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ISAR Journal of Multidisciplinary Research and Studies

Volume 4, Issue 11, 2026 | pp: 29-40

Abbriviate Title- ISAR J Mul Res Stud

ISSN *(Online)*- 2583-9705

https://isarpublisher.com/journal/isarjmrs

ASSESSMENT OF WATER POLLUTION, PUBLIC HEALTH AND SOCIO-ECONOMIC IMPLICATIONS IN RURAL COMMUNITIES OF SOUTH-EAST NIGERIA: THE ROLE OF SOLAR-POWERED WATER TREATMENT TECHNOLOGIES IN SUSTAINABLE WATER RESOURCE MANAGEMENT

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Article History

Received: 28.08.2026

Revised: 01.10.2026

Accepted: 21.10.2026

Published: 12.11.2026

Abstract: Safe drinking water is essential for good health, household welfare and sustainable rural development. Yet many rural communities continue to depend on wells, boreholes, springs and streams that may be affected by poor sanitation, agricultural runoff, unmanaged domestic waste and naturally occurring substances in the underlying rocks and soils. This review examines the links between water pollution, public health and socio-economic conditions in rural communities across South-East Nigeria, while considering the contribution that solar-powered water treatment systems could make to safer and more reliable water supplies.The review brings together four connected areas: the environmental condition of water sources, the health risks associated with contaminated water, the financial and social burden placed on households, and the practical value of renewable-energy-powered treatment. It proposes a research approach that combines laboratory testing, household questionnaires, field observations and a pilot treatment assessment. Water quality indicators include pH, turbidity, electrical conductivity, total dissolved solids, nitrate, phosphate, selected metals and microbial indicators such as Escherichia coli. Pearson correlation and multiple regression are discussed as complementary statistical approaches for examining relationships among water quality, household circumstances and reported health outcomes.The central argument is that solar energy can help power water abstraction and treatment, but it cannot make unsafe water safe without an appropriate treatment process. Treatment must be selected after the contaminants have been identified. The review therefore recommends an integrated approach based on regular water testing, source protection, contaminant-specific treatment, community participation and long-term maintenance planning.

Keywords: water pollution; rural communities; South-East Nigeria; public health; socio-economic implications; solar energy; water treatment; sustainable water management.

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Cite this article:

Peretomode, E., Ozobialu B. N, et. al., (2026). ASSESSMENT OF WATER POLLUTION, PUBLIC HEALTH AND SOCIO-ECONOMIC IMPLICATIONS IN RURAL COMMUNITIES OF SOUTH-EAST NIGERIA: THE ROLE OF SOLAR-POWERED WATER TREATMENT TECHNOLOGIES IN SUSTAINABLE WATER RESOURCE MANAGEMENT. *ISAR Journal of Multidisciplinary Research and Studies*, *4*(11), 29-40.

1. Introduction

Water is woven into almost every aspect of rural life. It is needed for drinking, cooking, washing, farming, livestock production and small-scale economic activities. When a community has dependable access to clean water, households spend less time searching for supplies and are better placed to protect their health and maintain their livelihoods. When water sources become polluted or unreliable, the effects are felt in homes, schools, farms and local businesses.

In rural parts of South-East Nigeria, households may obtain water from boreholes, hand-dug wells, springs, streams and rivers. These sources do not face the same risks. A properly constructed and maintained borehole may be better protected than an uncovered well, while a stream flowing through a settlement may receive runoff, wastewater and solid waste. Even groundwater that appears clear can contain dissolved chemicals or microorganisms that cannot be detected by sight, smell or taste. For this reason, water safety must be established through sanitary inspection and appropriate laboratory analysis rather than appearance alone.

The causes of water pollution are often connected. Poorly located pit latrines or septic systems can threaten nearby wells. Fertiliser and pesticide residues may be washed from farmland into streams or infiltrate shallow groundwater. Refuse dumps, animal wastes and wastewater can introduce organic matter, nutrients and disease-causing organisms. In some locations, the natural geology may also influence water chemistry through the dissolution of minerals or interaction between groundwater and the rocks through which it moves.

