USE OF GEOGRAPHIC INFORMATION SYSTEM AND WATER QUALITY INDEX TO ASSESS SUITABILITY OF GROUNDWATER QUALITY FOR DRINKING PURPOSES IN HEWANE AREAS, TIGRAY, NORTHERN ETHIOPIA

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Abstract

The study area Hewane is situated in the southern zone of Tigray Regional State, Hintalo Wajirat wereda. It is geographically located between 1444000 to 1454000m N and 550000 to 558000m E with an aerial extent of 47.66 sq. km. The study was conducted having an objective of assessing suitability of groundwater quality for drinking purposes through geographic information system (GIS) and water quality index (WQI). Ten groundwater samples were collected from the study area and 13 physico-chemical parameters such as TDS, TH, Alkalinity, pH, EC, Temperature, Na^+, K^+, Mg^{2+},Ca^{2+}, Cl^-, HCO_3^- and SO_4^{2-} were analyzed. Inverse distance weighted (IDW) interpolation method has been used to generate the spatial distribution of the groundwater physico-chemical parameters and water quality index map. To estimate the water quality index, 9 parameters have been considered: pH, Na^+, K^+, Mg^{2+},Ca^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, and TDS. The WQI estimated for the groundwater samples of the study area ranges from 86.1 to 180.5 at groundwater samples GWS_2 and GWS_5, respectively. Based on the analysis, most of the area under study falls 70% in poor water class and 30% in good water class. Hence, the result revealed that 70% of the groundwater samples of the study area are hardly suitable for drinking purposes without water quality management activities.

Key words: *spatial distribution, GIS, WQI, groundwater quality, Hewane, Tigray, Ethiopia*

Introduction

Water quality is a term used to describe the chemical, physical and biological characteristics water, usually in respect to its suitability for a particular purpose (Sargaonkar and Deshpande, 2003; Khan *et al*., 2003). Groundwater has long been regarded as the pure form of water compared to surface water, because of purification of the former in the soil column through anaerobic decomposition, filtration and ion exchange. This is one of the reasons for the excessive consumption of groundwater in rural and semi-urban areas all over the world (Kannan and Joseph, 2009). Groundwater, being a fragile and important source of drinking water, must therefore be carefully managed to maintain its purity within standard limits. Groundwater degradation occurs when its quality parameters are changed beyond their natural variations by the introduction or removal of certain substances (Ramesh, 2001; Todd, 2001).

Geographic information system can be a powerful tool for developing solutions for water resources problems, assessing water quality, flooding, understanding the natural environment and for managing water resources on a local and/or regional scale (Ferry *et al*., 2003). It is a very powerful tool for processing, analyzing and integrating spatial data sets. In a very comprehensive sense, GIS may mean identifying data needs, acquiring data, data management, processing and analysis of data and decision-making.

Chemical quality of groundwater is an important attribute data which controls water use. These data, being spatially different, can be processed and analyzed in the GIS software in a highly efficient manner. The chemical quality of groundwater is expressed in terms of various parameters like Temperature, Total dissolved solids (TDS), Total hardness (TH), Alkalinity, pH, Electrical conductivity (EC), Na^+, K^+, Mg^{2+},Ca^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, etc. In GIS software, each of these parameters can be treated as a data layer.

The data layer can be suitably contrasted, manipulated and displayed as a black-and-white output.

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For any city, a groundwater quality map is important for drinking purposes and as a precautionary indication of potential environmental health problems (Challerjee *et al.*, 2009). Hence, the study was conducted having an objective of assessing suitability of groundwater quality for drinking purposes through geographic information system (GIS) and water quality index (WQI).

Methodology

LocationThe study was carried out in Hewane situated in the southern zone of Tigray Regional State, Hintalo Wajirat wereda. It is geographically located between 1444000 to 1454000m N and 550000 to 558000m E and covering an area of 47.66 sq. km. The area is surrounded by mountains with streams flowing towards the central parts of the area. The drainage pattern is mainly dense and shows dendritic pattern. The general flow direction of the streams is directed together towards the northwestern part (Figure 1).

