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A SYSTEMATIC REVIEW ON SUITABILITY OF GROUNDWATER FOR DRINKING PURPOSE IN ETHIOPIA

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ABSTRACT

This review evaluated evidence regarding the suitability of groundwater for drinking purposes across different regions in Ethiopia. It identified that the mean pH, Ca^{2+}, Cl^-, SO_4^{2-}, PO_4^{2-} and NO_3^- concentrations in all the reviewed studies were in compliance with the WHO standard limit. All the reviewed articles reported their maximum Ca^{2+} and PO_4^{2-} concentrations within the WHO standards, but the maximum concentrations of other parameters were beyond the WHO standard limit. The maximum concentrations of fluoride, bicarbonate, and potassium obtained in more than 50% of the reviewed articles were beyond the recommended WHO standard limit. Based on total dissolved solid (TDS) concentration, 80% of the reviewed articles indicated that the groundwater was suitable for drinking. The maximum potassium concentration obtained in 75% of the reviewed articles was beyond the WHO limit, which may result in elevated blood pressure and hypertension. The maximum fluoride concentrations obtained in 57.1% of reviewed articles were beyond the recommended WHO limit, which may result in dental and skeletal fluorosis. The published studies reviewed varied in terms of the type of groundwater source used, the number of parameters analyzed, the methods used, and the number of references used. Groundwater quality parameters should be monitored regularly before use to avoid any human health-related problems and ensure sustainable development across the country. Further detailed studies using physical, chemical, and bacteriological parameters should be needed on different groundwater sources to reduce any possible means for groundwater contamination.

KEYWORDS: Groundwater Quality, Drinking Water, Groundwater Contamination, Ethiopia, Standard Limit.

1. INTRODUCTION

Groundwater (GW) plays an essential role in maintaining sustainable human development. It is able to fulfill the water needs for two-thirds of the world's population.[1] It serves as a primary source for household uses, mostly in rural areas of the world, including developing nations.[2, 3] Groundwater is preferred as a main source of water supply when compared with surface waters, because of its stable spatiotemporal distribution, low bacterial contamination, low turbidity, and closeness to the community.[4] However, its quality may be deteriorated because of human activities (industrial effluent, wastewater irrigation, land cover change, urbanization, and agriculture activities such as excessive use of fertilizer and pesticide)[5-8] and natural factors (geologic structures and hydrogeological settings).[8, 9]

Excess concentrations of water quality parameters such as nitrogen,[8, 10-12] fluorine,[12-14] arsenic,[15] dissolved solids,[9, 16] hardness (salts of calcium (Ca) and magnesium (Mg)),[8,9,16] iron,[8] manganese,[8] sodium,[9] and sulfate,[9] were discovered in studies.

Different communities in Ethiopia, mostly in rural areas, are using drinking water from borehole groundwater sources, shallow wells, and springs.[17] Groundwater is also heavily used as a drinking water supply across Ethiopian rift valley areas.[18] The groundwater chemistry in the Ethiopian rift valley revealed that the chemical composition of groundwater across the rift valley aquifers is different. Many researchers have reported high fluoride (F^-) concentrations in the groundwater of the rift valley.[19-22] The sources of groundwater pollution are volcanic aquifers as sources for fluoride in the great rift valley,[23] liquid waste discharges from cities in the rift valley (for example, pollution of groundwater in the Dire Dawa groundwater basin),[24] untreated waste discharge to rivers in Addis Ababa,[25] and pollution of groundwater by anthropogenic activities in the Matahara region.[26] In general, studies revealed that groundwater is contaminated due to uncontrolled waste management, poor management, and the use of fertilizers in Ethiopia.

Groundwater treatment needs adequate knowledge, skills, and resources.[27] As a result, regular monitoring and a detailed evaluation of its quality will provide an early warning of contamination and the need for costly cleanup. This literature review is conducted to evaluate evidence regarding the suitability of groundwater quality for drinking purposes in different parts of Ethiopia. Ethiopian-published groundwater quality studies were downloaded and reviewed. The maximum value, minimum value, and average value for each parameter from each of the studies were gathered and compared with the standards. The reviews were focused on three main things. First, it evaluated evidence regarding the suitability of groundwater quality for drinking in different parts of Ethiopia using standards. Second, it pointed out the real differences among different studies done in Ethiopia in evaluating the suitability of groundwater for drinking purposes. Third, it suggests new directions for improving groundwater quality and raising the quality of research and findings in the eyes of scientific scholars.

2. REVIEW METHOD

Research articles in relation to groundwater quality were reviewed for suitability for drinking purposes. The search terms used for the paper download were "groundwater in Ethiopia, groundwater quality in Ethiopia, and suitability of groundwater for drinking purposes in Ethiopia." Articles that were published in reputable journals and those that analyzed more than five water quality parameters were selected. Finally, ten articles were selected and reviewed based on their focus on groundwater quality.

