Assessment of Groundwater Quality Along the Coastal Aquifers of Kollam Corporation, Southern Kerala, India

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Abstract

Background: Groundwater serves as a primary resource for drinking water, irrigation, and industrial activities, primarily accessed through wells. Out of the 3% of the global freshwater supply, a significant portion is locked in glaciers, and the remainder is present as groundwater. In India, limited resources and rising pollution rates make groundwater a critical resource, providing nearly 80% of the country's drinking water. **Aim:** The present study aims to examine the quality of groundwater, especially for domestic and irrigational purposes, in the Corporation area of Kollam, a prominent coastal district in southern Kerala, India. **Methods:** Twelve pre-monsoon water samples were collected from wells across the area and analyzed for physical and chemical parameters to assess the influence of natural and anthropogenic factors on groundwater quality. Poor water quality can have a severe impact on both human health and agricultural productivity, particularly in regions where groundwater is the primary source of water. The analyzed data were compared with the drinking and irrigation water quality standards set by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO). **Results:** The study shows that the groundwater system exhibits an acidic characteristic due to continuous interaction with the lateritic aquifer. The samples predominantly belong to the Na-Cl or Na-HCO_3 types, indicating the influence of seawater intrusion. Most samples met the criteria for 'good-quality irrigation water, while others fell in the classification for 'poor-quality. **Conclusion:** The findings highlight the increasing challenges associated with groundwater utilization and emphasize the importance of sustainable groundwater management practices in Kollam, a rapidly growing coastal urban center in the state.

Keywords: drinking water standards; hill piper diagram; hydro geochemistry; seawater intrusion; water pollution

Introduction

The Kerala state is bestowed with an annual rainfall of 3000mm and the occurrence of 44 rivers flowing across the state. Even though the surface water resources are abundant, the presence of steep slopes towards the seaward direction and small-sized rivers quickly discharge to the sea without getting enough time for a recharge. So the state depends on groundwater to meet its needs. The overutilization of groundwater in Kerala is due to high population density, rapid urbanization, land use, and land cover changes. These developments in the state have resulted in the groundwater declining, along with the threat of saline water influx towards coastal areas. The present study has an objective to investigate the groundwater for its hydrogeochemical properties to establish the quality and to determine its utility for irrigation in a small area of Kollam Corporation, South Kerala, which is a coastal region. Throughout Kerala, several studies were conducted to assess the quality of groundwater(Anitha et al., 2014; Anoop et al., 2022; Manjula, 2015). Several studies have been conducted to understand the groundwater resources in Kollam district, including the one by (George et al., 2023), who explored heavy metal contamination in both soil and groundwater in and around industrial areas, and (Nair et al., 2020), who studied spring water quality in the Kallada and Ithikkara river basins. Though these studies offer valuable insights, but don't fully address the specific issues facing the coastal aquifers of Kollam Corporation, a rapidly growing city in southern Kerala. As the city grows in both population and economic activity, its coastal aquifers are becoming increasingly vulnerable to threats like seawater intrusion, pollution from industrial sources, and over-extraction of water. Compared to other coastal cities in Kerala, such as Kochi or Thiruvananthapuram, which have been studied well in addressing groundwater management, Kollam isn’t being studied in detail. This leaves an important gap in understanding the long-term sustainability of the city’s groundwater resources. With the rapid urban area expansion, along with tourism and industry development, and poor waste management, demand for a more focused and holistic approach to manage and protect the coastal aquifers in Kollam, which in turn will lead to the improvement of groundwater quality in Kollam.

Methods

A systematic hydrogeochemical study was conducted in the coastal areas of Kollam Corporation, Kerala. Kollam Corporation falls in the Survey of India Toposheet No: 56D/10 of 1:50,000 scale. The area lies between Longitude $75^{o}36’$ to $75^{o}40’$E and Latitude $8^{o}50’$ to $8^{o}54’$N (Figure 1). Chemical analysis provides valuable insights into the composition of groundwater, reflecting the characteristics of the aquifer, such as its geological formation, depth from the surface, and permeability. Also, it helps to assess the suitability and quality of groundwater for specific purposes. Groundwater quality is influenced by a combination of natural processes and human activities, making hydrochemical studies essential for understanding and managing water resources effectively.

