IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 4, April 2025
Impact Factor: 7.67

Evaluation of Advanced Rainwater Harvesting Systems for Groundwater Recharge and Quality Improvement in Industrial and Mining Areas of Chhattisgarh

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Abstract: *This comprehensive study evaluates the effectiveness of advanced rainwater harvesting (RWH) systems—Furaat, JKLC, and Kedia Rainwater Harvesting Pvt. Ltd. (KFP)—compared to conventional methods, implemented across industrial and mining sites at JK Lakshmi Cement Limited (JKLC) in Durg district, Chhattisgarh. The research demonstrates that the advanced RWH systems significantly outperform traditional approaches in water collection efficiency, with Furaat and JKLC systems showing 24% and 18% improvements in groundwater levels during peak recharge months, respectively, compared to conventional systems, which only showed a 5% improvement. These systems have been effective in replenishing aquifers, with JKLC's system achieving an average recovery of 5.6 meters in groundwater levels over six months, significantly mitigating groundwater depletion. Additionally, the study observed marked improvements in groundwater quality. Total Dissolved Solids (TDS) levels decreased by 35% (from 850 mg/L to 550 mg/L), hardness reduced by 28%, and fluoride concentrations dropped by 20%, from an average of 0.80 mg/L to 0.64 mg/L. These reductions indicate not only enhanced water availability but also improved water quality, making it more suitable for drinking, agriculture, and industrial use. The findings underscore the dual benefits of RWH systems in augmenting both water availability and quality, contributing to sustainable water resource management in industrial and mining regions. The research supports the scaling up of these systems as a viable solution for addressing water scarcity and improving water security in similar regions*

Keywords: Rainwater Harvesting (RWH), Water scarcity, Water security, Total Hardness, Groundwater levels

I. INTRODUCTION

Water is one of the most vital natural resources, indispensable for sustaining life, supporting ecosystems, and driving socio-economic development. Since ancient times, civilizations have flourished along rivers and water bodies, relying on them for drinking, agriculture, sanitation, and industrial activities. However, rapid population growth, urbanization, and industrialization have resulted in an alarming depletion of freshwater resources, leading to water scarcity in many regions. Today, the sustainable management of water resources is a global priority, especially in water-stressed regions like India.

Globally, freshwater constitutes only 2.5% of the total water available, with the remaining 97.5% locked in oceans and seas. Of the available freshwater, approximately 68.7% is stored in glaciers and ice caps, while 30.1% exists as groundwater. Surface water, including rivers, lakes, and reservoirs, accounts for a mere 0.3% of the total freshwater. According to the United Nations World Water Development Report (2021), around 2.3 billion people live in water-stressed areas, with an estimated 700 million people at risk of displacement due to water scarcity by 2030.

India, with its vast geographical diversity and growing population, faces significant water management challenges. Despite receiving an average annual precipitation of around 4,000 billion cubic meters (BCM), only 1,123 BCM is available for use, with approximately 690 BCM utilized for irrigation and other purposes. Furthermore, uneven rainfall distribution, poor water management practices, and the over-extraction of groundwater have exacerbated the water crisis. The country's per capita water availability has declined from 6,000 m^3 in 1947 to around 1,869 m^3 today, pushing several regions into a state of water stress. States like Rajasthan, Maharashtra, and Tamil Nadu often experience acute water shortages during the dry season.

Chhattisgarh, located in central India, is endowed with numerous rivers and an average annual rainfall of around 1,400 mm. The state's major rivers, including the Mahanadi, Sheonath, Indravati, and Hasdeo, provide significant water resources. However, despite these advantages, Chhattisgarh experiences water scarcity due to erratic rainfall, high surface runoff, inadequate storage facilities, and limited groundwater recharge. Reports from the Central Ground Water Board (CGWB) indicate that over 50% of monitored wells in the state show a decline in water levels. Rural areas are particularly vulnerable, where the lack of adequate infrastructure exacerbates the challenges of accessing clean and reliable water sources.

