Research Journal of Agricultural Sciences **14**(6): 1692–1697 (Nov-Dec 2023)
DOI: http://rjas.org/Article/Article/5668

Full Length Research Article

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

Evaluation of Groundwater Quality using Hydrochemical Characters and Water Quality Index- A Case Study of Chikkanayakanahalli Taluk of Tumkur District, Karnataka

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Received: 03 Aug 2023; Revised accepted: 22 Oct 2023; Published online: 07 Nov 2023

Abstract

A total of 42 groundwater samples were randomly collected from the Chikkanayakanahalli region of Tumkur district during the pre-monsoon of March 2022. The physicochemical parameters of pH, electrical conductivity (EC), total dissolved solids, total hardness, sodium, potassium, total alkalinity, chloride, sulphate, fluoride, nitrate, calcium, bicarbonate phosphate, magnesium, boron, and silica were analyzed as per standard methods. The analytical results of bicarbonate, total hardness, calcium and magnesium were exceeded the acceptable limit of BIS and WHO (2017) Standards, and the same standards were used for calculating the water quality index. Water quality index results were presented in water quality index map reveals that 19.04%, 38.09% and 42.85%, area respectively, fall under the poor, very poor, and unfit categories as per WQI classification for drinking purposes. The Piper diagram indicates the dominance of Ca^{2+}-Mg^{2+}-Cl^{-}-SO_4^{2-} hydro chemical facies in some of the samples. The higher value of the water quality index revealed that some of the study areas are highly contaminated due to excessive concentration of one or more water quality parameters, and the groundwater needs pre-treatment before consumption. This study would help to trace the major source and contamination level through which suitable planning and management of groundwater resources can be achieved.

Key words: Groundwater resources, Chikkanayakanahalli, Water quality index, Contamination, Groundwater quality

Water is a unique natural resource since its total quantity available on a global basis remains constant compared to any other renewable resource. Groundwater is a significant resource for drinking, irrigation, and industrial purposes in many regions [1]. According to WHO, worldwide, 80% of diseases and one-third of deaths are caused by polluted drinking water [2]. In India, scarcity of clean and potable drinking water has emerged as a serious issue in recent years, particularly in West Bengal, Jharkhand, Orissa, Uttar Pradesh, Andhra Pradesh, Rajasthan, Karnataka, and Punjab [3]. In India, over 60% of agricultural production and 85% of drinking water supplies depend on groundwater. Many groundwater issues arise as a result of a lack of surface water and excessive use of groundwater [4]. In recent years it has been recognized that the quality of the groundwater is of nearly equal importance as quantity [5]. Groundwater is a natural replenishable resource, which is safer than surface water. However, human activities can contaminate aquifers, and over the withdrawal of groundwater leads to a decline in its water levels consequently, it becomes poor in quality due to the increase in residence time of water with aquifer material and leakage of poor-quality water [6]. Hornblende, biotite, apatite, and fluorite are the major minerals present in the aquifer geology that contaminate groundwater through the rock-water interaction [7]. Depiction of data sets in an elemental way fails to draw consideration and understanding ability about the suitability of water quality for various uses. Therefore, representing complex data into physicochemical parameters in a useful format is one of the major tasks. The representation should be simple enough so that even the general public can easily understand. Interpretation of the data set integrates appropriate techniques such as indexing and environ metrics. One of the most used indices is the water quality index (WQI). Horton (1965) proposed a procedure for aggregating data of water quality parameters into useful indexing, and later Brown (1970) postulated the WQI based on the weighted arithmetic average method to evaluate the suitability of groundwater [8]. There are numerous indexing approaches that generate single numeric values by compiling all the parameters related to water quality. The water quality index determines the overall status of groundwater [9].

In the context of the above scenario, an attempt has been made to study the hydro chemistry and evaluation of groundwater in Chikkanayakanahalli Taluk, since groundwater is the main source for drinking and irrigation purposes in the study area.

