Heliyon 10 (2024) e36363

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Evaluation of drinking water quality and associated health risks in Adama City, Ethiopia

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ARTICLE INFO

Keywords:
Aquachem
Chlorine decay
Water quality index
Hazardous index
Hydro-geochemistry
WaterGEMS

ABSTRACT

Drinking water deterioration causes to risk of public health which is essential to supply safe water to the public. This study assessed groundwater quality and health risks in Adama City by analyzing groundwater and chlorine samples. Ion photometry techniques detected anions and cations, ensuring accuracy with quality control protocols. Water Quality Index (WQI) and chlorine decay modeling via WaterGEMs assessed water quality. Hazard index (HI) calculations evaluated exposure risks; Pearson correlation analyzed physicochemical relationships. Findings highlighted water quality and hazards. Aquachem software analyzed Adama's groundwater, revealing high total alkalinity and potassium exceeding WHO limits. Other parameters (nitrate, nitrite, chloride, fluoride, and sulfate) met WHO standards. Sodium, calcium, magnesium, iron, manganese, and boron also complied. Multivariate analysis showed significant parameter associations. Water types included Ca–Na–HCO_3 (27.27 %), Na–Ca–HCO_3 (36.36 %), Na–Ca–Mg–HCO_3, Na–HCO_3 (9.09 % each), and Na–Mg–HCO_3 (18.18 %). Drinking Water Quality Index rated boreholes as "Good." Health risk assessments found no significant fluoride, iron, or manganese risks across ages. Chlorine residual analysis indicated 74 % had levels below WHO recommendations, prompting chlorine dosing adjustments. Findings inform groundwater management in Adama City.

1. Introduction

Access to safe water is crucial globally, significantly impacting public health and well-being, especially vulnerable groups like children, people with disabilities, and the elderly [1–3]. Water quality degradation presents a significant global challenge influenced by diverse factors. Factors such as population growth, urbanization, industrialization, and agricultural practices contribute to widespread contamination of water sources [4–6]. Improper waste disposal, chemical runoff from agricultural fields, and industrial effluents introduce harmful substances into water bodies, thereby impairing their quality [7] (see Fig. 4).

In Africa, water quality deterioration is exacerbated by inadequate sanitation practices, industrial activities without pollution control measures, intensive use of fertilizers and pesticides in agriculture, rapid urbanization, and population growth [4,6]. Access to safe water is crucial for community welfare in Africa, fostering progress and reducing disease burdens [1,8]. Addressing these pollution

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https://doi.org/10.1016/j.heliyon.2024.e36363
Received 30 May 2024; Received in revised form 10 August 2024; Accepted 14 August 2024

sources necessitates comprehensive strategies, including improving sanitation infrastructure, promoting sustainable agricultural practices, implementing rigorous regulation and monitoring, and investing in water quality preservation. High-quality water plays a pivotal role in promoting livelihoods, resilience, and economic growth [9,10], thereby facilitating sustainable development and ensuring the well-being of the population [11]. Ethiopia faces water quality challenges stemming from agricultural pollution, inadequate sanitation infrastructure, and the impacts of rapid urbanization and industrial activities [12].

Access to potable water is crucial for economic development, supporting industries, businesses, and agriculture. Preservation and conservation of water resources are essential for ecological balance, biodiversity, and ecosystem sustainability [6,13]. Contaminated water has profound and deleterious effects on communities [6,14]. Contaminated water poses significant health risks, harboring pathogenic microorganisms that can spread through consumption, bathing, or contact, thereby increasing the likelihood of outbreaks [15]. Furthermore, water pollution adversely impacts aquatic ecosystems, causing ecosystem degradation, loss of biodiversity, and long-term ecological damage [16,17]. Communities affected by deteriorating water quality also experience economic burdens, such as increased healthcare expenses and productivity losses due to waterborne illnesses [18]. Additionally, contaminated water significantly affects social and cultural aspects, playing a crucial role in cultural practices, agriculture, and daily routines [19,20].

Various solutions are employed to provide communities with high-quality water. Sanitation infrastructure, including sewage systems and wastewater treatment plants, plays a critical role in preventing water source contamination [2,21]. Source protection measures, such as buffer zones and monitoring programs, are implemented to safeguard water sources from agricultural and industrial pollution [22,23]. Effective collaboration among stakeholders is essential for tailoring these solutions to specific community needs and ensuring universal access to clean and safe water [24,25].

Adama City, located in the Rift Valley region, is characterized by significant volcanic activity and geothermal energy resources. These geological conditions contribute to the presence of natural contaminants such as fluoride, arsenic, and heavy metals in groundwater [26]. Elevated concentrations of these contaminants often exceed safe drinking water standards, posing substantial health risks to the local population dependent on these groundwater sources [27]. Consequently, rigorous monitoring and effective mitigation strategies are essential to ensure the supply of safe and potable water to communities in Adama City.

The study aimed to investigate water quality and associated health risks in Adama, Ethiopia. Its objectives included: (i) collecting water quality samples across the study area, (ii) analyzing physicochemical parameters of water sources, (iii) assessing the hydrogeochemistry of groundwater, (iv) evaluating the Water Quality Index (WQI) of eleven boreholes (deep wells), (v) analyzing residual chlorine concentrations in the water distribution system, and (vi) assessing concentrations of fluoride, iron, and manganese and their associated health risks to the community. The findings are intended to benefit the management of Adama Water Supply and Sewerage Enterprise, as well as the Ministry of Water and Energy, providing valuable input for future strategies related to water quality and health risk management.

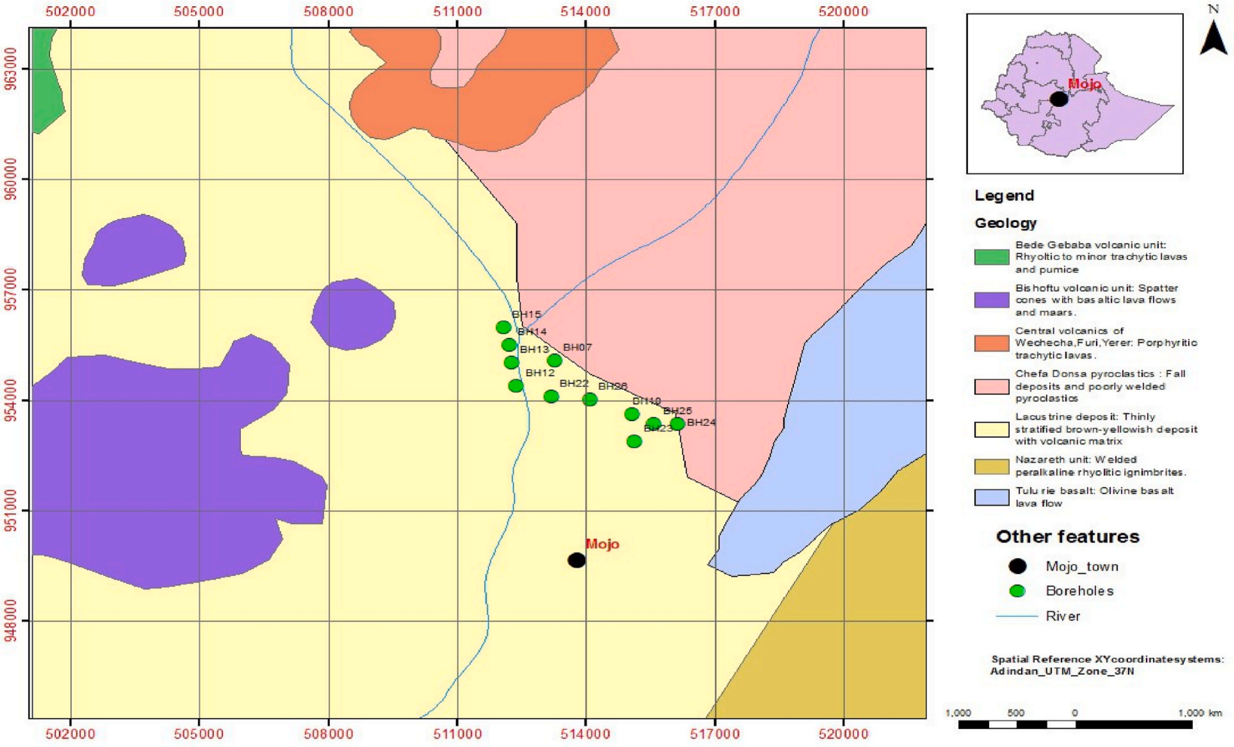


Fig. 1. The geological formation Map of study area.

2. Materials and methods

2.1. Study area

Adama, an urban center experiencing rapid growth, is located in the East Shoa Zone of the Oromia National Regional State in Ethiopia [28]. Positioned approximately 100 km southeast of Addis Ababa, the city spans coordinates 8°27′N to 8°36′N and 39°12′E to 39°20′E. Adama comprises six sub-cities, namely Aba-Geda, Boku, Dabe, Bolle, Lugo, and Dembella, covering a total land area of 136 square kilometers. The city's water supply system is meticulously organized into ten pressure zones, ensuring optimal water pressure through the utilization of pipes, valves, and pumps that efficiently transport treated water from strategically positioned service reservoirs across Adama City. The system includes three booster stations located in elevated areas to facilitate equitable access to water resources [29]. Adama is currently experiencing significant urban expansion, ranking second only to Addis Ababa, and is currently confronted with notable challenges regarding its water supply services. In order to address the issue of water scarcity, the Adama City Water Supply and Sewerage Enterprise has drilled 11 additional boreholes beside the existing conventional drinking water treatment plant to meet the national standard (80 litter per person per day).

