Larhyss Journal, ISSN 1112-3680, n°60, Dec 2024, pp. 213-230

AN INTEGRATED APPROACH FOR EVALUATING WATER QUALITY

SAHU S.[1], SUPE J.[2*], RATHORE K.[3], VERMA S.[4], MEHTA D.[5]

[1] Mtech Scholar Department of Civil Engineering, Rungta College of Engineering and Technology, Bhilai, 490023, India
[2] Professor Department of Civil Engineering, Rungta College of Engineering and Technology, Bhilai, 490023, India,
[3] Assistant Professor Department of Civil Engineering, Rungta College of Engineering and Technology, Bhilai, 490023, India
[4] Project Scientist Civil Engineering Department, National Institute of Technology, Raipur, Chhattisgarh, 492010, India.
[5] Assistant Professor Civil Engineering Department Dr. S. & S. S. Ghandhy Government Engineering College, Surat, Gujarat, 395001, India

(*) dr.jayant.supe@rungta.ac.in

Research Article – Available at http://larhyss.net/ojs/index.php/larhyss/index

Received January 7, 2024, Received in revised form November 22, 2024, Accepted November 24, 2024

ABSTRACT

In low- and middle-income areas, we developed the Water Quality and Safety (WQS) hybrid technique to evaluate drinking water quality and related knowledge, attitudes, and practices (KAP). The methodology integrates subjective and objective data, addressing biological, physical, and chemical aspects. Our findings show that household (HH) treatment significantly increased turbidity from 2.75 NTU to 5.36 NTU, further rising to 6.5 NTU with additional chemicals. Conductivity slightly increased, and the oxidation-reduction potential (ORP) decreased. pH levels remained within acceptable ranges. According to public perception, 81% of respondents treat their water primarily due to health concerns, emphasizing the need for ongoing water quality management and education. Therefore, this useful technique enables the generation of significant insights that can inform the implementation of effective sustainable development programs. We evaluated and analyzed a specific community in Bhilai City, Chhattisgarh, India, to determine the effectiveness of this method.

Keywords: Water quality, Integrated approach, Water Quality and Safety, Physiochemical aspects, KAP

Abbreviation

WQS	Water Quality and Safety
KAP	Knowledge, attitudes, and practices
HH	Household
NTU	Nephelometric turbidity units
ORP	Oxidation-reduction potential
mg/L	Milligrams per liter
NTU	Nephelometric turbidity units
SDG	Sustainable Development Goal
WHO	World Health Organization
POU	Point-of-use
JMP	Joint Monitoring Programme
MICS	Multiple Indicator Cluster Surveys
TDS	Total Dissolved Solids
IQR	Interquartile range
MPN	Most probable number
BIS	Bureau of Indian Standards

INTRODUCTION

Ensuring universal and equitable access to clean and inexpensive drinking water by 2030 is the aim of the United Nations' sixth Sustainable Development Goal (SDG 6). To achieve this goal, it is critical to closely monitor the quality and availability of water obtained and used by economically disadvantaged households. Previous interventions implemented by government agencies, private corporations, and public organizations in underdeveloped countries have often failed to be sustainable, mostly because they lacked a complete approach and did not adequately include the end-users (Ramesh et al., 2016; Chaudhari et al., 2022; Chaudhari et al., 2021). When properly structured, effective surveillance can facilitate the measurement of advancements, guarantee responsibility and openness, detect and resolve problems, and potentially shape the formulation of new objectives and benchmarks. Hence, it is crucial to continuously develop and modify monitoring mechanisms to effectively tackle the diverse issues associated with SDG 6 (Khan et al., 2017; Ramesh et al., 2017; Charles et al., 2020; Verma et al., 2024).

Access to safe drinking water is essential for maintaining public health (Remini, 2010; Ayari and Ayari, 2017; Aroua, 2022; Aroua, 2023; Ihsan and Desroya, 2024). However, over 2 billion people worldwide still lack access to safely managed drinking water services, according to the World Health Organization (WHO) (WHO, 2010). Contaminated water sources pose significant health risks, as they can carry pathogens and pollutants that lead to diseases like cholera, dysentery, and typhoid fever, particularly prevalent in low-income regions (Amrose et al., 2015; Adjagodo et al., 2016; Baba Hamed, 2021; Patel et al., 2023).

In these areas, challenges related to water quality are intensified by factors such as inadequate infrastructure, limited access to advanced water treatment technologies, and frequent contamination of water sources (Faye, 2017; Glade and Ray, 2022; Surati et al., 2022). Conventional water quality assessments often rely on single-parameter tests or a limited set of indicators, which may not fully capture the complexity of water quality issues or address the specific needs of these communities (Gordon et al., 2020; Li and Wu, 2019; Patel et al., 2023).

An integrated approach to water quality assessment merges various methods and perspectives to offer a more comprehensive evaluation of water safety (Rouissat and Smail, 2022; Mohamad et al., 2024). This approach considers chemical, biological, and physical aspects of water quality and includes community involvement to ensure that assessments are both relevant and actionable (Laghzal and Salmoun, 2014a; Ramada et al., 2023). By combining multiple assessment methods and engaging local stakeholders, this approach aims to overcome the limitations of traditional methods and enhance the overall effectiveness of water quality management (Pandey et al., 2022; Kouloughli and Telli, 2023).

