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Irrigation Suitability Assessment of Groundwater in Upper Karha Drainage Basin

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Abstract

Groundwater serves as an essential source of water for household consumption, livestock, and agricultural irrigation. However, its quantity and quality are increasingly under pressure due to the expansion of irrigation, industrial growth, and rapid urban development (Lloyd & Heathcote, 1985; Raghunath, 1987). In many semi-arid parts of India, improper management of solid and liquid wastes, along with insufficient treatment and disposal systems, enables pollutants to infiltrate subsurface formations. This process leads to the degradation of groundwater quality and raises significant health concerns for communities that depend primarily on groundwater for drinking purposes (APHA, 1998; BIS, 2003). The present investigation focuses on assessing groundwater quality in the Upper Karha River Basin, situated in Purandar Tahasil, District Pune, Maharashtra State. This region represents the origin zone of the Karha River and has recently been facing issues related to groundwater depletion and declining water quality, largely as a result of excessive extraction and changes in land use patterns. A total of 30 groundwater samples were gathered and examined to assess their key physico-chemical properties as well as their suitability for irrigation purposes. The laboratory findings were subsequently integrated into a GIS framework to generate thematic maps illustrating the spatial variation of parameters such as pH, electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), sodium percentage (Na%), and total dissolved solids (TDS) (APHA, 1998; Piper, 1953). These maps helped in identifying areas experiencing groundwater quality degradation, evaluating its appropriateness for irrigation use, and highlighting zones where over-reliance on groundwater may pose risks to sustainable water resource management in the basin.

Keywords: Irrigation, Groundwater Quality, Drainage Basin, GIS.

Introduction

Groundwater systems are highly variable in nature and continuously respond to human-induced stresses such as irrigation withdrawals, industrial use, and expanding urban areas. These pressures make regular monitoring and careful management necessary to ensure their long-term sustainability (Lloyd & Heathcote, 1985; Raghunath, 1987). The quality of water is determined by a combination of physical, chemical, and biological characteristics, and these properties play a crucial role in defining its appropriateness for drinking, agriculture, industry, and other purposes (Sargaonkar & Deshpande, 2003; Khan et al., 2003).

Earlier methods of groundwater quality evaluation were mainly based on laboratory examination of discrete water samples. However, the development of remote sensing techniques and Geographic Information Systems (GIS) has significantly improved the ability to analyze groundwater conditions over large areas by integrating spatial information with analytical data (Mouna Ketata et al., 2011; Piper, 1953). Assessing groundwater quality is especially vital in regions where aquifers serve as the primary source of drinking water, since the chemical composition directly influences both human consumption safety and agricultural usability (Sivasankar & Gomathi, 2009; Schulz & Howe, 1999). In semi-arid regions undergoing rapid urban growth and intensive farming, groundwater often shows increasing levels of salinity and sodium hazards. These changes are commonly associated with evaporation effects, irrigation return flows, and the widespread application of agrochemicals such as fertilizers and pesticides (Golekar et al., 2013; Golekar et al., 2014).

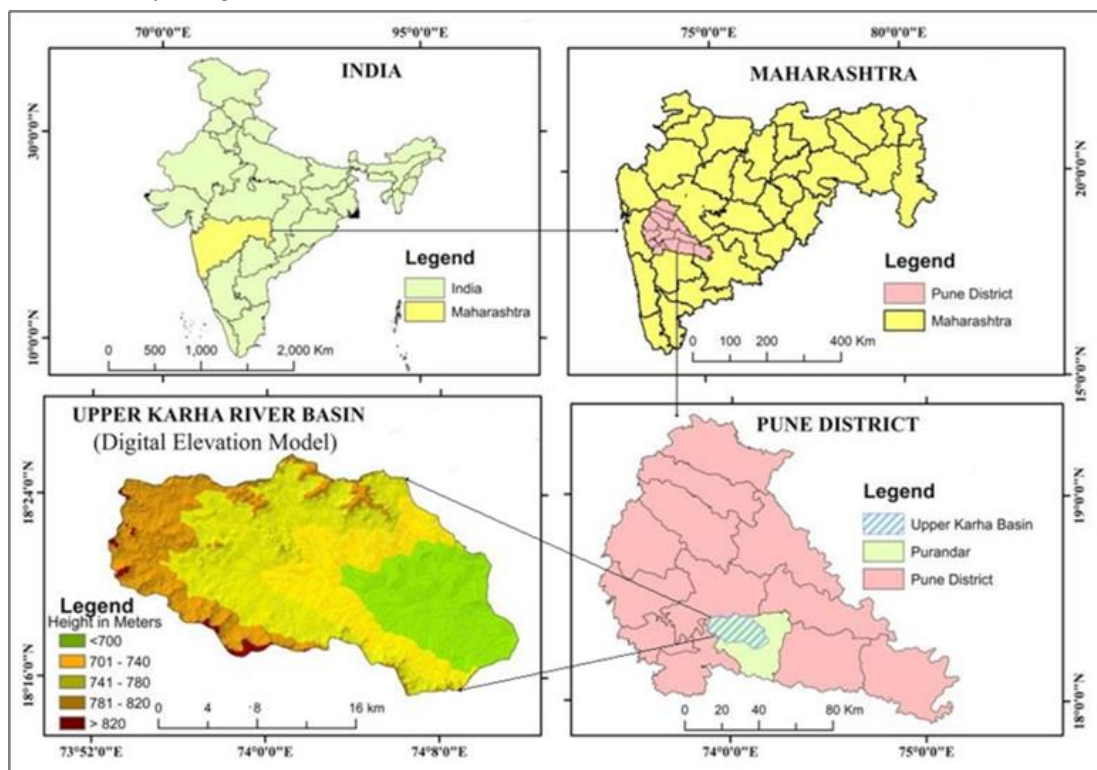
Against this background, the present study focuses on the assessment of groundwater quality in the Upper Karha River Basin, located in Purandar taluka of Pune district. Particular attention is given to the influence of urban expansion, industrial development, and agricultural activities regarding the appropriateness of groundwater for agricultural irrigation purposes. A hydrochemical examination of 30 groundwater samples was conducted to determine key indices such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), sodium percentage (Na%), electrical conductivity (EC), and total dissolved solids (TDS).

