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Suitability of Groundwater Resources for Irrigation in the Upper Gadilam River Basin Villupuram District, Tamil Nadu, India

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Abstract: The main goal of the study is to identify groundwater quality suitable for irrigation in the upper Gadilam river basin of Villuppuram District of Tamil Nadu, India. An investigation was carried out by collecting a total of 25 groundwater samples for one season to decipher hydrogeochemistry and groundwater quality for determining its suitability for irrigation purposes. The Standard methods for physicochemical determinations were employed. The samples have been analyzed to determine physical parameters like pH, EC, TDS and Hardness, the chemical parameters like Na, K, Ca, Fe, HCO_3, SO_4 and Cl. From the analyzed data, some parameters like Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Total Hardness (TH), Magnesium Absorption Ration (MAR) and Kelly's Ratio (KR) have also been determined for irrigation purposes. The important chemical constituents that affect the suitability of water for irrigation are total concentration of dissolved salts, relative proportion of bicarbonate to calcium, magnesium and relative proportion of sodium to calcium. To ascertain the suitability of groundwater for any purposes, the TDS should be below 500 mg/L. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. Kelly's index in the present study varied from 0.84 to 1.68, and ten water samples suitable for irrigation and other are not suitable for irrigation. Sodium Absorption Ratio can indicate the degree to which irrigation water tends to enter into cation-ex-change reactions in soil. The SAR value of all the samples are found to be less than 10 and are classified as excellent for irrigation. The majority of the samples (59.58%) belong to the high salinity category, indicating that the water is of permissible quality. From the Wilcox plot, it is observed that most of the samples from the study area fall in the good to permissible classes for irrigation purpose. The hydrochemical analyses reveal that the present status of groundwater in in the upper Gadilam river basin is good for irrigation. The overall quality of groundwater in upper Gadilam river basin is controlled by lithology apart from local environmental conditions.

Keywords: *Irrigation, salinity, chlorinity, Sodium, SAR.*

1. Introduction

Agriculture is a dominant sector in the economic development of India, as it is the source of sustenance for the majority of the population, and contributes 46% of the gross national product Singh, 1983. The dependence on groundwater has increased tremendously in recent years in many parts of India, especially in the arid and semi-arid regions, due to the vagaries of monsoon and the scarcity of surface water. Rapidly shrinking surface water resources due to over-exploitation and resultant contamination with several chemical and biological agents all over the globe has shifted tremendous pressure on the groundwater resources, contributing to the complexity of its quality assessment.

The quality of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions (weathering), as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes. The composition of groundwater in a region can be changed through the operation of the processes such as evaporation and transpiration (evapo-transpiration), wet and dry depositions of atmospheric salts, selective uptake by vegetation, oxidation/reduction, cation exchange, dissociation of minerals (soil/rock–water interactions), precipitation of secondary minerals, mixing of waters, leaching of fertilizers and manure, pollution of lake/sea, and biological process Appelo and Postma, 1993.

The weathering of igneous and sedimentary rocks brought ions in groundwater yousef, et al. 2009. The ion distribution is influenced by the surface and subsurface physicochemical environmental Aghazadeh and Mogaddam, 2010.The type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of the soil through which the water flows prior to reaching the aquifers Zuane, 1990. Since it is impossible to control the dissolution of undesirable constituents in the waters after they enter the ground Johnson, 1979; Sastri, 1994, groundwater quality data has given important clues to the geologic history of rocks in the study area and indications of groundwater recharge, movement, and storage Walton, 1970 and the residence time of water in contact with rock material.

It was observed that the criteria used in the classification of waters for a particular purpose considering the individual concentration do not find its suitability for other purposes, and better results can be obtained only by considering the combined chemistry of all the ions rather than individual or paired ionic characters Handa, 1964, Hem 1985.

Hence, in order to assess the fate and the impact of the chemical discharge onto the soil, it is important to understand the Hydrogeochemistry of the chemical–soil–groundwater interactions Miller, 1985 and to determine the origin of chemical composition of groundwater Zaporozec, 1972. A number of studies on groundwater quality with respect to drinking and irrigation purposes have been carried out in the different parts of India Durvey, et al. 1997; Agrawal and Jagetia,1997; NiranjanBabu, et al. 1997; Subba Rao, et al. 1999; Majumdar and Gupta, 2000; Dasgupta and Purohit, 2001; Khurshid, et al. 2002; Sujatha and Reddy, 2003; Sreedevi, 2004; Pulle, et al. 2005; Hussain, et al. 2005; Sunitha, et al. 2005; Subba Rao, 2006 Ramesh K.,2012.