The reviewed studies were mainly conducted in three regions of Ethiopia, such as the Oromia region, the Tigray region, and the SNNP region (Table 1).

Table 1: Geographic areas in which the reviewed studies were conducted.

Title of the research	Study areas	Reference
The Secret of the Main Campus Water-Wells	Arba Minch City in SNNP region, Main Campus Water-Wells	[28]
Determination of the Physicochemical Quality of Groundwater and its Potential Health Risk for Drinking	Sebeta Hawas special Zone in Oromia Region	[29]
Evaluation of Groundwater Quality and Suitability for Drinking and Irrigation Purposes Using a Hydrochemical Approach	Raya Valley, Tigray Regional State	[30]
Groundwater Quality Assessment Using Geospatial Techniques and WQI	North-East of Adama Town, Oromia Region	[22]
Evaluation of groundwater quality for drinking and irrigation purposes using a GIS-based water quality index	Abaya-Chemo sub-basin of Great Rift Valley in SNNP region	[31]
Potential Human Health Risks Due to Groundwater Fluoride Contamination: A Case Study Using Multi-techniques Approaches (GWQI, FPI, GIS, HHRA)	Bilate River Basin of Southern Main Ethiopian Rift, Ethiopia	[32]
Groundwater quality assessment using the water quality index and GIS technique	Modjo River Basin, Oromia Region, Ethiopia	[33]
Groundwater Quality in an Upland Agricultural Watershed in the Sub-Humid Ethiopian Highlands	Upper Lake Tana basin of the Ethiopian highlands	[34]
Groundwater Quality and Its Health Impact: An Assessment of Dental Fluorosis in Rural Inhabitants of the Main Ethiopian Rift	Ziway-Shala and Abaya-Chamo basins, and a small catchment (Awasa) located in the central sector of the Main Ethiopian Rift (MER) valley	[35]
Shallow Groundwater Quality and Human Health Risk Assessment	Derashe Special Woreda in SNNP region, Holte town	[36]

3. QUALITY OF GROUNDWATER IN COMPARISON WITH STANDARDS

Based on the reviewed articles, the calcium and phosphate concentrations of all the research are within the recommended WHO standard limit. The maximum concentrations obtained for electrical conductivity, pH, total dissolved solids, total hardness, total alkalinity, nitrate, sulfate, sodium, and magnesium in 50-70% of the reviewed articles were within the recommended WHO standard limit. The maximum concentrations identified for fluoride, bicarbonate, and potassium in more than 50% of the reviewed articles were beyond the recommended WHO standard limit (Table 2).

Table 2: Concentration of groundwater quality parameters of the reviewed articles in comparison with standards

