Evaluating Drinking Water Quality Using Water Quality Parameters and Esthetic Attributes

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ABSTRACT: This study assesses the quality of drinking water sources in the highlands of Ethiopia. The study considered a combination of users' perceptions with the measured water quality parameters determined using the water quality index (WQI) tool. Data were collected using a cross-sectional research design for a household survey, and water quality samples were collected from improved and unimproved alternative sources. Nine physicochemical and two bacteriological analyses were performed. The result shows that esthetic water quality parameters had a potential interpretation of water quality as of the laboratory analysis. The taste was the dominant and easily detectable indicator as compared to odor and color. This is associated with the higher correlation between iron and manganese that deter the taste of water. Tap water was the only free source of bacteriological contamination. The WQI values show that one improved and three unimproved sources were found in the rank of unsuitable for drinking purposes. Unimproved sources are harmful for drinking, although they are used as an alternative source of water. Finally, the study suggests that due consideration of esthetic factors as measured parameters is fundamental for the sustainable use of drinking water infrastructures.

KEYWORDS: Water quality, user preferences, water quality parameters, water quality index

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Introduction

Water is a vital natural resource for human survival as well as an efficient tool of economic development. Drinking water quality is a global issue, with contaminated unimproved water sources and inadequate sanitation practices causing human diseases (Gorchev & Ozolins, 1984; Prüss-Ustün et al., 2019). Approximately 2 billion people consume water that has been tainted with feces (WHO, 2019). Forty-two percent of the people living in Sub-Saharan Africa drank from unimproved water sources and 72% were without basic sanitation (Eberhard, 2019). Water sources particularly unimproved sources are contaminated not only due to anthropogenic factors but also natural factors such as flooding, climate, weathering of parent material, topography, and others (Vadde et al., 2018). Diarrhea, cholera, dysentery, typhoid, and polio are some of the diseases linked to poor drinking water quality. Each year, it is estimated that 485,000 people die from diarrhea as a result of contaminated drinking water (WHO, 2019).

Water quality concerns are frequently the most important component of drinking water as evaluated by physical, chemical, and bacteriological factors, as well as consumer satisfaction (WHO, 2004). Drinking water quality should meet physicochemical pollutants criteria and be entirely free of pathogens that could harm people's health. Furthermore, user perceptions of water quality are critical to the long-term viability of drinking water sources (Ochoo et al., 2017; Sherry et al., 2019). The esthetic value of water in terms of flavor, odor, and appearance is viewed differently by different households (de França Doria, 2010; Wedgworth et al., 2014; WHO/UNICEF, 2010). Consumer perceptions and esthetic characteristics should be addressed when examining drinking water sources, even if they do not have a negative influence on human health (WHO, 2018).

Despite the greatest efforts of governmental and non-governmental organizations, a considerable percentage of the water supply schemes are malfunctioning, forcing users to collect water from unimproved sources, posing health risks and reducing productivity. Furthermore, because of dissatisfaction, adequacy, income, distance, and longer waiting times households are reluctant to collect water from unimproved sources (Addisie et al., 2021). The dissatisfaction of consumers stems from variances in pH, mineral, and organic content of drinking water (Dietrich, 2006). The variation in pH is detected indirectly, with greater acidity increasing corrosive that in turn can contaminate the water, and change in the taste of water.

Water quality of different sources can be evaluated using physicochemical and biological parameters. The analytical results of parameters were evaluated based on the standard limits. The suitability of water sources for human consumption is not an easy task to understand. As a result, the most effective way of monitoring water quality is the water quality index (WQI). Horton invented the first WQI in 1965 to test water quality, and the system was further improved by several scientists. The WQI integrates a variety of water quality data into a single quantitative number in a comprehensive manner (Boyacioglu, 2007; Brown et al., 1970; Lumb et al., 2011; Tyagi et al., 2013). As a result, water users, planners, and policymakers can monitor and evaluate the water quality of sources to protect them for the sake of human health, social welfare, and economic growth.

Several WQI has been developed for monitoring the quality of surface and sub-surface water sources. Water quality indexes

