Research Article
Volume 13:2, 2023

Journal of Civil and Environmental Engineering

ISSN: 2165-784X Open Access

Characterization and Water Quality Assessment of Groundwater for Irrigation Enhancement in Cheha, Woreda, Gurage Zone, Ethiopia

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Abstract

Now a day's irrigation practice in Ethiopia has given more attention to struggle poverty and increase prosperity in the country. To do so, assessments of the irrigation water quality is one of the crucial parameter for successful irrigation implementation. The researchers try to make an assessment on Gurage zone, Cheha Wereda for two periods of sampling time Pre Monsoon (PRM) starting from November up to February, 2022 and Post Monsoon (POM) starting from April up to Jun, 2022. A representative sample borehole has been identified and samples had been taken for the physic-chemistry analysis by laboratory tests in order to check their suitability for irrigation water quality assessments. For the classification of different physiochemical parameters laboratory results irrigation water quality (WHO 2008) and irrigation water quality standards (US Regional Salinity Laboratory and FAO) standards had been used. After analysis of groundwater samples from the study area, the PH of water indicates that acidic character with a PH ranging from 6.63 to 6.8 in PRM and 6.84 to 7 in POM. Accordingly the result shows that 81.92% the water quality index parameters indicates that the water in the study area is suitable for irrigation and the rest 18.18 % of water quality index parameters the water is not suitable for irrigation. Based on the analyzed result the following water quality indexes SSP, EC, Na, Cl, NO_3, MAR, SAR, PI, and KI result indicates that the water is suitable for using irrigation purpose both in rainy (POM) and dry (PRM). Whereas the TH and RSC WQI result shows that the water is not suitable for irrigation purpose.

Keywords: Physiochemical parameters • Groundwater • Water quality index • Irrigation uses

Introduction

Over the few decades, struggle for financial development, related with fast growth in population and urbanization, and has brought in momentous changes in land use, follow-on in more demand of water for agriculture, domestic and industrial activities [1].

The monitoring of water quality is one of the significant tools for justifiable development and provides important information for water controlling. The prominence of water quality in human health has in recent times attracted a great deal of interest. In the developing world, 80% of all diseases are unswervingly related to poor drinking water and contaminated conditions [2].

Agricultural water sources must be of good enough in there quality before it is acceptable for a given use in the command area for irrigation purpose [3]. Pertaining irrigation, several scientists have advocated and expounded that different water quality parameters have existed for evaluating irrigation water quality which aims to give a standard whether the water is permitted or not for irrigation use.

Form those parameters the following are listed as follow, salinity hazard, water infiltration rates (sodium hazard), pH, carbonate and bicarbonates, and specific ion toxicities, and concluded that irrigation water quality is assessed based upon total salt content, sodium and specific ion toxicities. Thus, evaluating the composition of the effluent waters is very imperative, and helps in ascertaining the suitability of the effluent for irrigation purpose [4].

For any irrigated agriculture to be effective and efficient, the assessment of the water quality is one of the most important aspects, because water quality has direct effect on crop growth and development as well as soil itself [5].

Human activities that involved urbanization, agricultural activities, over use of fertilizers or chemicals, inadequate management of land use and sewage disposal have directly or indirectly affected the quality of water and makes it unsuitable for irrigation as a result of excess salts and other pollutants being present in the water. Hence, continuous application of irrigation water without effective irrigation water quality assessment gives rise to salts and other pollutants

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Received: 22 November, 2022, Manuscript No. JCDE-22-80833; **Editor assigned:** 25 November, 2022, PreQC No. JCDE-22-80833 (PQ); **Reviewed:** 09 December, 2022, QC No. JCDE-22-80833; **Revised:** 10 February, 2023, Manuscript No. JCDE-22-80833 (R); **Published:** 20 February, 2023, DOI: 10.37421/2165-784X.2023.13.495

accumulation in the soil which will generally affect the growth and development of crops [6].