So far, the geochemistry and the suitability of the groundwater for drinking and irrigation purposes in the Upper Gadilam River Basin area have not been studied in great detail. Since groundwater is intensively used for irrigation purposes, an effort is made in the present studies to discern the hydrogeochemistry of groundwater and to classify the water in order to evaluate its suitability for irrigational use.

2. Materials and Methodology

2.1. Description of study Area

The upper Gadilam River basin stretches geographically from 11°37’ 30”Nto 11° 57’ 0” N latitude and 78°58’30”Eto 79° 25’30”E longitude, positioned in the midst of Villupuram district of Tamil Nadu. It occurs within the Survey of India toposheets of 58M/1, 2, 5, 6 and 9 covering a total area of about 823 km^2.

The upper Gadilam River is adjoining Sescha Nadi in the south eastern basin of the study area. The total length of the upper Gadilam River is about 82 km and Sescha Nadi is about 45 km. The study area is surrounded by a number of lakes which are used for irrigation purposes.

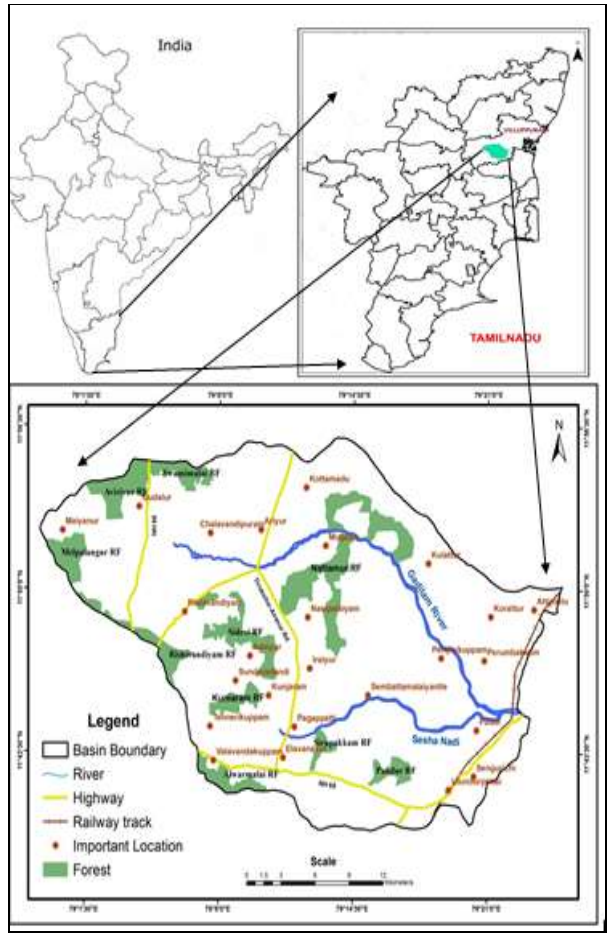

Figure 1.*Key map of study area.*

2.2. Irrigation Water Quality

Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity and miscellaneous Ayers and Westcot, 1985. To assess water quality for irrigation, there are four most popular criteria: TDS or EC, sodium adsorption ratio (SAR), chemical concentration of elements like Na^+, Cl^- and/or B^- and residual sodium carbonate (RSC) Michael, 1992 and Raghunath, 1987. For current irrigation water quality assessment, the following parameters were considered.

$$SAR = \frac{Na+}{(Ca2+ + Mg2+)/2} \quad (1)$$

Todd (1980) defined soluble sodium percentage (SSP) as:

$$SSP = \frac{Na+ + K}{(Ca2+ + Mg2+ + Na+ + K+)/2} \times 100 \quad (2)$$

Doneen (1962) defined permeability index (PI) as:

$$PI = \frac{Na + +\sqrt{HCO3-}}{(Ca2 + +Mg2 + +Na +)} \times 100 \quad (3)$$

Magnesium adsorption ratio (MAR) (Raghunath, 1987) was calculated as:

$$MAR = \frac{Mg2+}{(Ca2 + +Mg2 +)} \times 100 \quad (4)$$

Kelley's ratio (KR) (Kelley, 1963) described as:

