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Research Article

Hydrochemical Characterization and Water Quality Assessment for Drinking and Irrigation Purposes Using WQI and GIS Techniques in the Upper Omo River Basin, Southern Ethiopia

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Groundwater is an important source of drinking water and irrigation in Ethiopia's present study area of the upper Omo River catchment. The present study area has an increasing demand for high-quality groundwater. Extensive irrigation and urban expansion are ongoing in the study area, seriously compromising groundwater quality. A study was conducted in Ethiopia's upper Omo River catchment to assess groundwater's suitability for drinking water and agricultural purposes. In total, 58 water samples were collected for this study. Based on the WHO and Ethiopian standards for assessing water quality, the study's results have been analyzed and compared. The groundwater's primary ion and physicochemical properties were plotted using GIS technology. Based on the results of the hydrochemical analysis, three water quality index (WQI) zones were identified: excellent (58.82%), good (35.29%), and poor (5.88%). From the Piper diagram plots, five different types of water were identified as Ca-HCO_3, Na-HCO_3, mixed Ca-Na-HCO_3, NaCl, and CaCl, out of the total of fifty-eight samples collected from the study area. The present study found that in the area, most water samples are suitable for drinking, except for a few parameters above the standards for drinking water set by the World Health Organization and Ethiopian drinking water quality standards. Except for the three samples, EC, SAR, and PI data indicate that most of the area's water samples are suitable for irrigation. Water quality indices, irrigation water quality methods, and GIS techniques are crucial for assessing water quality based on the study.

1. Introduction

Groundwater is one of the most valuable resources in the world. It serves various functions, including domestic, agricultural, and industrial. Groundwater quality deteriorates most clearly in arid and semiarid regions [1]. To determine the quality of groundwater, its physical, chemical, and biological properties are considered [2]. Hence, natural and anthropogenic activities such as precipitation, rock mineralogy, rock-water interaction, aquifer nature, climate condition and topography variation, and industrial and domestic use have impacted groundwater quality [3]. In most developing countries, and especially African countries, groundwater quality is very complicated because of reasons that their issues are associated with four key points such as a poor water resources management system, lack of accurate identification and prioritization of contamination sources, poor improved vulnerability and protection assessment of groundwater, and mismanagement of boreholes and hand-dug wells performance. In sub-Saharan countries, groundwater quality problems are associated more with the above points. Governments pay more attention to assessing water resources than managing and protecting them [4].

Poor groundwater quality in Ethiopia is caused by several factors, including high fluoride concentrations in the central Rift Valley, high salinity levels in the south and east, and high microbiological and nitrate concentrations in shallow unconfined aquifers near major towns [5–7]. Groundwater is used for drinking and other uses in the upper Omo subbasin. Currently, increasing urban and rural populations and the expansion of towns have resulted in high demand for water for domestic, irrigation, and animal consumption use. For instance, the primary modern small-scale irrigation schemes in the study area are Soke, Sana, Senbeta, Ufute, Ketala, Bekera, and Walana [8]. All irrigation schemes used water from surface river sources. In the study area, the suitability of groundwater quality was not analyzed and documented correctly. Many surface and groundwater sources, including rivers, dug wells, shallow wells, and boreholes, are unfit for human consumption owing to contamination by humans and natural activity. For instance, the fluoride concentration in the present study area is higher than the standard recommended by the WHO and Ethiopia's drinking water quality standards of 1.5 mg/l.

Water quality evaluation is crucial for developed and developing nations to determine whether water can be used for drinking, agriculture, or industry. Various researchers have studied and evaluated groundwater quality and hydrochemistry using different techniques. Groundwater quality can be interpreted using various conventional tools and methods, from graphical to statistical [9–11]. Multivariate statistics, time series modelling, and geostatistical modelling are some of the cutting-edge techniques that researchers have found essential for providing a complete picture of groundwater quality, which is crucial for efficiently managing and protecting these vital resources [12–14].

Many countries, including Ethiopia, have used GIS-based water quality index methodologies to assess the suitability of their groundwater for human consumption and agricultural irrigation [13, 15–22], and the researchers [6, 23–27] considered "drinking water quality index, sodium adsorption ratio (SAR), percentage sodium (Na%), residual sodium carbonate (RSC), and permeability index (PI) techniques for drinking and irrigation suitability assessment." Regarding WQI, there were no dimensions, and the values ranged from 0 to 100. WQI describes the overall quality of groundwater for drinking purposes. According to various water quality parameters, the WQI results help classify groundwater as excellent, good, poor, etc., at a particular location and season.

No hydrogeochemical studies have been performed to evaluate the hydrochemistry and spatial distribution of groundwater quality or to evaluate water quality for different purposes in the present study area. Hence, the present study aimed to assess the suitability of groundwater for drinking and irrigation purposes using water quality indices and GIS tools. In addition, this study assessed the spatial distribution of various hydrogeochemical parameters. Furthermore, this study focused on the hydrochemical processes and geochemical classification of groundwater in the study area.

2. Methods and Materials

2.1. The Study Area Description. The study area is located in southern Ethiopia's upper Omo River catchment. The study area is on the western plateau at the border west of the main Ethiopian rift. Geographically, the area encompasses 1,011 km^2 and extends from 7°5′052″ to 7°8′050″ north latitude and 37°51′30″ to 37°86′31″ east longitude. It is located 315 km southwest of Addis Ababa and 150 km northwest of the regional town of Hawassa. An asphalt road connects capital and regional cities. Addis Ababa's capital and regional cities are connected through Butajira-Hosaina-Sodo-Arba Minch and Hadero-Shinshicho-Durame-Alaba. In addition, the area can access foot trails and gravel roads that run from major towns in various directions in the study area. The location map is shown in (Figure 1).

2.2. Geology, Drainage, and Physiography. The geology of the area under investigation consists of Tertiary and Quaternary rhyolite and basalt volcanic rocks, covered by Quaternary alluvial deposits and Precambrian basement gneiss and granite. The mountains of the northern parts of the study area are surrounded by Tertiary volcanic rocks such as plateau basalts, in the southern part (lower Omo areas) by Precambrian basement rocks with tertiary volcanic, and in the central and eastern regions by Tertiary and Quaternary volcanic rocks. Basalt, rhyolite, quaternary alluvial deposits, trachyte, Tertiary ignimbrites/consolidated ash flows, volcanic ash, and tuffs are the dominant rock units exposed in the Omo-Gibe River basin. Recent Quaternary volcanic rocks such as pitchstone, pumice, and obsidian outcrops are among the significant Quaternary volcanic rocks. In the study areas, these rocks form cones and calderas [28]. Figure 2 shows the lithological features of the present study area.

The study area has four perennial rivers, Bucho, Shapa, Sana, and Soke, which feed on the Omo River (Figure 1). The rivers emerge from the Kembata Tembaro zone (Kacha Bira, Kedida Gamela, Doyogena, Tembaro, and Hadero) woredas; the Hadiya zone (Duna, Soro, Merab, and Misrak Badawacho) woredas; and the Wolayita zone (Damot Gale and Pulasa and Boloso Sore and Bonibe). Mt. Ambericho, Mt. Soro, Mt. Damot, and the Soke River outlet areas were located in the highland and lowland areas, respectively. The rivers have been perennial for a long time and flow in the Omo River basin from northeast to southwest (Figure 1).

Physiographically, the area is characterized by a high elevation of 3,000 m at Mt. Ambericho and a low elevation of 755 m a.s.l. downstream of the Soke River outlet (Figure 3). The elevation map of the area was derived from SRTM-DEM data at 30 m resolution using ArcGIS-based analysis tools. The major physiographic configurations include mountains,

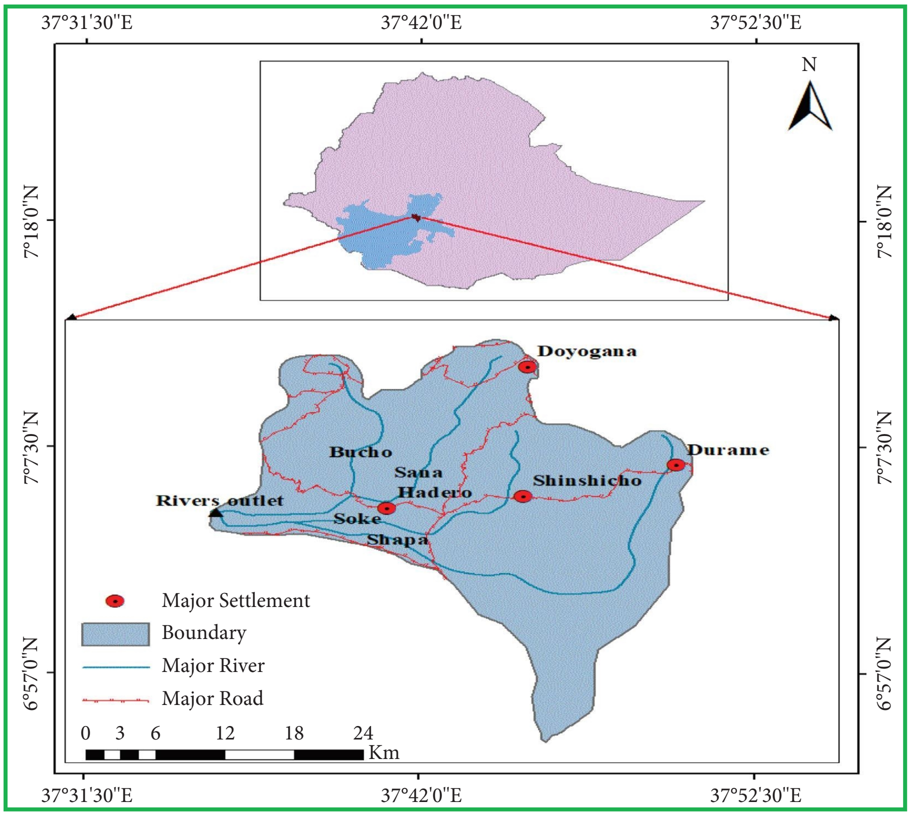

Figure 1: Study area map.