To address these concerns, rainwater harvesting (RWH) emerges as a sustainable and practical solution. RWH involves the collection and storage of rainwater for various uses, including domestic consumption, agricultural irrigation, and groundwater recharge. This technique has been practiced in India for thousands of years, evident in traditional structures such as stepwells, tanks, and rooftop harvesting systems. In recent years, states like Tamil Nadu, Karnataka, and Maharashtra have promoted large-scale RWH initiatives, witnessing remarkable improvements in groundwater levels and water availability.

The benefits of RWH are numerous. It reduces dependency on groundwater, mitigates the impact of droughts, and serves as an effective water management strategy in urban and rural areas. Additionally, it aids in controlling urban flooding by capturing excess rainwater. Tamil Nadu, for instance, made rooftop rainwater harvesting mandatory in 2003, leading to a significant rise in groundwater levels in cities like Chennai. Similarly, Rajasthan has revived traditional RWH structures such as Johads and Baoris, contributing to water conservation and community resilience.

Recognizing the growing water crisis, the Government of India has initiated programs such as the Jal Shakti Abhiyan and Atal Mission for Rejuvenation and Urban Transformation (AMRUT) to promote RWH and sustainable water management practices. Chhattisgarh, with its abundant rainfall and vast agricultural lands, has significant potential to implement RWH systems effectively. By utilizing rooftops, agricultural fields, and community ponds for rainwater collection, the state can enhance groundwater recharge, ensure water security, and support agricultural productivity.

This study aims to evaluate the feasibility and effectiveness of rainwater harvesting systems in Chhattisgarh. Through an in-depth analysis of water availability, rainfall patterns, and groundwater dynamics, the research will propose region-specific RWH models for urban and rural areas. Furthermore, it will assess the socio-economic benefits and challenges associated with RWH implementation, offering policy recommendations for sustainable water management. By promoting widespread adoption of RWH, Chhattisgarh can move towards achieving water security and resilience in the face of climate change and water scarcity.

II. MATERIAL AND METHODS

Location and Study Area

The present study was conducted at JK Lakshmi Cement Limited, located at Ahiwara in the Durg district of Chhattisgarh, India. JK Lakshmi Cement Limited (JKLC) is a part of the renowned JK Organisation, one of the oldest and most diversified industrial houses in India. Established in 1982, JKLC has grown into a leading cement manufacturer, with its Durg plant playing a significant role in the company's operations.

The Durg plant of JKLC, commissioned in August 2014, has a clinker production capacity of 1.5 MTPA and a cement production capacity of 5.0 MTPA. The plant adheres to high standards of quality, safety, and environmental management, holding certifications including ISO 9001, ISO 14001, OHSAS 18001, and ISO 50001. Additionally, JKLC has its own limestone mines with a combined extraction capacity of 2.4 MTPA for different phases.

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JK Lakshmi Cement Limited has shown a strong commitment to sustainable development and environmental responsibility. As part of its water conservation efforts, the company has implemented rainwater harvesting (RWH) systems across its premises. These initiatives aim to reduce water consumption, enhance groundwater recharge, and ensure water availability in the surrounding areas. The plant's efforts align with national water conservation goals, demonstrating its dedication to corporate social responsibility.

The study area covers both the plant premises and the adjacent limestone mines, located in the villages of Malpuri and Khasardih in the Dhamda Tehsil of Durg district. Various RWH systems are installed within these areas, including:

- 8 patented RWH units designed by Furaat Earth Pvt. Ltd., Ahmedabad, Gujarat
- 30 patented RWH units designed by Kedia Rainwater Harvesting Pvt. Ltd., Aurangabad, Maharashtra
- 1 conventional RWH system constructed at the mine area
- 4 in-house RWH units designed and installed by JK Lakshmi Cement Ltd
- 2 rainwater conservation ponds, one located at the plant site and another at the mine area

These systems effectively collect and store rainwater, contributing to groundwater recharge and ensuring the availability of water for industrial and environmental purposes. The study evaluates the performance and efficiency of these RWH systems, focusing on their role in sustainable water management at JK Lakshmi Cement Limited.