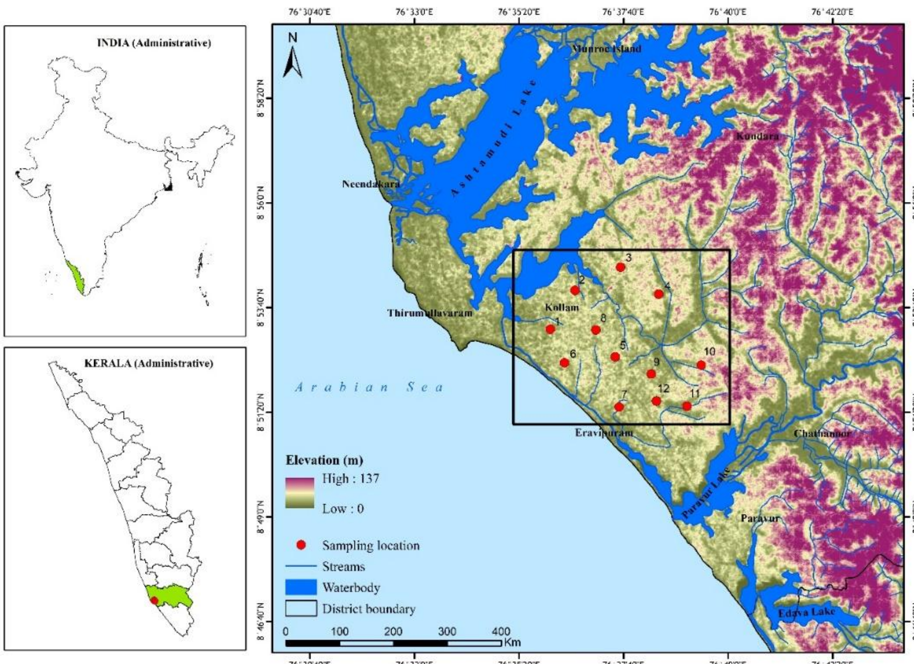

Figure 1. Location map and Digital Elevation Model of the study area

For detailed hydrochemical studies, twelve representative groundwater samples were collected during the pre-monsoon season. For getting a better understanding, the samples were collected from different parts of the study area, covering both inland and coastal regions, and the sampling locations are shown in the location map (Figure 1). Extreme care was taken for the selection of wells and is done based on the depth, its accessibility, and by considering local conditions and land use. The chemical analyses of samples were done using the facilities of the Department of Geology, University of Kerala. In situ measurements were taken for parameters like pH, Electrical Conductivity (EC), and Total Dissolved Solids (TDS) using the digital portable meter. Samples were analysed by following the procedures prescribed by (APHA, 1998; R. K. Trivedy & Goel, 1984). For the analysis of magnesium, calcium, chloride, bicarbonate, and total hardness, titrimetry is used. Potassium and sodium are estimated by using a flame photometer. Analyses were done in triplicate having less than 2% standard deviation. The accuracy of the analyses was examined by calculating the ionic balance, and it was found that all samples show ionic balance errors within $\pm$10%.

Water quality is paramount for various purposes, including domestic use and agriculture. Parameters like anions, cations, pH, electrical conductivity (EC), total dissolved solids (TDS), and others are major indicators of groundwater quality. Comparing these values with established standards such as those set by the (BIS, 2012; WHO, 2004) helps in assessing the suitability of water for domestic purposes. In irrigated agriculture, water quality is equally significant. Poor water quality can affect crop growth, soil health, and overall productivity. It can introduce harmful elements or pathogens into the soil, affecting plant health and yield. Monitoring water quality ensures that agricultural practices are sustainable and minimize potential risks to crops, soil, and the environment.

