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Evaluation of Groundwater Quality for Irrigation Purposes and Impact of Irrigation on Water in Golina River Basin, Northern Ethiopia

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ABSTRACT

Groundwater is a natural freshwater resource and very important for multipurpose use in the Golina River basin. The determination of groundwater resource sustainability is depends on the groundwater quality evaluation for specific uses. The objectives of this research work are: (1) to evaluate the groundwater quality and suitability for irrigation purposes and (2) to study the impact of irrigation activities on groundwater quality in the Golina River Basin. Alluvial deposits, basalts, granite, and rhyolite are the main stratigraphic units in the area. 34 groundwater and 3 river water samples were collected from the study area for water quality analysis purposes. Parameters of pH and EC were measured using WTW Multi 3430 and HCO_3^- was measured using Hach digital titrator in the field while parameters of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, PO_4, and F^-, were analyzed in the lab using Ion Chromatography (IC) in the Technical University of Darmstadt. Besides these, total dissolved solids (TDS), total hardness (TH), sodium absorption ratio (SAR), magnesium hazards (MH), Soluble Sodium Percentage (SSP)(Na%), Residual sodium carbonate (RSC), Permeability Index (PI) and Kelly´s index (KI) were calculated and interpreted. Based on the result of the analysis, the abundance of cations in groundwater in the study area is arranged as Ca > Na > Mg > K, and the anions are arranged as $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- > PO_4^{3-}$. Similarly, the result also showed that the common water types in the area are Ca^{2+}-Mg^{2+}-HCO_3^- and Mg^{2+}-Ca^{2+}-HCO_3^-. TDS, TH, EC, SAR, MH, SSP, RSC, PI and KI have respective mean values of 530.45 mg/l, 279 mg/l $CaCO_3$, 657 µS/cm, 1.24, 48%, 26%, 0.23 meq/l, 61% and 0.57. The suitability of the dominant water points in the Golina River Basin for irrigation is moderate in terms of TDS, hard to very hard water for irrigation in terms of hardness, medium salinity for irrigation in terms of salinity hazard and low sodium hazards, suitable for irrigation in terms of magnesium hazards, good and excellent water for irrigation in terms of soluble sodium percentage, safe for irrigation in terms of residual sodium carbonate, good for irrigation in terms of the permeable index, and suitable water for irrigation in terms of Kelly ratio. Few water samples in the Golina River Basin show slight contamination of nitrate from the irrigation activities which needs special attention.

Keywords: Golina River Basin, Physicochemical parameters, Groundwater quality, Suitability, Impact of irrigation, Ethiopia.

1. INTRODUCTION

Groundwater is a natural freshwater resource crucial for drinking, industrial, agricultural, recreation, and other purposes. The main advantage of using groundwater resources is that it is free from suspended and organic impurities due to natural filtration through soils and sediments

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(Karanth, 1989). However, groundwater quality is significantly influenced by the geological formations, agricultural and anthropogenic activities, and urbanization (Zulu et al., 1996; Dechesne et al., 2004; Nas and Berktay, 2010; Dhanasekarapandian et al., 2016). Once the aquifer is contaminated, it is difficult to remove the contaminant from the groundwater system. Agriculture accounts for roughly 70% of the total freshwater withdrawals globally and for over 90% in most of the Least Developed Countries (FAO, 2011).

Ethiopia has rich water resource and presently, it is mainly used for domestic and industrial purposes (Kawo and Karuppannan, 2018) though, it has a high potential for the country's agriculture development. Golina River Basin is one of the basins in Ethiopian which has also attracted attention in terms of its groundwater potential. The groundwater potential of the Golina River Basin was identified using integrated methods of analytical hierarchy process, GIS, and Remote sensing. As a result, it was classified into very poor, poor, moderate, good, and very good groundwater potential zones (Gebru et al., 2020). The boreholes drilled accordingly and validated the results. Studies related to the quality of groundwater suggested that the groundwater is primarily acquiring the solutes from the natural weathering of Ca^{2+} and Mg^{2+}-rich silicate minerals (Gebru et al., 2023). According to Gebru et al. (2023), groundwater of the Golina River Basin is recharged from direct infiltration of the precipitation and recharged from the nearby mountainous regions.

Golina river basin one of the basins where the irrigation projects are under development using groundwater resources without proper monitoring and management of groundwater quality as well as quantity. Moreover, fertilizers and pesticides are commonly used in the area without due attention to the impact of the chemicals on the quality of the surface water and groundwater in the basin. Poor quality of surface water and groundwater for irrigation adversely affects the arable land and the crops (Ayers and Westcot, 1985). Studies by Sileshi, (2007); and Ayenew et al. (2013) suggest that the salinity and sodicity of groundwater do not limit the use of groundwater for agricultural activities e,g. Kobo and Raya valleys.

Prsent study is intended to evaluate the suitability of the groundwater for irrigation and to study the impact of irrigation activities on groundwater quality for effective management and utilization of the available surface and groundwater resources.

1.1. Study Area

Golina River Basin is in the northeastern part of the Northwestern Ethiopian Plateau (NWEP) and it is part of the Ethiopian rift margin escarpment. It is in Amhara Regional State, Northern Ethiopia (Figure 1) with an area of 917 km^2. The elevation vary from 1330 to 3970 m above mean sea level. The physiography of the Golina River Basin includes a plateau in the western part, escarpments, valley floor, and inselberg. The valley floor is bounded by western (Rasta) and eastern (Zobel) mountains and is characterized by a flat plain and very gentle slope with accessible terrain. The west (Rasta) mountains area is characterized by rugged topography and moderately steep to very steep slopes and inaccessible terrain.