2.2. Water sampling and laboratory analysis

Samples (n = 23) were collected from a wetland between January and December 2023 (Fig. 1 and Table 1). The rationality behind sample became 23 was due to total number of deep wells were eleven and samples collected at dry and rainy seasons. Groundwater samples from boreholes were collected in 250 mL polyethylene sterilized bottles after flushing for 15–20 min. Basic parameters were measured on site using a multi-parameter analyzer (wagtech, a planitest brand, England). Samples were promptly sealed, labeled, and transported in an icebox to the laboratory of Adama Water Supply and Sewerage Services Enterprise within 8 h to maintain sample integrity. Chlorine samples (n = 73). Using GIS mapping, twelve samples were collected in each sub-city, considering their proximity to water sources. The samples were distributed strategically, with three collected near the sources, three at intermediate distances, and three from farther locations within the water distribution system in each sub city. According [30] the minimum water quality should be 50 samples for reliable results. Stratified random sampling was employed to represent the six sub-cities.

Anions (chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^{-2}), fluoride (F^-)) and cations (calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+)) were analyzed using ion-specific analytical techniques. Ion photometry and photometry supplementary methods (.) were used for accurate quantification of both anions and cations in the samples [31]. Piper diagrams were generated using Aquachem software. For chlorinated water samples, glass bottles were autoclaved to eliminate potential contaminants [32,33].

2.3. Accuracy and precision

Samples were meticulously handled to maintain precision and accuracy in accordance with established quality control protocols [31]. Prior to analysis, instruments were calibrated daily using freshly prepared standard stock solutions diluted with deionized water. Each sample underwent rigorous analysis, incorporating blanks, replicates, and standards to ensure the reliability and reproducibility of results. Laboratory analyses were conducted using analytical grade reagents and chemicals. Duplicate analyses were performed for each sample, and average values were employed for result interpretation, achieving a confidence level of 95 % ± 3. As [34] reported a confidence level of 92 % ± 6.

2.4. Water Quality Index

The drinking Water Quality Index (WQI) serves as a convenient tool for assessing the combined influence of various water quality indicators by condensing them into a single numerical value. This value can be readily assigned to a specific quality class for easy identification. The calculations for WQI were conducted following the provided equations [35,36].

Table 1
Sampling Boreholes references and geographical coordinates in Adama City Water supply system.

S.N.	Descriptions	Depth (M)	BH yield (l/s)	Latitude	Longitude
1	Borehole 07 (BH07)	500	98	513285	955061
2	Borehole 10 (BH10)	600	88.2	515069	953616
3	Borehole 12 (BH12)	500	110	512389	954397
4	Borehole 13 (BH13)	502	80	512267	955011
5	Borehole 14 (BH14)	500	80	512217	955489
6	Borehole 15 (BH15)	502	80	512094	955970
7	Borehole 22 (BH22)	600	110	513205	954096
8	Borehole 23 (BH23)	584	98	515139	952875
9	Borehole 24 (BH24)	500	82	516147	953356
10	Borehole 25 (BH25)	650	92	515593	953354
11	Borehole 26 (BH26)	500	102	514102	954009

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

$$qi = \frac{Ci}{Si} * 100 \tag{2}$$

$$SIi = wiqi \tag{3}$$

$$\mathrm{WQI} = \sum SIi \tag{4}$$

Where: "wi" represented the assigned weight for each parameter. "Wi" denoted the relative weight, "qi" stood for the quality rating, "Ci" represented the concentration of a specific parameter, "Si" referred to the guideline value, and "SIi" represented the sub-index value. The values assigned to "wi" for each parameter in this study were derived and adapted from previous research studies [30,37]. The computed WQI values were classified into five categories as follows [38]; <50: excellent water; 50–100: good water; 100–200: poor water; 200–300: very poor water; >300: unsuitable for drinking [34,39]

2.5. *Chlorine decay modeling*

WaterGEMs software was utilized for modeling chlorine decay in the water supply system. This specialized tool facilitated analysis of chlorine concentrations, identification of areas with low residual chlorine, assessment of disinfection effectiveness, and optimization of disinfection processes. The modeling approach employed the First-Order Kinetics Model, which assumes chlorine decay follows an exponential pattern where the decay rate is proportional to the chlorine concentration [40]. Regression analysis was used to estimate the decay rate constant and initial chlorine concentration by fitting the model equation to observed data. Chlorine degradation in the network was influenced by chlorine consumption from water and formation of microfilms on pipes, with an overall coefficient applied to calculate comprehensive chlorine degradation [41].

2.6. *Exposure assessment*

The Estimated Daily Intake (EDI) and health risks from high fluoride, iron, and manganese levels were assessed across various age groups based on average water consumption and body weight. Exposure frequency was assumed as 365 days annually. Exposure duration for Infants, children, adolescents, adults, and the elderly were exposed for 1, 4, 18, 25, and 35 years respectively. Average body weights used were 8.4 kg for infants, 17.2 kg for ages 2–5, 58.2 kg for ages 18–34, and 63.25 kg for ages 35 and older [42–44]. Quantitative risk assessment model was used for determining acceptability of risk of fluoride, iron and manganese by age categories using the EDI and Hazard Index (HI) model developed by the U.S. Environmental Protection Agency (EPA) [31,45] for water samples with fluoride, iron and manganese concentration above the WHO limits.

$$EDI = \frac{(C * IR * EF * ED * AF * CF)}{Bw * AT} \tag{1}$$

The variables used in the assessment included EDI (estimated daily intake, mg/kg/day), C (concentration in medium, mg/L), IR (ingestion rate, mg/day), EF (exposure frequency, days/year), ED (exposure duration, years), AF (absorption factor), CF (conversion factor, 10^{-6} kg/mg), BW (body weight, kg), and AT (averaging time, days) [43] and guideline values [31]. The recommended maximum acceptable concentrations for contaminants in water were 1.5 mg/L for fluoride (F), 0.3 mg/L for iron (Fe), and 0.4 mg/L for manganese (Mn) [30].

2.7. *Health risk characterization*

The hazard index (HI), was calculated by dividing the cumulative dose (EDI) by the safe dose or reference dose (RfD). The RfD was an estimate of the daily exposure to children and adults that was likely to be without substantial risk during a lifetime. The RfD for fluoride, manganese, and iron, which were based on the no observation adverse effect level (NOAEL), were expressed in milligrams per kilogram per day (mg/kg/day). The RfD values were 0.06 for fluoride, 0.3 for manganese and 0.02 for iron [42,46].

$$HI = \frac{EDI}{RfD} \tag{2}$$

2.8. *Statistical analysis*

The physicochemical water quality was assessed in accordance with WHO drinking water quality guideline. The Pearson correlation matrix was applied to determine the relationships among the physicochemical parameters of groundwater sources (boreholes). Statistical significance was considered at a p-value of less than 0.05. Besides, the connection between the physicochemical parameters including the fluoride ions, and heavy metals was examined through the Pearson correlation test using SPSS (version 24). The Pearson linear correlation coefficient (r) was calculated, ranging from −1 to +1. A value of −1 signified a perfect negative correlation, +1 indicated a perfect positive correlation, and 0 denoted no correlation between the parameters [47].

3. Results and discussions

3.1. Groundwater quality characteristic

In Table 2, the mean total alkalinity in Adama's groundwater sources was 261.37 mg/L (±28.99), exceeded the WHO recommended limit of 200 mg/L. According to Ref. [48], alkalinity levels recorded in the Kopargaon Area of Maharashtra State, India, were found to be within the permissible limit set by the WHO of 200 mg/L. In contrast, the average potassium concentration was measured at 13.33 mg/L (±6.10), which was nine times higher than the WHO standard of 1.5 mg/L. According to Ref. [49], Potassium in Sebeta, Oromia Ethiopia were 14.706 ± (7.556) mg/L and 9.094 ± (3.199) mg/L during the dry season and wet season, respectively, surpassed the WHO standard limit of 1.5 mg/L. This study revealed that the total alkalinity and potassium concentration in Adama's borehole water exceeded the WHO recommended limit. The mean pH value was 7.29 (±0.34) in Adama was WHO value (6.5–8.5). Finding indicated that pH value 7.29 (±0.34) met the WHO limit. Author [50] discovered that pH levels exceeded the WHO standard limit could pose health risks, primarily affecting areas such as the mouth, nose, eyes, anus, and abdomen. pH values were 9.7 in Tigraye, and 11.8 in Addis Ababa and 10.35 in Amhara, 9 in Afar, 9.1 in Orgomia [51,52].

The study, in Adama, revealed a low turbidity level of 2.81 NTU (±2.53), indicated clear water with minimal suspended particles, which was below the WHO limit of 5 NTU. Other studies in different locations found variations in turbidity levels, with some exceeded the WHO limit [53,54], while better result was observed in Adama. The mean total dissolved solids (TDS) concentration of 297.77 mg/L (±42.89) was below the WHO limit of 1000 mg/L, indicated low levels of dissolved solids. However, the mean total alkalinity of 261.37 mg/L (±28.99) exceeded the WHO recommended limit of 200 mg/L. Nitrate and nitrite levels were significantly below the WHO maximum permissible levels of 50 mg/L and 3 mg/L, respectively, in Adama City. Other studies in different locations found variations in Nitrate and nitrite levels, with some exceeded the WHO limit [49,54].