The South-East provides a useful setting for this investigation because its states contain varied geological formations, drainage systems, settlement patterns and land-use activities. These differences make it important to examine water quality at the community and source level. A single regional conclusion should not be assumed to apply equally to every village, aquifer or water source.

Solar energy offers a practical opportunity to support rural water services, especially where electricity supply is unreliable or expensive. Photovoltaic systems can power pumps and selected treatment equipment. However, solar power is an energy source, not a treatment process. The actual purification steps must be chosen to address the contaminants found in each water source. This distinction is central to the proposed research.

2. Problem and Rationale for the Study

The key concern is not simply that rural communities may lack water infrastructure. It is that the water available to them may not consistently meet acceptable quality requirements, while the resources needed to test, treat and maintain supplies are limited. Households may respond by boiling water, buying packaged water, using treatment chemicals or travelling to another source. These responses can increase household costs and take time away from farming, education and other productive activities.

The problem is made more difficult when a water source is used for years without regular testing. A well may be regarded as safe because it has been used for a long time, even though its surroundings have changed or its water quality has deteriorated. Similarly, a borehole may provide water throughout the year but still require treatment for specific chemical or microbial contaminants.

A research approach that studies water quality, household experiences and renewable-energy options together can provide a more complete picture. It can help identify where contamination occurs, which households are most exposed, what the consequences may be, and whether a solar-powered treatment system is technically and financially suitable.

3. Significance of the Study

The study is significant because it links environmental monitoring with the everyday consequences of unsafe water. By examining physicochemical and microbiological indicators together, it can help identify whether the principal concerns are turbidity, nutrient enrichment, metals, faecal contamination or a combination of these factors. This information is important for selecting treatment processes and prioritising vulnerable water sources.

For public-health agencies, the study provides a framework for relating water-quality conditions to self-reported illness, healthcare use and household coping practices. Such evidence can guide health education, sanitary inspection and targeted surveillance. For rural households, improved water services may reduce the time spent collecting water, lessen reliance on expensive alternatives and support more consistent school and work attendance.

The research is also relevant to energy and infrastructure planning. Solar-powered systems may reduce dependence on grid electricity and diesel generators, but their benefits must be evaluated across the full life cycle, including capital cost, battery replacement where applicable, filter changes, disinfection components and operator training. The findings can inform local governments, development partners and community water committees considering decentralized treatment.

Academically, the work contributes an integrated framework for studying water pollution, health and socio-economic outcomes in rural South-East Nigeria. It also identifies the need to distinguish measured field results from illustrative

data and to test the performance of solar systems under locally relevant operating conditions.

Aim and Research Objectives

The aim is to assess water pollution, its public health and socio-economic implications in selected rural communities of South-East Nigeria, and to evaluate the role of solar-powered water treatment technologies in sustainable water resource management.

Specific objectives

- Identify the main sources and likely pathways of water pollution in selected rural communities.
- Determine the physicochemical and microbiological quality of selected groundwater and surface-water sources.
- Examine the relationship between water quality, household water practices and self-reported health experiences.
- Assess the financial, time-related and livelihood implications of inadequate access to safe drinking water.
- Evaluate the technical suitability and likely operating requirements of solar-powered water treatment options.
- Develop a practical framework for community-based water safety management supported by renewable energy.

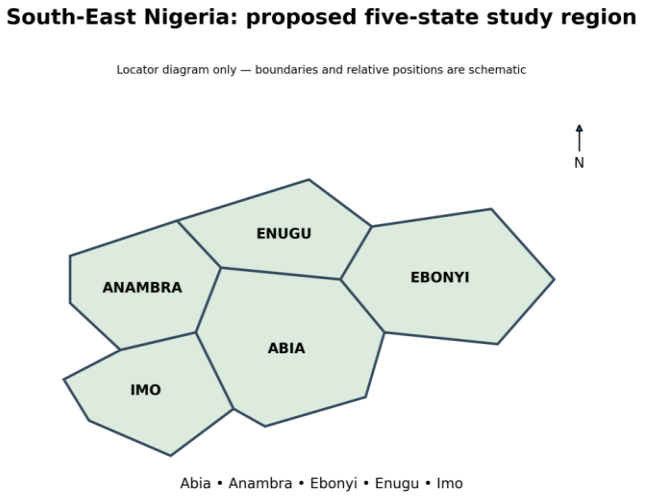

Figure 1. Schematic locator diagram of the five states proposed for the study. It is for orientation only and is not an authoritative state-boundary map.