MATERIALS AND METHODS

Chikkanayakanahalli is a Taluk headquarters of Tumkur district with a total area is 1113 sq km, and it is 67 km away

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Citation: Pushpa KL, Prakash KL. 2023. Evaluation of groundwater quality using hydro chemical characters and water quality index- A case study of Chikkanayakanahalli Taluk of Tumkur district, Karnataka. *Res. Jr. Agril. Sci.* 14(6): 1692-1697.

from Tumkur. There are 5 hoblis, 28-Gram panchayaths and 221 villages. It lies at 13º 25′12″ N latitude and 76º 37′ 12″ E longitude with an average elevation of 804 m.

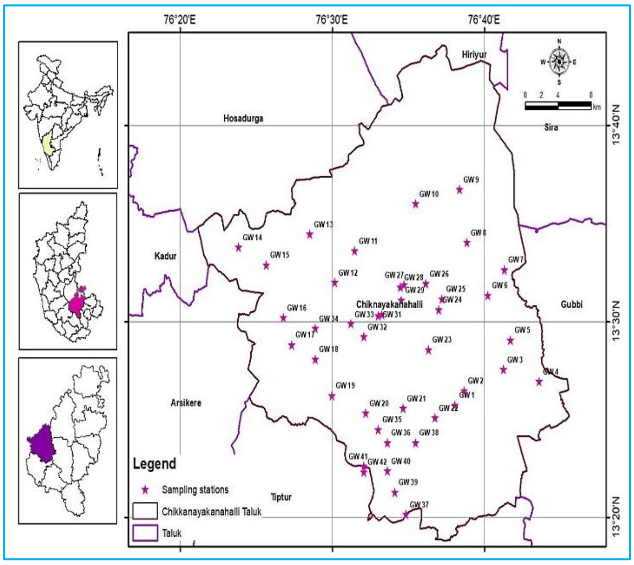

Fig 1 Location map of sampling stations of the study area

It falls under the SOI toposheets of 57 C/6, C/7, C/10, C/11 and C/15. The taluk experiences a sub-tropical climate, and southwest monsoon rainfall commences from June to October. The average rainfall in the taluk is 755mm. The area records a maximum temperature of 36 °C from April to May. As per the Central Groundwater board notification, 2012, groundwater is overexploited for irrigation and other purposes in Chikkanayakanahalli Taluk [10]. The schistose rocks pass through Chikkanayakanahalli and other taluks to the west of chain hills, a low range commencing near Kibbanahalli runs northwest past Chikkanayakanahalli and joins the central belt of the Chitradurga district. Chikkanayakanahalli schist belt forms the southern extension of the Chitradurga schist belt, and it is composed of laterite, quartzite, phyllites, conglomerate, meta-basalts, dolomites, limestones, Banded iron formations and banded Manganeferous formations. A few important iron ore deposits occurring within Chitradurga -Tumkur Schist belt falls under the Central dry zone (Zone 4). A major part of the taluk is occupied by red sandy soil, and a very small part in North West part of Chikkanayakanahalli Halli taluk is occupied by mixed red and black soils. The principal crops are Coconut, Arecanut, Ragi, Cereals, Fruits, vegetables, pulses, and minor millets [11].

A total of 42 groundwater samples were collected during the pre-monsoon season (March 2022). Borewells were continuously pumped for a while (10-15 mins) before sampling to ensure that all the samples were representative of their aquifers. Samples were collected in polyethene bottles of 1-litre capacity, labelled, sealed, and transported to the laboratory as per the standard methods. To prevent changes in equilibrium and adsorption on the inner surface of the bottles, the samples were acidified with 1:1 extra pure HNO_3 without disturbing the sample volume. The water samples were analyzed for physical and chemical parameters by adopting APHA (2017) standard methods [12]. Double distilled deionized water was used for the rinsing of the glassware after cleaning with 2% HNO_3 to prevent interference in the result. A Blank reagent was used to correct the readings of the instruments. pH, electrical conductivity (EC) and Total dissolved solids (TDS) were measured on-site by using HACH HQ30D multiparameter kit. Sodium (Na) and Potassium (K) were analyzed by Systronics flame photometer-128 by the flame photometric method. Total Hardness (TH), Calcium (Ca^{2+}), Bicarbonate (HCO_3) and chloride were analyzed by titrimetric method. Magnesium (Mg^{2+}) by calculation method. Fluoride was analysed by using the Calorimetric method. Sulfate, Nitrate, Silica, Boron, and phosphate were estimated by using Elico SL 171 Mini Spectrophotometer. The units of all chemical variables (except pH and EC) are expressed in milligrams per liter (mg/L). The EC is expressed in micro-mhos per centimeter (µs/cm) at 25 °C.