The average chloride concentration of 13.84 ± (10.05) in Adama City was below the WHO limit of 250 mg/L, while the average fluoride concentration of 0.56 ± (0.52) also remained below the WHO limit. Variations in chloride concentration were observed in different studies, indicated significant variability in the chloride levels. Chloride contamination could pose risks to freshwater ecosystems and aquatic life [55]. Similarly, the average Sulfate concentration of 6.62 ± (4.64) in Adama City was within the WHO limit of 250 mg/L, although higher concentrations were reported in other regions [56]. Generally, the concentrations of sodium, calcium, magnesium, iron, manganese, and boron in Adama's groundwater sources were found within the WHO standards, similar to Sebeta town [49].

3.2. Multivariate statistics

The results presented in Table 3, derived from a Pearson correlation analysis using SPSS V. 24, highlight significant associations among various water quality chemical parameters. Notably, Total Hardness displayed a negative significant correlation with Electrical Conductivity (EC) but not significant correlations with other parameters. Ammonia (NH3) exhibited negative significant correlations with EC and pH. On the other hand, Ammonium (NH4) demonstrated a highly significant positive correlation with EC and highly significant negative correlations with pH, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS). Bicarbonate showed a negative significant correlation with Total Hardness and a significant correlation with Nitrate (NO3). Fluoride (F) displayed significant correlations with Bicarbonate and Nitrate. Sulfate (SO3) showed a highly significant correlation with EC and a significant correlation with Nitrate. Sodium (Na) exhibited significant correlations with Total Hardness, Fluoride, and Potassium (K). Potassium (K) demonstrated significant correlations with Fluoride, Sodium, and Calcium (Ca). Calcium (Ca) displayed a significant correlation with Potassium. Magnesium (Mg) showed significant correlations with Calcium and Iron (Fe). Iron (Fe) had negative significant correlations with Total Hardness and Magnesium. Manganese (Mn) exhibited a significant correlation with Calcium and Boron. Lastly, Boron showed highly significant correlations with Calcium and Manganese.

3.3. Hydrogeochemistry

Fig. 2, presented the distribution of water types based on their composition. The water types were categorized by the predominant ions present in the water samples. Among the water samples analyzed, 27.27 % were classified as Ca–Na–HCO3 type, indicated the presence of calcium, sodium, and bicarbonate ions as the major components. The Na–Ca–HCO3 type accounted for 36.36 % of the samples, signified a composition dominated by sodium, calcium, and bicarbonate ions. A smaller proportion, 9.09 % each, was classified as Na–Ca–Mg–HCO3 and Na–HCO3 types, suggested the presence of sodium, calcium, magnesium, and bicarbonate ions as the primary constituents. Lastly, Na–Mg–HCO3 type was identified in 18.18 % of the samples, indicated the prevalence of sodium, magnesium, and bicarbonate ions in the water composition. According to author [34] revealed that the predominant influence on the water in the Dera Ismail, was the rock weathering (Ca–Mg–HCO3) and followed by the Na–HCO3 type. This distribution of water types provided valuable information about the dominant ions presented in the water samples, which could be useful for various purposes such as water treatment, understanding the water chemistry, and assessing its suitability for specific applications (see Fig. 3).

Table 2

Physicochemical parameters of newly drilled boreholes for Adama City drinking water supply system.

S. N	Parameters	unit	BH07	BH10	BH12	BH13	BH14	BH15	BH22	BH23	BH24	BH25	BH26	mean	SD	Mean ± SD
1	PH		7.26	7.30	7.33	7.47	7.79	6.45	7.17	7.25	7.12	7.60	7.46	7.29	0.34	7.29 ± 0.34
2	Turbidity	NTU	4.51	8.91	2.20	0.90	1.20	1.49	1.99	5.64	1.77	1.00	1.33	2.81	2.53	2.81 ± 2.53
3	Electrical Conductivity	µs/cm	534.00	438.67	520.67	584.00	547.00	571.00	543.33	578.00	461.00	513.00	571.00	532.88	47.39	532.87 ± 47.39
4	TDS	mg/L	267.00	330.67	260.33	321.00	301.00	314.00	355.30	300.00	230.50	241.67	354.02	297.77	42.89	297.77 ± 42.89
5	Total Solids at 105°C	mg/L	400.00	173.33	233.33	223.28	223.00	223.50	160.00	308.00	65.00	224.00	223.34	223.34	83.70	223.34 ± 83.70
6	Total Alkalinity	mg/L	250.00	270.00	218.33	296.40	296.60	280.00	278.33	254.00	205.00	261.43	265.01	261.37	28.99	261.37 ± 28.99
7	Ca Hardness	mg/L	27.47	87.77	176.27	77.59	80.00	78.00	80.20	77.00	16.23	76.79	77.83	77.74	40.17	77.73 ± 40.17
8	Mg Hardness	mg/L	55.86	156.27	39.44	70.80	71.00	70.00	51.37	69.00	51.09	70.00	71.50	70.58	30.47	70.57 ± 30.47
9	Total Hardness	mg/L	83.33	127.03	45.76	148.00	169.68	157.56	166.87	138.00	67.31	204.44	179.02	135.18	49.95	135.18 ± 49.95
10	NH3	mg/L	0.00	0.00	0.00	0.25	0.04	0.04	0.06	0.03	0.00	0.00	0.04	0.04	0.08	0.04 ± 0.08
11	NH4+	mg/L	0.05	0.01	0.00	0.02	0.01	3.00	0.06	0.02	0.00	0.01	0.02	0.29	0.90	0.29 ± 0.90
12	Carbonate	mg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0 ± 0
13	Bicarbonate	mg/L	305.00	280.36	266.37	361.58	361.90	341.60	312.13	310.20	250.10	318.93	323.31	311.95	36.01	311.95 ± 36.01
14	Nitrate	mg/L	0.75	0.00	1.06	0.47	0.23	0.07	0.24	0.29	0.03	0.00	0.00	0.29	0.35	0.28 ± 0.35
15	Nitrite	mg/L	0.03	0.00	0.00	0.13	0.00	0.05	0.01	0.02	0.00	0.00	0.00	0.02	0.04	0.02 ± 0.04
16	Chloride	mg/L	9.00	28.87	11.50	9.70	12.00	0.00	34.83	6.09	8.75	13.60	17.92	13.84	10.05	13.84 ± 10.05
17	Fluoride	mg/L	0.13	0.17	0.09	0.10	1.10	1.00	0.23	1.00	0.08	1.03	1.34	0.57	0.52	0.56 ± 0.52
18	Sulfate	mg/L	3.46	3.37	3.34	11.95	14.96	13.34	4.03	6.63	4.90	1.10	5.77	6.62	4.64	6.62 ± 4.64
19	Sodium	mg/L	58.40	64.13	63.40	65.60	58.60	59.60	63.73	89.07	65.40	34.60	55.20	61.61	12.62	61.61 ± 12.62
20	Potassium	mg/L	17.77	14.07	11.08	18.00	16.30	15.73	13.83	22.19	3.16	2.03	12.50	13.33	6.10	13.33 ± 6.10
21	Calcium	mg/L	11.00	34.83	2.53	37.88	54.14	46.06	46.30	28.00	6.48	80.60	68.90	37.88	25.01	37.88 ± 25.01
22	Magnesium	mg/L	13.57	0.53	9.58	9.60	8.24	10.18	12.37	16.32	12.41	1.40	2.20	8.76	5.25	8.76 ± 5.25
23	Iron	mg/L	0.08	0.13	0.35	0.12	0.00	0.00	0.03	0.28	0.25	0.02	0.02	0.12	0.13	0.12 ± 0.13
24	Manganese	mg/L	0.11	0.00	0.02	0.02	0.00	0.00	0.13	0.09	0.00	0.00	0.00	0.03	0.05	0.03 ± 0.05
25	Boron	mg/L	0.00	0.00	0.00	0.10	0.21	0.31	0.00	0.00	0.00	0.07	0.06	0.07	0.11	0.06 ± 0.11
26	OH, Solids 105°C	mg/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0 ± 0

Table 3
Pearson correlation coefficients among water quality variables.

