
ASSESSMENT OF GROUNDWATER QUALITY AND IRRIGATION SUITABILITY IN JERE LGA, BORNO STATE: ENGINEERING SOLUTIONS FOR SUSTAINABLE AGRICULTURAL DEVELOPMENT IN NIGERIA

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ABSTRACT

Groundwater is the principal domestic and irrigation water source in Jere Local Government Area (LGA), Borno State, Nigeria, but population growth, agriculture and inadequate sanitation threaten its quality. This study assessed water from five boreholes (BH1-BH5), five hand-dug wells (HW1-HW5) and one lake source (LW1) using physicochemical and bacteriological analyses, Water Quality Index (WQI), and irrigation indices (SAR, Na%, KR, PI and RSC). pH ranged from 6.7-7.5, EC from 420-1,210 $\mu\text{S}/\text{cm}$ and TDS from 280-790 mg/L. Nitrate ranged from 12.5-72.6 mg/L, with HW3-HW5 exceeding 50 mg/L. All hand-dug wells and the lake exceeded 5 NTU turbidity and were positive for *E. coli*, whereas boreholes had turbidity below 5 NTU and no detected *E. coli*. WQI values of 42.6-57.8 classified boreholes as good, while HW3-HW5 were unsuitable for drinking. All sources were generally suitable for irrigation, but HW3-HW5 were classified as permissible and require active sodium-management measures. Engineering responses include priority boreholes (80-120 m depth; 150 mm PVC casing; gravel pack and sanitary seal), multi-barrier treatment for hand-dug wells, wellhead protection, differentiated irrigation management, and tiered monitoring. These interventions translate the empirical findings into practical measures supporting SDGs 2, 3 and 6.

Keywords: groundwater quality; engineering solutions; water treatment; irrigation management; borehole design; sustainable development

1. INTRODUCTION

Groundwater is a critical resource for domestic supply, agriculture and economic activity, particularly in regions where surface-water infrastructure is inadequate. In Jere Local Government Area (LGA), Borno State, communities depend heavily on boreholes and hand-dug wells, while increasing population, intensive agriculture, waste disposal and inadequate sanitation create pathways for groundwater contamination. Shallow wells are especially vulnerable because of their hydraulic connection with surface activities, including septic-tank seepage, agricultural runoff, livestock wastes and refuse leachate.

Groundwater-quality assessment increasingly combines physicochemical and bacteriological indicators with integrated indices. Water Quality Index (WQI) provides a single decision-support measure for drinking-water quality, while Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), Kelly Ratio (KR), Permeability Index (PI) and Residual Sodium Carbonate (RSC) provide complementary evidence for irrigation suitability. Nigerian studies have reported nitrate enrichment, microbial contamination and spatial variation associated with urbanisation, waste-management practices and land use (Banerjee et al., 2023; Ezechinyere & Stanislaus, 2023; Abanyie et al., 2023; Opasola et al., 2025; Thomas, 2023).

Despite these findings elsewhere, empirical information integrating drinking-water and irrigation suitability in Jere LGA remains limited. This study therefore evaluates selected groundwater and surface-water sources to establish a baseline for evidence-based water-resource management. The objectives were to determine major physicochemical parameters; assess bacteriological quality through

coliform and E. coli detection; compare results with WHO and Nigerian drinking-water standards; calculate WQI and irrigation-quality indices; and translate the empirical findings into engineering interventions. The work directly addresses the conference sub-themes of Innovative Resource Utilization and Management and Emerging Technologies for Safe Engineering Practices and Environmental Protection.

2. METHODOLOGY

2.1 Study Area

The study was conducted in Jere LGA, Borno State, north-eastern Nigeria, between 11°45'N-11°55'N and 13°05'E-13°20'E. The area has distinct wet and dry seasons, annual rainfall of approximately 500-700 mm and mean temperatures of 25-40°C. The geology is dominated by Chad Formation sediments comprising sands, silts and clays that host productive aquifers. Farming, livestock rearing, trading and small-scale commercial activities are major land uses and potential pressures on groundwater quality (NMA, 2008).