The results were interpreted based on the drinking water guidelines set by the Bureau of Indian Standards and the irrigation suitability standards recommended by the US Salinity Laboratory. (BIS, 2003; Richards, 1954; Wilcox, 1955).

Study Area

The Upper Karha Drainage Basin is situated in Purandar tahasil of Pune district, Maharashtra State, and located in between latitudes 18°15'00" N and 18°25'00" N, and longitudes 73°52'40" E and 74°15'00" E. The area falls within the coverage of Survey of India toposheets numbered 47F/15 and 47J/3.

The basin extends over an area of about 396.2 km² and represents the origin zone of the Karha River. The region experiences a semi-arid climate and is largely dominated by agricultural activities. In recent years, the basin has been subjected to growing human pressures due to the expansion of settlements and the development of infrastructure, which have influenced the natural and hydrological environment.



Location Map of the Study Area

Methodology

Groundwater samples were obtained from 30 sites located throughout the Upper Karha River Basin. The sampling locations were selected using a random distribution approach to ensure proper representation of spatial variations in hydrochemical characteristics. At each site, the exact geographic position was recorded using a handheld GPS device, and water samples were collected in accordance with the standard sampling procedures recommended by APHA (1998) for laboratory analysis.

In the laboratory, the collected samples were examined to determine pH, electrical conductivity (EC), major cations and anions, and other derived indices, following established analytical methods (APHA, 1998; BIS, 2003). The pH values were measured with a properly calibrated portable pH meter, using standard buffer solutions of pH 4.0, 7.0, and 9.2 to maintain accuracy during measurement (Bouwer, 1978). Electrical conductivity was measured using a conductivity meter calibrated with a 0.01 M KCl standard solution, and the results were expressed in $\mu\text{S}/\text{cm}$ at the standard reference temperature of 25 °C, as commonly adopted in hydrogeological studies (Davis & De Wiest, 1967; Todd, 2006). Total Dissolved Solids (TDS) were measured by applying the gravimetric technique. In this method, the filtered water sample is evaporated, and the residue left after oven drying is weighed to determine the dissolved solid content, following the standard procedures recommended by APHA (1998). To assess whether groundwater is appropriate for irrigation use, key indices including sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and sodium percentage (Na%) were computed using established equations (Eaton, 1950; Raghunath, 1987). The SAR was obtained by relating the sodium content to the combined levels of calcium and magnesium, with all concentrations expressed in milliequivalents per litre. Similarly, RSC was derived by subtracting the total concentration of calcium and magnesium from the combined concentration of carbonate and bicarbonate ions. Sodium percentage was computed by expressing sodium concentration as a proportion of the total major cations, presented as a percentage (Li et al., 2010).

The analytical data were then integrated with their respective geographic locations within a GIS platform. Spatial interpolation techniques were applied to prepare thematic maps illustrating the distribution of parameters such as pH, EC, SAR, RSC, Na%, and TDS (Piper, 1953; Wilcox, 1955). These maps were used to identify groundwater quality zones and to estimate the spatial extent of areas falling under different irrigation suitability categories.