4. Review of the Main Research Themes

4.1 Water pollution in rural settings

Water pollution occurs when physical, chemical or biological substances enter a water body at levels that reduce its suitability for a particular use. In rural settlements, the sources may include household wastewater, leaking sanitation facilities, agricultural runoff, animal wastes, poorly managed refuse and small-scale commercial activities. Pollution can reach surface water directly or move through soil into shallow groundwater. The likelihood of contamination depends on factors such as distance from pollution sources, soil permeability, depth to groundwater, well construction, rainfall and local drainage.

A useful assessment should distinguish between contamination caused by human activity and chemical characteristics that arise naturally. For example, iron may occur naturally in groundwater because of water-rock interaction, while elevated lead may arise from geological or human-related sources. Identifying the source requires more than a single laboratory result; it may require repeat sampling, field inspection and, where appropriate, further chemical analysis.

4.2 Public health implications

Microbial contamination is an immediate concern because water containing faecal organisms may transmit intestinal infections. Escherichia coli is commonly used as an indicator of faecal contamination. Its detection in water intended for drinking signals that the source or supply chain requires investigation and corrective action. Chemical contaminants raise different concerns. Lead, for example, is associated with serious health effects, while excessive nitrate exposure can be particularly harmful to infants. The health significance of a result depends on the concentration, duration of exposure, amount consumed and vulnerability of the exposed population.

The study should avoid treating every illness reported by a household as proof of waterborne disease. Diarrhoea and abdominal discomfort can have several causes, including food contamination, poor hand hygiene and infections transmitted through routes other than drinking water. Household reports are valuable indicators of community experience, but they should be described as self-reported outcomes unless supported by clinical records or an appropriately designed epidemiological investigation.

4.3 Socio-economic implications

Unsafe or distant water supplies can affect household welfare in ways that are not always reflected in water-quality results. Families may pay for alternative supplies, purchase fuel to boil water, buy treatment products or spend time travelling to a safer source. These costs can be

significant for households with irregular or seasonal income. Time spent collecting water may also reduce the time available for farming, trading, schooling and caregiving.

The burden may not be shared equally within a household. In many communities, women and children undertake much of the domestic water collection. A nearby, reliable and safe supply can therefore provide benefits beyond health protection, including reduced physical effort, more available time and improved school attendance. The questionnaire should capture these dimensions rather than limiting the socio-economic assessment to household income alone.

4.4 Solar-powered water treatment

Solar photovoltaic systems can provide electricity for water pumps, control units and selected treatment devices. In rural locations where grid electricity is unreliable, solar pumping may improve the consistency of water abstraction. A treatment system can include sedimentation, filtration, activated carbon, membranes and disinfection, depending on the quality of the raw water.

The design must follow the laboratory evidence. Sand or multimedia filtration can reduce suspended particles but will not reliably remove dissolved lead or nitrate. Activated carbon can help with some organic compounds, taste and odour, but it is not a universal treatment for dissolved inorganic contaminants. Ultraviolet disinfection can inactivate microorganisms when water is sufficiently clear and the equipment is correctly operated, but it does not remove dissolved chemicals and provides no lasting disinfectant residual. Chlorination may be appropriate for microbial control and residual protection, provided dosing and contact time are properly managed.

A sustainable installation must also account for replacement filters, lamp life, pump servicing, battery replacement where batteries are used, safe disposal of treatment residues and the availability of trained local operators. Community ownership and a transparent maintenance fund are as important as the initial installation.

4.5 Research Design and Sampling

A cross-sectional, mixed-method design with wet- and dry-season sampling is proposed. An illustrative sampling plan include three rural communities per state, with approximately ten water sources per state selected across boreholes, hand-dug wells, springs and streams, giving 50 sources and 150 sample events if each source is sampled in three rounds. The actual sample size should be finalised using a power calculation, expected variability, laboratory capacity and available funding. Sampling locations should include potential upstream/reference points and locations close to suspected pollution inputs.