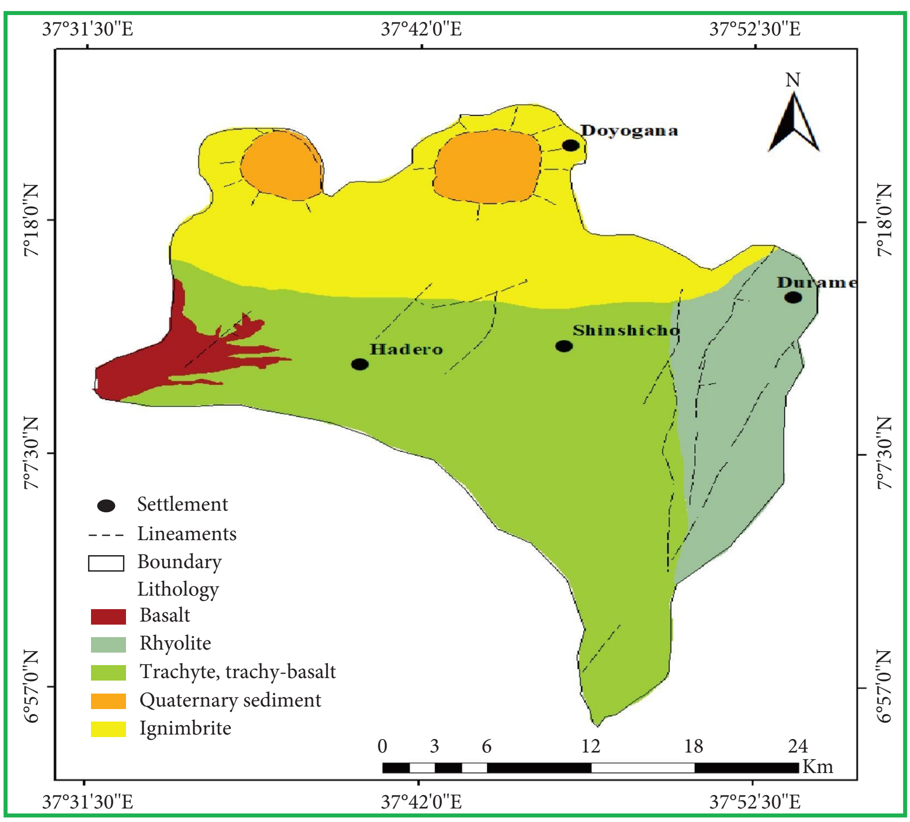

Figure 2: Lithology map of the study area.

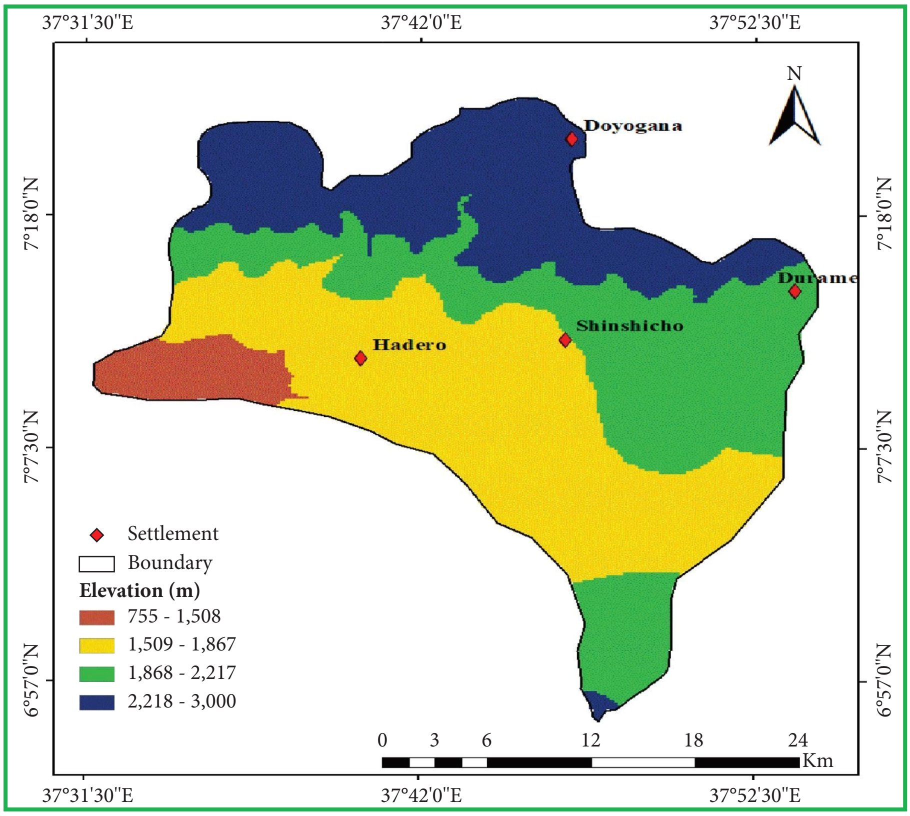

Figure 3: The elevation map of the study area.

undulating topography, flat land, and valley areas. The upstream region is mountainous in the northeast. It is commonly connected to a volcano-mountain ridge known as Mount Ambericho. In the research region's southeast, east, central, and southern portions, undulating landforms and plains dominate the terrain. The northern part is distinguished by graben and horst features, and the Wagebeta areas are covered with Quaternary sediments. The western part of the Soke river outflow is determined by a valley area dominated by a very gentle slope.

2.3. Methods

2.3.1. Evaluation of the Drinking Water Quality Index (WQI). There are several methods for analyzing and monitoring the overall quality of drinking water, but the water quality index (WQI) is by far the most effective way. Based on a comparison of the WHO and Ethiopian standards, the suitability of groundwater quality was evaluated using the WQI technique in this study. This method was first developed by the authors of [29] and modified by the authors of [30]. Several researchers have used this technique to evaluate water quality in different parts of the world [31–34]. This study has fourteen (14) parameters (pH, EC, TDS, turbidity, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Cl^-, F^-, NO_3^-, SO_4^{2-}, and HCO_3^-) that have been used for WQI calculations. This WQI method needs four main steps, and the phases are clearly defined as follows:

Step 1: The weight (wi) value is assigned to each of the fourteen factors based on each factor's relative weight in determining the overall quality of drinking water based on their relative importance. According to the relative significance of each factor, the weight (wi) value varies from 1 to 5. The most crucial criteria were given a maximum weight of 5 out of ten. On the other hand, parameters considered to have no or negligible impact on human health are given a weight of 1.

Step 2: The relative weight (Wi) is found using the weighted arithmetic index method shown in the following equation:

$$\mathrm{Wi} = \frac{\mathrm{wi}}{\sum_{i=1}^{n} \mathrm{wi}}, \tag{1}$$

where Wi is the relative weight, wi is the weight of each parameter, and *n* is the number of parameters.

Step 3: Using equation (2), it is necessary to divide the concentration of each sample by its associated standard, based on the groundwater quality guidelines published in [35], and then multiply the resulting value by 100 to determine the quality rating scale (Qi):

$$\mathrm{Qi} = \left(\frac{\mathrm{Ci}}{\mathrm{Si}}\right) * 100, \tag{2}$$

Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and

Si is the [35] drinking water standard for each chemical parameter in mg/l.

Step 4: According to equation (3), to determine WQI, the Si for each chemical parameter must be determined first:

$$\mathrm{Si} = \mathrm{Wi} * \mathrm{Qi}, \quad (3)$$

where Si is the subindex of the i^{th} parameter, Wi is the relative weight of the i^{th} parameter, and Qi is the rating based on the concentration of the i^{th} parameter.

The overall water quality index (WQI) was calculated by adding each subindex value of each groundwater sample using the following equation:

$$\mathrm{WQI} = \sum \mathrm{Si}_{\mathrm{i-n}}. \quad (4)$$

2.3.2. Evaluation of Irrigation Water Quality. Assessing the safety of irrigation water is crucial for farming operations. Salinity (salinity hazard) and sodium are linked to irrigation water quality difficulties [36] (Sodium hazard). The electrical conductivity (EC), salt absorption ratio (SAR), and permeability index (PI) were used to evaluate groundwater for irrigation. Among the many measures of salinity, electrical conductivity provides the most comprehensive picture of the potential dangers posed by irrigation water. Plant roots are physiologically parched when they cannot overcome the strong osmotic pressure of the soil water. The sodium adsorption ratio (SAR) is a helpful tool for gauging both the sodium concentration in soils and the suitability of irrigation water. Salty soils are more challenging to cultivate because of reactions that decrease permeability, soil structure, and hardness. It has been hypothesized [37] that the sodium effect can be estimated by using equation (5) and SAR technology used by the U.S. Salinity Laboratory:

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\left(\mathrm{Ca}^{2+}\right) + \left(\mathrm{Mg}^{2+}\right)/2}}, \quad (5)$$

where the concentration of Na^{+}, Ca^{2+}, and Mg^{2+} ions is expressed in meq/l.

Permeability indices help assess irrigation water quality. Irrigation water quality can be severely affected by soil permeability following long-term irrigation water usage, as determined by the quantities of Na^{+}, Ca^{2+}, Mg^{2+}, and HCO^{3-} in the soil. Therefore, the permeability index (PI) was calculated for each water sample to obtain an accurate reading of water permeability. Class I irrigation water (high quality and permeable water), class II irrigation water (appropriate for irrigation), and class III irrigation water (poorly permeable and unsuitable for irrigation) can all be distinguished by their PI range values. With all the ionic levels in the solution listed in meq/l, PI may be calculated using the following equation:

$$\mathrm{PI} = \frac{\mathrm{Na}^{+} + \sqrt{\mathrm{HCO}_3^{-}}}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^{+}} * 100. \quad (6)$$

2.4. Materials

2.4.1. Water Sampling and Analysis. Representative groundwater samples were collected for water analysis from boreholes, shallow wells, hand-dug wells, and springs. Groundwater sampling techniques depend on the location of the groundwater source, road accessibility, water point availability, and population settlement distribution. There were no water sample sites in most of the southern and northwestern portions of the study area due to the absence of water points. For this investigation, a total of 58 water samples were gathered, and out of those 58 samples, 11, 28, 2, and 17 of them were chosen from boreholes (BHs), shallow wells (SWs), hand-dug wells (HDWs), and springs (SPs), respectively (Figure 4).

To comprehensively analyze the groundwater quality in the study area, representative water samples were collected from various sources, including boreholes, shallow wells, hand-dug wells, springs, and rivers. The selection of groundwater sampling techniques depended on factors such as the location of the water source, accessibility of the area, availability of water points, and distribution of population settlements.

