Int.J.Curr.Microbiol.App.Sci (2023) *12*(06): 251-259

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 12 Number 6 (2023)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2023.1206.031

Evaluation of Groundwater Quality for Irrigation Using GIS in Northeastern Karnataka, India

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Keywords

Groundwater quality, irrigation use

Article Info

Received: 08 May 2023
Accepted: 04 June 2023
Available Online: 10 June 2023

A B S T R A C T

The assessment of groundwater quality for its suitability for irrigation was carried out in northeastern Karnataka, India. To study, groundwater samples were collected from randomly selected sixty-five bore well. The following physicochemical parameters like electrical conductivity, total dissolved solids, calcium, magnesium sulphate, chloride, sodium and potassium were quantified as per standard methods. An irrigation quality was assessed based on indices like sodium adsorption ratio, residual sodium carbonate, sodium per cent, salinity hazard and USSL diagram, magnesium hazard, permeability index, potential salinity and Kelly's ratio. The spatial variability map for all parameters prepared using ArcGIS ver. Xx.xxx software.

Introduction

Groundwater plays an important role in irrigation, especially in semi arid regions due to lack of surface water resources. However, the over-exploitation of groundwater for irrigation resulting in declining groundwater level. Groundwater quality is also a major concern and the suitability of irrigation water depends on the quality of water, type of soil, drainage and climate characteristics etc., (Venkateswaran and Vediappan, 2013). Groundwater also contain certain amount of soluble salts dissolved in it. The solubility of various salts depends upon the source of the recharge and type of geology of the area. The quality of irrigation water is directly affects on the crops as well as soils on which they are grown, thus high quality crops can be achieved by using desired irrigation water (Adegbola *et al.*, 2019).

The important parameters consider for the suitability of groundwater for irrigation includes sodicity, salinity, and toxicity (Khodapanah *et al.*, 2009). Therefore, assessment of groundwater quality for irrigation is essential for sustainable agriculture production.

Materials and Methods

The study carried out in Shahapur taluk of Yadgir district of northeastern Karnataka (India). The study area lies between latitudes 16°22.30' N to 16°53.15 N and longitudes of 77°15.25 E to 77° 37.30 E. The study area experiences a temperature ranging from 12°C to 42°C and average annual rainfall is about 640 mm. The relative humidity varies from 26% in summer to 62% in winter.

Geology

The part of the study comprises the Peninsular Gneiss and granites. Central, the northeastern and southwestern part comprises of sedimentary formations viz. sandstone, quartzite, shale, slate, limestone and dolomite. Deccan Trap basalts cover Northeastern parts of the area.

Groundwater sampling and analysis

A total of 65 groundwater samples collected from bore wells in post-monsoon season during November 2013. The sampling locations coordinates recorded using GPS (Garmin). The recorded location of the sampling points depicted in Fig. 1. The static water depth was ranging in between 10 and 20m below ground level. The groundwater sampling and qualitative analysis of physico-chemical parameters of water carried out as per the standard methods (APHA, 1998 and BIS, 1991). Specific methods used for calculation of indices of groundwater indicated in Table 1.

GIS-analysis

The spatial maps for physicochemical parameters and irrigation water quality indices prepared using the ArcGIS ver. Xx.xxx software. The spatial interpolation of data carried out using Inverse Distance Weighted (IDW) method (Basavaraja *et al.,* 2018). This method interpolates a value for each grid node in the proximity data points that lie within a user-defined search radius (Burrough and McDonnell, 1998). All of the data points used in the interpolation process and the node value determined by averaging the weighted sum of all the points. The GIS database helps in identifying the most sensitive zones that need immediate attention.

Results and Discussion

The analytical results evaluated thoroughly to distinguish the quality of groundwater in the study area for irrigation purposes presented in Table 2. Salinity and indices such as sodium absorption ratio (SAR), Electrical conductivity (mS/cm), sodium percentage (Na %), residual sodium carbonate (RSC), permeability index (PI), magnesium hazard index (%) and Kellys ratio are the important parameters used for groundwater classification for irrigation uses (Srinivasa, 2005 and Raju, 2006).