$$KR = \frac{Na+}{(Ca2 + +Mg2 +)} \quad (5)$$

3. Results and Discussion

3.1. General Physico-Chemical Characteristics

Based on the physico-chemical analyses, irrigation quality parameters like sodium absorption ratio (SAR), %Na, residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), soluble sodium percentage (SSP), noncarbonated hardness, potential salinity, permeability index, Kelley's ratio and magnesium hazard (MH)/ratio were calculated. The correlation of the analytical data has been attempted by plotting different graphical representation such as those of Piper ,1994; Doneen diagram ,1961; and Hanshaw ,1965; Wilcox ,1995; Eaton ,1950; Gibbs ,1970; USSL diagram, Hem, 1985; Todd,1959; Handa,1969; and Richards ,1954 for the classification of water and to study the suitability of groundwater for utilitarian purposes by ascertaining various factors on which the chemical characteristics of water depend. The suitability of the water from the groundwater sources for irrigation purposes was evaluated by comparing the values of different water quality parameters with World Health Organization (1984) guideline values for drinking water. In addition to this, visually communicating spatial distribution maps were constructed using ArcGIS-9.3 software to delineate spatial variation of physico-chemical and irrigation quality parameters in the study. Spatial analysis tools were used for the preparation of interpolation map. The maps were interpolated by using inverse distance methods to generate the spatial distribution map. Water sample collection locations are given in Fig. 1.

***Table 1** Physico-chemical values of the study area compared with WHO: 2006 standards*

S. No	Parameters	WHO:2006	Range(No.of Sample)
1	Ph	6.5-8.5	**6.88-8.03(25)**
2	Ca	75	**36-72(14)**
3	Mg	30	**16-30(8)**
4	Na	200	**56-196(23),244-302(2)**
5	Fe	0.3	**0-0.3(16)**
6	TDS	500	**418-467(3),525-2114(22)**
7	Cl	200	**48-180(20),180-544(5)**
8	SO_4	200	**12-200(25)**
9	NO_3	45	**6-44(24),44-72(1)**
10	F	1.5	**0.6-1.4(17),1.8-2.6(8)**

3.2. Ground Water Quality for Irrigation Purpose

Water quality, soil types and cropping practices play an important role for a suitable irrigation practice. Excessive amounts of dissolved ions in irrigation water affect plants and agricultural soil physically and chemically, thus reducing productivity. The physical effects of these ions are to lower the osmotic pressure in the plant structural cells, thus preventing water from reaching the branches and leaves. The chemical effects disrupt plant metabolism. Water quality problems in irrigation include indices for salinity, Chlorinity, sodicity Mills, 2003 and alkalinity. EC and Na+ play a vital role in suitability of water for irrigation. Higher EC in water creates a saline soil. Harmful effects of irrigation water increases with the total salt concentration, irrespective of the ionic composition. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure Thorne and Peterson, 1954. The salts apart from affecting the growth of plants also affect the soil structure, Permeability and aeration which indirectly affect plant growth. SAR is the most commonly used for evaluating groundwater suitability for irrigation purposes Ayers and Westcot, 1985. It is normally expressed as Na content or alkali hazard which is normally expressed in Sodium adsorption ratio SAR Rao, 2005). The important chemical constituents that affect the suitability of water for irrigation (Table .2), which can be utilized to verify the suitability, are as follows: Salinity index or salinity hazard or total concentration of soluble and dissolved salt as computed by measured EC values.

- The sodium hazard or relative proportion of sodium to other principal cations as expressed by SAR.
- Sodium hazard has expressed as percent sodium of total cations.
- Bicarbonate hazard or bicarbonate (HCO_3) concentration as related to the concentration of calcium plus magnesium such as RSC and RSBC.
- The Chlorinity index has been measured by chloride ion concentration in water.
- Magnesium hazard/ratio, Kelly index (KI), permeability index (PI), potential salinity (PS), SSP.

***Table 2:** irrigation water quality*

Parameters	Maximum	Minimum
SAR	4.16	1.49
MR	52.39	28.89
KR	1.68	0.88
SSP	1517.8	411.2

RSC	2.97	-0.69
RSBC	6.69	1.65
Na%	43.20	36.84
PI	128.7	70.5
PS	13.26	1.23

3.2.1. Results of GIS Spatial Distribution map:

Figure 2.*Spatial distribution map of Sodium in the Study area;*

Table 3.*Results of GIS Spatial Distribution of Sodium*

Potable Class	Limiting Value	Area in Km^2	Percentage of the Area
Potable limit	< 250	817	99.15
Not Potable	> 250	7	0.84

Sodium is observed in potable limit during seasons indicating there are suitable for drinking purpose in the study area. The post-monsoon season sodium spatial distribution results are given in the Figs. 4.8 and the results are given in Table 3. Sodium imbalance in drinking water has been reported to cause a large number of lives threatening diseases**.** Hence, the excess consumption of sodium has been recognized as risk factor in hypertension (WHO Guidelines, 2006).

