GROUNDWATER CHEMISTRY OF SHALLOW AQUIFERS IN THE COASTAL ZONES OF COCHIN, INDIA

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Abstract. The coastal aquifers of Kerala, India experience severe degradation of water quality due to various anthropogenic activities. An attempt is made here to study the groundwater chemistry of aquifers, which lie along the coastal zone of central Kerala. Results in general indicated that the groundwaters in the shallow aquifers were found to be deteriorated. Based on Hill-Piper trilinear diagram it is confirmed that some of the dug wells were characterised by high amount of sodium and chloride (>200 mg/l) indicating the influence of saline water incursion. The presence of *E. coli* in all dug wells indicated potentially dangerous fecal contaminations, which require immediate attention. The study further raises points for the need of action for a sustainable utilization of precious resources.
Keywords. *coastal aquifer, groundwater, trilinear diagram, saline water incursion*

Introduction

Kerala, the southernmost state of India has unique hydrogeological characteristics with wide variation in the rainfall pattern (average 3107 mm). Both qualitatively and quantitatively, the coastal zones of Kerala in recent years witnessed serious groundwater problems [8, 9, 11, 24, 25]. Several studies invariably showed that water quality in the shallow aquifers situated in the coastal zone of Kerala is deteriorating alarmingly amidst plenty of water all around [1, 6, 7, 10, 12, 21, 33]. Owing to the high demand of groundwater to cater a large population in the coastal zones of Cochin, mitigation of the deterioration in the quality of groundwater in shallow coastal aquifers was initiated through groundwater recharge [30]. High population pressure, intense human activities, inappropriate resource use and absence of proper management practices leads into the deterioration. The coastal sedimentary formation serves as an excellent condition for aquifer and the average groundwater potential of this region is estimated to be more than 0.3 MCM/km [b]. In the shallow coastal aquifer, open wells are the dominant groundwater abstraction structures and the density of the open wells in the coastal area is high in the range of 400 wells/km^2 [30]. During rainy seasons, the sea becomes rough and encroaches towards land and during summer seasons the saline water finds its way through tidal channels and it admixes with shallow coast aquifers. So the qualities of water in the shallow and deeper zones become brackish [9, 20, 30].

Added up problems such as urbanisation, industrialization, unscientific landuse, lack of awareness of the people and saline intrusion all makes the quality of groundwater in Cochin coastal zone worsen. All these contribute to less recharge into the coastal aquifers thereby accentuating groundwater quality and the problem of salt water intrusion. The present investigation attempts to illustrate the scenario of groundwater quality and saline water intrusion during post monsoon (November 2003) in the coastal zones of Cochin.

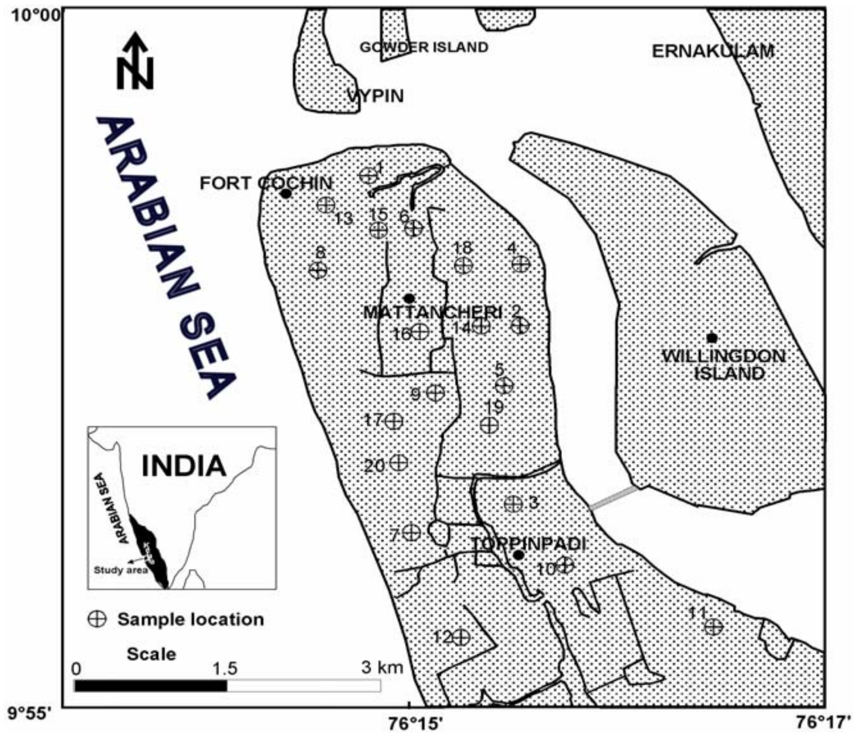

Figure 1. *Base map and sample locations of the study area*

Study area

The study area extends from north of Fort Cochin to the south of Thoppumpadi which lies between 9°55'–10°00'N and 76°13'–77°17'E (*Fig. 1*).