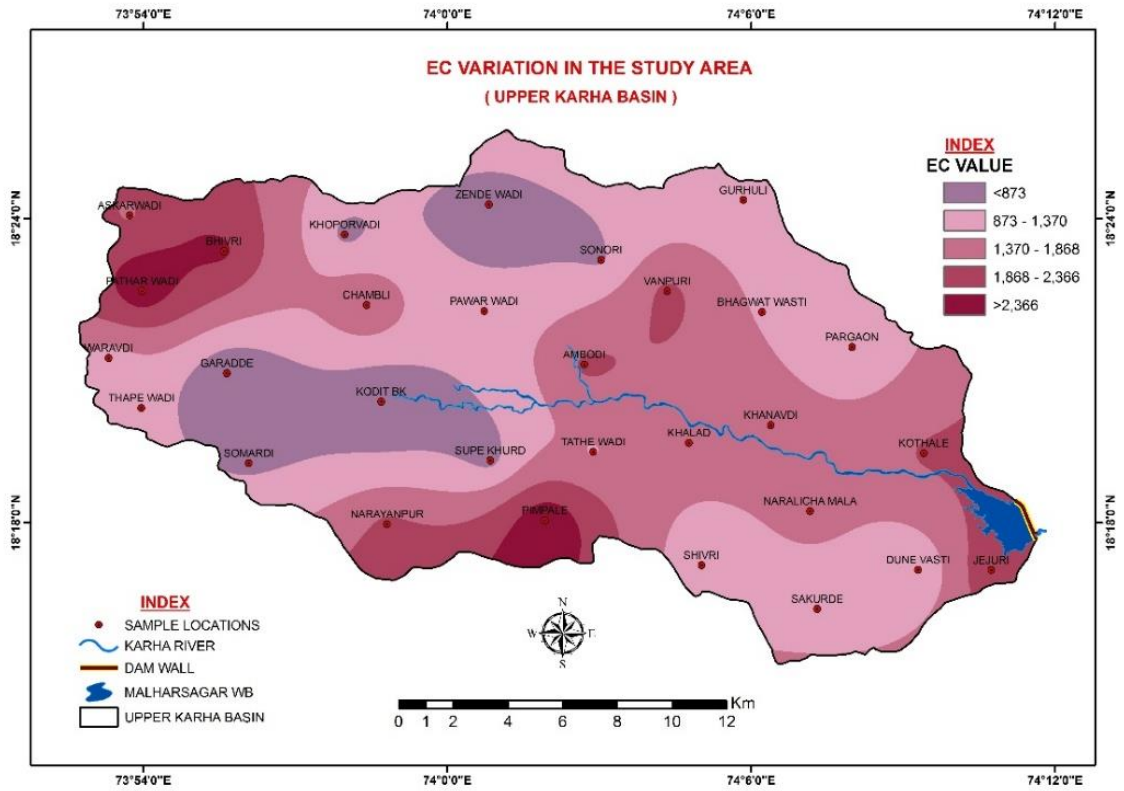
Assessment of Agricultural Suitability of Groundwater

Besides these indicators, total dissolved solids (TDS) reflect the total concentration of dissolved minerals in groundwater. This parameter is useful in assessing salinity levels, which can directly affect soil properties and crop yield. Higher TDS levels can reduce the osmotic availability of water to plants, thereby affecting their growth and yield. The pH of groundwater also plays an important role, as excessively alkaline water can alter soil chemical properties and reduce the availability of essential nutrients to crops. Therefore, maintaining pH within an acceptable range is necessary for sustaining soil health.

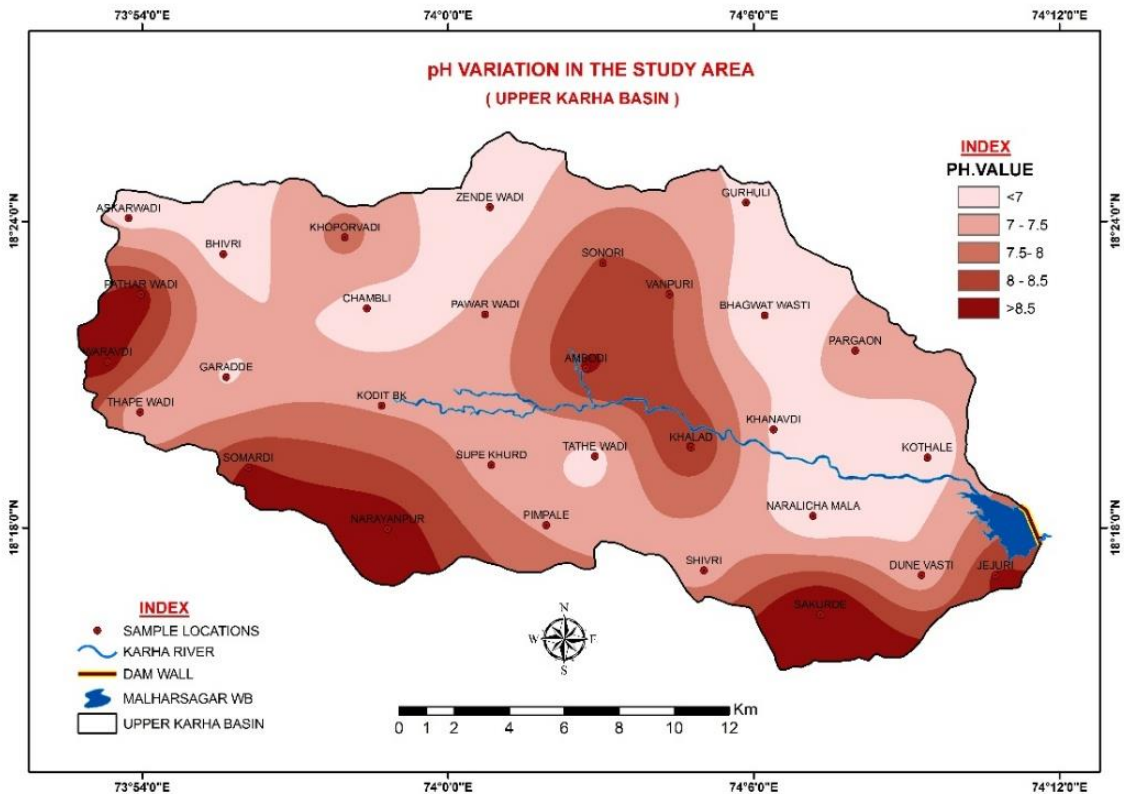
The combined interpretation of EC, SAR, RSC, Na%, pH, and TDS provides a comprehensive understanding of groundwater suitability for irrigation. These parameters were compared with established classification criteria to categorize groundwater into different suitability classes such as suitable, marginally suitable, and unsuitable for irrigation. Such classification helps in identifying areas where groundwater can be safely used for agricultural purposes without causing long-term soil degradation. Furthermore, this assessment supports farmers and planners in selecting appropriate crop types and irrigation management practices based on water quality conditions. It also assists in identifying regions where precautionary measures, such as soil amendments and improved drainage, to minimize adverse impacts.

