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Full Length Research Paper

Application of water quality index to assess suitablity of groundwater quality for drinking purposes in Hantebet watershed, Tigray, Northern Ethiopia

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The study was conducted in Hantebet catchment area which has a total area of 24.5 km^2 with the major objective of assessing suitability of groundwater quality for drinking purposes through water quality index (WQI) investigation of the different hand dug wells in the watershed. This was done by subjecting the 20 groundwater samples collected to comprehensive physico-chemical analysis using APHA standard methods of analysis. For calculating the WQI, 10 parameters have been considered: pH, sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), sulphate (SO_4^{2-}-S), nitrate (NO_3^--N) and total dissolved solids (TDS). The WQI for these samples ranges from 54.41 to 86.24. All the groundwater samples estimated using the water quality index fall in the good water class and are all suitable for drinking purposes.

Key words: Groundwater, water quality index, quality rating, weight, Hantebet.

INTRODUCTION

Groundwater is used for domestic and industrial water supply and irrigation all over the world. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization. Human health is threatened by most of the agricultural development activities particularly in relation to excessive application of fertilizers and unsanitary conditions. Rapid urbanization, especially in developing countries like India, has affected the availability and quality of groundwater due to its overexploitation and improper waste disposal, especially in urban areas (Ramakrishnaiah et al., 2009).

Intensive irrigated agricultural discharges into the groundwater can bring about considerable change in the groundwater quality. These anthropogenic activities on the groundwater pose serious threat to the groundwater users. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the sources. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it. Water quality index (WQI) is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of groundwater. WQI is defined as a rating reflecting the composite influence of different water quality parameters (Ramakrishnaiah et al., 2009).

The study area, Hantebet catchment, is found in the Southeastern Zone of Tigray, Seharti-Samre Woreda that has a total population of 61,945 males, 62,545 females and a total population of 124,499. Seharti-Samre has total area coverage of 1538.74 km^2 where the density of population living per square kilometer is 80.70 (FDRECSA, 2008).

Specifically, Adiss Alem tabia in which the study area is found consisting of four kushets, namely: Atsgebta where the tabia administration and agricultural bureau is found, Gonekat, Hantebet, kushet and Astah.

The total population size of the tabia is 8109, which is

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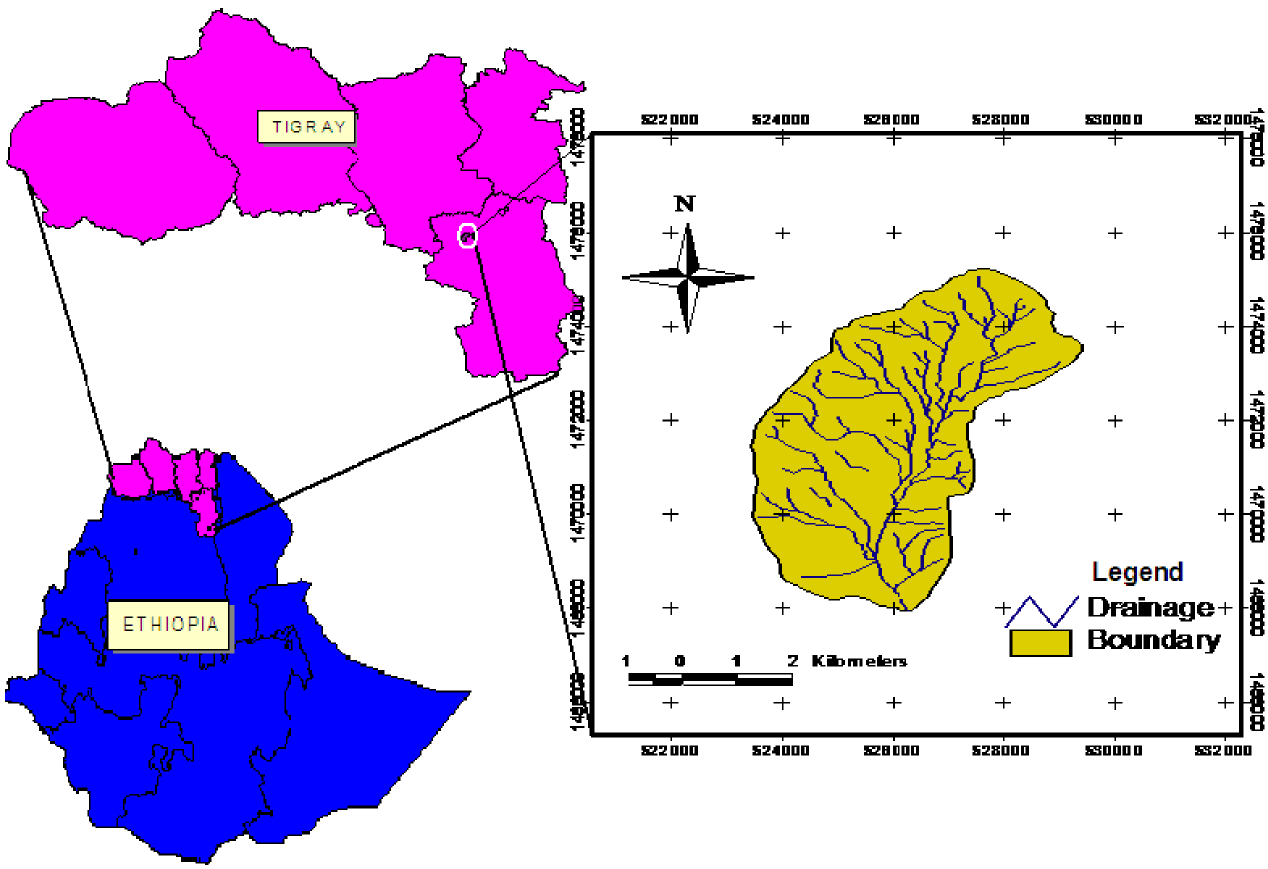