RESULTS AND DISCUSSION

Groundwater chemistry of Chikkanayakanahalli Taluk

The descriptive statistics of all the geochemical parameters and major ion compositions for the groundwater samples from the study area are presented in (Table 1).

Table 1 Descriptive statistics of Physico-chemical parameters in groundwater samples of Chikkanayakanahalli taluk

S. No	Category	Parameter	Unit	Min	Max	Mean
1		pH	-	7.22	8.19	7.70
2		EC	µS/cm	467	2582	1351.74
3		TDS		291.41	1611.17	843.48
4		Total alkalinity (as $CaCO_3$)		96.00	504.00	203.05
5		Total Hardness (as $CaCO_3$)		152.00	900.00	425.14
6		Calcium		30.40	174.40	80.91
7		Magnesium		10.74	113.22	54.37
8	Physico-chemical parameters	Sodium		9.31	215.60	108.38
9		Potassium		1.86	23.71	5.59
10		Boron	mg/L	0.13	0.8	0.61
11		Bicarbonates		117.6	614.88	247.79
12		Chlorides		59.0	615.81	118.92
13		Nitrates		6.74	46.23	19.24
14		Fluoride		0.30	1.30	0.81
15		Phosphates		0.02	0.71	0.32
16		Sulphates		16.32	388.57	89.56
17		Silicates		0.83	18.01	7.52

The pH values vary from 7.22 to 8.19 (mean, 7.70), indicating the alkaline nature of groundwater samples (Table 1). All pH values are within the acceptable limit (6.5–8.5) of the Bureau of Indian Standards (BIS) (2012) [13].

Electrical Conductivity ranged from 467 to 2582 µS/cm with an average value of 1351.74 µS/cm in the study area (Table 1). Large variation in conductivity value is mainly attributable to geochemical processes [14]. In natural waters, dissolved solids contain mainly inorganic salts such as bicarbonates, carbonates, sulphates, chlorides, nitrates and phosphates of calcium, magnesium, sodium, potassium, iron etc. and a small amount of organic matter and dissolved gases [15]. The TDS Values varied between 291 and 1611 mg/L, with a mean value of 843.48 mg/L (Table 1). About 85.71% of the samples showed TDS a value above the BIS (2012) acceptable limit of 500mg/L, attributed to the enrichment of salts in the groundwater [16].

The levels of total Hardness in water are mainly attributed to the presence of cations such as calcium, Magnesium, and anions such as carbonate, bicarbonate, chloride, and sulphate in water. The Total Hardness values range from 152 to 900mg/L (mean, 425.14 mg/L), with 97.61% of samples having a higher total hardness above the BIS (2012) acceptable limit of 200mg/L (Table 1). According to Sawyer and McCarty's (1967) classification of groundwater, 30.95% of the samples were hard, and the remaining 69.04% of the samples were very hard in nature (Table 2).

The Calcium concentration ranges between 30.4 to 174.40 mg/L with a mean value of 80.91mg/L in the groundwater samples. About 54.76% of samples exceeded the BIS (2012) acceptance limit of 75mg/L, remaining 42.23% of the samples were well within limits. While the concentration of magnesium was in the range of 10 to 113 mg/L with a mean value of 54.38 mg/L and it was apparent that 92.85% of samples showed magnesium values beyond the BIS (2012) acceptable limit of 30mg/L. The high concentration of calcium ions can cause abdominal ailments and is undesirable for domestic use as it causes encrustation and scaling [18].