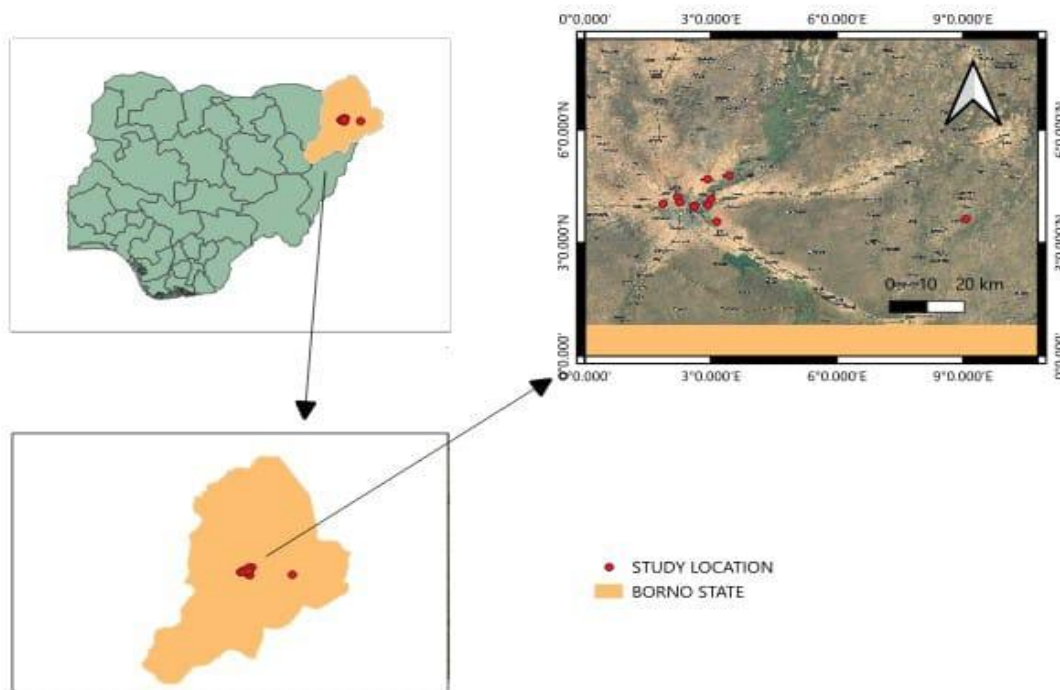


Figure 1: Map of the study area (Source: QGIS 3.44.12)

2.2 Sampling Locations and Collection

Eleven sampling locations were selected: five boreholes (BH1–BH5), five hand-dug wells (HW1–HW5) and one lake source (LW1). Selection considered accessibility, usage intensity, population served and proximity to potential contamination sources. Samples were collected in pre-cleaned 1-L polyethylene bottles following American Public Health Association (APHA, 2017); bacteriological samples were collected in sterile containers, transported in ice-packed coolers, and physicochemical analyses were completed within 24 h.

Table 1: *Sampling Locations and Water Sources*

Sample Code	Water Source	Location
BH1	Borehole	Cross Na Mala
BH2	Borehole	Gomari Airport
BH3	Borehole	Mairi Kuwait
BH4	Borehole	Mashamari
BH5	Borehole	Custom Area
HW1	Hand-dug Well	Jakana
HW2	Hand-dug Well	Dusuman
HW3	Hand-dug Well	Gongulong
HW4	Hand-dug Well	Old Maiduguri Road
HW5	Hand-dug Well	Shuwari
LW1	Lake Water	Coca-Cola Area

2.3 Parameters Analyzed

Analysed parameters comprised pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, hardness, nitrate, chloride, colour, acidity, alkalinity, total coliform count and E. coli presence. Laboratory analyses were conducted at the Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria.

2.4 Analytical Methods and Instrumentation

Physicochemical analyses followed APHA (2017): pH by electrometric method (4500-H⁺ B; Jenway 370); EC by conductivity (2510 B; Jenway 470); TDS by gravimetry at 180°C; turbidity by nephelometry (2130 B; HACH 2100P); hardness by EDTA titration (2340 C); nitrate by cadmium-reduction spectrophotometry (4500-NO₃⁻ E; Genesys 10S at 540 nm); chloride by Mohr titration (4500-Cl⁻ B); alkalinity by titration to pH 4.5 (2320 B). Total coliform and E. coli were determined by membrane filtration (9222 B and 9222 G, respectively). Detection limits ranged from 0.01 pH unit to 5 mg/L for the principal physicochemical measures and 1 CFU/100 mL for bacteriological counts; calibration used certified standards and daily checks.