During the fieldwork phase, the primary groundwater samples were collected specifically during the dry season between February and March 2022. To ensure accurate representation of water quality, the wells were pumped for 5–10 minutes before sample collection to remove stagnant water. Careful attention was given to maintaining the integrity of the samples, as 1 L plastic water bottles were thoroughly washed with distilled water three times before being used for sampling. From each individual site, a single 1 L representative water sample was collected.

Within a two-day timeframe, the primary samples were transported to the Water Quality Laboratory of the Arba Minch University Technology Institute, Faculty of Water Supply and Environmental Engineering. In the laboratory, various measurements and analyses were conducted. The physical parameters of groundwater, including in situ pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, and total hardness, were determined using specialized scientific instruments such as pH meters, TDS meters, and conductometers. These meticulous sampling and laboratory procedures ensured reliable data collection to assess groundwater quality in the study area. Table 1 shows a hydrochemical analysis of the study area for both primary and secondary water samples. The present study's overall methodology is shown in Figure 5.

3. Results and Discussion

3.1. Calculation of the Ionic Balance Error. Using the electroneutrality principle, chemical analysis accuracy was performed before the interpretation of the hydrochemistry

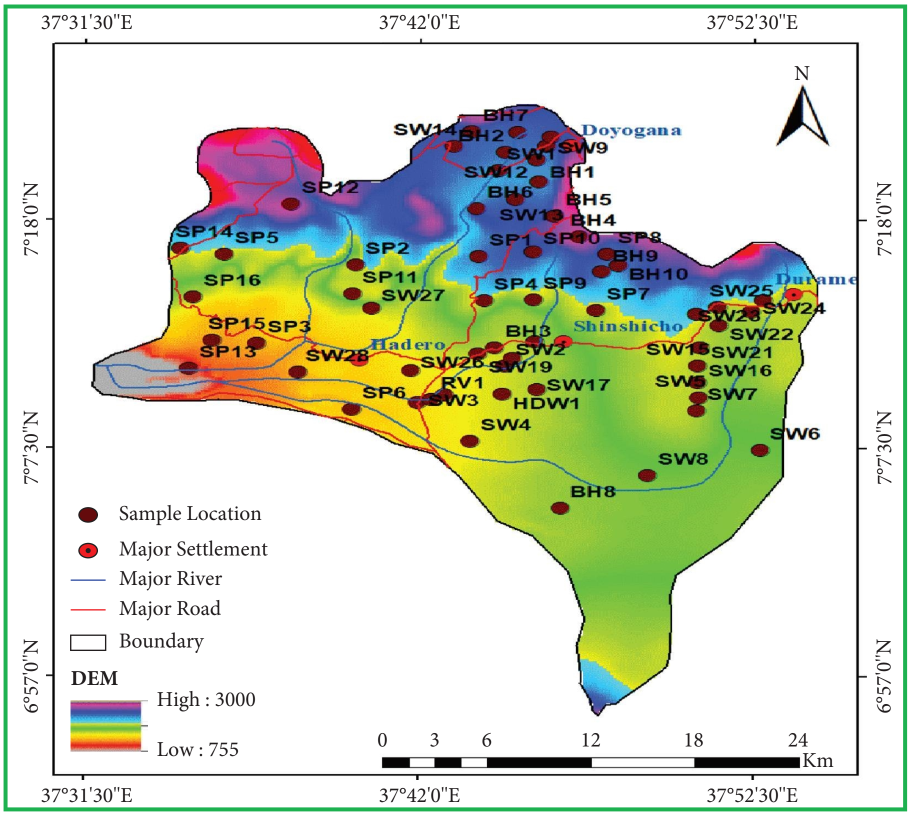

Figure 4: Water sample location map.

data of the area. In order to maintain electroneutrality, the sum of the positive ions (cations) must be equal to the sum of the negative ions in meq/l (anions). The level of the error in the data was calculated using the following equation [38]:

$$\text{Reaction error} = \frac{(\Sigma\,\text{cations} - \Sigma\,\text{anions})}{(\Sigma\,\text{cations} + \Sigma\,\text{anions})} * 100. \quad (7)$$

Based on this principle, the charge balance error of the chemical analysis was estimated using the major cation (Na^+, K^+, Mg^{2+}, and Ca^{2+}) and anions (HCO_3^-, CO_3^-, SO_4^-, Cl^-, and PO_4^{3-}). The present study has analyzed the hydrochemical data with an ionic balance below 5% after calculating the charge balance error using the AquaChem software. An error up to plus or minus 5% is preferable [38].

3.2. Physicochemical Parameters. Fifty-eight (58) water samples and eighteen (18) parameters were collected and analyzed to determine the hydrochemical properties of water and evaluate groundwater quality for drinking and irrigation. Six of the 18 parameters were measured in situ, and the remaining 12 were analyzed in the laboratory. The final parameters were computed following the WHO and Ethiopian standards [35, 39].

3.3. In Situ Measurements

3.3.1. pH. At SW3, in the southern part of Achura kebele (Gebiya sefer) village in Boloso Sore woreda, the pH value reached its highest point (7.9). The pH value reached its lowest point at SP3 in Hadero Tunto woreda, Tunto-01 town (6.5). According to [35, 39], the pH values in the study area do not exceed the recommended pH values for drinking water, which range from 6.5 to 8.5 in pH. Based on the pH value range, the groundwater classification in the study area lies between low acidity and weak alkalinity (Figure 5).

3.3.2. EC. It is directly related to the water's salt concentration and temperature. It is advised that the maximum acceptable level of EC for human consumption does not exceed 1000 μS/cm [35]. The maximum EC values were measured at BH3 with 4380 μS/cm in Kacha Bira (Gemesha), and the minimum is 95.3 μS/cm at HDW2 in Danishe village at Kacha Bira woreda, with an average value of 1182.35 μS/cm shown above (Table 2 and Figure 5). Seven water samples, BH1, BH2, BH3, SW5, SW6, SW7, and SW8, with 1278, 1666, 4380, 1810, 3420, 1362, and 2600 μS/cm, respectively, exceed [35] standards. Higher EC values were recorded in the deep boreholes and shallow wells, whereas the lowest values were measured in the hand-dug wells and spring sources. Thus, the water in the study area cannot be consumed as drinking water due to its contaminants.

3.3.3. Temperature. In the physical analysis of water samples, the temperature is another parameter measured in the field and is usually expressed as °C. The water temperature is important when evaluating water for drinking and irrigation

Table 1: Hydrochemical analysis of the study area for both primary and secondary water samples.

Sample ID	Na^+ (meq/l)	K^+ (meq/l)	Ca^{+2} (meq/l)	Mg^{+2} (meq/l)	Fe^{2+} (meq/l)	Cl^- (meq/l)	F^- (meq/l)	NO_3^- (meq/l)	SO_4^{2-} (meq/l)	PO_4^{3-} (meq/l)	HCO_3^- (meq/l)	CO_3^{2-} (meq/l)	IBE (%)	Remark
BH1	2.26	0.32	1.11	0.95	0	0.62	0.08	0.03	0.04	0.00	3.03	0	9.91	Primary
BH2	3.41	0.29	0.27	0.28	0	0.49	0.12	0.00	0.02	0.01	3.36	0	3.03	”
BH3	2.17	0.71	0.22	0.26	0	0.39	0.15	0.27	0.04	0.08	2.16	0	4.26	”
SP1	0.57	0.08	0.17	0.26	0	0.45	0.03	0.04	0.04	0.01	0.52	0	−0.62	”
SP2	0.69	0.17	0.24	0.09	0.01	0.28	0.04	0.03	0.04	0.04	0.66	0	4.45	”
SP3	0.70	0.14	0.07	0.08	0.01	0.45	0.02	0.02	0.02	0.03	0.75	0	−13.06	”
SP4	0.53	0.10	0.20	0.26	0	0.34	0.04	0.01	0.02	0.02	0.54	0	6.35	”
HDW1	1.31	0.29	0.15	0.16	0.01	0.25	0.04	0.19	0.01	0.02	1.23	0	4.74	”
HDW2	1.35	0.40	0.17	0.24	0	0.34	0.05	0.32	0	0.03	1.34	0	1.93	”
SW1	1.48	0.34	0.40	0.08	0.01	0.45	0.05	0.13	0.01	0.03	1.51	0	2.91	”
SW2	0.65	0.10	0.35	0.19	0.00	0.45	0.02	0.41	0	0.04	0.26	0	4.91	”
SW3	1.65	0.30	0.13	0.14	0.01	0.34	0.04	0.00	0.04	0.03	1.74	0	0.88	”
SW4	1.50	0.34	0.11	0.19	0.01	0.28	0.04	0.03	0.04	0.06	1.51	0	4.26	”
SW5	3.76	0.42	0.27	0.08	0.01	0.34	0.09	0.00	0.04	0.05	3.69	0	3.79	”
SW6	2.10	0.70	0.30	0.21	0.01	0.45	0.08	0.00	0.02	0.05	2.43	0	4.52	”
SW7	2.43	0.39	0.21	0.30	0.01	0.28	0.04	0.00	0.05	0.03	2.61	0	4.97	”
SW8	1.01	0.52	0.43	0.08	0.01	0.45	0.05	0.01	0.05	0.04	1.28	0	4.31	”
SW9	0.82	0.24	1.10	0.80	0	0.04	0.02	0.06	0.02	0.01	3.39	0	−8.95	Secondary
SW10	0.95	0.24	1.00	0.60	0.01	0.01	0.02	0.18	0.02	0.01	2.60	0	−0.66	”
SW11	0.82	0.24	1.10	0.80	0	0.04	0.02	0.06	0.02	0.01	3.39	0	−8.95	”
SW12	1.51	0.31	0.50	0.92	0.01	0.04	0.02	0.01	0.02	0.01	3.66	0	−7.38	”
SW13	0.75	0.27	1.10	0.92	0.01	0.01	0.03	0.00	0.04	0.08	3.61	0	−10.6	”
SW14	1.09	0.29	1.10	0.80	0.01	0.04	0.04	0.12	0	0.01	3.69	0	−8.50	”
SW15	1.07	0.19	1.04	0.16	0.01	0.07	0.03	0.16	0.05	0.02	2.20	0	−1.16	”
SW16	0.94	0.20	1.00	0.80	0	0.01	0.02	0.32	0.02	0.02	2.61	0	−0.81	”
SW17	0.64	0.14	0.50	0.50	0.01	0.07	0.02	0.22	0	0.02	1.51	0	−1.31	”
SW18	0.80	0.12	0.80	0.80	0.00	0.01	0.02	0.10	0	0.02	3.39	0	−17.03	”
SW19	0.86	0.11	0.20	0.20	0.01	0.11	0.02	0.35	0.05	0.02	0.60	0	9.15	”
SW20	0.76	0.17	1.00	0.80	0	0.01	0.02	0.07	0.02	0.05	2.60	0	−0.47	”
SW21	0.57	0.11	0.90	0.89	0	0.01	0.02	0.02	0.02	0.01	2.70	0	−5.78	”
SW22	3.57	0.37	1.06	0.88	0.01	0.02	0.03	0.02	0.04	0.03	3.61	0	8.07	”
SW23	0.58	0.24	0.48	0.26	0.01	0.09	0.02	0.37	0.05	0.07	0.80	0	5.66	”
SW24	0.71	0.17	0.84	0.42	0.01	0.11	0.02	0.04	0.04	0.05	1.70	0	4.36	”
SW25	0.53	0.09	0.10	0.08	0.00	0.04	0.02	0.02	0.03	0.00	0.60	0	6.28	”
SW26	0.58	0.13	0.50	0.40	0.01	0.07	0.01	0.00	0	0.02	1.30	0	7.22	”
SW27	0.65	0.10	0.32	0.18	0.01	0.02	0.02	0.12	0	0.02	1.03	0	1.87	”
SW28	0.56	0.18	0.52	0.38	0.01	0.02	0.02	0.00	0.02	0.04	1.56	0	−0.27	”
BH4	1.52	0.31	0.65	0.40	0.00	0.00	0.06	0.01	0.04	0	2.79	0	−0.31	”
BH5	1.63	0.23	0.80	0.10	0.01	0.01	0.07	0.14	0.00	0.01	2.61	0	−1.21	”
BH6	3.17	0.30	1.11	0.66	0	0.15	0.06	0.00	0.03	0	3.68	0	14.44	”
BH7	1.43	0.28	0.83	0.42	0	0.05	0.11	0.01	0.04	0	3.20	0	−6.96	”
BH8	0.54	0.13	0.85	0.12	0	0	0.04	0.01	0.04	0	1.62	0	−2.09	”
BH9	0.54	0.29	0.56	0.12	0.01	0.04	0.02	0.06	0.04	0	1.51	0	−4.45	”