Table 1. Proposed sampling framework (planning targets, not completed fieldwork)

Component	Proposed coverage	Purpose
States	5: Abia, Anambra, Ebonyi, Enugu, Imo	Geographical representation
Communities	15 (3 per state)	Rural settlement coverage
Water sources	50 (approx. 10 per state)	Source-type comparison
Sampling rounds	3 seasonal rounds	Seasonal variation
Water samples	Up to 150 source-round samples	Laboratory assessment
Household respondents	300 (approx. 20 per community)	Health and socio-economic survey
Key informant interviews	15–25	Governance and maintenance context

4.6 Water Sampling and Laboratory Analysis

Water samples were collected in clean, appropriately prepared containers. Sterile bottles required for microbiological analysis, and samples should be transported under recommended conditions and analysed within the specified holding time. Field measurements should include temperature, pH, electrical conductivity and, where equipment is available, dissolved oxygen and oxidation-reduction potential. Laboratory analysis covered turbidity, total dissolved solids, total suspended solids, nitrate, phosphate, iron, lead and other locally relevant contaminants. Microbiological assessment include E. coli and total coliforms using recognised methods. The WHO drinking-water guidelines provide health-based guidance for interpreting results, but regulatory compliance should also be checked against applicable Nigerian standards (WHO, 2022; SON, 2015).

Quality assurance should include instrument calibration, field blanks, laboratory blanks, duplicate samples, control standards and documented chain of custody. Results were reported with units, detection limits and the analytical method used.

4.7 Household Survey and Public-Health Assessment

A structured questionnaire collected information on primary and secondary water sources, treatment and storage practices, water collection time, monthly water expenditure, household size, education, occupation and income band. Health questions should focus on self-reported episodes of diarrhoea and other relevant symptoms over a clearly

defined recall period, healthcare visits and days of work or school missed. These responses are not clinical diagnoses. Where feasible and ethically approved, aggregate health-facility data may be reviewed to complement household reports. Informed consent, confidentiality and institutional ethical approval are required.

4.8 Solar-Powered Water Treatment Assessment

Solar-powered options should be evaluated against the raw-water profile and the intended use. A possible treatment train may include raw-water storage, screening, coagulation or settling where needed, filtration, and disinfection. Solar photovoltaic electricity may power a pump and ultraviolet unit, while battery storage may be considered where treatment must continue after sunset. UV disinfection is less effective where turbidity is high, so pre-treatment and maintenance of lamp intensity are important. Dissolved metals, nitrate and salinity require contaminant-specific processes; UV alone does not remove them. Pilot testing should measure influent and effluent quality, flow rate, energy demand, downtime, consumables and user acceptance.

4.9 Data Analysis

Descriptive statistics summarized water-quality results and respondent characteristics. Differences among states, seasons and source types examined using suitable parametric or non-parametric tests after checking assumptions. Pearson correlation assess linear associations between continuous indices, while multiple regression can estimate adjusted associations between pollution, sanitation, treatment access and health or socio-economic outcomes. The analysis should report effect sizes, confidence intervals, p-values and model diagnostics. Correlation should not be interpreted as proof of causation.

5. Results and Discussion

5.1 Physicochemical Characteristics of Water Samples

Table 2. Illustrative mean physicochemical characteristics by state

Parameter	Abia	Anambra	Ebonyi	Enugu	Imo	Reference guide
pH	6.4 ± 0.5	6.3 ± 0.4	6.2 ± 0.5	6.5 ± 0.4	6.3 ± 0.5	6.5–8.5
Turbidity (NTU)	8.8 ± 2.1	7.9 ± 1.9	9.4 ± 2.4	8.2 ± 2.0	8.6 ± 2.2	Operational target often ≤5
EC (µS/cm)	265 ± 54	248 ± 49	281 ± 61	239 ± 47	257 ± 52	No single health-based value
Nitrate (mg/L as NO_3^-)	24.2 ± 7.3	21.8 ± 6.5	27.1 ± 8.2	23.5 ± 7.0	25.4 ± 7.7	50
Iron (mg/L)	0.42 ± 0.13	0.38 ± 0.11	0.47 ± 0.15	0.36 ± 0.10	0.41 ± 0.12	Aesthetic/acceptability concern
Lead (mg/L)	0.012 ± 0.004	0.011 ± 0.003	0.014 ± 0.005	0.010 ± 0.003	0.013 ± 0.004	0.010