The graphical representation of chemical analysis data is more useful for comparing and emphasizing similarities and differences in the concentrations of various constituents present in the groundwater samples. In order to classify groundwater samples based on composition, the Piper diagram has been used and is helpful in the identification of chemical facies of the groundwater. It was (Hill, 1940) who first tried to describe groundwater chemistry based on a trilinear diagram, which was modified by (Piper, 1944). In this diagram cations and anions were plotted in two triangles and one diamond field that sum up the triangles and the total ion relationship can be decided from the diamond field through the projected anion's and cation's locations.

The suitability of water for irrigation is controlled by several chemical constituents. The dominant ions Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^-, Cl^- and SO_4^{2-} in a water sample can be represented in several ways, which are functional for display purposes and for emphasizing similarities and differences. Epm values are most commonly used for this purpose. Salinity can be derived by measuring the EC of water. Besides salinity, sodium hazard sometimes exists and can be estimated by the Sodium Adsorption Ratio (SAR), which is expressed by **Equation 1**, in which Ca, Na, and Mg represent the concentration in milliequivalents per litre.

$$\mathbf{SAR} = \frac{Na+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \text{(meq/l)} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1)$$

The values are plotted in the U.S Salinity diagram for determining the suitability of groundwater for irrigation purposes. Based on SAR values, irrigation waters are grouped into four types- excellent, good, fair, and poor (Richards, 1954) (Table 1).

Table 1. Shows irrigational suitability classes based on SAR values.

SAR	Quality
0-10	Excellent
10-18	Good
18-26	Fair
>26	Poor

Results and Discussion

Suitability of water for domestic use

Results of the water quality parameters are compared with WHO standards. (Table 2). Results of the chemical analyses were summarized and compared to (BIS, 2012; WHO, 2004) criteria by evaluating each variable (Table 2). The variation of pH in the study area ranges from 4.93 to 7.41 with an average of 7.45. Measured pH values of water samples indicate that some of the samples are lying outside the safe limits of BIS and WHO standards (6.5 to 8.5) and exhibit an acidic nature. The consumption of this water may additionally cause gastrointestinal issues like belly aches, hyperacidity and burning sensation due to its acidic nature. It can also lead to corrosion in pipes, thereby releasing metals like zinc, lead, cadmium and copper (R. K. Trivedy & Goel, 1984). The interaction of the laterite in the study area with the groundwater may be the major reason for the acidic nature. Iron present in the laterite react with the chloride of the circulating groundwater and produce a compound called ferric chloride, which is of acidic nature.

Electric conductivity (EC) is the indication of salt content of groundwater in the form of ions and is measured in micro siemens/cm (μS/cm) (Karanth, 1987). EC values of groundwater samples in the study area range from 162 to 3980 μS/cm with an average of 821.8μS/cm. According to BIS and WHO standards, all water samples fall in the good water class. Total Dissolved Solids (TDS) indicate the overall nature of water salinity. Excessive degree of TDS in water, ie, >500 ppm, adversely affects the deliciousness of groundwater and may cause gastrointestinal inflammation (Park, John Everett, Park, 1980). In the study area, TDS varies from 119 ppm to 2180 ppm with an average of 447.5 ppm. High values of EC and TDS may be due to the influence of adjacent saline water system.

Hardness can destroy the ability of soap to form a lather. Basically, two types of hardness: temporary due to carbonate content and permanent due to non-carbonate content. Total hardness (TH) is the sum of both types. In the present study area, the maximum value of total hardness is 98 ppm and minimum value is 15 ppm with a mean value 37.25 ppm. Consequently, all samples lie within the highest desirable limit of BIS (500 ppm). The high concentration of chloride in groundwater may be due to processes like evaporation and dissolution of salts, association with evaporites, and saline water intrusion. Soluble salts may be generated by reacting chlorides with metal ions in metal pipes, which can lead to the enhancement of metallic concentrations in drinking water (WHO, 2004). High amounts of chloride in drinking water may create heart or kidney problems in human beings (Khurshid & Zaheeruddin, 1988). Even though the permissible limit specified by WHO is 250 ppm, chloride content above 100 ppm itself may lead to physiological damage. In the Kollam region, the maximum chloride content is 106.35 and the minimum of 21.27, which suggests a safe condition.

