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ABSTRACT

OBJECTIVE: To assess the sanitary condition and water quality of household wells and to depict it spatially using Geographic Information System (GIS) in an urban area of Trivandrum, Kerala state, India.

STUDY DESIGN: A community-based cross-sectional census-type study.

METHODS: Study was conducted in an urban area of Trivandrum. All households (n = 449) residing in a 1.05 km^2 area were enrolled in the study. Structured questionnaire and Differential Global Positioning System (DGPS) device were used for data collection. Water samples taken were analyzed in an accredited laboratory.

RESULTS: Most of the wells were in an intermediate-high contamination risk state, with more than 77% of wells having a septic tank within 7.5 m radius. Coliform contamination was prevalent in 73% of wells, and the groundwater was predominantly acidic with a mean of 5.4, rendering it unfit for drinking. The well chlorination and cleaning practices were inadequate, which were significantly associated with coliform contamination apart from a closely located septic tank. However, water purification practices like boiling were practiced widely in the area.

CONCLUSION: Despite the presence of wells with high risk of contamination and inadequate chlorination practices, the apparent rarity of Water-borne diseases in the area may be attributed to the widespread boiling and water purification practices at the consumption level by the households. GIS technology proves useful in picking environmental determinants like polluting sources near the well and to plan control activities.

KEYWORDS: Groundwater contamination, Health, GIS, Kerala

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Introduction

Water in its diverse forms constitutes the major component in cellular to the inanimate global level. Only about 3% of the total water available on earth is freshwater, of which 68% is groundwater and 30% surface water.[1] In developing countries, 90% to 95% of all sewage and 70% of all industrial wastes are dumped untreated into surface waters.[2] Approximately 22% of the freshwater found at the Earth's terrestrial surface is stored as groundwater.[1] Groundwater maintains its quality by the natural filtering mechanisms inherent to the soil strata by virtue of gradation in the physical parameters of soil and rock as water seeps downwards.[3] Alarmingly though, with the exponential growth in human activities allied to urbanization and industrialization, the groundwater sources are now facing threats of contamination.

Groundwater contamination, be it physical, chemical, or microbiological, can cause a myriad of health hazards. At present, 1.1 billion people are drinking water that is not safe, especially among the developing countries, contributing to millions of young deaths.[4] An estimated 2.6 billion people lack adequate sanitation globally.[5] Those most susceptible to water-borne illnesses are children, elderly, pregnant women, and immuno-compromised individuals. Water-borne illnesses are one of the five leading causes of death among children under the age of 5 years. Approximately 5000 people die every day from water-borne diarrheal illnesses.[6] It is estimated that around 37.7

million Indians are affected by water-borne diseases annually, 1.5 million children are estimated to die of diarrhea alone, and 73 million working days are lost due to water-borne disease each year. The resulting economic burden is estimated at US$600 million a year.[7]

It is well established that microbial contamination imposes immediate disease burden and chemical contamination causes chronic diseases. Acute diarrheal diseases constitute the bulk of the immediate disease burden, whereas slow accumulating chemical toxic conditions like fluorosis constitute chronic diseases. The Goal 6 of Sustainable Development Goals refers to "Ensure availability and sustainable management of water and sanitation for all," which also addresses to the quality of available water.[8] The provision of clean drinking water has been given priority in the Constitution of India, with Article 47 conferring the duty of providing clean drinking water and improving public health standards to the State.[9]

Broadly speaking water is defined as unfit for drinking as per Bureau of Indian Standards (BIS), IS-10500-2012, if it is bacteriologically contaminated, or if chemical contamination exceeds maximum permissible limits.[10] Access to safe drinking water depends not only on the quality of water at source but also on contamination throughout its way to the user and practices related to purification and sanitation. The global volume of waste disposed of via latrines is approximately 800 million gallons per year, almost all of which is disposed in the subsurface, making latrines the leading contributor to the total volume of waste discharged directly to groundwater.[11] Assessment of water is therefore very crucial to safeguard public health and the environment.

In India, groundwater resources are widely used for drinking and domestic purposes. Estimates indicate that surface and groundwater availability is around 1869 billion cubic meters (BCM). Of this, 40% is not available for use due to geological and topographical reasons.[12] Groundwater has been extensively exploited in India to meet the demands of its population with dug wells serving as the most common source of extraction of groundwater. In Kerala, the groundwater caters to 80% of the rural and 50% of the urban communities for their drinking and domestic needs,[6] mostly by means of dug wells and rarely via bore wells.[17] Kerala is endemic for Water-borne diseases like enteric fever and viral hepatitis apart from acute diarrheal diseases, all of them showing seasonal trends, with aggravation in summer. Cases of cholera have also been reported from within the state.[13]

Geographic Information System (GIS) is a powerful software tool for the manipulation and analysis of spatial data, making maps into dynamic objects.[14] GIS is a useful tool that aids and assists in health research for the control and prevention of diseases and epidemics. Majority of data in public health has a spatial (location) component, to which GIS adds a powerful graphical and analytic dimension by bringing together the fundamental epidemiological triad of person, time, and the often-neglected place. The attribute of location proves to be useful in the estimation of groundwater contamination as it gives valuable inputs regarding distance of well from nearest contamination source, also taking into account the geological profile of the area.