Figure 1. Location map of Hantebet watershed.

6.51% of the total population of Seharti-Samre Woreda. Out of the total population 3696 are females and 4431 are males (Addis Alem tabia administration report, 2008). The people are currently getting their water supply from the shallow wells that are found constructed in the catchment area. The constructed hand dug wells at same time serve for irrigated agriculture in the area. Hence, the main objective of this study is to investigate the groundwater quality of Hantebet watershed for human consumption by using a water quality index (WQI).

METHODOLOGY

Location

The study area, Hantebet catchment, is located in the southeastern zone of Tigray National Regional State, about 50 km southwest of Mekelle, which is the capital city of Tigray. The catchment is one of the tributary of the Tekeze River, which is a tributary to Atbara. Geographically the study area is located between latitude 13° 16' and 13° 24' N and longitude 39° 12' and 39° 20'E having an area of about 24.5 km^2(Figure 1).

Data collection

The water samples were collected in January, 2010 from hand dug wells with the aid of environmental sampler in order to have representative sample free from contamination from sampling tools. After each sample is collected, an insitu measurement was made for temperature, electrical conductivity (EC), pH and TDS immediately at the sampling sites using standard equipment (Century Water Analysis Kit). Also measured at the field are coordinates and elevation of each of the locations sampled using GPS. All the water samples were collected in 2 L plastic bottles which were washed and triple-rinsed with distilled water and with the collection water before sampling and transporting them to the laboratory.

Sampling

A total of 20 water samples were selected and collected approximately with uniform spatial distribution over the study area (Figure 2). The adopted sampling technique was depth integrated sampling.

Data analysis

The water samples were analyzed for sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), sulphate (SO_4^{2-}-S) and nitrate (NO_3^--N) in Water Works Design and Supervision Enterprise Laboratory Service, Addis Ababa. The analysis of the groundwater samples was done as per the standard methods of APHA (2005) and Eaton et al. (1998). The statistical analysis: minimum, maximum, mean,