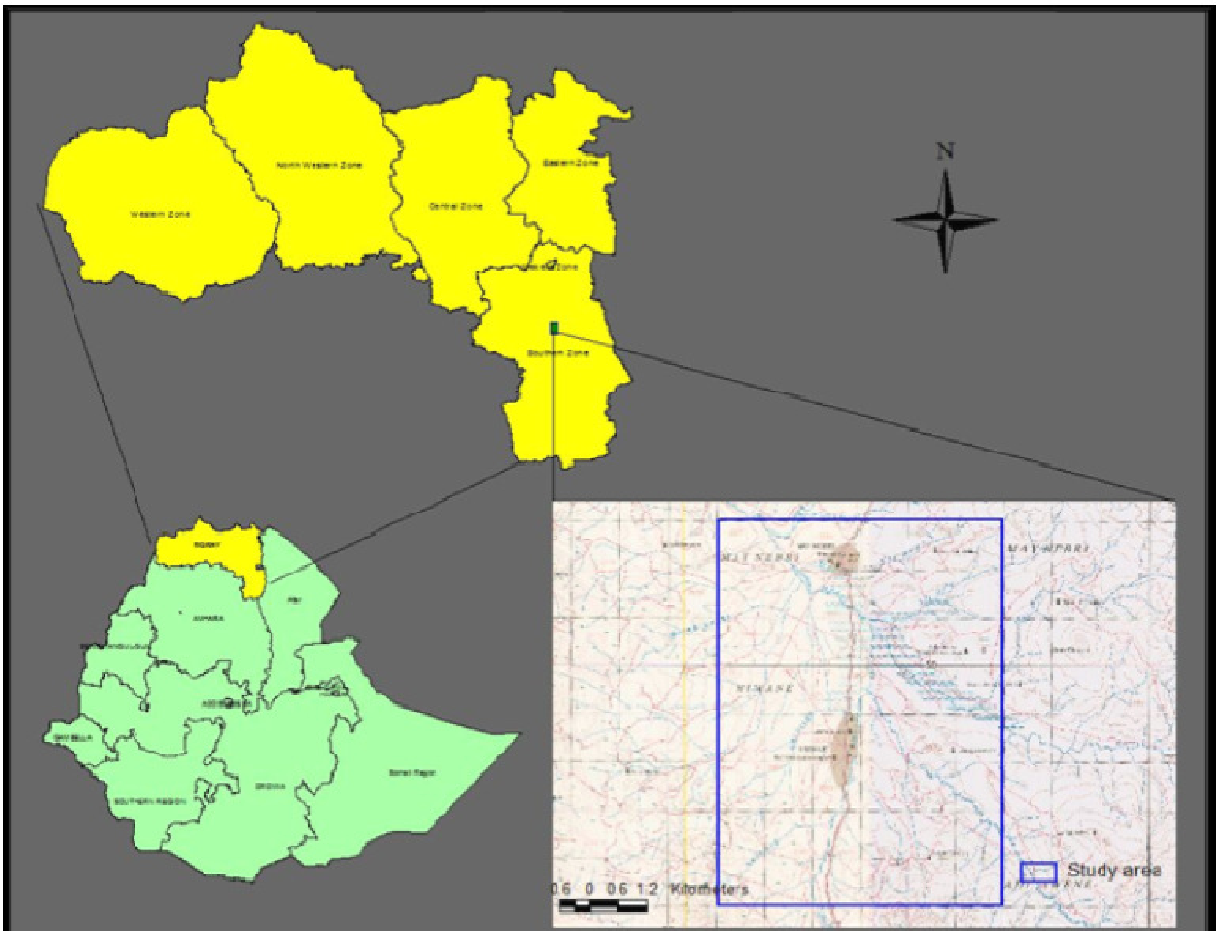

Figure 1 Location map of the study area

Data Collection and Analysis

Geographic locations, latitude, longitude and elevation of the water points were collected with the help of GARMIN etrex GPS. A total of ten groundwater samples were collected from the study area. All groundwater samples were collected in 2 L plastic bottles which were washed and triple-rinsed with distilled water and with the water of interest before sampling and transported them to the laboratory. For each groundwater sample a number of physico-chemical parameters like TDS, TH, Alkalinity, pH, EC, Temperature, Na^+, K^+, Mg^{2+},Ca^{2+}, Cl^-, HCO_3^- and SO_4^{2-} were analyzed. Temperature, EC and pH measurements were taken in-situ using standard equipment (Century Water Analysis Kit). The major cations and anions were analyzed using Atomic

Adsorption Spectrophotometer (AAS) and Ultra Violet Spectrophotometer (UVS), respectively by Tigray Agricultural and Rural Development Bureau Soil and Groundwater Laboratory as per the standard methods of APHA (2005) and Eaton *et al*. (1998).

TDS is estimated using the empirical formula after Raghunath (2003).

TDS (mg/l) = 0.64 * EC (µS/cm)……………………………………. (1)

Total hardness (TH) is estimated using the following formula adopted from Fournier (1981).

Total hardness (TH) = $2.5Ca^{2+}$ + $4.1Mg^{2+}$……………………………………….. (2)

Where: TH, Ca and Mg are measured in milligrams per liter.

Alkalinity is also calculated from the equilibrium constants for the speciation reaction and the measured pH of the solution with the following equation (Deutsch, 1997).

$$\text{Alkalinity (mg/l } CaCO_3) = [HCO_3^-] \text{ mg/l x } \left(1 + \frac{2 \times 10^{-10.3}}{10^{-pH}}\right) \text{ x } 50 / 61 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Statistical analyses of the physico-chemical parameters was done with the aid of SPSS 15.0 version software package and presented as minimum, maximum, mean, standard deviation and also graphical presentations of physico-chemical parameters of the groundwater samples.

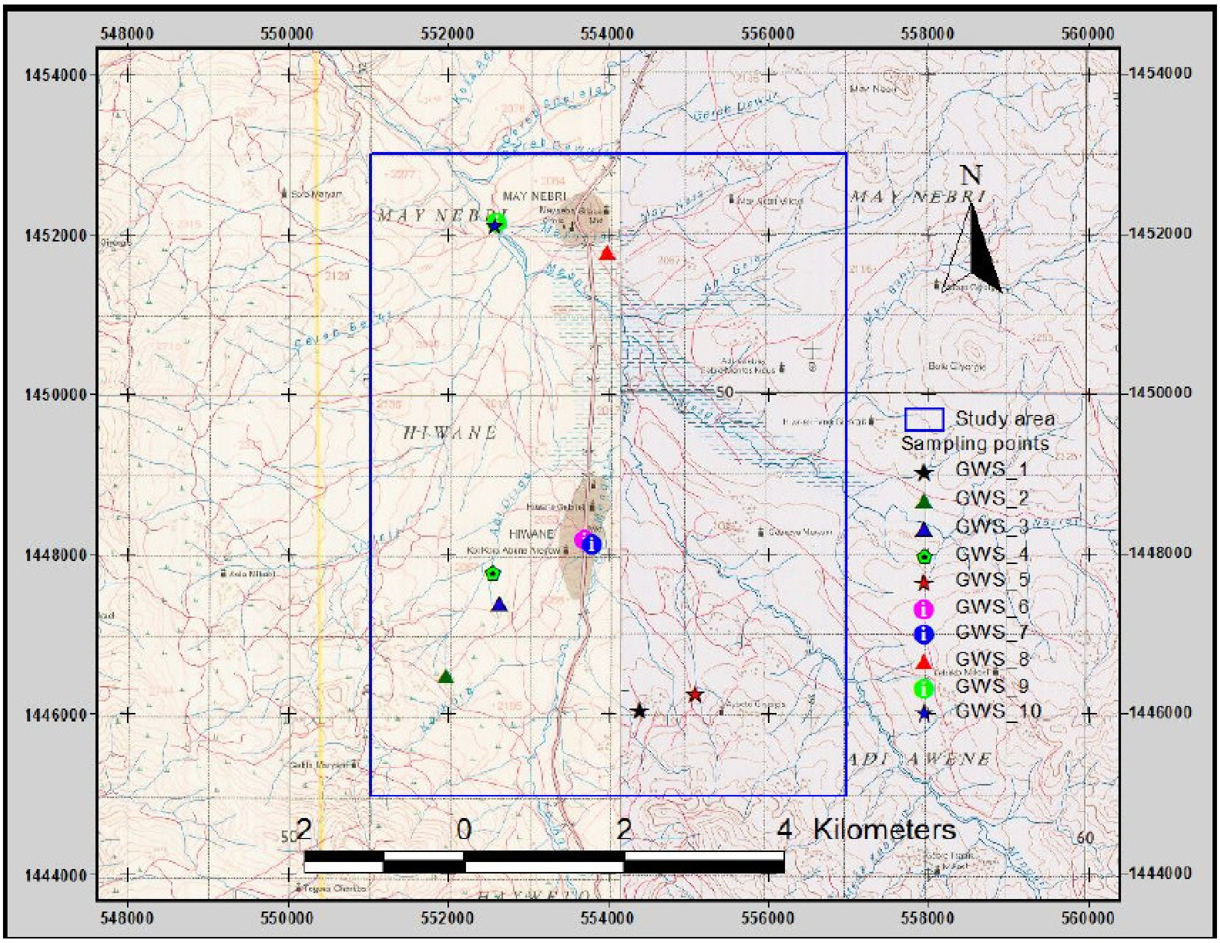

Figure 2 Ground water sampling points map

Geo-data Preparation and Interpolation

In the preprocessing phase analyzed groundwater parameters were prepared in a DBF 4 format in the MS Excel Program suitable for exporting into GIS database and make them amendable for integrated analysis.