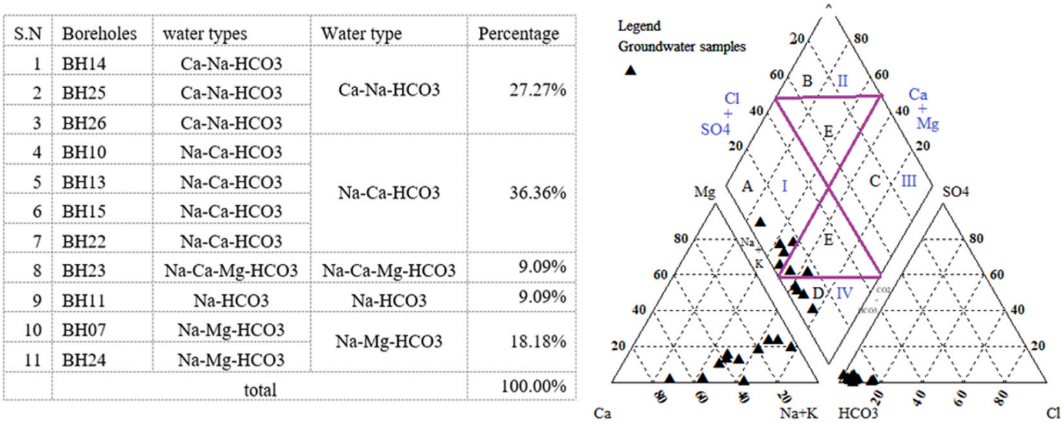
Test parameter		TRD	PH	EC	TDS	TS	TA	CH	M H	TH	NH3	NH4	Bic	NO2	NO3	Cl	Fl	SO3	Na	K	Ca	Mg	Fe	Mn	Bor
Turbidity	Pearson Correlation	1.00																							
	Sig. (2-tailed)																								
PH	Pearson Correlation	−0.08	1.00																						
	Sig. (2-tailed)	0.80																							
EC	Pearson Correlation	−0.47	−0.05	1.00																					
	Sig. (2-tailed)	0.12	0.89																						
TDS	Pearson Correlation	0.14	−0.08	0.39	1.00																				
	Sig. (2-tailed)	0.67	0.81	0.21																					
TS	Pearson Correlation	0.21	0.09	0.49	−0.01	1.00																			
	Sig. (2-tailed)	0.51	0.77	0.11	0.98																				
TA	Pearson Correlation	−0.10	0.16	0.49	0.678[a]	0.18	1.00																		
	Sig. (2-tailed)	0.77	0.63	0.11	0.02	0.58																			
MH	Pearson Correlation	0.713**	0.06	−0.45	0.36	−0.12	0.34	−0.03	1.00																
	Sig. (2-tailed)	0.01	0.85	0.14	0.25	0.71	0.27	0.94																	
TH	Pearson Correlation	−0.26	0.21	0.40	0.49	−0.02	0.757**	−0.07	0.23	1.00															
	Sig. (2-tailed)	0.41	0.52	0.20	0.11	0.96	0.00	0.84	0.46																
NH3	Pearson Correlation	−0.34	0.13	0.54	0.40	−0.02	0.57	−0.01	−0.05	0.26	1.00														
	Sig. (2-tailed)	0.28	0.70	0.07	0.20	0.95	0.05	0.98	0.88	0.42															
NH4	Pearson Correlation	−0.17	−0.821**	0.27	0.13	0.01	0.22	−0.01	−0.01	0.15	−0.01	1.00													
	Sig. (2-tailed)	0.59	0.00	0.39	0.68	0.98	0.49	0.97	0.98	0.64	0.98														
Bic	Pearson Correlation	−0.40	0.18	0.736**	0.46	0.32	0.897**	−0.03	0.00	0.717**	0.620[a]	0.28	1.00												
	Sig. (2-tailed)	0.20	0.58	0.01	0.13	0.32	0.00	0.92	0.99	0.01	0.03	0.38													
NO3	Pearson Correlation	−0.02	0.10	0.19	−0.25	0.51	−0.28	0.45	−0.47	−0.643[a]	0.08	−0.20	−0.15	1.00											
	Sig. (2-tailed)	0.95	0.76	0.56	0.43	0.09	0.38	0.14	0.13	0.02	0.80	0.53	0.64												
NO2	Pearson Correlation	−0.22	−0.16	0.52	0.22	0.17	0.46	−0.09	−0.05	0.09	0.903**	0.24	0.54	0.18	1.00										
	Sig. (2-tailed)	0.49	0.62	0.08	0.50	0.60	0.14	0.77	0.88	0.77	0.00	0.45	0.07	0.58											

(continued on next page)

Table 3 (*continued*)

Test parameter		TRD	PH	EC	TDS	TS	TA	CH	M H	TH	NH3	NH4	Bic	NO2	NO3	Cl	Fl	SO3	Na	K	Ca	Mg	Fe	Mn	Bor
F	Pearson Correlation	−0.26	0.11	0.47	0.22	0.17	0.37	0.03	0.02	0.708[a]	−0.14	0.28	0.52	−0.50	−0.22	−0.24	1.00								
	Sig. (2-tailed)	0.41	0.73	0.12	0.49	0.59	0.24	0.94	0.96	0.01	0.66	0.39	0.09	0.10	0.49	0.44									
SO3	Pearson Correlation	−0.35	−0.12	0.53	0.30	0.00	0.598[a]	−0.07	−0.03	0.26	0.53	0.48	0.725**	−0.10	0.51	−0.44	0.32	1.00							
	Sig. (2-tailed)	0.27	0.72	0.08	0.34	1.00	0.04	0.83	0.92	0.41	0.08	0.12	0.01	0.76	0.09	0.15	0.31								
Na	Pearson Correlation	0.44	−0.24	0.18	0.23	0.08	−0.12	−0.03	0.02	−0.38	0.16	−0.05	−0.15	0.20	0.19	−0.11	−0.20	0.21	1.00						
	Sig. (2-tailed)	0.16	0.45	0.57	0.47	0.79	0.72	0.93	0.96	0.23	0.62	0.87	0.64	0.52	0.55	0.73	0.53	0.52							
K	Pearson has Correlation	0.35	−0.11	0.58	0.55	0.596[a]	0.50	0.04	0.13	0.03	0.37	0.14	0.47	0.30	0.43	−0.11	0.07	0.48	0.655[a]	1.00					
	Sig. (2-tailed)	0.27	0.74	0.05	0.06	0.04	0.10	0.91	0.68	0.92	0.23	0.67	0.13	0.35	0.16	0.72	0.84	0.11	0.02						
Ca	Pearson Correlation	−0.32	0.28	0.29	0.39	−0.06	0.638[a]	0.02	0.22	0.962**	0.14	0.11	0.617[a]	−0.633[a]	−0.04	0.22	0.737**	0.15	−0.56	−0.16	1.00				
	Sig. (2-tailed)	0.30	0.38	0.36	0.21	0.85	0.03	0.95	0.48	0.00	0.67	0.73	0.03	0.03	0.90	0.49	0.01	0.65	0.06	0.62					
Mg	Pearson Correlation	−0.06	−0.35	0.35	−0.17	0.25	−0.23	−0.25	−0.598[a]	−0.44	0.11	0.10	−0.06	0.44	0.24	−0.37	−0.28	0.20	0.661[a]	0.44	−0.615[a]	1.00			
	Sig. (2-tailed)	0.86	0.26	0.26	0.59	0.43	0.47	0.43	0.04	0.16	0.73	0.76	0.85	0.16	0.45	0.23	0.38	0.53	0.02	0.16	0.03				
Fe	Pearson Correlation	0.30	−0.03	−0.26	−0.43	−0.07	−0.732**	0.31	−0.17	−0.774**	−0.15	−0.32	−0.684[a]	0.50	−0.08	−0.19	−0.47	−0.32	0.589[a]	−0.01	−0.767**	0.39	1.00		
	Sig. (2-tailed)	0.34	0.92	0.41	0.17	0.83	0.01	0.33	0.59	0.00	0.64	0.31	0.01	0.10	0.79	0.56	0.12	0.30	0.04	0.97	0.00	0.21			
Mn	Pearson Correlation	0.21	−0.11	0.27	0.20	0.43	0.02	−0.17	−0.32	−0.10	0.00	−0.20	−0.04	0.35	0.03	0.29	−0.28	−0.27	0.40	0.45	−0.26	0.643[a]	0.07	1.00	
	Sig. (2-tailed)	0.50	0.73	0.40	0.53	0.17	0.96	0.60	0.32	0.76	0.99	0.53	0.89	0.26	0.93	0.36	0.38	0.39	0.20	0.14	0.41	0.02	0.83		
Bor	Pearson Correlation	−0.44	−0.30	0.42	0.17	0.00	0.56	0.02	0.00	0.44	0.23	0.771**	0.688[a]	−0.26	0.30	−0.47	0.52	0.817**	−0.24	0.16	0.41	−0.09	−0.57	−0.44	1.00
	Sig. (2-tailed)	0.15	0.34	0.17	0.60	1.00	0.06	0.95	0.99	0.16	0.47	**0.00**	0.01	0.41	0.34	0.12	0.09	**0.00**	0.46	0.63	0.18	0.78	0.06	0.15	

[a] This indicated that the $p \leq 0.05$ which meant that significant whereas ** denoted that $p \leq 0.01$which has highly significant. TRD = Turbidity, EC = Electrical conductivity, TDS = Total dissolved solids, TS = Total solids, TA = Total alkalinity, CH= Calcium Hardness, MH = Magnesium Hardness, TH = Total Hardness, NH3= Ammonia, NH4= Ammonium, Bic = Bicarbonate, NO2= Nitrite, NO3= Nitrate, Cl= Chlorine, Fl = Fluoride, SO3= Sulfate, Na= Sodium, K= Potassium, Ca= Calcium, Mg = Magnesium, Fe= Iron, Mn = Manganese and Bor = Boron.



S.N	Boreholes	water types	Water type	Percentage
1	BH14	Ca-Na-HCO3	Ca-Na-HCO3	27.27%
2	BH25	Ca-Na-HCO3		
3	BH26	Ca-Na-HCO3		
4	BH10	Na-Ca-HCO3	Na-Ca-HCO3	36.36%
5	BH13	Na-Ca-HCO3		
6	BH15	Na-Ca-HCO3		
7	BH22	Na-Ca-HCO3		
8	BH23	Na-Ca-Mg-HCO3	Na-Ca-Mg-HCO3	9.09%
9	BH11	Na-HCO3	Na-HCO3	9.09%
10	BH07	Na-Mg-HCO3	Na-Mg-HCO3	18.18%
11	BH24	Na-Mg-HCO3		
	total			100.00%

Fig. 2. Groundwater Hydrogeochemistry of sampled boreholes in the study area.