Over several decades, the monitoring of water quality in low-income areas has changed (Bartram et al., 2014). Usually, these endeavors depend on either data collected through self-reported surveys or direct measurements, with minimal coordination between the two approaches. Measurements frequently prioritize the assessment of microbiological pollution, specifically Escherichia coli, and typically concentrate on the water source's quality (Laghzal and Salmoun, 2014b; Tir et al., 2017). Evaluation of home-consumed water, sometimes referred to as "point-of-use" (POU) water, receives relatively less attention. For instance, a comprehensive analysis found that only 15% of studies observed the water stored in households, and only 7% evaluated both the source and point-of-use (POU) water, even though the microbiological quality can differ greatly between the two (Bain et al., 2014; Gundry et al., 2004; Wright et al., 2004). Household surveys often prioritize doing sanitary inspections and categorizing water sources into different classifications, such as "improved sources." However, Bain et al. (2012, 2014) have criticized this methodology for its inadequate comprehensiveness.

In the same sample, there has historically been limited integration of physical measurements with household survey data. The 6th edition of the Multiple Indicator Cluster Surveys (MICS), created by the World Health Organisation (WHO 2022)/UNICEF Joint Monitoring Programme (JMP), now encourages the gathering of both types of data from the same home at the same time. Numerous areas have previously employed this strategy. Khan et al. (2017) in Belize and Moreno et al. (2020) in Ecuador conducted significant instances of effective application of this integrated approach.

We developed the WQS to supplement and bolster ongoing initiatives aimed at establishing a comprehensive strategy for monitoring water quality. Our tool distinguishes itself in three notable ways:

Firstly, it encompasses not only biological data but also chemical and physical evaluations of water quality. This comprehensive strategy tackles the changing circumstances of health concerns associated with water, specifically in middle-income nations where there is a rising level of pollution from agriculture and industry, but microbiological contamination may be decreasing. Furthermore, the WQS collects both subjective (reported by households themselves) and objective (based on measurements) evaluations of water quality, as well as data on households' knowledge, attitudes, and practices (KAP). This allows for an assessment of whether families can effectively recognize pollutants and the corresponding health hazards in comparison to the actual assessed risks, thereby aiding in the development of targeted educational interventions. Furthermore, it assesses the importance of subjective evaluations, which may lead to the development of more economical monitoring methods on a large scale. Finding the relevance of subjective evaluations could potentially reduce the need for expensive physical measurements.

Furthermore, the WQS monitors the water quality starting from its collection at the source, whether it is a public or private source, and continues to follow it throughout storage and any treatment procedures. It measures the water's quality both at the beginning and end of the process. Although it is uncommon to do so for non-microbial indicators, it is essential to identify the origins of contamination and develop appropriate remedies. For instance, it assists in determining whether contaminants originate from the original water supply or enter through domestic storage methods, and whether household remedies are effective and suitable.

PROBLEM STATEMENT

Current methods for assessing drinking water quality often depend on isolated techniques, which may not provide a complete view of water safety, particularly in low-income settings where water quality issues are complex and multifaceted. Traditional approaches might concentrate mainly on a narrow set of parameters, such as bacterial contamination or chemical pollutants, without considering the broader context or including community perspectives (Nare et al., 2011).

In resource-limited settings, there is a critical need for a more integrated and comprehensive approach to water quality assessment. Developing a framework that incorporates various assessment methods such as chemical analysis, biological testing, and physical measurement alongside community feedback could offer a more accurate and actionable understanding of water quality issues.

OBJECTIVE OF THE STUDY

The main objectives of the present study are:

1. Design a comprehensive framework that combines chemical, biological, and physical methods for evaluating drinking water quality, while also integrating community feedback to enhance its relevance and applicability.
2. Implement the integrated assessment approach in selected low-income communities to determine its effectiveness in identifying and addressing water quality issues.

MATERIAL AND METHODS

Overall structure of the system

We devised the data collection procedure by conducting pilot studies and experimenting with actual field settings. A cooperative team of students and faculty members carried out the live-in-lab concept. The study employed a participatory rural evaluation methodology, which included on-site visits, discussions about ideas, and questionnaires (Kadiveti et al., 2019). The procedure combines household surveys with water-quality data obtained from communal sources and household "point-of-use" (POU) settings. An on-site assessment was conducted to evaluate the physical characteristics of water quality, while samples were taken and transported to a laboratory for biological and chemical investigations. All public sources of drinking water in the town, including natural bodies of water, wells, and accessible taps (whether publicly held or privately owned but available for purchase), underwent a comprehensive assessment during the first stage. This assessment involved mapping and testing these sources for various physical (on-site), chemical, and biological (laboratory) attributes.

During the second phase, a selection of houses was visited, and surveyed, and their water tested for identical parameters. We surveyed the household members responsible for supplying potable water. If this individual was not accessible, the survey was carried out at the adjacent residence instead. Each visit to a household had a duration of around 20 minutes, which encompassed the survey, on-site testing of water quality, and preparation of samples.

Water quality testing

We specifically developed the water-quality tests to collect crucial local indicators using methods that are practical for a mobile team of enumerators with minimal training. Water-We conducted water-quality tests at community sources and within residences, categorizing them into three groups: physical, chemical, and biological (Table 1). The variables examined:

Oxidation-Reduction Potential (ORP): This quantifies the water's ability to undergo oxidation or reduction reactions. Experts consider a measurement of oxidation-reduction potential (ORP) over 200 mV as a reliable indicator of high-quality drinking water.

