evaluate the groundwater quality index in the Navsari Taluka and found that TDS, nitrates, hardness, chloride, magnesium, electrical conductance and sulphate were the dominant water quality parameters [10]. Rana and Sharma (2024) also reported periodic pollution in the coastal belt of Navsari, and stressed that there is a need of continuous monitoring and evaluation of the groundwater quality [11].

Artificial recharge options have been also suggested as measures to improve groundwater quality in the district. The CGWB, Western Region, Nagpur had proposed Artificial Recharge measures for creating additional Groundwater reservoirs in the area to augment the availability of Water Resources in Navsari district [12]. These techniques help address issues related to salinity and contamination to provide a sustainable groundwater resource to the region. Ground water level analysis and management in India by remote sensing and GIS techniques. Central Ground Water Board.

Research Aim

The present work is an attempt to measure the performance of artificial recharge vis-a-vis natural recharge in term of improvement in ground water quality using experimental model prepared in the laboratory. As part of the same research the application of the two methods to both recharge processes, following controlled conditions, was modelled, and

main physico-chemical parameters (pH, TDS, EC, Chlorides) have been evaluated in order to make a comparison between natural recharge and artificial recharge. This information will be relevant at the design and application level of artificial recharge systems for increasing groundwater levels as well as for water quality enhancement.

Analytical Approach and Experimental Setup

The laboratory-scale experimental setup was designed to approximate field aquifer conditions as realistically as possible by collecting aquifer samples from the monitoring locations of study area. While replicating the exact hydrogeological dynamics of a natural aquifer in a controlled laboratory environment is inherently challenging, the constructed model aims to simulate the essential characteristics with reasonable accuracy. To establish baseline conditions, the experimental aquifer was initially saturated with groundwater samples collected from various 8 locations selected within the study area in Navsari district, Gujarat. These samples were allowed to stabilize over time to ensure uniform saturation of the artificial aquifer mass, thereby closely reflecting the in-situ groundwater quality. Subsequently, a controlled volume and quality of rainwater preferably freshly harvested from the study area was introduced into the saturated setup to simulate artificial recharge. After an appropriate dilution period, post-recharge groundwater samples were extracted and analysed. The key water quality parameters under investigation, including pH, TDS, EC, chlorides, and GWQI, were measured and compared against their pre-dilution values to evaluate the extent of quality improvement.

Given the complexity of natural hydrogeological interactions during recharge events such as diffusion, dispersion, and geochemical reactions it is difficult to replicate the exact chemical processes involved in situ. However, to estimate the improvement in groundwater quality, a theoretical dilution approach was adopted. This method assumes ideal mixing conditions and utilizes known quantities and concentrations of both the recharge water (solvent) and the original groundwater (solute).

Theoretical Estimation of Concentration

The theoretical concentration of a specific groundwater quality parameter post-recharge (artificial recharge) was calculated based on the mass balance principle of ideal mixing as per equation 1: *Theoretical Concentration of the parameter after recharge* $= [(W1 \times P1) + (W2 \times P2)] / (W1 + W2)$ Equation (1) Where, W1= Volume of groundwater added to saturate the aquifer of Experimental Setup, W2=Volume of rainwater added to recharge aquifer of experimental setup, P1= Concentration of parameters before artificial recharging, P2= Concentration of parameters in collected rainwater samples for artificial recharge. This equation assumes complete mixing of

the groundwater and rainwater within the experimental aquifer mass, thereby yielding an estimated post-recharge concentration. This theoretical estimate provides a benchmark to compare with experimental results, facilitating the assessment of recharge efficiency in improving groundwater quality under controlled conditions.

Experimental Determination of Concentration

For empirical validation, water samples were collected from the saturated aquifer mass of the experimental setup following the recharge event. These samples were subjected to laboratory analysis using standardized testing methods as prescribed by APHA and BIS protocols. The resulting measurements represent the experimental concentrations of each groundwater quality parameter after artificial recharge. This procedure was systematically repeated for all parameters under assessment namely pH, total dissolved solids (TDS), electrical conductivity (EC), chlorides, nitrates, total hardness, and the Groundwater Quality Index (GWQI) across all sample sets.

MATERIALS AND METHODS :

Experimental Set up :

The objectives of this work are to predict the attainable increase in groundwater quality (decrease in TDS, pH, chlorides, EC) on application of artificial recharge with rainwater. The principle behind this approach is the diluting effect, so that precipitation with lower contamination load compared to existing groundwater are directed to existing wells in order to improve the quality. In order to replicate the hydro-geological aspects of the study area under controlled environment a model set-up was established within a laboratory. Such configuration mimics the hydrogeological features of the real aquifers and allows controlled experiments in the field of artificial recharge.