Salinity hazard

Electrical conductivity is a good measure of salinity hazard to crops as it reflects the total dissolved solids in water. The US Salinity Laboratory (USSL, 1954) classified ground waters based on electrical conductivity (Table 6). Based on this classification, 38.46 % of samples found unsuitable category, 58.46% of samples are belonging to the doubtful category, and 3.07% fall good category. The spatial distribution map of EC illustrated in Fig. 2(a)

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) one of the parameters used to judge groundwater for irrigation as it is a measure hazard to crops due to sodium (Karanth, 1987). It can indicate the degree to which irrigation water tends to enter into cation exchange reactions in the soil ecosystem. This sodium in future replace calcium and magnesium and causes changes in physic-chemical properties of soil (Raju, 2006). The SAR values range from 0.25 to 15.21. According to Richards (Richards, 1954) classification based on SAR values (Table 2), a total of 60 samples observed belong to the excellent and 05 samples belongs to the good category. The spatial distribution map of SAR illustrated in Fig. 2(b)

Sodium Percentage (% Na^+)

In irrigation water quality classification, sodium plays a vital role because it reduces the permeability and also reacts with soil. Wilcox, (1955) observed that, % Na^+ is a major parameter to assess the suitability of water for irrigation.

Generally, % Na^+ should not exceed 60% in irrigation waters. Table 2 demonstrate that 44.61 %, 40 % and 12.3 % water samples observed respectively a first, good and permissible quality category and only 3.07 % under the doubtful category. Since 96.93 % of samples of % Na^+ observed below 60 %, there is no adverse effect on the permeability of the soil. The spatial distribution map of % Na illustrated in Fig. 2(c)

Residual sodium carbonate (RSC)

To determine the suitability of water for irrigation purposes, Eaton (1950) recommended the concentration of Residual Sodium Carbonate (RSC). The RSC calculated to find out the hazardous effect on the quality of irrigation water of carbonate and bicarbonate. According to the classification of irrigation water, the RSC more than 2.5 meq/L not recommended for irrigation. In the present study, RSC value ranged from -24.43 to 6.08 meq/L A total of 50 sampling locations observed with less than 1.25 meq/L and are good for irrigation, 10 samples belong to moderate and 5 samples belong to the unsuitable category. The spatial distribution map of RSC displayed in Fig. 2(d)

Magnesium Hazard

Usually, alkaline earth (Ca^{2+} and Mg^{2+}) are in an equilibrium state in groundwater. Both Ca^{2+} and Mg^{2+} ions linked with soil friability and aggregation, but both are also essential nutrients for the crop. Excess concentration of magnesium in groundwater affects the soil quality by converting it into alkaline and decreases the crop yield (Srinivasa, 2005; Kambale *et al.*, 2017). Szabolcs and Darab (1964) projected magnesium hazard index (MH) values for irrigation water. The $MH > 50$ not suggested for irrigation use (Khodapanah *et al.*, 2009). In this study, 73.84 % of samples observed suitable, and 26.15 % of samples found unsuitable for irrigation. The spatial distribution map of magnesium hazard illustrated in Fig. 2(e)

Permeability index (PI)

The permeability index (PI) also calculated for all sampling locations to specify the groundwater suitability irrigation. WHO (WHO, 1989) uses a criterion for assessing the suitability of water for irrigation based on permeability index. The PI observed in the range of 13.13 to 129.42, with an average of 45.42. According to PI standard values, classified as class I (>75%) and Class II (25-75%). It observed that 87.69 % are suitable and 12.31 % unsuitable for irrigation purposes. The spatial distribution map of the permeability index illustrated in Fig. 2(f)

Kellys ratio

Kelly (1940) introduced another factor called Kelly's Ratio (KI) for classification irrigation water. $KI > 1$ indicates an excess level of Na^+ in waters. Therefore, water with a $KI \leq 1$ has been recommended for irrigation, while water with $KI \geq 1$ not recommended for irrigation due to alkali hazards (Karanth, 1987). In the present study, the highest KI value was 0.15. Here, all the samples observed within the permissible range. The spatial distribution map of Kelly's ratio illustrated in Fig. 2(g)

Potential salinity (PS)

Doneen (1962) believes that low solubility salts precipitated in the soil and accumulate with each unnecessary irrigation highly soluble salts which increases the salinity of the soil. The PS of water samples ranges from 2.06 to 133.26, with a mean of 15.23. The high amount of PS was due to the presence of chlorides. The spatial distribution map of PS illustrated in Fig. 2(g).