Keyboard and digitization for entering attribute data of groundwater sample parameters and location data respectively were used to enter the data input into ArcGIS 9.3 software. Once the input data was imported as a point layer, geo-database was created to generate the spatial distribution maps of selected water quality parameters.

Interpolation is the process of predicting unknown values using the known values in the vicinity. For the sake of this research work, point-based Inverse Distance Weighted (IDW) interpolation method was used to produce spatial distribution thematic maps for each of the groundwater parameters: TDS, TH, Alkalinity, pH, EC, Ca, Mg, K, Na, Cl, CHO_3 and SO_4. This interpolation method determines cell values using linearly weighted combination of a set of sample points. The weight is a function of inverse distance. Similarly, Inverse Distance Weighted (IDW) interpolation method was used to produce the WQI map of the study area.

Water Quality Index (WQI)

Water quality index is computed to reduce the large amount of water quality data to a single numerical value. It reflects the composite influence of different water quality parameters on the overall quality of water. WQI has been computed to determine the suitability of the groundwater for drinking purposes.

Result and Discussion

Major Cations and Anions

The major ions of the groundwater samples in the study area were in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+} = HCO_3^{-} > Cl^{-} > SO_4^{2-}$ while carbonates remain nil throughout the groundwater samples. Calcium is the dominant cation and its concentration ranges from 84.00 to 412.00 mg/l at groundwater samples GWS_7 to GWS_5 and GWS_10, respectively. Based on Todd (2005), concentration of all groundwater samples were above the maximum permissible limits (100mg/l) except 1 groundwater sample, GWS_7 as far as calcium is concerned (Table 1, Figure 3 and 4). Magnesium is the second dominant cation in the study area and its concentration varies from 96.00 to 211.20mg/l at GWS_2 and GWS_9, respectively. All the groundwater samples showed a magnesium concentration above the maximum permissible limit (50mg/l), Todd (2005) (Table 1 and Figure 3 and 5).

The concentration of sodium ranges between 19.09 and 43.93mg/l at GWS_2 to GWS_3 and GWS_9 respectively with an average value of 32.32mg/l (Table 1). According to the WHO (2004) guideline, the maximum admissible limit is 200mg/l. In the study area, all the groundwater samples were found within the maximum permissible limit as far as it is concerned (Figure 3 and 6).

In the study area, the concentration of potassium ranges from 2.34 to 51.09mg/l at GWS_1 and GWS_5 respectively with an average value of 18.06mg/l (Table 1); and it was found that 4 groundwater samples were having potassium values within the permissible limit and 6 groundwater samples above the permissible limit (10mg/l) (Todd, 2005) (Figure 3 and 7).

Bicarbonate is the dominant anion in the groundwater samples of the study area and its concentration ranges from 244.00 to 585.60mg/l at samples GWS_10 and GWS_6, respectively (Table 1). Based on Todd (2005), concentration of all groundwater samples were within the maximum permissible limits (500mg/l) except 3 groundwater samples, GWS_1, GWS_6 and GWS_7 as far as bicarbonate is concerned (Figure 3 and 8).

Chlorine is the second dominant anion in the study area and its concentration varies from 71.00 to 340.80mg/l at GWS_1 and GWS_10 respectively with an average value of 147.68mg/l (Table 1). All the groundwater samples showed a chlorine concentration above the maximum permissible limit (10mg/l), Todd (2005) (Figure 3 and 9).

Concentration of sulphate ranges from 49.49mg/l in GWS_1 up to 122.5 mg/l in GWS_8 with an average value of 69.14mg/l (Table 1). According to the WHO (2004) guideline, the maximum admissible limit is 300mg/l. Sulphate in all the groundwater samples of the study area were found within the maximum permissible limit as far as it is concerned (Figure 3). The spatial distribution of sulphate concentration in groundwater of the study area is illustrated in figure 10. This map shows that all the groundwater samples were within the maximum allowable limit of 200mg/l.