In the samples result, mean turbidity ranged from 7.9 NTU in Anambra to 9.4 NTU in Ebonyi. These values exceed the commonly used operational target of 5 NTU for effective disinfection, indicating that clarification or filtration would be important before disinfection if similar values were confirmed in the field. Mean pH values were slightly below the lower end of the WHO guideline range in the illustrative dataset. Nitrate means remained below 50 mg/L, but individual source results could still differ from state averages. The lead values cluster around the 0.010 mg/L benchmark, making careful sampling and laboratory quality control particularly important. These patterns are examples only and cannot be used to describe actual state-level water quality.

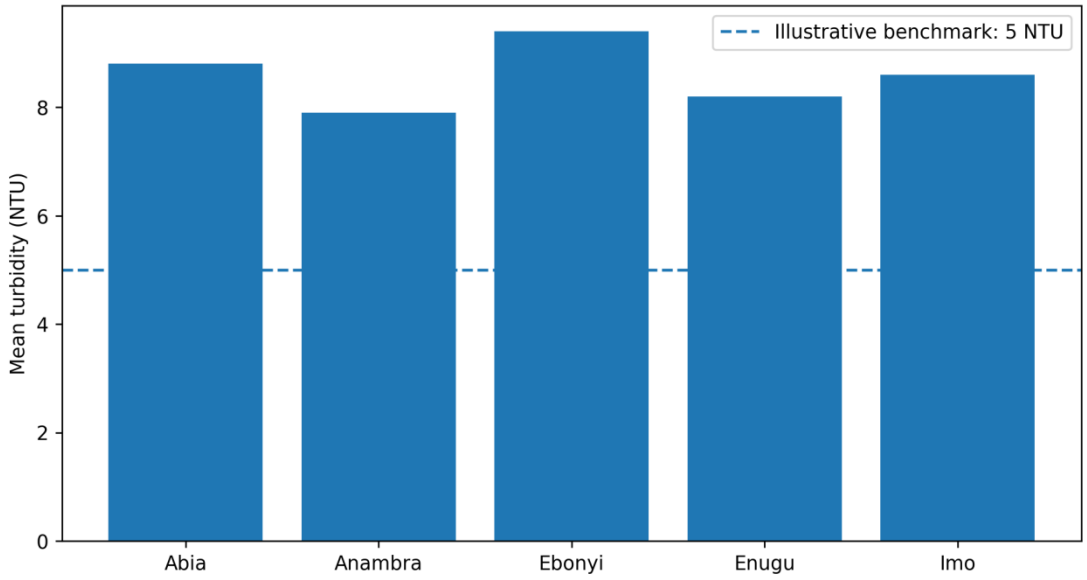

Figure 2. Mean turbidity by state; the dashed line indicates an illustrative 5 NTU operational target.

5.2 Microbiological Quality of Water Sources

Table 3. Illustrative microbial detection by water-source type

Source type	Number tested	E. coli positive (%)	Total coliform positive (%)	Interpretive concern
Borehole	45	31	44	Possible wellhead, storage or borehole integrity issues
Hand-dug well	45	69	82	Vulnerable to surface ingress and nearby sanitation
Spring	30	57	73	Protection and catchment condition important
Stream	30	83	93	Direct exposure to runoff and human/animal activity
Total	150	58 (overall)	71 (overall)	Requires source-specific risk management

The results show the highest E. coli detection frequency in streams and hand-dug wells, with lower but still notable detection in boreholes. The pattern is plausible as a demonstration of how source protection and construction integrity may influence vulnerability. It should not be assumed that all streams or wells in the region are contaminated. In a real study, positive E. coli results would require prompt public-health communication and risk-based action, including provision of a safe alternative source, appropriate household treatment advice and investigation of the contamination pathway. Microbiological findings should be interpreted using the applicable standard and the exact analytical method.