GIS technology is a relatively new public health tool to study health-related events in Kerala, and its vast potential of opportunities remain hidden to the public health experts of the state. The Department of Community Medicine, Government Medical College Trivandrum in association with Inter University Centre for Geospatial Information Science and Technology, University of Kerala has embarked on this venture to assess the contamination status of household wells in an urban area of Trivandrum and to map the same using GIS.

Methods and Materials

A community-based cross-sectional study was conducted in the smallest defined health care unit in the community known as "sub-center." This study was conducted in Pangappara Public Health sub-center area which is the field practice area of the Government Medical College at Trivandrum, India. The study region covers an area of 1.05 km^2 and geographically lies between 76°53′50.36″E to 76°55′1.96″E longitudes and 8°33′45.83″N to 8°32′57.36″N latitudes (Figure 1). An integrated approach has been followed in this study, which involves four steps. The study started with the collection of data by questionnaire survey at each house and collecting geographical coordinates of each house, well, and nearest septic tank by using Trimble Differential Global Positioning System (DGPS). It was followed with another fieldwork for collecting groundwater samples for estimating major ions, pH, electrical conductivity, total dissolved solids, and certain trace elements by inductively coupled plasma mass spectrometry (ICPMS) analysis. The generated hydrogeochemical data and the health data were integrated to create the geo database in GIS platform. The final step involved the analysis of the data using GIS tools and statistical software.

The study area has 540 individual houses and 4 multi-storied buildings which houses 274 apartments in it. The study region covers an area of 1.05 km^2. All individual houses were included in the study and no sampling technique was adopted.

Data collection period was from February 1 to April 30, 2016, which is the summer season in Kerala, where water-borne diseases are most common. Data collection was conducted jointly by a team of postgraduates from the Department of Community Medicine and researchers from Inter University Centre for Geospatial Information Science and Technology (IUCGIST), wherein data collection and geospatial mapping were done simultaneously. Study population comprised all the households residing in the area, enrolled by census method. Details were obtained from an adult member of the household present at the time of data collection. Dwellings found closed/uninhabited were visited on three separate days at different