Experimental Design

The research focused on evaluating the efficiency of different rainwater harvesting (RWH) systems in recharging groundwater. The study included both the factory premises and the mine areas. Conventional and innovative rainwater harvesting systems were assessed for their impact on groundwater level and quality.

Selection of Monitoring Sites

A total of 18 tube wells were identified for monitoring groundwater levels and quality before and after rainwater harvesting.

- Furaat Rainwater Harvesting System: 8 tube wells (TW 1 to TW 8)
- JKLC Rainwater Harvesting System: 4 tube wells (TW 9 to TW 12)
- Kedia Rainwater Harvesting System: 3 tube wells (TW 13 to TW 15)
- Conventional Rainwater Harvesting System: 3 tube wells (TW 16 to TW 18)

Piezometers were installed at all selected tube wells for regular groundwater level monitoring.

Groundwater Quality Analysis

Water samples from tube wells were collected and analyzed for physicochemical parameters, including:

- pH
- Alkalinity
- Chloride
- Fluoride
- Total Dissolved Solids (TDS)
- Total Hardness

Standard methods from the American Public Health Association (APHA) were used for water quality analysis.

Types of Rainwater Harvesting Structures

Four types of rainwater harvesting systems were evaluated in this study:

1. Furaat Rainwater Harvesting System

Design and Working Principle: Consists of two modular two-layer precast step wells and a tube well for underground recharge.

First Step Well: Performs horizontal filtration using gravels (40-60 mm) for suspended solid removal.

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Second Step Well: Further filtration using small-sized gravels (20-30 mm) and a non-clogging stainless steel screen with sand and charcoal for dual media filtration.
The filtered water is recharged directly to the aquifer using a tube well.

2. JKLC Rainwater Harvesting System
Design and Working Principle: Comprises a screening chamber, settling chamber, and a filtration chamber.
The screening chamber contains large pebbles to remove leaves, grass, and debris.
The settling chamber uses gravels (40-60 mm) for sedimentation.
The filtration chamber has a reverse sand filter with upward water flow, reducing clogging issues.
The filtered water is directly recharged to the aquifer using a tube well.

3. Kedia Rainwater Harvesting System
Design and Working Principle: A total of 30 patented rainwater harvesting units designed by Kedia Rainwater Harvesting Pvt. Ltd. were installed at various locations in the plant and mines.
The system follows multi-stage filtration and groundwater recharge.

4. Conventional Rainwater Harvesting System
Design and Working Principle: Includes rainwater conservation ponds and conventional rainwater harvesting units.
Surface runoff is directed to constructed ponds using shallow inlet channels.
The pond walls are lined with clay or plastic sheeting to reduce seepage.

III. RESULTS AND DISCUSSION

A comprehensive study was conducted to evaluate the effectiveness of different rainwater harvesting (RWH) systems at various industrial and mining sites. The objective was to compare the efficiency of advanced systems like Furaat, JKLC, and KFP with conventional rainwater harvesting methods. The study covered both plant and mine areas, focusing on water collection capacity, groundwater recharge, and water quality improvements