Fig.1 Geology and sampling locations of the study area

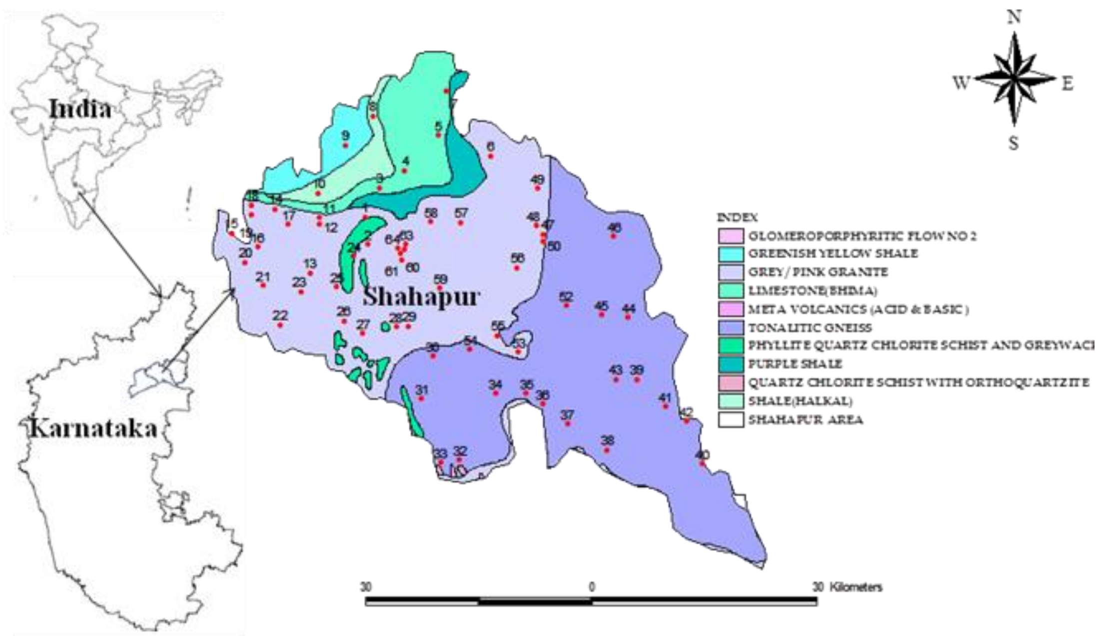


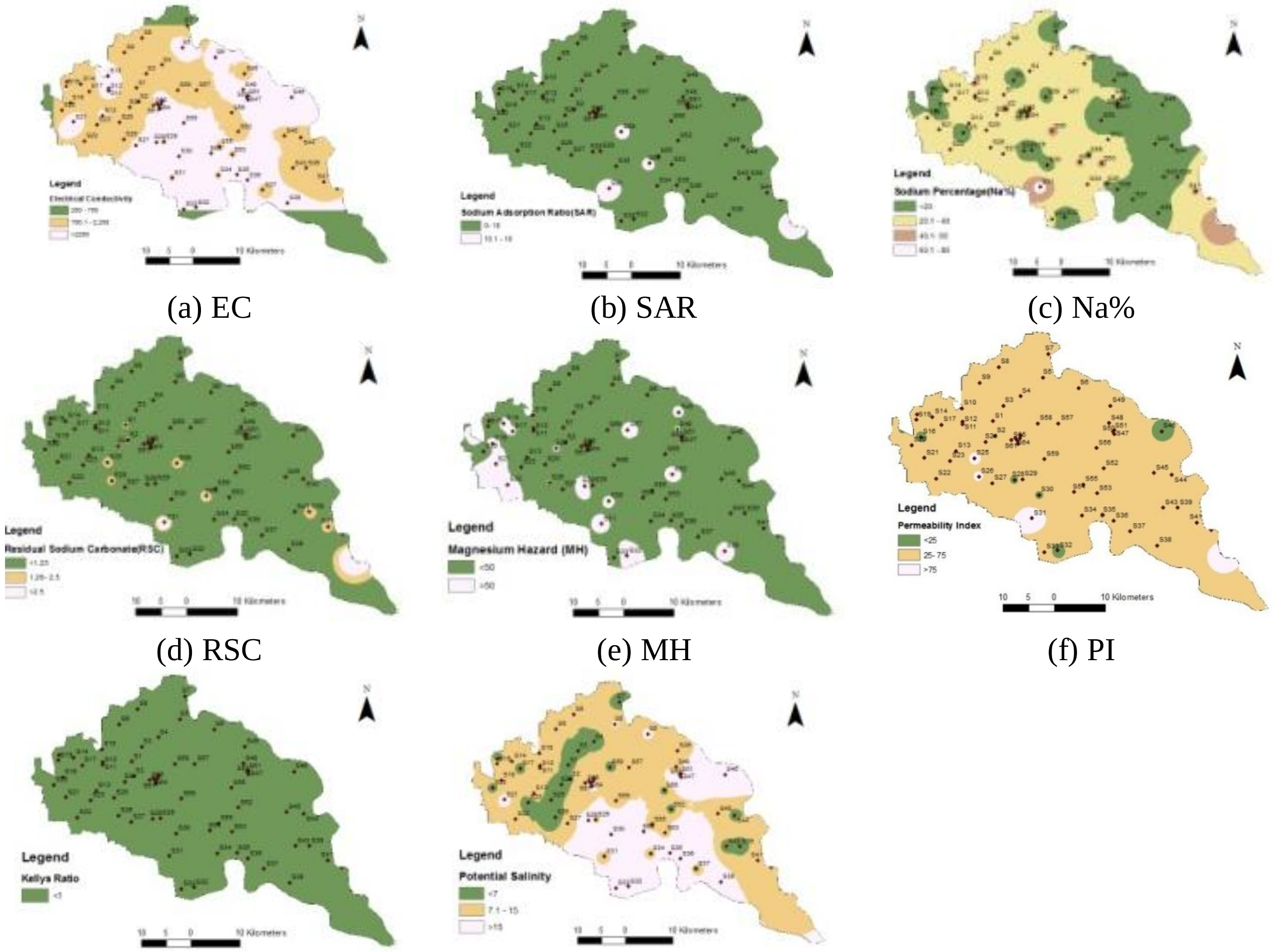
Table.1 Specific methods used for calculation of indices of groundwater