Table 2. Mean and range values of physico-chemical parameters (all values are in ppm except pH which has no unit, EC which is expressed in µS/cm and salinity in ppt)

	Range			WHO(2004) standards		BIS (2012) Range	
Parameter	Maximum	Minimum	Mean	Highest Desirable limit	Maximum Permissible Limit	Highest Desirable limit	Maximum Permissible Limit
pH	7.41	4.93	6.3	7-8.5	6.5-8.5	6.5-8.5	No Relaxation
EC	3980	162	821.8	1000	1400	1000	2000
TDS	2180	119	447.5	600	1000	500	2000
Salinity	2.1	0.1	0.42				
TH	98	15	37.25			200	600
Ca	31	1.2	12.92	75	200	75	200
Mg	29.16	1.19	9.48	30	150	30	100
Na	167	9	48.5	50	200	200	400
K	32	2	11.08	10	12		
SO4	29.51	2.825	9.99	250	400	200	400
Cl	106.35	21.27	47.51	250	300	250	1000
HCO_3	4.1	0.2	1.73				
Alkalinity	100	5	38.64		300		

As per the chemical analyses, bicarbonate values range between 0.2 ppm to 4.1 ppm, falling within the highest desirable limit of (BIS, 2012). In the present study area, Total alkalinity (TA) varies between 5 and 100 ppm with a mean of 38.64 ppm. It is a measure of the groundwater's ability to neutralize acids. Soluble salts of sodium, magnesium and calcium commonly exist as sulfates in water (NAS, 1977). Sulphate content also falls within the safe category, which varies from 2.8 ppm to 29.51 ppm with a mean of 9.99 ppm.

The highest value of calcium observed is 25.2 ppm, and the lowest with 1.2 ppm, with an average of 12.92 ppm. Thus, all the samples in this area are coming under the highest desirable limit of 75ppm as stipulated by (BIS, 2012; WHO, 2004). Since calcium is naturally present in most rocks, it is found almost everywhere in groundwater. When the rainwater is strongly acidic, the leaching rate of calcium will be high (Overrein, 1972). Lack of an optimum level of calcium concentration in drinking water may cause serious health issues like rickets and teeth problems. The concentration of magnesium also falls within the safe category, and it varies from 1.19 ppm to 29.16 ppm. The major source of magnesium in groundwater is mafic minerals such as amphiboles, olivine, pyroxene, etc. Normally, the waters that have undergone base exchange may have high magnesium content, and their concentration may reach up to 38300ppm (John David, 1970). It is generally observed that coastal aquifers have high magnesium content, probably due to seawater intrusion.

Sodium concentration varies from 18ppm to 167ppm in the study area with an average of 49.33 ppm falling within the maximum permissible limit of 200ppm as recommended by BIS and WHO. The most common cause of high sodium levels in groundwater is due to sodium-containing minerals in rocks such as albite, nepheline, sodalite, etc. The occurrence of brackish water in some aquifers and saline water intrusion in coastal aquifers can also be attributed to high levels of sodium in groundwater. High levels of sodium create serious health problems, especially for heart and kidney patients (Khurshid & Zaheeruddin, 1988).

In the present study, Potassium concentration ranges from 2 to 32 ppm with an average of 11.08 ppm. Potassium concentration values are also within the safe limit when compared with the BIS and WHO standards. The release of potassium from land fill of domestic waste is very high by means of soluble potassic compounds. Potassium concentration in groundwater also increases due to the increased usage of synthetic fertilizers in agriculture. Potassium concentration in groundwater is negligibly low compared to sodium. This low content is due to two factors- resistance of potassium-bearing minerals to decomposition as part of weathering (Goldich, 1938) and fixation of potassium in clay minerals derived by weathering.