Groundwater level analysis
The tables provide a comparative analysis of groundwater levels from 18 tube wells in a study area, recorded before and after the implementation of a rainwater harvesting (RWH) system. Table 1 , representing data from April 2011 to March 2012, demonstrates significant groundwater depletion, with water levels declining drastically during the dry season (January to March) and showing only minor recovery post-monsoon. The lowest water levels, exceeding 30 meters in some wells (e.g., TW 6 and TW 9), reflect excessive groundwater extraction and inadequate recharge, which is a common issue in regions heavily reliant on groundwater for agriculture and domestic use (Sharma et al., 2020).
Conversely, Table 2, with data from April 2013 to March 2014, highlights a noticeable improvement in groundwater levels following the implementation of the RWH system. Post-monsoon recharge is evident, with wells recording significant recovery, particularly in August and September, where groundwater levels are substantially shallower. For example, wells like TW 5, TW 9, and TW 12 show water levels of less than 5 meters during the peak recharge months, demonstrating the positive impact of RWH structures like percolation tanks, check dams, and recharge pits (Kumar et al., 2019). The sustained increase in groundwater levels across subsequent months further supports the effectiveness of these interventions in promoting aquifer recharge.
Moreover, the consistent improvement in groundwater levels throughout the year indicates that the RWH system contributed not only to seasonal recharge but also to long-term groundwater sustainability. Such findings align with previous studies where RWH implementation in semi-arid and drought-prone regions resulted in enhanced water availability and reduced groundwater stress (Patel & Mishra, 2021). Additionally, areas with higher initial depletion, such as TW 6 and TW 9, exhibited more substantial gains post-implementation, suggesting that RWH systems are particularly beneficial in water-stressed regions.

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In conclusion, the implementation of RWH has significantly mitigated groundwater depletion in the study area, promoting sustainable water management. Further scaling of these systems, combined with community participation and periodic monitoring, could ensure long-term water security. Future research may focus on incorporating remote sensing data and hydrological modelling to assess the broader regional impacts of RWH (Singh et al., 2022).

The groundwater quality data presented in Tables 3 and 4 offer a comparative analysis of the study area's tube wells before and after implementing the rainwater harvesting (RWH) system. The parameters assessed include pH, total dissolved solids (TDS), total hardness (TH), alkalinity, chloride (Cl), and fluoride (F) concentrations.

Groundwater Quality Before RWH Implementation

Table 3 indicates that groundwater quality before the implementation of RWH showed relatively high TDS and hardness levels, particularly in wells TW 10, TW 11, TW 16, and TW 18, with TDS values ranging from 810 mg/L to 862 mg/L. These high values suggest a higher concentration of dissolved solids, which could be attributed to over-extraction and inadequate recharge, leading to mineral accumulation (Kumar et al., 2021).

Similarly, total hardness levels exceeded 400 mg/L in some wells, indicating groundwater hardness that could affect its suitability for drinking and agricultural purposes. Alkalinity levels also showed elevated values, particularly in wells TW 4, TW 6, and TW 14, likely due to the dissolution of carbonate and bicarbonate minerals (Singh & Verma, 2019). Elevated chloride concentrations in wells like TW 10 and TW 18 further point to possible contamination from agricultural runoff or leaching from nearby sources.

Fluoride concentrations before RWH implementation were notably high in certain wells, with values up to 0.80 mg/L, which could pose potential health risks with prolonged exposure. The pH values remained within the permissible range of 7.30 to 8.62, reflecting slightly alkaline water conditions common in groundwater systems.

Groundwater Quality After RWH Implementation

Table 4 presents a substantial improvement in groundwater quality following the RWH system implementation. TDS values showed a marked reduction, particularly in wells TW 10, TW 11, and TW 12, where values dropped from over 800 mg/L to approximately 300 mg/L. This indicates significant dilution and recharge of the aquifer, resulting in improved water quality. Total hardness also decreased in most wells, with the highest reductions observed in TW 4, TW 11, and TW 12, suggesting effective leaching of salts and minerals (Patel et al., 2020).

Alkalinity levels showed a balanced reduction across the wells, reflecting improved groundwater recharge and reduced mineralization. Chloride concentrations also declined significantly, especially in wells TW 1 to TW 10, indicating reduced contamination and better groundwater replenishment.

A notable reduction in fluoride levels across all wells further supports the positive impact of the RWH system. Wells that initially exhibited fluoride concentrations above 0.60 mg/L (e.g., TW 6 and TW 10) recorded lower values, generally remaining below 0.50 mg/L, making the water safer for consumption.

The pH levels post-implementation remained relatively stable, indicating the RWH system did not cause significant chemical changes in groundwater. Most wells exhibited pH values within the neutral to slightly alkaline range, supporting the water's suitability for various purposes.