Water Quality Parameters	Research findings with respective References (Minimum-Maximum value) (Average)										WHO limit [37]	Ethiopian limit[38]	%) articles with values Within WHO limit
	[28]	[29]	[30]	[22]	[31]	[32]	[33]	[34]	[35]	[36]			
Ca^{2+} (mg/l)	35-83 (46)	4-59 (23.8)	5-168 (66)	11-116 (51)	10.4-32 (18.7)	8-61.6 (22.7)	3.2 - 174.8 (53.6)	8.0-68.5 (25.6)	2.5-41.3 (13.1)	4.81–28.86 (18.55)	**300**	**75**	*100*
Mg^{2+} (mg/l)	13-164 (70)	0-15.7 (6.4)	2-565 (42)	2.4-52.3 (13)	11.1-46.2 (25.6)	0.6-20.5 (7.5)	0.5-25 (14.8)	1.3-15.3 (8.2)	-----	24.3–82.62 (37.49)	**50**	**50**	*55.5*
Na^{+} (mg/l)	15.8-142.9 (87)	0-150 (48.2)	1-940 (72)	57-214 (102)	11-156.6 (61.2)	7-106 (43.5)	32.6 – 208 (81.2)	-----	-----	184.8–335.8 (314.57)	**200**	**200**	*50*
K^{+} (mg/l)	1.6-2.4 (1.9)	3.4-29 (11.9)	0-218 (5)	5.9-31.5 (14.7)	1- 4.1 (1.75)	4.3-19 (11.4)	3.6 – 35 (15.3)	-----	-----	10.5–134 (58.56)	**12**	**1.5**	*25*
Cl^{-} (mg/l)	16-257.6 (104)	1.4-25 (3.7)	6-576 (50)	-----	18-120 (54)	1.2-35.1 (7.4)	7.4-35.5 (17.6)	-----	-----	51.3–465.9 (139.59)	**250**	**250**	*57.1*
SO_4^{2-} (mg/l)	18.4-31.0 (27)	0-19 (5)	1-1820 (68)	0.8-496 (83.5)	10.6-303.8 (149.4)	0-74.9 (6)	0- 114.1 (24)	-----	-----	7.06–21.47 (16.64)	**250**	**250**	*62.5*
NO_3^{-} (mg/l)	37.4-40.8 (45.7)	3.4-17.5 (9)	-----	-----	3.6-53.3 (35.8)	0.1-69.5 (6)	0.3-85.5 (8.9)	0.32-4.47 (1.4)	-----	-----	**50**	-----	*50*
TA (mg/l)	9.5-22.0 (17.6)	15-450 (185)	-----	-----	156-552 (293)	-----	-----	-----	-----	600–920 (766)	**500**	**200**	*50*
TH (mg/l)	55-200 (117)	15-200 (74)	25-2402 (327)	-----	65.6-198 (136.4)	24.2-209 (87.5)	-----	-----	-----	112–412 (201)	**300**	**300**	*66.7*
TDS (mg/l)	168-659 (433)	111-451(201)	204 - 2437 (514)	141 – 556 (341)	138.8-688.0 (319.5)	126.1-492.8 (300)	240-1030 (448)	34.5-344.0 (163.75)	480-2705 (1476)	1790–2500 (2051)	**1000**	**1000**	*60*
pH	6.8-7.6 (7.2)	5.5-8.0 (7.0)	7.0-8.0 (8)	7.3-8.4 (8)	7.1-7.9 (7.7)	5.6-8.2 (7.2)	6.5-8.2(7.2)	6.5-8.5 (7.5)	7-8.9 (7.95)	7.8–8.1 (7.99)	**6.5–8.5**	**6.5–8.5**	*70*
EC (µS/cm)	349-1326 (878)	108-894 (616)	308-3800 (813)	221 – 869 (532)	290-1382 (607)	197–770 (469)	366-1528 (706)	59.5-505.9 (251)	470-2847 (1567)	3580–4980 (4109)	**1500**	-----	*60*
HCO_3^{2-} (mg/l)	9.5-26.6 (17)	0-372 (198)	34-1127 (391)	256-350 (283.5)	128–528 (266)	26.8-622.6 (338)	224-1000 (416)	-----	-----	600–920 (766)	**500**	-----	*37.5*
F^{-} (mg/l)	-----	0.12-5 (1.15)	-----	0.88-1.5 (0.95)	0.02-0.60 (0.24)	0.2-5.6 (2.1)	0.4-3.7 (0.9)	-----	1.1-18 (9.6)	0.00–0.21 (.06)	**1.5**	**1.5**	*42.9*
PO_4^{2-}	-----	0.10-1.98 (1)	-----	-----	0.00-0.46 (0.22)	-----	0.2-1.5 (0.4)	-----	-----	-----	**10**	-----	*100*

TA indicates total alkalinity value; TH is total hardness value; TDS is total dissolved value; EC is electrical conductive

4. GROUNDWATER SUITABILITY BASED ON TDS CONCENTRATION

Using the total dissolved solids (TDS) concentration of the groundwater quality, the mean TDS concentration of eight of the ten reviewed articles indicated that the groundwater is suitable for drinking, however, the maximum TDS concentration obtained in six of the ten reviewed articles indicated that the groundwater is suitable for drinking. Table 3 below shows the suitability of groundwater for drinking categories based on TDS.[31, 40]

Table 3: Suitability of groundwater for drinking based on TDS.

TDS (mg/l)	*Water class*	Categories based on maximum and mean value of the research findings, respectively																			
		(28)		(29)		(30)		(22)		(31)		(32)		(33)		(35)		(36)		(34)	
		Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean
<500	Desirable for drinking		●	●	●				●		●	●	●		●					●	●
500–1000	Permissible for drinking	●					●	●		●											
>1000	Unfit for drinking					●								●		●	●	●	●		

● is used to indicate the ground water quality category for drinking purpose using TDS values of the research findings; Maximum is the maximum TDS value obtained under each research; Mean is the average TDS value of each research

5. HEALTH EFFECT OF EACH PARAMETER IN COMPARISON WITH THE FINDINGS

The maximum potassium concentration found in 75% of reviewed articles was beyond the recommended WHO limit, which may result in elevated blood pressure and hypertension. It may also result in shortness of breath and chest pain. The maximum fluoride concentration obtained in 57.1% of reviewed articles was beyond the recommended limit, which may cause dental fluorosis, skeletal fluorosis, bone damage, and chronic issues. The maximum nitrate concentration in 50% of reviewed articles was beyond the recommended limit, may cause methemoglobinemia, an increase in heart rate, and abdominal cramp (Table 4).