Indices	Formula	Reference
Sodium Adsorption Ratio(SAR)	$SAR = \frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$	Todd, 1980
Sodium percentage(Na%)	$Na\% = \frac{(Na^+ + K^+)}{(Ca^{2+}+Mg^{2+}+Na^++K^+)}$	Wilcox, 1955
Residual Sodium Carbonate(RSC)	$RSC = (HCO_3^- + CO_3^-) - (Ca^{2+} + Mg^{2+})$	Eaton, 1950
Magnesium hazard(MH)	$MH = [Mg^{2+}/(Ca^{2+} + Mg^{2+})] X 100$	Paliwal, 1972
Permeability Index(PI)	$PI = \frac{Na^+ \sqrt{HCO_3^-}}{Ca^{2+}+Mg^{2+}+Na^+}$	Doneen, 1962
Potential Salinity(PS)	$P.S = Cl^- + {}^1/_2\, SO_4^{2-}$	Doneen, 1962
Kelly's ratio	$\text{Kelly's ratio} = Na^+/(Ca^{2+} + Mg^{2+})$	Kelly, 1940
Gibbs ratio I (for anions)	$\text{Gibbs ratio I} = \frac{Cl^-}{Cl^-+HCO_3^-}$	Gibbs, 1970
Gibbs ratio II (for cations)	$\text{Gibbs ratio II} = \frac{Na^++K^+}{Na^++K^++Ca^{2+}}$	Gibbs, 1970