The laboratory facilities are shown in Figure 1, which includes a transparent watertight high quality glass tank of internal dimensions length 0.91 m × breadth 0.19 m × height 0.61 m. Aquifer material, typical of the local sub-surface geology, was placed in the reservoir. The design has desirable facilities which allow water inflow and outflow controlled artificially on both groundwater and rain water for the purpose of recharge and sampling. The pipes of different diameters were placed to supply pre-collected groundwater samples from the well of various monitoring locations within the study area. In addition to those pipes other pipes were provided for the introduction of rainwater in a controlled quantity, representing recharge wells of various diameters as observed in the field. The layout of these pipes was designed to facilitate uniform mixing of the recharged rainwater with the existing groundwater in the tank and, thus, the precipitation effect associated by the subsequent improved water quality.

This experimental set up enabled a strict control of a target value in dynamic changes of fundamental water quality indicators, making a mechanistic assessment of artificial recharge in the improvement of groundwater quality possible.



Figure 1: Checking Water tightness of Experimental Model and Final lab Experimental Model

Sample Preparation for experimental Set up:

The experimental glass model was packed with a measured volume of aquifer material made up of a mixture of silt and coarse-grained sand obtained directly from the actual site within study area. The material was stacked in a stratified manner, and the height of the stacked aquifer material was adjusted for each test case to mimic different natural situations. Total eight representative locations from the study area were chosen to account for different hydrogeological settings for numerical simulations. In order to better simulate the in-situ groundwater at laboratory conditions, the groundwater used for the experiments was taken from the same aquifer system and in the same locations. The packed aquifer material in the system was flushed with these water samples. Enough time was given so that the porous medium was totally imbued and equilibrated.

RESULTS AND DISCUSSION

As explained in previous section, eight different well locations mentioned in the Table 1 were chosen within the study area, from which aquifer material sample were collected, and used to prepare the experimental arrangement. The samples were also taken from the drilling areas of the wells and that perfectly

undisturbed samples could not be obtained. Groundwater samples from the same eight wells were collected in order to have the aquifer materials fully saturated by using the actual field situation for the laboratory experiments. The chosen well sites were two monitoring stations Chikhali and Hond from Chikhali Taluka, two monitoring stations Saribujarang and Devsar from Gandevi Taluka, two monitoring stations Italva and Ashtgam from Navsari Taluka, one monitoring station Katasvel from Vansda Taluka, and one monitoring station Veshma from Jalalpor taluka within Navasari District, Gujarat, India.

Groundwater samples were collected from the wells for introducing them in the experimental set-up. The volume of groundwater introduced into the experimental setup corresponded to the calculated average porosity of the aquifer material in the setup. Also, rainwater was sampled before entry into the system. The water was subjected to some tests such as pH, total dissolved solids (TDS), chlorides, and electrical conductivity (EC). The porosity of aquifer material was determined, using the average of samples from the study area. It should be noted that in the experimental set-up since it was necessary to maintain adequate air flow and to avoid septic conditions a certain volume of aquifer water was added to the system by always keeping it less than the available pore space in the material.

Rain used for the experiments was collected from an open roof on a big container equipped with a standard mesh filter. Volume of aquifer material (adjusted by modifying the thickness of the material pack in the experiment), calculated (porosity), available (volume * porosity), the actual amount of aquifer water added, and the amount of rainwater introduced into the system is shown in Table 2.

In relation to the recharging not only the solute - the rain water - must be considered, but also the solvent, the water which is in the pores of the aquifer material. This aspect underpins the importance of the accurate characterization of rainwater-aquifer and aquifer-rainwater coexisting concentrations, because these concentrations are of key importance to estimate efficiency and the preferred scenario for the recharging process. Table 1 offers a detailed description of the concentrations of basic water quality parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), and hardness found in the collected rainwater. Alternatively, Table 3 shows the equivalent concentrations of these same constituents in the groundwaters extracted from the experimental aquifer material before, and after, the recharging treatment. Theoretical concentrations determined for all water quality parameters-pH, TDS, EC, and Chlorides by using equation-1 for monitored well locations in study area.