Turbidity: Turbidity is the result of suspended particles in water that decrease its clarity. We quantify it by measuring the light scattering these particles cause. It functions as a rapid and cost-effective measure to detect possible pollution, and it is efficient in monitoring the quality of water from its source to the point of consumption. The World Health Organisation (WHO) has established a turbidity level of 1 NTU. However, Reddy (2023) states that the permissible limit in India is 5 NTU.

pH: This parameter is of utmost importance in water treatment and has a direct impact on distribution system corrosion. The World Health Organisation stated in its 2011 edition that monitoring pH is an essential component of operational schemes that guarantee the quality of water.

Water temperature: Water temperature has an impact on other factors, including density, solubility, and the speed at which certain reactions occur in water.

Total Dissolved Solids (TDS): TDS measures the collective presence of ions in a solution. The World Health Organisation (WHO) sets the maximum allowable limit for total dissolved solids (TDS) at 300 mg/L. In contrast, India's guidelines permit TDS levels of up to 500 mg/L, and in situations where alternate sources are not available, levels of up to 2000 mg/L are considered acceptable.

Alkalinity: The World Health Organization (WHO) and Indian norms define the limit for alkalinity as 200 mg/L of CaCO3.

Hardness: The amount of dissolved minerals in the water determines the classification of water hardness. We classify it as soft (0–60 mg/L), moderate/hard (60–120 mg/L), hard (120–180 mg/L), and very hard (>180 mg/L). Excessive amounts of calcium and magnesium in hard water can have negative effects on health, as stated by the World Health Organisation in 2010.

Iron: Iron affects the flavor of drinking water as well as how users perceive it

Ammonia: Ammonia is an indicator of potential contamination from bacteria, sewage, or animal waste, and it presents health hazards (Akpor and Muchie, 2011).

Coliforms and E. coli: These are important markers for assessing water safety and public health (Bain et al., 2014).

We performed several tests on-site, while others required off-site laboratory examination of 500 mL samples from both treated and untreated water sources. In addition, a portion of the population had 500 mL samples examined at a different location to detect the presence of E. coli and coliforms, as these tests are more expensive. Prospective users of the WQS can modify the recorded water-quality metrics to suit their specific requirements and location-specific circumstances.

Table 1: Water quality parameters as per Baird et al. (2017)

Parameters	Measurement method	Standard limits
Oxidation-reduction potential (ORP)	On-site measurement	>200 mV for good drinking water
Turbidity	On-site measurement	WHO: ≤ 1 NTU, India: ≤ 5 NTU
pH	On-site measurement	6.5-8.5 general standard
Water temperature	On-site measurement	No specific limit; typically measured to monitor effects
Total dissolved solids (TDS)	On-site measurement	WHO: ≤300 mg/L, India: ≤ 500 mg/L, Absence of alternative source: ≤ 2000 mg/L
Water hardness	On-site measurement	Soft: 0-60mg/L, Moderate/Hard: 60-120 mg/L, Hard: 120-180 mg/L, very hard: > 180 mg/L
Iron	On-site measurement	WHO and India: varies by taste and color standards
Ammonia	Laboratory analysis	WHO: ≤ 0.5 mg/L (Drinking water)
Coliforms	Laboratory analysis	WHO: None detected in 100 mg/L (Drinking water)
E. coli	Laboratory analysis	WHO: None detected in 100 mg/L (Drinking water)

Detailed survey description

Demographic and socioeconomic status

The survey aims to collect comprehensive demographic and socioeconomic data to gain insights into a population's features and living situations. The survey encompasses inquiries regarding age, gender, ethnicity, education, employment status, income levels, household composition, and housing circumstances. The objective is to examine patterns and connections between socioeconomic position and different demographic characteristics, offering insights into inequalities, resource availability, and overall welfare. The survey findings will assist policymakers and organizations in formulating focused policies and initiatives to enhance the standard of living and mitigate disparities within the community.

Water Sources

The water source survey aims to determine the main and secondary sources of water used by households. The data collection process encompasses a wide range of sources, such as piped water, shallow and deep wells, boreholes, rivers, lakes, rainfall harvesting, and bottled water. The survey also examines the accessibility, quality, and dependability of these sources, including factors such as their proximity to the nearest source, the duration required to gather water, and any fluctuations that occur due to different seasons. Furthermore, it examines water treatment methodologies and the frequency of water scarcity. The gathered data will provide valuable insights for the development of policies aimed at enhancing water supply infrastructure and guaranteeing universal and sustainable access to safe water.

Household treatment

This module investigates whether respondents utilize the water from their primary household source and, if yes, how they do so. Possible treatment procedures encompass boiling, straining, incorporating chemical or herbal compounds, or employing commercial filters. We meticulously question participants about their specific treatment methods, including the duration of boiling or settling, the specific vessel they use, and the compounds they introduce. The purpose of these questions is to identify critical factors in the treatment process that may impact the quality of the water. We also take photographs of the treatment equipment.

Throughout this module, participants are also asked to permit enumerators to gather water samples from both the source (referred to as "untreated household water") and the treated point-of-use (POU) drinking water (in families that use treatment methods). We then examine the samples for the markers listed in Table 1 and provide further details in Section 2.

RESULTS AND DISCUSSION

Water quality and household treatment

Fig. 1 depicts a boxplot that visually represents the interquartile range (IQR), which encompasses the middle 50% of the data and excludes any outliers. The black horizontal line inside the box represents the median value. The whisker lines extend from the lowest to the highest data points, eliminating any outliers depicted as empty dots. Fig. 1 shows that the median water turbidity was 2.75 NTU when there was no household treatment. However, the application of household treatment led to an increase in turbidity to 5.36 NTU. After undergoing HH treatment and adding additional compounds, the median turbidity increased to 6.5 NTU, with the highest recorded value reaching 15 NTU. This indicates that adding substances resulted in an elevated level of turbidity. The majority of turbidity outliers were located above the upper whisker line. Clay, silt, precipitated iron compounds, and other rock erosion byproducts, along with organic matter and microbes found in water bodies, commonly cause elevated turbidity in groundwater. Increased turbidity levels can also occur due to decreased groundwater volume or pollution from unclean faucets or storage tanks.