QA/QC included field blanks, duplicate analysis of at least 10% of samples, spike-recovery tests, method-detection-limit assessment, daily instrument calibration and positive/negative bacteriological controls. Physicochemical RSD was below 5%, bacteriological RSD below 10%, nitrate recovery 95-103%, chloride recovery 97-101%, all samples exceeded MDLs, and accepted calibration curves had $R^2 > 0.995$.

2.5 Statistical Analysis

Descriptive statistics comprised mean, standard deviation, minimum and maximum. Differences among water sources were evaluated by one-way ANOVA at $\alpha = 0.05$, followed where significant by Tukey's HSD. Analyses were performed in IBM SPSS Version 25. The model was $Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$, where Y_{ij} is the observed parameter, μ the overall mean, α_i the effect of water source i , and ε_{ij} the random error.

2.6 Water Quality Index (WQI)

WQI was calculated using the Weighted Arithmetic Index method (Shukla & Ram, 2015; Opasola et al., 2025). Nine parameters were included: pH, EC, TDS, turbidity, hardness, nitrate, chloride, alkalinity and total coliform count. The adopted weights were 0.09, 0.11, 0.10, 0.14, 0.07, 0.19, 0.07, 0.06 and 0.17, respectively; ideal values were 7.0 for pH and 0 for the other parameters. The WQI values were interpreted using the classification scheme adopted in the present study: < 50 = Excellent, $50-100$ = Good, $100-200$ = Poor, $200-300$ = Very Poor, and > 300 = Unsuitable for drinking. The selected classification scheme was retained consistently for all sampling sources to permit direct comparison among the sampled groundwater sources

2.7 Irrigation Water Quality Assessment

Irrigation-water suitability was evaluated using the Sodium Adsorption Ratio (SAR), sodium percentage (Na%), Kelly's Ratio (KR), Permeability Index (PI), and Residual Sodium Carbonate (RSC). The interpretation of these indices was based on established irrigation-water classification criteria reported in the literature (Richards, 1954; FAO, 2009). SAR was used primarily to assess the potential sodium hazard, while Na%, KR, PI, and RSC were used to evaluate complementary sodium, alkalinity, and soil-permeability hazards. Accordingly, the irrigation-water quality classes reported in this study were assigned from the respective published classification ranges for each index rather than from SAR alone. The combined interpretation of the indices was used to determine the overall irrigation suitability of each sampled water source. $SAR = Na^+ / \sqrt{[(Ca^{2+} + Mg^{2+})/2]}$, $Na\% = [(Na^+ + K^+) \times 100] / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$, $KR = Na^+ / (Ca^{2+} + Mg^{2+})$, $RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$, and $PI = [(Na^+ + \sqrt{HCO_3^-}) \times 100] / (Ca^{2+} + Mg^{2+} + Na^+)$. All ionic concentrations were expressed in meq/L.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Parameters

Table 4 presents the physicochemical results. pH ranged from 6.7-7.5; EC from 420-1,210 $\mu S/cm$; TDS from 280-790 mg/L; turbidity from 2.1-18.3 NTU; hardness from 118-245 mg/L; nitrate from 12.5-72.6 mg/L; chloride from 32-125 mg/L; and alkalinity from 94-161 mg/L. All boreholes complied with the cited limits for the measured parameters. In contrast, all hand-dug wells and the lake exceeded the 5-NTU turbidity guideline, while HW3, HW4 and HW5 exceeded 50 mg/L nitrate. Hand-dug wells also showed higher EC and TDS, indicating greater exposure to surface-derived inputs.