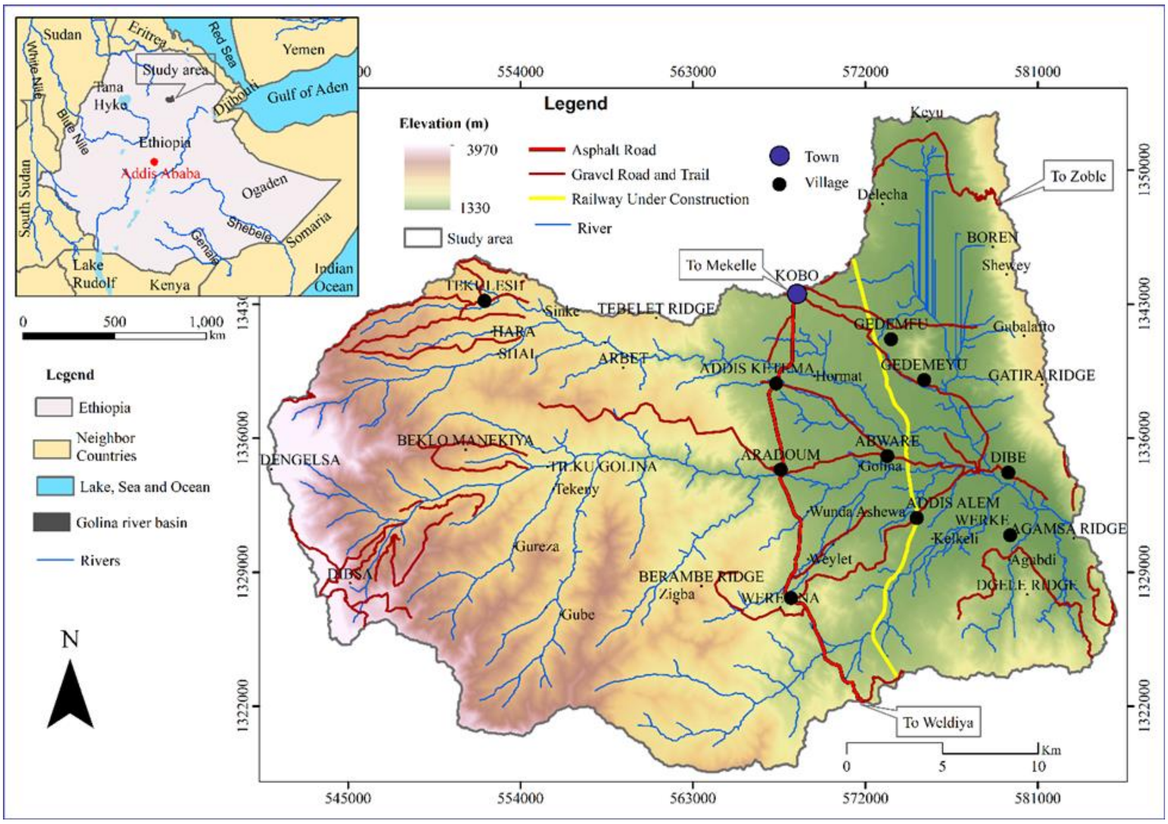

Figure 1. Location map of Golina River Basin.

The study area is drained by Golina, Hormat, and Kelkel rivers which are merged near the outlet and exit the basin through the Golina outlet in the eastern part. The Golina River is perennial while the other two are intermittent streams. The drainage system of the Golina River basin shows a dendritic pattern. The Golina River Basin is characterized by semi-arid climate conditions with a mean annual precipitation of about 903 mm. The area has maximum and minimum temperatures varying from 18 – 30°C and 5 – 15°C, respectively, and an annual mean temperature of 20 °C (Gebru et al., 2020). Based on the soil data from the survey report of MCE (2008) and the soil grid map of Hengl et al. (2014), the study area is covered with sand, sandy loam, sandy clay, loam, clay loam, silty clay, and clay soils. Gebru et al. (2020) categorised the land use/cover of the basin into water body, cultivated land, natural forest, shrubland, bare land, and residential land. The basin is dominated by the alluvial deposits, basalts, rhyolites, and granites (Gebru et al., 2020). Alluvial deposits host the main aquifer that comprises productive layers of sand and gravel. The boreholes drilled for domestic and irrigation purposes are mostly concentrated in the alluvial deposits. The weathered and fractured basalt rocks are the other permeable and productive aquifer in the study area. The granites and rhyolites located in the eastern part of the study area are impervious and unproductive acidic volcanic rocks.

2. MATERIALS AND METHODS

2.1. Sampling and Analytical Methods

In this study, 34 groundwater samples (from both irrigational and water supply boreholes (29 samples), hand-dug wells (2 samples), and springs (3 samples)), and 3 river water samples were collected (Figure 2, Table 1).

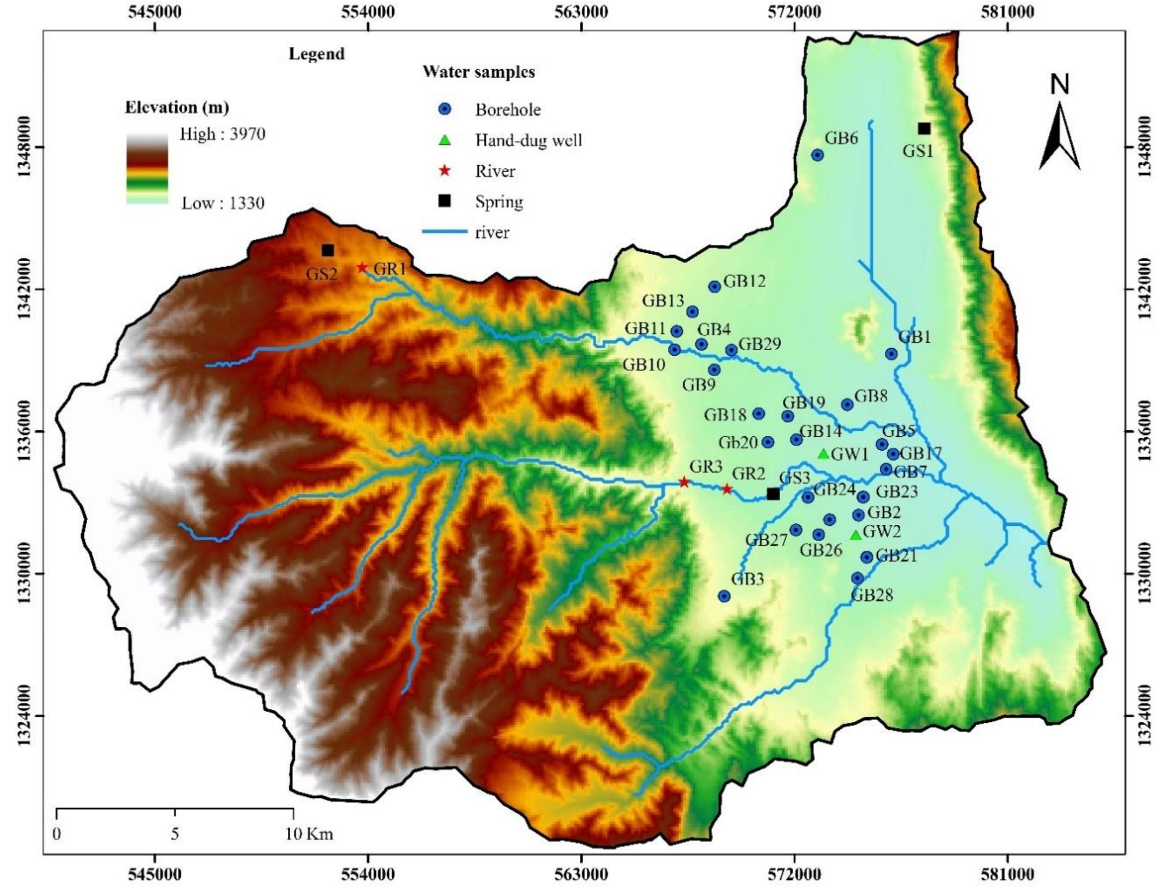

Figure 2. Location of water sampling points for water quality analysis.

The sampled boreholes and hand-dug wells are dominantly concentrated in the alluvial deposit which covers the valley floor of the Golina River Basin. The water samples were collected randomly from all accessible water points of the basin during the fieldwork conducted during 2018. The boreholes and hand-dug well are pumped for 10 minutes or above in order to avoid stagnant water sampling.

Table 1. Sample type, depth and country rock of the water sampling points in the Golina River Basin.