Irrigation water quality indices

Electrical Conductivity (EC), pH and Total dissolved solids were the major parameters used to determine the water quality indices. The range of pH is from 0 (maximum acidic) to 14 (maximum basic); pH of a neutral solution is 7. All geochemical reactions are affected by pH.

Surface waters become acidic when additions of acid exceed the buffering capacity of the carbonate system [7].

The correlation between total dissolved solids and EC is: The EC of the water (ECp) was measured by inserting the electrical conductivity cell directly in the solution above a 1:1 soil: water paste. This is different from measuring the apparent EC of the soil paste where the electrodes are embedded in the wall of the container. Many recommendations are based on the salt content in a soil sample. Different types of salts present in the soil and the various analyses of the samples complicate the direct conversion of EC into (TDS), and vice versa. Some salts have a higher EC compared to other salts. Conversion of ECw to TDS was determined based on of salinity level. True color could be measured by filtering the water after removing all suspended material [8].

Soluble Sodium Percentage (SSP): This term is also referred to as soluble sodium percentage or percent sodium. It is a computed by the following equation [9].

$$SSP (Na\%)=Na^{+}+K^{+}/Ca^{2+}+Mg^{2+}+Na^{+}+K^{+} \times 100,$$

Where the concentrations are in meq per litter.

Sodium Adsorption Ratio (SAR): The portion of sodium ions present in the soils is generally measurable by a factor called Sodium-Absorption Ratio (SAR) and represents the sodium hazards of water. SAR is defined as:

$$SAR=Na^{+}/\sqrt{}(Ca^{2+}+Mg^{2+}$$

Where,

$Ca^{2+}Na^{2+}$, and Mg^{2+} are concentrations of sodium, calcium, and magnesium in mille-equivalents per liter respectively.

Magnesium Adsorption Ratio (MAR): By nature ground water sources are better in there water quality than surface water sources and required small degree of treatments. Groundwater sources have alkaline earth metals which are found in state of equilibrium. Since, magnesium is a crucial nutrient for plant growth and its deficiency causes yellowing and reduction in growth and yield of crops. Magnesium percentage of water for irrigation is calculated by the formula [10].

$$MAR=Mg^{2+}/Ca^{2+}+Mg^{2+} \times 100,$$

Where,

Ca^{2+} and Mg^{2+} are concentrations of calcium and magnesium in Mille-equivalents per liter respectively.

Depending on the result of MAR, SAR, and SSP a scientist called Doneen formulates an empirical mathematical model which can predict the amount of water which can pass through a given area called Permeability Index (PI)'after carrying a series of investigations for which he used enormous number of irrigation water samples of variable ionic relationships and concentration [11].

$$PI=Na^{+} +\sqrt{}HCO^{3-}/Ca^{2+}+Mg^{2+}+Na^{+} \times 100$$

From the ecological perspective, in combination with subsurface structural features high permeability index would facilitate extensive contamination of groundwater [12].

Total hardness: The hardness of water is generally caused by calcium and magnesium. However, total hardness of water can be classified into two types, *i.e.,* temporary, and permanent hardness. The total hardness (as $CaCO_3$) of water samples can be calculated using the following equation;

$$TH=2.497\ Ca^{2+}+4.115\ Mg^{2+}$$

Chloride its high solubility in water chlorine exists as chloride ion and is the predominant natural form of chlorine [13].

Nitrate

Nitrogen is a plant nutrient that stimulates crop growth, when applied in excess affects the crop by over stimulation of growth, delayed maturity and poor quality of crop yield [14].

Sensitive crops may be affected by nitrogen concentrations above 5 mg/l. Most other crops are relatively unaffected until nitrogen exceeds 45 mg/l [15].

Consumption of nitrogen above the permissible limit creates severe problem of blue baby disease/methemoglobinemia in children and gastric carcinomas. The concentration of nitrate greater than 45 mg/l causes a disease in humans called as methemoglobinemia or blue baby syndrome Durfe and Baker [16].