The area is bordered by Arabian Sea on west and a part of Cochin estuary in the eastern side. The area is characterised by a number of tidal channels, results into seawater encroachment, which deteriorate the water quality.

Exploratory borehole study conducted by Central Groundwater Board indicates the recent coastal alluvium followed by Tertiary sediments consists of two distinct formations. The upper most formation is Warkalais with thickness of nearly 80 m underlined by thick sequences of sediments called Vaikom beds. The Tertiary sedimentary formation of Kerala basin unconformably overlays Precambrians. In the present study most of the dug wells are tapping groundwater at depth ranging 2 to 8 m fall in recent coastal alluvium [29].

Data and methodology

Groundwater samples have been collected from 20 dug wells during post monsoon (November 2003) at stations as shown in *Fig. 1*. The pH was measured at the spot, whereas the concentration of major cations, anions and *E. coli* were analysed at the laboratory as per the standard analytical procedures [2, 14].

Sodium and potassium in groundwater samples were analysed using Flamephotometer (Systronics FPM digital model). Calcium and magnesium were estimated by EDTA titri metric method, whereas chloride was determined by argentometric titration using standard silver nitrate as reagent. Carbonate and bicarbonate concentrations of the groundwater were determined titrimetrically [2, 14]. Sulphate concentration was carried out following turbidity method using double beam UV-Visible spectrophotometer

(Hitachi Model 2000) [2]. The microbiological quality of samples were analysed in terms of most probable number (MPN) of faecal coliforms using lactose broth and incubation at 44.5 °C. Tubes showing positive results after 24 to 48 hours of incubation were streaked on to Mac Conkey Agar and esoine methyl blue (EMB) agar and incubated at 37 °C for 24 to 48 hours. Typical *E. coli*-like colonies were isolated and confirmed biochemically as *E. coli* using IMViC test. The number was expressed as MPN index / 100 ml.

Results and discussion

Table 1 presents the results of groundwater analysis.

pH

The pH values of groundwater were varied from 7.01 to 8.2 indicating slightly alkaline nature. Groundwaters with pH value above 10 are exceptional and may reflect contamination by strong base such as NaOH and $Ca(OH)_2$ [22]. The range of desirable limit of pH of water prescribed for drinking purpose by ISI [27] and WHO [35] is 6.5–8.5 while that of EEC [23] is 6.5–9.0.

The analysed groundwater samples are within the limit prescribed by ISI [17], WHO [35] and EEC [23]. There is no much distinct variation of pH in the different wells selected for the present study, indicating that the groundwater is tapping from aquifers of a single formation. The slight alkaline nature of groundwater may be due to the presence of fine aquifer sediments mixed with clay and mud, which are unable to flush off the salts during the monsoon rain and hence retained longer on other seasons.

Table 1.*: Chemical and E. coli analysis data of groundwater*

well no.	pH	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	CO_3^{2-} and HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	MPN index FC / 100 ml
1	8.08	380.7	23.5	57.9	20.2	200.2	470.4	1.8	150
2	7.61	145.7	90.6	102.1	12.0	317.8	145.2	2.1	290
3	8.01	480.4	110.0	190.4	22.7	334.1	749.4	5.6	95
4	7.67	457.1	75.2	117.7	10.3	321.9	640.3	2.4	95
5	7.10	120.0	18.2	72.9	22.5	352.4	36.1	1.8	460
6	7.14	110.9	19.8	74.1	26.5	310.1	63.5	2.2	290
7	8.20	546.0	72.2	122.0	11.2	276.9	757.4	3.8	93
8	7.26	90.7	30.2	52.8	5.0	179.7	96.7	2.2	460
9	7.30	70.6	38.4	48.8	4.8	187.0	49.8	1.1	460
10	7.36	445.9	45.9	70.2	11.0	160.1	612.0	3.4	120
11	7.53	110.6	38.3	50.8	15.3	203.6	128.2	2.5	240
12	7.60	339.0	95.1	87.0	22.8	187.4	541.6	3.5	150
13	7.57	111.5	65.2	54.4	3.6	185.7	126.0	1.9	210
14	7.20	65.0	23.7	82.6	3.5	238.5	23.7	0.9	240
15	7.67	85.3	42.5	97.1	2.5	234.0	70.6	2.1	210
16	7.54	64.5	15.2	61.4	1.2	167.4	37.5	0.8	460
17	7.50	34.0	8.9	24.6	2.3	77.0	23.1	0.6	290
18	7.07	20.1	10.2	25.6	1.7	62.5	26.0	1.2	460
19	7.50	48.5	27.6	83.2	10.1	202.2	55.4	1.3	240
20	7.01	11.7	5.2	34.0	8.9	74.1	25.2	0.9	460