3.4. *Groundwater drinking Water Quality Index*

The study calculated the Drinking Water Quality Index (WQI) for eleven boreholes assessing their suitability for drinking purposes and evaluated the overall impact of chemical components. Table 4 displayed the findings of the Water Quality Index (WQI) analysis conducted on groundwater sources, specifically boreholes (Figs. 3, 4 and 5). The finding revealed that 18.18 % of the boreholes attained the classification of "Excellent" quality, signified exceptional water conditions. In contrast, the majority, accounted for 81.82 % of the boreholes, were classified as "Good" quality, denoted favorable water quality within acceptable parameters. The assessment of the study area resulted in an overall WQI value of 56.11, implied good quality. The WQI provided a measure of the cumulative effect on drinking water. Author [28] revealed that WQI valued range from 35 to 135, with an average value of 63. These values categorized the water quality from excellent to poor in Hangu, Pakistan. Author [34] indicated that the spatial distribution of WQI indicated that most of the region's water resources exhibited good water quality, except for the southern region, which has poor water quality. The WQI values were notably better than those reported for groundwater in the Hangu district.

3.5. *Health risk assessment*

3.5.1. *Fluoride health risk assessment*

The hazard index (HI) was analyzed the age categories using Estimated Daily Intake (EDI) and Reference Dose (RfD) (see Fig. 5). The analysis in Fig. 6 revealed that in Adama City, there was no significant risk of fluoride exposure for children below 1 year old (HI: 0.704 ± 0.625), children aged 1–5 years (HI: 1.3763 ± 1.221), individuals aged 6–18 years (HI: 1.163 ± 1.032), individuals aged 18–34 years (HI: 1.627 ± 1.443), and individuals above 35 years old (HI: 1.497 ± 1.328) in Adama City. However, a study conducted in Agaro town by Ref. [36] discovered higher HI fluoride values, indicated a severe risk of fluorosis for children below 1 year (HI: 3.13), 1–5 years (HI: 6.1), and 6–18 years (HI: 5.16). Other studies, like the one by Ref. [57], considered an HI value ranging from 3 to 5 as indicative of adverse health effects due to fluoride exposure. According to author [58] discovered that Infants in Achhnera, India were highly susceptible to fluoride exposure, followed by children, while adults were less vulnerable. Author [45] revealed that Children exposed the highest fluoride HQ levels (0.7), followed by adolescents (0.5), infants (0.1), and adults (0.05), highlighting their vulnerability to health index.

Table 4
Groundwater water quality index and water type in study area.

No.	Borehole Names	WQI Range	Type of Water
1	BH07	51.04	Good
2	BH10	51.68	Good
3	BH12	48.14	Excellent
4	BH13	60.29	Good
5	BH14	63.68	Good
6	BH15	59.70	Good
7	BH22	57.21	Good
8	BH23	64.57	Good
9	BH24	42.37	Excellent
10	BH25	55.50	Good
11	BH26	63.00	Good
	overall	56.11	Good

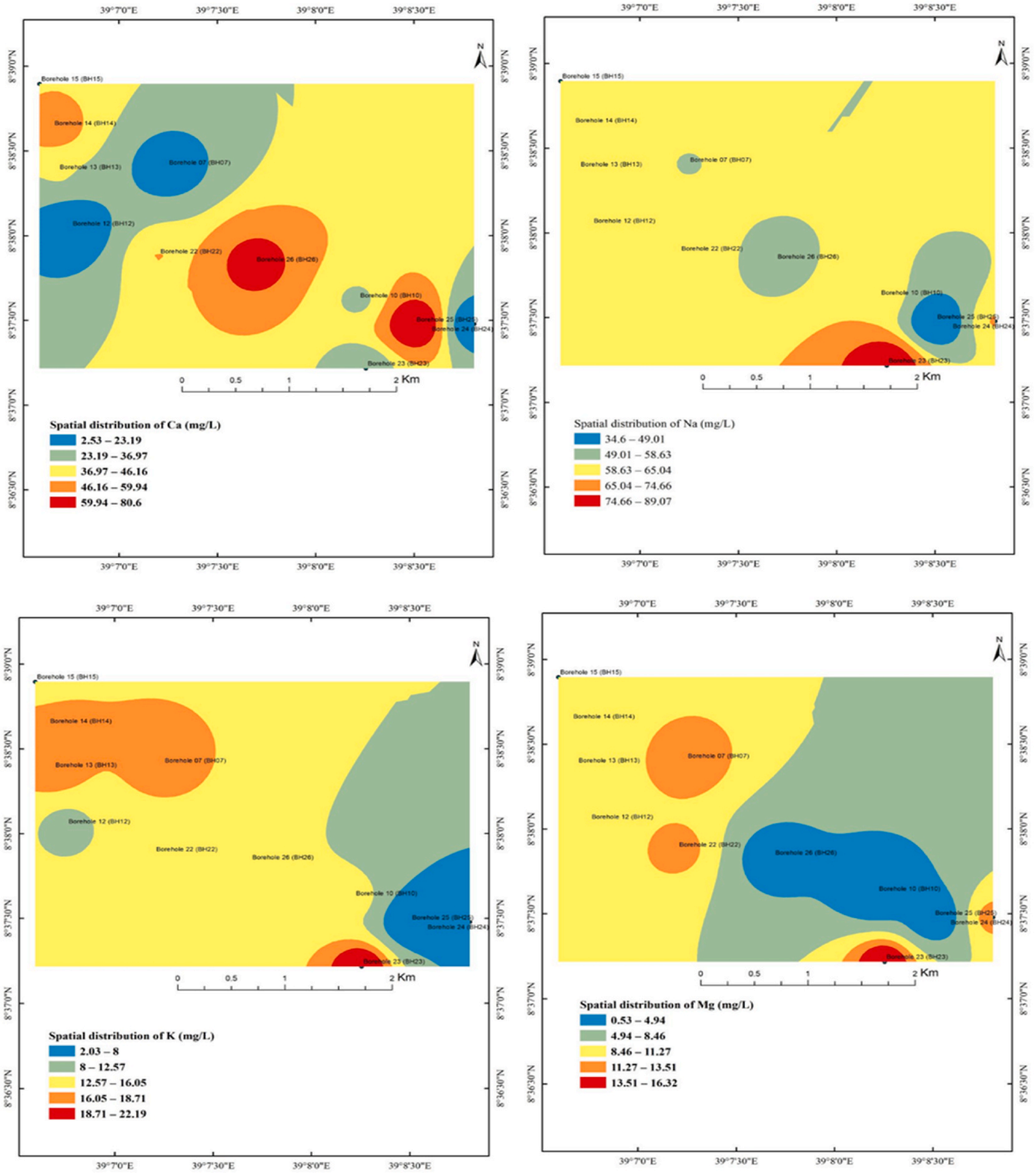


Fig. 3. Na, Ca, K and Mg Spatial Distribution of WQI in the study area.

3.5.2. *Iron health risk assessment*

The hazard index (HI) was analyzed the age categories using Estimated Daily Intake (EDI) and Reference Dose (RfD). Centered on the Health Index (HI) values in Fig. 7, there was no significant potential risk of iron exposure for children below 1 year old (HI: 0.551 ± 0.193), children aged 1–5 years (HI: 1.076 ± 0.378), individuals aged 6–18 years (HI: 0.909 ± 0.320), individuals aged 18–34 years (HI: 1.271 ± 0.447), and individuals above 35 years old (HI: 1.170 ± 0.411) in Adama City. However, author [59] found that the concentrations of iron exceeded the permissible limit values set by the World Health Organization (WHO) by 68 %. According to Ref. [60] stated hazard quotient (HQ) values for iron in water from Dadinkowa dam exceeded 1 for adults (HQ: 1.27) and children (HQ: 1.11), indicated values higher than the threshold. Conversely [61], noted that the hazard quotient (HQ) values for both children and adults were below one, suggested a relatively low health risk associated with drinking water in the Thulamela municipality, Limpopo Province, South Africa.

3.5.3. *Manganese health risk assessment*

In Fig. 8, the hazard index (HI) was calculated based on age categories using Estimated Daily Intake (EDI) and Reference Dose (RfD). The results indicated no significant potential health risks associated with manganese exposure across different age groups,