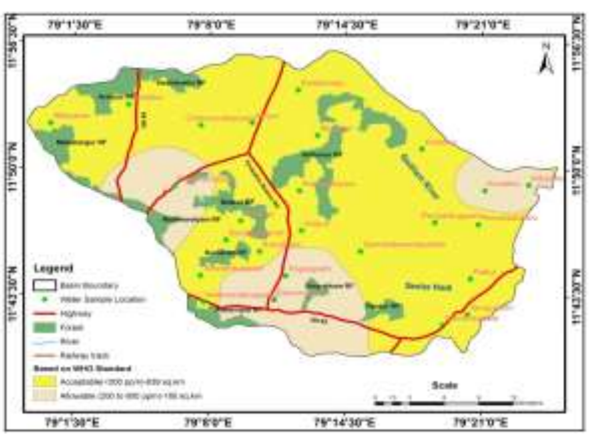

Figure 3 *Spatial distribution map of chloride in the Study area*

Table 4.*Results of GIS Spatial Distribution of Chloride*

Potable Class	Limiting Value	Area in Km^2	Percentage of the Area
Acceptable limit	<200	639	78
Allowable limit	200 - 600	185	22
Not Potable	**-**	**-**	**-**

Figure 4 *Spatial distribution map of SAR in the Study area*

Table 5 *Results of SAR values*

S. No	SAR values	Remark on quality	Samples
1	<10	Excellent	1.17-4.16 (all samples)
2	10-18	Good	-
3	19-26	Doubtful	-
4	>26	Unsuitable	-

Table 6 *Results of GIS Spatial Distribution of EC*

Potable Class	Limiting Value	Area in Km^2	Percentage of the Area
Good	250 to 750	15	**1.82**
Medium	750 to 2250	786	**95.50**
Bad	2250 to 4000	22	**2.67**

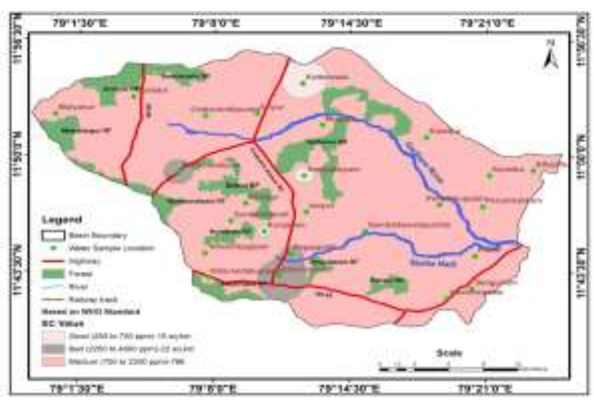

Figure 5 *Spatial distribution map of EC in the Study area*

3.3. Kelly's Index

Sodium measured against Ca2+ and Mg2+ is used to calculate Kelley's ratio (Kelly 1940, 1951, Paliwal1967). However, nowadays, SAR is a better measure for sodium, and this particular ration is not in common use, but this study also presents a review of all the quality criteria of classification to evaluate the obtained dataset.

A Kelly's index of more than 1 indicates an excess level of sodium in waters. Hence, waters with a Kelly's index less than 1 are suitable for irrigation, while those with a ratio more than 1 are unsuitable. Kelly's index in the present study varied from 0.84 to 1.68, and the ten water samples are suitable for irrigation and other are not suitable for irrigation.

***Table 7** Results of KR values*

S. No	KR	Remark on quality	Range (no. of samples)
1	<1	suitable	0.84-0.98 (10 samples)
2	>1	Unsuitable	1.00-1.68 (15 samples)