Table 2 Sawyer and McCarty's [17] classification for groundwater based on hardness

TH as $CaCO_3$ (mg/L)	Water classes	Range (No. of samples)	Percent (%)
<75	Soft	-	-
75-150	Moderately hard	-	-
150-300	Hard	(152-300) 13 samples	30.95
>300	Very hard	(316-900)29 samples	69.04

The alkalinity in natural waters is mainly due to the presence of carbonates, bicarbonates, and hydroxides. Bicarbonates constitute the major form because they are formed in a considerable amount from the action of carbonates upon the basic materials in the soil [19]. Bicarbonate may be derived from carbon dioxide in the atmosphere and from the surrounding soils, mainly due to weathering processes [3]. The BIS acceptable limit of total alkalinity for drinking water is 200 mg/L, and it was found that 33.33% of the samples showing total alkalinity beyond the BIS acceptable limit as it ranged between 96 to 504 mg/L with the mean value of 203 mg/L. As compared with WHO (2017) standards Bicarbonates range from 117.6 to 614.88mg/L with a mean value of 247.79. About 26.19% of samples were found well within the limit of 200mg/L remaining 73.80% of samples exceeded the desirable limit of WHO (2017) standards [20].

The desirable limit for sodium prescribed by WHO (2017) is 200 mg/L, and it varied from 9.31 to 215.60 mg/L with a mean value of 108.38mg/L. It was evident that 95.23% of the samples in the study area were well within the limits. Higher concentrations of sodium may be due to silicate weathering and dissolution of halites [21]. The Potassium values range between 1.86 to 23.71 mg/L, with a mean value of 5.59 mg/L in the groundwater samples. Nearly 88.09% of samples showed a potassium concentration well within the WHO (2017) desirable limit of 10mg/L, and 11.90% exceeds the desirable limit of WHO (2017) standards.

The chloride concentration varied between 16 and 615 mg/L, with a mean value of 266.77 mg/L. chloride concentration in 40.47% of the samples exceeds the BIS (2012) acceptable limit of 250 mg/L and the remaining 59.52% of samples are well within the permissible limits. The higher chloride content in the groundwater can be primarily attributed to anthropogenic sources like leaching from saline residues, sewage wastes, agricultural runoff, and discharge from various industrial processes [9].

The presence of Sulfate in drinking water can cause a noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers. The sulphate content in the groundwater of the study area ranged between 16.32 and 388.5 mg/L with a mean value of 89.5 mg/L. The sulphate concentration in 97.61% of the samples was well within the BIS (2012) acceptable limit of 200mg/L.

The nitrate concentration in the study area ranges from 6.7 to 46.2 mg/L with a mean value of 19.24mg/L. Among the analyzed samples, only 2.3% sample showed a nitrate concentration above the BIS (2012) permissible limit of 45 mg/L. High nitrate values in groundwater samples usually attribute to anthropogenic activities and agriculture practices. Nitrate concentration beyond 45 mg/L in drinking water is considered dangerous for human health, particularly for infants causing methemoglobinemia or blue baby syndrome and gastric carcinoma [22].

The fluoride concentration varied from 0.3 to 1.3 mg/L with an average value of 0.82mg/L in the study area. Nearly 85.71%samples were found to have a fluoride concentration within the BIS (2012) acceptable limit of 1.0 mg/Land 19.04% exceeds the BIS (2012) standards. Elevated levels of fluoride are furthermost associated with groundwater due to the accumulation of fluoride during weathering and circulation of water in rocks, soils, and geothermal sources containing fluoride-bearing minerals [23].