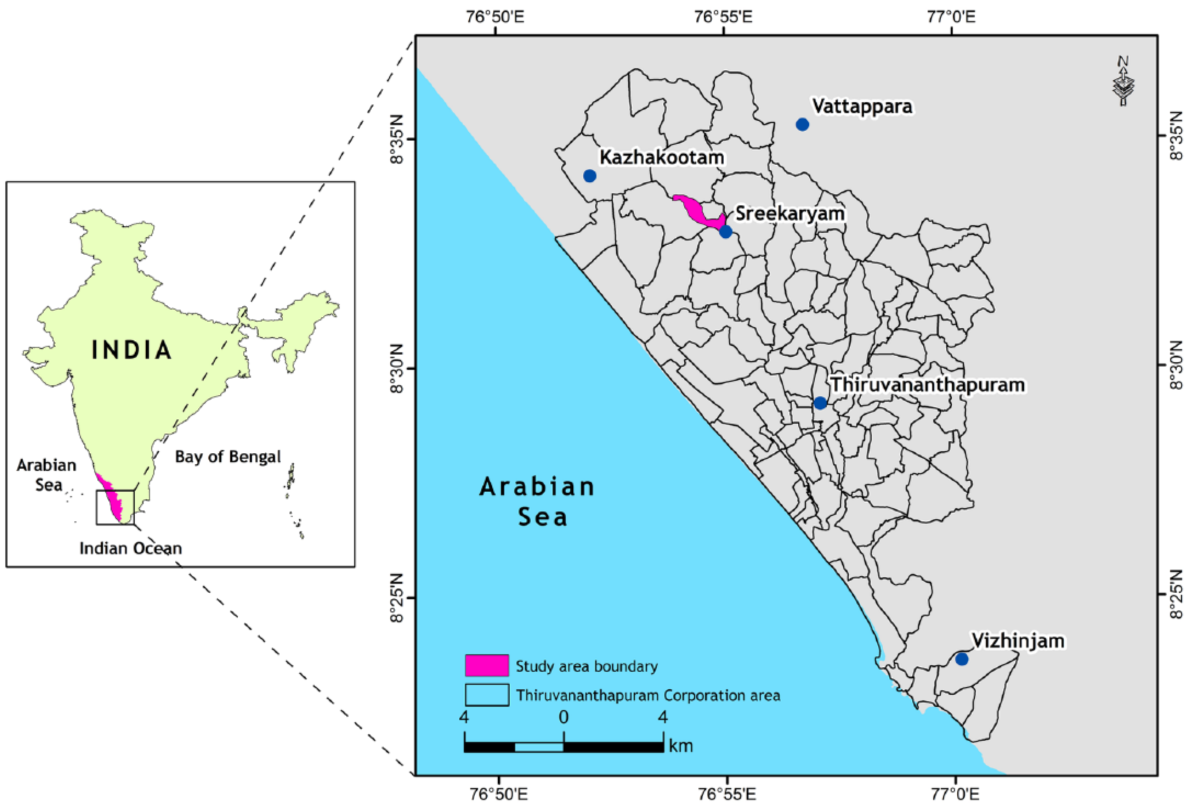

Figure 1. Location map of the study area (Pangappara PHC).

times of the day. Those houses still found to be locked were excluded from the study, which ultimately gave a study size of 449 households.

The study tool consisted of a structured questionnaire which had domains relating to the demographic profile of the household members, their water usage patterns, and sanitary survey (taken from the National Rural Drinking Water Quality Monitoring and Surveillance Program, Government of India).[7] Water usage pattern part had variables relating to the type of water sources, daily usage, and household practices concerning well chlorination, well cleaning, and boiling and filtering of well water. The sanitary survey included a visual inspection of the household wells and its surroundings. Apart from details pertaining to the well, that is, its built-up, dimensions, parapet, drainage, floor, lining, cover, and mode of drawing water, the survey also took into consideration the distance from the nearest septic tank and any other nearby contamination sources. The sanitary survey using the validated questionnaire[7] gave a contamination risk score for each well, which categorized the well into low risk, medium risk, high risk, and very high risk based on the contamination risk scores.

The location of each house, its well, and its distance from the nearest septic tank were recorded using hand-held Differential Global Positioning System (DGPS). Later, the Euclidian distance between each well with nearest septic tank was calculated using ArcGIS software. These data were later mapped in the GIS platform. The advantage of GIS mapping with the aid of Differential Global Positioning System is that the distance from a well to the nearest septic tank could be mapped very accurately, even if the nearest septic tank to the well belongs to the adjacent household, wherein manual measurements would be difficult.

In addition, water samples were taken from selected wells, which were used for drinking, taking into consideration the geology and geomorphology of the area. Samples were not taken from the corporation-supplied water or from the six bore wells present in the area. A total of 50 water samples were taken for physical and chemical quality analyses and 30 samples for bacteriological analysis from the 1.05 km^2 area. Water samples for analysis were directly drawn from the well using the same rope and bucket brought by the data collection team. Water quality parameters pH, total dissolved solids (TDS), electro-conductivity (EC) and temperature were taken on the spot and recorded using EUTECH water quality testing portable meter (Cyber-Scan series 6000). Water samples were collected in 1000 mL bottles and transported to the laboratory as soon as possible within 2 hours of sample collection. Inverse distance weighted (IDW) interpolation method in ArcGIS is used to create continuous raster surface of these parameters. Further heavy metal concentrations in the water samples were analyzed using inductively coupled plasma mass spectroscopy (ICPMS) through Merck multi-elemental standard and ICPMS Thermoscientific iCAP™ Qc instrument.