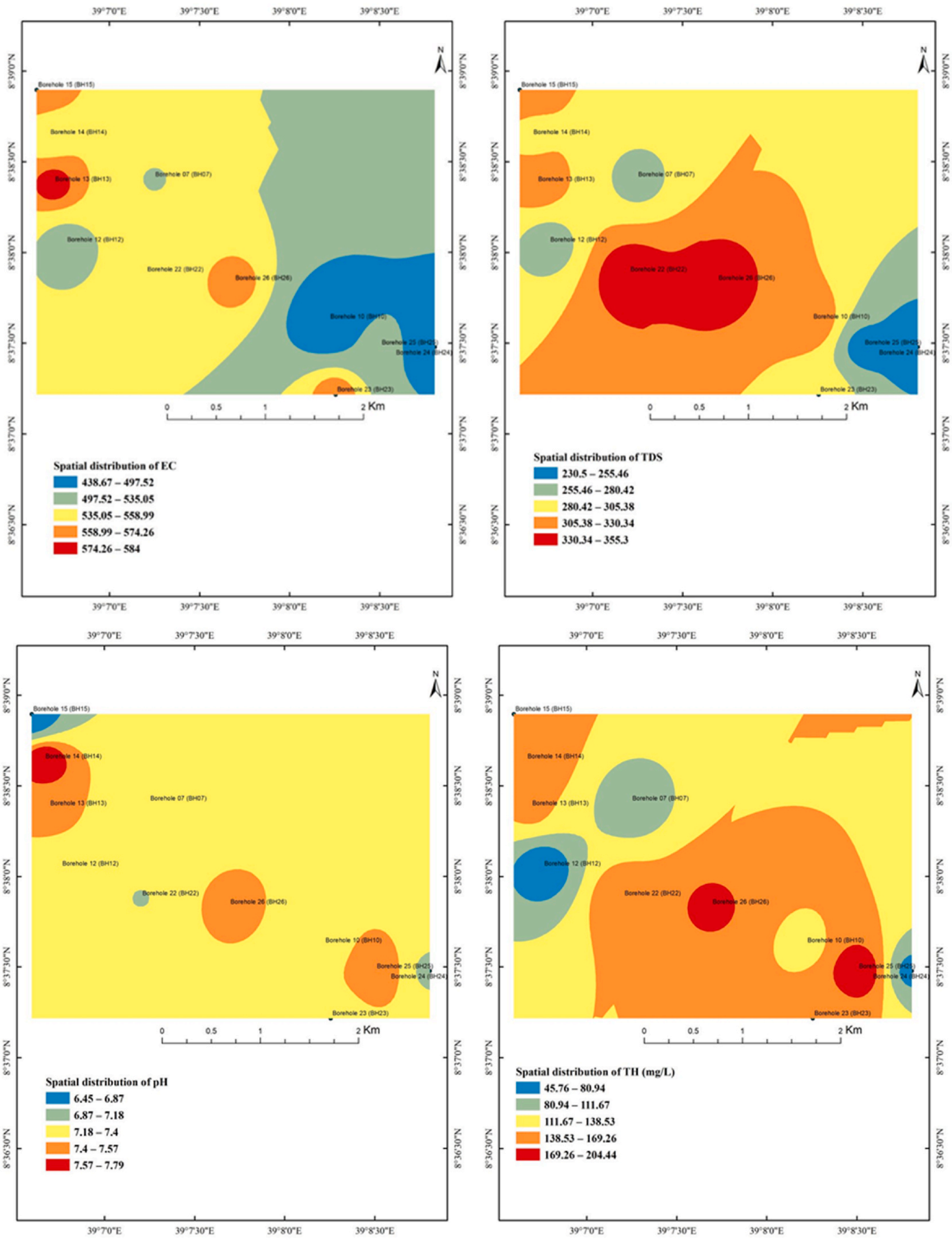


Fig. 4. EC, TDS, pH and TH Spatial Distribution of WQI in the study area.

including children below 1 year old (HI: 0.011 ± 0.005), children aged 1–5 years (HI: 0.021 ± 0.010), individuals aged 6–18 years (HI: 0.018 ± 0.008), individuals aged 18–34 years (HI: 0.025 ± 0.011), and individuals above 35 years old (HI: 0.023 ± 0.011). However, according to Ref. [60] found that manganese in water from Dadinkowa dam had hazard quotient (HQ) values of 1.07 for adults and 1.52 for children, indicating a risk of exposure to manganese as the HQ values exceeded unity. Dadinkowa dam's water had manganese the health risk reported by Ref. [60]. According to Ref. [45] discovered that the higher manganese levels posed the health risks for children in Shiraz, Iran.

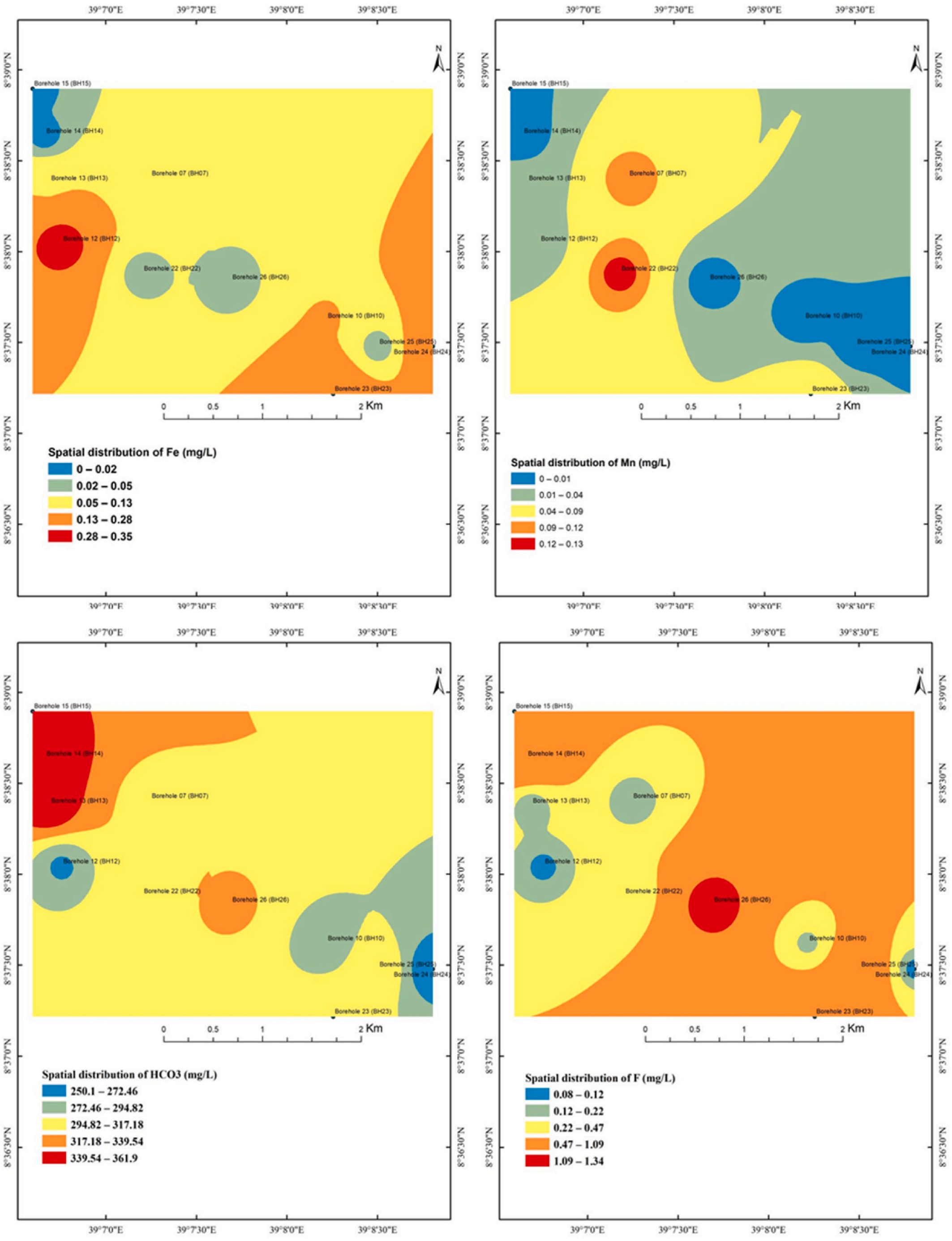


Fig. 5. Fe, Mn, HCO3 and F Spatial Distribution of WQI in the study area.

3.6. *Analysis of chlorine residual in the water distribution system*

The chlorine residual concentration decreased from the sources to far end of the water distribution system [62]. The residual chlorine concentration decreased whereas the combined chlorine concentration increased. Fig. 9 provided an overview of various parameters measured in a water sample, included free chlorine, total chlorine and combined chlorine. The minimum values observed for free chlorine, total chlorine, and combined chlorine are 0, indicating the absence of these chlorine compounds in the water sample. This implied that there was microbial growth in the water distribution system system [62,63]. The minimum temperature was 7.88 °C, and the minimum pH was 7.8. according to Ref. [62] reviewed that the most significantly factored the chlorine by the pH and

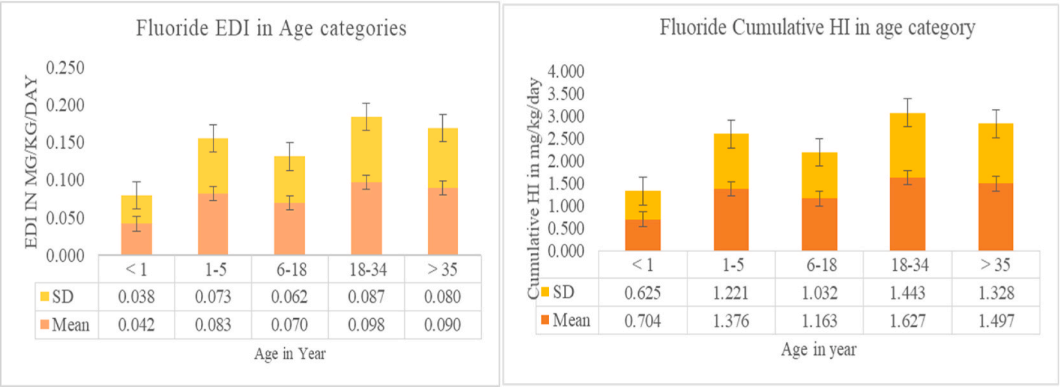


Fig. 6. Fluoride Estimated Daily Intake and cumulative Hazard Index of groundwater sources in age categories in Adama, 2023.