Table 1: Continued.

Sample ID	Na^+ (meq/l)	K^+ (meq/l)	Ca^{+2} (meq/l)	Mg^{+2} (meq/l)	Fe^{2+} (meq/l)	Cl^- (meq/l)	F^- (meq/l)	NO_3^- (meq/l)	SO_4^{2-} (meq/l)	PO_4^{3-} (meq/l)	HCO_3^- (meq/l)	CO_3^{2-} (meq/l)	IBE (%)	Remark
BH10	1.71	0.15	0.50	0.50	0.01	0	0.02	0.17	0	0.02	2.70	0	−0.67	”
BH11	0.62	0.11	0.50	0.30	0.01	0.04	0.02	0.04	0	0.03	1.33	0	2.62	”
SP5	0.69	0.13	0.19	0.16	0	0.04	0.02	0.04	0.03	0	0.95	0	4.05	”
SP6	0.73	0.14	0.11	0.11	0	0.05	0.02	0.01	0.03	0	0.91	0	3.28	”
SP7	0.69	0.16	0.07	0.14	0.01	0.10	0.03	0.10	0.02	0	1.07	0	−9.98	”
SP8	0.76	0.08	0.08	0.09	0.01	0.04	0.02	0.07	0.01	0	0.80	0	4.25	”
SP9	0.55	0.12	0.08	0.12	0.01	0.11	0.02	0	0.03	0	0.57	0	8.45	”
SP10	0.55	0.16	0.80	0.30	0.01	0.01	0.02	0.01	0.02	0	1.80	0	−1.25	”
SP11	0.53	0.11	0.90	1.10	0	0.32	0.02	0.32	0	0	1.25	0	16.18	”
SP12	0.56	0.14	0.13	0.14	0	0.04	0.02	0.07	0.05	0	0.79	0	0.21	”
SP13	0.57	0.16	0.09	0.19	0	0	0.02	0.01	0	0.01	0.96	0	0.70	”
SP14	0.83	0.15	0.13	0.26	0	0	0.02	0.04	0	0.01	1.25	0	2.11	”
SP15	0.76	0.13	0.19	0.18	0	0	0.02	0.01	0.01	0.01	1.08	0	4.88	”
SP16	0.74	0.13	0.28	0.26	0	0	0.02	0.01	0.00	0	1.26	0	4.25	”
RV1	0.90	0.13	0.32	0.68	0.01	0.04	0.02	0.28	0.02	0.01	1.70	0	−0.67	”

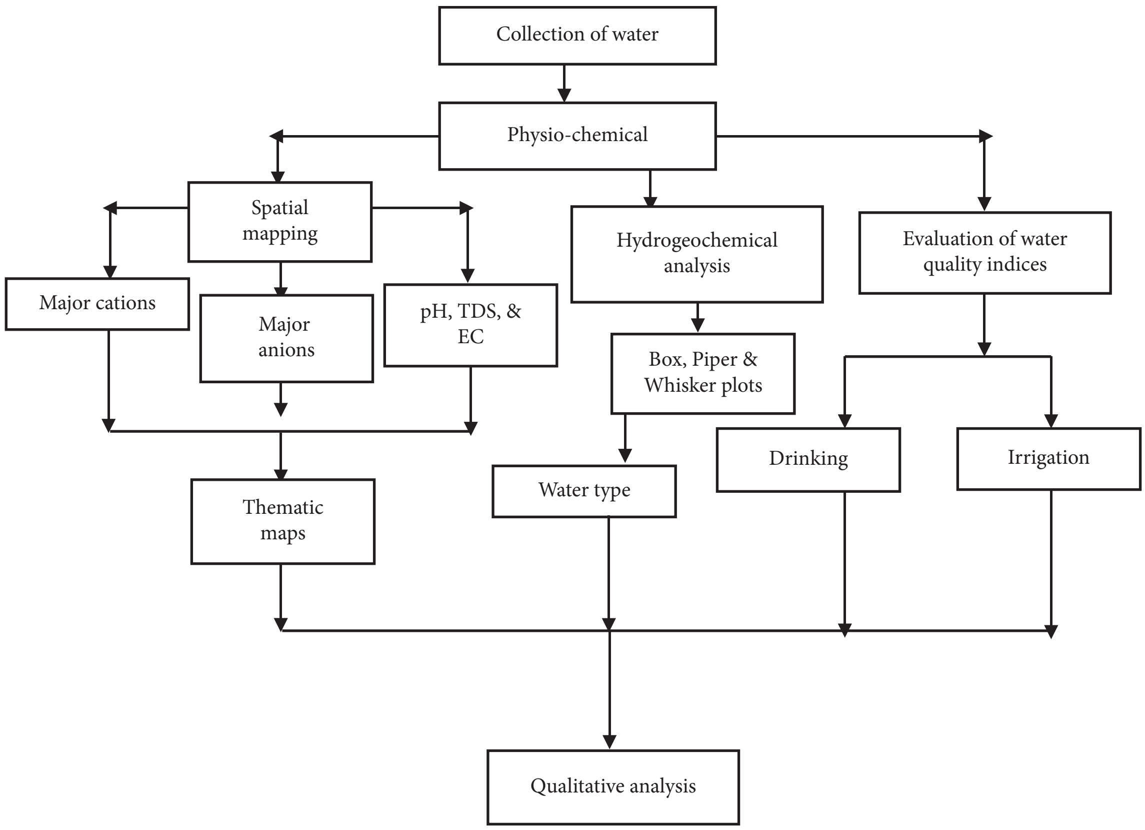

Figure 5: Methodology flowchart.

purposes. The maximum temperature values were measured at SW4 in the southern part of Boloso Sore woreda, Ouguma site at 26.8°C, and the minimum was 22.5°C at BH1 and BH2 in the northern part of the study area, with a mean value of 25.060 C in all groundwater samples of the study area (Table 2 and Figure 6). This revealed that altitude variations primarily controlled the study area's temperature. Field measurement evidence shows that the temperature recorded in relatively higher elevation (3000 m) of Wagebeta and Duna areas ranges between 22.4 and 23.9°C and a relatively lower elevated (750 m) area of Soke outlets and surrounding ranges between 25.4 and 26.8°C (Figure 5).

3.3.4. Turbidity. Turbidity is an in situ water quality parameter used to measure the physical properties of water in the field and is commonly expressed in nephelometric turbidity units (NTUs). Cloudiness or suspended solids in water are caused by fine suspended matter, organic and inorganic particles, microscopic organisms, and water's muddy or turbid appearance [2]. Following the guidelines for drinking water quality, the highest permissible level of turbidity is 5 NTU, which is the maximum allowed value [35, 39]. A variation of 0.7 to 44 NTU was found to be the turbidity of the water samples analyzed at SP1 and SW2 in the Hadero Tunto (Wachisa) and Kacha Bira (Gemesha) sites, respectively (Table 2 and Figure 6). Five water samples, HDW1, HDW2, SW1, SW2, and SW8, with 14, 31, 11, 44, and 6 (NTU) values, exceeded the drinking water quality [35, 39] guidelines, respectively. Therefore, these waters are not suitable for drinking purposes.

3.3.5. TDS. The total dissolved solids in groundwater include all the solid materials present, whether ionized or not. Water contains several inorganic solutes, most of which are ions, solutes of trace elements, and gases that are dissolved. It is mainly made up of inorganic salts, including sodium, magnesium, calcium, potassium, sulfates, chlorides, and bicarbonates, and only a trace amount of organic materials is dissolved in water [35]. The TDS value is directly related to electrical conductivity and has a positive correlation. The TDS value of groundwater tends to be higher than that of surface water. Groundwater contacts a much larger mineral surface area over a much longer time. Water is unfit for human consumption if the TDS concentration exceeds 1,000 mg/l.

On the other hand, a TDS value of less than 600 mg/l is usually good for drinking water [35, 39]. In the eastern portion of the research area at Merab Badawacho (Weberena), the highest TDS value was obtained at SW5 at 909 mg/l. The lowest reading was 128.1 mg/l at SW2 in the study's central Kacha Bira (Gemesha) location, with an average value of 409.47 mg/l across all groundwater samples (Table 2 and Figure 7). Table 3 displays all groundwater samples from the research area classified as freshwater based on TDS values [9]. The general TDS value increases with altitude variation, attributed to the increase in

Table 2: Statistical analysis of the physicochemical parameter result.

