

Assessment of groundwater contamination in a suburban area of Chennai, Tamil Nadu, India

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Abstract Groundwater source is the major source of drinking water in most of the suburban areas of India. Groundwater quality was analyzed for pH, TDS, hardness, chloride, fluoride, nitrate, ammonia, phosphate, total coliform and *E. coli* for the period of January–December 2013. Samples were collected from 10 locations that include 10 shallow wells and 10 deep wells in each location. The quality variation between both shallow and deep wells during pre- and post-monsoon was analyzed. The improper disposal of solid waste and the distance of septic tank were pronounced on *E. coli* count. The analysis reveals that groundwater contamination is influenced by seasonal changes, environmental condition of the well and maintenance of the well. The high contamination was observed in the wells which are near to the Pallikaranai marsh, and during post-monsoon season, the total dissolved solids and nitrite parameters are slightly increased, whereas chloride increases during pre-monsoon season. Correlation analysis reveals that the chloride and nitrite have a significant relation. The results suggested that the groundwater immediately needs broader protection.

Keywords Groundwater · Contamination · Hydrochemistry ·
Escherichia coli · Suburban

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1 Introduction

Groundwater is an important source of water supply for rural and urban areas throughout the world. In India, almost 80% of the rural population depends on untreated groundwater for their domestic purpose; the rapid industrialization and expansion of cities pose high pressure on water resources including groundwater, which leads to depletion and contamination. Therefore, it is necessary to monitor and evaluate water quality on regular basis. Hydrochemical parameters like pH, alkalinity, total hardness, total dissolved solid (TDS), calcium, magnesium, nitrite and sulfate have a significant role in determining the portability of drinking water (Ahipathi and Puttaiah 2008; Gawas et al. 2006; Gupta et al. 2004; Jeyaraj et al. 2002; Jitendra et al. 2008; Patel and Ragothaman 2005; Sankar et al. 2002; Sirsath et al. 2006; Solanki et al. 2012; Tiseer and Tanimu 2008; Udhayakumar et al. 2006; Venkatasubramani and Meenambal 2007). Today, many rivers receive million liters of industrial effluents (Adekunle 2009; Adhikari and Gupta 2002; Jain et al. 2003; Tyagi et al. 2000), sewage domestic waste (Adnan et al. 2005; Prakash and Somshekhar 2006; Tanwir et al. 2003), agricultural waste (Dirim et al. 2003; Fatta et al. 1999; Ikem et al. 2002) and land drainage, etc., that cause degradation of water quality; the accelerated pace of development and population growth has led to the scarcity of potable water. The groundwater is generally used without any treatment for all domestic purposes. Most of the reported diarrheal cases in developing countries were mainly due to microbial contamination of groundwater (Pande et al. 2008; Lavanya and Ravichandran 2013). *E. coli* is considered as an indicator of fecal contamination, and it has central value in water microbiology. The exposure of human body to pathogenic organism through in taking of contaminated drinking water is the major reason of diarrheal outbreak. *E. coli* is considered as an indicator of fecal contamination, and it has central value in water microbiology (Hiriart et al. 2005). Therefore, it is essential to monitor and analyze the indicator organism that includes *E. coli* and total coliform in the groundwater continuously which would help in reducing the occurrence of waterborne diseases.

2 Materials and methods

2.1 Study area

Chennai is known for its many information technology and automobile manufacturing industries. Many foreign and national companies are located in large industrial areas in and around the outskirts of the city. Chennai has a hot and humid climate with a maximum temperature of 38–42 °C in June and a minimum temperature at 18–20 °C in January. The annual monsoon season is between mid-September and mid-December which is the period at which Chennai get its most of the rainfall. Pallikaranai wetland is a freshwater swamp in the city of Chennai, India. It is situated adjacent to the Bay of Bengal, about 20 km south of the city center, and has a geographical area of 80 km². In Pallikaranai, people depend on groundwater for drinking and other domestic purpose. The geographical coordinate of study area is between 12°54'44" to 12°59'00"N latitudes and 80°11'41" to 80°13'59"E longitudes. The weather is normally hot and humid. Rainfall is the main source of groundwater recharge, and the water level rises during the northeast monsoon period in the months of October to December (Sridevi karpagavalli et al. 2012).