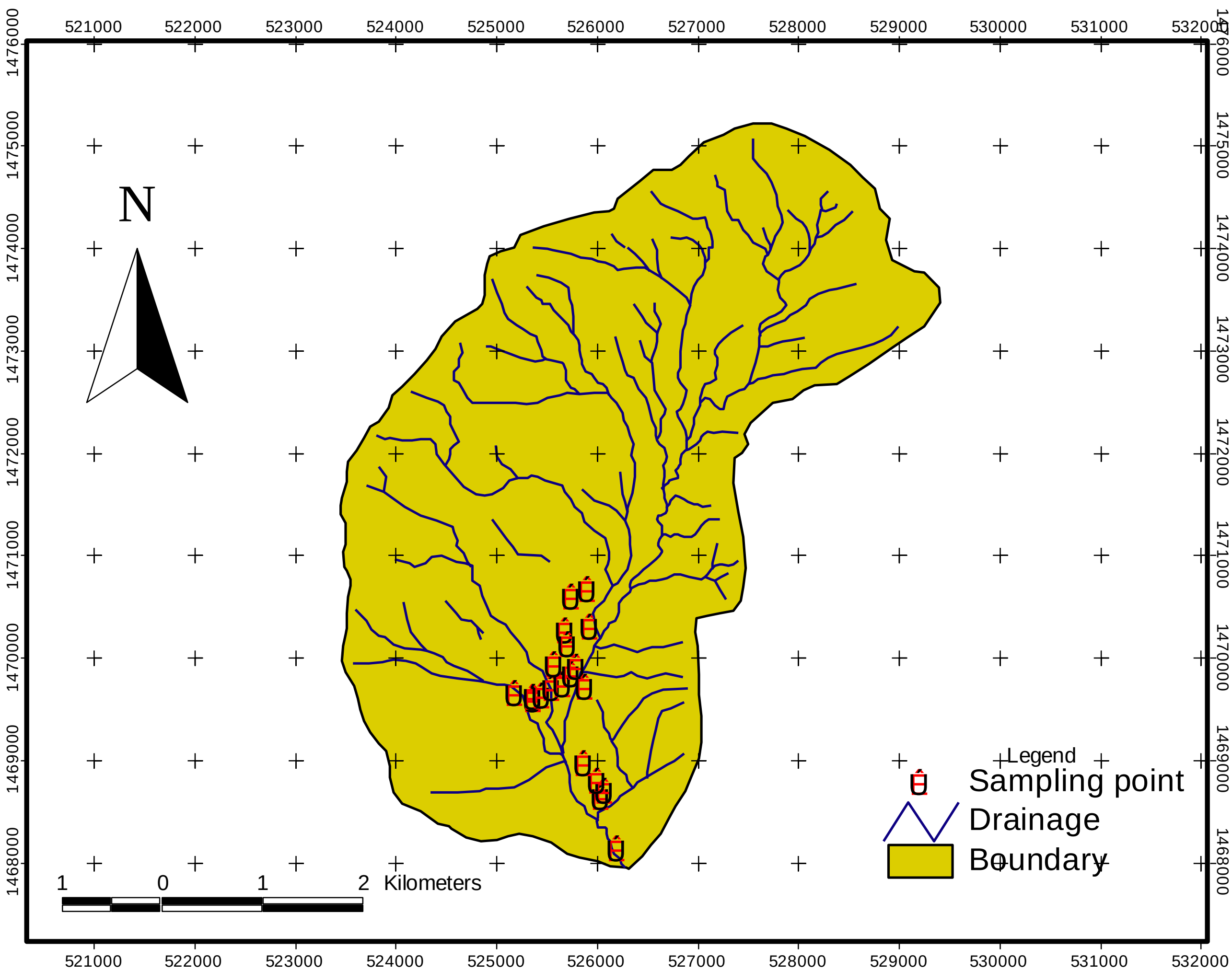

Figure 2. Sampling location of the hand dug wells in the study area.

standard deviation and graphs of the physico-chemical parameters of the groundwater samples of the study area was done using SPSS 15.0.

Water quality index (WQI)

Water quality index is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water (Deininger and Maciunas, 1971; Harkins, 1974; and Tiwari and Manzoor, 1988). The concept of indices to represent gradation in water quality was first proposed by Horton (1965). The WQI has been calculated to evaluate the suitability of groundwater quality for drinking purposes.

RESULTS AND DISCUSSION

Cations

The cationic concentrations in the groundwater samples of the study area were presented in Table 1 and Figure 3. The respective ranges for Na^+, K^+, Ca^{2+}, and Mg^{2+} in mg/L are 22.5 to 128, 0.2 to 5.3, 75.6 to 117.6 and 4.59 to 33.15, respectively. The mean concentration values for Na^+, K^+, Ca^{2+}, and Mg^{2+} in mg/L were 50.275, 0.975, 94.236 and 17.339, respectively. The predominant cations trend in Hantebet watershed is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. Calcium is the dominant cation in the study area.