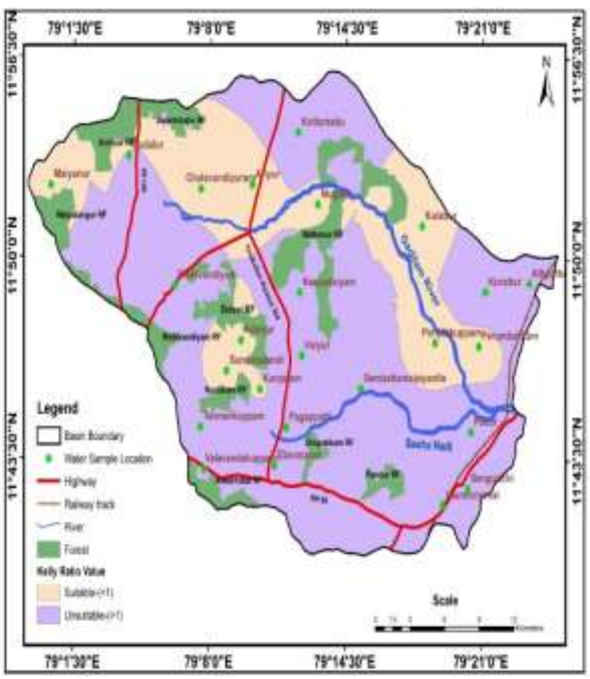

***Figure 6** Spatial distribution map of KR in the Study area*

***Table 8** Results of Mg Ratio values*

S. No	Class	Remarks	Range (no. of samples)
1	<1.5	Safe	0.67-1.45(all samples)
2	1.5-3.0	Moderate	-
3	>3.0	Unsafe	-

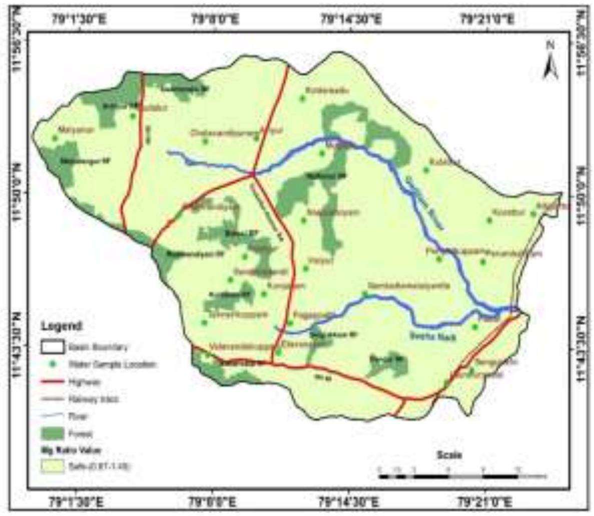

***Figure 7** Spatial distribution map of Mg Ratio in the Study area*

3.4. Residual Sodium Carbonate (RSC)

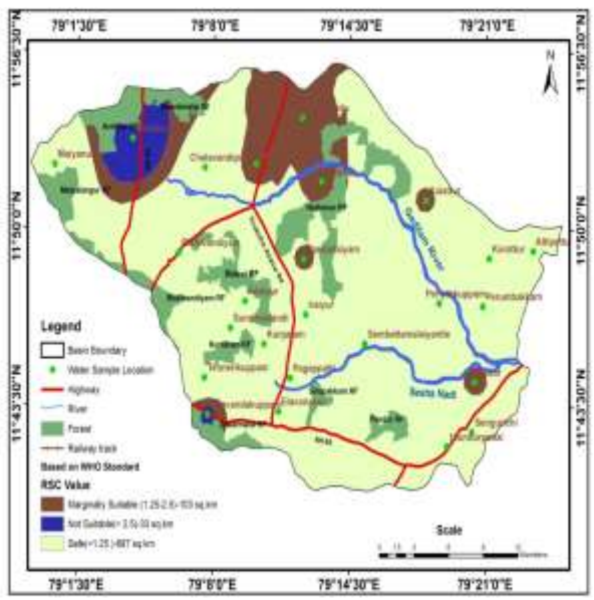

***Figure 8** Spatial distribution map of RSC in the Study area*

***Table 9** Results of GIS Spatial Distribution of RSC*

Potable Class	Limiting Value	Area in Km^2	Percentage of the Area
Good	<1.25	687	83.47
Marginally Suitable	1.25 to 2.5	103	12.51
Not Suitable	>2.5	33	4.00

3.5. Soluble Sodium Percentage

Water quality for agricultural purposes in the Upper Gadilam River basin shows variation between excellent and good based on Todd's classification of SSP values, where, all concentrations are in milli equivalents per liter. The SSP values ranged from 411 to 1517

3.6. Potential Salinity

Potential salinity (Doneen 1961, 1964) pointed out that the suitability of water for irrigation is not dependenton the concentration of soluble salts. (Doneen1962) is of the opinion that low solubility salts precipitate in the soil and accumulate with each successive, whereas the concentration of highly soluble salts increases the salinity of the soil. “Potential salinity is defined as the chloride concentration plus half of the sulfate concentration.”