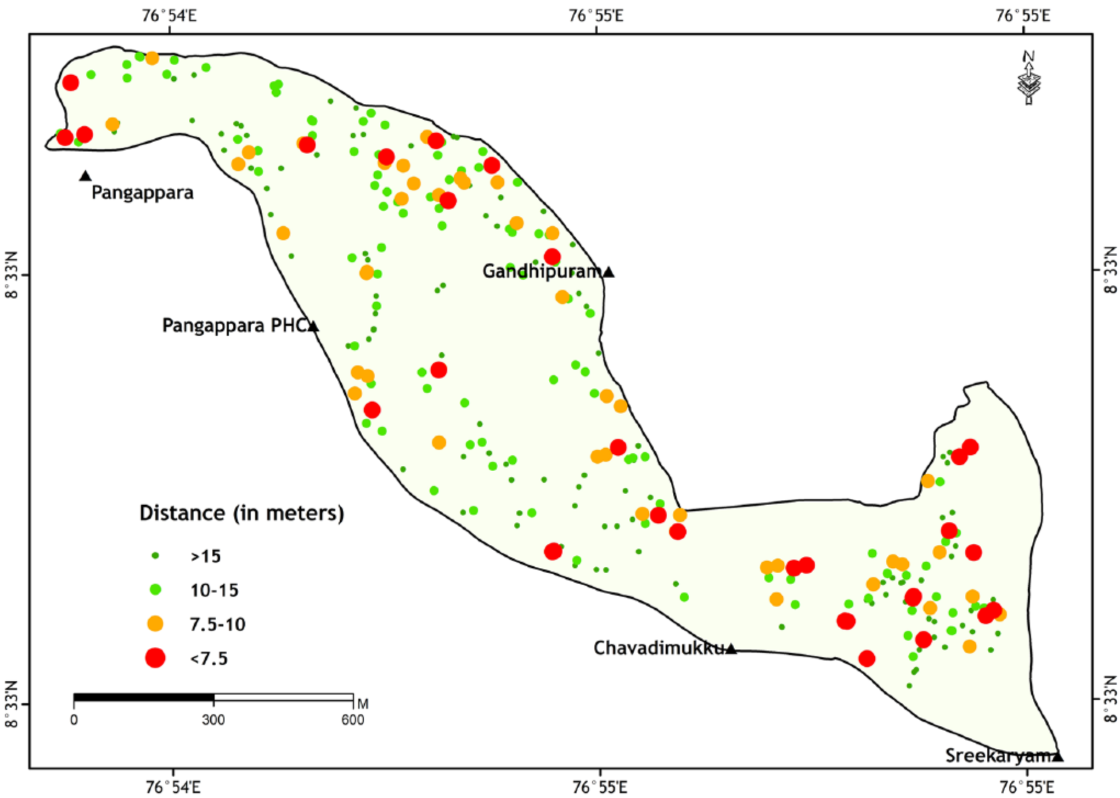

Figure 2. Map showing the distance of each well from the nearest septic tank. Larger dots depict a well with a septic tank nearer.

Map of each variable were generated using ArcGIS software. Quantitative variables were expressed as mean (SD) or median (interquartile range [IQR]), whereas categorical variables were expressed as proportions. Independent sample *t*-test was used to test significant association between variables. A linear regression model was attempted to predict the risk of contamination of household wells.

The project was funded by the State Board of Medical Research, Government of Kerala. Ethical clearance for the study was obtained from the Human Ethics Committee of Government Medical College, Trivandrum (IEC. No.01/27/2016/MCT).

Results and Discussion

The study area had a population of 1649 individuals, with 810 men and 839 women. The mean age of the population was 37.72 ± 21.5 years. Among the households, 83% (n = 372) were above poverty line (APL) families. The map of the study area is given as Figure 1. Majority of the households used dug wells as the prime source of drinking water (73%) in the study area, followed by the corporation-supplied tap water. A very few households used bore wells. The location of the dug wells was also mapped using DGPS.

The sanitary assessments of each of the 354 household wells were done, with the 11-point validated questionnaire, which gave contamination risk score for each well. The distance from the nearest septic tank to each well was measured using DGPS, which showed a median of 13.40 ± 12.77 m, with a minimum of 1 m and maximum of 139 m. Here, the septic tank may be of the adjacent household, not necessarily within the same household boundary. This was then mapped, as shown in Figure 2. The sanitary survey results are depicted in Table 1.

The net contamination score from the survey was used to predict the contamination risk for each of the well. Most of the wells (39%) in the area had intermediate risk for contamination, followed by high risk (31%) of contamination (Table 2 and Figure 3).

The water purification practices of the households were assessed, and majority (91.8%) of them boiled water before consumption. A few households filtered the water without boiling, and a very few used no purification techniques. Well chlorination frequency and well cleaning frequency were also enquired, which showed a dismal result. The mean chlorination frequency was once in 8.46 ± 11.60 months, whereas that of well cleansing was 13.24 ± 14.12 months.

Out of the 30 samples that collected for bacteriological analysis, 22 were positive for Coliforms (both Total Coliforms and Fecal Coliforms), as mapped in Figure 4. The chemical analysis of open well water revealed the low pH or acidic nature of the groundwater (Median: 5, 40) as compared with the BIS for drinking water. The groundwater pH pattern of the area was mapped using GIS and is given as Figure 5.

Table 1. Sanitary survey results of household wells in the study area.