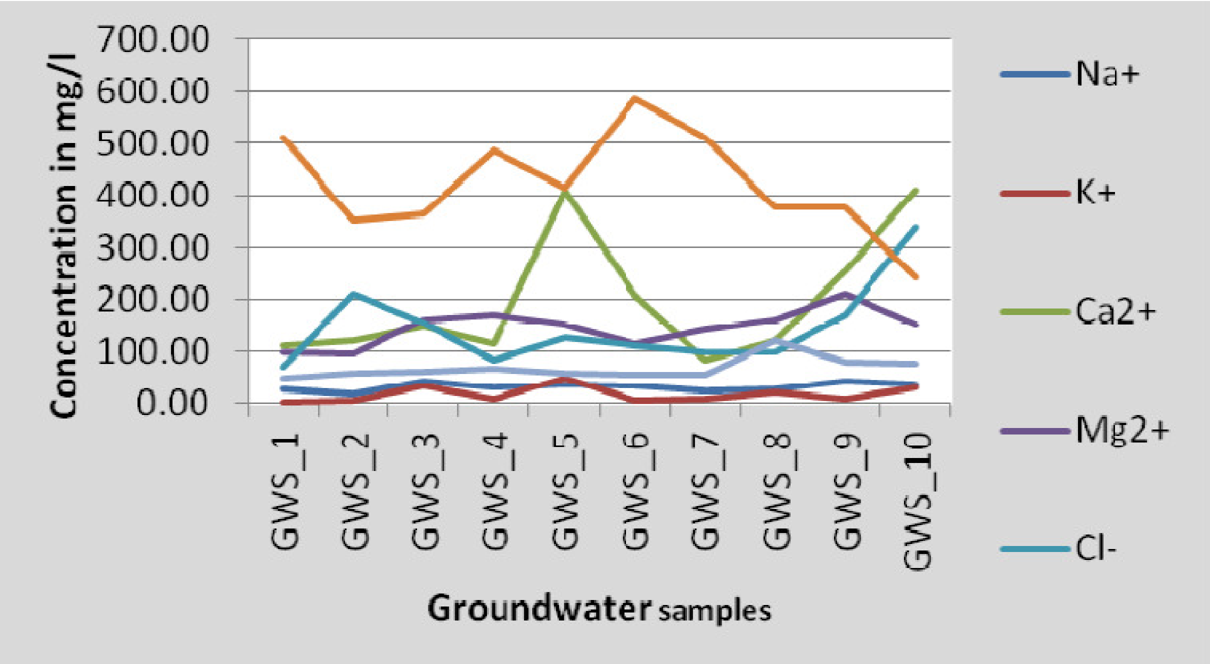

Figure 3 Concentration of major ions in the groundwater samples of Hewane area

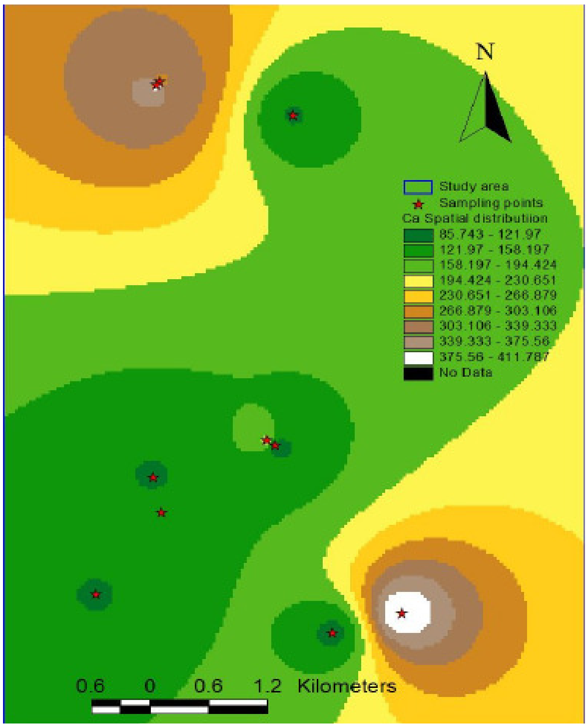

Figure 4 Spatial distribution map of calcium (mg/l) in Hewane area

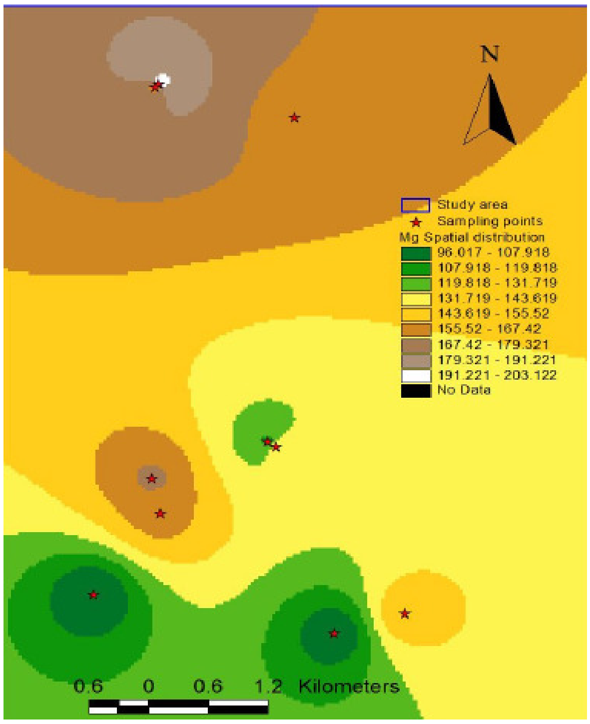

Figure 5 Spatial distribution map of magnesium (mg/l) in Hewane area

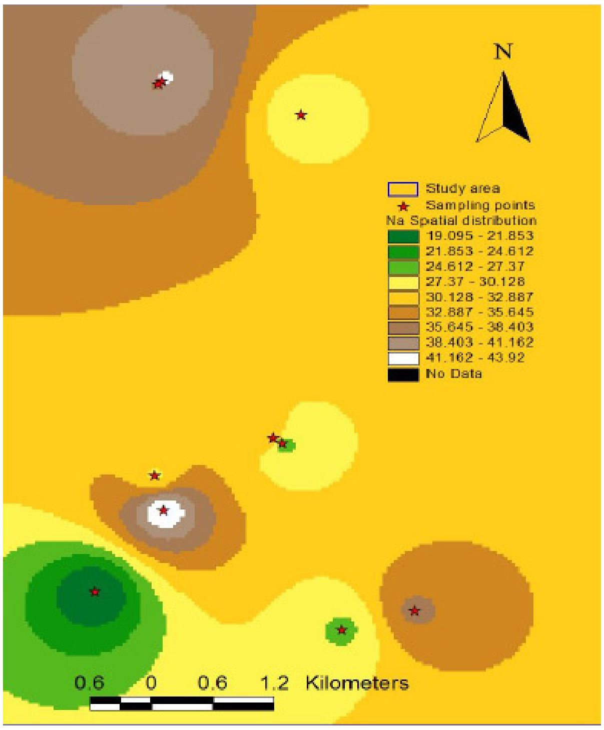

Figure 6 Spatial distribution map of sodium (mg/l) in Hewane area

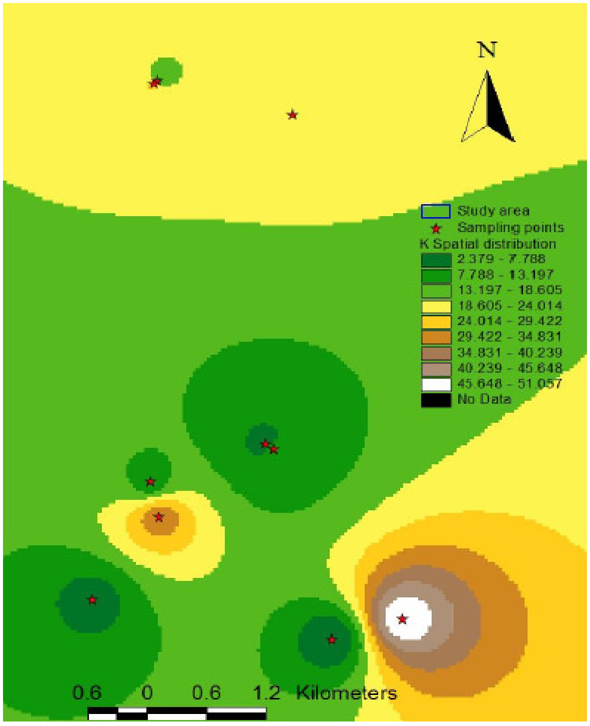

Figure 7 Spatial distribution map of potassium (mg/l) in Hewane area

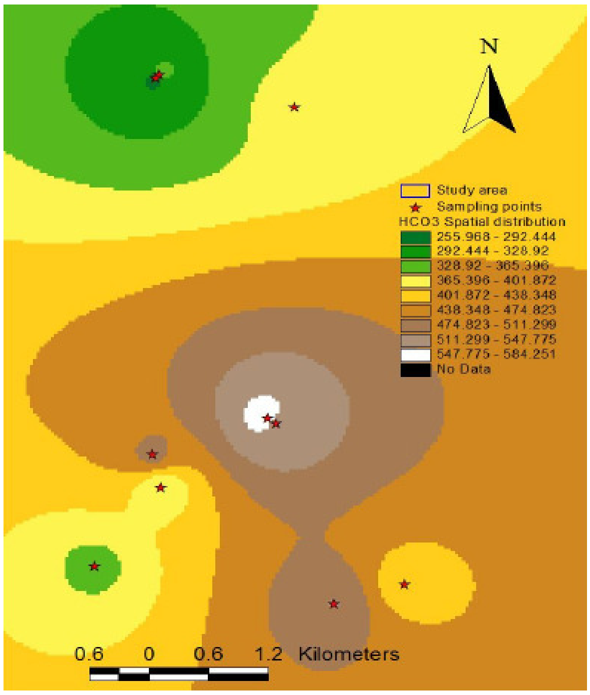

Figure 8 Spatial distribution map of bicarbonate (mg/l) in Hewane area

Figure 9 Spatial distribution map of chlorine (mg/l) in Hewane area

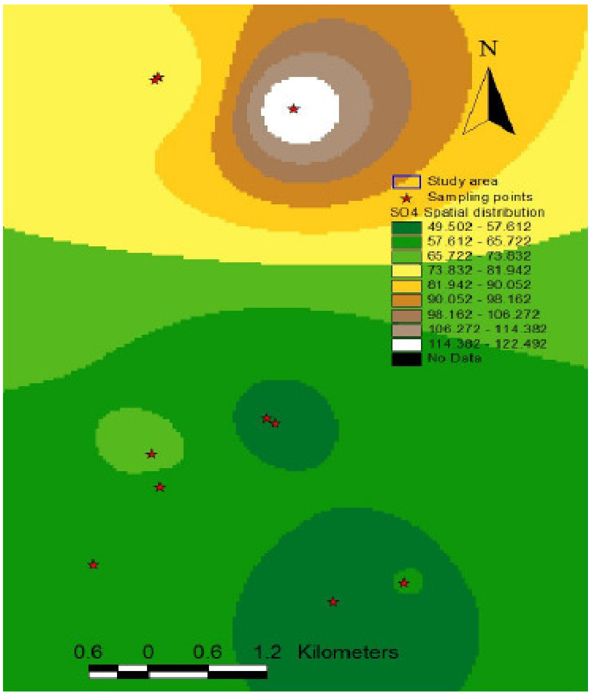

Figure 10 Spatial distribution map of sulphate (mg/l) in Hewane area

EC and TDS

EC of the study area at 25°C varies from 0.88 to 3.01dS/m at GWS_2 and GWS_5, respectively (Table 1). Hence, according to Driscoll (1986), the EC of 6 groundwater samples were found within the good water class while the remaining 4 groundwater samples were found within the fair water class for the EC between 0.7 – 1.5dS/m and 1.5 – 3.7dS/m, respectively. The interpreted water quality with respect to EC indicates that 60% the groundwater samples of the study area lies in good water class and 40% lies in fair water class for drinking water purposes. The spatial distribution map EC of the study area is shown in figure 11.