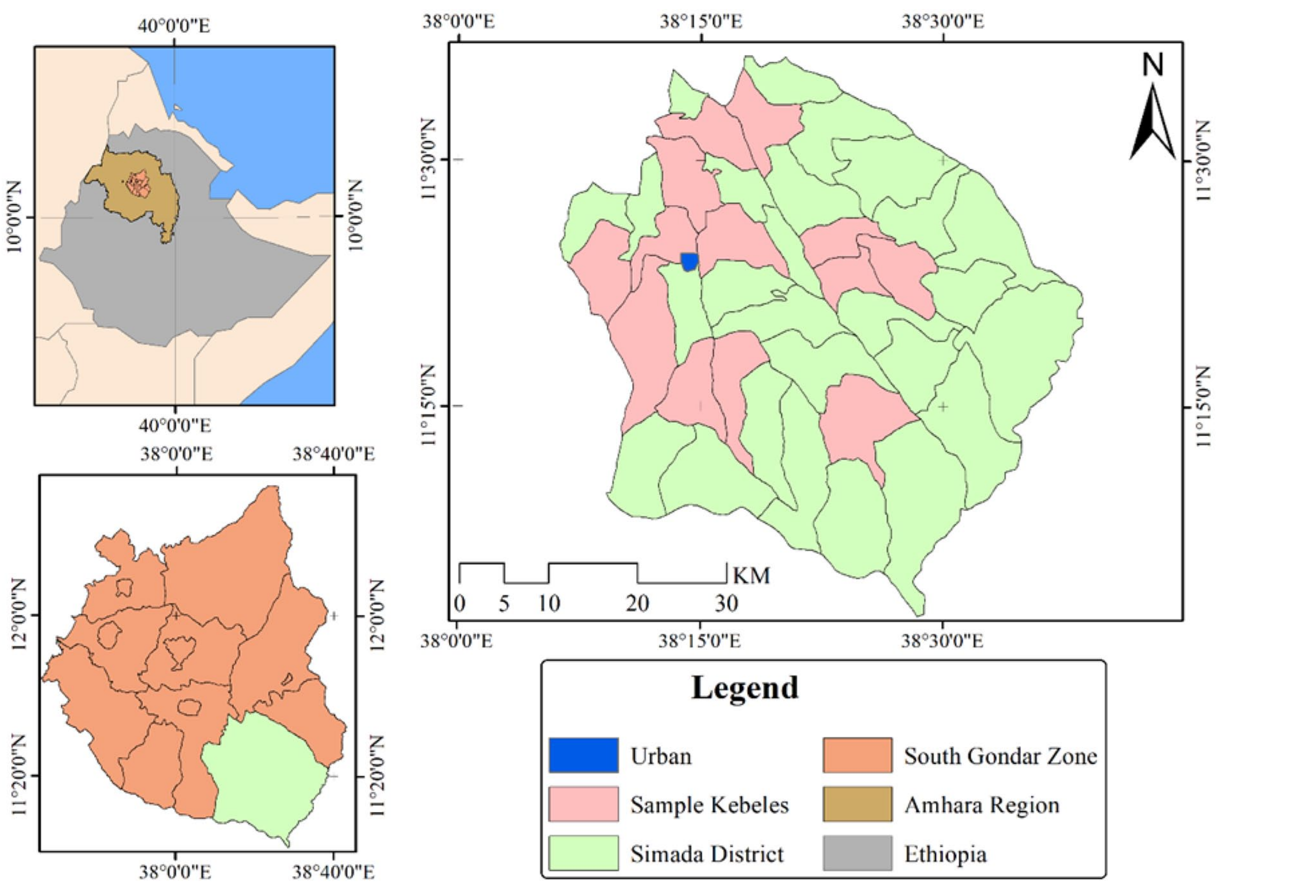

Figure 1. The map depicted Ethiopia with Amhara regional state and the South Gondar zone, including the district of Simada in the left upper and lower corners, respectively. On the district map, sample locations are marked (Addisie et al., 2021).

have been developed, modified and adopted worldwide such as the Nation Sanitation Foundation Water Quality Index (NSFWQI) (Noori et al., 2019), the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) (Hurley et al., 2012; Lumb et al., 2011; Noori et al., 2019; Tyagi et al., 2013), Oregon Water Quality Index (OWQI) (Said et al., 2004), and the Weighted Arithmetic Water Quality Index (WAWQI) (Chandra et al., 2017). Furthermore, various water pollution indexes were adopted like the Comprehensive Pollution Index (CPI) (Matta et al., 2020), the Organic Pollution Index (OPI) (Chen et al., 2016), the Trace Metal Pollution Index (TPI) (Reza & Singh, 2019), the Eutrophication Index (EI) (Van Puijenbroek et al., 2014) based on the selected water monitoring parameters. The difference between the above indexes is being the statistical integration and interpretation of parameter values.

In Ethiopia, the majority of the research done so far has focused on assessing water quality by comparing the concentration of water quality parameters to the WHO water quality standard. However, the application of WQI to measure the drinking water quality is barely sufficient. This study adopts WAWQI, which is a widely used and universally applicable approach for assessing the drinking water quality (Liou et al., 2004; Oni & Fasakin, 2016; Singh et al., 2020; Tokatli, 2019; Tyagi et al., 2013). Furthermore, a combination of households' perceptions and measured water quality parameters were not well investigated. Therefore, the objective of this study was to evaluate drinking water quality using water quality parameters and esthetic attributes.