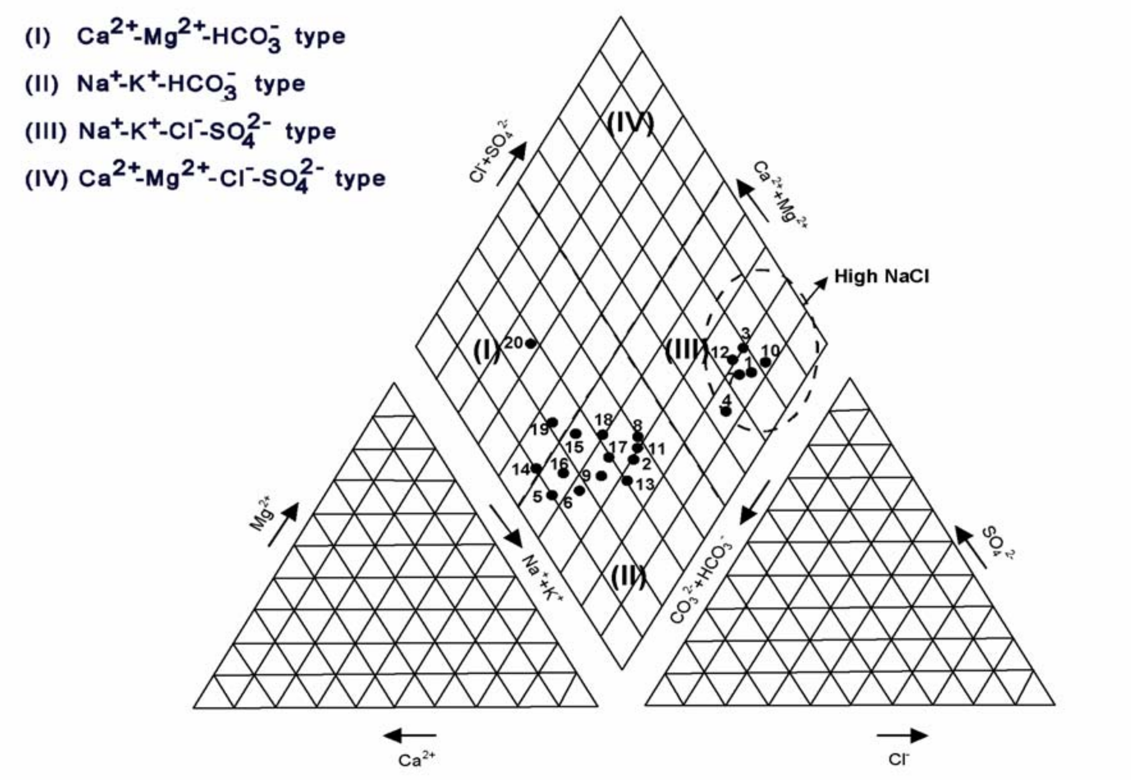

***Figure 2.**: Trilinear diagram of dugwell samples*

Major cations and anions

Major cations and anions such as Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-}, SO_4^{2-} and Cl^- (*Table 1*) were plotted in hydrochemical trilinear diagram. In general high concentrations of chloride in groundwater is attributed to rainwater, seawater, natural brines, evaporate deposits and pollution [18, 19]. In dug wells (Nos. 1, 3, 4, 7, 10 and 12) high concentrations of chloride and sodium were measured. This high concentration can be due to the proximity of the wells to the tidal channel and the poor muddy sediments present in the aquifer system which further infers saline incursion. The high chloride content is generally taken as an index of impurity of groundwater. The clogging nature of sediments permit only intermittent flushing and hence the impurity (sodium and chloride) was sustained longer as compared to other wells. The dug wells (Nos. 1, 3, 4, 7, 10 and 12) had higher values, which were above the permissible limit of 250 mg/l [17, 23, 35]. Sulphate concentration in groundwater of coastal zone were within the permissible values recommended by WHO [35], EEC [23] and ISI [17]. The major cations and anions were further analysed based on Hill-Piper trilinear diagram.