S. No.	***Sample Code***	***Sample type***	***Latitude***	***Longitude***	***Depth of Borehole (m)***	***Country rock***
1	GB1	Water supply	576264	1339071	58	Alluvial deposit
2	GB2	Water supply	574360	1331750	70	Alluvial deposit
3	GB3	Water supply	568499	1328446	46	Alluvial deposit
4	GB4	Water supply	573168	1335378	69	Alluvial deposit
5	GB5	Water supply	575974	1334714	66	Alluvial deposit
6	GB6	Water supply	568109	1356681	43	Alluvial deposit
7	GB7	Water supply	575927	1334584	Artesian well	Alluvial deposit
8	GB8	Irrigation Supply	574272	1336796	125	Alluvial deposit and Basalt
9	GB9	Irrigation Supply	568691	1338809	119	Alluvial deposit and Basalt
10	GB10	Irrigation Supply	566944	1339454	128	Alluvial deposit and Basalt
11	GB11	Irrigation Supply	567346	1340025	110	Alluvial deposit
12	GB12	Irrigation Supply	568570	1341340	160	Alluvial deposit
13	GB13	Irrigation Supply	568163	1341138	137	Alluvial deposit
14	GB14	Irrigation Supply	572306	1335796	108.5	Alluvial deposit
15	GB15	Irrigation Supply	574472	1332357	100	Alluvial deposit and Basalt
16	GB16	Irrigation Supply	574995	1330597	117	Alluvial deposit
17	GB17	Irrigation Supply	575950	1334735	Artesian well	Alluvial deposit
18	GB18	Irrigation Supply	571060	1336473	116.5	Alluvial deposit
19	GB19	Irrigation Supply	571689	1336366	110	Alluvial deposit
20	GB20	Irrigation Supply	571055	1335920	110	Alluvial deposit
21	GB21	Irrigation Supply	574870	1331228	99	Alluvial deposit and Basalt
22	GB22	Irrigation Supply	574671	1331878	120	Alluvial deposit
23	GB23	Irrigation Supply	574472	1332357	119	Alluvial deposit
24	GB24	Irrigation Supply	572982	1332682	123	Alluvial deposit and basalt
25	GB25	Irrigation Supply	573491	1332283	124	Alluvial deposit and Basalt
26	GB26	Irrigation Supply	572994	1331732	116	Alluvial deposit and basalt
27	GB27	Irrigation Supply	572366	1331807	150	Alluvial deposit and Basalt
28	GB28	Irrigation Supply	574692	1330076	112	Alluvial deposit and Basalt
29	GB29	Irrigation Supply	569380	1339575	153	Alluvial deposit and Basalt
30	GW1	Water supply	574359	1331732	Not Available	Alluvial deposit
31	GW2	Water supply	567975	1339716	Not Available	Alluvial deposit
32	GS1	Water supply	570347	1357013	Spring	Rhyolite
33	GS2	Water supply	552309	1343650	Spring	Basalt
34	GS3	Water supply	571110	1333366	Spring	Alluvial deposit
35	GR1	…….	552095	1342836	River	Alluvial deposit
36	GR2	Irrigation supply	567572	1334139	River	Basalt
37	GR3	Irrigation supply	567208	1333872	River	Alluvial deposit

Note: GB = Borehole samples developed for domestic water supply and irrigation supply.

During the water samples collection, the water was filtered using 0.45µm in the field in order to remove any suspended particles. Two 50ml plastic bottles were used to collect water samples from each water point for major cations and anions. The water samples collected for cation measurements were preserved by using HNO_3 weak acid and refrigerated at normal room temperature conditions until the analysis is complete. Parameters of pH and EC were measured using WTW Multi-Parameter model 3430 field kit (WTW pH electrode senTix-940 and WTW conductivity electrode) and HCO_3^- were measured and analyzed using HACH Digital Titrator in the field. While parameters of Na^+, K^+, Ca^2, Mg^2, Cl^-, SO_4^{2-}, NO_3^-, NO_2^-,

PO_4^{2-}, and F^- were analyzed using Ion Chromatography (IC), in the Technical University of Darmstadt (TUD) Water Laboratory. The accuracy of laboratory results was checked using ion balance or electro-neutrality (EN) method that is expressed as

$$\text{Ion Balance} = \frac{\text{Sum of cation} - \text{sum of anion}}{\text{sum of cation} + \text{sum of anion}} * 100$$ (Matthess, 1982; Singhal and Gupta, 2010).

Laboratory analysis results of all samples fall within the acceptable range of ion balance which is from -5% to +5%.

2.2. Groundwater Quality for Irrigation

Each water sample is evaluated for its suitability for irrigation purposes using specific ions and the impact of irrigation on both surface water and groundwater quality. Parameters used to evaluate the suitability of groundwater for irrigation are total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), sodium absorption ratio (SAR), magnesium hazards (MH), soluble sodium percentage (SSP)(Na%), residual sodium carbonate (RSC), permeability index (PI) and Kelly´s index (KI). The data of these parameters was treated using standard empirical formulas and Aquachem4.0 software. Piper and Wilcox diagrams were produced using Aquachem4.0; and hardness, salinity hazard, permeability index, Kelly's index etc are calculated using standard empirical formulas.

Total hardness using the following empirical formula as shown in equation (1), where, Ca^{2+} and Mg^{2+} are concentrations in mg/l and the factors 2.5 and 4.1 are the ratio of $CaCO_3$ formula mass to calcium and magnesium atomic mass, respectively (Charles, 2002).

$$\mathbf{Hardness = 2.5(Ca^{2+}) + 4.1(Mg^{2+})} \qquad (1)$$

The total hardness of water is classified into soft (TH<75mg/l CaCO3), moderate (75<TH<150), hard (150<TH<300), and very hard (TH>300mg/l CaCO3) (Sawyer and McCarty, 1967).

Salinity Hazard of water equals the inverse of the electrical resistance across one cubic centimeter of water (Charles, 2002; Hem, 1985). Thus the electrical conductivity of water is an indication of salinity hazard. Excess values of electrical conductivity (salinity) will affect the water percolation and its availability for the crop (Ayers and Westcot, 1985). It can alter the accessibility of water to crops and reduce the absorption of water by the plant roots which results in a physiological drought condition. High salinity in irrigation water is responsible for salt accumulation in the root zone which damages to the plant cells. Based on salinity, Wilcox (1955) has classified the hazard into four salinity hazard classes, low (<250), medium (250-750), high (750-2250) and very high (>2250 µS/cm).

Where sodium rich waters are used on regular basis the sodium hazard helps to estimate the sodium accumulation in the soil (water movement) at the expense of Ca^{2+} and Mg^{2+} (Rawat et al., 2018). Sodium hazard is expressed in terms of Sodium Adsorption Ratio (SAR). It is a relative ratio of Na^+ ion to Ca^{2+} and Mg^{2+} ions present in water. Sodium hazard is calculated using the following equation (2), where the values are in meq/l (Singhal and Gupta, 2010). Irrigation waters are classified into four classes based on SAR values as excellent (SAR < 10), good (10-18), fair (18-26) and poor or unsuitable (> 26) (Table 2).

$$\mathbf{SAR} = \frac{\mathbf{Na}}{\sqrt{(\mathbf{Ca}+\mathbf{Mg})/2}} \qquad (2)$$

Magnesium hazard is another parameter of water suitability for irrigation. It depends on the amount of magnesium ions. It is the magnesium ratio (MR) against calcium, calculated using the following equation (3) of Paliwal (1972) where all concentrations are in meq/l. If the magnesium ratio is higher than 50 it affects the soil properties by making it alkaline and decreases the crop yield (Kumar et al., 2007; Rawat et al., 2018; Paliwal, 1972; Elango et al., 2003).

$$\boldsymbol{MR} = \frac{\boldsymbol{Mg^{2+}}}{\boldsymbol{Ca^{2+}+Mg^{2+}}} * \mathbf{100} \qquad (3)$$

Soluble sodium percentage (%Na) is used in classify water for irrigation purposes (Rawat et al., 2018). It is widely used for assessing groundwater suitability for irrigation purposes (Wilcox., 1955). The reaction of sodium with soil reduces the permeability of the soil by making chemical bonding with clay minerals (Ayers and Westcot, 1985). Sodium concentrations when high, removes calcium and magnesium ions from clay through a base exchange reaction and that will reduce air and water movement capacity of the soil (Collins and Jenkins, 1996). Soluble sodium percentage is the ratio of sodium and potassium ions to the overall cations (Wilcox, 1955). It is expressed as a percentage of sodium or soluble sodium percentage (SSP) as shown in equation (4), where all are in meq/l.