The phosphate concentration was found to vary from 0.02 to 0.7 mg/L with an average value of 0.32mg/L in the study area. The concentrations of SiO_2 range from 0.84 to 18 mg/L with an average of 7.52 mg/L. In addition to this, the Boron concentration varied from 0.13 to 0.8 mg/L with an average value of 0.32mg/L in the study area.

Hydro chemical facies

The Piper trilinear diagram was constructed by plotting major cationic and anionic chemical data (Piper, 1944 & 1953) to establish the hydrogeochemical regime. The trilinear plot of cations expresses an abundance of each species (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) as a percentage of their sum while a trilinear plot of anions expresses an abundance of each species (HCO_3^-, SO_4^{2-} and Cl^-) as a percentage of their sum. The diamond-shaped field of the Piper trilinear diagram can be further classified into four Hydrochemical facies, namely (1) Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-}, (2) Na^+-K^+-Cl^--SO_4^{2-}, (3) Na^+-K^+-HCO_3^- and (4) Ca^{2+}-Mg^{2+}-HCO_3^- [24].

A perusal of the Hydrochemical facies (Fig 2) clearly illustrated the dominance of Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} hydrochemical facies in the majority of the samples from the study. Further, divalent cations (Ca^{2+} and Mg^{2+}) predominate monovalent cations (Na^+ and K^+), and strong acidic anions

(SO_4^{2-} and Cl^-) are dominant over weak acidic anions (HCO_3^-) in the study area [25].

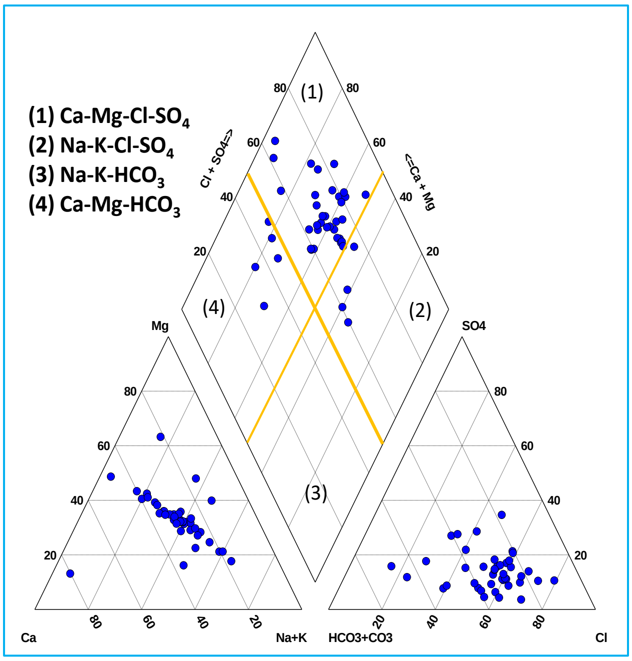

Fig 2 Piper trilinear diagram

Water quality index (WQI)

The water quality index is the most effective tool to monitor both surface and groundwater pollution. The water quality index was calculated from the point of view of the suitability of the water for human consumption [26]. Water quality index is a very useful tool for communicating the information on overall quality of water [27]. A water quality index is a significant tool for the examination of water quality and its suitability for drinking purposes. The water quality index is calculated by using a weighted arithmetic water quality index method. The weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most measured water quality variables [28]. For computing WQI, the following three steps are involved in WQI calculation: (i) assignment of weights (wi) to each water quality parameter involved ;(ii) calculation of relative weights (Wi) (based on Eq. 1); and (iii)quality rating scale calculation (Qi) (based on Eq. 2). The computed WQI values are then categorized into five classes, excellent, good, poor, very poor and unsuitable for drinking as well irrigation [29]. The following steps are involved in WQI determination.

Weightage factor (Wi)

In the first step weight (wi) is assigned to each parameter as per its relative significance in the water for drinking purposes. The weightage factor is calculated by the following equation:

$$Wi = wi / \sum_{i=1}^{n} wi$$

Where Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters. The assigned weight for each parameter is given in (Table 3).