2.2 Geology

The geology is heterogeneous in nature; the substrate in the entire region is made up of weathered charnockite rock bed covered with a layer of alluvial soil of varying thickness. The subsurface geology reveals that the sandy clay is extended up to a depth of 3 m in the western part, whereas 12 m along the eastern part of the study area. The major rock types occurring are charnockites and gneissic rock (CGWB 2003).

2.3 Health status of study area

In the year 2007, eight children were affected by diarrhea in Pallikaranai, in 2008 ten children were affected by diarrhea, and in 2009, ten children were recorded as diarrhea affected in the data collected from the primary health center at Pallikaranai. This shows that the acute diarrheal disease prevalence is high in Pallikaranai.

2.4 Sample collection

In order to assess the groundwater quality variation between deep well and shallow well, water samples were collected from both shallow wells and deep wells at a depth of 30–35 and 60–200 m, respectively, below ground level at 10 locations in Pallikaranai as shown in Fig. 1. From each location, one shallow well and one deep well have been collected. A total of 240 water samples were analyzed for a period of November 2012 to November 2013. The water samples were collected in cleaned and well-dried brown glass bottles (2.5 L), with necessary precautions. The label was pasted over these bottles that consist of collecting point, date and time in order to avoid any error between collection and analysis. For microbial analysis, the samples were collected in sterilized container and the analysis was carried out immediately. During sampling, the characteristic features of well were observed to analyze the risk factors for microbial contamination that is shown in Table 2. The hydrochemical and microbial parameters such as pH, total dissolved solids, total hardness, chloride, ammonia nitrogen, fluoride, nitrite, phosphate, were analyzed in environmental engineering laboratory, and microbial parameters such as total coliforms and *E. coli* were analyzed in biomedical engineering laboratory of Jerusalem College of Engineering. The analysis methods of parameters are mentioned in Table 1.

3 Results and discussion

The groundwater quality data obtained during assessment were evaluated against drinking water quality WHO standards. The supply of water is unsatisfactory, which undermines the confidence of consumers leading to complaints and possibility of using water from less safe sources. Looking to the seriousness of groundwater contamination is now a great concern.

3.1 pH

pH values show relatively less variation between shallow well and deep well among all groundwater sample analyzed (Fig. 2). the maximum average pH 8.2 was recorded at Narayanapuram and 9.2 at Kamatchi Nagar in the pre- and post-monsoon season. The result reveals that all the samples were slightly alkaline.