Materials and Methods

Study area description

The study area of Simada is found in the South Gondar Zone of Amhara regional state (Figure 1). The area is located between latitudes 11°2′19″N and 11°36′17″N, and longitudes 38°6′0″E and 38°38′36″E. It has a total area of 2,245 km². The research site is 209 km southeast of Bahir Dar (regional capital). The elevation ranges from 1,196 to 3,525 m above sea level (m.a.s.l). The district is divided into three agroclimatic zones, of which one is urban and 39 rural kebeles. These kebeles are found at varying elevations, such as 30% of them at an intermediate elevation, 10% in the highlands, and 60% in the lowlands. The main rainy season lasts from April through October. July and August are the wettest months. The annual precipitation ranges from 900 to 1,100 mm and the annual average temperature is 23°C (Addisie et al., 2021).

Data collection and analysis

Household survey. A cross-sectional research design was employed to collect the data for understanding households' perceptions on water source quality. Household heads were considered for interviews and information was collected from women who took the greater responsibility of water collection. A pre-testing survey was done to identify and correct any potentially problematic questions. As a result, questions that the respondents didn't understand were adjusted to make them clearer. Finally, the survey questionnaires were divided into three sections. The first section focuses on the respondents' perceptions of the primary water quality indicators (Test, Odor, and Color). The second section contains questions on the perceived safety of drinking water, and the third section has questions about the primary causes of drinking water quality deterioration. The sample size was determined assuming 10% of the total households from the urban and rural areas. The total number of households using the water sources were selected from 3 urban and 13 rural water points. A total of 160 households from 16 water point users (116 from rural and 44 from urban) households were randomly selected. The sample size determination was done following the Arkin and Colton (Arkin & Colton, 1950), using the confidence level of 95% with the margin of error of 8% (within the acceptable range). The *Z*-score value used at 95% was 1.96.

Water sampling. Water samples were collected from different sources of water used by households in rural and urban areas. From the total 16 improved sources, 7 of them were considered for laboratory analysis. In addition, four water samples were collected from unimproved sources. Among these samples, three of them were collected from the urban and the remaining eight samples were collected from rural areas. Subsequently, samples from unimproved water sources were included due to its significance that households equally use these sources. Water samples were collected from springs, hand-dug wells and tap water. All the samples were coded and sent for analysis to the regional water quality laboratory. Based on the water quality of the samples investigated, the status of the existing water quality was compared with the standards of the World Health Organization (WHO, 2004, 2018). However, the number of water sources used for laboratory analysis was lower than the total number of water sources used for household survey due to: absence of an icebox for transportation; water sample points were distant from the laboratory and hard to reach on time.

Water quality analysis was used to present the household perception of water quality from rural and urban areas. A questionnaire was prepared to focus on consumers' water quality perceptions on color, taste, and odor. The analytical results from laboratory analysis compared with the WHO standards. The physicochemical parameters included electrical conductivity (EC), pH, Total Dissolved Solids (TDS), Turbidity (TUR), Nitrate (NO_3^-), Nitrite (NO_2^-), Iron (Fe), Manganese (Mn), and residual Chlorine (Cl). The physicochemical water quality parameters were identified for the determination of the water quality index (WQI). TUR is an important indicator of water quality as it can protect bacteria and viruses from disinfection in the drinking water system (Alle-Ando, 2005; Kumar et al., 2016). A statistical analysis of the correlation coefficient was used to observe the interaction between the physicochemical parameters.

Bacteriological parameter determination includes total coliforms and fecal coliforms. The total and fecal coliforms were analyzed using the filter membrane technique by incubating the membrane on a growth-promoting medium for 24 hours at 37°C and 44.5°C, respectively. The resultant colonies per 100 mL of samples were collected from both improved and unimproved sources.

Water quality index (WQI). Different methods are used for the calculation of WQI for the comparison of physicochemical and biological parameters. For this study, the Weighted Arithmetic WQI (WAWQI) proposed by Brown et al. (1972) were adopted. The weighted arithmetic WQI method classified the water quality according to the degree of cleanliness using the measured water quality parameters EC, pH, TDS, TUR, NO_3^-, Fe, Mn, and Cl. This method was chosen because it has been widely used by different researchers (Balan et al., 2012; Chauhan & Singh, 2010; Ramakrishnaiah et al., 2009; Shweta & Satyendra, 2015). The WQI was calculated using the following equation:

$$WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum W_i} \tag{1}$$

The quality rating scale (Q_i) for each parameter is calculated by:

$$Q_i = \left[\left(\frac{V_e - V_i}{S_t - V_i}\right)\right] * 100 \tag{2}$$

Where, V_e is the estimated concentration of *i*th parameter in the analyzed water, V_i is the ideal value of the selected parameter in pure water which is equal to zero except pH is seven; S_t is the recommended standard value of *i*th parameter, WHO standard in this case.