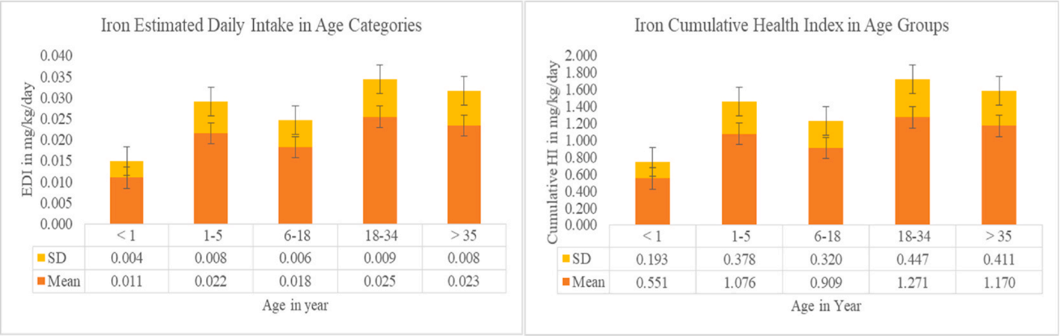


Fig. 7. Iron Estimated Daily Intake and cumulative HI of groundwater sources in age categories in Adama, 2023.

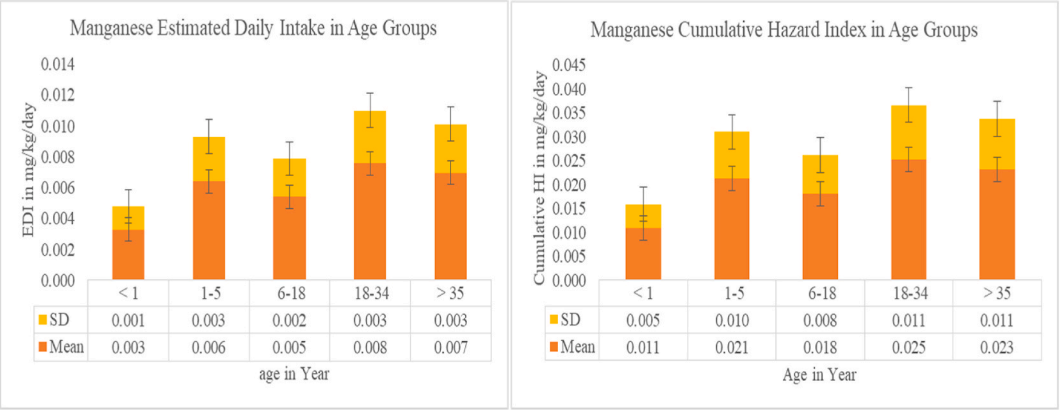


Fig. 8. Manganese Estimated Daily Intake and cumulative Hazard Index of groundwater sources in age categories in Adama, 2023.

temperature. The maximum values observed are 0.63 for free chlorine, 0.65 for total chlorine, and 0.37 for combined chlorine in Boku reservoir. The maximum temperature was 21.2 °C, and the maximum pH was 18.1. The mean values for these parameters were 0.149 for free chlorine, 0.95 for total chlorine, 0.23 for combined chlorine, 17.34 °C for temperature, and 8.68 for pH. These mean values provided an average representation of the concentrations or levels of the respective parameters in the water sample (see Fig. 10).

The measurement of free residual chlorine in the water distribution system indicated a decrease in levels as the water traveled further from the conventional drinking water treatment plant [64,65]. In Adama, 74 % (based on 37 sample results), discovered below the minimum value of 0.2–0.5 mg/L recommended by the World Health Organization for safe drinking water [30]. According to Ref. [62] reviewed that the excessive chlorine dosage could result in water that was corrosive to pipes and had an unpleasant taste and color. Conversely, insufficient chlorine dosage encouraged regrowth of microorganisms, increased risk of infections for consumers [41,

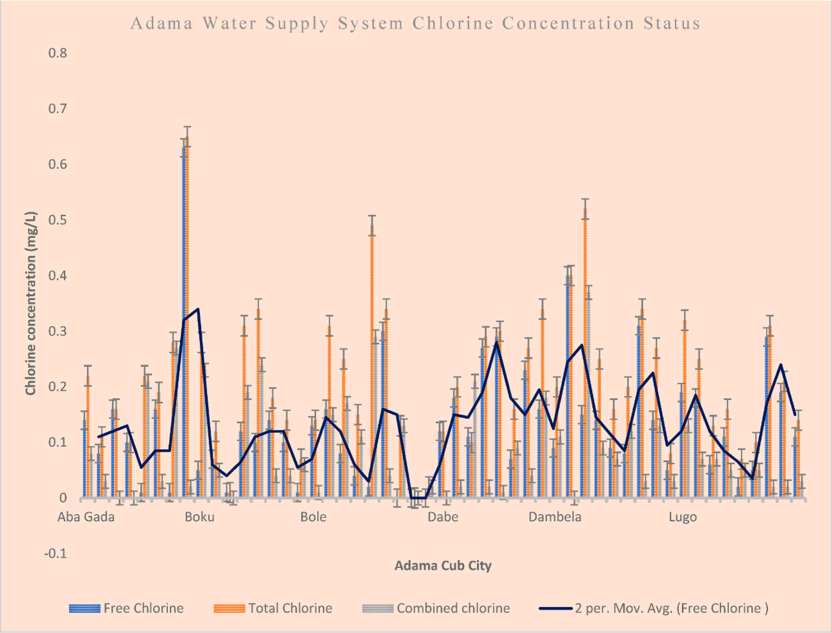


Fig. 9. Free, residual and combined chlorine concentration in water supply system of Adama City.

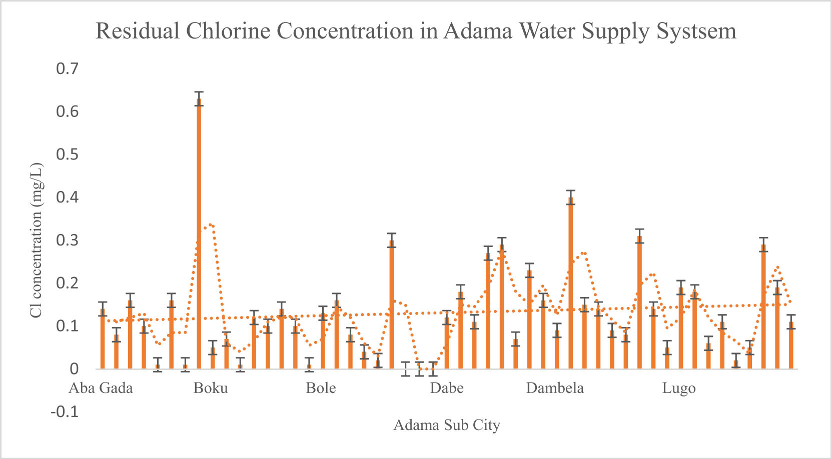


Fig. 10. The free residual chlorine concentration in water distribution system of Adama sub-cities.

66,67].

Fig. 11 presented detailed measurements of chlorine concentrations at different temperature levels in various locations. The locations included the Koka Water Treatment Plant after the chlorination process, Lugo Reservoir, Aba Gada Reservoir, and Geda Kebele. The concentrations of free residual chlorine (FRC), combined chlorine (CC), and total chlorine (TC) were notified for each location and temperature. According to Ref. [68] showed that chlorine concentration was varies with various of location and temperature. At lower temperatures (10 °C and 15 °C), the chlorine concentrations varied across the locations. The Koka Water treatment plant displayed different concentrations, while Lugo Reservoir, Aba Gada Reservoir, and Geda Kebele exhibited their own distinct measurements. As the temperature increased to 20 °C, 25 °C, and 30 °C, the chlorine concentrations continued to fluctuate across all locations. Similar results were supported this finding [62,69,70].

Fig. 12 presented the measurements of various parameters at different sample locations during the morning and afternoon periods. The sample locations included A/Geda Reservoir, Haile Resort, Lugo Reservoir, 03 Condominium, Dada Mole, 02 Reservoir, Daka Adi Reservoir, and Ali Birra Adebabay. For free chlorine, the measurements ranged from 0.03 mg/L to 3.10 mg/L. Total chlorine levels varied between 0.08 mg/L and 0.40 mg/L, while combined chlorine concentrations ranged from 0.01 mg/L to 0.53 mg/L. The pH values in all locations were within a narrow range of 7.94–8.04. The temperature measurements ranged from 16.3 °C to 20.9 °C. Different scholars revealed that the chlorine concentration varied with different location and temperatures [71–73].

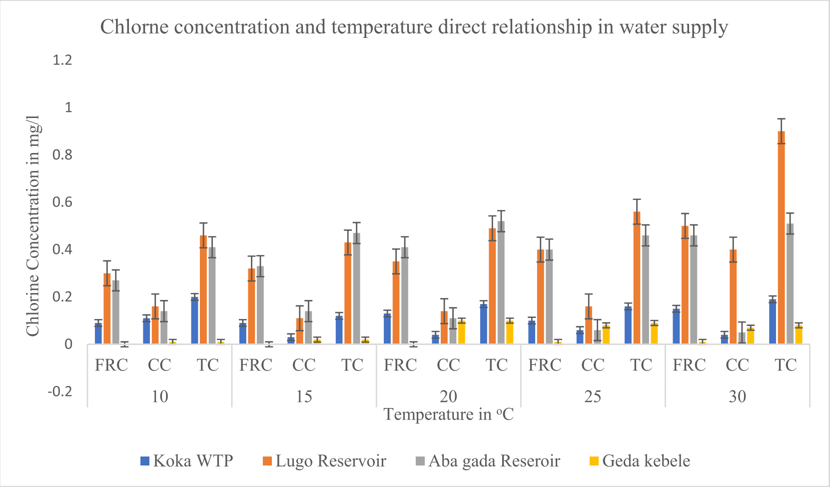


Fig. 11. Chlorine concentration in Water Supply system increased as the temperature rose from 10 °C to 30 °C.