$$\boldsymbol{SSP}\ (\boldsymbol{Na}\%) = \frac{\boldsymbol{Na^+ + K^+}}{\boldsymbol{Ca^{2+} + Mg^{2+} + Na^+ + K^+}} * \mathbf{100} \qquad (4)$$

The irrigation water is classified into five classes based on %Na as Excellent (<20%), good (20-40%), permissible (40-60%), doubtful (60-80%), and unsuitable (>80%) (Table 2)

Residual sodium carbonate (RSC) is a very important parameter for the irrigation water quality index. RSC is the difference between the sum of bicarbonate and carbonate to the sum of calcium and magnesium ions in water samples. Excess amounts of RSC in water influence the physical properties of soil. It facilitates dissolution of organic matter in soil that leaves a black stain on its surface when dry (Kumar et al., 2007). RSC is calculated using the following equation (5) where, ionic concentrations are expressed in meq/l (Raghunath, 1987).

$$\mathbf{RSC} = (\mathbf{HCO_3^-} + \mathbf{CO_3^{2-}}) - (\mathbf{Ca^{2+}} + \mathbf{Mg^{2+}}) \qquad (5)$$

The irrigation water is classified into three classes based on RSC value low (<1.25), medium (1.25-2.5), and high (>2.5). The values >2.5 it is not recommended for irrigation purposes. Higher values of RSC in irrigation water causes an increase in the adsorption of sodium in the soil and affects plant growth (Rawat et al., 2018).

Permeability index (PI) is one of the important indexes to evaluate water movement capability in the soil as the suitability of water for irrigation. Sodium, calcium, magnesium, and bicarbonate contents in the soil have affected the permeability of the soil and influence the quality of irrigation water on long-term use (Srinivasamoorthy et al., 2014). The suitability of the groundwater for irrigation based on PI is determined using the following equation (6) developed by Doneen (1964), where, ions are expressed in meq/l.).

$$\boldsymbol{PI} = \frac{(\boldsymbol{Na^+} + \sqrt{\boldsymbol{HCO_3^-}}\ )}{(\boldsymbol{Ca^{2+}} + \boldsymbol{Mg^{2+}} + \boldsymbol{Na^+})} * \mathbf{100} \qquad (6)$$

The irrigation water is classified into three classes, Class I (> 75%, suitable), Class II (25-75%, good), and Class III (< 25%, unsuitable) (Doneen, 1964). Class I and Class II are recommended for irrigation while Class III are not suitable for irrigation use. Kelly´s index (KI) is used for the classification of water for irrigation purposes based on Na^+ concentration against Ca^{2+} and Mg^{2+}. KI value >1 indicate an excess sodium and is not recommended for irrigation due to alkali hazard. KI value <1 indicates lower values for sodium and is recommended for irrigation (Kelley, 1940). Kelly’s index is calculated using the following formula (Kelley, 1940) where, ions are expressed in meq/l.

$$\mathbf{KI} = \frac{\mathbf{Na^+}}{\mathbf{Ca^{2+}+Mg^{2+}}} \qquad (7)$$

3. RESULTS

3.1. Major Cations and Anions

The analytical results of the parameters of groundwater (sources from boreholes, springs, and had-dug wells) and river water samples of the study area are presented (**Error! Reference s ource not found.**) with their descriptive statistics (Table 2). Calcium, sodium, magnesium, bicarbonate, and sulfate were observed as major ions in the samples of the study area (Fig 3). Water quality suitability for irrigation and the impact of irrigation on groundwater quality were interpreted from the given analytical results.

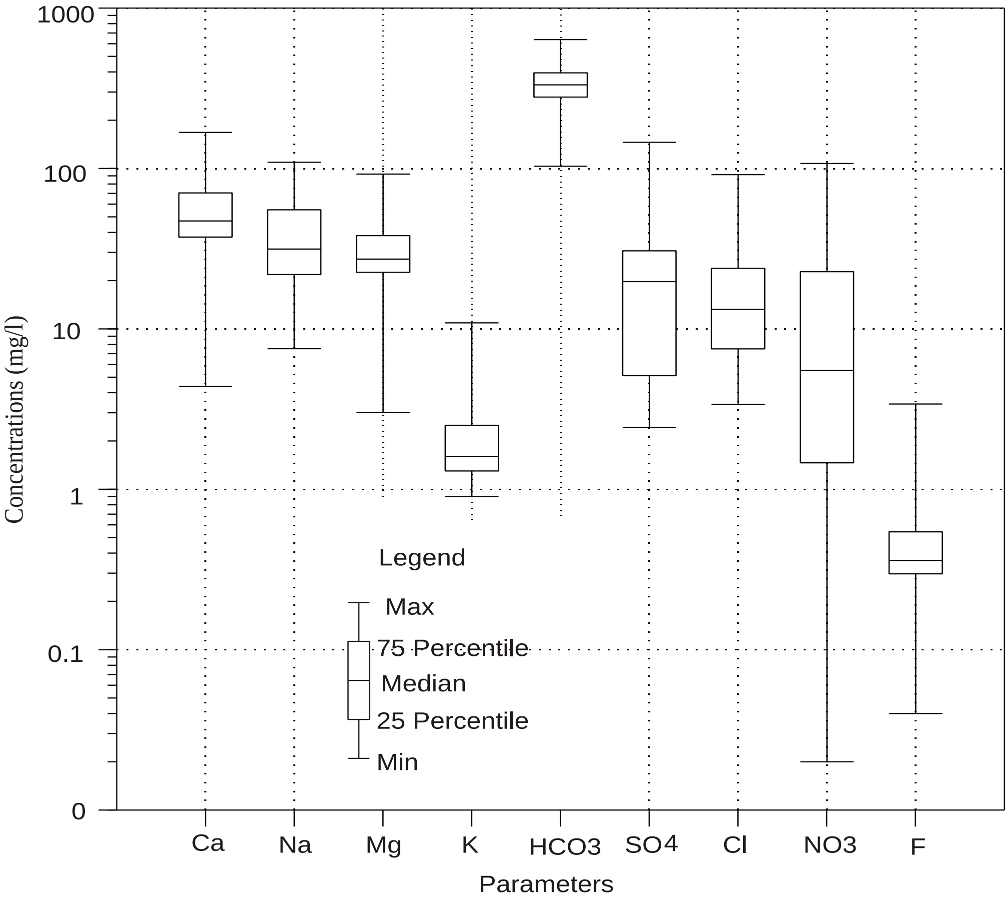

Figure 3. Boxplot of the major ions in the Golina River Basin.

Table 2. Descriptive statistics of river, spring, hand dug well and borehole water chemistry of the Golina River Basin.