Q. NO.	SANITARY PARAMETER		PROPORTION (%)
Q. 1	Distance from latrine	Less than 7.5 m	77.3
		More than 7.5 m	22.7
Q. 2	Height of nearest latrine	Higher or same level than the well	36.3
		Lower than the well	73.7
Q. 3	Source of pollution within 10 m	Yes	51.8
		No	48.2
Q. 4	Drainage—stagnation	Poor, causing stagnation	43.9
		No stagnation	56.1
Q. 5	Drainage—make	Faulty/broken	46.2
		Normal/functioning	53.8
Q. 6	Parapet	Inadequate (<1 m)	41.6
		Adequate	58.4
Q. 7	Floor	Not cemented/inadequate (<1 m)	68.2
		Cemented, adequate	31.8
Q. 8	Walls	Inadequately sealed (<3 m below ground)	40.2
		Adequate	59.8
Q. 9	Cracks in cemented floor	Yes	60.1
		No	39.9
Q.10	Poor maintenance of rope and bucket	Yes	24.4
		No	75.6
Q. 11	Covering of well	Sealed	51.3
		Open	48.7

Table 2. Contamination risk score for household wells.

CONTAMINATION RISK	SCORE RANGE	PROPORTION (%)
Low risk	0-2	16.4
Intermediate risk	3-5	39.7
High risk	6-8	31.7
Very high risk	9-11	12.2

Total mean contamination risk score = 5.20 (2.63), 25th quartile = 3, median = 5 and 75th quartile = 7.

Other chemical parameters were within the normal limits. The presence of trace elements/heavy metals was also tested in 10 samples from the area. The sample size was restricted owing to financial constraints in performing heavy metal chemistry analysis (ICPMS). The results, however, were within normal limits except for aluminum and copper (Table 3).

Inadequate chlorination is found to be significantly associated with coliform contamination in household wells when independent *t*-test was applied (*P* value <.05). Similarly, bivariate analysis using independent *t*-test showed a significant association between coliform contamination in wells with the closely situated septic tanks (*P* value <.05). Wells that were inadequately cleaned were also found to be significantly

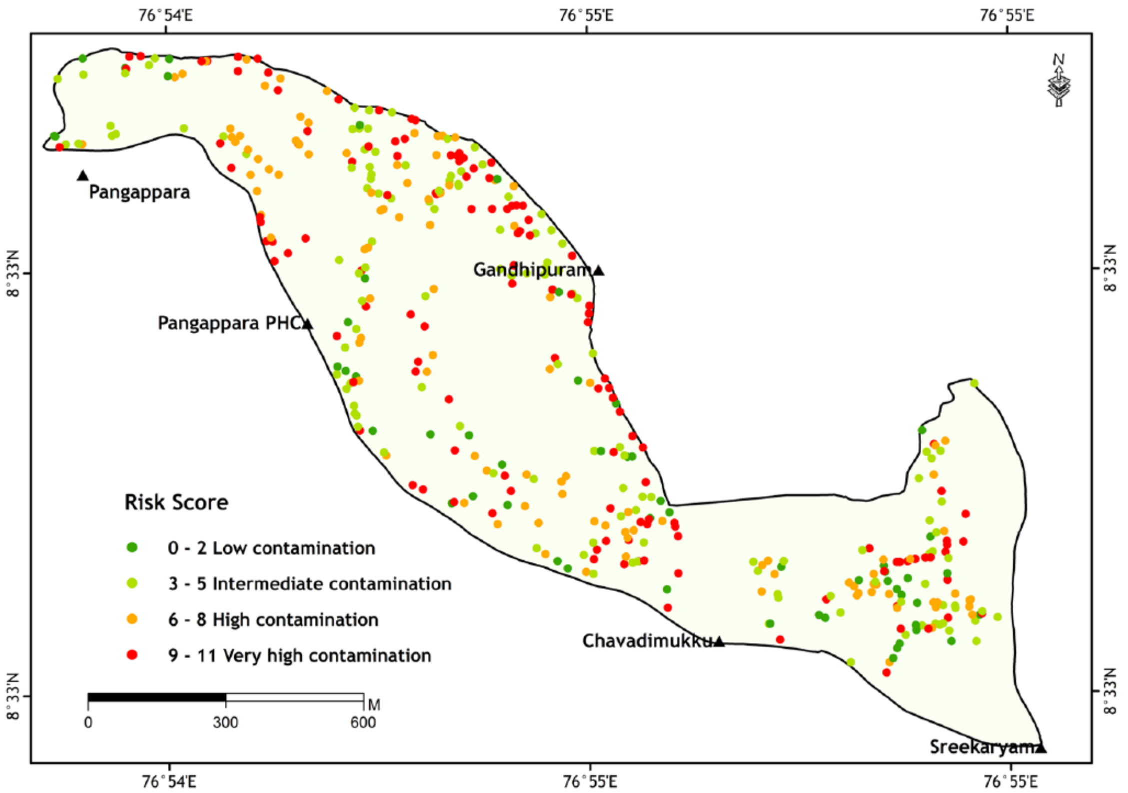

Figure 3. Spatial distribution of contamination risk score of each well in the study area. Red dots denote the wells with highest risk of contamination, and green dots the least risk.