Electrical conductivity of water is considered to be an indication of total dissolved solids (Hem, 1985). Total dissolved solids (TDS) in the study area vary from 564.10 to 1929.48 mg/l at GWS_2 and GWS_5, respectively (Table 1). Based on the WHO (2004), the groundwater samples are classified in to four categories: 1 groundwater sample is categorized as good (300 – 600mg/l), 4 groundwater samples are fair (600 – 900mg/l) and 1 groundwater sample is poor (900 – 1200mg/l) and the remaining 4 groundwater samples are unacceptable (>1200mg/l). The spatial distribution map of total dissolved solids illustrated in figure 12 shows that the groundwater samples were good, fair, poor and unacceptable.

Total Hardness

Water hardness is primarily caused by the presence in water of cations such as calcium and magnesium; and of anions such as carbonate, bicarbonate, chloride and sulfate (Ravikumar *et al.*, 2010). In the study area total hardness varies from 683.44 to 1768.32 mg/l of $CaCO_3$ at groundwater samples GWS_1 and GWS_5, respectively (Table 1).

The total hardness of 150-300mg/l and above may cause heart diseases and kidney problems (Ramesh and Elango, 2006). All the groundwater samples of the study area exceed 300mg/l which is considered to be very hard (Sawyer and McCarty, 1976). The spatial distribution map of total hardness shows that all the groundwater samples (100%) falls in the very hard category (Figure 13).