Para-meters	***Range***	***Median***	***Mean***	***STDEVA***	***Range***	***Median***	***Mean***	***STDEVA***
	Borehole water				***Spring water***			
EC	420 -1270	611	679.14	234.34	427 - 659	558	548	116.32
pH	7.17 - 8.17	7.74	7.72	0.25	7.5 - 8.2	7.9	7.86	0.31
HCO_3^-	210 - 636.7	361.4	376.74	106.03	103.3 - 386	250	246.45	141.36
F^-	0.04 - 2.92	0.37	0.5	0.5	0.33 – 1.06	0.47	0.62	0.38
Cl^-	4.709 - 91.54	13.19	19.51	17.83	13.27 – 21.72	13.47	16.15	4.82
$NO_3{}^{2-}$	0.02 - 107.53	5.53	15.42	23.37	1.3 – 18.42	7.62	9.12	8.66
PO_4^{3-}	0.01 - 1.00	0.15	0.28	0.25	0.1 - 1.55	0.16	0.60	0.82
SO_4^{2-}	2.43 - 145.67	19.73	29.56	38.81	14.04 – 39.54	22.48	25.35	12.99
Na^+	15.89 - 109.36	32	39.58	22.59	22.21 – 83.12	59.54	54.95	30.71
K^+	0.90 - 10.90	1.6	2.47	2.51	1.34 - 2.43	1.88	1.88	0.54
Mg^{2+}	8.36 - 91.67	30.77	33.29	17.11	3.01 – 42.85	10.60	18.82	21.16

Ca^{2+}	18.60 - 168	52.5	65.78	36.32	4.38 – 57.6	20.64	27.54	27.27
TDS	344 – 997.4	542.32	583.86	210.59	266.7 – 556.89	380.89	401.49	146.19
TH	80.88 - 668.3	270.53	301.14	132.23	23.33 – 320.31	95.2	146.28	154.94
Alk	177.24 - 522.2	296.28	309.02	86.94	84.77 – 316.59	205.04	202.13	115.94
Para-meters	***Hand dug well water***				***River water***			
EC	899 - 1117	1008	1008	154.15	203 - 398	360	320	103.37
pH	7.8 - 8.0	7.91	7.91	0.12	8.13 – 8.71	8.24	8.36	0.31
HCO_3^-	295-555	425	425	183.85	110.2 – 278.48	200	196.23	84.21
F^-	0.04 - 3.4	1.90	1.90	2.12	0.27 – 0.33	0.30	0.30	0.03
Cl^-	16.2 - 39.49	27.83	27.83	16.44	3.39 – 10.54	5.71	6.55	3.65
NO_3^{2-}	3.14 - 62.43	32.79	32.79	41.92	3.29 – 5.72	5.22	4.74	1.28
PO_4^{3-}	0.11 - 0.14	0.13	0.13	0.03	0.17 – 0.30	0.18	0.21	0.07
SO_4^{2-}	19.95 - 33.32	26.63	26.63	9.45	4.35 – 10.63	7.43	7.47	3.14
Na^+	49.43 - 51.29	50.36	50.36	1.31	7.52 – 18.30	7.56	11.13	6.21
K^+	7.6 - 6.83	7.22	7.22	0.55	1.52 – 2.56	1.52	1.78	0.68
Mg^{2+}	26.88 - 92.31	59.6	59.6	46.27	10.46 – 23.43	21.19	18.36	6.94
Ca^{2+}	36.56 - 49.48	43.02	43.02	9.14	19.45 – 34.25	33.73	29.14	8.4
TDS	458.2 - 892.8	675.53	675.53	307.32	160.8 – 320	283.97	254.96	83.54
TH	202 - 503.71	352.86	352.86	213.34	91.65 - 182	171.50	148.39	49.42
Alk	241.95 - 455.2	348.58	348.58	150.79	90.4 - 164	164.04	143.59	46.49

Note: All ion concentrations and TDS are in mg/l, EC in µS/cm and total hardness (TH) and alkalinity (Alk) are in mg/l $CaCO_3$.

3.1.1. Cations (Calcium, Magnesium, Sodium and Potassium)

The concentration of calcium in groundwater (boreholes, spring, and hand-dug wells) and river water in the study area vary from 4.38 to 168 mg/l with an average value of 61.07 mg/l and 19.45 to 34.25 mg/l with an average of 29.14mg/l, respectively (Table 2). The magnesium concentration in the samples of groundwater ranged from 3.01 to 92.31mg/l while in river samples, it varies from 10.46 to 23.43 mg/l. The sodium and potassium ion concentrations in the groundwater samples ranged from 15.89 to 109.4 mg/l and 0.9 to 10.9 mg/l, respectively and in the river water samples ranged from 7.52 to 18.30mg/l (Table 2).

3.1.2. Anions (Bicarbonate, Sulfate, Chloride)

The concentration of HCO_3^- in the water samples from the Golina River Basin is between the lower value of 103.35 mg/l to the higher value of 636.7 mg/l with an average value of 354 mg/l. The alkalinity value of water in the Golina River Basin varies from 84.77 to 522 with an average value of 289 mg/l $CaCO_3$. The permissible value of alkalinity for irrigation is 150 mg/l $CaCO_3$. The sulfate (SO_4^{2-}) concentration in water samples of the study area varies from 2.43

to 145.67 with an average value of 27.27mg/l. The chloride concentration in water samples of the study area varies from 3.4 to 91.54 with an average value of 18.64 mg/l. The nitrate concentration level in groundwater and surface water in the Golina River Basin varies from 0.016 to 107.53 mg/l with an average value of 15 mg/l. The phosphate concentrations in the water samples of the study area vary from 0.01 to 1.55 with an average value of 0.29 mg/l.

3.1.3. Hydrogen-Ion Activity (pH), Total Dissolved Solids (TDS) and Total Hardness (TH)

The value of pH parameter in water samples from the area varies between 7.17 and 8.17 which is within the normal range. TDS values of the groundwater and river water in the study area vary from a minimum of 266.7 to a maximum of 997.38 mg/l with an average of 530.45 mg/l. The total hardness value of samples from the study area varies from 23.33 to 668.3 mg/l $CaCO_3$ with an average of 279 mg/l $CaCO_3$. Except for one sample from Golina Spring (GS3), all water samples are categorized as moderately hard and hard. About 54% of the water samples from the Golina River Basin are categorized as hard while 32.43% belong to very hard water (Table 3).

3.1.4. Salinity and Sodium Hazards

EC values are classified into Type-I for EC value below 1,500 µmhos/cm, Type-II for EC between 1,500 and 3,000 µmhos/cm and Type-III greater than 3,000 µmhos/cm. Water samples of the area have an EC value between 203 µS/cm and 1270 µS/cm with an average value of 657 µS/cm. The sodium hazard (SAR) value of the waters in the study area varies from 0.25 to 7.5 with an average value of 1.24.

3.1.5. Magnesium Hazards and Soluble Sodium Percentage (Na%)

The range of magnesium ratio in the water samples varies from 15 to 75.5% with an average value of 48%. The soluble sodium percentage (SSP) values of the groundwater samples range from 9.9 to 88.7% with an average value of 26%.

3.1.6. Residual sodium carbonate (RSC), Permeability Index (PI) and Kelly´s Index (KI)

The residual sodium carbonate values of the surface water and groundwater samples in the Golina River Basin vary from -2.93 to 3.61meq/l with an average value of 0.23meq/l (Figure 4). The permeability index of water samples in the study area varies from 37.17% and 120.3% with an average value of 61% (Fig 5). Kelly´s index of water samples in the study area ranges between 0.10 and 1.70 with an average value of 0.57.

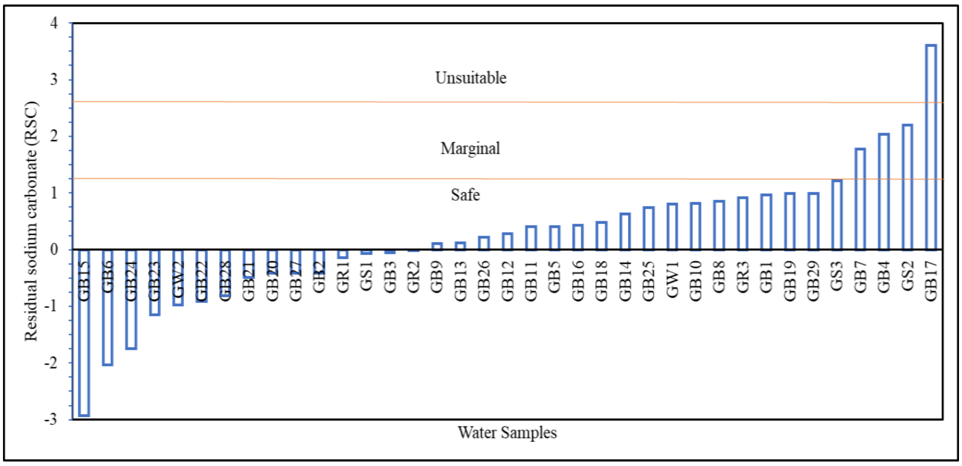

Figure 4. Plot graph of residual sodium carbonate of the water samples in the Golina River Basin.