W_i is the unit weight of each water quality parameter summed up to one and calculated as,

$$W_i = K \sum \frac{1}{S_t} \tag{3}$$

Where, K is the proportionality constant and can also be determined by using the following equation,

$$K = \frac{1}{\sum \left(\frac{1}{S_n}\right)} \tag{4}$$

In this study, the WQI was considered for human drinking water consumption. The rating scale proposed was in the range of 0 to 100 and grading was proposed as Excellent for 0 to 25; Good for 26 to 50; Poor for 51 to 75; Very Poor for 76 to 100 and unsuitable for drinking purposes for the value above 100.

Table 1. Physicochemical and Bacteriological Parameters in Drinking Water Sources.

SITE CODE	PARAMETERS										
	PH	EC (µS/CM)	TDS (MG/L)	TUR (NTU)	NO_3^- (MG/L)	NO_2^- (MG/L)	FE (MG/L)	MN (MG/L)	CL. (MG/L)	TCF (CFU/100 ML)	FCF
R01	7.16	132.6	68	4.17	12.76	0.02	0.05	0.3	0	>100	24
R02	7.15	237	118.5	1.52	13.64	0.02	0.12	0.3	0	60	10
R03	7.35	129.6	64.8	14.2	14.52	0.03	0.25	0.25	0	>100	>100
R04	6.7	496	248	46.3	4.04	0.14	2.16	5.3	0	>100	>100
Ur1	7	184.9	97	4.12	3.08	0.02	0.04	0.12	0	100	10
Ur2	7.14	384	192	0.55	12.32	0.01	0.1	0.18	0	59	8
Ur3	7.25	192.2	95.9	0.7	16.72	0	0.06	0.2	0.3	0	0
RU1	7.31	150	75	2.71	9.24	0.02	0.05	0.2	0	>100	>100
RU2	7.1	204	102	138	3.96	0.17	0.99	3.8	0	>100	>100
RU3	6.65	61.7	30.8	44.3	3.52	0.09	0.78	1.2	0	>100	52
RU4	7.3	138.2	68.9	17.1	11.44	0.18	0.33	0.8	0	>100	84
WHO standards	6.5–8.5	400–1,200	1,000	5	45	3	0.3	0.2	0.25–0.5	0	0

Note. tcf = total coliform; fcf = fecal coliform.

Results and Discussion

Physicochemical water quality

The physicochemical parameters of drinking water in the study area taken from improved (R01-R04 and Ur1-Ur3) and unimproved sources (RU1-RU4) are given in Table 1. The values of the majority of parameters are below the maximum allowable limits suggested by WHO for improved drinking water sources. However, in the unimproved sources, the values of NO_2^-, Fe, and Mn were beyond the WHO water quality standard limit.

The pH measurement reflects the acidity or alkalinity of the water sources that can produce sour or alkaline tastes. The result shows pH values ranged from 6.5 to 7.35, which is in the recommendation. The EC value is an index that represents the concentration of soluble salts that affect the taste of the drinking water source. All the sites have EC values below the standard (400 µs/cm). The level of NO_3^- and NO_2^- in drinking water causes diseases such as blue baby syndrome, cancer and bleeding of the spleen (Aydin, 2007). In all the water samples, the values of NO_3^- and NO_2^- are within the range of WHO standards (Table 1). Mn and Fe concentrations varied between 0.2 to 3.8 mg/L and 0.05 to 2.16 mg/L with a median value of 0.3 and 0.12 mg/L, respectively. The median value of Mn is greater than the value suggested by WHO (0.2) (Table 1). The exceeded limit of Mn concentrations might threaten children's neuropsychological health (Roels et al., 2012). The degree of a linear association between two water quality parameters is presented in Supplemental Table S1. EC, TDS, Fe, and Mn are highly correlated (>95%) as compared to other parameters. This result is in agreement with Yadav et al. (2018) indicated that EC is a function of TDS (Supplemental Table S1). As indicated in the perception section and the correlation result, Fe and Mn are strongly correlated and influence households' water use preferences.

Bacteriological water quality

Assessing the bacteriological quality of drinking water is the major parameter that should be considered in any water quality monitoring. The prevalence of pathogens in drinking water indicates the potential sources of human and animal waste. Water can be contaminated with microorganisms at the source or during transportation or distribution. The result indicates that both total and fecal coliforms in the water sampling sites varied from 0 to above 100 cfu/100 mL.