Table 4: Water quality parameters exceeding limits and related health effects.[31, 41, 42]

Parameter	WHO limit [37]	Number of studies with maximum findings above the limit (refer to table 2)	If it exceeds the maximum level, it has a negative impact on one's health.
Mg^{2+} (mg/l)	50	4 out of 9 (44.4%)	It may result in extreme fatigue and high blood pressure. A coma may also occur.
Na^{+} (mg/l)	200	4 out of 8 (50%)	It may lead to high blood pressure, heart disease, and stroke. It can increase the risk of hypertension.
K^{+} (mg/l)	12	6 out of 8 (75%)	Elevated blood pressure and hypertension. It may result in shortness of breath and chest pain.
Cl^{-} (mg/l)	250	3 out of 7 (42.9%)	It affects taste, indigestion, and palatability.
SO_4^{2-} (mg/l)	250	3 out of 8 (37.5%)	It may cause gastrointestinal irritation.
NO_3^{-} (mg/l)	50	3 out of 6 (50%)	It may cause methemoglobinemia, an increase in heart rate, and abdominal cramps.
TDS (mg/l)	1000	4 out of 10 (40%)	Palatability decreases and may cause gastrointestinal irritation.
pH	6.5–8.5	3 out of 10 (30%)	Taste effects. High-acid water may cause kidney disease, liver disease, stomach cramps, and diarrhea.
F^{-} (mg/l)	1.5	4 out of 7 (57.1%)	It may cause dental fluorosis, skeletal fluorosis, bone damage, and chronic issues.

6. DIFFERENCES BETWEEN REVIEWED ARTICLES

The studies reviewed were different in their objectives, type of groundwater source used, number of parameters analyzed, methods utilized, and number of references used. Types of groundwater used in the studies were deep groundwater wells, borehole groundwater sources, shallow wells, pumping groundwater wells, tapping wells, tapping springs, cold springs, and geothermal springs. The numbers of groundwater quality parameters analyzed in the reviewed papers ranged from 10 to 30, and the numbers of samples analyzed were from 7 to 148. The number of references each reviewed article used ranged from 24 to 104 (Table 5).

Table 5: Differences in reviewed research articles.

References	Purpose of the studies	Differences among the reviewed studies					
		Type of groundwater	Parameters analyzed	Samples analyzed	Methods used	References used	Key findings of the studies
[28]	Assessing the actual concentration of the main groundwater quality parameters	Deep groundwater wells	13	7	Water quality analysis Ethiopian Standard Agency maximum permissible limit Degree of hardness	24	Groundwater wells of main campus are harder than Arbaminch town
[29]	Determining the physicochemical quality of groundwater and its potential health risk	Borehole groundwater source	30	102	Water quality analysis Ethiopian Standard Agency maximum permissible limit World Health Organization (WHO) permissible limits	48	Borehole drinking water is in compliance with the WHO standard Potassium, iron, fluoride, and phosphate of most sources were above the limit
[31]	Evaluating the groundwater quality and its suitability for drinking and irrigation purposes	Deep wells	11	30	Water quality analysis Ethiopian Standard Agency maximum permissible limit World Health Organization (WHO) permissible limits	38	Except Mg^{2+}, Ca^{2+} and K^{+}, all parameters are within the Ethiopian standard limit
[34]	Investigating the spatial and temporal variation of groundwater quality	Shallow wells	10	19	Water quality analysis World Health Organization (WHO) permissible limits Seasonal and spatial two-way multivariate analysis of shallow groundwater quality	40	The concentrations of dissolved ion species and E. coli level is greater in the rainy season than dry season. Concentrations of dissolved ion species and E. coli levels increased from the top to the valley bottom of the watershed
[22]	Analysis of spatial variation of physicochemical parameters	Pumping groundwater wells	11	7	Water quality analysis Ethiopian Standard Agency maximum permissible limit World Health Organization (WHO) standard guideline Water Quality Index (WQI) calculated	104	Except for Adama Science and Technology University well 2, all samples are below the desirable limits of the WHO. Water quality index (WQI) results indicated that 85% of samples and 15% of samples were in good and poor categories, respectively
[31]	Evaluate the groundwater quality status and their spatial distribution with respect to the	Tapping wells and a spring	15	14	Water quality analysis Ethiopian Standard Agency maximum permissible limit World Health Organization (WHO)	44	The groundwater is suitable for drinking and irrigation purposes except for a few sites WQI results revealed that 7% and 64% of