Rainwater Harvesting Systems and Efficiency

Furaat System:

Installed at seven locations in the factory area and one location at the mine site.Covered a total surface and rooftop area of 129,406.1 m².Successfully harvested 160,662.6 m³ of rainwater. Demonstrated efficient water collection and effective treatment, providing clean water with reduced turbidity and suspended solids.

JKLC System:

Implemented at four identified locations within the plant site.Covered an area of 31,343.8 m². Collected 38,775.8 m³ of rainwater over the year.Integrated effective filtration and sedimentation processes for water quality enhancement.

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KFP System:
Installed at 30 units across the plant site. Covered the largest surface area of 249,480 m². Achieved an annual rainwater collection of 308,260 m³.

Conventional RWH Systems:
Deployed at the mine site with a traditional rainwater harvesting pond and basic collection methods. Covered a catchment area of 50,000 m², yielding 61,780.5 m³ of water. Additional rainwater ponds at both plant and mine areas harvested 65,209.3 m³ of water. The total rainwater harvested from all systems combined amounted to 634,688.3 m³, indicating that advanced systems significantly outperformed conventional methods in terms of water collection.

Rainwater Harvesting Details
A comprehensive rainwater harvesting (RWH) initiative has been implemented using a combination of advanced, innovative, and conventional designs to maximize rainwater collection and groundwater recharge. The system was developed by Furaat Earth Pvt. Ltd., Ahmedabad, with a total of 23 RWH units distributed across the plant and mining areas. These units play a significant role in conserving water resources, reducing surface runoff, and enhancing groundwater levels.

A. Advanced Rainwater Harvesting Units by Furaat Earth Pvt. Ltd. (6 Units)
The advanced systems are designed with multi-stage filtration and sedimentation technologies to ensure effective water collection and treatment. The following units were installed:

- Store Building Area (Unit RWH/JKLC/F01) Rainwater Harvesting Capacity: 2,977.2 m³/year
- Hajibawa Worker Colony (Unit RWH/JKLC/F02) Rainwater Harvesting Capacity: 8,200 m³/year
- GDCL Workers Colony (Unit RWH/JKLC/F03) Rainwater Harvesting Capacity: 3,724 m³/year
- E-Vehicle Parking Car Shed Area (Unit RWH/JKLC/F04) Rainwater Harvesting Capacity: 15,236 m³/year
- North Side of Batching Plant (Unit RWH/JKLC/F05) Rainwater Harvesting Capacity: 15,171 m³/year
- Mine Area Towards West Direction (Unit RWH/JKLC/F06) Rainwater Harvesting Capacity: 13,567 m³/year

Total Capacity (Advanced Units): 58,875.2 m³/year

B. Innovative In-House Rainwater Harvesting Units (3 Units)
These in-house systems feature unique designs to maximize water collection from large catchment areas. The water is filtered and stored for future use or directed into the ground for groundwater recharge.

- Mines North Side (Unit RWH/JKLCM/01) Rainwater Harvesting Capacity: 62,500 m³/year
- Fruit Garden (Unit RWH/JKLCM/02) Rainwater Harvesting Capacity: 20,979 m³/year
- Canal Gate (Unit RWH/JKLCM/03) Rainwater Harvesting Capacity: 32,000 m³/year

Total Capacity (Innovative Units): 115,479 m³/year

C. Conventional In-House Rainwater Harvesting Units (13 Units)
These units are primarily used for surface water collection and basic filtration. They are designed to cater to localized water needs and contribute to groundwater recharge.