Parameters	Units	Minimum	Maximum	Average	Maximum permissibility level [35]	Maximum permissibility level [39]	Number of samples exceeding (ESA) standard
pH	—	6.50	7.90	7.10	6.5–8.5	6.5–8.5	None
Temperature	°C	22.50	26.80	25.06	—	—	None
Electrical conductivity	μs/cm	95	380	1182	1000	—	—
Total dissolved solids	mg/l	128.10	909	409.97	1000	1000	None
Turbidity	NTU	0.70	44	—	5	5	5
TH	mg/l	0.00	100	5.56	300	600	None
Na^+	mg/l	12.10	86.50	35.96	200	200	None
K^+	mg/l	3.20	27.80	12.58	12	15	6
Ca^{2+}	mg/l	1.4	22.4	10.06	75	75	None
Mg^{2+}	mg/l	0.96	11.52	4.56	50	50	None
Fe^{2+}	mg/l	0.02	0.28	0.15	0.30	0.30	None
Cl^-	mg/l	0	22	4.98	250	250	None
F^-	mg/l	0.32	2.76	1.07	1.50	1.50	5
NO_3^-	mg/l	0.10	25.60	5.24	50.00	50	None
SO_4^{2-}	mg/l	0.05	2.50	1.42	250	250	None
HCO_3^-	mg/l	16.00	225.00	96.61	500	600	None
CO_3^{2-}	mg/l	0.00	0.00	0.00	—	—	None
PO_4^{2-}	mg/l	0.00	2.60	—	—	—	—

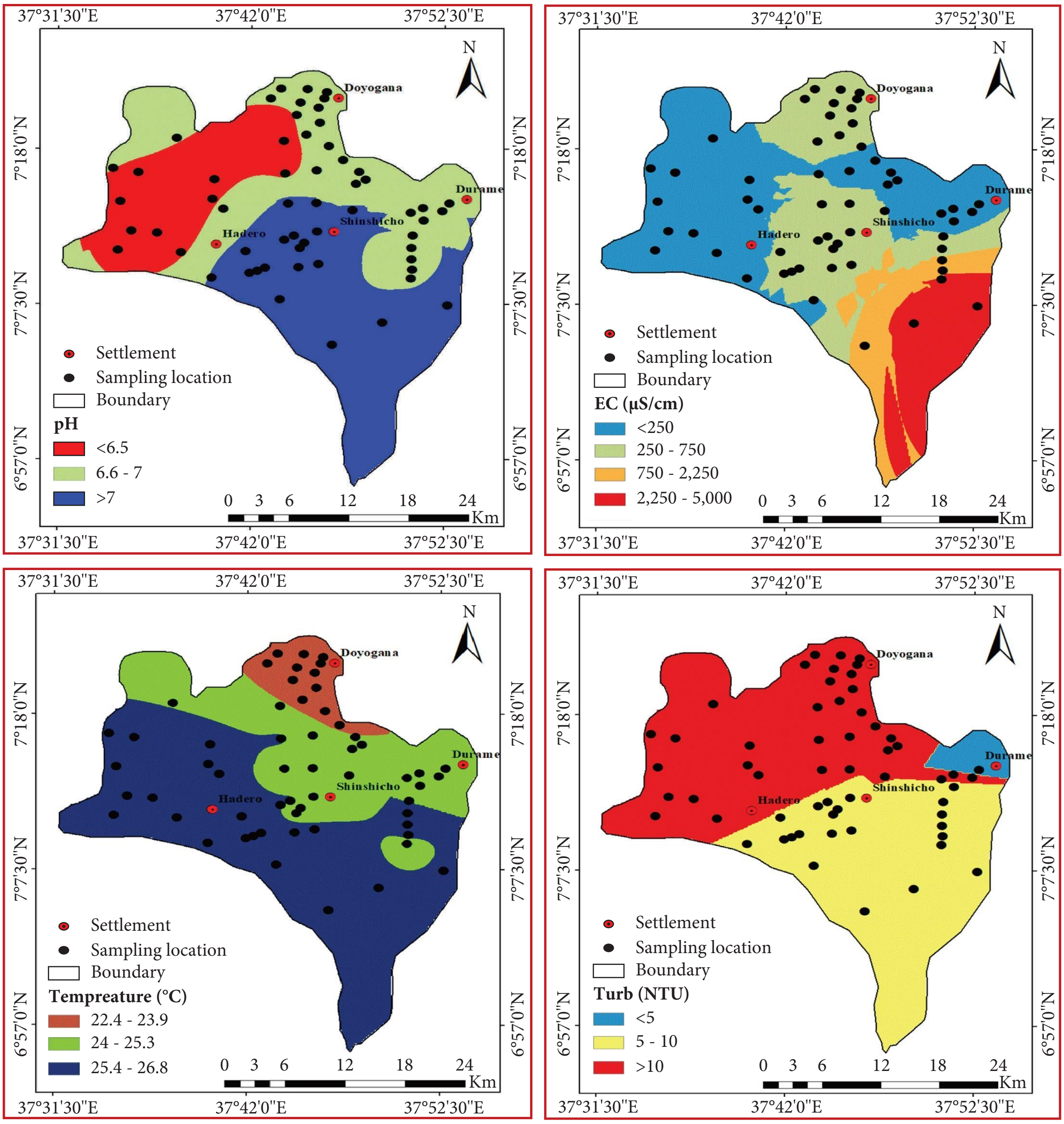

Figure 6: Spatial distribution of pH, EC, temperature, and turbidity.

evapotranspiration of the low-altitude areas and possibly the dissolution of mineral constituents by groundwater during its movement through geologic media.

3.3.6. Total Hardness. There are two types of hardness: carbonate (removable) and noncarbonate (irremovable). As a measure of groundwater total hardness (TH), calcium and magnesium concentrations in milligrams per litre of calcium carbonate ($CaCO_2$) were added to the solution. Anions, such as calcium and magnesium, and cations, such as carbonate, chloride, bicarbonate, and sulfate in water, are responsible for this phenomenon. Notably, the hardness levels of the measured water ranged from 0 to 100 mg/l, with an average value of 5.56 mg/l (Table 1). The water hardness at the Wagebeta BH1 well was the highest of all wells measured. According to the total hardness (as $CaCO_3$) standards [40], the groundwater samples were classified as soft or moderately soft as determined by the $CaCO_3$ standards.

3.4. Major Anion and Cation Analysis Result. Measuring the amounts of organic and inorganic substances dissolved in groundwater enables chemical analysis. Typically, natural waters are not clean and are always contaminated with dissolved gases and particles. Several natural and anthropogenic factors, such as the source of recharge water, its chemistry, rock composition, retention time, and the

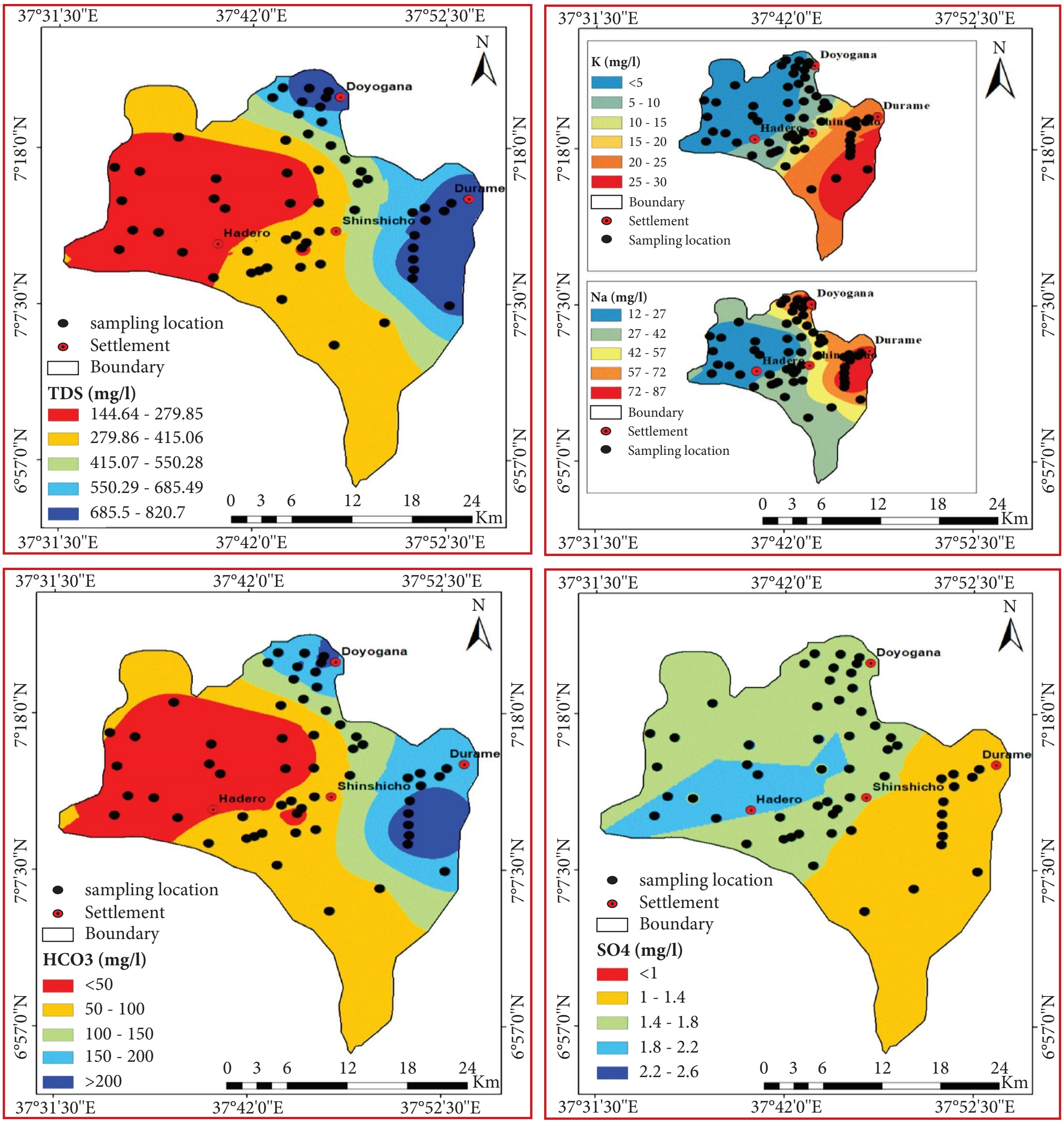

Figure 7: Spatial distribution of TDS, K, Na, HCO_3, and SO_4.

amount of dissolved minerals, can influence groundwater quality. Twelve chemical laboratory investigations were conducted to assess the quality of groundwater used for drinking and irrigation in the study area. Several dissolved constituents, including both major and minor ions, are present, and their concentrations have been determined using the WHO and ESA guidelines [35, 39].