Residual Sodium Carbonates (RSC)

It is used to predict the additional sodium hazard associated with $CaCO_3$ precipitation involve calculation of the residual sodium carbonate. RSC is another alternative measure of the sodium content in relation with calcium and magnesium. This can be calculated as:

$RSC=CO_3^{2-}+HCO^{3-})-(Ca^{2+}+Mg^{2+})$, where all concentrations is in me q/l

Kelly's index

Kellys Index (KI) is used for the classification of water for irrigation purposes. Sodium measured against calcium and magnesium is considered for calculate this parameter. A KI (>1) indicates an excess level of sodium in waters. Therefore, waters with a KI (<1) is suitable for irrigation, while those with greater ratio are unsuitable. KI is calculated by using the formula; where all the ions are expressed in meq/l.

$$KI=Na^{2+}/(Ca^{2+}+Mg^{2+})$$

Materials and Methods

The study has been conducted in south nation nationalities and peoples region in Gurage zone Cheha Worede which have high potential in ground water resources and irrigation potentials too. It is located at 430 km north of the southern nation's nationalities and peoples, regional state capital (Hawassa) and 155 km south of Addis Ababa. Astronomically, the study area found in the geographical coordinates of 7.760-8.450 north latitude and 37.450-38.710 east longitude (Figure 1) [17].

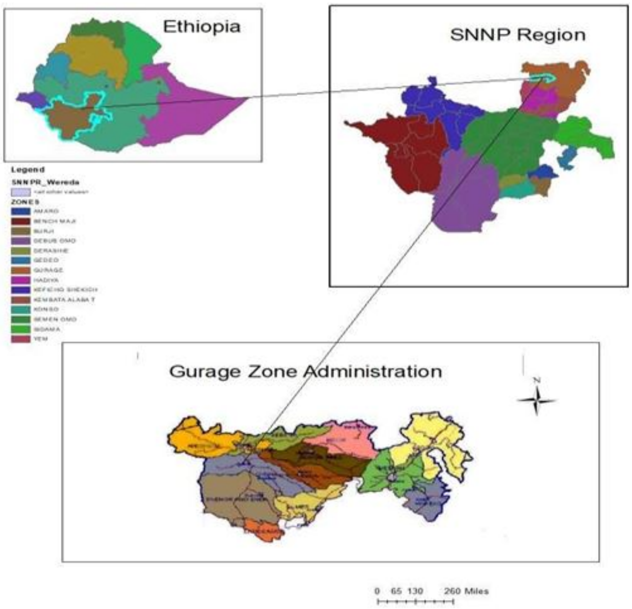

Figure 1. Location Map the study area and its administration.

Sample data collection

The researcher has tried to assesses the study area in details to understand the existing trends of the community about irrigation development and there practices too. From the field inspection period the communities had use different alternatives of water sources for their irrigation practices, from those some had use a traditional hand dug wells in a household level, some had use medium to high depth drill tube well, and some had used rainwater harvested stored water at temporary ponds water in the area. Generally, depending on the economical level for the community, the area of coverage, the investment amount, and number of employees a quality assessment test should give prior for those irrigation practices which have use a medium to high depth drill tubes. The samples were collected according to specified distance of well from each point from selected area. Materials required for the study are specimen bottle or container, portable pocket size pH meter RH and temperature measuring portable Electrical Conductivity (EC) meter at field level, depth water level measuring devices or stick meter measuring tape.

Physico-chemical analysis

Samples were analyzed in two different well known laboratory test companies (Helemes General Trading Plc. and Luci Engineering Plc.). The major activities conducted by the companies were for determining of major ions chemistry by employing standard methods of (American Public Health Association, 1995). Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) was determined titrimetric ally using standard EDTA. Chloride by standard $AgNO_3$ titration, Bicarbonate (HCO-) by titration with HCl, Sodium (Na^+) and Potassium (K^+) by flame photometry and EC, pH and TDS were measured *in situ*. Sulphate (SO_2^-) was determined by a spectrophotometer. Measurements were done in triplicate to ensure reliability and good quality control.