Spatial Information			PH	EC	SAR	RSC	Na %	TDS
Zende wadi	74.013706	18.404509	7	499.8	0.94	-2.75	32.92	324.9
Tathe wadi	74.048030	18.323172	7.1	1332.8	3.04	-4.92	67.31	866.3
Khalad	74.079531	18.326150	8.2	1607.2	1.81	-6.78	40.02	1044.7
Khanavdi	74.106407	18.331966	7.2	1705.2	1.22	-8.16	23.54	1108.4
Pargaon	74.133197	18.357684	7.5	911.4	1.72	-4.19	45.42	592.4
Gurhuli	74.097434	18.405994	7.2	921.2	1.8	-3.92	47.3	598.8
Vanpuri	74.072356	18.376050	7.9	1999.2	1.78	-7.6	35.43	1299.5
Sakurde	74.121711	18.271496	8.8	1156.4	0.88	-2.94	34.98	751.7
Pimple	74.032127	18.300695	7.5	2871.4	2.65	-8.07	62.03	1866.4
Narayanpur	73.980214	18.299427	8.4	1999.2	1.95	-7.36	48.15	1299.5
Kodit.bk	73.978308	18.339705	7.5	372.4	1.27	-1.24	68.75	242.1
Garade	73.927527	18.349027	7.2	372.4	1.04	-1.63	50.83	242.1
Bhivri	73.926567	18.389195	7.1	2459.8	3.38	-6.58	72.13	1598.9
Chambhli	73.973489	18.371482	7.1	1881.6	3.07	-5.7	73.62	1223.0
Thape wadi	73.899354	18.337599	7.3	1146.6	2	-5.02	46.95	745.3
Pathar wasti	73.899530	18.376045	8.3	2763.6	2.18	-10.06	43.2	1796.3
Varavadi	73.888621	18.354030	8.3	1127	2.2	-4.4	61.72	732.6
Somardi	73.934729	18.319465	8.2	784	2.2	-2.91	79.62	509.6
Askarwadi	73.895514	18.400942	7.1	1813	1.71	-10.16	32.42	1178.5
Khopor Wadi	73.966278	18.394668	7.7	754.6	1.57	-3.72	45.6	490.5
Supe.kh	74.014144	18.320361	7.4	714	1.31	-2.48	42.14	502.0
Sonori	74.050690	18.386324	7.9	812	1.48	-2.53	48.17	414.0
Ambodi	74.045120	18.351927	8.2	1960	1.89	-6.69	41.4	1274.0
Pawar Wadi	74.012202	18.369515	7.3	1127	1.99	-5.18	47.66	732.6
Shivri	74.083658	18.285880	7.4	921.2	1.95	-4.39	50.86	598.8
Dune Wasti	74.154842	18.284389	7.3	872.2	2.25	-1.82	85.07	566.9
Kothale	74.156789	18.322762	7.1	1930.6	2.63	-10.01	55.77	1254.9
Naralicha Mala	74.119363	18.303707	6.9	1639	1.65	-7.55	39.55	1039.0
Bhagwat Wasti	74.103549	18.369181	6.8	1296	1.55	-7.65	37.12	789.0
Jejuri	74.178979	18.284273	8.2	2303	2.5	-3.23	83.98	1497.0

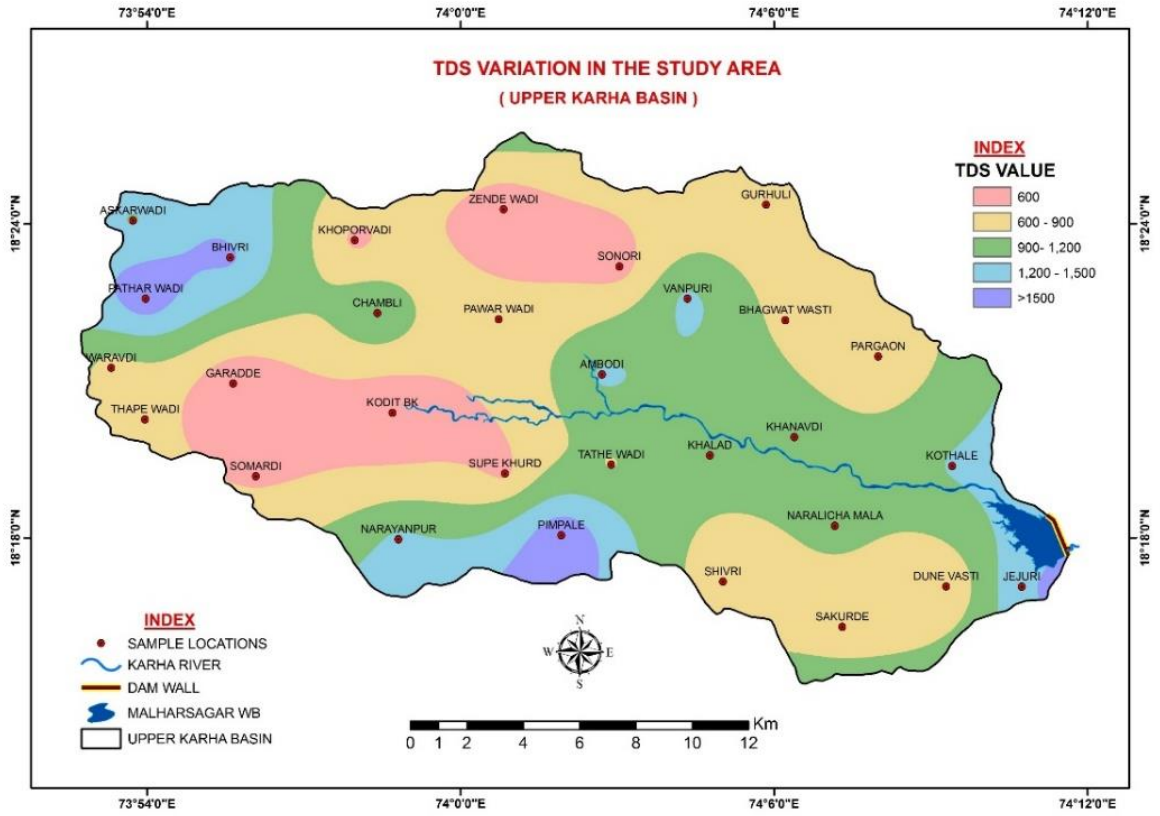
Data Collected from Field and Laboratory