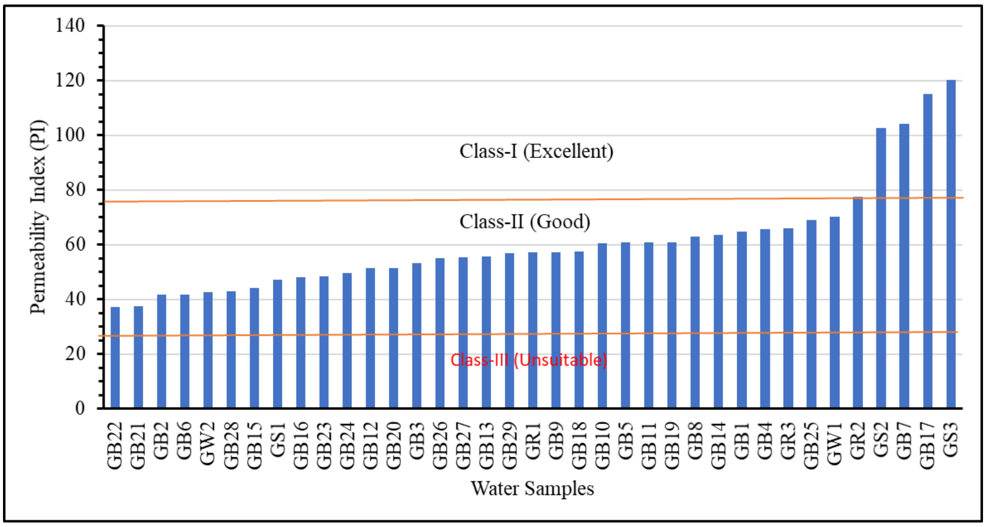

Figure 5. Permeability index of water samples in the Golina River Basin.

4. DISCUSSION

4.1. Groundwater Suitability for Irrigation

4.1.1. Cations (Calcium, Magnesium, Sodium, and Potassium)

The water samples taken from alluvial deposits are enriched with calcium and magnesium ions probably due to the dissolution of $CaCO_3$ and $MgCO_3$. The spring samples from the mountainous area have lower calcium and magnesium values relative to Sodium. Both calcium and magnesium are very important for irrigation, but they also contribute to the hardness of the water. Both low and high concentrations of calcium and magnesium can be a cause of plant and crop deficiency. The permissible range of calcium in the water for irrigation is between 40 and 100 mg/l and for magnesium between 25 and 50 mg/l (Swistock, 2016). Among the water samples from the study area, 14 water samples were found to be contained below 25 mg/l of magnesium, while only three samples (GB15, GW2, and GB6) are above 50 mg/l of magnesium. Therefore, about 46% of the water samples in the area are unsuitable for irrigation based on magnesium ion concentration. Similarly, 11 water samples are found to contain below 40 mg/l of calcium while only 5 water samples have above 100 mg/l of calcium ion concentration. Overall, about 43% of the water samples from the area are found to be not permissible for irrigation use based on calcium ion concentration.

High levels of sodium can cause various problems to plant growth (Swistock, 2016). The level of 10 mg/l of potassium concentration is an indication of contamination from different natural and anthropogenic sources. According to the result, all groundwater samples are suitable for irrigation except water sample GB29 which has 10.09 mg/l of potassium. The sources of potassium in groundwater are the weathering of K-feldspars (for those samples that have low potassium concentrations) and fertilizer applications (for those samples that have high potassium concentrations) in the study area.

4.1.2. Anions (Bicarbonate, Sulfate, Chloride)

Bicarbonate is very high at the floor of the valley which is covered by alluvial deposits rather than on the mountain that is covered by basaltic rocks. This is as a result of water interaction with the existence of soil carbon dioxide (CO_2) in the alluvial deposits to form carbonic acid (Fenta et al., 2020). Knowing the concentration of bicarbonate helps to understand the sources of alkalinity and the level of contamination in water. Carbonate and bicarbonate ions in irrigation water help facilitate precipitation of lime (calcium carbonate or magnesium carbonate) when combined with calcium or magnesium (Hannam et al., 2016). Furthermore, high carbonate and bicarbonate in irrigation water tend to increase sodium absorption ratio (SAR) and residual sodium carbonates, cause an alkalizing effect, and increase the pH value in water which adversely affects the soil property, and crop and plant species (Murray and Grant, 2007). Except for spring and river water samples all groundwater samples in the study area exceed the maximum permissible limit of HCO_3^- ion concentration for field crops which is 244 mg/l.

From an irrigation point of view, total alkalinity is very important. The permissible value of alkalinity for irrigation is 150 mg/l $CaCO_3$. Based on the alkalinity classification of waters for irrigation, except samples of GS3 and GR1, all water samples in the Golina River Basin are not permissible for irrigation (Table 3). Sulfate occurs naturally from the dissolution of sulfate-rich minerals like pyrite and discharge from industries (Gebru et al., 2012). In the study area, the sulfate doesn’t have a significant impact on the soil and crops because the range of the sulfate is within the desirable for irrigation which is 400mg/l. High chloride concentration in irrigation water can damage plants and crops. However, most plants and crops are tolerant to chloride concentrations up to 100 mg/l with few sensitive plants and crops tolerant to below 30 mg/l of Cl^- concentrations (Swistock, 2016). So, the chloride concentration in the study area is permissible for most plants and crops.

4.1.3. Hydrogen-Ion Activity (pH), Total Dissolved Solids (TDS) and Total Hardness

pH is a measure of acidity or alkalinity of the water and provides vital information in any type of geochemical equilibrium or solubility calculation in water (Hem, 1985). pH is a vital factor in evaluating the suitability of water for irrigating plants and crops. However, pH alone does not have a significant impact on crops and plants unless associated with alkalinity. The normal pH of irrigation water ranges from 6.5 to 8.4 (Ayers and Westcot, 1985). All samples taken from the study area are within the normal range.

TDS is a measure of the total amount of dissolved solids in the water. In other words, TDS can be determined by evaporating a known volume of the sample and weighing or by summing the concentrations of the individual ions (Fetter, 2001). For irrigation, the TDS has been classified as best (<450), moderate (450-2000) and hazard (>2000mg/l) water types (Ayers and Westcot, 1985). In the study area, 10 groundwater and 3 river water samples fall on the best water type for irrigation while 24 groundwater samples fall on the moderate water types. Sample of GS3 from spring and GB7 and GB17 from artesian wells have low total hardness as compared to other water points in the Golina River Basin due to containing low concentrations of calcium and magnesium. The total hardness of water is a crucial parameter for the determination of the suitability of water for irrigation use. The total hardness of water is a measure of the relative abundance of bi-valent cations that will react with soaps to form a soft precipitate or react in boilers to form a solid scale precipitate (Charles, 2002). These harnesses are driven from calcium and magnesium-rich water-bearing formations. Both hard and very hard water types can affect the health of crops through damage to soil properties and clogging of irrigation equipment.