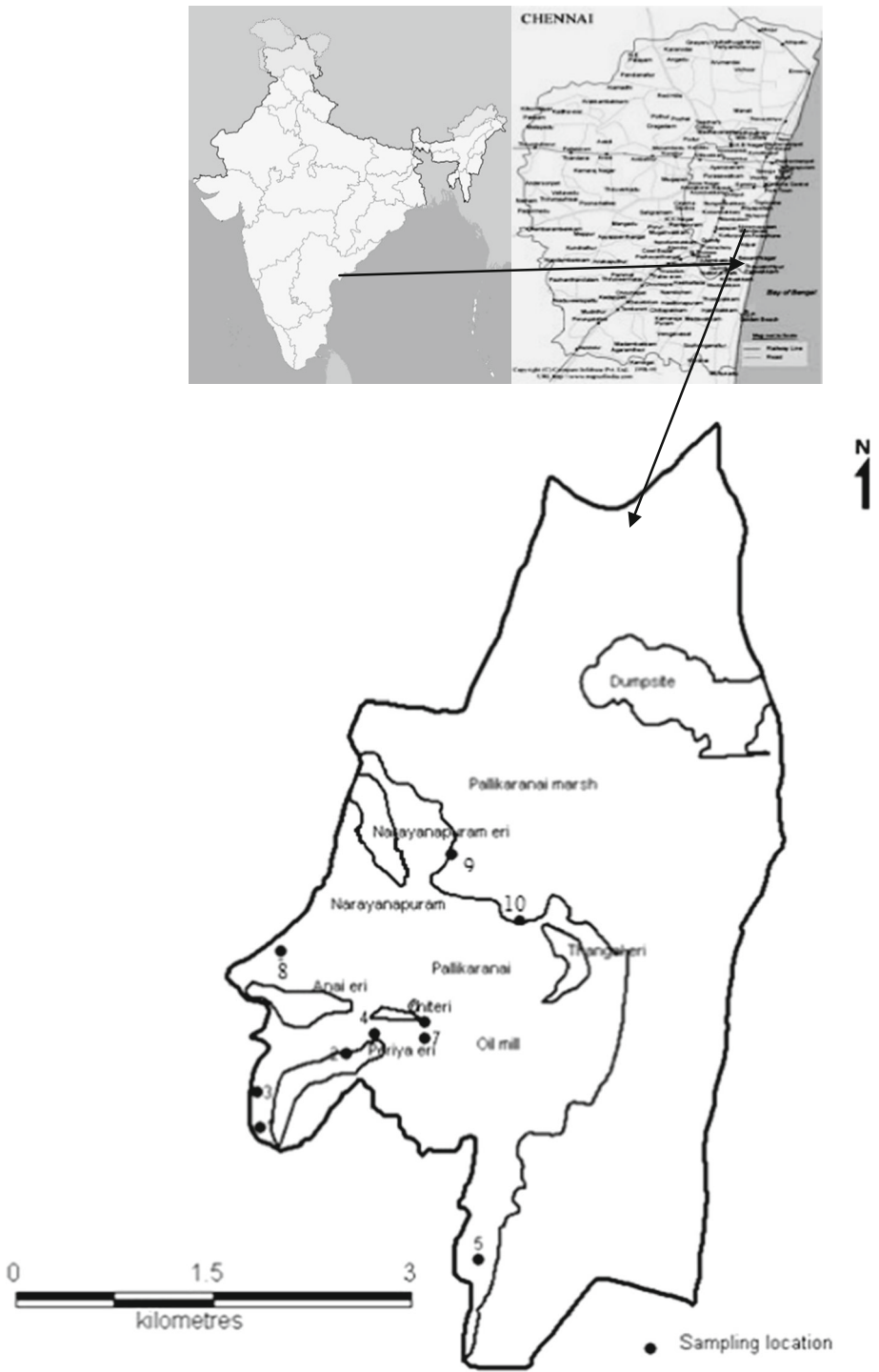


Fig. 1 Study area map with sampling location

Table 1 Methods used for analysis of water quality parameters

Parameters	Methods of analysis
pH	pH meter
Total dissolved solids	Evaporation method
Total hardness	EDTA titration method
Chloride	Argentometric method
Fluoride	UV spectrophotometer
Ammonia	UV spectrophotometer
Nitrite	UV spectrophotometer
Phosphate	UV spectrophotometer
Total coliform	MPN method
<i>E. coli</i>	Spread plate method

3.2 Total dissolved solids

The concentration variation of total dissolved solids (TDS) is shown in Fig. 2. The concentration of TDS in water is due to the presence of sodium, potassium, calcium, phosphate and other organic matters (Sharma et al. 2013). The values of TDS show spatial and temporal variations, whereas it shows inconsistent variation between shallow well and deep well in both the seasons. The concentration of TDS gradually increased from 1st sampling location to the 10th sampling location that is from south to northeastern part of the study area. This may be due to the influence of geological features. High > 10,000 mg/l TDS values were recorded in deep well of 4th, 6th and 10th locations; the values were 6064, 2364, 4116, 2232, 5208 and 5364 mg/l, respectively, as shown in Fig. 2. These values were too higher than permissible limit, and it should be treated properly before usage to remove the molecular, ionized or microgranular particles present in those samples.

3.3 Chloride

High chloride concentration in water is the indicator of organic pollution (Hanipha and Hussain 2013). The concentration of chlorides for all groundwater samples ranged from 137 to 2049 mg/l. Among the analyzed sample, the chloride content shows significant variation between shallow well and deep well as shown in Fig. 3, the maximum values were recorded in shallow well of 5th, 6th and 7th locations during pre-monsoon season; this may be due to risk factors mentioned in also observed substantial spatial variation in both pre- and post-monsoon seasons. The concentration is gradually increased from the 1st location to 10th location that is from south to northeastern direction where Pallikaranai marsh is located. Figure 2 shows the shallow wells of 5th, 6th, 7th and 8th locations; the chloride content was found to be too higher than the permissible limit, and its values were 1149.11, 2049.36, 1949.39, 1949.39 mg/L, respectively. So it should be treated for further usage, and all other samples are safe regarding chloride content. High concentration of chloride imparts salty taste (Bishnoi and Arora 2007). This high concentration of chloride occurrence during pre-monsoon season may be due to high rate of evaporation and invasion of solid waste dumped nearby areas as shown in Table 2. As solvent action of water dissolve all salt in waste material may increase the concentration. Similar result were reported by (Prasath et al. 2013) but the contrast result were obtained by Smitha et al. (2007).