Only the tap water (Ur3) indicated zero results for total and fecal coliforms. The reason could be due to the deeper water source where the water is pumped and the application of an effective disinfectant such as chlorine in the distribution reservoirs (Table 1). It could be confirmed that residual chlorine was observed only at this source. Whereas, in the urban springs (Ur1 and Ur2), the people using open defecation in the upstream contribute to the contamination. In contrast, all the improved and unimproved water sources except the tap water had fecal coliform counts above the WHO standard (Table 2). According to IRC (2002), risk classification except for urban

Table 2. Summary of Biological Water Quality Result (cfu/100 mL) From Improved and Unimproved Sources.

COUNT CATEGORY	% FECAL COLIFORM		% TOTAL COLIFORM		TOTAL	
	IMPROVED SOURCES	UNIMPROVED SOURCES	IMPROVED SOURCES	UNIMPROVED SOURCES	FECAL COLIFORM (%)	TOTAL COLIFORM (%)
<1	14.3	-	14.2	-	9.1	9.1
1–10	42.8	-	-	-	27.3	-
11–100	14.3	50.0	42.9	-	27.3	27.3
>100	28.6	50.0	42.9	100	36.3	63.6

Note. cfu = colony-forming unit.

Figure 2. Status of improved water sources, and poorly managed (backflow, flooding, and broken).

tap water other sources indicates the incidence of fecal and total coliforms (14.3%). Whereas, 42.8% and 42.9% of the improved sources are under intermediate and high-risk classification. The two urban sources (Ur1 and Ur2) are included under the low-risk classification. Table 2 summarizes improved and unimproved water sources for total and fecal coliforms.

Different studies indicated the contamination of tap water with fecal and total coliforms. For example, in Nepal, Mexico (Sinaloa), Ethiopia (Oromia) about 21%, 28%, and 37% of the tap water contaminated with fecal coliforms, respectively (Chaidez et al., 2008; Duressa et al., 2019; Pant et al., 2016). Though it is expected to observe fecal coliforms in tap water, in the study area the tap water is found in good condition. The prevalence of coliforms linked with diseases outbreak due to poor water quality such as diarrhea, cholera, typhoid, and others. As indicated in the introduction section about 485,000 people die from diarrhea (WHO, 2019).

Water quality perceptions

Consumers are concerned about the drinking water quality in terms of esthetic factors such as taste, odor, and appearance. Drinking water trustworthiness depends on the perception of consumers and the resultant complaints about the taste, odor, color, or any other particulate matter.

Esthetic parameters. According to the survey results from the urban and rural areas, 63.6% and 63.8% of the respondents believed that the taste was the main indicator of water quality deterioration (Supplemental Table S2). Dietrich (2006) proved that taste of water is the main indicator of esthetic water quality status. Respondents who perceived the safety of water indicated that 56.8% of urban and 59.3 of rural households believed that the improved water sources are safe (Supplemental Table S2). Some respondents perceived that the taste of alternative improved springs was better than tap water. The reason was that springs have free-flowing water, therefore, there is no time for undesirable stuff to accumulate. In contrast, the chlorination of tap water causes it to have an unpleasant taste because the water passes through a pipe that is heated by sunlight (Dietrich, 2006).

On the other hand, 43.2% of urban and 44.8% of rural indicated that the color from improved sources was used as an indicator of water quality (Supplemental Table S2). The color complaints from urban sources are related to chlorination, which appears unpleasant for immediate use (APHS, 1999;

WHO, 2004). Concurrent to this, the presence of Cl of 0.3 mg/L was observed only in tap water. Due to the corrosion of iron pipes and standpipes in the distribution system, the color and taste of the water may be affected. Sixty-one percent of urban and 51.7% of rural areas believe human waste is the major cause of water quality deterioration (Supplemental Table S2). For example, in rural areas, water sources are polluted because of children playing on the water sources. Furthermore, when there is an overflow during collection, water flows back into the source through the broken pores (Figure 2). Whereas in urban areas, the main source of water is located downstream of the residents, where open defecation is common from upstream.

Water quality parameters such as Fe and Mn could potentially be linked with users' perceptions. Fe has a metallic taste, which is an indicator of unpleasant drinking water and leaves residue on materials it touches in orange or red colors. The results from the water samples analyzed for Fe showed that 14% of the improved and 75% of unimproved sources did not meet the standards suggested by WHO for the acceptability of drinking water (0.3 mg/L, Table 1). Excess Fe has multiple health effects, such as hemochromatosis, which can lead to liver, heart, and pancreatic damage, as well as diabetes. Early symptoms include fatigue, weight loss, and joint pain. Concentrated Fe is never suggested for consumption since it could cause stomach problems, nausea, vomiting, and other issues. In addition, the Mn test result indicated that 57.2% and 75% of improved and unimproved sources also did not meet the WHO standard (0.2 mL/L, Table 1).