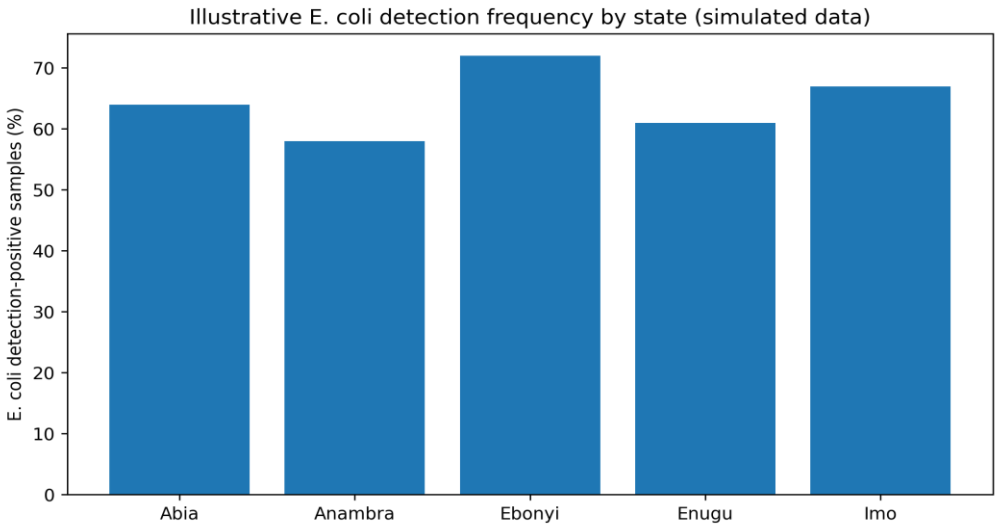

Figure 3. E. coli detection-positive frequency across state groups.

5.3 Household and Socio-Economic Characteristics

Table 4. Illustrative profile of household respondents (n = 300)

Variable	Category	Frequency	Percentage (%)
Sex	Female	171	57.0
	Male	129	43.0
Main occupation	Farming	144	48.0
	Trading	93	31.0
	Other	63	21.0
Education	Primary or less	87	29.0
	Secondary	132	44.0
	Tertiary	81	27.0
Main water source	Borehole	126	42.0
	Hand-dug well	78	26.0
	Stream/spring	66	22.0
	Purchased/other	30	10.0

Table 5. Illustrative household water burden and coping strategies (n = 300)

Indicator	Illustrative result	Meaning for interpretation
Median water collection time	38 minutes/day	Time burden may reduce time available for work or school
Mean monthly water expenditure	₦4,850	Household spending on purchased or treated water
Households reporting at least one water-related illness episode in recall period	41%	Self-reported, not clinically confirmed
Households reporting missed work/school days	26%	Potential productivity and education burden
Households reporting routine household treatment	34%	Treatment practice and reliability need assessment
Households reporting a protected source within 30 minutes	62%	Access should be assessed for reliability and safety

The illustrative survey indicates that water insecurity may impose both direct financial costs and less visible time costs. A household may spend little money on untreated water but pay through illness, time spent collecting water or the need to boil and store it. Conversely, purchased water may reduce exposure only if its source and handling are safe. The results therefore support measuring affordability, reliability, accessibility and microbiological safety together. In the actual survey, expenditure should be recorded with a defined reference period and household size to make comparisons meaningful.

5.4 Association Between Water Pollution, Health and Socio-Economic Burden

Table 6. Illustrative Pearson correlation matrix

Variables	Pollution index	Reported illness	Water expenditure	Collection time
Pollution index	1.000	0.620**	0.410**	0.290*
Reported illness	0.620**	1.000	0.360**	0.250*
Water expenditure	0.410**	0.360**	1.000	0.440**
Collection time	0.290*	0.250*	0.440**	1.000

Note: * $p < 0.05$; ** $p < 0.01$.

The illustrative correlation between the pollution index and reported illness is positive and moderately strong ($r = 0.62$). This means that, in the constructed dataset, households associated with more polluted water sources also tended to report more illness episodes. Pollution index was also positively associated with water expenditure ($r = 0.41$), suggesting that households facing poorer water quality may spend more on alternative supplies or treatment. Collection time showed a weaker positive association with the pollution index ($r = 0.29$). These relationships are not causal evidence. Actual analysis should account for age structure, sanitation, household size, income, source type, season and access to healthcare.