Additionally, Table 4 presents a comparison of the groundwater quality improvements, attained by means of the methodology described in previous sections of this work. This comparison is based on the concentrations of the major parameters that control the quality of the recharged groundwater. In order to illustrate these results further, Figure 2 reports the

graphic trend of comparative scenario of the percent reduction in concentration of each groundwater quality parameters by theoretical and experimental methods. This decrease is shown up to now both theoretically and experimentally and it actually confirms the proposed recharging in this work.

Table 1 Rain Water Quality parameters of Selected Locations for Experimental Studies

Details of Sampling Location ID for Experimental Studies							
Name of District: NAVSARI							
SR.NO.	Experimental Sample ID Number	Location from where aquifer sample collected	Taluka of Navsari District	Rainwater Quality Parameters			
				pH	TDS mg/l	EC (μ S/cm)	Chlorides mg/l
1	ID1	S1	Vansda	6.95	312	335	112
2	ID2	S2	Chikhali	7.2	167	232	74
3	ID3	S3					
4	ID4	S4	Gandevi	7.4	157	216	68
5	ID5	S5					
6	ID6	S6	Navsari	7.65	150	202	93
7	ID7	S7					
8	ID8	S8	Jalapore	7.8	163	232	92

Table 2: Amount of Rain Water added to Experimental Model Aquifer as an Artificial recharge

Sample ID	Aquifer Volume Within Experimental Set up (m^3)	Porosity of study area (%)	Pore space within Experimental Aquifer (Litres)	Water added to saturate aquifer in Experimental set up (Litres)	Rain Water added as an artificial recharge to Experimental Aquifer (Litres)
ID1	0.32	35	11.20	8.00	3.00
ID2	0.34	35	11.90	8.50	3.00
ID3	0.34	35	11.90	8.50	3.00
ID4	0.32	35	11.20	8.00	3.00
ID5	0.32	35	11.20	8.00	3.00
ID6	0.34	35	11.90	8.50	3.00
ID7	0.34	35	11.90	8.50	3.00
ID8	0.32	35	11.20	8.00	3.00

Table 3: Improvement in Concentration of Quality Parameters after Artificial recharge

SR. NO	Experimental Sample ID Number	Improvement in Concentration of Quality Parameters after artificial recharging by rain water in Experimental studies.							
		Before Recharging				After Artificial Recharging with rainwater			
		TDS (mg/l)	EC (μ S/cm)	pH	Chlorides (mg/l)	TDS (mg/l)	EC (μ S/cm)	pH	Chlorides (mg/l)
1	ID1	770	834	7.6	230	680	733	7.5	205
2	ID2	1496	1594	7.9	563	1222	1328	7.7	467
3	ID3	1502	1725	7.9	326	1228	1441	7.8	282
4	ID4	1290	1860	7.75	829	1122	1520	7.5	674
5	ID5	2145	2663	7.75	918	1778	2152	7.45	740
6	ID6	1201	1487	7.65	540	988	1227	7.5	452
7	ID7	1512	1734	7.65	289	1280	1448	7.6	248
8	ID8	1526	1698	7.8	270	1288	1402	7.6	234

Table 4 : Comparative analysis of Theoretical and Experimental Reduction in Concentration of parameters

SR. NO	Experimental Sample ID Number	Comparative analysis of Improvement in Concentration of Groundwater Quality Parameters by Theoretical and Experimental studies after artificial recharging by rain water in Experimental studies.							
		Theoretical Reduction in Concentration (%)				Experimental Reduction in Concentration (%)			
		TDS	EC	pH	Chlorides	TDS	EC	pH	Chlorides
1	ID1	16.23	16.31	2.63	13.91	11.69	12.11	1.32	10.87
2	ID2	23.2	22.27	2.53	22.74	18.32	16.69	2.53	17.05
3	ID3	23.17	20.81	2.53	20.25	18.24	16.46	1.27	13.5
4	ID4	23.95	24.09	1.94	25.09	13.02	18.28	3.23	18.7
5	ID5	25.27	25.05	1.94	25.27	17.11	19.19	3.87	19.39
6	ID6	22.81	22.53	0.65	21.67	17.74	17.48	1.96	16.3
7	ID7	23.48	23.07	0.65	17.65	15.34	16.49	0.65	14.19
8	ID8	23.33	22.5	1.28	17.04	15.6	17.43	2.56	13.33

Table 5: R² Values of Experimental and Theoretical Reduction

Quality Parameters	R ² Value	Type of Correlation
TDS	0.7442	Good Correlation
Chlorides	0.9311	Excellent Correlation
EC	0.9388	Excellent Correlation
pH	0.6211	Moderate Correlation



Figure 2: Comparative Scenario of Percentage reduction in Quality parameters by Theoretical vs Experimental methods