Results and Discussion

After a careful laboratory tests has been conducted and revenant data's has been recorded for this research the following major irrigation water quality indexes had been analyzed and tabulated in the following Tables 1 and 2 and also the results has been shown in detail by a graph in Figures 2 and 3 in this documents too.

PRM				POM			
Parameters	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**WHO standard**
Turbidity	1.06	2.97	2.015	2.4	3.46	2.93	5
EC	225	262	243.5	374	376	375	2000
PH	6.63	6.97	6.8	6.84	7	6.92	6.5-8.5
TDS	112	132	122	186	187	186.5	1000
Total alkalinity	125	205	165	235	240	237.5	200
Ammonium, NH_4	0	0.06	0.03	0.11	0.17	0.14	1.5
Bicarbonate, HCO_3	152.5	250.1	201.3	286.7	290	288.35	--
Calcium, Ca	97	170	133.5	95	134	114.5	200
Chloride, Cl	2	6	4	5	11	8	250
Carbonate	0	0	0	0	145	72.5	Nil
Fluoride, F	1.34	1.76	1.55	0.97	1.35	1.16	1.5
Magnesium, Mg	5	12	8.5	5	12	8.5	150
Manganese, Mn	0.11	0.29	0.2	0.26	0.58	0.42	0.1

Nitrate, NO_3	0.28	0.3	0.29	0.2	0.48	0.34	10
Nitrite NO_2	0	0	0	0.01	0.05	0.03	1
Phosphate, po_4	0.28	0.49	0.385	0.38	0.63	0.505	--
Potassium, K	5.4	5.7	5.55	8.4	9	8.7	--
Sodium, Na	7	17	12	14	18	16	200
Sulfate, so_4	1	1	1	2	9	5.5	250
Total iron, Fe	0.08	0.1	0.09	0.15	0.15	0.15	0.3

Table 1. Statistics of ground water chemistry in both seasons (all values in mg/l except pH and EC).

Parameters	Range	Class	Study areas sample collected				
			Ewan borehole	Condominium site	University borehole	Buchacha borehole	Average value for the study area
EC	<250	Excellent	225	376	374	262	309.25
	250-750	Good					
	750-2000	Permissible					
	2000-3000	Doubtful					
	>3000	Unsuitable					
SSP	200	Maximum allowable limit	18.12	20.886	13.6095	6.522	14.784
	>200	Above allowable limit					
NO_3	<200	Most desirable limit	0.3	0.2	0.48	0.28	0.315
	600	Maximum allowable limit					
	>600	Above allowable limit					
MAR	<50	Suitable	4.92	5	8.21918	6.5934	6.178
	>50	Unsuitable					
TH	<75	Soft	262.784	257.79	383.978	473.87	344.6
	75-150	Moderately					
	150-300	Hard					
	>300	Very hard					
RSC	<1.25	Safe	50.2	335	140.7	68.1	148.5
	1.25-2.5	Marginally suitable					
	>2.5	Not suitable					
SAR	<20	Excellent	2.38	2.545	1.64	0.74	1.824
	20-40	Good					
	40-60	Permissible					
	60-80	Doubtful					
	>80	Unsuitable					
KI	<1	Suitable	0.167	0.18	0.096	0.039	0.12

	>1	Unsuitable					
TDS	<160	Excellent	112	187	186	132	154.25
	160-500	Good					
	500-1500	Medium					
	1500-2500	Bad					
	>2500	Very bad					
PI			24.69	29.68	19.33	12.071	21.436

Table 2. Classification of groundwater quality based on suitability of water for irrigation purposes (us regional salinity laboratory and FAO).