Fig. 2 shows the electrical conductivity of the water source, with medians of 207 µS/cm without household (HH) treatment and 210 µS/cm with HH treatment. The interquartile ranges for untreated water were found to be around 136 and 222 µS/cm, whereas for treated water, they ranged from 153 to 331 µS/cm. These results indicate that the conductivity range in the treated water samples was wider, regardless of the presence of additional compounds. The mean conductivity was 186 µS/cm before treatment and increased to 272 µS/cm after treatment, indicating elevated levels of dissolved salts in the treated water, notably due to the introduction of additional compounds. In addition, the temperature of the drinking water increased to 50 °C, as opposed to 37 °C for untreated water, which can also impact the concentrations of dissolved substances.

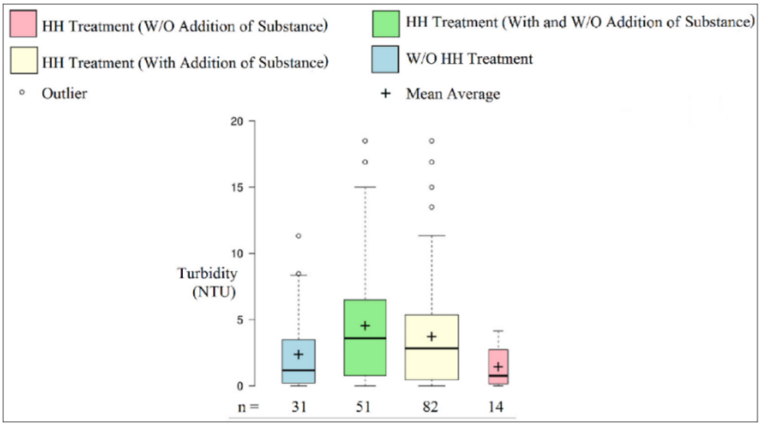

Figure 1: Whisker plots for the turbidity parameters illustrating household treatment

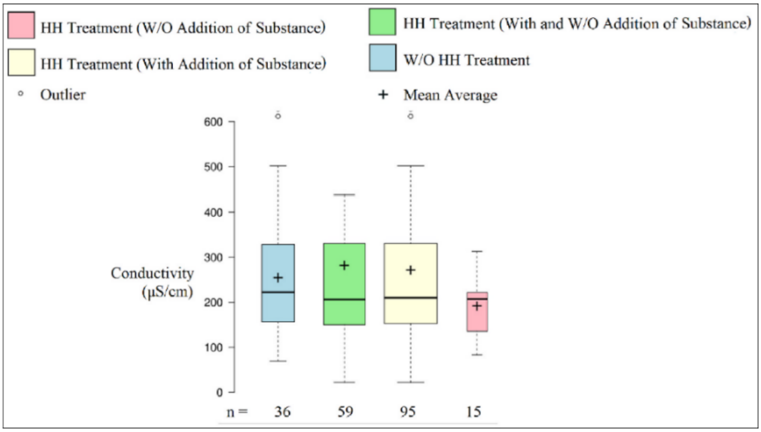

Figure 2: Whisker plots for the conductivity parameters illustrating household treatment

For the Oxidation-Reduction Potential (ORP) shown in Fig. 3, the range for 50% of values was 325 to 403 mV without household (HH) treatment and 194 to 393 mV with HH treatment, with medians of 395 mV and 314 mV, respectively. The median ORP value decreases with HH treatment when substances are added, although the average ORP remains relatively constant.

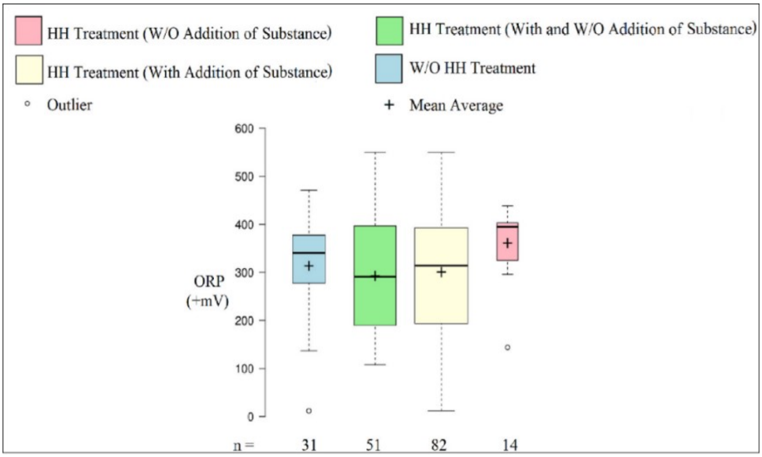

Figure 3: Whisker plots for the ORP parameters illustrating household treatment

In terms of pH, as depicted in Fig. 4, the values ranged between 7.4 and 8.2 without HH treatment and between 7.7 and 8.21 with HH treatment, with medians of 7.6 and 7.9, respectively. The pH ranged from 6.5 to 8.5 in both cases, all within acceptable regulatory limits.