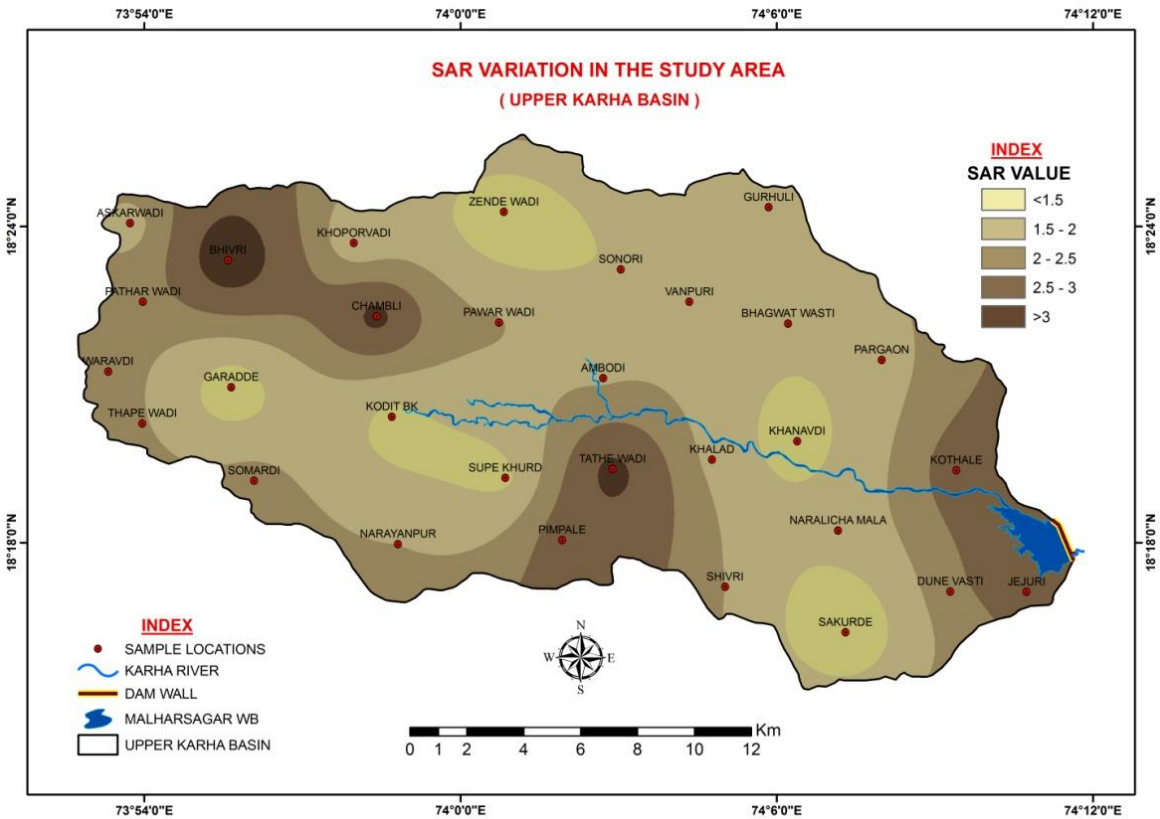
Map of Eclectic Conductivity



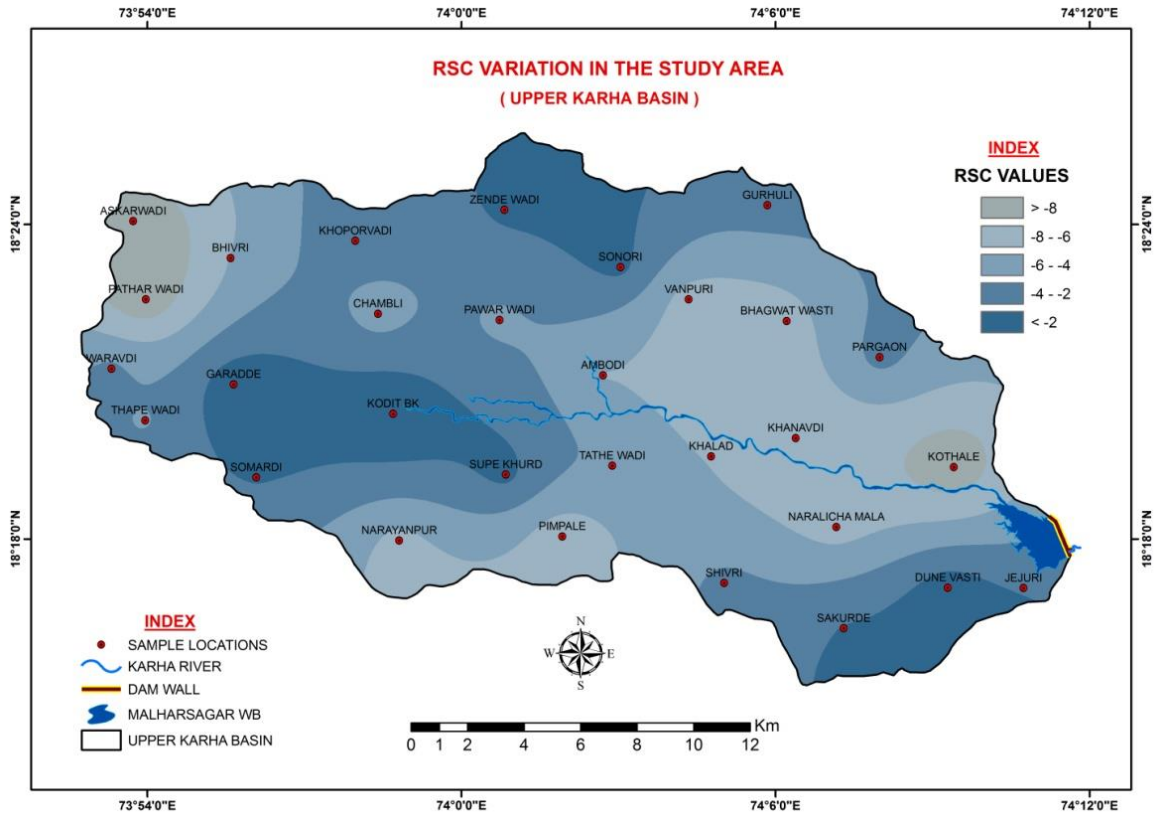
Map of pH



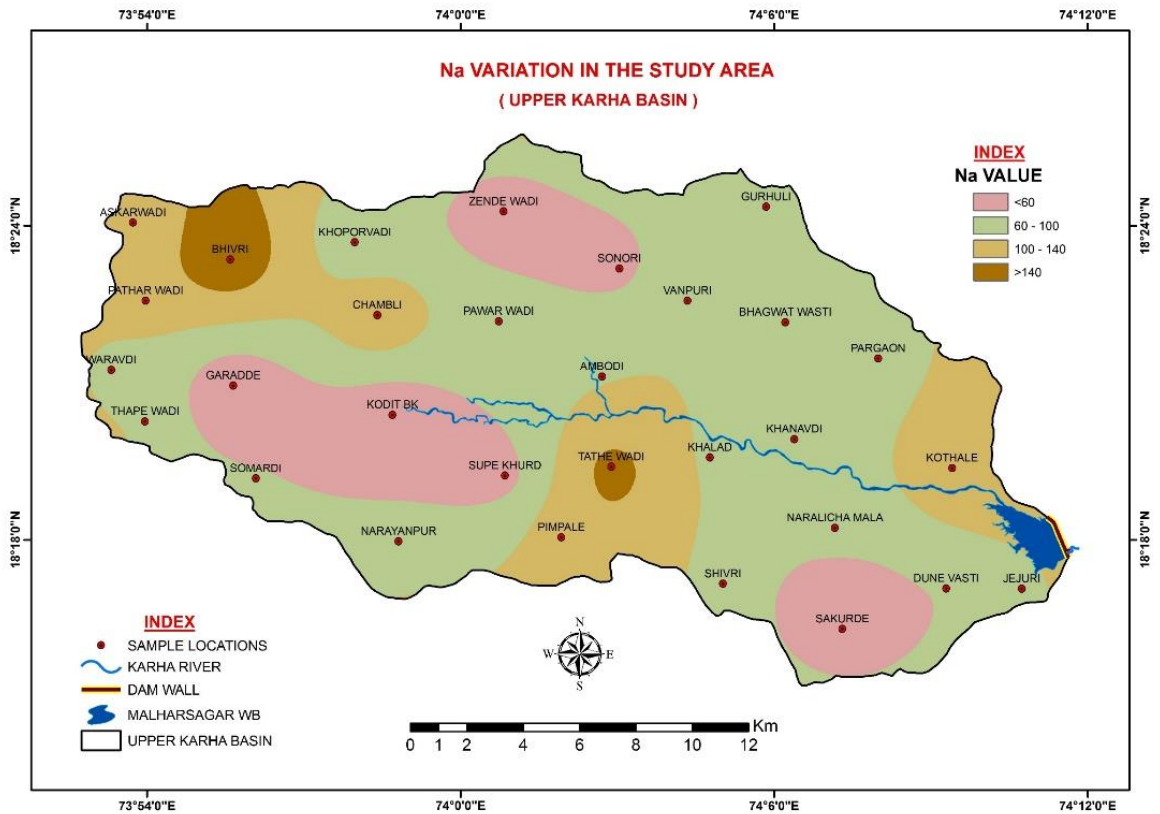
Map of TDS



Map of SAR



Map of RSC



Map of Na%

Assessment of Groundwater for Irrigation Suitability

1. Sodium Adsorption Ratio:

Sodium adsorption ratio (SAR) was determined using the standard equation, with all ionic concentrations expressed in milliequivalents per litre (meq/L), and the results were interpreted according to the classification given by Raghunath (1987). Based on this classification, SAR values below 10 represent irrigation water of excellent quality in terms of sodium hazard. The analysis of groundwater samples from the study area revealed that all SAR values were less than 10, indicating that the groundwater poses minimal risk of sodium-related soil deterioration and is generally suitable for irrigation from a sodicity perspective.