Hill-Piper diagram

Pattern diagram was initially conceived by Hill [16] and later improved by Piper [27] and the detailed analysis of Hill-Piper trilinear diagram for post monsoon season (*Fig. 2*) is explained below using facies diagram.

The hydrochemical pattern diagram helps in hydrogeochemical facies classification [5]. The trilinear diagram of this study is classified into four hydrochemical facies based on the dominance of different cations and anions: facies 1: Ca^{2+}-Mg^{2+}-HCO_3^- type I; facies 2: Na^+-K^+-Ca^{2+}-HCO_3^- type II; facies 3: Na^+-K^+-Cl^--SO_4^{2-} type III and facies 4: Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} type IV.

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Fig. 2 shows that the majority of samples were in type II (Na^{+}-K^{+}-Ca^{2+}-HCO_3^{-}) followed by type III (Na^{+}-K^{+}-Cl^{-}-SO_4^{2-}) and type I (Ca^{2+}-Mg^{2+}-HCO_3^{-}). This indicates that post monsoon samples are enriched with sodium, bicarbonate and chloride types and, from this it is evident that sea water and tidal channel/canals plays a major role in controlling the groundwater chemical composition in the coastal shallow aquifer, which consists of recent alluvium. Nageswara [26] conducted study on groundwater salinity of the shallow aquifers in the central Kerala and inferred that salt-water encroachment into shallow aquifers can be minimised by construction of tidal barriers. The removal of sodium ions from seawater which has infiltered into fresh water aquifer has been described by a number of workers by the method of ion exchange [28, 31]. Sodium ion present in seawater will exchange to Ca^{2+} ions. The conversion of calcium bicarbonated water to sodium bicarbonate water in many aquifers is also undoubtedly due to ion exchange [4, 13]. The freshwater will change into $NaHCO_3$ type water [3]. Further, the trilinear diagram (*Fig. 2*) revealed that dug wells (Nos. 1, 3, 4, 7, 10 and 12) falling in facies 3 showed the saline water intrusion of coastal aquifers with high percentage of sodium and chloride.

Escherichia coli

The bacteriological content is one of the most important aspects in drinking water quality. The most common and widespread health risk associated with drinking water is the bacterial contamination caused either directly or indirectly by human or animal excreta. *E. coli*, a typical fecal coliform is selected as an indicator of fecal contamination. The present study revealed a high incidence of fecal coliform, which ranged 93 to 460 MPN index FC / 100 ml (*Table 1*), indicating poor sanitary condition and improper waste disposal. The seepage of *E. coli* is easier in the sedimentary formation compared to hard rock terrains [15], which supported the present study. The fecal contamination is mainly due to improper solid waste disposal from farmyard into the soak pits located very near to drinking water wells, which do not have any protecting wall [34]. According to Woods [34], effluents from point-like sources such as septic tanks and general farmyard wastes are considered as the main sources of contamination of groundwater. The lack of protecting walls will lead to the entry of contaminated runoff water into the well from the upstream. Rojas *et al.* [32] have studied the contamination of the waters of River Rimac, Peru, and the adjoining groundwater and found that the cause of pollution is due to mining and agricultural activities as well as domestic fecal pollution upstream. The presence of *E. coli* in groundwater indicates potentially dangerous situation, and requires immediate attention.

Conclusion

Analysis of groundwater samples from the study area indicated signs of deterioration, which highlights the need for a sustainable utilization of precious resources. Groundwaters present in the shallow aquifers of some of the stations were poor in quality and beyond potable limit as per the standard set by WHO and ISI. Samples from rest of these zones indicated that the groundwater quality is satisfactory (geochemically) but requires attention, with a thrust on proper sanitation and waste disposal of the adjacent coastal region. The groundwater collected from the six dug wells indicated that there is a mixing of fresh and saline water during post monsoon. The study revealed that these wells need more controlled withdrawal of water with more

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recharging in order to maintain fresh-saline water equilibrium. Further, it stressed that the coastal zone of the study area need more attention in order to maintain the ground water quality. The study also recommends the necessity of proper sanitation and waste disposal to sustain the groundwater quality.

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