Anions

The anionic concentration of Cl^-, SO_4^{2-}, NO_3^- and HCO_3^- in mg/L ranges between 15.45 to 49.44, 16.3 to 148, 0.3 to 5.87 and 312.56 to 589.26, respectively, with a mean concentration values of 23.84, 66.22, 1.42 and 420.42, respectively.

The abundance of the major anions in Hantebet watershed is in the following order: $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$ while carbonates remain nil throughout the groundwater samples (Table 1 and Figure 4).

Table 1. The major, minor ions, pH, TDS and ECw determined in the groundwater samples of Hantebet watershed.

Sample	GPS Location (in UTM)			T	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-	pH	TDS	ECw
code	UTME	UTMN	Elevation (m)	(°C)	(mg/L)	(mg/L)	(mg/L)	(mg/l)	(mg/L)	(mg/L)	(mg/L)	(mg/L)		(mg/L)	(µS/cm)
HAGW-S1	526210	1468122	2198	15.6	33	1.7	114.24	26.5	19.57	148	2.1	399.67	6.64	500	1010
HAGW-S2	526046	1468624	2197	18.2	128	0.6	84.84	27.03	46.35	136	0.97	550.83	7.26	540	1020
HAGW-S3	526085	1468678	2198	18.7	47	0.7	93.84	26.52	25.75	47.6	2.09	491.9	6.55	490	1080
HAGW-S4	526016	1468783	2202	15.9	68	5.3	117.6	33.15	49.44	88.6	0.4	581.57	6.61	560	1120
HAGW-S5	525877	1468954	2206	20.5	58	0.7	88.2	33.15	22.66	16.3	0.4	589.26	6.65	570	1090
HAGW-S6	525195	1469634	2212	17.1	29	2	96.6	8.16	17.5	23.6	0.49	391.98	6.76	310	1010
HAGW-S7	525381	1469597	2206	16.9	61	0.5	79.8	13.26	21.63	65.2	0.64	397.11	6.83	400	900
HAGW-S8	525459	1469612	2208	19.1	51	0.3	84	15.3	15.45	43.6	0.5	430.42	6.88	390	900
HAGW-S9	525557	1469682	2208	20.4	48	0.5	84.84	14.79	18.54	44.8	0.55	409.92	6.94	340	710
HAGW-S10	525673	1469720	2209	20.7	56	0.4	75.6	21.42	23.69	80.3	0.75	384.3	6.68	300	620
HAGW-S11	525753	1469816	2214	21.1	49	0.5	94.08	5.61	22.66	39.39	0.79	397.11	6.91	340	680
HAGW-S12	525807	1469894	2213	19.8	38	0.8	93.24	15.81	15.45	64.07	1.7	376.61	6.86	310	610
HAGW-S13	525582	1469921	2214	17.4	38	0.8	93.24	15.81	15.45	32.46	1.51	376.61	6.98	330	660
HAGW-S14	525719	1470113	2212	17.5	54	1	79.8	19.38	37.08	90.73	1.23	312.56	6.90	300	600
HAGW-S15	525700	1470242	2217	17.3	60	0.7	85.68	6.63	26.78	83.29	2.61	345.87	6.80	370	760
HAGW-S16	525761	1470576	2226	21.2	30	0.4	115.92	4.59	17.51	70.07	4.3	361.24	6.87	370	680
HAGW-S17	525921	1470646	2222	17.0	22.5	0.9	93.24	11.73	17.51	39.13	0.3	320.25	6.81	410	840
HAGW-S18	525938	1470285	2215	18.9	56	0.4	105.84	17.34	29.7	80.3	5.87	453.47	6.79	310	610
HAGW-S19	525381	1469570	2207	15.7	35	0.2	94.92	12.24	18.54	54.62	0.88	381.74	7.22	350	680
HAGW-S20	525891	1469697	2214	22.0	44	1.1	109.2	18.36	15.45	76.25	0.34	456.04	7.12	380	760
Minimum				15.6	22.5	0.2	75.6	4.59	15.45	16.3	0.3	312.56	6.55	300	600
Maximum				22	128	5.3	117.6	33.15	49.44	148	5.87	589.26	7.26	570	1120
Average				18.55	50.275	0.975	94.236	17.339	23.836	66.216	1.421	420.423	6.853	393.5	817.000
Standard deviation				1.980	22.040	1.111	12.437	8.499	9.915	33.889	1.441	79.093	0.190	89.635	182.961