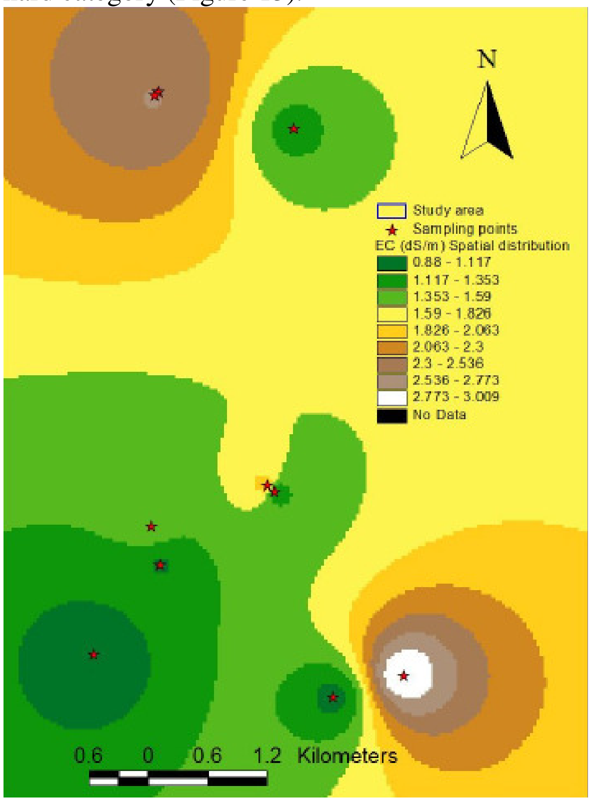

Figure 11 Spatial distribution map of electrical conductivity (dS/m) in Hewane area

pH

The groundwater of the study area was found basic as its pH values ranges from 6.84 to 7.43 at groundwater samples GWS_6 and GWS_10, respectively (Table 1). The groundwater samples were found within the Secondary Maximum Contaminant Level (SMCL) for pH is 6.5 to 8.5 on pH scale as established by the APHA (2005).

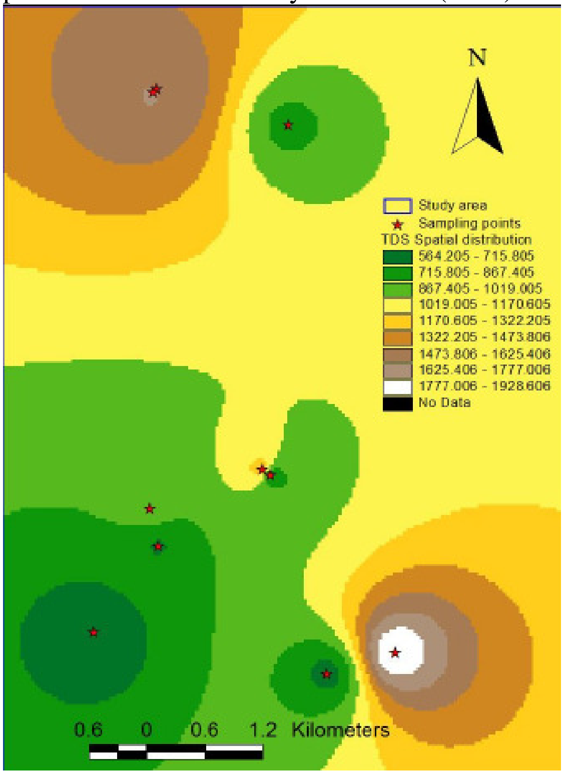

Figure 12 Spatial distribution map of total dissolved solids (mg/l) in Hewane area

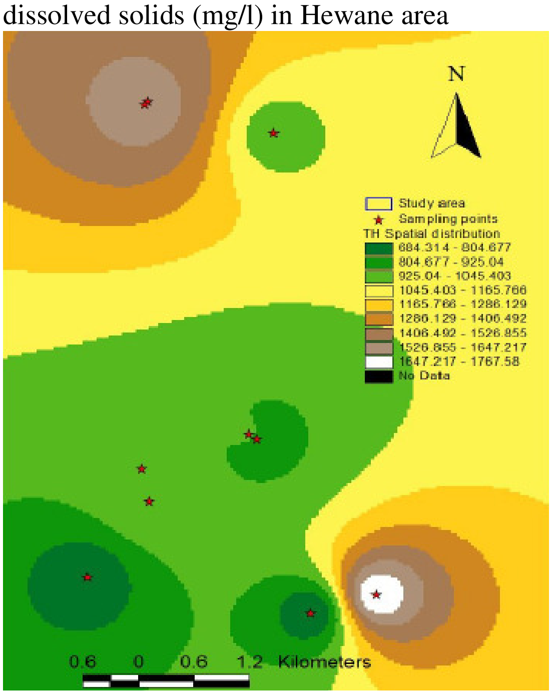

Figure 13 Spatial distribution map of total hardness (mg/l of $CaCO_3$) in Hewane area

The spatial distribution map of pH concentrations is shown in figure 14 that all the groundwater samples displayed a pH value within the maximum permissible limit.

Alkalinity

Alkalinity was values range from 200.61mg/l of CaCO3 at GWS_10 to 480.12mg/l of CaCO3 at GWS_6 (Table 1). All the groundwater samples of the study area exhibit alkalinity values above the permissible limit of 120 mg/l (WHO, 2008). The spatial distribution map of alkalinity shows that all the groundwater samples fall above the permissible limit (Figure 15).