Quality rating (qi)

$$qi = (Ci - Cio) / (Si - Cio) * 100$$

Where, Ci is the concentration of each chemical parameter in each water sample in mg/L, Cio is the ideal value of the parameter in pure water and, Si is the standard value.

Table 3 Weight (wi) and relative weight (Wi) of each parameter

S. No.	Parameters	BIS/WHO Standard	Ideal Value (Vid)	Weight (wi)	Relative weight (Wi)
1.	pH	8.5	7	3	0.091
2.	TDS	500	0	5	0.152
3.	TA	200	0	2	0.061
4.	TH	300	0	3	0.091
5.	SO_4	200	0	3	0.091
6.	K*	10	0	2	0.061
7.	Na*	200	0	3	0.091
8.	F	1.0	0	5	0.152
9.	Ca	75	0	2	0.061
10.	Mg	30	0	2	0.061
11.	Cl	250	0	3	0.091
12.	NO_3	45	0	5	0.094
				$\sum wi = 38$	$\sum Wi = 1.000$

*WHO (2017) acceptable limit; all other are BIS (2012) standard

Table 4 WQI classification based on WQI value

Water quality index (WQI)	Water quality	No of samples (%)
0-25	Excellent	-
26-50	Good	-
51-75	Poor	8(19.04)
76-100	Very poor	16(38.09)
>100	Unsuitable for drinking water	18 (42.85)

WQI calculation

For calculating the WQI, the sub-index is first calculated for each parameter by using the following equation:

$$SIi = wi * qi$$

Where SIi is the sub-index of the i^{th} parameter, qi is the rating based on the concentration of the i^{th} parameter and n is the number of parameters. The overall water quality index (WQI) was figured by adding together each sub-index value of each groundwater sample as follows [5], [30].

$$WQI = \sum SIi$$

Computed WQI values were classified into six categories excellent, good, poor, very poor and unsuitable for human consumption as given in (Table 4).

In the present study, twelve groundwater parameters like pH, TDS, Alkalinity, Sulfate, potassium, Sodium, Fluoride, calcium, magnesium, chloride, Hardness and nitrate were analyzed to assess the suitability of groundwater for drinking purposes. It is found that the groundwater of some parts of the Chikkanayakanahalli Taluk is unsuitable due to elevated concentrations of total hardness, sodium and fluoride beyond acceptable limits as prescribed by BIS (2012) and WHO (2017) standards. To evaluate groundwater suitability for drinking purposes water quality index of the study area was calculated using different groundwater quality parameters during March 2022.The water quality index values for eight samples (19.04%) falls under poor quality category and sixteen (38.09%) samples were under very poor category. Remaining eighteen samples (42.85%) were not suitable for drinking as per the WQI classification (Table 4). The variation of the Water quality index of the samples in the study area has shown in (Fig 3). The spatial distribution of water quality index of the study area has shown in (Fig 4). About 19% of the water samples are under the poor category (WQI<75), 40.5% samples are under very poor (75>WQI<100) and remaining 40.5% of the samples were under the unsuitable for drinking (WQI>100). The frequency distribution of water quality index has shown in (Fig 5). Sadat-Noori [31] classified the groundwater based on water quality index in Saveh-Nobaran aquifer of Iran. This study concludes that the groundwater quality decreases northwest to the east of the study area. This is mainly due to the effects of the hydraulic gradient and the groundwater direction moving towards the south-east bound. Jai Kumar [32] also made an effort to study water quality index, majority of the samples are not suitable for drinking. The high-water quality index is mainly due to geographical reasons and also the higher presence of inorganic dissolved solids. Anitha Pius [33] has also made similar studies in Peenya industrial area of Bangalore and reported that safer zone is in the north western part of the study area, which has comparatively lesser number of industries than the rest of the study area.