3.4.1. Calcium and Magnesium. Calcium and magnesium are the most abundant cations in all waters, in the form of Ca^{2+} and Mg^{2+} ions. Their natural sources include rocks, minerals, and soils. Calcium is dissolved in major natural rocks rich in calcium minerals. These rocks have amphiboles, feldspars, pyroxenes, aragonite, and clay minerals. For example, acidic precipitation may accelerate calcium loss from soil. Magnesium is found in pyroxenes, amphiboles, magnetite, olivine, and clay minerals. Magnesium is mainly found in groundwater because it is a byproduct of the weathering of rocks containing ferromagnesian minerals. The maximum permissible limits of calcium and magnesium for drinking water quality are 75 and 50 mg/l, respectively [35, 39]. The minimum and maximum calcium and magnesium values were 1.4 mg/l, 22.4 mg/l, 0.96 mg/l, and 11.52 mg/l, respectively. This revealed that all the water samples did not exceed the WHO and Ethiopian standards for drinking water quality in the study area.

Table 3: WHO [35] and Ethiopian Standard Agency [39] standards exceeded parameters in the area.

Parameters	Maximum permissibility level [35]	Samples and their values as per [35] standard	Maximum permissibility level [39]	Samples and their values as per [39] standard
Electrical conductivity (μS/cm)	1000	BH1 (1278), BH2 (16660), BH3 (4380), SW5 (1810), SW6 (3420), SW7 (1362), and SW8 (2600)	—	—
Turbidity (NTU)	5	HDW1 (14), HDW2 (31), SW1 (11), SW2 (44), and SW8 (6)	The same as with WHO	The same as with WHO
K^+ (mg/l)	12	BH1 (14.5), BH3 (27.8), SW1 (13.4), SW4 (13.2), SW5 (16.5), SW6 (27.5), SW7 (15.2), SW8 (20.4), and HDW2 (15.7)	15	BH3 (27.8), SW5 (16.5), SW6 (27.5), SW7 (15.2), SW8 (20.4), and HDW2 (15.7)
F^- (mg/l)	1.5	BH1 (1.59), BH2 (2.29), BH3 (2.76), SW5 (1.67), and SW6 (1.6)	The same as with WHO	The same as with WHO

3.4.2. Sodium and Potassium. Sodium and potassium are cations in natural water. They are found in the form of Na^+ and K^+ ions. Earth materials, such as rocks, soils, and minerals, are major natural sources of sodium and potassium. For example, clay minerals and feldspars are sources of sodium. The potassium sources are feldspars (orthoclase, K-feldspars, and microcline), feldspathoids, micas, and clay minerals. The highest permissible limits of sodium and potassium for drinking water quality are 200 mg/l and 12 mg/l as per guidelines [35] and 200 mg/l and 15 mg/l as per the standard [39], respectively. Na^+ and K^+ concentrations in groundwater range from 12.1 at SP4 (Waose) to 86.5 at SW5 (Weberena), with mean values of 35.96 and 3.2 at SP1 (Wachisa) to 27.8 at BH3 (Gemesha) with a mean value of 12.58 mg/l, respectively (Figure 7), in the present study area. Based on the potassium concentration, about nine groundwater samples, BH1, BH3, SW1, SW4, SW5, SW6, SW7, SW8, and HDW2, exceeded the drinking water quality guidelines of WHO [35], and six samples BH3, SW5, SW6, SW7, SW8, and HDW2 were above 15 mg/l [39]. The higher concentration of K^+ was due to the weathering of K^+ source mineral-bearing acidic volcanic rocks (K-feldspars/orthoclase, mica, and clay minerals). The spatial distribution map of sodium and potassium is shown in Figure 7.

3.4.3. Bicarbonate. A bicarbonate molecule is produced during the decomposition of organic matter in the soil due to root respiration and humus degradation, during which CO_2 is produced, which then reacts with precipitation to produce bicarbonate ions [41, 42]. It was found that the bicarbonate level in groundwater was approximately 225 mg/l at SW5 in Merab Badawacho and 16 mg/l at SW2 at the Gemesha site, with an average of 96.61 mg/l among all groundwater samples collected in the area (Figure 7). It has been found that all of the groundwater samples in the region were below the level of bicarbonate that is considered safe, as per [35, 39] based on the spatial distribution map of bicarbonate in the region.

3.4.4. Sulfate. There is a need to assess the sulfate concentration in natural groundwater before it can be used for human consumption. The maximum allowable concentration of sulfate ions in drinking water is 250 mg/l, according to [35, 39]. In all groundwater samples, SW7 and SW8 had the highest sulfate concentration (2.5 mg/l), while SW2 had the lowest (0.05 mg/l), with a mean value of 1.42 mg/l (Figure 7). The examination revealed that all samples were within the WHO-prescribed limits for potable water [35, 39].

3.4.5. Chloride (Cl^-). Another anion recognized for its conservative tendency in chemical evolution is chloride. Compared to other main ions, this is an excellent indication of the age of groundwater. According to [35, 39], a chloride concentration of 250 mg/l in drinking water is appropriate. The chloride content of all the groundwater samples from the study area was determined to be minimum and maximum 0 mg/l and 22 mg/l, respectively. According to the Ethiopian regulations and World Health Organization recommendations, all water sources in the research region are suitable.

3.4.6. Phosphate (PO_4^{2-}). Phosphate is one of the anions present in groundwater, with concentrations ranging from 0 to 2.6 mg/l at BH1 and BH3 in the northern portion of the study region and an average of 1.2 mg/l (Table 2 and Figure 7). Based on these findings, soil phosphate was added to the soil via the breakdown of organic matter in weathered rocks, leaching of phosphate from fertilizers, and other anthropogenic impacts. As has been demonstrated, silicate weathering may have a secondary effect on groundwater quality if an alkaline environment is present, with increased solubility of silica in groundwater samples owing to alkaline conditions.

3.4.7. Carbonate (CO_3^-). In all groundwater samples from the study area, the carbonate value was 0 mg/l (Table 1). The results showed that pH concentrations controlled the carbonate value in all water sources in the study area. The relative amount of carbonates in pure water was related to the pH concentration. For instance, if pH is less than 8, the carbonate concentration in the groundwater samples is negligible.

3.4.8. Nitrate (NO_3^-). High nitrate levels in groundwater are typically attributable to the overuse of agricultural fertilizers, animal and human waste, and plant debris [43]. The maximum acceptable nitrate level in drinking water is 50 mg/l [35, 39]. SW2 in Kacha Bira (Gemesha) had the highest nitrate concentration in the study's groundwater samples at 25.6 mg/l, whereas SW3 and SW6 had the lowest amounts at 0.00 mg/l and 5.24 mg/l, respectively (Table 2 and Figure 8). All water samples in the study area were found to have nitrite concentrations within an acceptable range.

3.4.9. Fluoride (F^-). Fluoride is a primary water quality problem in Ethiopia. Thirty percent of Ethiopia's groundwater reserves are considered unsuitable for direct consumption due to salinity and fluoride concentrations [2]. Fluoride poisoning of drinking water is a major issue in this research region. Fluoride ions are naturally present in amphiboles (hornblende), apatite, fluorite, and mica. Fluorides are spread in the form of ionized minerals, termed fluorides, during the formation of rocks. Most fluoride in the groundwater in the research area is sourced from acidic volcanic rocks, including ignimbrite, pyroclastic debris, trachyte, and rhyolite. Fluoride ions have beneficial and harmful effects on human health. Fluoride is a crucial ingredient for humans, as drinking water with less than 0.6 mg/l of fluoride promotes tooth decay. When fluoride concentrations exceed 1.5 mg/l, the teeth of children become mottled. In addition, fluoride concentrations above 6.0 mg/l result in significant mottling and deformation of the teeth. Fluorosis of the teeth and bones may arise from the high fluoride content in groundwater.