Table.2 Groundwater classification for irrigation based on various indices

Parameter	Category	Water Classification	Number of Samples	% of sample	Representing Samples
EC	<250	Excellent	-	-	-
	250–750	Good	02	3.07	S23, S65
	750–2250	Doubtful	38	58.46	S1-S4,S7-S9,S12,S14, S16-S18, S20, S22, S24-S26, S29, S31,S34, S37, S39,S41-S45,S47,S49,S51-S53,S55-S58,S63,S64
	>2250	Unsuitable	25	38.46	S5,S6,S10,S11,S13,S15,S19,S21, S27,S28,S30,S32,S33,S35,S36,S38,S40,S46,S48
SAR	0-10	Excellent	60	92.3	S1-30, S32-39, S41-53, S55-58, S60-61, S63-65
	10-18	Good	05	7.69	S31, S40, S54, S59, S62
	18-26	Doubtful	-	-	-
	>26	Unsuitable	-	-	-
Na%	<20	Excellent	29	44.61	S3, S7, S14-19, S23, S28-30, S32, S35-39, S43-47, S49, S51, S55-56, S58, S64-65
	20-40	Good	26	40	S1, S4-6, S8-9, S11-13, S17, S20-22, S24-27, S33-34, S42, S48, S50, S52, S57, S60-61
	40-60	Permissible	08	12.3	S2, S10, S41, S53-54, S59, S62-63
	60-80	Doubtful	02	3.07	S31, S40
	>80	Unsuitable	-	-	-
RSC	<1.25	Safe	50	76.92	S3-16, S18-19, S21-23, S27-30, S32-38, S42-47, S49-53, S55-58, S60-61, S63-65
	1.25-2.5	Moderate	10	15.38	S1-2, S17, S20, S24-26, S39, S41, S48
	>2.5	Unsuitable	05	7.69	S31, S40, S54, S59, S62
PI	>75(Class I)	Good	05	7.69	S25-26, S31, S40, S62
	25-75(Class II)	Good	52	80	S1-14, S17-24, S27, S29, S33-34, S36-39, S41-45, S47-49, S51-61, S63-65
	<25(Class III)	Unsuitable	08	12.30	S15-16, S28, S30, S32, S35, S46, S50
MH	<50	Good	48	73.84	S1-13, S18-20, S23, S25, S27, S29, S33-37, S39-47, S50-51, S53-56, S58-65
	>50	Unsuitable	17	26.15	S14-17, S21-22, S24, S26, S28, S30-32, S38, S48-49, S52, S57
Kellys ratio	0-1	Permissible	65	100	S1-65
	1-3	Doubtful	-	-	-
	>3	Unsuitable	-		-

Fig.2 Spatial distribution of various indices for irrigation water quality



(a) EC (b) SAR (c) Na% (d) RSC (e) MH (f) PI (g) Kellys ratio (h) Potential salinity

Wilcox diagram

Based on the Wilcox (1955) diagram 26.15% of the groundwater samples observed unsuitable, 20% found doubtful to unsuitable, 49.23% witnessed good to permissible, and 3.07 % noted excellent to good for irrigation (Fig. 3).

USSL classification

The US salinity diagram illustrates that 59.92% of samples fell in the zone of C3S1 with indicating high salinity, and it cannot use on soils with restricted drainage and low sodium. 32.31% samples in the zone of C4S1 with indicating very high salinity and are not suitable for irrigation under ordinary conditions. But it may be used occasionally under very special conditions and low sodium water. 6.00% samples observed under C4S2 zone with indicating very high salinity and are not suitable for irrigation under ordinary conditions. One sample from the zone of C3S2 and 2 samples observed in the zone of C2S1 can used for irrigation almost all soils (Fig. 4).

Fig.3 Marking of groundwater samples on the basis of electrical conductivity and percent sodium (Wilcox, 1955)