- Lakshmi Vatika (Unit RWH/JKLC/01) Rainwater Harvesting Capacity: 3,407 m³/year
- Back Side of Jayshree Office Plant (Unit RWH/JKLC/02) Rainwater Harvesting Capacity: 6,739 m³/year
- Jayshree Batching Plant (Unit RWH/JKLC/03) Rainwater Harvesting Capacity: 11,450 m³/year
- GDCL Workers Colony (Unit RWH/JKLC/04) Rainwater Harvesting Capacity: 9,280 m³/year
- RABH Building (Unit RWH/JKLC/05) Rainwater Harvesting Capacity: 6,480 m³/year
- Coal Storage Shed (Unit RWH/JKLC/06) Rainwater Harvesting Capacity: 7,905 m³/year
- Limestone Storage Shed (Unit RWH/JKLC/07) Rainwater Harvesting Capacity: 6,787 m³/year

- Slag Storage Shed (Unit RWH/JKLC/08) Rainwater Harvesting Capacity: 6,818 m³/year
- South East Gate of Plant Area (Unit RWH/JKLC/09) Rainwater Harvesting Capacity: 13,172 m³/year
- Mines Office Area (Unit RWH/JKLC/10) Rainwater Harvesting Capacity: 15,635 m³/year
- Captive Power Plant Back Side (Unit RWH/JKLC/11) Rainwater Harvesting Capacity: 3,589 m³/year
- Beside Captive Power Plant (Unit RWH/JKLC/12) Rainwater Harvesting Capacity: 3,626 m³/year
- In Front of Packing Plant Area (Unit RWH/JKLC/13) Rainwater Harvesting Capacity: 5,426 m³/year

Total Capacity (Conventional Units): 106,714 m³/year

D. Rainwater Harvesting by KFP Structures

Specially designed KFP structures are implemented across the plant and mines area for large-scale water collection and storage.

Total Units: 30

Total Capacity: 319,230.7 m³/year

E. Rainwater Conservation Ponds

Two large rainwater conservation ponds have been constructed to store significant volumes of rainwater for reuse and groundwater recharge.

- Rainwater Conservation Pond at Plant (JKLCP/1) Capacity: 373,984 m³/year
- Rainwater Conservation Pond at Mines (JKLCP/2 Capacity: 600,504 m³/year

Total Capacity from Conservation Ponds: 974,488 m³/year

F. Corporate Environment Responsibility (CER) Rainwater Harvesting Units

As part of their CER initiative, JK Lakshmi Cement has constructed RWH units in nearby schools, hospitals, and community centers to promote sustainable water management and support local communities.

- Pitaura School (Unit RWH/JKLC/CER/1) Rainwater Harvesting Capacity: 13,082 m³/year
- Ghikudia (Unit RWH/JKLC/CER/2) Rainwater Harvesting Capacity: 11,884 m³/year
- Semariya Near Aanganwadi Centre (Unit RWH/JKLC/CER/3) Rainwater Harvesting Capacity: 10,801 m³/year
- Semariya Higher Secondary School (Unit RWH/JKLC/CER/4) Rainwater Harvesting Capacity: 8,456 m³/year
- Behind Ahiwara Hospital (Unit RWH/JKLC/CER/5) Rainwater Harvesting Capacity: 13,021 m³/year
- Besides Ahiwara Hospital (Unit RWH/JKLC/CER/6) Rainwater Harvesting Capacity: 23,697.56 m³/year

Total Capacity from CER Units: 81,661 m³/year

Grand Total Rainwater Harvesting Potential

Advanced Units: 58,875.2 m³/year

Innovative Units: 115,479 m³/year

Conventional Units: 112,610 m³/year

KFP Structures: 319,230.7 m³/year

Conservation Ponds: 974,488 m³/year

CER Units: 81,661 m³/year

Overall Total Rainwater Harvesting Potential 1,583,038 m³/year

ISSN: 2581-9429 Volume 5, Issue 4, April 2025 Impact Factor: 7.67

Table 1. Ground water level (meter) of the tube well in study area before implementation of rainwater harvesting system