Table 2: Physicochemical Characteristics of Water Samples

Parameter	WHO Limit	BH1	BH2	BH3	BH4	BH5	HW1	HW2	HW3	HW4	HW5	LW1
pH	6.5–8.5	7.2	7.4	7.1	7.5	7.3	6.8	6.9	6.7	6.8	6.9	7.1
EC ($\mu S/cm$)	1500	420	510	580	640	690	980	1040	1180	1210	1105	970
TDS (mg/L)	1000	280	340	380	430	450	620	680	760	790	720	610
Turbidity (NTU)	5	2.1	2.5	2.8	3.1	3.5	8.4	10.2	12.5	14.6	11.8	18.3
Hardness (mg/L)	500	118	132	145	152	167	185	210	230	245	221	196
Nitrate (mg/L)	50	12.5	14.3	16.7	18.4	20.1	41.5	48.2	68.3	72.6	61.4	42.1
Chloride (mg/L)	250	32	38	42	48	51	86	102	116	125	118	95
Alkalinity (mg/L)	200	94	98	102	106	112	135	148	152	161	158	148

Hardness remained below the 500 mg/L WHO limit. Borehole hardness ranged from 118-167 mg/L, whereas hand-dug wells ranged from 185-245 mg/L and the lake was 196 mg/L. The higher hardness has mainly operational implications, including scale formation and increased detergent demand, rather than a direct health hazard at the measured concentrations. These patterns are consistent with Nigerian groundwater studies reporting greater dissolved-ion loading in shallow sources (Ezechinyere & Stanislaus, 2023; Opasola et al., 2025; Thomas, 2023).

3.2 Bacteriological Quality Assessment

Total coliform counts ranged from 0-85 CFU/100 mL. No *E. coli* was detected in BH1–BH5, whereas all hand-dug wells and LW1 were positive. The pattern indicates greater vulnerability of shallow sources to faecal contamination associated with poor sanitation, septic seepage, livestock activities and runoff.

Table 3: Bacteriological Characteristics of Water Samples

Source	Total Coliform (CFU/100 mL)	E. coli
BH1	0	ND
BH2	0	ND
BH3	1	ND
BH4	2	ND
BH5	1	ND
HW1	35	Present
HW2	49	Present
HW3	78	Present
HW4	85	Present
HW5	69	Present
LW1	45	Present

3.3 Comparative Evaluation with WHO (2017) and NIS/NSDWQ (2015) Standards

Boreholes complied with the cited WHO (2017) and NSDWQ (2015) requirements for pH, EC, TDS, hardness, chloride, alkalinity and nitrate. All hand-dug wells exceeded the turbidity guideline, and HW3-HW5 exceeded the nitrate limit. E. coli occurrence in all hand-dug wells and the lake makes these sources unsuitable for direct drinking without treatment. The results reinforce evidence that shallow groundwater is more susceptible to anthropogenic contamination than deeper aquifer sources.

3.4 Water Quality Index (WQI) Assessment

WQI values ranged from 42.6-136.2. BH1–BH5 ranged from 42.6-57.8 and were classified as Good; HW1 and HW2 were Poor (88.5-97.3); HW3, HW4 and HW5 were Unsuitable (118.7-136.2); and LW1 was Poor (95.2). The principal contributors to deterioration were nitrate, EC, turbidity and coliform contamination.

Table 4: Water Quality Index Classification

Sample	WQI	Classification
BH1	42.6	Good
BH2	46.1	Good
BH3	49.4	Good
BH4	53.2	Good
BH5	57.8	Good
HW1	88.5	Poor
HW2	97.3	Poor
HW3	128.4	Unsuitable
HW4	136.2	Unsuitable
HW5	118.7	Unsuitable
LW1	95.2	Poor

3.5 Irrigation Suitability Assessment

SAR ranged from 2.1-4.9, Na% from 24.3-44.1%, KR from 0.31-0.82, PI from 61.5-72.4% and RSC from 0.8-1.9 meq/L. All sampled sources were usable for irrigation, with BH1-BH2 classified Excellent, BH3-BH5, HW1-HW2 and LW1 Good, and HW3-HW5 Permissible. The latter category does not mean unsafe irrigation; it indicates a higher sodium-management requirement. Recommended controls are a 10-20% leaching fraction, gypsum at 2-5 t/ha every 3-5 years, salt-tolerant crops, soil EC/SAR monitoring and blending where feasible.