Temperature, total dissolved solids (TDS) and pH

The physico-chemical parameters have shown spatial variations. The groundwater samples were colorless, odorless, and tasteless, as well as no turbidity and water temperature was almost low throughout the study area ranging from 15.6 to 22°C. TDS values of the groundwater samples of the study area ranges between 300 to 570 mg/L where the lowest value was obtained in the groundwater samples of HAGW-S10 and HAGW-S14 and the highest value was obtained in the groundwater sample HAGW-S5. The pH value of the groundwater samples of Hantebet basin lied between the ranges of 6.55 to 7.26 at the hand dug wells coded HAGW-S3 and HAGW-S2, respectively (Table 1).

Calculation of WQI

The WQI has been calculated to evaluate the suitability of groundwater quality of Hantebet watershed for drinking purposes. The WHO (2004) standards for drinking purposes have been considered for the calculation of WQI. For the calculation of WQI 10 parameters such as: pH, sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}),

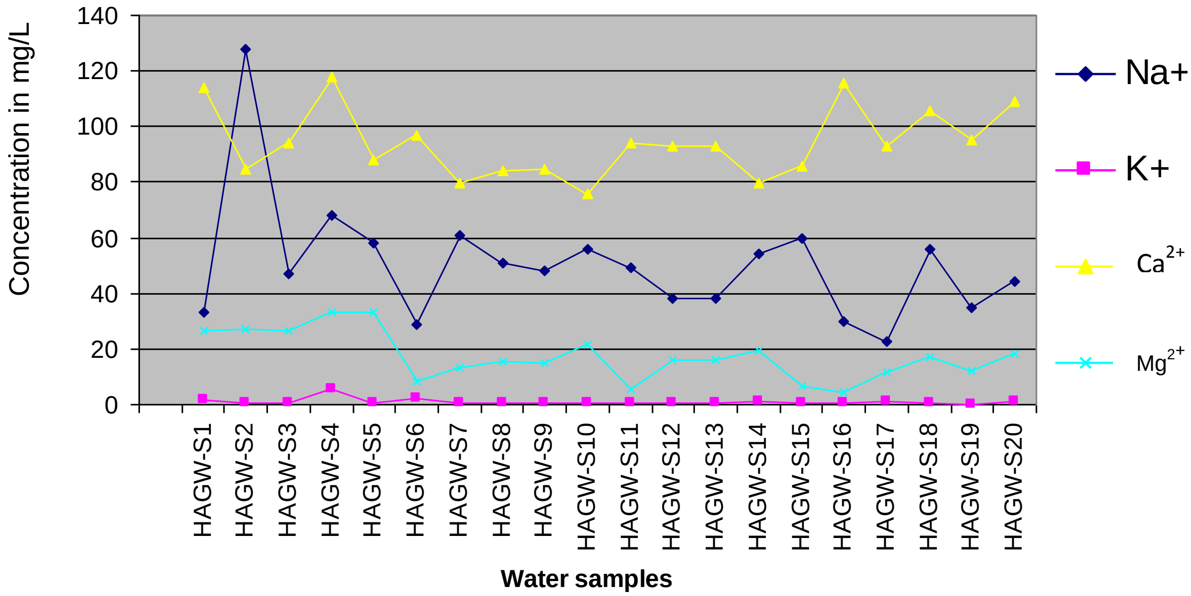

Figure 3. Concentration of major cations in the groundwater samples.