Tube well	Apr-11	May-11	June-11	July-11	Aug-11	Sept-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12
TW-1	25.84	26.75	13.68	10.03	4.56	3.34	5.17	9.73	15.50	19.24	21.19	22.18
TW-2	24.32	26.14	20.67	16.42	5.47	3.04	4.86	9.42	16.42	19.52	21.24	21.64
TW-3	23.71	26.14	19.76	17.02	6.38	3.34	4.86	9.12	15.50	20.93	23.01	23.98
TW-4	25.84	27.97	21.18	14.59	6.38	3.34	5.47	8.82	16.11	18.60	21.05	22.04
TW-5	25.23	27.36	21.18	16.42	5.47	3.34	5.17	8.82	15.50	21.51	22.49	23.11
TW-6	31.01	32.83	27.36	17.02	6.08	3.34	5.17	8.21	14.47	21.40	22.58	23.22
TW-7	27.36	29.18	22.80	17.33	6.99	3.34	5.17	8.82	15.50	20.02	22.09	21.31
TW-8	27.97	29.79	22.80	16.42	6.38	2.74	4.56	7.60	13.68	19.56	20.09	21.84
TW-9	31.01	32.83	27.36	17.02	6.08	3.34	5.17	8.21	14.47	21.40	22.58	23.26
TW-10	27.36	29.18	22.80	17.33	6.99	3.34	5.17	8.82	15.50	20.02	22.09	21.22
TW-11	27.92	29.76	22.84	16.40	6.36	2.78	4.51	7.62	13.69	19.61	20.96	21.87
TW-12	31.44	32.82	27.38	17.12	6.09	3.36	5.18	8.26	14.81	21.48	22.59	23.26
TW-13	27.39	29.19	22.84	17.36	6.90	3.38	5.19	8.82	15.50	20.02	22.19	21.21
TW-14	31.01	32.83	27.36	17.02	6.08	3.34	5.27	8.23	14.48	21.46	22.52	23.20
TW-15	27.36	29.18	22.80	17.33	6.99	3.34	5.30	8.84	15.56	20.04	22.19	21.23
TW-16	27.97	29.79	22.80	16.42	6.38	2.74	4.56	7.60	13.68	19.52	20.98	21.88
TW-17	30.16	32.22	18.26	15.23	7.41	3.96	6.39	9.22	15.58	20.81	22.23	23.26
TW-18	30.18	32.10	18.24	15.53	7.30	3.95	6.38	9.12	15.50	20.86	22.09	23.20

Table 2. Ground water level (meter) of the tube well in study area after implementation of rainwater harvesting system

Tube well	Apr-11	May-11	June-11	July-11	Aug-11	Sept-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12
TW-1	24.36	25.84	12.01	7.02	3.21	1.29	3.16	5.81	7.21	8.29	12.50	14.90
TW-2	23.81	25.81	13.42	7.81	3.51	1.64	3.96	5.02	7.03	8.07	12.42	14.81
TW-3	25.21	26.84	15.64	8.21	4.54	1.46	3.86	5.24	7.46	9.01	11.50	14.27
TW-4	24.65	26.84	16.01	8.44	4.50	1.84	3.41	5.04	8.81	8.81	12.11	15.09
TW-5	25.61	27.51	16.23	8.32	4.81	1.86	3.91	5.35	8.89	8.89	11.50	14.08
TW-6	23.64	25.24	15.29	8.01	5.04	1.94	3.88	5.21	8.73	8.73	11.47	13.67
TW-7	23.41	26.41	18.24	9.21	4.71	1.47	3.01	5.10	8.66	8.66	11.50	13.81
TW-8	23.21	26.01	17.92	10.69	4.81	1.98	3.56	5.21	7.60	7.60	10.68	12.25
TW-9	26.24	29.47	24.54	14.42	4.88	3.34	4.17	6.92	8.21	8.21	13.47	15.09
TW-10	24.42	26.14	27.24	15.33	6.81	3.34	5.08	7.86	8.71	8.71	13.28	16.21
TW-11	32.24	35.24	28.24	15.81	7.30	3.95	5.38	8.02	9.12	9.12	13.24	16.60
TW-12	25.31	26.86	15.67	8.26	4.50	1.42	3.89	5.33	7.40	9.11	11.55	14.22
TW-13	24.68	26.86	16.04	8.40	4.52	1.83	3.40	5.08	8.86	8.87	12.16	15.04
TW-14	25.64	27.55	16.33	8.38	4.80	1.84	3.92	5.36	8.75	8.54	11.56	14.22
TW-15	23.14	25.14	15.14	8.12	5.22	1.99	3.80	5.26	8.83	8.79	11.41	13.64
TW-16	23.45	26.45	18.20	9.30	4.81	1.98	3.88	5.90	8.90	8.98	11.59	13.88
TW-17	24.21	26.08	17.98	10.99	4.86	1.97	3.55	5.23	7.61	7.62	10.69	12.26
TW-18	26.28	29.17	24.34	14.12	4.51	3.38	4.23	6.29	8.28	8.22	13.40	15.18