Coastal groundwater is one of the major water resource for many purposes and can be an inevitable part of coastal ecosystems. Stressors, like groundwater extraction, may interact with possible climate change impacts to influence coastal groundwater system at different temporal and spatial scales. Groundwater quality in the coastal aquifers of Kollam corporation is currently in almost safe condition, when it is assessed for domestic purposes.

Hill-Piper Trilinear Diagram

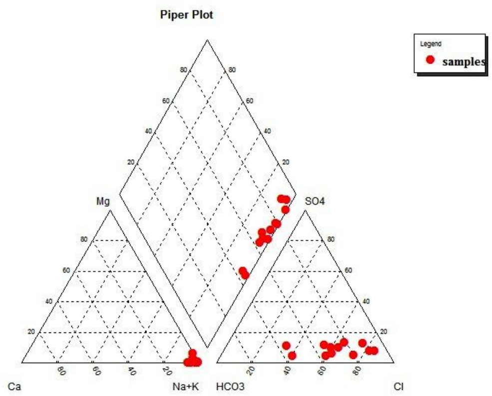

Figure 2. Hill-Piper Trilinear Diagram of samples in the study area.

A piper diagram was developed using the hydrochemical analytical results. It shows the intrinsic chemical relationship between the groundwater samples. From the Hill-Piper Trilinear diagram (Figure 2) it is observed that there are two different water types in the study area, with ten samples falling in the field of Area 7, i.e., Na-Cl type, which suggests that samples are dominated by alkalis and strong acids. The other two samples represent the Na-HCO_3 type. The dominance of sodium facies in the groundwater system suggests the interaction of nearby sea or chemical decomposition of sodium-bearing minerals or some cation exchange mechanisms, and agricultural activities.

U.S Salinity diagram

As per SAR values, all samples, except sample number 7, fall into fair, good, and excellent categories. The US Salinity Laboratory diagram was used to confirm the assessment of water quality for irrigation purposes. When plotted in the US Salinity diagram, the majority of the groundwater samples fall under the good category, and a few of them fall under the bad to very bad category (Figure 3). It suggests that most of the water samples are suitable for irrigating most of the soil and crops with less negative impact.