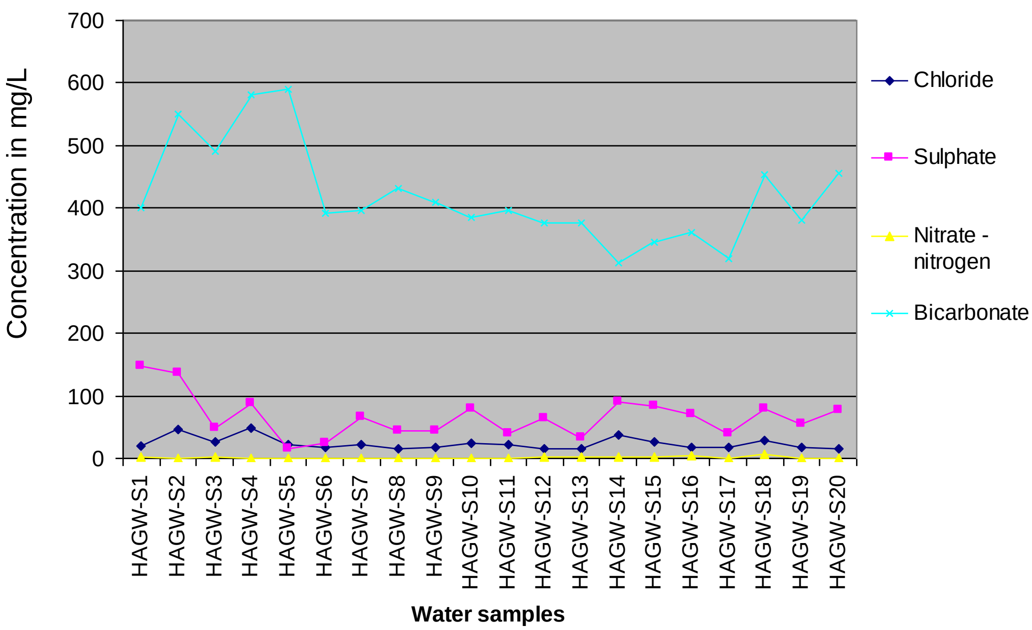

Figure 4. Concentration of anions in the groundwater samples.

calcium (Ca^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), sulphate (SO_4^{2-}-S), nitrate (NO_3^--N) and total dissolved solids (TDS) have been used.

To compute WQI four steps are followed. In the first step, each of the 10 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 parameters like total dissolved solids, chloride, sulfate and nitrate due to their major importance in water quality assessment (Srinivasamoorthy et al., 2008). Bicarbonate is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment.

Other parameters like calcium, magnesium, sodium

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

Chemical parameter (mg/L)	WHO standards	Weight (wi)	Relative weight (Wi)
Na^+	200	3	0.103
K^+	12	1	0.034
Ca^{2+}	75	2	0.068
Mg^{2+}	50	2	0.068
Cl^-	250	3	0.103
SO_4^{2-}	250	3	0.103
NO_3^-	45	5	0.172
HCO_3^-	120*	2	0.068
pH	8.5	3	0.103
TDS	500	5	0.172
		∑wi=29	∑Wi=0.994

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

and potassium were assigned a weight between 1 and 5 depending on their importance in the overall quality of water for drinking purposes.

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:

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

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:

$$Qi = (Ci / Si) \times 100 \quad (2)$$

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:

$$SIi = Wi \times Qi \quad (3)$$

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:

$$WQI = \sum SIi \quad (4)$$

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 al., 2009).

The physico-chemical parameters analyzed were all within the WHO standards for groundwater samples of the study area except Ca^{2+} and HCO_3^- parameters which were above the WHO standards and TDS parameter was within the WHO standards except samples HAGW-S2, HAGW-4 and HAGW-S5, which were above the WHO standards for drinking water quality WHO (2004). The lower values of WQI show that the water is very clear, that is, it is free of any impurities throughout the study area. Calculation of WQI for individual groundwater sample represented in Table 3 and Figure 5 varies from 54.41 to 86.24. It is obvious from this classification that on the basis of the WQI, groundwater samples from the study area is of acceptable quality for human consumption. In contrast to the current study, Khalid (2011) reported that more than 90% of groundwater samples were found within the poor water class for drinking purposes. On the basis of the WQI, groundwater (from the study area is not of acceptable quality for human consumption except one sample with a WQI less than 50 (6%) (Mouna et al., 2011). About 83% of the groundwater samples of Zone II and III, Greater Visakhapatnam, laid under moderately polluted to severely polluted category revealed by the WQI studies Swarna and Nageswara (2010). In this research paper the application of WQI approach to groundwater quality in Hantebet watershed 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

Table 3. Quality rating (Qi), Sub index of each chemical parameter (SIi), WQI and water classification of each groundwater sample of Hantebet watershed.