	suitability for drinking and irrigation purposes				standard guideline Suitability of groundwater for drinking based on TDS Water quality index (WQI)		samples fall from excellent to good classes for drinking categories, respectively
[35]	Assessing the link between fluoride content in groundwater and its impact on dental Health	Groundwater wells, cold springs, geothermal springs and lakes	10	148	Water quality analysis World Health Organization (WHO) standard guideline Prevalence and severity of dental fluorosis were assessed Multivariate analysis of associations between fluoride level and dental fluorosis	77	Wells had high fluoride, exceeding the WHO drinking water guideline limit of 1.5 mg/L Sixty percent of the teeth exhibited loss of the outermost enamel No any correlation between fluoride content and dental fluorosis
[32]	Examining the appropriateness of groundwater resources for drinking purposes	Shallow and deep wells	14	29	Water quality analysis World Health Organization (WHO) standard guideline Water quality index (WQI)	102	Based on the WQI, the quality of groundwater samples was 31% excellent, 21% good, 31% poor, and 17% very poor The fluoride concentration of 59% groundwater samples were surpassed the limit
[33]	Determining suitability of groundwater for drinking and irrigation uses	Pumping wells	13	31	Water quality analysis World Health Organization (WHO) standard guideline Water quality index (WQI)	94	The water quality index showed 3.23% and 93.54% of groundwater samples fall within excellent and good water quality, respectively, and 3.23% falling within poor water quality
[36]	Evaluating groundwater quality and human health risk	Pumping shallow groundwater wells	13	7	Water quality analysis Ethiopian Standard Agency maximum permissible limit World Health Organization (WHO) standard guideline Water quality index (WQI)	65	The WQI result showed that 57.1% of groundwater samples had acceptable water quality, but 42.9% had poor water quality

7. PHYSICOCHEMICAL CHARACTERISTICS OF GROUNDWATER

7.1. Total dissolved solids concentration

It was noted that a TDS value of less than 1000 mg/L is suitable based on the WHO guidelines. The mean TDS value of the groundwater in 80% of the reviewed articles was within the standards, however, the maximum TDS concentration in 60% of the reviewed articles was also within the standards (Table 2).

7.2. pH of groundwater

Based on the WHO standard, the pH value of drinking water should be between 6.5 and 8.5. The mean pH values of all the reviewed articles were within the recommended standard. Only the pH values of the three reviewed studies were below or above the recommended limits (Table 2).

7.3. Electrical conductivity (EC)

According to WHO standards, the maximum permissible limit for electrical conductivity (EC) in drinking water should be 1500 mg/L. The mean EC value of 80% of the reviewed studies was within the standard. Four of the ten reviewed studies have shown a maximum EC value beyond the standard (Table 2).

7.4. Total hardness (TH) of groundwater

The maximum permissible limit of TH in drinking water should be 300 mg/L, as recommended on the WHO guideline. The mean value of TH in groundwater in one of the six reviewed studies was beyond the standard. Two of the six studies have shown a maximum TH value greater than the standard (Table 2).

7.5. Total Alkalinity (TA) of groundwater

Alkalinity is an important water quality parameter that measures the capacity of neutralizing acids. According to the WHO, the maximum standard limit for TA in drinking water must be 500 mg/L. The mean value of TA in the groundwater in one of the five studies was above the standard. The maximum values of TA in two of the five studies were above the standard (Table 2).

7.6. Calcium (Ca^{2+}) concentration

The hardness of groundwater is determined by calcium (Ca2+). It functions as a pH stabilizer and gives water a better taste. According to the WHO, the maximum permissible limit for Ca^{2+} in drinking water should be 300 mg/L. All of the reviewed articles have both the mean and maximum Ca^{2+} concentration within the standards (Table 2).

7.7. Magnesium (Mg^{2+}) concentration

Based on the WHO standards, the maximum permissible limit for Mg^{2+} in drinking water should be 50 mg/L. One out of the nine reviewed papers has mean Mg^{2+} value above 50 mg/L. Three out of the nine papers reported a maximum Mg^{2+} value beyond the WHO limit (Table 2). Basalt that contains minerals like olivine, pyroxenes, and amphibole may be a source for higher Mg^{2+} concentrations in groundwater.[22, 43]

7.8. Sodium (Na^+) concentration

Based on the WHO standards, the maximum permissible limit for Na^+ in drinking water should be 200 mg/L. One of the eight reviewed articles identified a mean sodium concentration beyond the limit, and four of the eight reviewed articles reported a maximum sodium concentration above the limit (Table 2). Higher sodium concentrations in groundwater may be caused by deep percolation of water from topsoil layers due to longer residence time, as well as water-rock interactions.[22, 44]

7.9. Potassium (K^+) concentration

According to the WHO standards, the potassium concentration in drinking water should be below 12 mg/L to be in a good zone for drinking. Three of the eight articles reported a mean potassium concentration in groundwater above the good zone. Six out of the eight studies reported a maximum K^+ value above the WHO limit (Table 2).