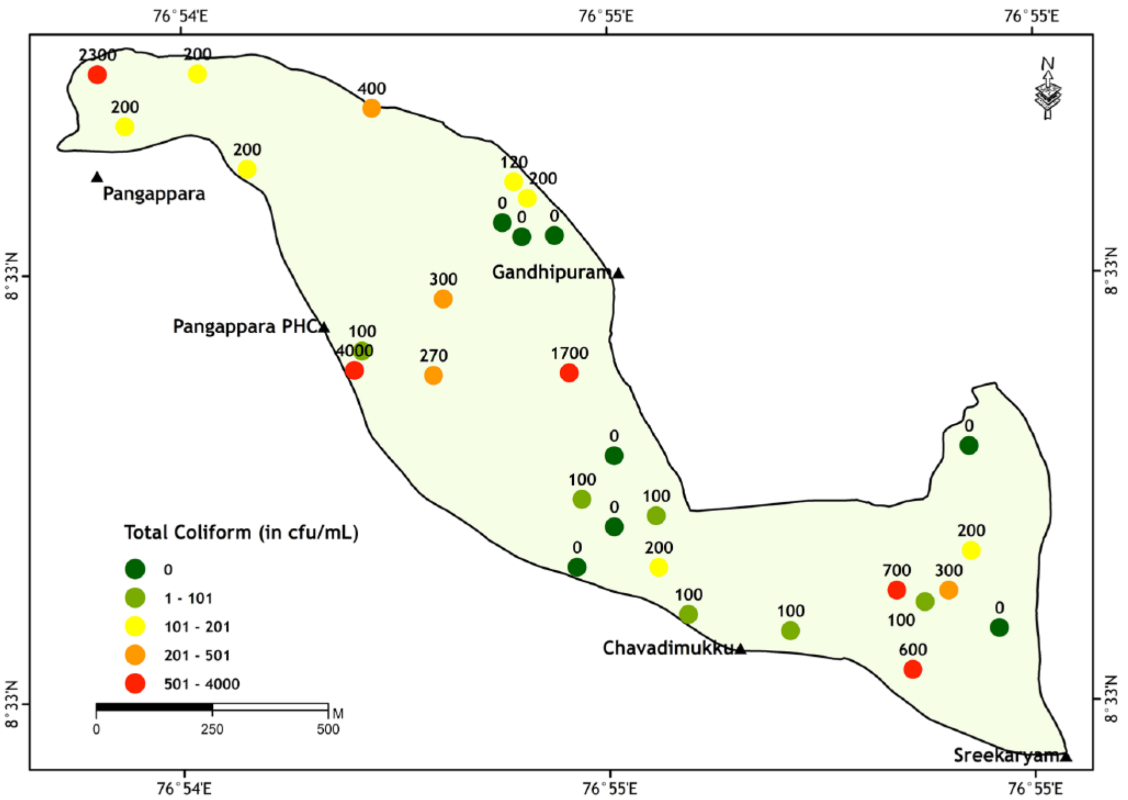

Figure 4. Distribution of coliform contamination in the sampled wells (n = 30). Red dots are the wells with highest coliform load. Dark green dots denote wells free of coliforms.