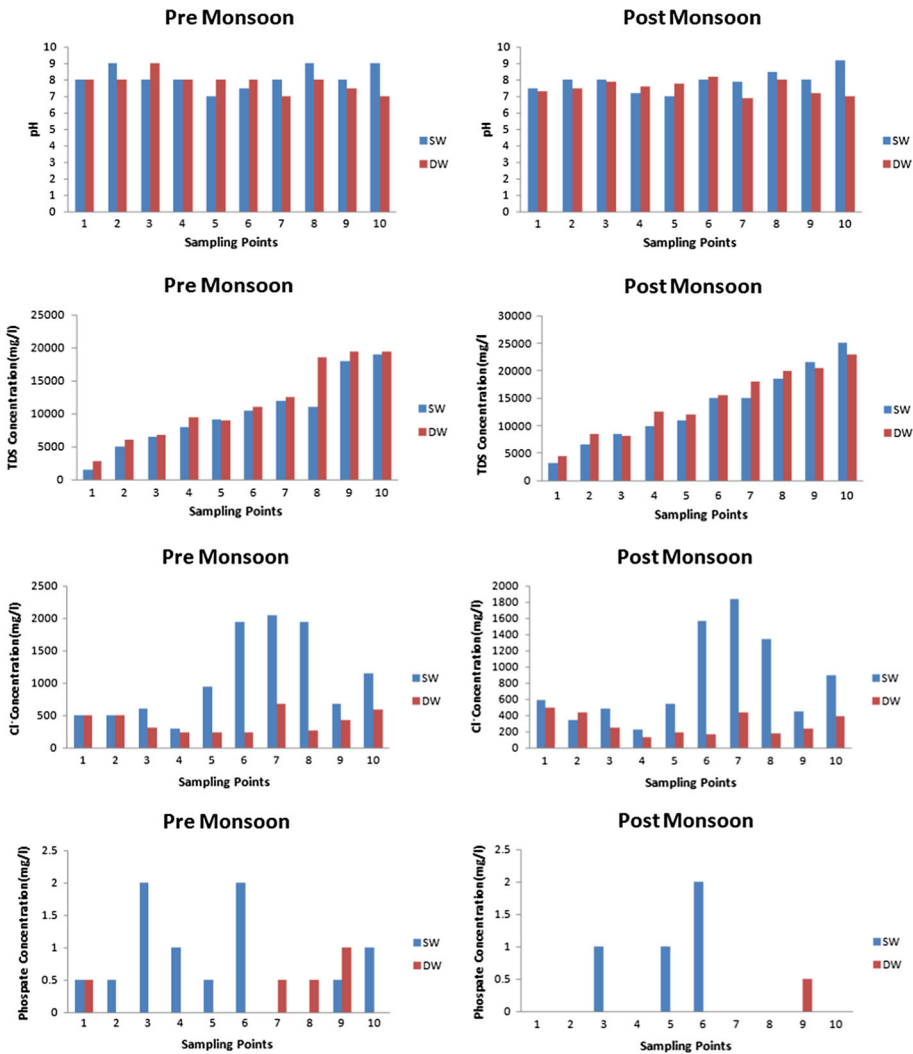


Fig. 2 Average concentration variation of pH, TDS, chloride and phosphate between shallow and deep wells during pre- and post-monsoon seasons

3.4 Phosphate

The value of phosphate in the groundwater sample lies between 0.02 and 2 mg/l. Figure 3 depicts the concentration variation of phosphate. Highest value of 2 mg/l was recorded at shallow well of 3rd and 6th locations. Minimum value was recorded at deep well of all the location except at 1st, 7th, 8th, and 9th locations during pre-monsoon, whereas in post-monsoon season phosphate was not found in all the deep wells except at 9th sampling location. In the present study, the phosphate values are found to exceed the permissible limits; normally groundwater contains only less concentration because of the low solubility of native phosphate minerals. This may be due to the fact that runoff leaches fertilizer from the agricultural field and increases the concentration of phosphate in the groundwater.