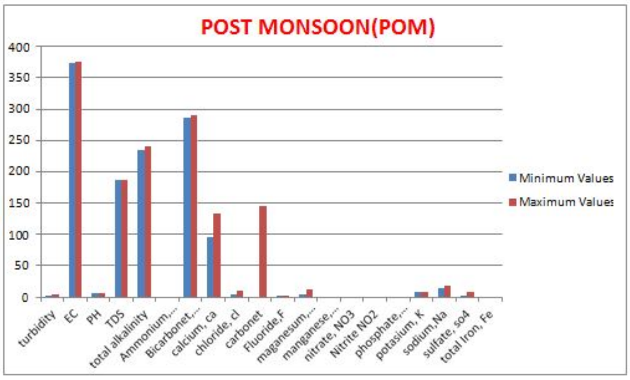

Figure 2. Different physiochemical concentration in POM.

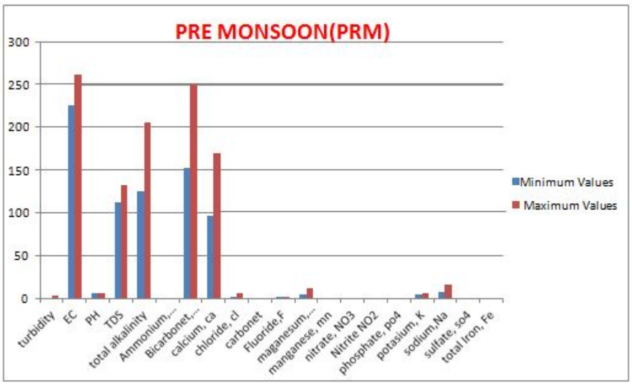

Figure 3. Different physiochemical concentration in PRM.

Electrical conductivity

EC is the most significant parameter to determine salinity hazard and suitability of water for irrigation purpose. The EC varies from a minimum of 225 to a maximum 262 μS/cm during pre-monsoon (PRM) November up to February 2022 and a minimum of 374 to a maximum 376 μS/cm in Post monsoon (POM) April up to Jun 2022 in the study area. The value of EC is higher at the time of POM than PRM by 55.8% to 14.16% in a minimum to maximum value range respectively.

The classification of groundwater on the basis of irrigation quality and irrigation water quality standards (US Regional Salinity Laboratory and FAO) shows that 100% of the water quality tested samples falls within the good range.

Sodium

The amount of Na^{+} ion ranges between a minimum of 7 to a maximum of 17 mg/l during PRM and 14 to 18 mg/l in POM season. When we compare the value of sodium ions in POM and PRM, the value is greater for POM by 50% to 5.55% both on the minimum and maximum values respectively.

The classification of groundwater on the basis of irrigation quality (WHO 2008) and irrigation water quality standards (US regional salinity laboratory and FAO) shows that 100% of the water quality tested samples <200 mg/l, this falls within the range of most desirable limit.

Chloride

When we check the laboratory results of Chloride (Cl^{-}) ranges from 2 to 6 and from 5 to 11 mg/l for PRM and POM with a minimum to a maximum values respectively. POM values are higher than PRM by 60% in the minimum values to 45.45% in the maximum values.

When we evaluate the suitability of Cl^{-} for irrigation purpose based on the classification of groundwater on the basis of irrigation quality shows that 100% of the water quality tested samples <250 mg/l, this value falls within the acceptable limits.

Nitrate

The laboratory result analysis for NO_3^{-} in the sample ranges from 2 to 6 and 5 to 11 mg/l with an amount ranging from minimum values of 40% to maximum values of 37.5% in PRM to POM respectively. Higher NO_3^{-} was noted during PRM throughout the study area.

When we evaluate the suitability of NO_3^{-} for irrigation purpose based on the classification of groundwater on the basis of irrigation quality shows that 100% of the water quality tested samples <10 mg/l, this value falls within the acceptable limits.