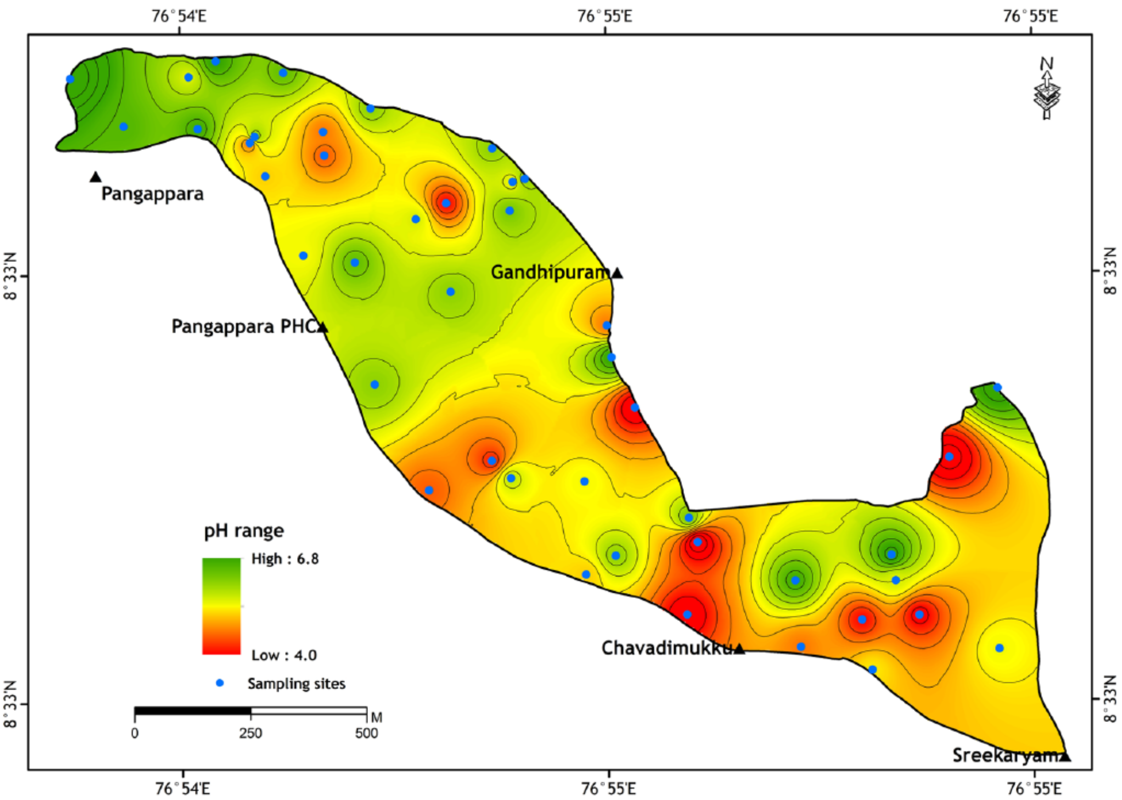

Figure 5. Spatial distribution of well water pH of the study area. Green color depicts a pH close to the normal recommended range and orange to red shows highly acidic well water.

Table 3. Abnormal parameters found in water chemistry analysis.

PARAMETER	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	FREQUENCY (%) OF ABNORMAL PARAMETERS	NORMAL LIMITS (WHO)
pH	5.40	0.70	4.00	6.80	95.91	6.5-8.5
Electrical conductivity (μS/cm)	162.40	86.60	39.90	514.00	6.12	300
Total dissolved solids (ppm)	158.10	87.20	30.70	500.00	2.04	500
Total alkalinity (mg/L)	30.0	20.94	15	130	2.04	120
Aluminum (ppb)	35.31	134.33	2.92	871.21	2.04	50-200
Copper (ppb)	3.26	3.86	0.86	11.01	70	1.5

associated with the contamination by coliforms (P value <.05; Table 4).

A Multiple regression model is used to predict the coliform contamination in the household wells by using contamination risk score, septic tank proximity, frequency of chlorination and cleansing. However the level of significance was not sufficient. In the regression analysis, the coliform count is taken as dependent variable, and proximity of septic tank to well, frequency of chlorination in months, frequency of well cleansing in months, and contamination risk score are taken as independent variables. The derived regression equation could be written as follows

$$\begin{aligned}\text{Coliform count} = &-0.455(\text{distance from septic tank}) \\ &+-0.335(\text{frequency of well cleansing in months}) \\ &+0.337(\text{frequency of well chlorination in months}) \\ &+0.369(\text{contamination risk score})\end{aligned}$$

Discussion

This study was conducted to assess the sanitary conditions and groundwater contamination of an urban area in Trivandrum and to map the findings spatially using GIS. Deviating from the popular notion that most of the urban households in Kerala depended on Kerala Water Authority (KWA)-supplied tap

Table 4. Bivariate analysis.

VARIABLE	COLIFORM-CONTAMINATED WATER	WATER WITH NO COLIFORMS	*P* VALUE
	MEAN (SD)	MEAN (SD)	
Chlorination (in months)	15.27 (12.96)	4.50 (4.10)	.002*
Cleansing (in months)	19.91 (13.14)	7.62 (5.80)	.002*
Distance from septic tank (in meters)	7.68 (2.40)	31.76 (13.13)	.001*

*significance.

water,[15] this study showed that most of the households in the study area depended on well water for domestic and peridomestic purposes.

Kerala has emerged in a big way from the 1980s, when half of the households in Kerala had no protected water supply and latrines.[16] In this study, the entire households had access to some form of water supply, and all of them had latrines. The sanitary condition of the wells though was inadequate in about half of the study units in this study, thus making them at risk for contamination. Although the sanitary condition of the wells as such was not remarkable, almost all of the households practiced some kind of water filtration/purification method.