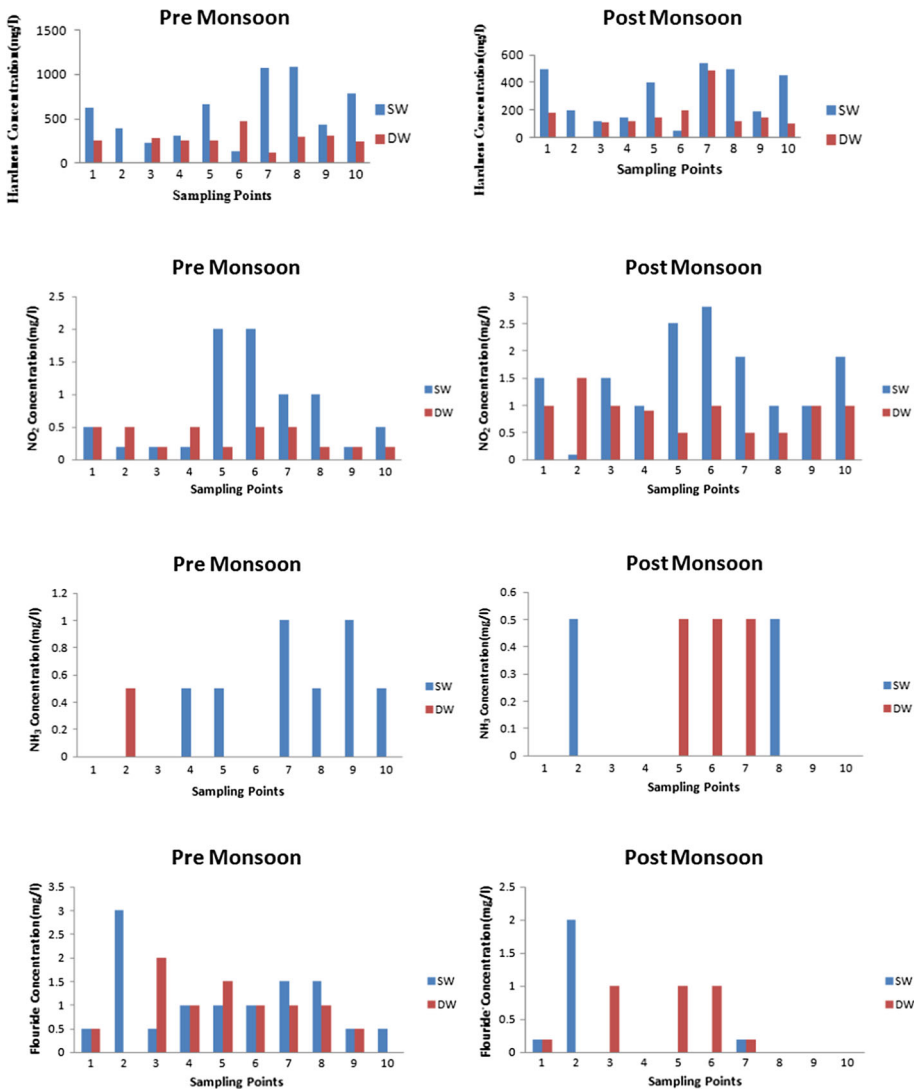


Fig. 3 Average concentration variation of nitrite, ammonia nitrogen and fluoride between shallow and deep wells in pre- and post-monsoon seasons

3.5 Total hardness

On the whole total hardness of water during study period across all stations ranged between the values 200 and 1085 mg/l. Considerable variation were observed between shallow and deep well, almost all the shallows high concentration of total hardness except 3 and 6th location in both pre- and post-monsoon season as shown in Fig. 3. The maximum average value recorded in the pre-monsoon season is 1085 at 7th and 8th locations; the findings of the study coincide with Sharma et al. (2013).