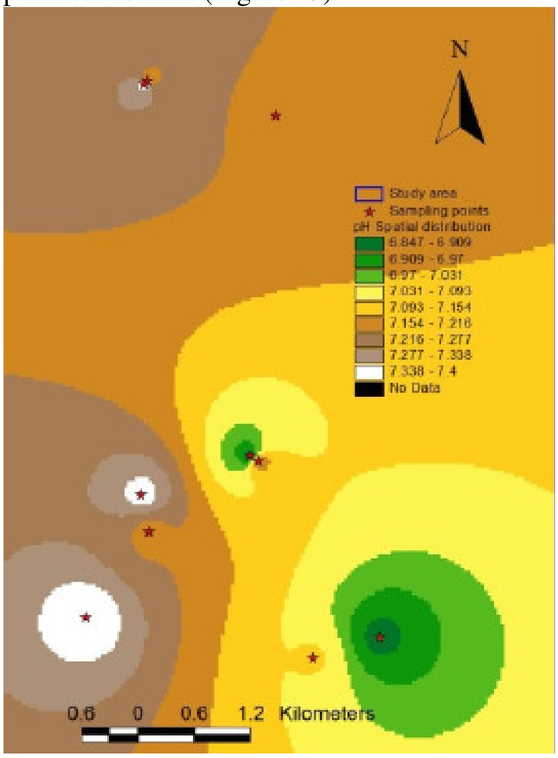

Figure 14 Spatial distribution map of pH in Hewane area

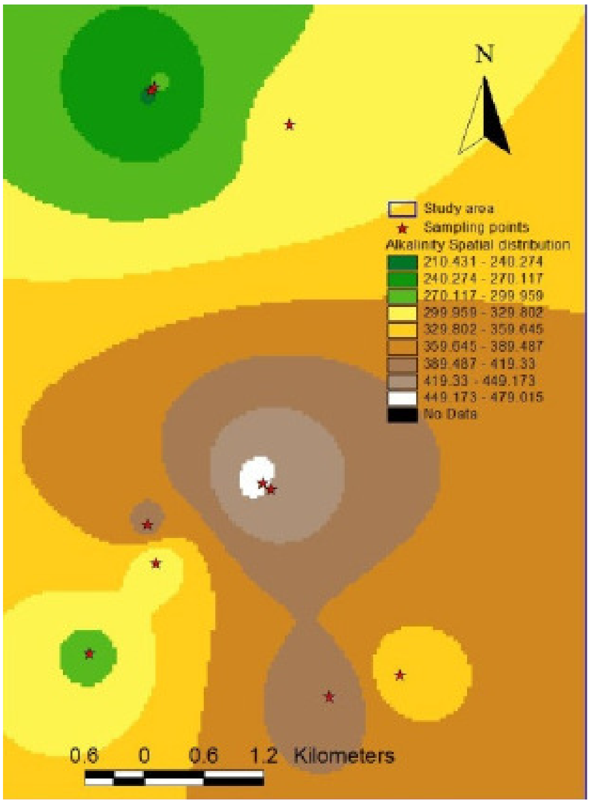

Figure 15 Spatial distribution map of alkalinity (mg/l) in Hewane area

Calculation of WQI

The WQI has been calculated to evaluate the suitability of groundwater quality of Hewane areas for drinking purposes. The WHO (2004) standards for drinking purposes have been considered for the calculation of WQI. For the calculation of WQI 9 parameters such as: pH, sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), sulphate (SO_4^{2-}-S), and Total Dissolved Solids (TDS) have been used.

To compute WQI four steps are followed Gebrehiwot et al. (2011). In the first step, each of the 9 parameters has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes (Table 2). The maximum weight of 5 has been assigned to TDS; weight of 3 has been assigned to parameters pH, chloride, sulphate and sodium; weight of 2 has been assigned to parameters calcium, magnesium, and bicarbonate depending on their importance in the overall quality of water for drinking purposes (Srinivasamoorthy *et al.*, 2008). Potassium is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment.

In the second step, the relative weight (Wi) is computed using a weighted arithmetic index method given below (Brown *et al.*, 1972; Horton, 1965; Tiwari and Manzoor, 1988) in the following steps.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

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

In the third step, a quality rating scale (Qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines of WHO (2004) and then multiplied by 100:

Qi = (Ci / Si) x 100…......……………. (5)

where Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and Si is the WHO drinking water standard for each chemical parameter in mg/l according to the guidelines of WHO (2004) (Table 3).

In the fourth step, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

SIi = Wi x Qi…………………………… (6)

SIi is the sub index of ith parameter and Qi is the rating based on concentration of ith parameter.

The overall Water Quality Index (WQI) was calculated by adding together each sub index values of each groundwater samples as follows:

WQI = ∑SIi…………………………… (7)

Computed WQI values are usually classified into five categories (Table 4): excellent, good, poor, very poor and unfit water for drinking purposes (Sahu and Sikdar, 2008; Ramakrishnaiah *et a*l., 2009).

Table 1 Physico-chemical parameters of groundwater samples of Hewane areas

Sample code	UTME	UTMN	Elev(m)	EC dS/m	pH	Temp °C	Na^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO_3^- mg/l	SO_4^{2-} mg/l	TDS mg/l	TH mg/l	Alkalinity mg/l
GWS_1	554398	1446044	2215	1.04	7.10	21.30	26.91	2.34	112	98.4	71.0	512.4	49.49	666.66	683.44	420.00
GWS_2	551983	1446472	2232	0.88	7.39	21.10	19.09	5.46	120	96.0	213.0	353.8	60.27	564.10	693.60	290.60
GWS_3	552652	1447377	2074	1.10	7.19	22.00	43.93	34.32	148	160.8	156.2	366.0	62.72	705.12	1029.28	300.72
GWS_4	552568	1447769	2087	1.50	7.37	22.30	29.90	9.36	116	170.4	85.2	488.0	69.58	961.53	988.64	400.78
GWS_5	555107	1446263	2064	3.01	6.89	23.10	36.11	51.09	412	153.6	127.8	414.8	57.82	1929.48	1768.32	340.13
GWS_6	553729	1448177	2061	2.11	6.84	22.60	34.04	5.46	208	115.2	113.6	585.6	56.84	1352.56	992.32	480.12
GWS_7	553812	1448121	2025	1.04	7.25	21.40	25.07	10.14	84	144.0	99.4	512.4	54.39	666.66	800.40	420.16
GWS_8	554000	1451777	2016	1.28	7.20	21.20	28.06	22.23	120	163.2	99.4	378.2	122.50	820.51	969.12	310.51
GWS_9	552633	1452152	1968	2.42	7.09	23.30	43.93	10.14	256	211.2	170.4	378.2	79.87	1551.28	1505.92	310.74
GWS_10	552601	1452117	1965	2.62	7.43	23.50	36.11	30.01	412	153.6	340.8	244.0	77.91	1679.48	1659.76	200.61
Minimum				0.88	6.84	21.10	19.09	2.34	84.00	96.00	71.00	244.00	49.49	564.10	683.44	200.61
Maximum				3.01	7.43	23.50	43.93	51.09	412.00	211.20	340.80	585.60	122.50	1929.48	1768.32	480.12
Average				1.70	7.18	22.18	32.32	18.06	198.80	146.64	147.68	423.34	69.14	1089.74	1109.08	347.44
Standard deviation				0.77	0.20	0.92	8.04	15.92	123.30	35.26	80.38	100.45	21.19	495.11	394.19	82.15

N.B.: TDS=Total Dissolved Solids, TH= Total Hardness, Elev = Elevation and Temp=Temperature

Table 2 WHO Standards, weight (wi) and calculated relative weight (Wi) for each parameter

Chemical parameters	WHO standards	Weight(wi)	Relative weight(Wi)
Na^+ (mg/l)	200	3	0.103
K^+ (mg/l)	12	1	0.034
Ca^{2+} (mg/l)	75	2	0.068
Mg^{2+} (mg/l)	50	2	0.068
Cl^- (mg/l)	250	3	0.103
SO_4^{2-} (mg/l)	250	3	0.103
HCO_3^- (mg/l)	120*	2	0.068
pH	8.5	3	0.103
TDS (mg/l)	500	5	0.172
		∑wi=24	∑Wi=0.822

*US Public Health Service values (WHO Standards are not available).