The PS value is more pronounced in the estuarine region than in the fresh region samples and is expressed in milli equivalents per liter. The potential salinity of the water samples varied from 1.23 to 13.26 meq/L

3.7. Salinity Index

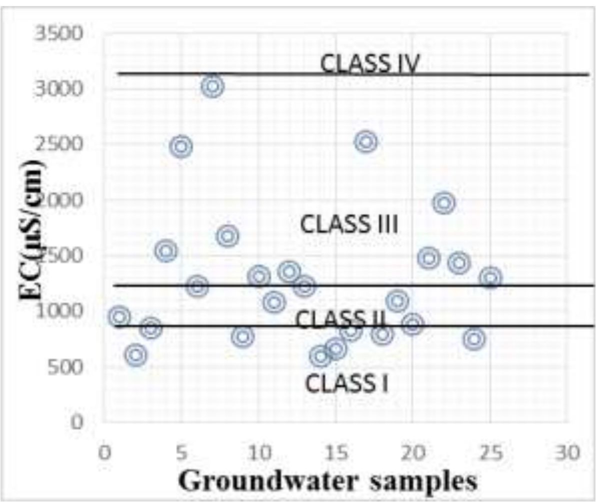

***Figure 6**.Salinity index for the groundwater samples*

Salinity index Handa, 1969 found that all the samples collected during January 2014 are categorized under low to high extensive salinity classes. The majority of the samples (59.58%) belong to the high salinity category, indicating that the water is of permissible quality. The salinity index of the groundwater samples was computed using the measured electrical conductivity values. Water exhibiting low to moderate salinity (classes I and II) are not considered very harmful to soils or crops, whereas those exhibiting high salinity (class III) are suitable for irrigating the medium and high salt-tolerant crops. High salinity water (class IV) is suitable for irrigating high salt-tolerant crops, whereas water of salinity class 5 or above is generally unsuitable for irrigation. Majority of the groundwater samples (100%) in the study region are categorized as classes’ I–III and thus may be considered as suitable for irritation Fig. 6.

3.8. Total Hardness (TH)

The hardness is an important criterion for determining the usability of water for drinking. Traditionally, the hardness is a measure of the capacity of water to react with soap and form the precipitate. Water hardness is caused by dissolved polyvalent metallic ions. In fresh water, the hardness causing ions are calcium and magnesium, which exists in the form of bicarbonates, chlorides, sulphates and nitrates (WHO). The maximum permissible limit of total hardness for drinking water is specified as 200 mg/l. In the study area majority of the samples have exceeded the permissible limit of total hardness in present study region.

3.9. Sodicity Index

The sodicity index was calculated using the SAR, with water up to class 2 are generally considered suitable for irrigation, and was used for the classification of the groundwater samples. Based on the sodicity index, all the samples belong to class 0, except for one sample with SAR values of 4.16 that belongs to class 1.

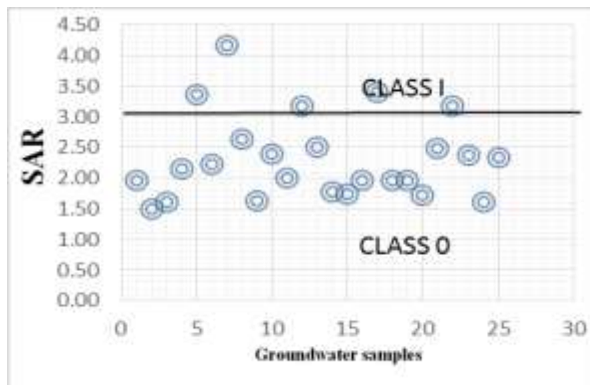

***Figure 9** Sodicity index for the groundwater samples of the study region.*

3.10.Chlorinity Index

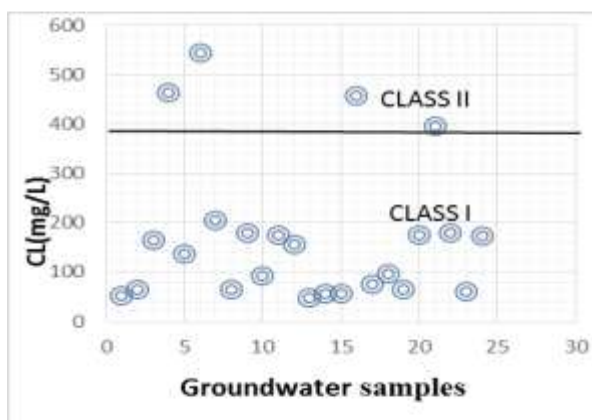

***Figure 10.**Chlorinity index for the groundwater samples of the study region.*

Low salt tolerance crops are usually chloride sensitive. The Chlorinity index of the groundwater sources was calculated using the measured chloride ion concentration in water. Majority of the groundwater samples (84%) are classes I and (16%) are found to be suitable class II for irrigation Fig 7.