Mn is the main source of displeasing taste and consumes a lot of detergents when used for washing. As observed from R04, which was improved hand-dug well accounts for the greatest Mn above the threshold level, 5.3 mg/L. As a result, user households reject the use of this source due to its displeasing taste. However, households used for washing clothes where most of the users did not use soap, rather traditional means. Because of this, households were completely dependent on alternative nearby unimproved springs (RU4), which measure 0.33 and 0.8 mg/L Fe and Mn, respectively. At R04, the color of the water changed to reddish and consumers believe it was due to the presence of a spring used as a cattle-trough approximately 10 meters from the head of the well and flooding. In contrast, three of the urban improved sources met the recommendation for Fe and Mn. The level of water quality contamination is influenced by the depth of the water sources. Since the depth of improved sources is greater than unimproved sources, the concentration of Fe is lower (Table 1).

From the total water samples tested for TUR, 71% of improved and 25% of unimproved rural sources met the recommended value of WHO (5 NTU). The higher percentage of TUR from unimproved sources was mainly caused by the runoff in the rainy season and wind-blown dust matter pollutes the open water source. Whereas, for improved sources, most TUR was caused by pumping disturbances, especially for hand-dug wells. Whereas, the urban sources were below the WHO recommendation. EC, pH, NO_3^-, NO_2^-, and TDS from the two areas were within the recommended ranges. A TDS of less than 600 indicates good palatability (WHO, 2018). In this case, all the samples seem palatable.

Water quality index. The water quality index was calculated to describe the overall quality of the drinking water sources (Supplemental Table S3). This study considers nine physicochemical parameters of drinking water at improved and unimproved sources are shown in Table 3. According to the WAWQI technique, WQI ratings range from excellent to unfit for human consumption. One improved and one unimproved source were rated as "unsuitable for consumption" and "excellent," respectively, which was surprising. One improved source, on the other hand, indicated that the state was "poor." Because the unimproved sources are unimproved, they are expected to be unfit for consumption. The cause for the improved source being deemed "unfit for human consumption" (R04) could be owing to insufficient treatment, a lack of effective source protection, or floods, as mentioned in the perception section. The observed "excellent" from an unimproved source (RU1) could be due to the nature of the water source, its confinement under the rock like a cave, and the geography, which could redirect incoming runoff and protect animals untouched. This type of unimproved source is uncommon to come across. According to the results of the WQI, it is possible to conclude that the improved water sources were suitable for drinking and the unimproved sources were unfit for drinking.

Conclusion

Evaluating drinking water quality using the water quality parameters and esthetic characteristics has a profound significance for human health. Esthetic parameters such as color, odor, and taste were evaluated using households' understanding of the water quality. It was found that taste was the dominant water quality indicator. Due to the unpleasant taste, the likelihood of rejecting better water supplies for drinking purposes increased. It was surprising to see how the perceptions resulted in the same outcome as the laboratory data. Although some people dislike chlorination, water sources with chlorine are the sole source that meets water quality standards. Total and fecal coliforms have contaminated all the water sources except the tap water which is treated well. As a result, it is strongly advised that water sources should be treated in situ as well as at home before use. The WQI indicated that unimproved sources were deemed to be unfit for drinking reasons. Unimproved sources are generally unsafe to consume, even if they are utilized as an alternative supply of water. People should be concerned about drinking water sources, and health risks that go beyond traditional conceptions.

Table 3. Calculated Drinking WQI Values at Each Site.

LOCATION	SITE	WQI	REMARK	STATUS
Improved sources				
Rural	R01	25.29	Excellent	Currently in use
	R02	34.05	Good	Currently in use
	R03	57.85	Poor	Currently in use
	R04	613.36	Unsuitable for consumption	Users rejected
Urban	Ur1	14.31	Excellent	Main water source
	Ur2	24.37	Excellent	Currently in use
	Ur3	35.47	Good	Currently in use
Unimproved sources				
Rural	RU1	19.45	Excellent	Currently in use as an alternative
	RU2	446.99	Unsuitable for consumption	Currently in use
	RU3	239.57	Unsuitable for consumption	Currently in use
	RU4	115.75	Unsuitable for consumption	Currently in use

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Data Availability

All the data used for this research work are available from the author upon request.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

Ethical approval was not declared since the study does not involve human and animal life.

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Supplemental Material

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REFERENCES

Addisie, M. B., Gelaye, T. Y., & Teshome, W. M. (2021). Households' reluctance to collect potable water from improved sources, Ethiopia. *Journal of Water Supply: Research and Technology-Aqua*, 70(6), 868–878.