Table 5: Irrigation Water Quality Indices

Source	SAR	Na%	KR	PI (%)	RSC	Classification
BH1	2.1	24.3	0.31	61.5	0.8	Excellent
BH2	2.4	26.2	0.35	63.0	0.9	Excellent
BH3	2.8	28.5	0.44	65.2	1.0	Good
BH4	3.1	30.8	0.49	66.8	1.1	Good
BH5	3.3	32.1	0.55	67.5	1.2	Good
HW1	3.9	36.4	0.64	68.1	1.4	Good
HW2	4.2	39.5	0.71	69.8	1.6	Good
HW3	4.6	42.7	0.78	71.6	1.8	Permissible
HW4	4.9	44.1	0.82	72.4	1.9	Permissible
HW5	4.5	41.8	0.76	70.9	1.7	Permissible
LW1	3.9	38.2	0.69	69.4	1.5	Good

3.6 Engineering Implications

3.6.1 Borehole Design Specifications

The superior quality of borehole samples (WQI: 42.6-57.8; *E. coli*: absent; turbidity: <5 NTU; nitrate: 12.5-20.1 mg/L) supports source substitution as the preferred intervention for communities reliant on contaminated shallow wells. Borehole specifications are presented as preliminary design ranges rather than fixed values. Recommended parameters include: 80-120 m depth, 60-100 m screened interval, 150 mm PVC-U casing, 0.5-1.0 mm continuous-slot screen, 3-6 mm gravel pack, and 3 m bentonite sanitary seal-final dimensions to be confirmed by site-specific lithological logs, sieve analysis, and well-development results. Abstraction is via a solar-powered 1.5-3.0 HP submersible pump delivering approximately 2-5 L/s at 30-50 m total dynamic head, with final capacity determined by pumping-test results and community demand.

Estimated cost is ₦11.61-17.38 million per installation, covering survey, drilling, casing, screen, gravel pack, sanitary works, solar pumping, distribution, and supervision. The exchange rate adopted for this conference version is ₦1,350/USD (August 2026); direct Naira estimates are retained from the source manuscript (₦1,420/USD). Each borehole serves 300–500 persons, with a six-month implementation period encompassing hydrogeological survey, drilling and casing, pump installation and testing, community training, and baseline water-quality testing.

3.6.2 Treatment Train Configurations for Hand-Dug Wells

All hand-dug wells require treatment before drinking because turbidity was 8.4-14.6 NTU, coliform counts were 35-85 CFU/100 mL and *E. coli* was present. Three scalable configurations are proposed. Configuration A serves 5-7 persons using a 200-L sedimentation tank (24-h retention), three 100-L slow-sand filter drums and chlorination at 2-4 mg/L with 30-min contact; capital cost is ₦138,375 with annual O&M of ₦13,838. Configuration B serves 100-300 households using a 5,000-L baffled settling tank, roughing filter, 2-m-diameter × 1.5-m biosand filter and solar UV or chlorination; capital cost is ₦415,125 with chlorine or ₦718,875 with UV, with annual O&M of about ₦42,000. Configuration C serves 1,000-5,000 persons using coagulation–flocculation, sedimentation, rapid sand filtration and chlorination; capital cost is ₦10.1-16.9 million, with ion exchange for nitrate at ₦13.5-23.6 million or blending at ₦8.1-13.5 million where required. For Jere, borehole source substitution is preferred to intensive nitrate-removal treatment where feasible.

3.6.3 Wellhead Protection and Setback Distance Enforcement

Source-protection measures are proposed around boreholes and hand-dug wells as engineering control distances for Jere LGA, not universal statutory requirements, with final protection radii to consider local hydrogeology, groundwater flow, aquifer vulnerability, contaminant characteristics, well construction, and Nigerian regulations. Hand-dug wells require sanitary wellheads comprising a 1.5 m × 1.5 m × 0.15 m concrete platform, drainage apron, lockable cover, casing raised 0.3-0.5 m above platform, and bentonite or bentonite–cement sanitary seals to 3 m depth to reduce contaminant ingress.

Recommended setbacks for boreholes and hand-dug wells respectively are: septic systems 50 m and 30 m; agricultural fields 100 m up-gradient and 50 m; livestock areas 50 m and 30 m; refuse dumps 100 m and 50 m; fuel stations 150 m and 100 m. Within protection zones, waste disposal, wastewater discharge, sanitation facilities, and contaminating activities should be restricted, with enforcement combining GIS mapping, registration and licensing, annual compliance verification, and community-based surveillance.