4.1.4. Salinity and Sodium Hazards

The electrical conductivity of water equals the inverse of the electrical resistance across one cubic centimeter of water (Charles, 2002; Hem, 1985). The electrical conductivity of water is an indication of salinity hazard. The electrical conductivity of the waters affects crop water availability (Ayers and Westcot, 1985). Based on Prasanth et al. (2012), EC values are classified into Type-I for EC value below 1,500 µmhos/cm, Type-II for EC between 1,500 and 3,000 µmhos/cm and Type-III greater than 3,000 µmhos/cm. According to Prasanth et al. (2012) classification, all water samples of the Golina River Basin are grouped under type-I.

Based on the salinity hazard classification of Wilcox (1955), the groundwater samples are categorized under medium and high.

Sodium hazard (SAR) is directly proportional to sodium but inversely proportional to calcium and magnesium. Based on the sodium hazard classification, all the surface and groundwater samples fall on low sodium hazard which indicates that it is excellent in terms of suitability for irrigation use (Table 3). The combination of Sodium hazard and Salinity hazard are very important parameters for the classification of irrigation water and are used to determine the feasibility of water for irrigation purposes (Fig 6). These parameters are also very important to plot the Wilcox diagram which is Sodium hazard versus salinity hazard. According to this diagram, the water samples fall on S1C2 (26 water samples) > S1C3 (9 water samples) > S1C1 (1 water sample) = S2C2 (1 water sample). River water is better than the others because of its low electrical conductivity. The spring sample has a high SAR value due to the presence of a high sodium concentration level. Generally, as shown in the Wilcox diagram, all samples are suitable for irrigation (Fig 6).

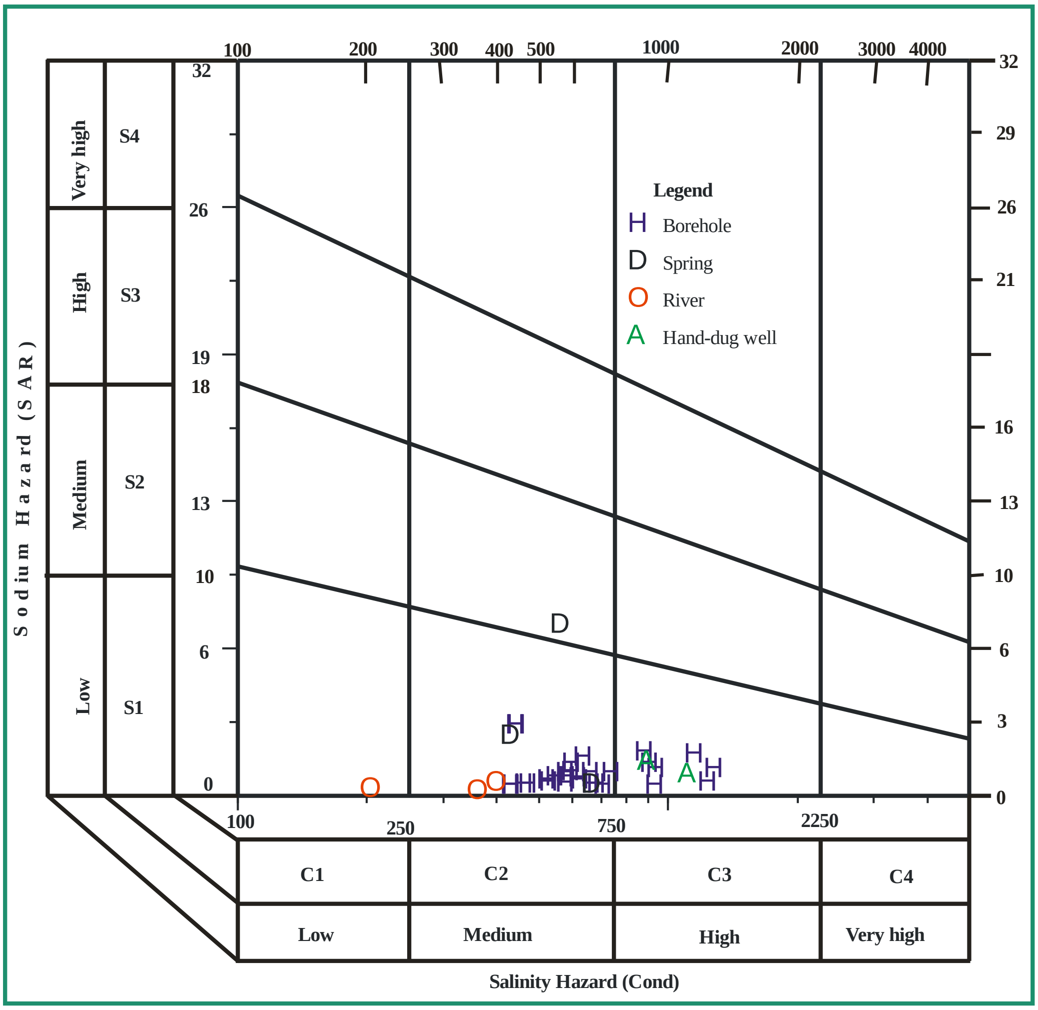

Figure 6. Wilcox diagram (Sodium hazard Vs Salinity hazard).

4.1.5. Magnesium Hazards and Soluble Sodium Percentage (Na%)

According to Hem (1985), calcium and magnesium ions maintain an equilibrium state in most groundwater. The result shows about 57% of the surface water and groundwater samples in the study area are within the permissible limit which is 50% while 43% is outside the permissible limit (Table 3). So, 43% of the water samples from the area are harmful to crop yield as the soil becomes more alkaline. About 92% of the groundwater in the area is good for the physical properties of the soil and suitable for irrigation in terms of soluble sodium percentage parameter. Samples of GS3, GB7, and GB17 are not suitable for irrigation and affect the physical properties of the soil because of the richness of sodium in the sample (Table 3).

Table 3. Classification of groundwater quality based on suitability of water for irrigation purposes.

Parameter	*Range*	*class*	*No. of samples*	*Percentage (%) of samples*
TDS (Ayers and Westcot, 1985)	<450	Best	13	35
	450–2000	Moderate	24	65
	>2000	Hazard		
TH (Sawyer and McCarty, 1967)	<75	Soft	1	2.7
	75-150	Moderate	4	10.81
	150-300	Hard	20	54.06
	>300	Very hard	12	32.43
Salinity hazard (Wilcox, 1955)	<250	Low (C1)		
	250-750	Medium (C2)	24	72.73
	750-2250	High (C3)	9	27.27
	>2250	Very high (C4)		
SAR (Wilcox, 1955)	<10	Excellent	36	97.3
	10-18	Good	1	3.7
	18-26	Fair		
	>26	Poor and unsuitable to use		
MH (Paliwal, 1972)	< 50	Suitable	20	60.61
	> 50	Unsuitable	13	39.39
SSP (Wilcox, 1955)	< 20	Excellent	18	48.65
	20 - 40	Good	15	40.54
	40 - 60	Permissible	1	2.70
	60 - 80	Doubtful	2	5.40
	> 80	Unsuitable	1.	2.70
RSC (Raghunath, 1987)	< 1.25	Safe	33	89
	1.25 – 2.5	Marginal	3	8
	> 2.5	Unsuitable	1	3
PI (Doneen, 1964)	< 25	Class III (unsuitable)	…..	…..
	25 - 75	Class II (Good)	30	90.91
	> 75	Class I (Excellent)	3	9.09
KI (Kelley, 1940)	< 1	Suitable	30	90.91
	> 1	Unsuitable	3	9.09

4.1.6. Residual sodium carbonate, Permeability Index and Kelly´s Index

From irrigation water point of view, GB17 groundwater sample is unsuitable whereas GB4, GS2, and GB7 are grouped within the marginal classes of waters in terms of residual sodium carbonate (Fig 4). Based on this concept 89% of the water samples are grouped within safe water for irrigation in the study area (Table 3).