2. Residual Sodium Carbonate:

Residual Sodium Carbonate (RSC) was estimated using the expression:

$$RSC = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

where all ionic concentrations are measured in milli equivalents per litre (meq/L), as outlined by Eaton (1950). Based on the criteria given by Lloyd and Heathcote (1985), irrigation water is classified as suitable when the RSC value is below 1.25 meq/L, marginal when it ranges from 1.25 to 2.5 meq/L, and unsuitable if it exceeds 2.5 meq/L. In the Upper Karha Basin, RSC values ranged from about -10.2 to -1.2 meq/L. These negative values indicate an excess of calcium and magnesium over carbonate and bicarbonate, suggesting that all groundwater samples are suitable for irrigation with respect to carbonate hazard.

3. Sodium Percentage (Na %)

Sodium percentage (Na%) was calculated as the proportion of sodium relative to the total concentration of major cations, expressed as a percentage, with all values in meq/L (Li et al., 2013). Water containing sodium percentages above approximately 60% can adversely affect soil properties by promoting sodium accumulation, which may reduce soil permeability and damage soil structure, particularly where leaching is limited (Richards, 1954; Wilcox, 1955). In the present study, 21 groundwater samples recorded Na% values below 60%, indicating acceptable quality for irrigation. However, 9 samples exceeded this limit, suggesting the possibility of sodium-related soil problems in certain locations, especially for sodium-sensitive crops and soils.

4. Hydrogen Ion Concentration (pH)

The pH of groundwater is largely controlled by the equilibrium between carbon dioxide, carbonate, and bicarbonate ions, which together act as a buffering system and maintain pH within a limited range (Davis & De Wiest, 1967; Bouwer, 1978). Within the study region, the pH levels ranged from 6.8 to 8.8, recording a mean value of approximately 7.6. These results indicate that the groundwater ranges from slightly acidic to moderately alkaline, reflecting the influence of dissolved carbon dioxide and bicarbonate ions and typical geochemical conditions of groundwater in semi-arid regions.

5. Electrical Conductivity (EC)

Electrical conductivity (EC) indicates the capacity of water to conduct electrical current and is directly proportional to the concentration of dissolved ions present in the water (Davis & De Wiest, 1967; Todd, 2006). In the Upper Karha Basin, EC values ranged from about 372.4 to 2871.4 $\mu\text{S}/\text{cm}$, with an average value of 1401.8 $\mu\text{S}/\text{cm}$. These values suggest moderate to high salinity levels in many groundwater samples. Based on the classification of the US Salinity Laboratory, most samples fall within medium to high salinity categories, which may impose limitations on irrigation, particularly for salt-sensitive crops (US Salinity Laboratory, 1994; Wilcox, 1955).

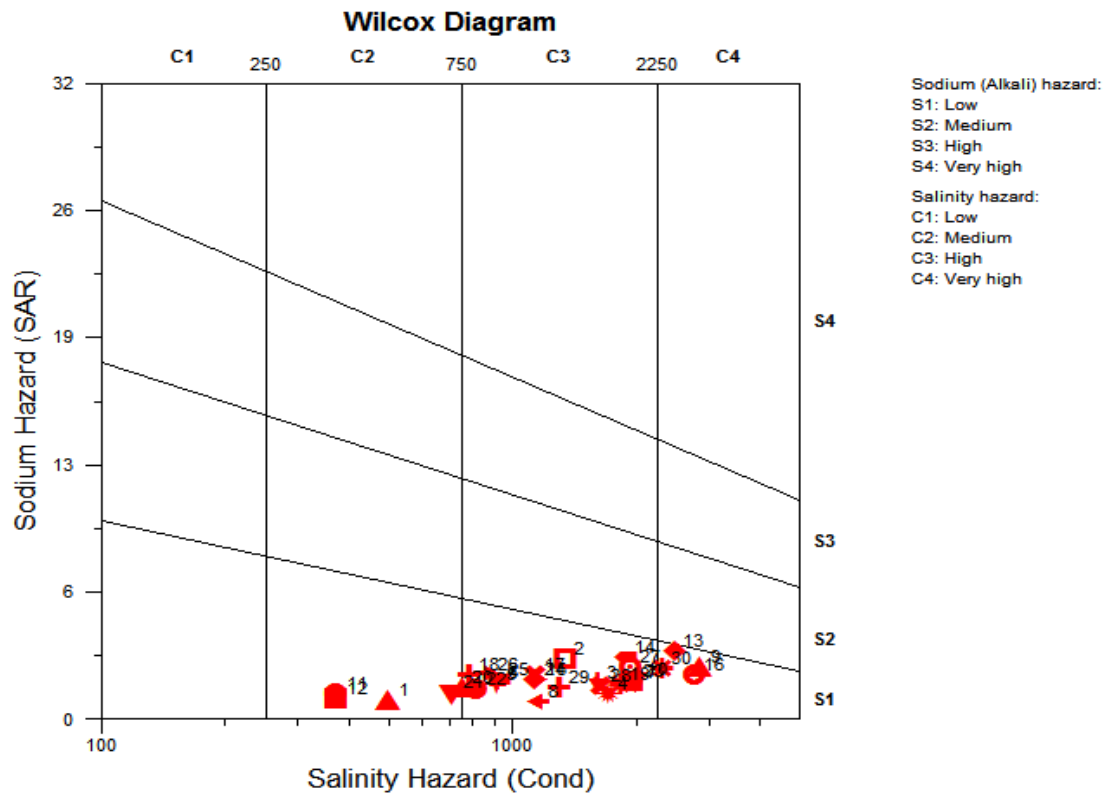
6. Total Dissolved Solids (TDS)