3.6.4 Irrigation Water Management Strategy

Excellent and Good sources can be managed with standard irrigation practices and annual soil monitoring. HW3-HW5 require active management because SAR is 4.5-4.9: apply gypsum at 2-5 t/ha every 3-5 years, maintain a 10-20% leaching fraction, use salt-tolerant crops such as millet, sorghum and date palm, monitor soil EC and SAR at least twice annually, maintain drainage and blend with lower-SAR water when available. Sensitive crops such as onion and pepper should preferentially use the better-quality borehole sources.

3.6.5 Groundwater Monitoring System

A tiered monitoring system is recommended: Tier 1 comprises quarterly manual sampling of all sources for pH, EC, TDS, nitrate, turbidity, coliform, and *E. coli* at ₦2.025-3.375 million/year; Tier 2 adds semi-automated sensors at 3-5 high-risk sites (₦6.75-10.1 million capital, ₦4.05-6.75 million/year O&M); Tier 3 provides telemetry and web dashboards (₦27-40.5 million capital, ₦20.25-33.75 million/year O&M) if capacity develops. Yellow alerts: nitrate 40-45 mg/L, turbidity 3-5 NTU, *E. coli* 1-10 CFU/100 mL, EC 1,200-1,500 $\mu\text{S}/\text{cm}$; red alerts: nitrate >50 mg/L, turbidity >5 NTU, *E. coli* >10 CFU/100 mL, EC >1,500 $\mu\text{S}/\text{cm}$.

The costs are preliminary estimates for planning and comparison, not fixed market prices; they require BOQ, unit-rate analysis, equipment specs, labour, installation, and local market validation, with updates using current supplier quotes at procurement. The monitoring programme is an engineering planning framework; final costs depend on monitoring points, sampling frequency, parameters, lab charges, field measurements, transport, equipment, and duration, with BOQ assumptions retained as supporting documentation.

3.6.6 Implementation Roadmap

The five-year phased roadmap priorities: Year 1-community awareness, wellhead platforms at HW1-HW5, household treatment kits for 500 households, and quarterly baseline monitoring; Years 2-3-5-10 priority boreholes, community bio-sand filters at three hand-dug wells, GIS-based setback enforcement, and annual soil monitoring; Years 4-5-Tier 2 monitoring upgrade, sustainable agriculture programme, and groundwater-quality protection by-laws.

The 2026 population projection for Jere LGA (306,400-337,108 persons) is extrapolated from the 2006 NPC census (209,107-211,204), supported by World Population Review (337,108) and City Population (306,400), and serves as a planning estimate. For actual implementation, design population should be based on the most recent authoritative data, incorporating design period, growth rate, per-capita demand, and allowances for institutional, commercial, and livestock uses.

3.7 Study Limitations

The study involved only eleven locations (five boreholes, five hand-dug wells and one lake), limiting representation of spatial variability and giving the lake sample ($n=1$) little statistical power. Sampling was conducted during one campaign, so seasonal variability was not evaluated. Heavy metals, pesticide residues, hydrocarbons and emerging contaminants were outside the analytical scope. Strategic rather than random site selection may introduce selection bias. Irrigation indices were based on one ionic-composition dataset and could change seasonally. Future work should use larger wet- and dry-season samples, broader contaminant screening and spatially explicit monitoring.

4. CONCLUSION

The investigation demonstrates a clear quality contrast between deeper boreholes and shallow hand-dug wells in Jere LGA. Boreholes recorded WQI values of 42.6-57.8, turbidity below 5 NTU,

nitrate of 12.5-20.1 mg/L and no detected *E. coli*, whereas hand-dug wells showed elevated turbidity, widespread faecal contamination and nitrate up to 72.6 mg/L. HW3-HW5 were unsuitable for drinking and require priority intervention. All sampled sources remained generally usable for irrigation, but HW3-HW5 require active sodium-management practices because of their Permissible classification. The engineering response should therefore prioritise source substitution through protected boreholes, multi-barrier treatment where shallow wells remain necessary, wellhead protection and setback enforcement, differentiated irrigation management, and a tiered monitoring system. These interventions directly address the identified microbial, nitrate, turbidity and sodium hazards and support SDGs 2, 3 and 6. The study consequently contributes to Innovative Resource Utilization and Management and Emerging Technologies for Safe Engineering Practices and Environmental Protection by converting site-specific water-quality evidence into implementable engineering decisions.

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