Sample code	Na^+		K^+		Ca^{2+}		Mg^{2+}		Cl^-		SO_4^{2-}		NO_3^-		HCO_3^-		pH		TDS		WQI	Water classification
	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi	Qi	SIi		
HAGW-S1	16.50	1.70	14.17	0.48	152.32	10.36	53.00	3.60	7.83	0.86	59.20	6.10	4.67	0.80	333.06	22.65	8.05	7.26	100.00	17.20	71.74	Good water
HAGW-S2	64.00	6.59	5.00	0.17	113.12	7.69	54.06	3.68	18.54	1.91	54.40	5.60	2.16	0.37	459.02	31.21	85.41	8.80	108.00	18.58	84.60	Good water
HAGW-S3	23.50	2.42	5.83	0.20	125.12	8.51	53.04	3.61	10.30	1.06	19.04	1.96	4.64	0.80	409.92	27.87	77.06	7.94	98.00	16.86	71.22	Good water
HAGW-S4	34.00	3.50	44.17	1.50	156.80	10.66	66.30	4.51	19.78	2.03	35.44	3.65	0.89	0.15	484.64	32.96	77.76	8.01	112.00	19.26	86.24	Good water
HAGW-S5	29.00	2.99	5.83	0.20	117.60	8.00	66.30	4.51	9.06	0.93	6.52	0.67	0.89	0.15	491.05	33.39	78.24	8.06	114.00	19.61	78.51	Good water
HAGW-S6	14.50	1.50	16.67	0.57	128.80	8.76	16.32	1.11	7.00	0.72	9.44	0.97	1.09	0.19	326.65	22.21	79.53	8.19	62.00	10.66	54.88	Good water
HAGW-S7	30.50	3.14	4.17	0.14	106.40	7.24	26.52	1.80	8.65	0.89	26.08	2.67	1.42	0.24	330.93	22.50	80.35	8.28	80.00	13.76	60.68	Good water
HAGW-S8	25.50	2.63	2.50	0.09	112.00	7.62	30.60	2.08	6.18	0.64	17.44	1.80	1.11	0.19	358.68	24.39	80.94	8.34	78.00	13.42	61.18	Good water
HAGW-S9	24.00	2.47	4.17	0.14	113.12	7.69	29.58	2.01	7.42	0.76	17.92	1.85	1.22	0.21	341.60	23.22	8.16	8.40	68.00	11.70	58.47	Good water
HAGW-S10	28.00	2.89	3.33	0.11	100.80	6.85	42.84	2.91	9.48	0.98	32.12	3.31	1.67	0.29	320.25	21.78	78.59	8.09	60.00	10.32	57.53	Good water
HAGW-S11	24.50	2.52	4.17	0.14	125.44	8.53	11.22	0.76	9.06	0.93	15.76	1.62	1.76	0.30	330.93	22.50	81.29	8.37	68.00	11.70	57.39	Good water
HAGW-S12	19.00	1.96	6.67	0.23	124.32	8.45	31.62	2.15	6.18	0.64	25.63	2.64	3.78	0.65	313.84	21.34	80.71	8.31	62.00	10.66	57.03	Good water
HAGW-S13	19.00	1.96	6.67	0.23	124.32	8.45	31.62	2.15	6.18	0.64	12.98	1.34	3.36	0.58	313.84	21.34	82.12	8.46	66.00	11.35	56.49	Good water
HAGW-S14	27.00	2.78	8.33	0.28	106.40	7.24	38.76	2.64	14.83	1.53	36.29	3.74	2.73	0.47	260.47	17.71	81.18	8.36	60.00	10.32	50.06	Good water
HAGW-S15	30.00	3.09	5.83	0.20	114.24	7.77	13.26	0.90	10.71	1.10	33.32	3.43	5.80	1.00	288.23	19.60	80.00	8.24	74.00	12.73	58.06	Good water
HAGW-S16	15.00	1.55	3.33	0.11	154.56	10.51	9.18	0.62	7.00	0.72	28.03	2.89	9.56	1.64	301.03	20.47	80.82	8.32	74.00	12.73	59.57	Good water
HAGW-S17	11.25	1.16	7.50	0.26	124.32	8.45	23.46	1.60	7.00	0.72	15.65	1.61	0.67	0.11	266.88	18.15	80.12	8.25	82.00	14.10	54.42	Good water
HAGW-S18	28.00	2.88	3.33	0.11	141.12	9.60	34.68	2.36	11.88	1.22	32.12	3.31	13.04	2.24	377.89	25.70	79.88	8.23	62.00	10.66	66.32	Good water
HAGW-S19	17.50	1.80	1.67	0.06	126.56	8.61	24.48	1.66	7.42	0.76	21.85	2.25	1.96	0.34	318.12	21.63	84.94	8.75	70.00	12.04	57.90	Good water
HAGW-S20	22.00	2.27	9.17	0.31	145.60	9.90	36.72	2.50	6.18	0.64	30.50	3.14	0.76	0.13	380.03	25.84	83.76	8.63	76.00	13.07	66.43	Good 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