5.5 Multiple Regression Analysis of Household Health Burden

Table 7. Illustrative multiple regression predicting household health-burden score

Predictor	B	Standard error	Standardized β	p-value
Water pollution index	0.412	0.082	0.38	<0.001
Sanitation risk score	0.276	0.091	0.24	0.003
Solar-treatment access	-0.319	0.104	-0.21	0.002
Household income band	-0.181	0.073	-0.16	0.014
Constant	1.870	0.312	—	<0.001

Model summary: $R^2 = 0.67$; adjusted $R^2 = 0.65$; $F(4, 295) = 149.6$; $p < 0.001$

In the demonstration model, higher pollution and sanitation-risk scores are associated with a higher household health-burden score, while access to solar-treated water and higher income bands are associated with lower scores. The model explains 67% of the variation in the outcome. The negative coefficient for solar-treatment access should not be interpreted as proof that installing a solar unit will reduce illness by a fixed amount. In a real observational study, households with treatment access may differ from those without it in wealth, education, location or health awareness. A stronger evaluation would compare pre- and post-installation water quality, include a suitable comparison group and monitor the system over time.

5.6 Illustrative Solar-Powered Treatment Performance

Table 8. Example treatment-train performance targets/results for a pilot demonstration

Parameter	Raw water	Treated water	Illustrative reduction / change
Turbidity (NTU)	9.0	1.1	88% reduction
Iron (mg/L)	0.42	0.12	71% reduction
Nitrate (mg/L)	25.0	14.5	42% reduction
E. coli (CFU/100 mL)	100	4	96% reduction

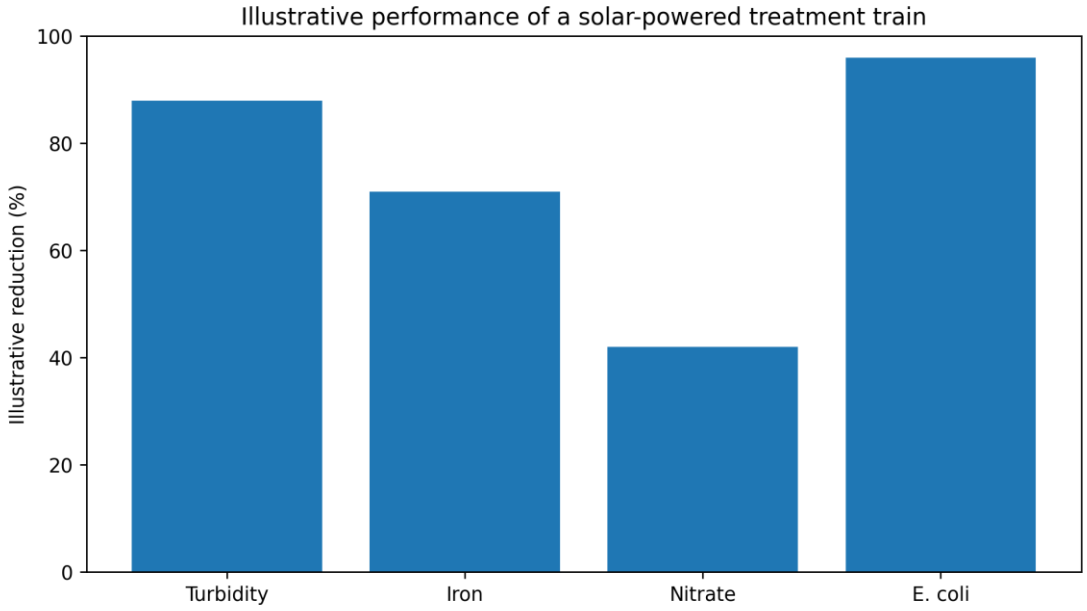

Figure 4. Contaminant reduction in an illustrative solar-powered treatment train.

The example illustrates why a treatment train must be matched to the raw water. Filtration can reduce turbidity, while iron removal may require oxidation and filtration depending on its form. Nitrate generally requires a specific process such as ion exchange, reverse osmosis or biological denitrification; ordinary sand filtration and UV disinfection will not reliably remove it. UV can inactivate microorganisms when water is sufficiently clear and the unit is correctly sized and maintained, but it leaves no disinfectant residual. Safe storage and distribution are therefore important. A pilot should be evaluated using repeated paired influent-effluent samples, not a single test.