The result of permeability index in the study area indicated about 86.5% of the water samples are categorized under Class II which is good for irrigation and about 13.5% of water samples are grouped in Class I which is excellent for irrigation in the study area (Table 3). In the study area, water samples of GR2, GS2, GB7, GB17, and GS3 are suitable for irrigation as compared to the other water samples (Fig 5). A total of 89% and 11% of groundwater samples are classified under suitable and unsuitable water for irrigation, respectively, in terms of Kelly´s index (Table 3). In the Golina River Basin, water samples of GS2, GS3, GB7, and GB17 are not suitable for irrigation due to the excess levels of sodium in the water samples.

4.1.7. Impact of Irrigation on Water

Nitrogen and phosphate are the primary nutrients for crop growth but when applied excessively can have a negative effect (Jeong et al., 2016). Phosphate is a very important compound for plant growth and development due to its role in plant metabolism and energy transformation (Zohar et al., 2010). However, excess utilization of phosphate fertilizer in the long term can affect the groundwater and surface water quality. The concentration of phosphate is very low in the Golina River Basin which cannot be a problem for the crops and plants in the Golina River Basin. This result is an indication of low contamination from fertilizers as well as from manure runoff in the Golina River Basin related to phosphate sources as compared to Nitrate and Potassium concentrations.

Nitrate is very important to evaluate the impact of anthropogenic activities on groundwater. The main sources of nitrate contamination in groundwater and surface water are leaching from agricultural land, solid waste dumping sites, or oxidation of ammonia (Górski et al., 2019; Shukla and Saxena, 2020). The high values of nitrate concentration levels were due to the excessive use of nitrogen-rich inorganic fertilizer for the last two decades and contamination from livestock wastes and plant nutrients in the study area. One-third (1/3) of groundwater and surface water samples reported greater than 20 mg/l, especially the irrigation boreholes. Groundwater samples of HG10, GW2, and GB6 measured nitrate concertation values greater than 50 mg/l. The utilization of excess nitrate from fertilizer and contaminated water in the irrigation area can cause water quality problems in crops and plants and vegetables grow excessively. Therefore, the water samples that have excess nitrate concentration are an indication of contamination from the fertilizers in the Golina River Basin which needs a good deal of attention to reduce the amount of nitrate-rich fertilizer to use in the area.

4.1.8. Water Types

The Piper diagram (Fig 7) of water samples from the study area indicates that more than 75% of the samples are categorized under no dominant water type cation facies and 100% within bicarbonate type anion facies. Diamond-shaped Piper diagram shows 89%, 11%, and 100% of the groundwater samples are grouped as alkaline earth exceeds alkalis, alkalis exceed alkaline earth and weak acids exceed strong acids, respectively (Piper, 1953; Singhal and Gupta, 2010).

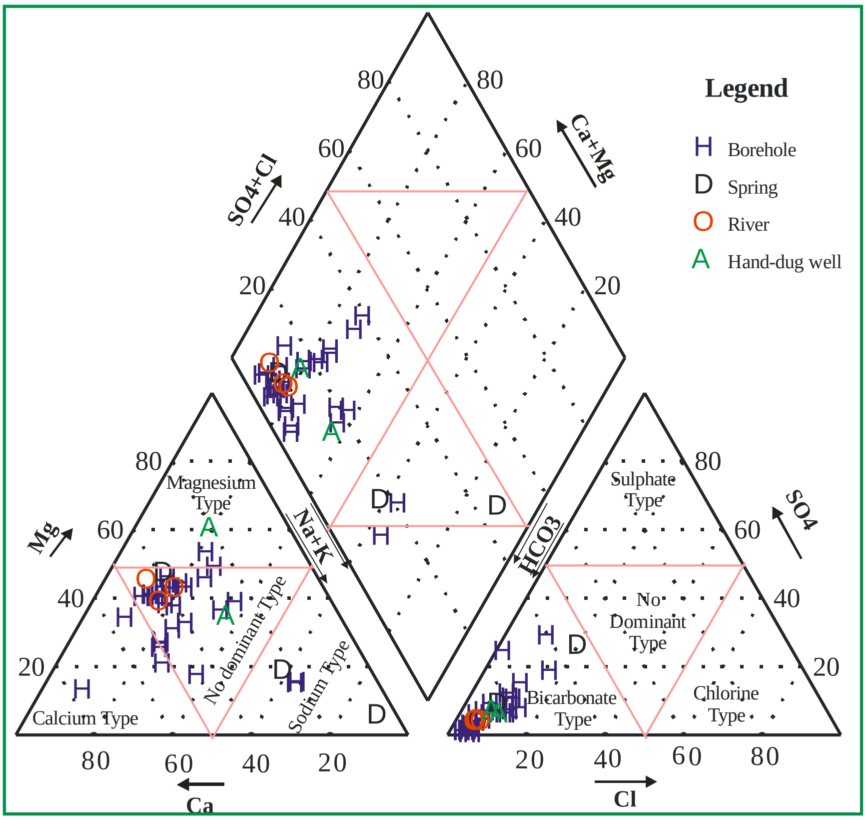

Figure 7. Piper diagram showing water type.

Hydrogeochemical facies or water types can be classified based on the dominant ions (Singhal and Gupta, 2010). In the study area, most of the groundwater samples belong to Ca^{2+}-Mg^{2+}-HCO_3^- and Mg^{2+}-Ca^{2+}-HCO_3^- but minor samples belong to Na^+-Ca^{2+}-HCO_3^- and Ca^{2+}-Na^+-HCO_3^- types (Fig 7).

5. CONCLUSION AND RECOMMENDATION

Groundwater is a natural freshwater resource and is very important for drinking, industry, agriculture, and other purposes. In principle, groundwater resource availability is no guarantee for sustainable utilization without evaluating its quality for a certain purpose. In the study area, a total of 34 groundwater and 3 river water samples were collected and analyzed for parameters of pH, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, NO_2^-, PO_4^{3-}, and F^-. Besides, TDS, TH, SAR, MH, SSP, RSC, PI, and KI were calculated and interpreted concerning groundwater suitability for irrigation purposes. The results of major cations and anions in the Golina River Basin show that few groundwater samples are unsuitable for irrigation. Most of the groundwater samples were hard and very hard waters. Based on TDS values the groundwater and river waters are suitable for irrigation. Among the boreholes serving for irrigation, nitrate contamination is noticed which could be from agricultural activities and waste material from animals in the Golina River Basin. Based on the Salinity hazard (EC) and SAR results, the groundwater and river water of the Golina River Basin can be tolerable by most crops and plants. Based on the results of RSC, PI, and KI parameters, GS2, GB7, and GB17 are not suitable for irrigation purposes because they contain excessive levels of sodium and bicarbonate which are harmful to crop health and permeability of soils. According to the overall results, the groundwater and river water samples are accepted for irrigation purposes.

This study was focused on the groundwater and surface water quality for irrigation purposes and the impact of irrigation on groundwater. However, it is also recommended for further investigation on the suitability of soil as well as the impact of the pressurized irrigation systems on soil fertility and salinity. According to the results based on the different parameters in groundwater and river waters, the study area has good potential for irrigation, but it is recommended water quality monitoring be made. Some of the water samples are found to be unsuitable for irrigation use, which indicates that the soil properties as well as crop production are being affected. Therefore, it is recommended that the selection of the crops should be based on the nature of the crop to tolerate the water quality.

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7. CONFLICT OF INTEREST

There is no conflict of interests.

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