3.11.Based on EC

Table 9.*Classification of waters based on of EC (Handa 1969)*

SI No	EC (µS/cm)	Water Salinity	Range (no. of samples)	%
1	0-250	Low(excellent quality)	-	-
2	251-750	Medium(good quality)	597-750(4 samples)	16
3	751-2,250	High(permissible quality)	778-1225(18 samples)	72
4	2,251-6,000	Very high	2480-3020(3 samples)	12

Based on EC have been classified Handa, 1969 and are given in Table 9. It is found that all the samples collected during January 2014 are categorized under medium to very high extensive Water Salinity. The majority of the samples (72%) belong to the high salinity category, indicating that the water is of permissible quality.

3.12.Water Quality Based on WILCOX's

Wilcox's proposed a classification in which percent sodium is correlated against electrical conductivity or total concentration of salts to find the suitability of water for irrigation. According to this classification, in the study area 72% samples are falls in the good to permissible field is the Wilcox diagram, 12% samples falls in doubtful to unsuitable field.

Table 10 *Sodium percent water class (Wilcox 1955)*

Na %	Water class	Range (no. of samples)
<20	Excellent	-
20-40	Good	36.84-39.92(18 samples)
40-60	Permissible	40.06-43.20(7 samples)
60-80	Doubtful	-
>80	Unsuitable	-

3.13.Sodium Absorption Ratio (SAR)

Table 11.*USSL classification*

SAR values	Class	Quality	Range (No. of samples)
<10	S1	Excellent	1.17-4.16 (all samples)
10-18	S2	Good	-
19-26	S3	Doubtful	-
>26	S4, S5	Unsuitable	-

3.14.Salinity Hazard

A more detailed analysis for the suitability of water for irrigation can be made by plotting the sodium absorption ratio and electrical conductivity Fig 8 .data on the US Salinity Laboratory (USSL) diagram Richards, 1954. Even with adequate drainage, special management for salinity control is required, and crops with good salt tolerance should be selected. Such areas need special attention as far as irrigation is concerned. A more detailed analysis for the suitability of water for irrigation can be made by plotting the sodium absorption ratio and electrical conductivity. Accordingly, 18 samples fall in the category of C3S1 (72%), indicating a high salinity and low sodium type. Of the remaining 4 samples, three samples belong to C4 and C5S1, indicating very a high salinity and low sodium type (12. %), while four and three samples belong to the C2S1 (16%) and C1S1 (0 %) groups, illustrating medium salinity/low sodium and low salinity/low sodium types, respectively.

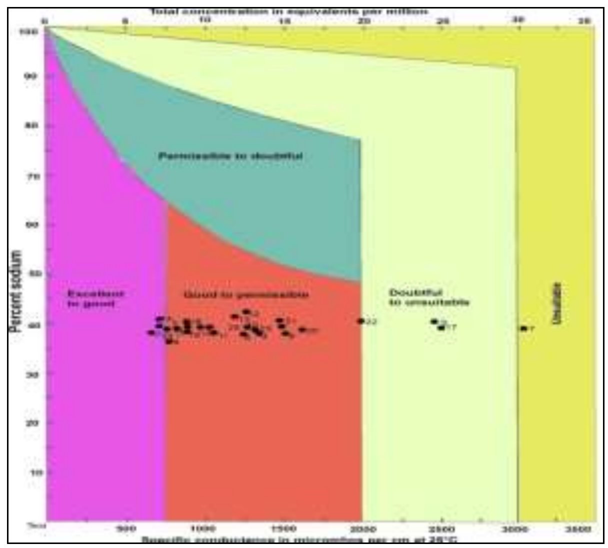

Figure 11.*WILCOX'S Diagram*

3.15.Permeability Index (PI)