The mean coliform levels, determined using the most probable number (MPN) technique, were 1604 MPN/100 mL (n = 6) in the absence of hand hygiene (HH) treatment, and 1544 MPN/100 mL (n = 33) with HH treatment. These numbers indicate that biological agents have polluted the water, rendering it unsafe for consumption without additional disinfection measures like chlorine or UV treatment. Notably, we documented the presence of E. coli in 0 out of 6 samples without treatment and 9 out of 24 samples with HH treatment. This indicates that the applied treatments, which probably involved boiling and potentially other techniques, did not yield water that is considered safe. This could be attributed to variables such as the length of time the items are stored, how they are handled, or the state of the containers being used, which may not be sufficiently addressed or managed. The data does not provide information on whether different treatment strategies differ in effectiveness or if traditional approaches help enhance water quality.

Indications of water quality

Next, we will examine the connections between participants' subjective assessments of their water and the measurable physicochemical markers acquired by the WQS tool. The objective of this analysis is to evaluate the extent to which respondents' subjective assessments of water quality accurately correspond to the measured values. This information can be valuable for implementing cost-efficient, widespread water monitoring efforts. First, we will analyze the association between subjective evaluations of water safety. Then, we will analyze the correlations between various subjective markers, such as color, smell, and hardness, and their corresponding physical measurements.

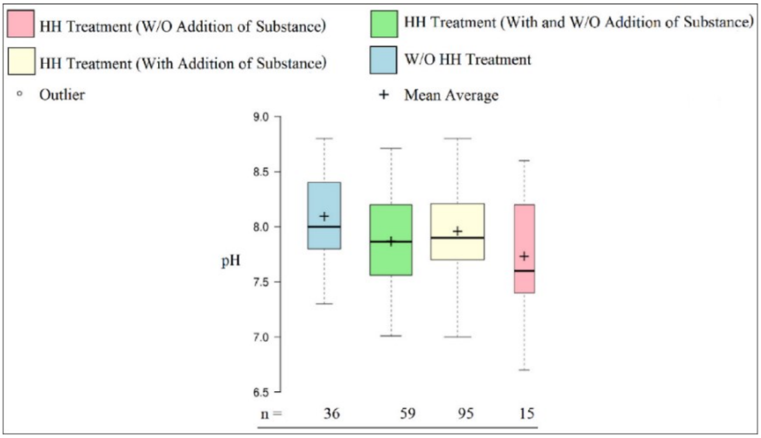

Figure 4: Whisker plots for the pH parameters illustrating household treatment

Out of the respondents, 81% stated that they do not consume untreated source water at home. However, only 63% of them attributed this behavior to concerns about getting sick. On the other hand, 14% of participants cited "habit" and "established routines" as reasons for not eating untreated source water (data not displayed). Fig. 5 displays the range of respondents' subjective evaluations of their water safety using a Likert scale, as documented by Ajith et al. in 2023. Fig. 6 depicts the probability of receiving a positive evaluation (such as very good, good, or satisfactory) for families who either treat or do not treat their source water. In general, the initial judgments of water safety were largely dissatisfactory. However, the majority of respondents reported a significant improvement in water quality to a satisfying level after implementing their chosen treatments.

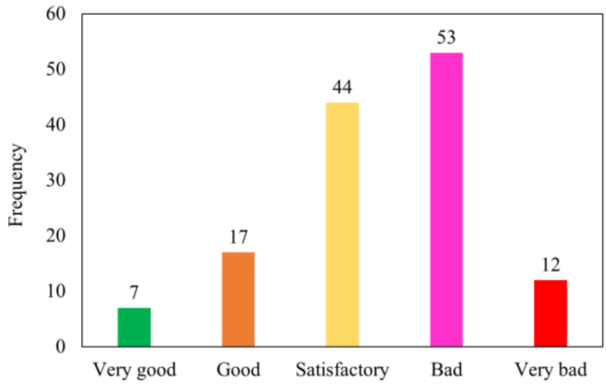

Figure 5: safety of your source water

Table 2: Presents the findings of the physicochemical analysis (WHO-Edition, F. 2011; BIS-Reddy, 2023).

Assessment of good vs. bad vs. physical water quality				WHO 2011	BIS 2012 (Reddy, 2023)	
Parameters	**Good**	**Bad**	**t-test**		**Acceptable limit**	**Permissible limit**
Turbidity	1.6±0.7	2.4±1.9	0.410	1.5	1	5
pH	7.5±0.3	7.1±0.3	0.0061	6.5-8.5	6.5-8.5	-
Conductivity	233±36.2	255±64.5	0.352	1500	-	-
TDS	162±24.6	185±46.3	0.301	500	500	2000
ORP	385±32	350±48	0.313	-	-	-
Total hardness	80±23	132±44	0.084	-	200	600
Alkalinity	73±11	92±16	0.121	500	200	600

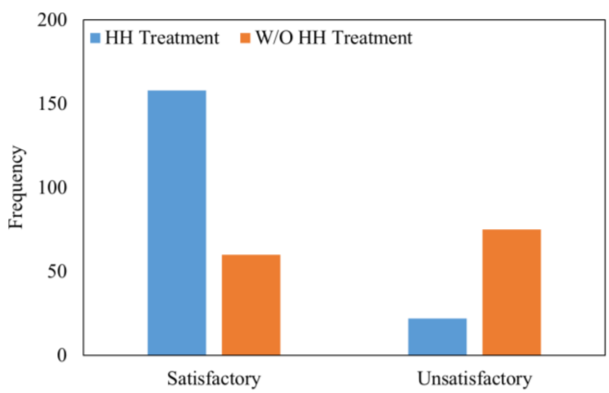

Figure 6: With and without household (HH) treatment

Measured Physiochemical Indicators

The comparison of water quality parameters between "Good" and "Bad" water samples (Table 2) reveals the following:

1. **Turbidity:** The turbidity levels in both water types are close, with averages of 1.6 NTU for good water and 2.4 NTU for unsafe water. The t-test result (0.410) shows no significant difference. Although "good" water meets the WHO's acceptable turbidity limit of 1.5 NTU, "bad" water exceeds this limit but remains within the BIS (Reddy, 2023) permissible limit of 5 NTU.
2. **pH:** Good water has a higher average pH (7.5) than bad water (7.1), indicating a significant difference in pH levels (p-value = 0.0061). Both values are within the acceptable pH range of 6.5–8.5 set by WHO and BIS (Reddy, 2023).
3. **Conductivity:** Conductivity levels are similar between excellent and bad water, with a t-test result of 0.352 indicating no significant difference. Both samples are well below the WHO's acceptable limit of 1500 µS/cm.
4. **Total Dissolved Solids (TDS):** TDS levels are slightly higher in contaminated water (185 mg/L) compared to excellent water (162 mg/L), but this difference is not statistically significant (p-value = 0.301). Both values are close to the BIS (Reddy, 2023) acceptable limit of 500 mg/L, with "bad" water approaching the BIS (Reddy, 2023) permissible limit of 2000 mg/L.
5. **Oxidation-Reduction Potential (ORP):** There is no significant difference in ORP values between good (385 mV) and bad (350 mV) water, and ORP data do not have specific limits provided by WHO or BIS (Reddy, 2023) for comparison.
6. **Total Hardness:** There is a significant difference in total hardness, with bad water (132 mg/L) significantly harder than good water (80 mg/L). The p-value of 0.084 indicates a trend towards higher hardness in bad water. "Bad" water exceeds the BIS (Reddy, 2023) acceptable limit of 200 mg/L, but it remains within the BIS permissible limit of 600 mg/L.
7. **Alkalinity:** Alkalinity is higher in undesirable water (92 mg/L) compared to good water (73 mg/L), though the difference is not statistically significant (p-value = 0.121). Both values are within the BIS (Reddy, 2023) permissible limit of 600 mg/L, but they exceed the BIS (Reddy, 2023) acceptable limit of 200 mg/L.

CONCLUSION

The assessment of water quality parameters demonstrates notable changes following household (HH) treatment. Without treatment, the median turbidity level was 2.75 NTU. After HH treatment, turbidity increased to 5.36 NTU; with the addition of chemicals, it further rose to 6.5 NTU. This significant increase in turbidity highlights the impact of additional compounds on water clarity, with many data points surpassing the maximum threshold. However, electrical conductivity also showed a slight increase, with the median rising from 207 µS/cm before treatment to 210 µS/cm after HH treatment. The treated water exhibited a broader range of conductivity values, suggesting elevated levels of dissolved salts, especially when substances were added. In addition, the oxidation-reduction potential (ORP) decreased from a median of 395 mV to 314 mV post-treatment, indicating a reduction in the water's oxidative capacity, though the average ORP remained relatively stable. While, the pH levels in both treated and untreated water were within acceptable ranges, with treated water ranging from 7.7 to 8.21 and untreated water from 7.4 to 8.2. There was a noticeable increase in median pH values with HH treatment. However, the public perception reveals that 81% of respondents treat their source water, with 63% citing illness concerns and 14% mentioning habit as reasons. Hence, these findings underscore the significant effects of HH treatment on turbidity, conductivity, and pH, highlighting the importance of continuous water quality management and public education.

Scope and limitations of the study

This study concentrates on developing and implementing an integrated approach to drinking water quality assessment within low-income settings. It will not address high-income or industrialized areas, and certain limitations may affect the research, including resource constraints, local infrastructure, and diverse community dynamics.

1. **Resource Constraints:** Limited access to advanced testing equipment and trained personnel in low-income settings may impact the implementation and effectiveness of the integrated approach (Mishra et al., 2021).
2. **Data Variability:** Water quality data may vary significantly based on local sources, contamination levels, and community practices, potentially affecting the applicability and generalizability of the results (Schuwirth et al., 2018).
3. **Community Participation:** The effectiveness of the integrated approach may be influenced by the extent of community engagement and cooperation, which can differ across communities (Glasgow et al., 2004).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors wish to express their gratitude towards the Rungta College of Engineering and Technology Bhilai (C.G.) for their kind support and for the opportunity to conduct the present study.

REFERENCES

AJITH V., FISHMAN R., YOSEF E., EDRIS S., RAMESH R., SURESH R.A., MAMANE H. (2023). An integrated methodology for assessment of drinking-water quality in low-income settings, Environmental Development, Vol. 46, Paper ID 100862. https://doi.org/10.1016/j.envdev.2023.100862

AKPOR O. B., MUCHIE B. (2011). Environmental and public health implications of wastewater quality, African Journal of Biotechnology, Vol. 10, Issue 13, pp. 2379-2387. eISSN: 1684-5315

AMROSE S., BURT Z., RAY I. (2015). Safe drinking water for low-income regions, Annual Review of Environment and Resources, Vol. 40, Issues 1, pp. 203-231. https://doi.org/10.1146/annurev-environ-031411-091819

AROUA N. (2022). Long term city development versus water strategy in Al-Maghreb, Larhyss Journal, No 50, pp. 173-197.

AROUA N. (2023). Setting out urban water issues examples from Algeria and worldwide, Larhyss Journal, No 56, pp. 309-327.