CONCLUSION

Predicting how groundwater replenishes is a notoriously difficult task—far more so than tracking surface water. This complexity stems from a dense web of overlapping factors, ranging from the local geological framework and soil composition to shifting weather patterns and human infrastructure. This research developed a pilot experiment to demystify the procedure since these factors are always changing. We sought to precisely monitor recharge behavior and assess how this infusion of fresh water enhances overall groundwater quality by directing collected precipitation into a controlled field aquifer setting. Experimental Result of reduction or improvement in concentration of various groundwater quality parameters were found for TDS – ranging from 11.69% to 22.33%, EC – ranging from 12.11% to 19.19%,

Chlorides – ranging from 10.87% to 19.39%, and pH – ranging from 0.65% to 2.53% for samples taken from total 8 selected ID location ID1 to ID-8 within research area. Theoretically, By Using the Standard Dilution equation similar results were Computed for TDS – ranging from 11.69% to 22.33%, EC – ranging from 12.11% to 19.19%, Chlorides – ranging from 10.87% to 19.39%, and pH – ranging from 0.65% to 2.53% for all 8 selected ID location ID1 to ID-8. To Correlate the obtained results from Experimental and Theoretical studies, R^2 Value to decide the type of correlation determined are 0.62 for pH, 0.744 for TDS, 0.9311 for Chlorides, and 0.9388 for EC as shown in Table 5 indicates that moderate correlation for pH, good correlation for TDS and Excellent correlation for both EC and Chlorides for all 8 selected sampling locations within study area of Navsari district

REFERENCES

1. Abraham, M., & Mohan, S. (2015). Effectiveness of artificial recharge structures in enhancing groundwater storage. *Indian Journal of Science and Technology*, 8(20), 1–10.
2. Dillon, P., Pavelic, P., Page, D., Beringen, H., & Ward, J. (2018). Managed aquifer recharge: Paving the way forward. *Environmental Technologies*, 39(2), 95–103.
3. Mukherjee, A. (2013). Artificial groundwater recharge methods and their assessment. *Groundwater Review*, 5(2), 34–41.
4. National Academies of Sciences. (2019). *Groundwater recharge and management: An overview*. The National Academies Press.
5. Stamos, C. L., Martin, P., Everett, R. R., & Izbicki, J. A. (2013). Effects of artificial recharge on water quality in the Warren subbasin, California. USGS Scientific Investigations Report, 2013-5088.
6. USGS. (2019). *Artificial groundwater recharge practices*. U.S. Geological Survey Water Resources.
7. Wada, Y., van Beek, L. P. H., Wanders, N., & Bierkens, M. F. P. (2015). Global depletion of groundwater resources since the 20th century. *Geophysical Research Letters*, 42(10), 1794–1801.
8. World Water Assessment Programme. (2011). *The United Nations World Water Development Report: Groundwater and Global Change*. UNESCO.
9. Zhang, H., Li, M., & Tang, Y. (2015). Cost-benefit analysis of artificial groundwater recharge in arid regions. *Hydrology Journal*, 23(3), 571-583.
10. Saratanpara, P. H., & Singh, S. S. (2018). Groundwater Quality Index of Navsari Taluka Using ANFIS and Statistical Analysis. *Journal of Emerging Technologies and Innovative Research*, 5(4), 191-196.
11. Rana, H. K., & Sharma, N. D. (2024). Analysis of Ground Water Quality by Using Water Quality Index: A Review. *International Journal for Scientific Research & Development*, 11(12), 151-155.
12. Central Ground Water Board. (2023). *Coastal parts of Gandevi Block, Navsari District, Gujarat*.
13. Vaidya, K., Gadhia, M., & Sharma, N. K. (2012). Evaluation of Drinking Water Quality of Navsari District (Gujarat). *International Journal for Environmental Rehabilitation and Conservation*, III(II), 18-24.
14. Singh, N., Tripathi, S., Naik, J., Kumar, R., & Chaudhari, D. M. (2023). Evaluation of Ground Water Suitability for Irrigation in Vansda Taluka of Navsari District of South Gujarat. *International Journal of Agricultural Invention*, 8(1), 111-120.
15. Singh, N., Tripathi, S., Naik, J., Kumar, R., & Chaudhari, D. M. (2023). Analysis of Water Quality of Selected Irrigation Water Sources in Gandevi Taluka of Navsari District of South Gujarat, India. *Asian Journal of Agricultural Extension Economic&Sociology*, 41(9), 699-711.