Table 12.*Classification of groundwater samples based on permeability index*

Water class	Sample location number	Type of Water
Class-I	4,5,8,17,21,22,23, 25(9)	Very good water quality >75% of maximum soil permeable
Class-II	1,3,6,7,10,11,13,18,19,20,24(10)	Good water quality 75% of maximum soil permeable
Class-III	2,9,12,14,16,15(6)	Bad water quality <25% of maximum soil permeable

The Permeability Index values are also indicate suitability of groundwater for irrigation, as the soil permeability is affected by long-term use of irrigation water, influenced by the Na+, Ca^{2+}, Mg^{2+}, and HCO_3^- contents of the soil. According to the permeability index values, 44% of the samples fall under class II and 24% belong to class I during January 2014. The concentration of cations and anions are in epm. The Groundwater samples of the study area fall in class I and II Doneen, 1962 on the basis of Permeability Index (PI) values Fig.9. The increased percentage of groundwater samples under class–I1 is due to dilution and subsequent lower values of permeability index.

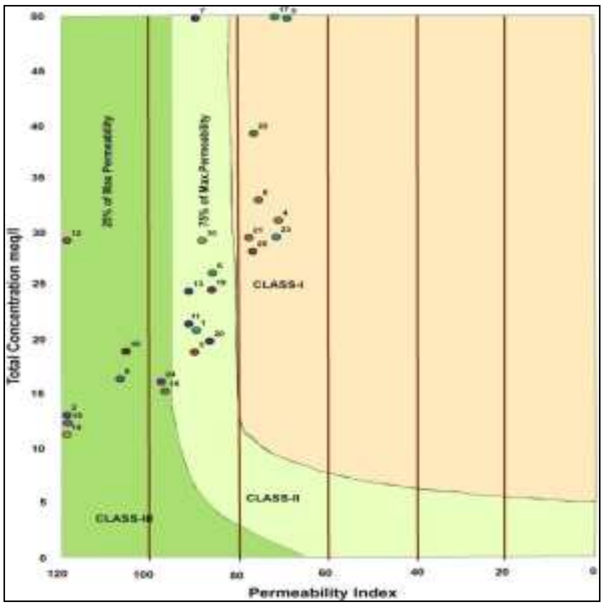

Figure12 *Permeability index (Doneen 1964)*

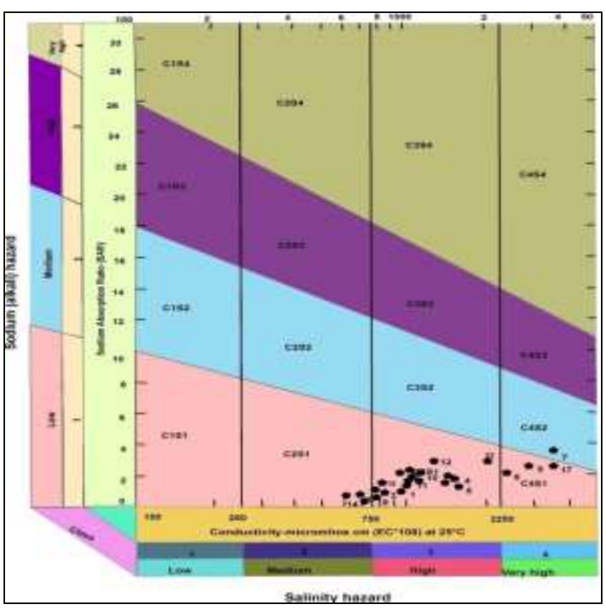

Figure 13 *USSL Diagram (after Richards 1954)*

Table 13.*Salinity hazard classes*

Class	EC	Quality	Range (no. of samples)
C1	100-250	Excellent	-
C2	250-750	Good	597-750(4 samples)
C3	750-2,250	Doubtful	778-1970(18 samples)
C4 and C5	>2,250	Unsuitable	2480-3020(3 samples)

4. Conclusion

The SAR value of all the groundwater samples are found to be less than 10 and are classified as excellent for irrigation. Permeability index recommends that the water samples from the Upper Gadilam River basin, belonging to classes I and II, are suitable for irrigation. The Chlorinity index of the groundwater samples are classes I (84%) and class II (16%) are found to be suitable for irrigation. The salinity index of the groundwater samples exhibiting low to moderate salinity classes I and II are not considered very harmful to soils or crops, whereas those High salinity water class IV is suitable for irrigating high salt-tolerant crops, whereas water of salinity class V or above is generally unsuitable for irrigation. From the Wilcox plot, it is observed that most of the samples from the study area fall in the good to permissible classes for irrigation purpose.

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