Magnesium Adsorption Ratio (MAR)

The MAR values ranges from 4.902 to 6.953 mg/l and 5 to 8.22 for PRM and POM season respectively. During both seasons (PRM and POM) the calculated values less than 50. The classification of groundwater on the basis of irrigation quality and irrigation water quality standards (US Regional Salinity Laboratory and FAO) shows that 100% of the water quality tested samples <50 mg/l, this falls within the range of suitable for irrigation.

Total hardness

The analyzed result for TH shows that a minimum of 262.78 to a maximum value of 473.87 during PRM and a minimum of 257.79 to a maximum of 383.97 in POM Total Hardness (TH) have been founded. The comparison result for TH during PRM and POM showed that the PRM greater than POM in the ranges of 1.93% to 23.41%, for both a minimum and maximum scenarios respectively.

During POM, TH found with an average of 320.88 mg/l representing (50%) and during PRM, TH found with an average values of 368.8 mg/l with exceeding the permissible limit. It is inferred that, on both seasons the recorded TH was higher than the allowable limits. Therefore the TH in the study area falls in to permanent hardness.

Residual sodium carbonate

The analysis result for RSC ranges from 50.5 for a minimum and 68.1 for maximum values of PRM season and from 177.7 for a minimum to 289 meq/l for POM seasons. The RSC value for POM is greater than PRM by 71.58% for a minimum to 76.43% for a maximum values.

Based on the classification of groundwater on the basis of irrigation quality (WHO 2008) and irrigation water quality standards (US regional salinity laboratory and FAO) shows that 100% of the water quality tested samples >1.25 mg/l, this falls within the range of not suitable for irrigation. Hence, continued usage of high RSC waters will affect the yields of crop.

Sodium adsorption ratio

The analyzed result for SAR ranges from 0.701 for a minimum values to 1.782 for PRM and 1.98 for a minimum values to 2.11 for POM seasons. The values of SAR in POM are greater than that of PRM seasons for both a minimum and maximum values.

Grounded on the classification of groundwater on the basis of irrigation quality (WHO 2008) and irrigation water quality standards (US regional salinity laboratory and FAO) shows that 100% of the water quality tested samples <20 mg/l, this falls within the range of the excellent irrigation water quality.

Permeability index

PI ranging from 17.571 to 16.49 meq/l and 27.133 to 21.36 meq/l is noted during PRM and POM, respectively. According to PI values, the groundwater samples fall in class I for PRM and class II during POM seasons indicating water is moderate too good for irrigation purposes.

Kelly's index

KI in the present study varied between 0.068 to 0.09 and 0.14 to 0.1123 during PRM and POM respectively. According to the classification is representing 100% (PRM) and (POM) falls the suitable limit.

Conclusion

Based on the generated groundwater quality analysis the researcher classifies the water quality in different groups based on the water quality index parameters. For the classification of different physiochemical parameters laboratory results irrigation water quality (WHO 2008) and irrigation water quality standards (US regional salinity laboratory and FAO) standards had been used.

Accordingly the result shows that 81.92% the water quality index parameters indicates that the water in the study area is suitable for irrigation and the rest 18.18 % of water quality index parameters the water is not suitable for irrigation.

Based on the analyzed result the following water quality indexes SSP, EC, Na, Cl, NO_3, MAR, SAR, PI, and KI result indicates that the water is suitable for using irrigation purpose both in rainy (POM) and dry (PRM). Whereas the TH and RSC WQI result shows that the water is not suitable for irrigation purpose. Therefore there should be some amendments for the RSC and TH treatment to reduce their concentration.

Acknowledgment

I would like to say thank you my institution Wolkite University for its effort to help the nearby community for fulfilling their basic needs. For those activities the bore hole drilling at different sites and assigned me to check the suitability of the drilling water quality.

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How to cite this article: Tegenu, Moges Tariku. "Characterization and Water Quality Assessment of Groundwater for Irrigation Enhancement in Cheha, Woreda, Gurage Zone, Ethiopia." *J Civil Environ Eng* 13 (2023): 495.