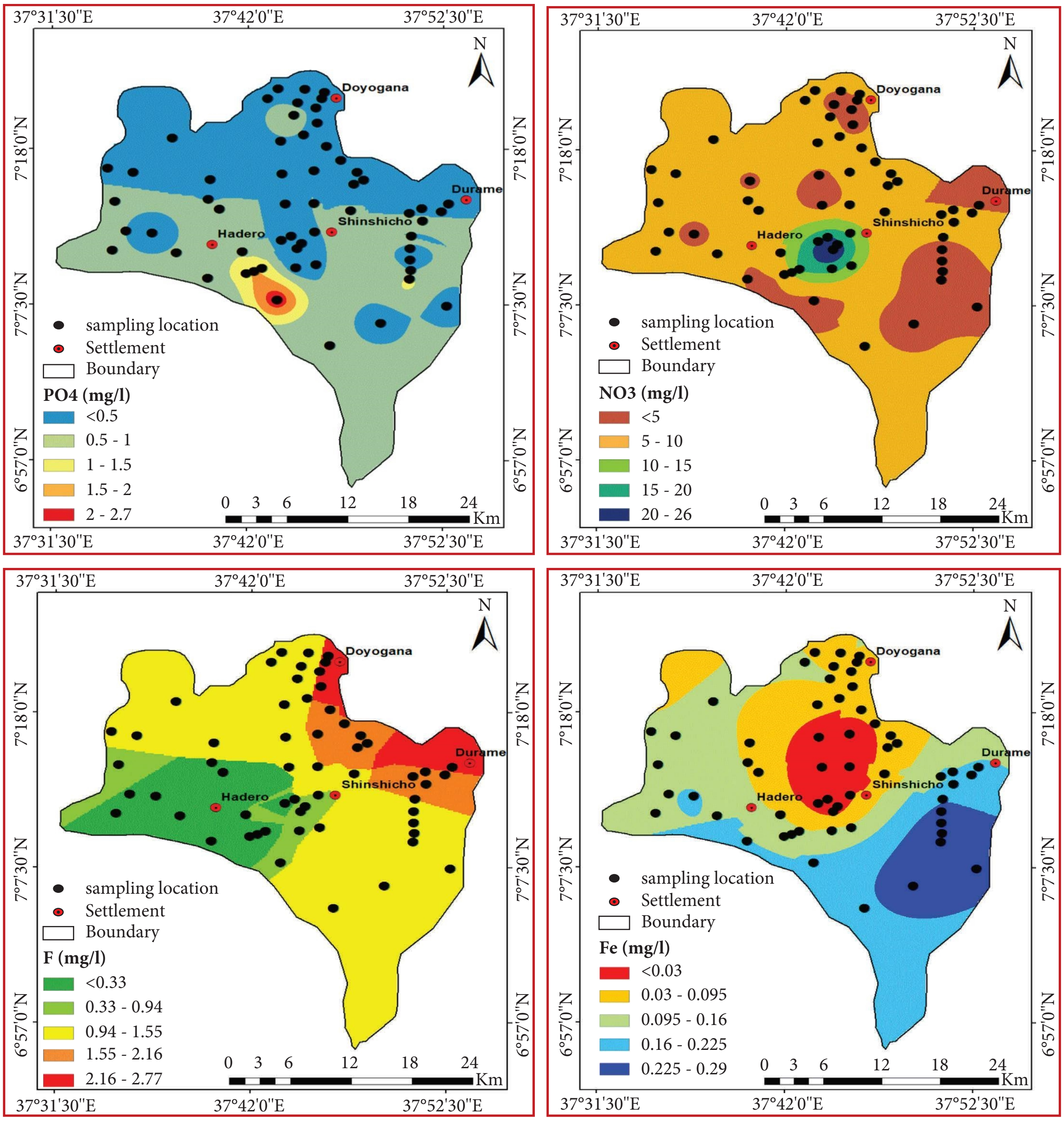

Figure 8: Spatial distribution of PO_4, NO_3, F, and Fe.

A maximum fluoride concentration of 1.5 mg/l was advised by the authors of [35, 39]. Fluoride concentrations in the research region ranged from 0.32 to 2.76 mg/l, with an average of 1.07 mg/l (Table 2), and Figure 7 depicts the spatial distribution of fluoride in the area. Five groundwater samples (BH1, BH2, BH3, SW5, and SW6) had fluoride concentrations above the regulatory level of 1.5 mg/l. The concentrations were 1.59, 2.29, 2.76, 1.67, and 1.6 mg/l. This shows that an excess fluoride water sample fails to meet the WHO and Ethiopian criteria and is, therefore, unfit for consumption. Water poses a significant health risk. Concentrations of high fluoride vary between the recharge and discharge zones. In the study region, a higher concentration of fluoride was evaluated. This phenomenon may result from rock-water interactions and weathering of fluoride source-bearing acidic volcanic rocks of pyroclastic formations, ignimbrite, and rhyolite.

3.4.10. Iron (Fe^{2+}). Iron is derived from major natural sources of igneous and sandstone rocks, for example, igneous rocks such as ferromagnesian micas, ferrous sulfide (FeS), amphiboles, magnetite (Fe_3O_4), ferric sulfide, or iron pyrite (FeS_2), and sandstone rocks such as carbonates, oxides, and sulfides or iron clay minerals. This minor iron ion is present in water as a rock-water reaction. For example, if pyrite reacts with water, water will continuously infiltrate deeper into the ground, contaminating the groundwater with iron ions. This iron ion increases acidity in the groundwater.

In addition, inadequately designed wells and steel pipes containing residual iron can impair drinking water quality. According to [35, 39], the maximum allowable iron level is 0.3 mg/l. Iron concentrations in the area varied between 0.02 and 0.28 mg/l, with a mean of 0.15 mg/l (Table 2 and Figure 8). According to the spatial pattern map of iron in the study area (Figure 7), all groundwater samples fell within the permitted limits of the criteria [35, 39].

3.5. Hydrogeochemical Characteristics of the Groundwater. Hydrogeochemical characteristics mainly depend on the ion balance between major cations and anions in natural groundwater. Groundwater hydrochemistry is primarily controlled by rock weathering (silicates, carbonates, and sulfates) and influenced by evaporation, cation exchange processes, and anthropogenic inputs [14]. In the study area, $Na^+ > Ca^{2+} > Mg^{2+}$ are the major dominant cations, while $HCO_3^- > SO_4^{2-} > Cl^-$ are the major dominant anions shown in (Figure 9).

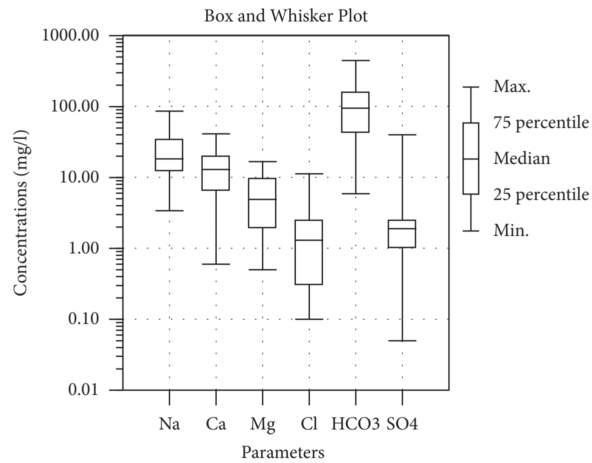

Figure 9: Box and Whisker plots show the concentration of major cations and anions in the area.

3.6. Graphical Presentation of Hydrochemical Data. According to the Piper diagram, groundwater can be categorized as HCO_3-Ca, Cl-Na, or mixed [44]. This Piper diagram was developed by the authors of [44] and used multiple water samples and trends in major cations and anions. In this Piper plot, total major cations and anions are projected at left- and right-side triangles. The Piper diagram shows the primary and secondary data of the groundwater sample's chemical analysis results. Based on major cation and anion dominance, the study area's five major water types were identified using the Piper diagram. Five water types were classified from the Piper diagram plots as Ca-HCO_3, Na-HCO_3, mixed Ca-Na-HCO_3, NaCl, and CaCl of the total fifty-eight water samples of the study area. The dominant water types in the study area belong to Ca-HCO_3 and Na-HCO_3 (Figure 10).

The majority of the shallow wells lie in the study area in the Ca-HCO_3 water types, and the majority of deep boreholes also overlie in the Na-HCO_3 water types. Some shallow wells were also found in the mixed Ca-Na-HCO_3 water classifications. In most cases, boreholes, shallow wells, springs, and hand-dug wells are the primary sources of Ca-HCO_3 and Na-HCO_3.

3.7. Evaluation of Water Quality. Determining whether water is suitable for drinking, agricultural, industrial, residential, municipal, and public recreation requires thorough water quality evaluation. Biological, chemical, and physical water components constitute water quality components. The major cations and anions were analyzed to determine the water quality in this study. Water utilization is intimately tied to water quality. The study area's drinking water quality was compared to the WHO [35] and Ethiopian standards [39]. Each water sample in the research area was evaluated using the water quality index (WQI).Irrigation water quality was evaluated by salinity hazard (EC), sodium hazard (sodium adsorption ratio), and permeability index (PI). In the research region, the suitability of groundwater as a source of potable water and irrigation was investigated.

3.7.1. Evaluation of the Drinking Water Quality Index. The drinking water quality parameters analyzed in the laboratory and the field for water samples collected from the study area are compared according to the World Health Organization [35] and Ethiopian Standards Agency [39] guidelines. Based on these principles, four parameters such as EC, turbidity, K^+, and F^- exceeded the WHO guidelines, while three parameters of turbidity, K^+, and F^- were above the Ethiopian standard (Table 3).

In this study, WQI techniques were used to evaluate the quality of drinking groundwater, and 15 parameters such as pH, EC, TDS, turbidity, TH, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Cl^-, F^-, NO_3^-, SO_4^{2-}, and HCO_3^- were selected. WQI has been calculated to evaluate the suitability of groundwater quality of study areas for drinking purposes. The overall WQI value in the groundwater samples of the area varied from excellent (20.25) to poor (110.45) at SP1 and BH3 in the Wachisa and Gemesha locations, respectively. In the present study, WQI values are usually classified into three categories as shown in Table 4, and 5.88% of groundwater was classified under the "poor" class, 58.82% under the "good" type, and 35.29% as an "excellent" class. According to the study's spatial WQI distribution map (Figure 11), all groundwater samples except one (BH3) could be used for safe drinking purposes as long as water quality was high enough.

3.8. Assessment of Irrigation Water Quality. In this present study, the electrical conductivity (EC), salt absorption rate (SAR), and permeability index (PI) were used to evaluate the irrigation compatibility of groundwater.

3.8.1. Electrical Conductivity (EC). In the present study, the highest EC values were measured at BH3 with 4380 μS/cm in

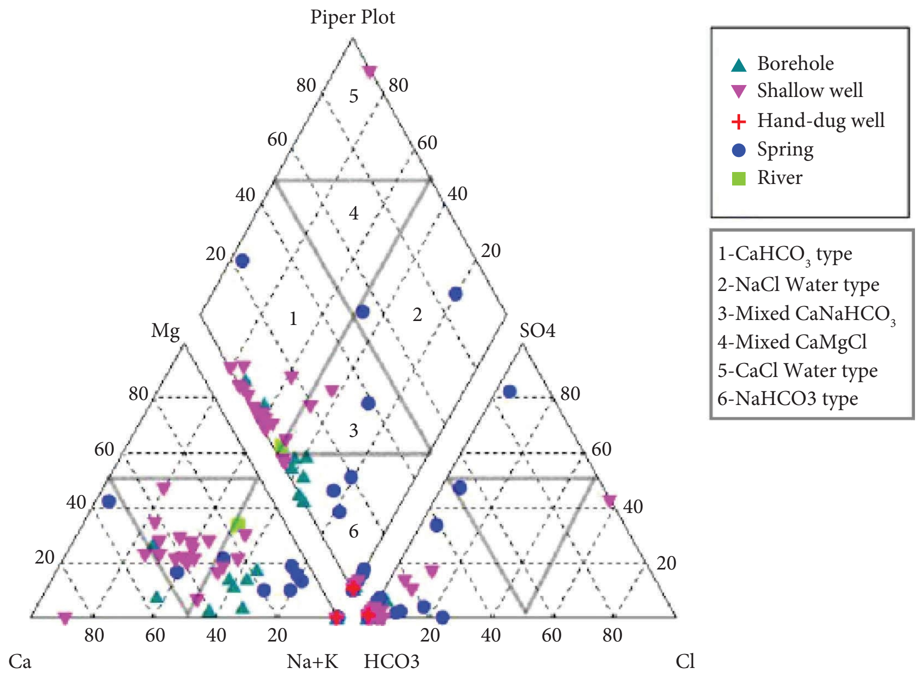

Figure 10: Piper diagram for groundwater facies classification.