Total dissolved solids (TDS) indicate the overall concentration of dissolved minerals present in water and serve as an important measure of salinity as well as the intensity of water-rock interaction within an aquifer system (APHA, 1998; Todd, 2006). In the present study area, TDS values were observed to vary from 242.1 to 1866.4 mg/L, with an average of about 906 mg/L. A majority of the samples recorded values above the desirable drinking water limit of 500 mg/L recommended by BIS (2003). These findings suggest that, except for a few locations such as Zende Wadi, Kodit Budruk, Garade, and Sonori, groundwater may require careful management for irrigation, including appropriate crop selection and irrigation practices, to prevent soil salinity problems over the long term.

7. Wilcox Salinity Hazard Diagram

The sodium adsorption ratio (SAR), when interpreted alongside salinity levels, is widely applied to evaluate irrigation water quality through the Wilcox diagram, which helps evaluate the potential effects of sodium and salinity on soil properties (Richards, 1954; Wilcox, 1955). Even when SAR values are low, high salinity levels may still create challenges for irrigation by affecting plant growth and soil conditions (Kumaresan & Riyazuddin, 2006; Golekar et al., 2014).

The Wilcox diagram prepared for groundwater samples from the Upper Karha Basin shows that all samples fall within the S1 category, indicating low sodium hazard. However, salinity classes vary from C2 (medium salinity hazard) to C4 (very high salinity hazard). Specifically, 23 samples belong to the C3 class, representing high salinity, while three samples from Zende Wadi, Garade, and Chambhli fall in the C2 class. Four samples from Pimple, Bhivri, Pathar Vasti, and Jejuri are classified under the C4 category, indicating very high salinity levels. These results demonstrate that although sodium hazard is generally low across the basin, elevated salinity levels may restrict the use of groundwater, and therefore some areas of the drainage basin is consider as susceptible to salinity-related issues.



Salinity and sodium hazard diagram

Discussion and Results

The hydrochemical characteristics presented in Table 1 indicate that groundwater pH values vary from 6.8 to 8.8, with an average of approximately 7.6. These values fall within the neutral to moderately alkaline range and reflect the influence of the carbonate–bicarbonate buffering system, which plays a key role in regulating groundwater chemistry (Davis & De Wiest, 1967; Bouwer, 1978). Electrical conductivity values range from 372.4 to 2871.4 $\mu\text{S}/\text{cm}$, with a mean of 1401.8 $\mu\text{S}/\text{cm}$, suggesting moderate to high salinity conditions. This elevated salinity may be attributed to factors such as extended interaction between water and geological formations, concentration of salts due to evaporation, and the return flow of irrigation water containing dissolved minerals (Todd, 2006; Golekar et al., 2014).

Total dissolved solids (TDS) concentrations vary from 242.1 to 1866.4 mg/L, with a mean value of approximately 906 mg/L. These levels exceed the desirable drinking water limit of 500 mg/L recommended by BIS (2003) for most of the samples, indicating that the groundwater is generally unsuitable for direct consumption without appropriate treatment. Spatial analysis of EC and TDS shows that relatively good quality groundwater is confined to a few locations, including Zende Wadi, Kodit Budruk, Garade, and Sonori, while the majority of the basin exhibits higher salinity levels, limiting its suitability for domestic and agricultural purposes.

Although salinity levels are elevated in many parts of the basin, SAR values for all groundwater samples remain below 10, which classifies them as excellent in terms of sodium hazard and indicates minimal risk of soil permeability problems due to sodium (Ragunath, 1987; Wilcox, 1955). Similarly, RSC values ranging from -10.2 to -1.2 meq/L suggest that carbonate hazard is not a concern, as the dominance of calcium and magnesium over carbonate and bicarbonate ions reduces the likelihood of adverse effects on soil quality (Eaton, 1950; Lloyd & Heathcote, 1985). However, sodium percentage values exceeding 60% at nine sampling sites highlight the presence of localized sodicity concerns, particularly in areas with poor drainage or clay-rich soils where sodium accumulation may negatively affect soil structure.

In summary, the overall evaluation of groundwater quality parameters, including pH, EC, TDS, SAR, RSC, and Na%, indicates that salinity is the primary factor limiting the use of groundwater for irrigation in the Upper Karha River Basin. Sodicity and carbonate hazards are generally low and do not pose significant constraints. This hydrochemical pattern is characteristic of semi-arid regions, where high evaporation rates, limited groundwater recharge, and human activities such as irrigation and fertilizer application contribute to increased salt concentration in groundwater systems (Golekar et al., 2014; Todd, 2006).

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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