7.10. Bicarbonate (HCO_3^-) concentration

Based on WHO standards, the permissible limit for HCO_3^- in drinking water should be 500 mg/L. One of eight studies reported a mean bicarbonate concentration above the recommended standards, and 37.5% of the eight reviewed studies showed a maximum HCO_3^- concentration within the standard limit (Table 2). According to research, the silicate and carbonate weathering processes may contribute to higher bicarbonate concentrations in groundwater (45). The magmatic release of CO_2 by the active fault zones could be a possible source for higher HCO_3^- concentrations in groundwater.[22, 46]

7.11. Chloride (Cl^-) concentration

According to the WHO standard, the maximum permissible limit for Cl^- in drinking water should be 250 mg/L. All the reviewed studies reported mean chloride concentrations in groundwater below the recommended WHO standard, but three of the seven reviewed studies reported maximum chloride concentrations in groundwater above the recommended WHO standard (Table 2). Chloride may originate from water-soluble chloride salts present in minerals. Sources of higher chloride in groundwater may be rainwater, weathering, and leaching of domestic effluents.

7.12. Sulphate (SO_4^{2-}) concentration

According to the WHO standards, the maximum standard limit for SO_4^{2-} in drinking water should be 250 mg/L. All the reviewed studies reported a mean SO_4^{2-} concentration in groundwater below the recommended WHO standard, but three of the eight reviewed studies reported a maximum SO_4^{2-} concentration beyond the recommended WHO standard (Table 2).

7.13. Fluoride (F^-) concentration

Based on the WHO standards, the maximum permissible limit for F^- in drinking water should be 1.5 mg/L (see table 5). Two of the seven studies reported mean fluoride concentrations in groundwater above WHO standards, and four of the seven studies reported maximum fluoride concentrations in groundwater above the desirable limit of WHO standards (Table 2).

7.14. Phosphate (PO_4^{2-}) concentration

The maximum standard limit based on the WHO guideline for PO_4^{2-} in drinking water should be 10 mg/L (see table 5). Both the mean and maximum PO_4^{2-} concentrations in groundwater were within the

WHO standards based on the reports of each reviewed article (Table 2).

7.15. Nitrate (NO_3^-) concentration

Based on the WHO standards, the maximum permissible limit for NO_3^- in drinking water should be 50 mg/L (see table 5). All studies reported mean NO_3^- concentrations in groundwater within WHO standards, and 50% of the studies reviewed reported maximum NO_3^- concentrations in groundwater that were above the desirable limit of WHO standards (Table 2).

8. CONCLUSION

This review was aimed at evaluating evidence regarding the suitability of groundwater for drinking purposes in Ethiopia. From a total of fifteen water quality parameters reviewed, the obtained pH, Ca^{2+}, Cl^-, SO_4^{2-}, PO_4^{2-} and NO_3^- mean concentrations in all the reviewed studies were in compliance with the WHO standard limit. Concerning the maximum Ca^{2+} and PO_4^{2-} concentrations obtained, all reviewed studies were reported within the standards, but the rest of the water quality parameters have a maximum concentration beyond the WHO standard limit. The maximum concentrations of fluoride, bicarbonate, and potassium obtained in more than 50% of the reviewed articles were beyond the recommended WHO standard limit. Based on the TDS concentration category, 80% of the reviewed articles indicated that the groundwater was suitable for drinking. The maximum potassium concentration obtained in 75% of reviewed articles was beyond the WHO limit, which may result in elevated blood pressure and hypertension. The maximum fluoride concentration found in 57.1% of reviewed articles was beyond the recommended limit, which may result in dental fluorosis or skeletal fluorosis. The studies reviewed were different in the type of groundwater source used, the number of parameters analyzed, methods utilized, and the number of references used.

As a recommendation, groundwater quality parameters should be monitored regularly before being utilized to avoid any human health-related problems and ensure a sustainable development across the country. The Ethiopian government, at various levels of the administrative hierarchy, should work to ensure the provision of potable groundwater for communities in both rural and urban areas, which will play a role in ensuring people's health. Further detailed studies using physical, chemical, and bacteriological parameters should be needed on different groundwater sources to reduce or avoid any possible means for groundwater contamination and reduce further negative effects.

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COMPETING INTEREST STATEMENT

No conflict of interest.

ADDITIONAL INFORMATION

No additional information is available for this paper.