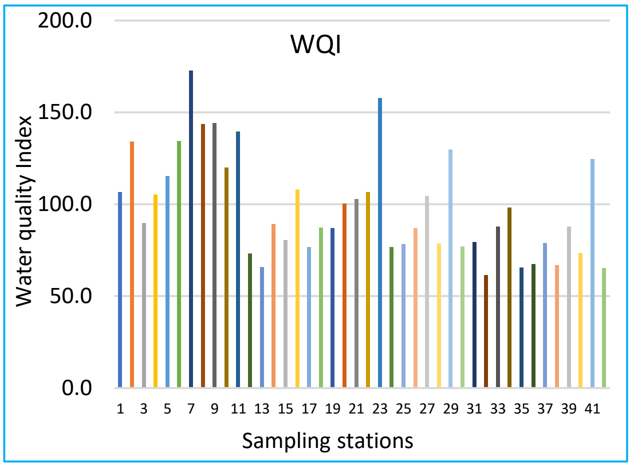

Fig 3 Variation of water quality index among the samples

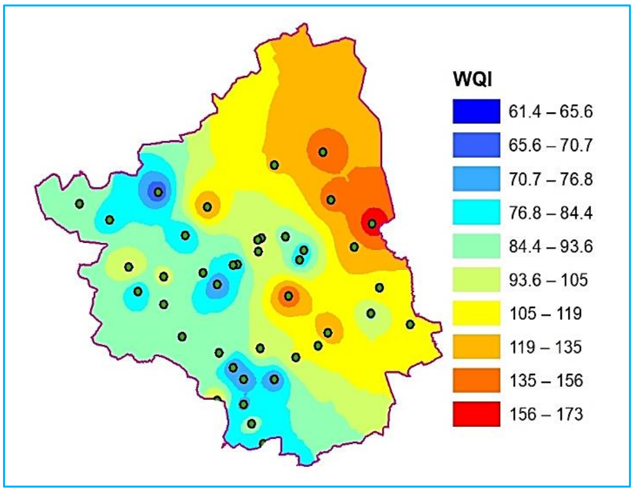

Fig 4 Spatial distribution of water quality index for groundwater samples

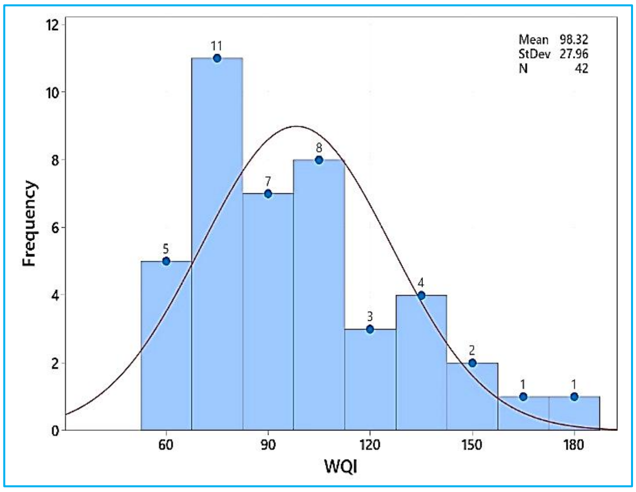

Fig 5 Frequency distribution of water quality index values

CONCLUSION

The groundwater of the study area is alkaline with a pH ranging between 7.22 to 8.19. More than 69.04% of water samples fall under the ‘very hard category. As far as the concentration of cations and anions is concerned, almost 54.76% of calcium, 92.85% of Magnesium water samples and 40.47% of chloride water samples were found to be beyond the acceptable limit of BIS standards. In this study, an effort has been made to investigate groundwater quality status combined with Water Quality Index. About 42.85% of samples were unfit for drinking as per the WQI classification shown in the water quality index map. Water quality indices are used to provide valuable tools for decision-makers to be able to understand the status of water quality and to have the opportunity to make suitable decisions for better use in future. Hence, the study shows that the frequent monitoring of groundwater is a vital step to avoiding human health risks.

Acknowledgement

The authors are grateful to the Department of Environmental Science, Bangalore University, Bangalore, for the constant encouragement and support in providing the necessary laboratory facility to carry out the work.

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