Table 4: Classification of groundwater quality in the area based on the WQI method.

S. No	Range of WQI classes	Water types	Number of water samples	Percentage (%)
1	<50	Excellent	6	35.29
2	50–100	Good	10	58.82
3	100–200	Poor	1	5.88
4	200–300	Very poor	—	—
5	>300	Unsuitable	—	—

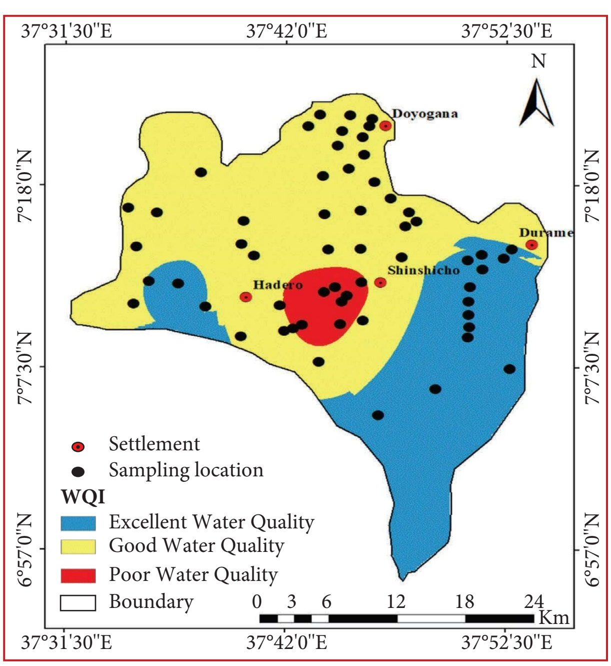

Figure 11: Water quality index (WQI) map for drinking purposes in the area.

Table 5: Classification of irrigation water quality based on the PI [46].

S. No	Range of PI	Class of water	Number of water samples	% (percentage)
1	>75	Class I	All	100
2	25–75	Class II	Nil	Nil
3	<25	Class III	Nil	Nil

the Gemesha site and the lowest at 95.3 μS/cm at HDW2 in Danishe village, an average of 1182.35 μS/cm shown in Table 2. The study area EC value was classified into four based on the [45] criteria rules (Table 5). Based on this classification, about 5.88%, 47.06%, 29.41%, and 17.65% of the groundwater samples of the study area belong to excellent, good, permissible, and doubtful classes for irrigation water quality purposes, respectively (Table 6). This revealed that water samples of 1 (excellent) and 8 (good) are suitable for irrigation use due to the low and medium concentrations of the EC value. Five water samples, namely, BH1, BH2, SW1, SW5, and SW7, with EC values of 1278, 1666, 997, 1810, and 1362 μS/cm, belong to the permissible water class. The remaining three water samples BH3, SW6, and SW8

Table 6: Classification of irrigation water quality based on EC [45].

S. No	Range of EC (μs/cm)	Class of water	Number of water samples	% (percentage)
1	<250	Excellent	1.00	5.88
2	250–750	Good	8.00	47.06
3	750–2250	Permissible	5.00	29.41
4	2250–5000	Doubtful	3.00	17.65
5	>5000	Unsuitable	Nil	Nil

Table 7: Classification of irrigation water quality in the area based on the SAR method.

S. No	Water class	Range of water samples	Number of water samples	% (percentage)
1.00	Excellent	<10	All	100
2.00	Good	18–26	Nil	Nil
3.00	Fair	18–26	Nil	Nil
4.00	Poor	>26	Nil	Nil

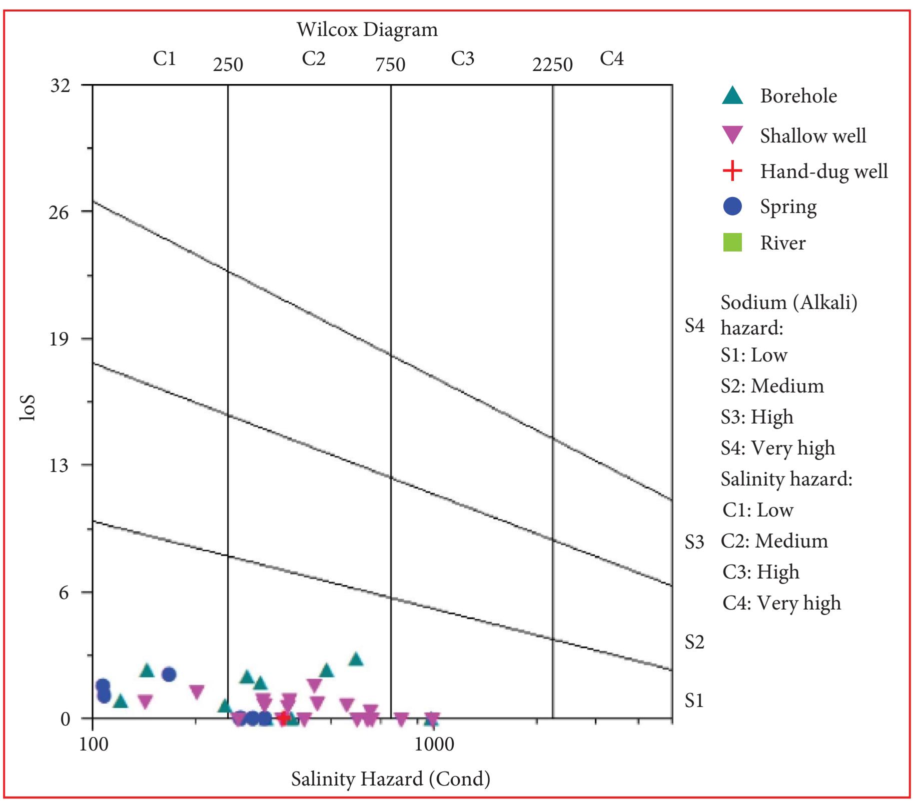

Figure 12: USSL diagram of sodium hazard vs. salinity hazard (EC) for irrigation use in the area.

with EC values of 4380, 3420 and 2600 μS/cm belong to the doubtful water class, and they are not suitable for irrigation due to their high salinity.

3.8.2. Sodium Adsorption Ratio (SAR). Based on the chemical analysis in the study area, all the samples with SAR values less than 10 are excellent for irrigation purposes, as shown in Table 7.

According to [37], Wilcox's diagram result in (Figure 11) shows that all of the water samples from the area fall into three categories such as C1and S1 (low salinity hazard with low sodium alkalinity hazard), C2 and S1 (medium salinity with low alkalinity hazard), and C3 and S1 (low salinity with low alkalinity hazard) classes, respectively. In terms of sodium (alkalinity) hazard, all water samples plotted on the diagram (Figure 12) fall in low sodium (alkali) hazard (S1), thus revealing that all water samples in the area are suitable for irrigation purposes. In terms of salinity hazard in the study area, all water samples fall in C1–C3 (low salinity to high salinity hazard). This revealed that all water samples from C1 to C3 are suitable for irrigation use, except three water samples of C3, namely, BH3, SW6, and SW8, are not suitable for irrigation purposes in the area.

3.8.3. Permeability Index (PI). The permeability index (PI) is vital for evaluating irrigation water quality. The calculated PI value varied from −17.39 (SW25) to 239.81 (SP3) meq/l in the study area. Based on the calculated PI values, 89.66% of the water samples fall in class I and 10.34% fall in class III, respectively (Table 5). This indicates that all class I (excellent) water categories are suitable for irrigation, while the class III type is unsuitable for irrigation purposes in the area.

4. Discussion

It was determined that 58 groundwater samples were collected from 28 shallow wells, 11 boreholes, two hand-dug wells, and 17 springs and analyzed for 17 parameters such as pH, temperature, TDS, EC, turbidity, Na^+, Ca^{2+}, Mg^{2+}, K^+, Fe^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, PO_4^{2-}, F^-, NO_3^-, and CO_3^{2-}. Based on the dominant cation and anion hydrochemical data analysis results, Na^+ and HCO_3^- are the dominant cations and anions for all groundwater samples in the study area. Ca-HCO_3, Na-HCO_3, and mixed Ca-Na-HCO_3 are the prevalent water types in the area. In the analysis of groundwater quality, four parameters were found to exceed the WHO guidelines, including nine water samples of EC, five water samples of turbidity, and nine water samples of K^+. Furthermore, three parameters, such as turbidity of five samples, K^+ of six samples, and F^- of five samples, exceeded the Ethiopian drinking water quality standards. Based on WQI, 58.82% of the groundwater samples were excellent, 35.29% were good, and 5.88% were poor in water quality. The results of this study showed that most of the water samples in the study area were suitable for drinking. Based on EC, approximately 95% of the irrigation water samples were classified as C1–C3 (low to high salinity hazards), with only 5% classified as C4 (very high). As a result, a significant number of water samples were suitable for irrigation, except for three groundwater samples, BH3, SW6, and SW8, which should not be used for irrigation purposes.

5. Conclusions

Water quality in Ethiopia's upper Omo River valley was assessed using the hydrogeochemical characterization, drinking water quality index, irrigation water quality index, and GIS techniques. There was a significant variation in subsurface water chemistry based on the physicochemical characteristics of the 58 water samples. The classification of groundwater quality based on WQI showed that 5.88% of groundwater was classified under the "poor" class, 58.82% under the "good" type, and 35.29% as an "excellent" class. This reveals that the major water samples in the area were suitable for drinking. Based on the EC, Wilcox diagram classification, sodium absorption ratio (SAR), and permeability index (PI), the calculated and analyzed results show that all water samples have very high to low salinity and sodium hazards. This indicates that significant water samples are suitable for irrigation, except for three groundwater samples. This study shows groundwater samples are generally ideal for drinking and irrigation. However, it should be noted that urbanization and extensive agricultural activities have affected the groundwater quality in the study area. The hydrogeochemical spatial distribution and drinking and irrigation water quality indices derived from the present study can be used by decision-makers, planners, and researchers in the present study area. Therefore, this study recommends that water resources and the environment be adequately protected with a good watershed management system to maintain groundwater quality suitable for drinking water and irrigation.

Data Availability

All data are included in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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