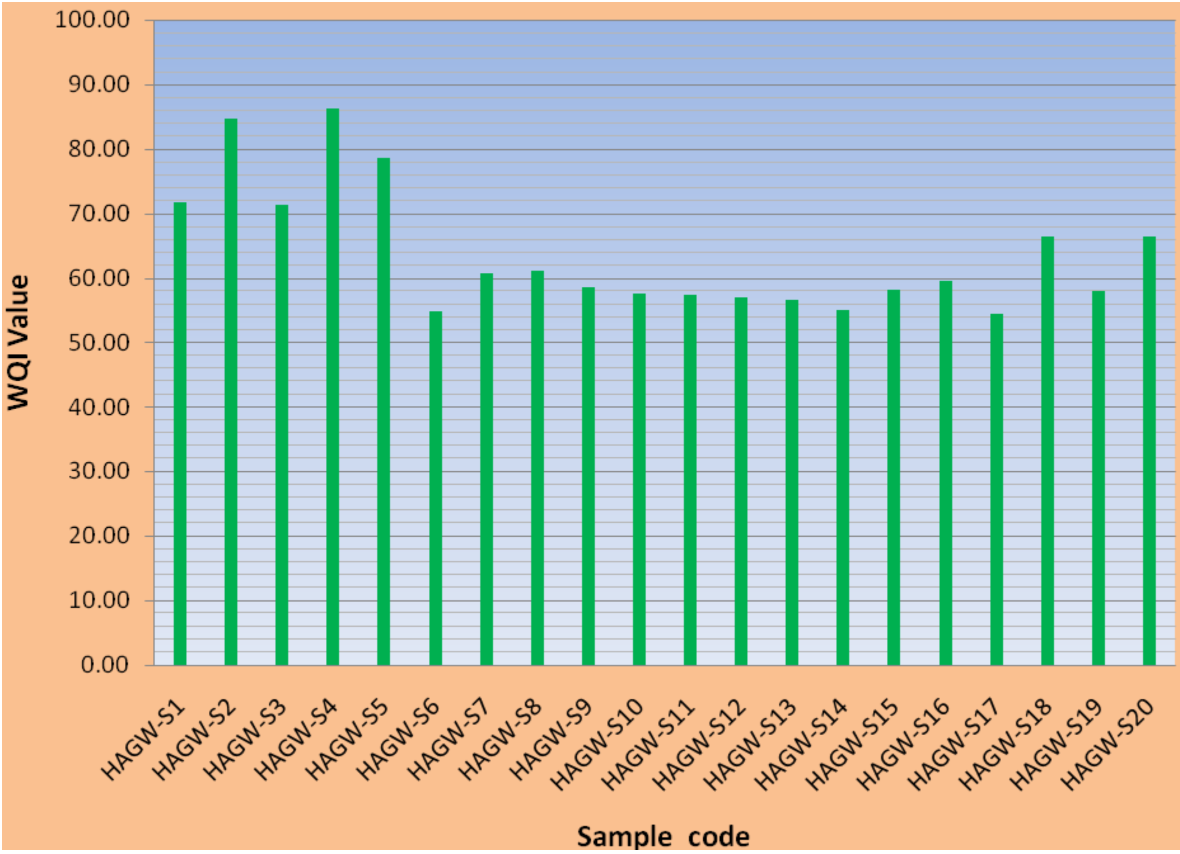

Figure 5. Water quality index (WQI) of groundwater samples of Hantebet watershed.

important tool for management purposes (Bordalo et al., 2001).

Conclusion

The WQI for the groundwater samples of Hantebet watershed ranges from 54.41 to 86.24. All the groundwater samples estimated using the water quality index fall in the good water class and are all suitable for drinking purposes. But, the groundwater quality needs further investigations to see if there exists violence in its quality as far as irrigation practice is undertaking. Thus, enables to conduct water quality management as the water quality indices are among the most effective ways to communicate the information on water quality trends to the general public or to the policy makers.

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