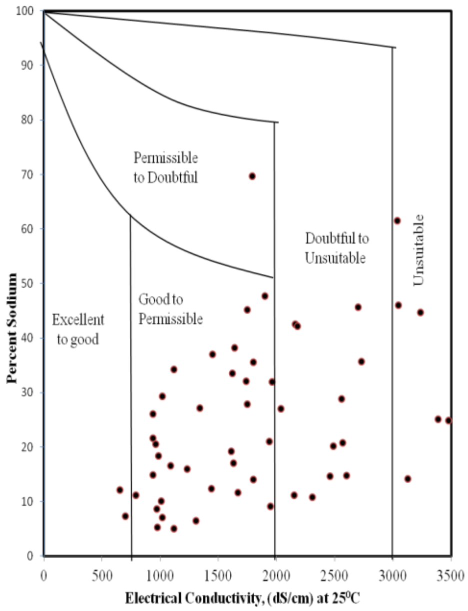


Fig.4 Rating of groundwater samples in relation to salinity and sodium hazard

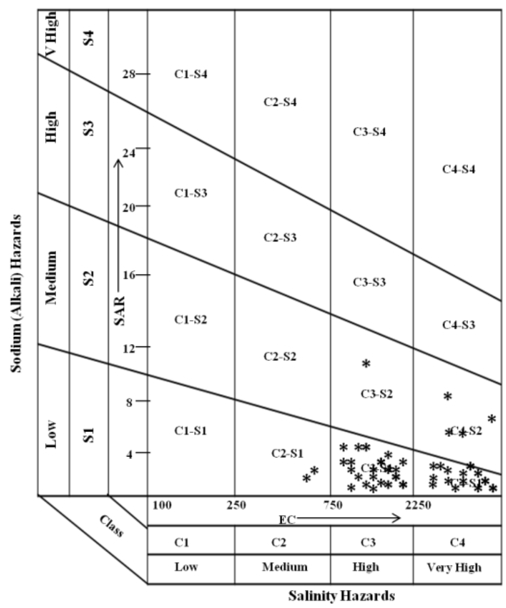
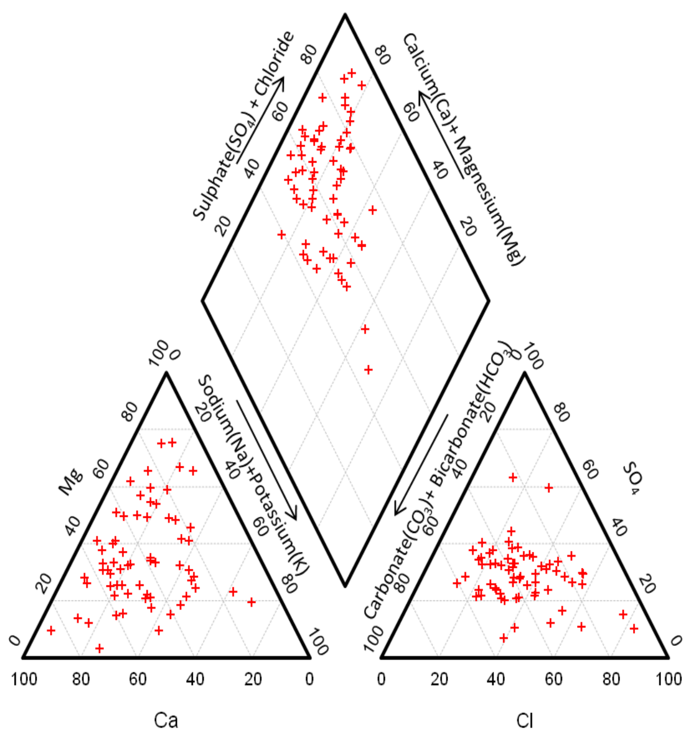


Fig.5 Trilinear piper diagram for graphical analysis



Geochemical classification and hydrogeochemical facies

To examine water composition and the chemical relationship between dissolved ions, the concept of hydrochemical facies of the studied area used in Pipers (1953) trilinear diagram for graphical analysis (Fig. 5). This reveals similarities and differences among water samples (Todd, 1980). The results suggested that mixed cation-HCO_3 is the dominant hydrochemical facies for the surveyed groundwater.

Sodium Adsorption Ratio shows that 92.3% of the samples belong to excellent and 7.69% of the samples belong to good category for irrigation. Sodium percentage confirms that 44.6%, 40%, 12.3% and 3.07% of the samples belong to excellent, good, permissible and doubtful respectively. Residual Sodium Carbonate value of 92.3% of the samples is less than 2.5 meq/L and are found to be suitable for irrigation and only 7.69% of samples more than 2.5 meq/L and are unsuitable for irrigation. Permeability values reveal that 87.69 % the groundwater is suitable for irrigation. The potential salinity of water samples ranges from 2.06 to 133.26 and was due to the presence of chlorides. Magnesium hazard shows that 73.84% of the samples were less than 50 and are in good condition. Kellys ratio value was 0.15 and all the groundwater samples were within the permissible range. US salinity diagram illustrates that 59.92% of the groundwater samples fall in the zone of C3S1 are indicating high salinity and it cannot be used on soils with restricted drainage and low sodium water, 32.31% samples in the zone of C4S1 are indicating very high salinity and are not suitable for irrigation under ordinary conditions. The Wilcox diagram shows that 49.23% of the groundwater samples fall in the field of good to permissible and 3.07 % of the samples fall in the field of excellent to good for irrigation.

Acknowledgements

We thank the Directorate of Research, University of Agricultural Sciences, Raichur for financial support under Demand Driven Research Project Scheme and Dr R S Giraddi, Former Dean(Agri.), College of Agriculture, Bheemarayanagudi for his support during research work.

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How to cite this article:

Basavaraja Dasappa, Janardan Bhima Kambale and Durgappa Kenchappa Hadimani. 2023. Evaluation of Groundwater Quality for Irrigation Using GIS in Northeastern Karnataka, India. *Int.J.Curr.Microbiol.App.Sci.* 12(06): 251-259. **doi:** https://doi.org/10.20546/ijcmas.2023.1206.031