Bacteriological contamination in the form of coliform organism poses a serious public health threat. Coliforms can cause a wide range of water-borne diseases ranging from diarrhea to urinary tract infections. Diarrhea is the leading cause of death in children under 5 years around the globe. A study conducted by Centre for Water Resources Development and Management (CWRDM), Kozhikode, indicates that 70% of the drinking water wells of Kerala have fecal contamination, which is at par with the results of this study (73.7%).[6,13] The cause of contamination is attributed to close proximity of latrines to wells, unhygienic usage of the wells, utilizing the adjacent area of wells for waste disposal and other purposes, thus making the water unfit for use, resulting into water-borne disease. The permitted minimum distance from a dug well to the septic tank is 15.24 m according to United States Housing and Urban Development, which is adopted by most of the developed countries around the globe.[18] In chapter 16 of Kerala Building Rules, the minimum distance between a well and a septic tank is fixed as 7.5 m.[19] Poor town planning and dilapidated well infrastructure add onto the bacteriological contamination. The distance from the nearest septic tank was measured here, which need not be the septic tank of the same household, owing to the thickly populated study area. The distance from the well to the septic tank has significant negative correlation in an earlier study[19] as well as in this study. Also, a quarter of the households had distance between well and the septic tank less than the prescribed standards set for urban areas of Kerala. Separate maps were made, which depict proximity of wells with the nearest septic tank and distribution of coliform contamination. The well chlorination and well cleaning practices by the households were also grossly inadequate and have shown a significant association with the coliform contaminations in the study area.

There are many studies about the physicochemical and bacteriological quality of groundwater in Kerala. The pH of water that is supplied by KWA has a mean ± SD of 7.17 ± 0.58 as obtained from a previous state-wide study.[19] A study conducted by the Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore[19] states that the groundwater in some areas of Trivandrum has a low pH as per World Health Organization (WHO) and BIS standards. This study also yielded similar result, but with an even lower pH range. At the same time, very few samples were within normal pH range. All other chemical parameters were within normal limits. Districts like Palakkad and Alappuzha had foci of chemical contamination of groundwater resulting in hard water, but the district of Trivandrum was relatively free of chemical or heavy metal contamination[20] except pH. Heavy metal presence was also searched for, but all metals except Al and Cu found in water samples were within normal limits. A study showing the relationship between aluminum and pH points to the risk of developing chronic diseases like arthritis, osteoporosis, and cardiovascular diseases owing to the consumption of long-term acidic water.[21] Aluminum toxicity is studied to cause encephalopathy, Alzheimer diseases, renal toxicity, and osteoporosis,[20] whereas copper in excess can be an irritant in an acute exposure and can lead to renal disorders in a long term.[22]

Summary and Conclusions

Dug wells still remain as a major source of drinking water in the study area. But, the sanitary conditions of the wells are a matter of concern, with 73% of the wells contaminated with coliform organisms. The reasons for the coliform contamination brought out from the study are the close proximity of septic tanks with the wells and inadequate chlorination and cleansing activities by the households. The pH of groundwater is also found to be low as per BIS and WHO standards.

With all these risk factors prevalent in the study area, water-borne diseases are probably kept at bay by the widespread boiling and filtering practices adopted by the households. Nevertheless, the study area is at high risk of water-borne epidemics, and urgent remedial measures must be taken. Initiatives with the active participation of the community like a mass cleanliness campaign, well chlorination campaign, and awareness and health education campaigns may be conducted as maintaining a proper sanitary well is the most cost-effective preventive measure against water-borne diseases. Such campaigns have to be supplemented with regular practice, monitoring, and evaluation of effectiveness of chlorination. Addition of lime can help in neutralizing the acidic well water. Also, house building rules should be made more stringent to reduce potential contamination of well. In urban areas, where the land is limited, KWA-supplied water use may be encouraged and polluting sources should be identified and remedial measures be taken accordingly.

Novelty of the study

Although there are few previous research works on the groundwater quality in Kerala, there is no spatial study that discusses the household groundwater contamination and health risk factor done in GIS platform. Geographic Information System proves to be an efficient tool in analyzing nearby contamination sources of a well, which may otherwise be difficult to assess owing to the physical barriers.

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Author Contributions

Design of Study: MA, RR, A-A L, MH, VS, VP, ZTN. Acquisition of Data: MA, RA, A-A L, MJV, MH, MS R, KB S, SS, SK D, AJJ, DS K, ISI. Analysis of Data: MA, RR, A-A L, MH, VP, ZTN. Interpretation of Data: MA, RR, A-A L, MH, VP, TS A, ZTN. Writing of Article: MA, RR, A-A L Critical Review of Article: VS, VP, TS A, ZTN.

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