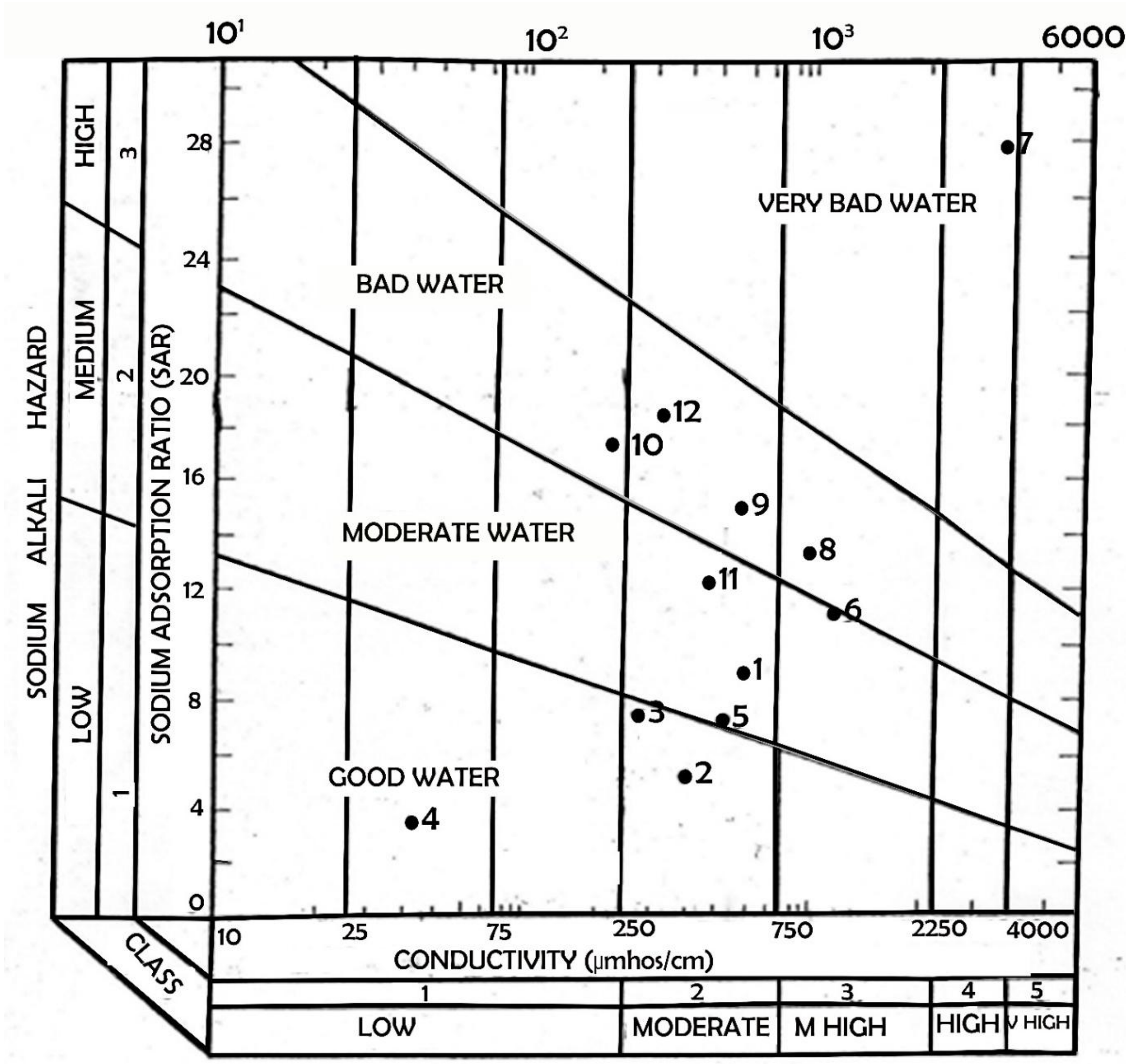

Figure 3. U.S. Salinity diagram

Conclusion

This study examines groundwater quality issues along the coastal aquifers of Kollam Corporation, Kerala. Representative groundwater samples were analysed and the results were compared with BIS and WHO standards for assessing the water quality for domestic purposes. The concentrations of water quality parameters in most of the samples are within the acceptable limits of the BIS and WHO standards for drinking water. However, some samples show an acidic nature, likely to be due to the interaction of groundwater with the lateritic aquifer. Classification of the water samples using the Hill-Piper diagram reveals that most of the samples are of Na-Cl type, suggesting the influence of seawater in the groundwater system. Additionally, the U.S. salinity diagram categorizes some water samples as 'bad' to 'very bad'. The study highlights the potential risks associated with the over-exploitation of groundwater resources. Excessive extraction of groundwater, driven by rapid urban development, may lead to a decline in the water table, which in turn enhances the seawater intrusion into the groundwater system, further deteriorating the groundwater quality. Appropriate steps should be taken to protect the groundwater system against the possible saltwater intrusion. Reduced pumping rates, natural recharge, reducing the dependence on groundwater resources and artificial recharge are some of the common methods that can be practiced in the study area to safeguard the coastal aquifers in the study area.

Acknowledgements

The authors express their sincere gratitude to the Head of the Department of Geology, University of Kerala, for facilitating the necessary analyses. We also acknowledge the support and facilities provided by the Principal of University College, which were instrumental in conducting this study. Our heartfelt thanks go to Dr. Gangadhar K for his invaluable assistance during the fieldwork. This study is a part of the MSc dissertation of the first author.

Credit Statement

Nima Zulthana: Field work, Analysis, Methodology, Data generation. Shinu: Conceptualization, Supervision, Methodology, Resources, Writing – original draft. Anoop: Writing – review & editing. Yamuna Sali: Map Preparation, review and editing, Anjana: Writing -review and editing.

Conflict of interest

We confirm that there are no known conflicts of interest associated with this publication, and that no substantial financial support has been received for this work.

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