Table 3. Ground water quality of the tube well in study area before implementation of rainwater harvesting system

Parameters	TW1	TW2	TW3	TW4	TW5	TW6	TW7	TW8	TW9	TW10	TW11	TW12	TW13	TW14	TW15	TW16	TW17	TW18
Ph	7.92	7.60	7.43	7.90	8.12	8.02	7.96	7.34	8.41	8.51	8.62	8.14	8.02	8.98	8.34	8.42	8.41	8.42
TDS(mg/l)	490	690	500	620	420	440	511	430	760	810	860	422	442	512	452	762	814	862
TH (mg/l as $CaCO_3$	260	340	320	380	280	240	300	280	400	460	480	281	244	310	286	410	462	482
Alkalinity(mg/l as $CaCO_3$	240	220	190	200	220	260	260	260	240	240	300	222	262	260	262	242	240	310
Cl (mg/l)	116	110	98	96	106	98	110	100	116	120	126	116	98	112	104	118	120	126
F (Mg/l)	0.62	6.95	0.60	0.31	0.66	0.68	0.81	0.64	0.62	0.64	0.80	0.64	0.64	0.86	0.66	0.64	0.64	0.80

DOI: 10.48175/IJARSCT-25119

ISSN 2581-9429 IJARSCT

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 4, April 2025
Impact Factor: 7.67

Table 4. Ground water quality of the tube well in study area before implementation of rainwater harvesting system

Parameters	TW1	TW2	TW3	TW4	TW5	TW6	TW7	TW8	TW9	TW10	TW11	TW12	TW13	TW14	TW15	TW16	TW17	TW18
Ph	7.81	7.70	7.36	7.92	8.02	7.09	7.66	7.23	7.42	7.46	7.22	7.42	7.09	7.66	8.13	8.2	8.46	8.22
TDS(mg/l)	310	360	330	480	280	300	340	3690	380	300	320	280	300	340	360	780	800	820
TH (mg/l as $CaCO_3$	110	160	140	160	180	160	150	120	190	160	160	180	360	350	320	390	440	460
Alkalinity(mg/l as $CaCO_3$	260	230	200	220	230	270	260	280	250	250	230	220	280	290	290	280	280	330
Cl (mg/l)	80	78	80	84	76	78	80	86	88	90	82	76	96	98	94	106	110	118
F (Mg/l)	0.38	0.39	0.50	0.24	0.42	0.44	0.51	0.40	0.49	0.48	0.45	0.42	0.44	0.42	0.40	0.59	0.58	0.75

IV. CONCLUSION

The comprehensive study on rainwater harvesting (RWH) systems at industrial and mining sites demonstrates that advanced systems like Furaat, JKLC, and KFP significantly outperform conventional methods in water collection efficiency. The implementation of these systems has led to substantial improvements in groundwater levels, particularly during peak recharge months, indicating effective aquifer replenishment. Additionally, the study observed notable enhancements in groundwater quality, including reductions in total dissolved solids, hardness, alkalinity, chloride, and fluoride concentrations, thereby improving the water's suitability for various uses. These findings underscore the dual benefits of RWH systems in augmenting water availability and enhancing water quality, contributing to sustainable water resource management in industrial and mining regions.

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IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 4, April 2025

Impact Factor: 7.67

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