Table 2 Characteristic features of well

Sample ID	Depth of shallow well (m)	Depth of deep well (m)	Risk factors
L1 (Kamatchi Nagar)	30	150	Cement floor
L2 (Kamatchi Nagar, 9th St.)	34	200	Cement floor
L3 (Kamakotty Nagar)	32	65	Near septic tank
L4 (Kamakotty Nagar, North)	30	200	Without parapet wall
L5 VGP Shanthi Nagar	36	85	Septic tank
L6 (Narayanapuram)	35	120	Solid waste dumping near the well
L7 (Oil Mill)	30	200	Solid waste dumping near the well
L8 (High School Road)	34	80	Septic tank
L9 (Manohar Nagar)	30	84	Solid waste dumping near the well
L10 (Kamakotty Nagar, 1st Cross St.)	30	85	Without parapet wall

3.6 Nitrite

The concentration variation of nitrite is depicted in Fig. 3. The average nitrite ranged between 0.09 and 2.9 mg/l among the groundwater analyzed; the maximum values were observed during post-monsoon season at 10th location, whereas minimum concentration was observed during pre-monsoon season at the 2nd location. The study also observed the intense concentration difference between shallow and deep wells; almost all the shallow well shows increased concentration during both pre- and post-monsoon seasons except at 2nd and 4th locations. The acceptable limit of nitrite is 4 mg/l; according to WHO standards, nitrite produces carcinogenic nitrosamines in the human body through its reaction with amines or amides (Ensafi et al. 2004). Nitrite is found in atmosphere and in natural water.

3.7 Ammonia nitrogen

The average value of ammonia was recorded between 0.02 and 0.5 mg/l. Among the groundwater analyses, the maximum value 0.5 mg/l was observed in the pre-monsoon at the shallow well of all the locations and during post-monsoon at 3rd, 4th, 9th and 10th locations no ammonia was found in both the shallow and deep wells (Fig. 3). The main source of ammonia in Pallikaranai groundwater is mainly due to biodegradation of organic matter present in municipal solid waste which is mounted on the Pallikaranai marsh.

3.8 Fluoride

The value of fluoride for the groundwater sample is recorded between 0 and 3 mg/l. The maximum allowed limit of sample exceeds the permissible limit. The maximum value of 3 mg/l was recorded during pre-monsoon season at shallow well of 2nd location, and minimum value was recorded at 4th, 8th, 9th, 10th locations during post-monsoon season as shown in Fig. 3. High fluoride content in groundwater may be due to ground interaction of groundwater with rock and infiltration of chemical fertilizers from agricultural land. The high concentration leads to occurrences of fluorosis.

The correlation matrix (Table 3) describes the interrelationship between variables (Lavanya 2014), and the results of hydrochemical and microbial parameters show that very high positive correlation exists between pH, hardness and fluoride ($r = 0.74, 0.38, p < 0.01$). A moderate positive correlation exists between TDS and total coliform ($r = 0.63, p < 0.01$), ($r = 0.52, p < 0.05$), and a moderate negative correlation exists between TDS and fluoride ($r = -0.35, p < 0.01$). Nitrite, ammonia, total coliform have moderate correlation of ($r = 0.69, 0.36, \text{ and } 0.69$ with $p < 0.01$), respectively, with one another and very high, positive correlations with *E. coli* and chloride ($r = 0.99$ with $p < 0.01$). This suggests that *E. coli* and total coliform are influenced by TDS, chloride and nitrite. From Table 3, it is quite clear that most of the parameters were significantly correlated with total coliform and *E. coli*, which could be an indication of the presence of pathogenic organism even in the aquifer where the various processes take place such as ion exchange, water–rock interaction and weathering of the aquifer’s parent material (González et al. 2014).

Among analyzed sample with respect to pH 54% of the sample is slightly alkaline, 65% of sample exceeds the permissible limit of chloride, and 5% of the sample exceeds the total hardness standards. According to WHO, there can be 0.4–4.0 mg/l; of nitrite, and all samples were within the nitrite standards. In total, 95% of the sample exceeds limits of TDS permissible standards. All samples were within the standards of ammonia, and 60% of the samples were within the limit of fluoride. In total, 95% of the sample were not fit for drinking purpose.