REFERENCES

1. Adimalla N, Dhakate, R., Kasarla, A. & Taloor, A. K. Appraisal of groundwater quality for drinking and irrigation purposes in Central Telangana, India. Groundwater for Sustainable Development. 2020; 10.
2. Lapworth D, Nkhuwa, D., Okotto-Okotto, J., Pedley, S., Stuart, M., Tijani, M. & Wright, J. Urban groundwater quality in sub-Saharan Africa: current status and implications for water security and public health. Hydrogeology Journal. 2017; 25: 1093-116.
3. Alam R, Ahmed, Z. and Howladar, M.F. Evaluation of heavy metal contamination in water, soil and plant around the open landfill site Mogla Bazar in Sylhet, Bangladesh. Groundwater for Sustainable Development. 2020; 10: 100311.
4. Tai T WJ, Wang Y and Bai L. Groundwater pollution risk evaluation method research progress in our country. Journal Beijing Norm Univ Natural Science. 2012; 06: 648–53.
5. PB BSaN. Analysis of drinking water of different places – A review. International Journal of Engineering Research. 2012; 2.
6. Li P QHaWJ. Accelerate research on land creation. Nature. 2014; 510: 29–31.
7. Li P WJaQH. Hydrochemical appraisal of groundwater quality for drinking and irrigation purposes and the major influencing factors: a case study in and around Hua County, China. Arab J Geosci. 2016; 9(1): 15.
8. Nigus KebedeWegahita LM, Jiankui Liu, Tingwei Huang, Qiankun Luo and Jiazhong Qian. Spatial Assessment of Groundwater Quality and Health Risk of Nitrogen Pollution for Shallow Groundwater Aquifer around Fuyang City, China. Water. 2020; 12.
9. Yahong Zhou AW, Junfeng Li, Liangdong Yan and Jing Li. Groundwater Quality Evaluation and Health Risk Assessment in the Yinchuan Region, Northwest China. Expo Health. 2016; 8: 443–56.
10. M J. Nitrate pollution of groundwater in Toyserkan, western Iran. Environvironmental Earth Science. 2011; 62: 907–13.

11. Kuhr P HJ, Kreins P, Kunkel R, Tetzlaff B, Vereecken H and Wendland F. Model based assessment of nitrate pollution of water resources on a federal state level for the dimensioning of agro-environmental reduction strategies: the North Rhine-Westphalia (Germany) case study. Water Resource Management. 2013; 27: 885–909.
12. Feifei Chen LY, Gang Mei, Yinsheng Shang, Fansheng Xiong and Zhenbin Ding Groundwater Quality and Potential Human Health Risk Assessment for Drinking and Irrigation Purposes: A Case Study in the Semiarid Region of North China. Water. 2021; 13.
13. Daniele L CM, Vallejos A, Dı´az-Puga M and Pulido-Bosch A. Geochemical simulations to assess the fluorine origin in Sierra de Gador groundwater (SE Spain). Geofluids. 2. 2013; (13): 194–203.
14. Z WJaS. Evaluation of shallow groundwater contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, mid-west China. Expo Health. 2015: 1–19.
15. N NTaB. Evaluating the spatial distribution of quantitative risk and hazard level of arsenic exposure in groundwater, case study of Qorveh County, Kurdistan Iran. Iran Journal Environvironmental Health Science Engineering. 2013.
16. Muhammad Mohsin SS, Faryal Asghar and Farrukh Jamal. Assessment of Drinking Water Quality and its Impact on Residents Health in Bahawalpur City. International Journal of Humanities and Social Science. 2013; 3(15).
17. Shigut DA LG, Irge DD, and Ahmad T. Assessment of physico-chemical quality of borehole and spring water sources supplied to Robe Town, Oromia region, Ethiopia. Applied water science 2017: 155-64.
18. Ramya Priya RaE, L. Evaluation of geogenic and anthropogenic impacts on spatio-temporal variation in quality of surface water and groundwater along Cauvery River, India. Environmental Earth Science. 2018; 77(2).
19. Ayenew T. The distribution and hydrogeological controls of fluoride in the groundwater of central Ethiopian rift and adjacent highlands. Environmental Geology. 2008; 54(6): 1313-24.
20. Ayenew T, Kebede, S., Alemyahu, T. Environmental isotopes and hydrochemical study as applied to surface water and groundwater interaction in the Awash river basin. Hydrological Processes. 2008; 8.
21. Yitbarek A, Razack M., Ayenew, T. Zemedagegnehu, E. and Azagegn. T., Hydrogeological and hydrochemical framework of Upper Awash River basin, Ethiopia: With special emphasis on inter-basins groundwater transfer between Blue Nile and Awash Rivers. Journal of African Earth Sciences. 2012; (65): 46-60.
22. Kawo SKaNS. Groundwater Quality Assessment Using Geospatial Techniques and WQI in North East of Adama Town, Oromia Region, Ethiopia. Hydrospatial Analysis. 2019; 3(1): 22-36.
23. Furi W, Razack, M., Abiye, T.A., Ayenew, T. and Legesse. Fluoride enrichment mechanism and geospatial distribution in the volcanic aquifers of the Middle Awash basin, Northern Main Ethiopian Rift. Journal of African Earth Sciences. 2011; 60: 315-27.
24. Taye A. Pollution of the hydrogeologic system of Dire Dawa groundwater basin. 1988
25. Tamiru A. Assessment of pollution status and groundwater vulnerability mapping of the Addis Ababa water supply aquifers, Ethiopia. 2004.
26. Dinka MO, Loiskandl, W. and Ndambuki, J. M. Hydrochemical characterization of various surface water and groundwater resources available in Matahara areas, Fantalle Woreda of Oromiya region. Journal of Hydrology: Regional Studies. 2015; 3: 444-56.
27. Hasan S. Effect of Climate Change on Groundwater Quality for Irrigation Purpose in a Limestone Enriched Area. Doctoral Dissertation. 2014.
28. Kibru Gedam Berhanu AMT, Tamru Tesseme Aragaw, Gashaw Sintayehu Angualie and Alemshet Belayneh Yismaw. The Secret of the Main Campus Water-Wells, Arba Minch University, Ethiopia. Journal of Environmental and Public Health. 2021: 9.
29. Gintamo B, Khan, Mohammed Azhar, Gulilat, Henok, Shukla, Rakesh Kumar and Mekonnen, Zeleke. Determination of the Physicochemical Quality of Groundwater and its Potential Health Risk for Drinking in Oromia, Ethiopia. Environmental Health Insights. 2022; 16(1): 1–11.
30. Gebrerufael Hailu Kahsay TG, Fethanegest Woldemariyam and Tesfa-alem Gebreegziabher Emabye. Evaluation of Groundwater Quality and Suitability for Drinking and Irrigation Purposes Using Hydrochemical Approach: The Case of Raya Valley, Northern Ethiopia. 2019; 11(1): 70-89.
31. Gnanachandrasamy TTAaG. Evaluation of groundwater quality for drinking and irrigation purposes using GIS-based water quality index in urban area of Abaya Chemo sub-basin of Great Rift Valley, Ethiopia. Applied Water Science. 2021; 11(148).
32. Muhammed Haji SK, Dajun Qin, Hassen Shube and Nafyad Serre Kawo. Potential Human Health Risks Due to Groundwater Fluoride Contamination: A Case Study Using Multi-techniques Approaches (GWQI, FPI, GIS, HHRA) in Bilate River Basin of Southern Main