AYARI K., AYARI A. (2017). For better governance of drinking water in Tunisian rural areas, Larhyss Journal, No 29, pp. 7-21. (In French)

BABA HAMED S. (2021). Impact of water pollution on public health and the environment in Oran, Larhyss Journal, No 45, pp. 203-222.

BAIN R.E., GUNDRY S.W., WRIGHT J.A., YANG H., PEDLEY S., BARTRAM J.K. (2012). Accounting for water quality in monitoring access to safe drinking-water as part of the Millennium Development Goals: lessons from five countries, Bulletin of the World Health Organization, Vol. 90, pp. 228-235. 10.2471/BLT.11.094284

BAIN R., CRONK R., WRIGHT J., YANG H., SLAYMAKER T., BARTRAM J. (2014). Fecal contamination of drinking-water in low-and middle-income countries: a systematic review and meta-analysis, PLoS medicine, Vol. 11, Issue 5, Paper ID e1001644. https://doi.org/10.1371/journal.pmed.1001644

BAIRD R., RICE E., EATON A. (2017). Standard methods for the examination of water and wastewaters, Water Environment Federation, Chair Eugene W. Rice, American Public Health Association Andrew D. Eaton, American Water Works Association, Vol. 1, pp. 71-90.

BARTRAM J., BROCKLEHURST C., FISHER M.B., LUYENDIJK R., HOSSAIN R., WARDLAW T., GORDON B. (2014). Global monitoring of water supply and sanitation: history, methods and future challenges, International Journal of environmental research and public health, Vol. 11, Issue 8, pp. 8137-8165. https://doi.org/10.3390/ijerph110808137

CHARLES K.J., NOWICKI S., BARTRAM J.K. (2020). A framework for monitoring the safety of water services: from measurements to security, NPJ Clean Water, Vol.3, Issue 1, Paper ID 36. https://doi.org/10.1038/s41545-020-00083-1

CHAUDHARI A.N., MEHTA D.J., SHARMA N.D. (2022). Coupled effect of seawater intrusion on groundwater quality: study of South-West zone of Surat city, Water Supply, Vol. 22, Issue 2, pp. 1716-1734. https://doi.org/10.2166/ws.2021.323.

CHAUDHARI A.N., MEHTA, D.J., SHARMA D.N.D. (2021). An assessment of groundwater quality in South-West zone of Surat city, Water Supply, Vol. 21, Issue 6, pp. 3000-3010. https://doi.org/10.2166/ws.2021.083.

EDITION F. (2011). Guidelines for drinking-water quality, WHO chronicle, Vol. 38, Issue 4, pp.104-108. ISBN 978 92 4 154761 1

FAYE C. (2017). Water pollution challenges, a threat to public health: strengths and weaknesses of water laws and policies in Senegal, Larhyss Journal, No 32, pp. 107-126. (In French)

GLADE S., RAY I. (2022). Safe drinking water for small low-income communities: the long road from violation to remediation, Environmental Research Letters, Vol.17, Issue 4, pp. 1-11, Paper ID 044008. 10.1088/1748-9326/ac58aa

GLASGOW H.B., BURKHOLDER J.M., REED R.E., LEWITUS A.J., KLEINMAN J.E. (2004). Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies, Journal of experimental marine biology and ecology, Vol. 300, Issues 1-2, pp. 409-448. https://doi.org/10.1016/j.jembe.2004.02.022

GORDON B., PATEL P., RAVI R. (2020). Innovations in Portable Water Filtration, Journal of Environmental Engineering, Vol. 146, Issues 3, Paper ID 04019053.

GUNDRY S., WRIGHT J., CONROY R. (2004). A systematic review of the health outcomes related to household water quality in developing countries, Journal of water and health, Vol. 2, Issue 1, pp. 1-13. https://doi.org/10.2166/wh.2004.0001

IHSAN T., DEROSYA V. (2024). Drinking water problems in rural areas: review of point-of-use methods to improve water quality and public health, Larhyss Journal, N°58, pp. 55-71.

KADIVETI H., ELESHWARAM S., MOHAN R., ARIPRASATH S., NANDANAN K., SHARMA S.D., SIDDHARTH B. (2019). Water management through integrated technologies, a sustainable approach for village Pandori, India, In 2019 IEEE R10 Humanitarian Technology Conference (R10-HTC) Vol. 47129, pp. 180-185.

KHAN S.M., BAIN R.E., LUNZE K., UNALAN T., BESHANSKI-PEDERSEN B., SLAYMAKER T., HANCIOGLU A. (2017). Optimizing household survey methods to monitor the Sustainable Development Goals targets 6.1 and 6.2 on drinking water, sanitation and hygiene: A mixed-methods field-test in Belize, PloS one, Vol.12, Issue 12, Paper ID e0189089. https://doi.org/10.1371/journal.pone.0189089

LAGHZAL A., SALMOUN F. (2014a). Contribution to the characterisation of the physico chemical quality of water of some springs in the region of Tangier-Tetouan (Morocco), Larhyss Journal, No 20, pp. 7-24.

LAGHZAL A., SALMOUN F.1 (2014b). Contribution to the bacteriological characterization of some sources in the region of Tangier-Tetouan (Morocco), Larhyss Journal, No 20, pp. 71-78.