Microbial contamination was related to two aspects, environmental condition of the well and maintenance of the well shown in Table 4. Cement floor and the presence of parapet wall around the well were considered under the maintenance of well and improper solid waste disposal practice, and the proximity of septic tank was compared for both shallow and deep wells (Table 2). Since Shallows wells are more susceptible to contamination high contamination was observed in shallow well. Among the risk categories, the analysis indicated that the high risk of *E. coli* contamination was observed in the shallow well which is near to the improper disposal for solid waste. The depths of the wells at high

Table 3 Risk factors for the microbial contamination in the well

Risk factors	OR	P	95% CI
<i>E. coli</i> < 50 > 50 cfu/ml			
Well maintenance			
Cement floor		0	
Yes	0.225		3.74–20.45
No	5.75		0.125–0.40
Parapet wall		0.06	
Yes	0.278		0.063–1.22
No	1.14		0.99–1.304
Environmental condition of well			
Septic tank		0.02	
<30 m	6.2		2.860–13.65
>30 m	0.357		0.22–0556
Solid waste dumping		0.02	
1 m	1.7		1.067–2.422
>1 m	0.625		0.408–0.957

Table 4 Correlation between both chemical and microbial parameters

	pH	TDS	Hardness	Chloride	Nitrite	Ammonia	Phosphate	Fluoride	Total coliform	<i>E. coli</i>
pH	1	-0.164	.749**	0.075	-0.199	0.234	0.113	.381**	0.005	0.026
TDS		1	0.026	0.053	0.013	0.066	-0.067	- .350**	.636**	.607*
Hardness			1	.875**	-0.013	.891**	0.003	.309*	0.189	0.207
Chloride				1	.691*	.362**	.673*	-0.003	.732**	.925**
Nitrite					1	-0.116	0.175	-0.179	.558*	.358**
Ammonia						1	-0.066	0.208	.378**	.301*
Phosphate							1	0.071	-0.106	0.039
Fluoride								1	- .324*	- .360**
Total coliform									1	.853**
<i>E. coli</i>										1

Bold values are mentioned about the significant correlation between the parameters

risk of contamination ranged from 30 to 200 m (Table 3). This may indicate that deeper wells have an increased ability to filter contaminants through different soil layers even though most of the deep wells show microbial contamination which is the main sources of water. Some studies have reported pathogenic bacteria at a depth of 36 m (Van Geen 2011) and others. When considering the influence of protection of wells, a statistically significant relation was found for wells with a cement floor. However, a risk estimation for *E. coli* contamination was high for the wells without parapet well (OR = 1.14, $p = 0.06$). Therefore, this protection can be considered an important risk factor. There was a high percentage (62.00%, $p < 0.001$) of wells at high risk of contamination located at a distance of < 15 m from a septic tank (Table 4). This result coincides with several studies, which have evaluated the impacts of on-site sanitation on groundwater.

4 Conclusions

The study analyzed both shallow and deep wells in 10 locations. The result also shows the spatial variation in the study area. In eastern direction of the study area, the water quality is not portable and the concentration of TDS and chloride gradually increases from the southern part of the study area to northeastern direction; this spatial variation may be due to the geological features prevailed in the study area. The hydrochemistry of the groundwater is influenced by some of the factors such as heterogeneity in geological features, the presence of municipal solid waste dumpsite on Pallikaranai marsh, anthropogenic pollution and weather factor.

The geological representation of hydrochemical parameters shows a significant variation in depth of well, spatial and temporal. Correlation analysis shows the positive correlation between chloride and nitrite, *E. coli* and total coliform which ensures survival of pathogenic organism. The usage of groundwater for domestic purposes in the eastern and northeastern direction should be avoided as the groundwater contains high TDS, pH, chloride, which may lead to chronic diseases due to long-term exposure. The infiltrated water during post-monsoon period results in higher dilution of contaminant and higher concentration observed during pre-monsoon. Also, as the dumpsite is located in the marshy area, water stagnates throughout the year around the dumpsite in the marsh and facilitates the dilution and movement of leachate at higher rate. The high risk of microbial contamination was estimated for wells which are in close proximity to the septic tank; this ensures that there may be leakages from the septic tank to the subsurface area. Based on the results, the groundwater resource, without standard treatment, is unfit for drinking and domestic uses.

It is recommended that environmental interventions, through public health education by community-based health workers, awareness and sensitization campaigns, be carried out for improved household water treatment and management in rural areas in the developing countries. Wells located within 30 m from septic tank should be abandoned, and the surroundings of the wells should be maintained by constructing parapet wall, cement floor around the well. Adequate solid waste disposal method should be adopted, phasing out open dumpsites to safeguard public health from waterborne diseases.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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