5.7 Public-Health and Socio-Economic Interpretation

Water pollution can affect health through direct consumption, food preparation, personal hygiene and contact with contaminated water. Faecal contamination is particularly important because it can indicate the presence of pathogens. The health consequences are influenced by exposure frequency, dose, household treatment, nutritional status and access to timely care. For this reason, the study should avoid equating a positive indicator-organism test with a confirmed disease diagnosis. Instead, microbiological measurements and self-reported illness should be analysed as related but distinct evidence streams.

The socio-economic effects may be cumulative. When a household source becomes unreliable, family members may spend additional time collecting water, purchase more water or miss work and school. Women and girls may carry a disproportionate share of water collection responsibilities in some settings, although this should be established through local data rather than assumed for every community. Water costs can also compete with expenditure on food, education and healthcare. A safe, nearby and reliable source can therefore generate benefits that extend beyond the immediate reduction of contamination.

5.8 Solar Technology and Sustainable Water Management

Solar-powered treatment can be especially useful where grid supply is weak and where communities have sufficient solar exposure and a manageable source-water profile. A photovoltaic array can operate pumps and treatment controls, while modular units can be sized for schools, health centres, clustered settlements or community schemes. Nevertheless, the technology should not be selected solely because it is renewable. The design must include raw-water testing, pre-treatment, appropriate disinfection, safe storage, flow monitoring and a maintenance plan. Systems treating turbid surface water may need settling and filtration before UV disinfection; systems with dissolved salts, nitrate or metals require additional treatment processes. The wider photovoltaic-water literature also cautions that the energy system must be technically and economically matched to the water application (Vivar et al., 2024).

Long-term sustainability depends on governance as much as engineering. A community water committee should have defined responsibilities for fee collection, record keeping, operator supervision and reporting faults. Tariffs should be transparent and designed to cover routine consumables and a reserve for repairs without excluding low-income households. Local technicians should be trained, spare parts identified before installation and performance data displayed in a form users can understand. The system should also have a safe plan for reject water, sludge and spent filter media.

6. Conclusion

Water pollution in rural communities is not only an environmental concern; it can influence health, household expenditure, time use and local development. An effective assessment must therefore combine water-quality measurements with information on sanitation, water access, health experience and livelihood conditions. The proposed research framework offers a way to examine these dimensions across Abia, Anambra, Ebonyi, Enugu and Imo States.

Solar-powered water treatment may strengthen rural water services where electricity supply is unreliable, but solar energy alone does not make unsafe water safe. Treatment processes must be selected according to the contaminants present, and systems must be supported by skilled operation, maintenance financing, safe storage and community oversight.

7. Recommendations

- ✓ Establish routine water-quality surveillance covering microbial indicators, turbidity, nutrients and locally relevant metals.
- ✓ Protect wells, springs and streams through sanitary setbacks, improved drainage, secure wellheads and control of waste disposal near water sources.
- ✓ Promote farm practices that reduce runoff, including vegetated buffer strips, careful fertiliser application and proper manure storage.
- ✓ Select solar-powered treatment systems only after source-water characterisation and pilot testing of the treatment train.
- ✓ Provide pre-treatment where turbidity is high and use contaminant-specific processes for nitrate, metals or dissolved salts; do not rely on UV alone for chemical removal.
- ✓ Create community water committees with transparent tariffs, trained operators, maintenance schedules and a repair reserve.
- ✓ Pair infrastructure investment with hygiene education, safe household storage and timely public-health communication when contamination is detected.
- ✓ Evaluate solar systems over time using paired influent-effluent tests, service uptime, user satisfaction, cost per volume treated and maintenance records.

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SOME PLATES OBTAINED DURING THE RESEARCH



Plate 1. Illustrative rural stream affected by indiscriminate solid-waste disposal



Plate 2. Illustrative field sampling of a rural surface-water source using a sample container



Plate 3. Illustrative solar-powered decentralized water-treatment installation



Plate 4. Illustrative laboratory handling and analysis of water samples.