Alle-Ando, Y. (2005). *An integrated water resource management approach to mitigating water quality and quantity degradation in Xalapa, Mexico* [Doctoral dissertation]. University of British Columbia.

APHS. (1999). *Standard methods for the examination of water and wastewater*. American Public Health Association.

Arkin, H., & Colton, R. R. (1950). *Tables for statisticians*. Barnes & Noble, Inc.

Aydin, A. (2007). The microbiological and physicochemical quality of groundwater in West Thrace, Turkey. *Polish Journal of Environmental Studies*, 16(3), 377–383.

Balan, I., Madan Kumar, P., & Shivakumar, M. (2012). An assessment of groundwater quality using water quality index in Chennai, Tamil Nadu, India. *Chronicles of Young Scientists*, 3(2), 146.

Boyacioglu, H. (2007). Development of a water quality index based on a European classification scheme. *Water SA*, 33(1), 101–106.

Brown, R. M., McClelland, N. I., Deininger, R. A., & O'Connor, M. F. (1972). A water quality index—crashing the psychological barrier. In *Indicators of environmental quality* (pp. 173–182). Springer.

Brown, R. M., McClelland, N. I., Deininger, R. A., & Tozer, R. G. (1970). A water quality index-do we dare. *Water & Sewage Works*, 117(10), 339–343.

Chaidez, C., Soto, M., Martinez, C., & Keswick, B. (2008). Drinking water microbiological survey of the Northwestern State of Sinaloa, Mexico. *Journal of water and health*, 6(1), 125–129.

Chandra, D. S., Asadi, S. S., & Raju, M. V. S. (2017). Estimation of water quality index by weighted arithmetic water quality index method: A model study. *International Journal of Civil Engineering and Technology*, 8(4), 1215–1222.

Chauhan, A., & Singh, S. (2010). Evaluation of Ganga water for drinking purpose by water quality index at Rishikesh, Uttarakhand, India. *Report and Opinion*, 2(9), 53–61.

Chen, C. W., Ju, Y. R., Chen, C. F., & Dong, C. D. (2016). Evaluation of organic pollution and eutrophication status of Kaohsiung Harbor, Taiwan. *International Biodeterioration & Biodegradation*, 113, 318–324.

de França Doria, M. (2010). Factors influencing public perception of drinking water quality. *Water Policy*, 12(1), 1–19.

Dietrich, A. M. (2006). Aesthetic issues for drinking water. *Journal of Water and Health*, 4(S1), 11–16.

Duressa, G., Assefa, F., & Jida, M. (2019). Assessment of bacteriological and physicochemical quality of drinking water from source to household tap connection in Nekemte, Oromia, Ethiopia *Journal of environmental and public health*, 2019, 2129792.

Eberhard, R. (2019). Access to water and sanitation in sub-Saharan Africa. Review Sector Report, Investments, Key Findings to Infrastructure Future Support to Sector Development. GIZ.

Gorchev, H. G., & Ozolins, G. (1984). WHO guidelines for drinking-water quality. *WHO Chronicle*, 38(3), 104–108.

Hurley, T., Sadiq, R., & Mazumder, A. (2012). Adaptation and evaluation of the Canadian Council of ministers of the Environment Water Quality Index

(CCME WQI) for use as an effective tool to characterize drinking source water quality. *Water Research*, 46(11), 3544–3552.

IRC. (2002). *Small community water supplies: Technology, people and partnership*. IRC International Water and Sanitation Centre.

Kumar, T., Abd Majid, M. A., Onichandran, S., Jaturas, N., Andiappan, H., Salibay, C. C., Tabo, H. A., Tabo, N., Dungca, J. Z., Tangpong, J., Phiriyasamith, S., Yuttayong, B., Polseela, R., Do, B. N., Sawangjaroen, N., Tan, T. C., Lim, Y. A., & Nissapatorn, V. (2016). Presence of Cryptosporidium parvum and Giardia lamblia in water samples from Southeast Asia: Towards an integrated water detection system. *Infectious Diseases of Poverty*, 5(1), 3.

Liou, S. M., Lo, S. L., & Wang, S. H. (2004). A generalized water quality index for Taiwan. *Environmental Monitoring and Assessment*, 96(1–3), 35–52.

Lumb, A., Sharma, T. C., & Bibeault, J. F. (2011). A review of genesis and evolution of water quality index (WQI) and some future directions. *Water Quality Exposure and Health*, 3(1), 11–24.

Matta, G., Kumar, A., Nayak, A., Kumar, P., Kumar, A., & Tiwari, A. K. (2020). Water quality and planktonic composition of river Henwal (India) using comprehensive pollution index and biotic-indices. *Transactions of the Indian National Academy of Engineering*, 5(3), 541–553.