Table 3 Quality rating (Qi), Sub index of each chemical parameter (SIi), WQI and water classification of each groundwater samples of Hewane areas

Sample code	Na^+		K^+		Ca^{2+}		Mg^{2+}		Cl^-		SO_4^{2-}		HCO_3^-		pH		TDS		WQI	WQI Classification
	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi		
GWS_1	13.5	1.4	19.5	0.7	149.3	10.2	196.8	13.4	28.4	2.9	20.0	2.0	427.0	29.0	83.5	8.6	133.3	22.9	91.1	Good water
GWS_2	9.5	1.0	45.5	1.5	160.0	10.9	192.0	13.1	85.2	8.8	24.1	2.5	294.8	20.0	86.9	9.0	112.8	19.4	86.1	Good water
GWS_3	22.0	2.3	286.0	9.7	197.3	13.4	321.6	21.9	62.5	6.4	25.1	2.6	305.0	20.7	84.6	8.7	141.0	24.3	110.0	Poor water
GWS_4	15.0	1.5	78.0	2.7	154.7	10.5	340.8	23.2	34.1	3.5	27.8	2.9	406.7	27.7	86.7	8.9	192.3	33.1	113.9	Poor water
GWS_5	18.1	1.9	425.8	14.5	549.3	37.4	307.2	20.9	51.1	5.3	23.1	2.4	345.7	23.5	81.1	8.3	385.9	66.4	180.5	Poor water
GWS_6	17.0	1.8	45.5	1.5	277.3	18.9	230.4	15.7	45.4	4.7	22.7	2.3	488.0	33.2	80.5	8.3	270.5	46.5	132.8	Poor water
GWS_7	12.5	1.3	84.5	2.9	112.0	7.6	288.0	19.6	39.8	4.1	21.8	2.2	427.0	29.0	85.3	8.8	133.3	22.9	98.5	Good water
GWS_8	14.0	1.4	185.3	6.3	160.0	10.9	326.4	22.2	39.8	4.1	49.0	5.0	315.2	21.4	84.7	8.7	164.1	28.2	108.3	Poor water
GWS_9	22.0	2.3	84.5	2.9	341.3	23.2	422.4	28.7	68.2	7.0	31.9	3.3	315.2	21.4	83.4	8.6	310.3	53.4	150.8	Poor water
GWS_10	18.1	1.9	250.1	8.5	549.3	37.4	307.2	20.9	136.3	14.0	31.2	3.2	203.3	13.8	87.4	9.0	335.9	57.8	166.5	Poor water

Table 4 Classification of computed WQI values for human consumption

WQI range	Type of water
< 50	Excellent water
50.1 – 100	Good water
100.1 – 200	Poor water
200.1 – 300	Very poor water
>300.1	Unfit for drinking

The lower values of WQI show that the water is very clear i.e., it is free of any impurities throughout the study area. Calculation of WQI for individual groundwater sample represented in table 3 and figure 16 varies from 86.1 to 180.5 at groundwater samples GWS_2 and GWS_5, respectively. It is obvious from this classification that on the basis of the WQI, seven groundwater samples from the study area are of poor quality for human consumption except in the groundwater samples GWS_1, GWS_2 and GWS_7 which are of good quality (Sahu and Sikdar, 2008; Ramakrishnaiah *et al.*, 2009). Similar to this study, Khalid (2011) reported that more than 90% of groundwater samples were found within the poor water class for drinking purposes in groundwater samples of Tikrit and Samarra Cities using water quality index. In contrast to this study, groundwater WQI estimation in Hantebet watershed for drinking purposes was found ranging from 54.41 to 86.24 which means that 100% of the groundwater samples of the area were found to be good water class Gebrehiwot *et al.*, 2011.

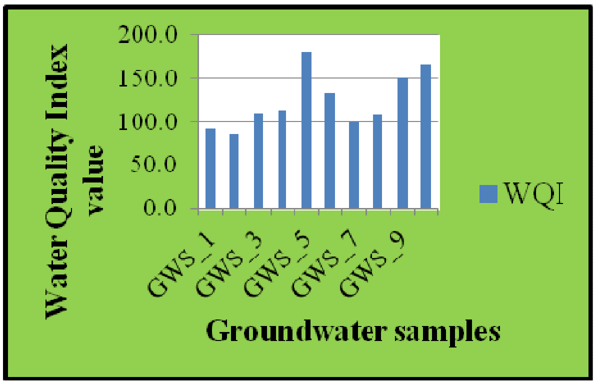

Figure 16 Water quality index classification of Hewane areas

The spatial distribution map of water quality index shows that most of the groundwater samples fall under the poor water class except some areas around samples GWS_1 and GWS_2 (Figure 17).

In this research paper the application of WQI approach to groundwater quality in Hewane areas had the purpose of providing a simple, valid method for expressing the results of several parameters in order to assess the groundwater quality. Assembling different parameters into one single number leads an easy interpretation of index, thus providing an important tool for management purposes (Bordalo *et al.*, 2001).

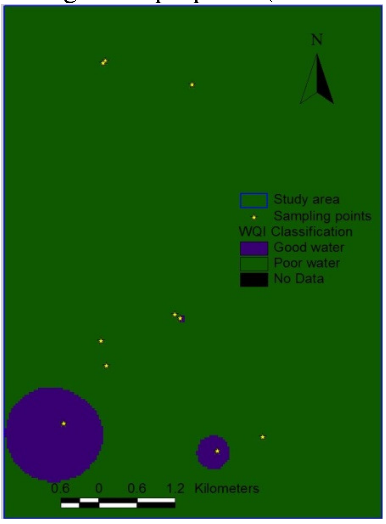

Figure 17 Spatial distribution map of water quality index in Hewane area

Conclusion

The physico-chemical parameters: Na^+, SO_4^{2-} and pH were found within; Mg^{2+}, Cl^-, TH and Alkalinity were found above while parameters K^+, Ca^{2+}, HCO_3^- , EC and TDS were found partially within and partially above the WHO (2004) standards for drinking purposes.

WQI estimation for each groundwater sample represented in table 3 and figure 16 varied from 86.1 to 180.5. The estimation showed that 30% of the groundwater samples were found to be in the good water class and the remaining 70 % were classified under poor water class based on the computed WQI classification scheme.

The spatial distribution maps generated for various physico-chemical parameters using ArcGIS software could be useful for planners, water quality managers and decision makers for initiating groundwater quality development and management in the study area. The spatial distribution map of water quality index shows that most of the groundwater samples fall under the poor water class except some areas around samples GWS_1 and GWS_2 (Figure 17).

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