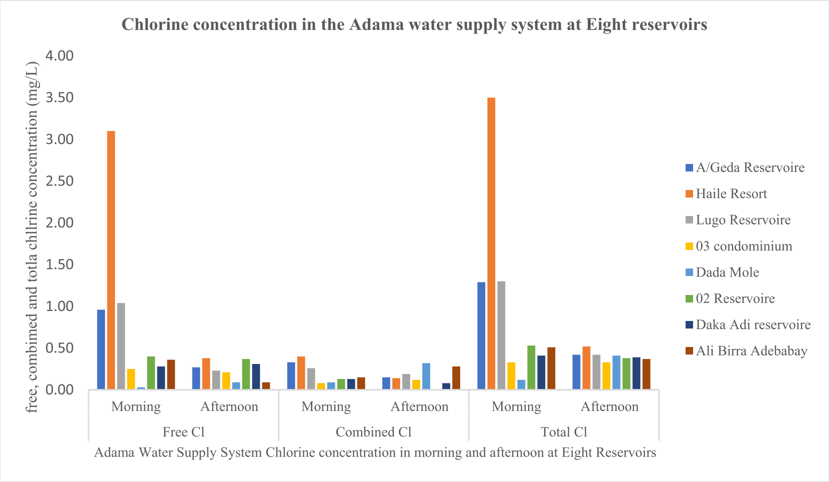


Fig. 12. Free residual, combined and total chlorine concentration in the morning and afternoon at eight reservoirs.

3.7. Modelling residual chlorine in water supply system via water CAD

According to Ref. [74] revealed that the hydraulic performance of water distribution system was poor in Adama City. In the modeling result of the residual chlorine concentration, Fig. 13, was below 0.2 mg/l in the water distribution. According to Ref. [75] revealed that the residual chlorine concentrations in the network during both testing periods were within the acceptable range of 0.4–0.7 mg/L the Adama Water Supply and Sewerage Enterprise should take immediate corrective action chlorine dosing at treatment sources.

4. Conclusions and recommendation

The mean total alkalinity and potassium concentration in Adama's borehole water exceeded the WHO recommended limits. However, the pH value was within the WHO range, indicating acceptable levels. The turbidity level was low, indicating clear water with minimal suspended particles, and the total dissolved solids concentration was below the WHO limit, indicating low levels of dissolved solids. Nitrate and nitrite levels were significantly below the WHO maximum permissible levels, and the concentrations of chloride, fluoride, and sulfate were within the WHO limits. Additionally, the concentrations of sodium, calcium, magnesium, iron, manganese, and boron in Adama's groundwater sources were found to be within the WHO standards.

The multivariate statistical analysis revealed significant associations among various water quality chemical parameters, providing insights into their relationships. Furthermore, the hydrogeochemical analysis categorized the water types based on their composition, indicating the dominant ions present in the samples. The identification of different water types based on the predominant ions present

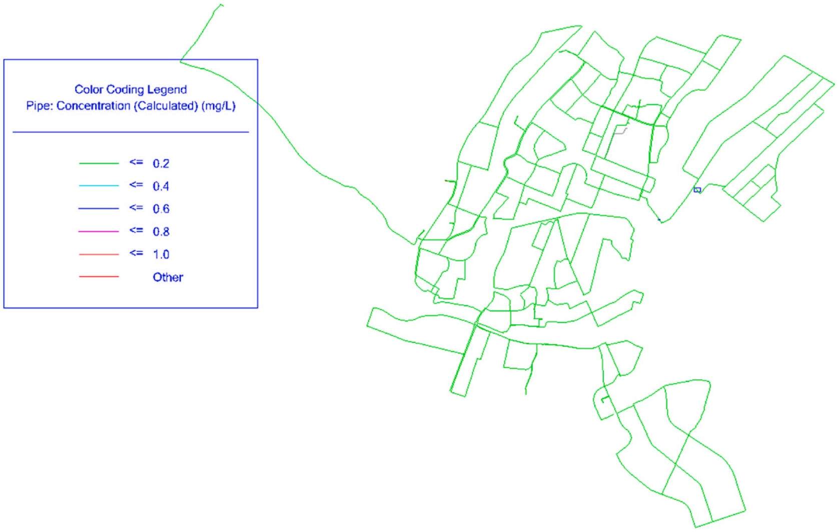


Fig. 13. Residual chlorine decay modelling of water distribution system of Adama city.

in the samples indicated that 27.27 % of the samples belonged to the Ca–Na–HCO3 type, while 36.36 % were classified as Na–Ca–HCO3 type. Besides, smaller proportions (9.09 % each) were identified as Na–Ca–Mg–HCO3 and Na–HCO3 types, and the Na–Mg–HCO3 type was present in 18.18 % of the samples. This information can be valuable for water treatment and assessing water suitability for specific applications.

The evaluation of the Drinking Water Quality Index (WQI) showed that the 81.82 % boreholes in Adama City had good water quality within acceptable parameters, with 18.18 % classified as excellent. The health risk assessments for fluoride, iron, and manganese exposure indicated no significant potential health risks across different age groups in Adama City. However, the analysis of chlorine residual in the water distribution system highlighted concentrations below the recommended level for safe drinking water, signified the need for corrective action in chlorine dosing at treatment sources. Overall, the study provided valuable insights into the groundwater quality characteristics in Adama City and underscored the importance of monitoring and maintaining water quality standards for the well-being of the population.

Funding

The fund is the self-sponsored of author for his PhD work.

Data availability statement

All relevant data are included in the paper or its Supplementary Information.

Limitation of research

Due to limited availability and high cost of the chemicals required, certain key heavy metals, including Cu, Pb, Zn, and Mercury, were not analyzed in this study. However, it is important to note that these parameters have significant contributions to chronic and carcinogenic health effects. Therefore, we recommend that future research should prioritize the analysis of these parameters and conduct a comprehensive health risk assessment.

CRediT authorship contribution statement

Abelkassim Beshir: Writing – review & editing, Investigation, Conceptualization. **Daniel Reddythota:** Writing – review & editing, Methodology. **Essays Alemayehu:** Supervision.

Declaration of competing interest

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

Acknowledgements

The authors wish to acknowledge the Main Advisory Prof. Dr. Ing: Esayas Alemayehu from Jimma University and Dr. Daniel Reddythota from Arba Minch University for making this research possible through the provision of technical advisory roles and support. Similarly, we are grateful to the research assistants and communities of Adama water supply sewerage service enterprise for provision of all necessary enquiry for the research work.

Appendence.

Table S1
Methods and instruments of Water quality parameter test in study area.

S.N.	Test parameter	Unit	Methodology	Instrument used
1	PH		Potentiometric	Digital pH Meter (+ electrode)
2	Turbidity	NTU	Turbidimetric	Compact Turbimeter plus
3	Electrical Conductivity	µs/cm	Potentiometric	Digital Conductivity Meter (+ electrode)
4	T. Dissolved Solid	mg/L	Potentiometric	Photometer 7500 BT
5	Total Alkalinity	mg/L as CaCO2	Titrimetric	Photometer 7500 BT
6	Ca Hardness	mg/l as CaCO2	Titrimetric	Photometer 7500 BT
7	Mg Hardness	mg/l as CaCO2	Titrimetric	Photometer 7500 BT
8	Total Hardness	mg/l as CaCO3	Titrimetric	Photometer 7500 BT
9	Ammonia (NH_3)	mg/l	Titrimetric	Photometer 7500 BT
10	Ammonium(NH_4^+)	mg/l	Titrimetric	Photometer 7500 BT
11	Carbonate (CO_3 $^{2-}$)	mg/l	Titrimetric	Photometer 7500 BT
12	Bicarbonate (HCO_3)	mg/l	Titrimetric	Photometer 7500 BT
13	Nitrate(NO_3)	mg/l	Photometric	Photometer 7500 BT
14	Nitrite(NO_2)	mg/l	Photometric	Photometer 7500 BT
15	Chloride (Cl^-)	mg/l	Mohr Argenometric	Photometer 7500 BT
16	Flouride (F)	mg/l	SPANDS	Photometer 7500 BT
17	Sulphate (SO_4^{2-})	mg/l	Titrimetric	Photometer 7500 BT
18	Sodium (Na)	mg/l	Spectrophotometric	Photometer 7500 BT
19	Potassium(K)	mg/l	Using analytik jena, novAA,800D AAS	Photometer 7500 BT
20	Calcium(Ca)	mg/l	Using analytik jena, novAA,800D AAS	Photometer 7500 BT
21	Magnsium(Mg)	mg/l	Using analytik jena, novAA,800D AAS	Photometer 7500 BT
22	Total Iron(Fe)	mg/l	Using analytik jena, novAA,800D AAS	Photometer 7500 BT
23	Manganese (Mn)	mg/l	Using analytik jena, novAA,800D AAS	Photometer 7500 BT
24	Boron(B)		Using analytik jena, novAA,800D AAS	Photometer 7500 BT

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