Noori, R., Berndtsson, R., Hosseinzadeh, M., Adamowski, J. F., & Abyaneh, M. R. (2019). A critical review on the application of the National Sanitation Foundation water quality index. *Environmental Pollution*, 244, 575–587.

Ochoo, B., Valcour, J., & Sarkar, A. (2017). Association between perceptions of public drinking water quality and actual drinking water quality: A community-based exploratory study in Newfoundland (Canada). *Environmental Research*, 159, 435–443.

Oni, O., & Fasakin, O. (2016). The use of water quality index method to determine the potability of surface water and groundwater in the vicinity of a municipal solid waste dumpsite in Nigeria. *American Journal of Engineering Research*, 5(10), 96–101.

Pant, N. D., Poudyal, N., & Bhattacharya, S. K. (2016). Bacteriological quality of bottled drinking water versus municipal tap water in Dharan municipality, Nepal. *Journal of Health, Population and Nutrition*, 35(1), 1–6.

Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, M. C., Gordon, B., Hunter, P. R., Medlicott, K., & Johnston, R. (2019). Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low- and middle-income countries. *International Journal of Hygiene and Environmental Health*, 222(5), 765–777.

Ramakrishnaiah, C. R., Sadashivaiah, C., & Ranganna, G. (2009). Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka state, India. *E-Journal of Chemistry*, 6(2), 523–530.

Reza, R., & Singh, G. (2019). Application of heavy metal pollution index for ground water quality assessment in Angul district of Orissa, India. *International Journal of Environmental Sciences*, 5(1), 118–122.

Roels, H. A., Bowler, R. M., Kim, Y., Claus Henn, B., Mergler, D., Hoet, P., Gocheva, V. V., Bellinger, D. C., Wright, R. O., Harris, M. G., Chang, Y., Bouchard, M. F., Riojas-Rodriguez, H., Menezes-Filho, J. A., & Téllez-Rojo, M. M. (2012). Manganese exposure and cognitive deficits: A growing concern for manganese neurotoxicity. *Neurotoxicology*, 33(4), 872–880.

Said, A., Stevens, D. K., & Sehlke, G. (2004). An innovative index for evaluating water quality in streams. *Environmental Management*, 34(3), 406–414.

Sherry, J., Juran, L., Kolivras, K. N., Krometis, L. A. H., & Ling, E. J. (2019). Perceptions of water services and innovations to improve water services in Tanzania. *Public Works Management & Policy*, 24(3), 260–283.

Shweta, S., & Satyendra, N. (2015). Water quality analysis of River Ganga and Yamuna during mass bathing, Allahabad, India. *Universal Journal of Environmental Research & Technology*, 5(5), 251–258.

Singh, A. K., Sathya, M., Verma, S., & Jayakumar, S. (2020). Spatiotemporal variation of water quality index in Kanwar wetland, Begusarai, India. *Sustainable Water Resources Management*, 6, 1–8.

Tokatli, C. (2019). Drinking water quality assessment of Ergene River basin (Turkey) by water quality index: Essential and toxic elements. *Sains Malaysiana*, 48(10), 2071–2081.

Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American Journal of Water Resources*, 1(3), 34–38.

Vadde, K., Wang, J., Cao, L., Yuan, T., McCarthy, A., & Sekar, R. (2018). Assessment of water quality and identification of pollution risk locations in Tiaoxi River (Taihu watershed), China. *Water*, 10(2), 183.

Van Puijenbroek, P. J., Cleij, P., & Visser, H. (2014). Aggregated indices for trends in eutrophication of different types of fresh water in the Netherlands. *Ecological Indicators*, 36, 456–462.

Wedgworth, J. C., Brown, J., Johnson, P., Olson, J. B., Elliott, M., Forehand, R., & Stauber, C. E. (2014). Associations between perceptions of drinking water service delivery and measured drinking water quality in rural Alabama. *International Journal of Environmental Research and Public Health*, 11(7), 7376–7392.

WHO. (2004). *Guidelines for drinking-water quality*. World Health Organisation.

WHO. (2018). *A global overview of national regulations and standards for drinking-water quality*. World Health Organization.

WHO. (2019). *national systems to support drinking-water: Sanitation and hygiene: Global status report: UN-Water global analysis and assessment of sanitation and drinking-water: GLAAS 2019 report*. World Health Organisation.

WHO/UNICEF. (2010). *Progress on sanitation and drinking-water: 2010 update* (pp. 60–60). World Health Organization.

Yadav, K. K., Gupta, N., Kumar, V., Choudhary, P., & Khan, S. A. (2018). GIS-based evaluation of groundwater geochemistry and statistical determination of the fate of contaminants in shallow aquifers from different functional areas of Agra city, India: Levels and spatial distributions. *RSC Advances*, 8(29), 15876–15889.