LI P., WU J. (2019). Drinking water quality and public health, Exposure and Health, Vol.11, Issue 2, pp. 73-79. https://doi.org/10.1007/s12403-019-00299-8

MISHRA B.K., KUMAR P., SARASWAT C., CHAKRABORTY S., GAUTAM A. (2021). Water security in a changing environment: Concept, challenges and solutions, Water, Vol. 13, Issues 4, Paper ID 490. https://doi.org/10.3390/w13040490

MOHAMAD N.D., ABDUL HAMID N.S., RAMLI R.R., AHMAD KAMAL N., ABDUL ADIS A.A., AMIR A. (2024). Water quality assessment at royal Belum state park, Perak, Malaysia, Larhyss Journal, No 57, pp. 101-120.

MORENO L., POZO M., VANCRAEYNEST K., BAIN R., PALACIOS J.C., JÁCOME F. (2020). Integrating water-quality analysis in national household surveys: water and sanitation sector learnings of Ecuador, Nature Partner Journals Clean Water, Vol. 3, Issue 1, pp. 23. https://doi.org/10.1038/s41545-020-0070-x

NARE L., ODIYO J.O., FRANCIS J., POTGIETER N. (2011). Framework for effective community participation in water quality management in Luvuvhu Catchment of South Africa, Physics and Chemistry of the Earth, Parts A/B/C, Vol. 36, Issues 14-15, pp.1063-1070. https://doi.org/10.1016/j.pce.2011.08.006

PATEL D.D., MEHTA D.J., AZAMATHULLA H.M., SHAIKH M.M., JHA S., RATHNAYAKE U. (2023). Application of the weighted arithmetic water quality index in assessing groundwater quality: A case study of the South Gujarat region, Water, Vol. 15, Issue 19, Paper ID 3512. https://doi.org/10.3390/w15193512.

PATEL P., MEHTA D.J., SHARMA N.D. (2023). A GIS-based DRASTIC Model for Assessing Groundwater Quality Vulnerability: Case Study of Surat and its Surroundings. Journal of the Geological Society of India, Vol. 99, Issue 4, pp. 578-582. https://doi.org/10.1007/s12594-023-2347-4.

RAMADA D.L., DE VRIES J., VOLLENBROEK J., NOOR N., TER BEEK O., MIHĂILĂ S.M., STAMATIALIS D. (2023). Portable, wearable and implantable artificial kidney systems: needs, opportunities and challenges, Nature Reviews Nephrology, Vol. 19, Issues 8, pp. 481-490. https://doi.org/10.1038/s41581-023-00726-9

RAMESH M.V., MOHAN R., MENON, S. (2016). Live-in-Labs: rapid translational research and implementation-based program for rural development in India, In 2016 IEEE Global Humanitarian Technology Conference (GHTC), pp. 164-171. https://doi.org/10.1109/GHTC.2016.7857275

RAMESH M.V., NIBI K.V., KURUP A., MOHAN R., AISWARYA A., ARSHA A., SARANG P. R. (2017). Water quality monitoring and waste management using IoT, In 2017 IEEE Global Humanitarian Technology Conference (GHTC), pp. 1-7. https://doi.org/10.1109/GHTC.2017.8239311

REDDY A.G.S. (2023). A review on violation of drinking water specifications in water supply and research publications, Environment, Development and Sustainability, Vol. 25, Issue 2, pp. 1084-1100. https://doi.org/10.1007/s10668-021-02038-z

REMINI B. (2010). The problem of water in northern Algeria, Larhyss Journal, No 8, pp. 27-46. (In French)

ROUISSAT B., SMAIL N. (2022). Contribution of water resource systems analysis for the dynamics of territorial rebalancing, case of Tafna system, Algeria, Larhyss Journal, No 50, pp. 69-94.

SCHUWIRTH N., HONTI M., LOGAR I., STAMM C. (2018). Multi-criteria decision analysis for integrated water quality assessment and management support, Water Research X, Vol. 1, pp. 1-11. Paper ID 100010. https://doi.org/10.1016/j.wroa.2018.100010

SURATI M.H., PRAJAPATI K.J., PARMAR U.K., MEHTA D.J. (2022). Assessment of Water Quality Index of Tapi River: A Case Study of Surat City, In Groundwater and Water Quality: Hydraulics, Water Resources and Coastal Engineering, Cham: Springer International Publishing, pp. 263-277. https://doi.org/10.1007/978-3-031-09551-1_20,

TIR E., DECHE M., BOUNOUIRA Y., CHEDAD A. (2017). Physico-chemical and microbiological quality of water from the sources of the community of Tissemsilt "case of Ain Loura and Ain Sfa", Larhyss Journal, No 29, pp. 111-119. (In French)

VERMA D., SUPE J., VERMA S., SINGH R.R. (2024). Removal of Fluoride from Drinking Water by Utilizing Modified Bagasse Sugarcane as Low-Cost Adsorbents for Bilaspur City, Chhattisgarh, Journal of Environmental Informatics Letter, Vol. 11, Issue 2. http://dx.doi.org/10.3808/jeil.202400126

WORLD HEALTH ORGANIZATION. (2010). Hardness in drinking-water: background document for development of WHO guidelines for drinking-water quality, (No. WHO/HSE/WSH/10.01/10), pp. 1-19. (Accessed December 10, 2010).

WORLD HEALTH ORGANIZATION. (2022). Guidelines for drinking-water quality: incorporating the first and second addenda, World Health Organization. pp. 1-563, ISBN: 978-92-4-004506-4. (Accessed March 21, 2022).

WRIGHT J., GUNDRY S., CONROY R. (2004). Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use, Tropical medicine & international health, Vol. 9, Issue 1, pp. 106-117. https://doi.org/10.1046/j.1365-3156.2003.01160.x