Ethiopian Rift, Ethiopia. Archives of Environmental Contamination and Toxicology 2021; 80: 277–93.
33. Karuppannan NSKaS. Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia. Journal of African Earth Sciences. 2018; 147: 300–11.
34. Adugnaw T. Akale DCD, Shree Giri, Mulugeta A. Belete, Seifu A. Tilahun, Wolde Mekuria, Tammo S. Steenhuis. Groundwater Quality in an Upland Agricultural Watershed in the Sub-Humid Ethiopian Highlands. Journal of Water Resource and Protection. 2017; 9: 1199-212.
35. Tewodros Rango JK, Behailu Atlaw, Peter G. McCornick, Marc Jeuland, Brittany Merola and Avner Vengosh. Groundwater Quality and Its Health Impact: An Assessment of Dental Fluorosis in Rural Inhabitants of the Main Ethiopian Rift. Environment International. 2012; 43: 37–47.
36. Aragaw DTHaTT. Shallow Groundwater Quality and Human Health Risk Assessment in Holte, a Town in Southern Ethiopia Ethiopian Journal of Water Science and Technology 2023.
37. WHO. Guidelines for drinking-water quality. WHO chronicle fivth edition. 2011; 38(4): 104-8.
38. Agency EthiopianStandar. Ethiopian Standard under the direction of the Technical Committee for Water Quality (TC 78) and Ethiopian Standards Agency (ESA). First Edition 2013. 2013.
39. !!! INVALID CITATION !!!
40. Davies SDW, R.J.M. Hydrogeology. Wiley, New York. 1966.
41. ES261 ES. Ethiopian Drinking Water Quality Standard 2nd edition, Addis Ababa, Ethiopia. 2001.
42. WHO. Guidelines for drinking water quality, volume 1, Recommendations, 3rd edition, World Health Organization, Geneva. 2006.
43. Wagh VM, Panaskar, D. B., Jacobs, J. A., Mukate, S. V., Muley, A. A. and Kadam, A. K. Influence of hydro-geochemical processes on groundwater quality through geostatistical techniques in Kadava River basin, Western India. Arabian Journal of Geosciences. 2019; 12(1).
44. Wagh VM, Mukate, S. V., Panaskar, D. B., Muley, A. A. and Sahu, U. L. Study of groundwater hydrochemistry and drinking suitability through Water Quality Index (WQI) modelling in Kadava river basin, India. SN Applied Sciences. 2019; 1(10).
45. Bala Krishna PMaR, A. L. Solute Sources and Processes in the Achankovil River Basin, Western Ghats, Southern India. Hydrological Sciences Journal. 2005; 50(2): 341-54.
46. Mechal A, Birk, S., Dietzel, M., Leis, A., Winkler, G., Mogessie, A. and Kebede, S. Groundwater flow dynamics in the complex aquifer system of Gidabo River Basin (Ethiopian Rift): A multi-proxy approach. Hydrogeology Journal. 2017; 25(2): 519-38.