Analyzing the Factors Contributing to Bacterial Contamination of Domestic Water Sources in Estuarine Islands of Coastal Karnataka, India

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ABSTRACT: Contamination of domestic water sources is a major concern in estuarine islands of coastal Karnataka. Awareness about practices for waste management and protection of water sources on these islands is poor. Using water having bacterial presence for domestic purposes can lead to various health risks in humans. The research investigates various factors leading to bacterial contamination of domestic water sources at Mudukudru island of Swarna river, in the Udupi district of Karnataka. Samples were collected during the Pre-monsoon (December–May) and Monsoon (June–September) seasons from 43 wells of individual houses on the island. The total concentration of bacteria, in the water samples was determined from microbial analysis. The multiple tube, most probable number (MPN), fermentation technique was adopted to determine the total coliform in the samples. Factors like the presence or absence of well lining, well housing, wellhead above or below ground level, the distance of well from sewage pits, and the distance of livestock from the wells were correlated. The results indicated bacterial contamination in 32 wells during the monsoon as compared to pre-monsoon data, with the total coliform count exceeding the standard of 500 MPN/100 mL. A significant relation between total coliform count in the water samples and the absence of well lining with sanitary protection is observed with p-value = .00 ($p \leqslant .05$) and wells located near (<10.0 m) to sewage pit with p-value $\leqslant .05$, were recorded respectively during both the seasons of sampling. The study highlights the major factors leading to bacterial contamination of wells on the island. Awareness about the planning of domestic wells through community-driven programs and hygiene education can be beneficial for the sustainable future of these islands.

KEYWORDS: Well protection, estuarine islands, microbial analysis, well contamination, domestic water

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Introduction

As per UNICEF, in India safe and quality drinking water is available to less than half the population (JMP, 2021). Bacterial contamination of water leads to the spread of water-borne diseases like dysentery, diarrhea, typhoid, gastroenteritis, and viral hepatitis diseases, affecting children and often people with a low immune system (Li et al., 2021). It is reported that more than 25% of the global health-related issues are due to a lack of awareness of sanitation and hygiene. Control measures should be taken to restrict the causes (Gwimbi, 2019). The probable cause of contamination of groundwater with fecal and total coliform could be due to leaching of effluents from the septic tank or sewage pits, the insinuation of domestic or wild animals' excreta, and runoff from agricultural grounds (Sasakova et al., 2018). As specified by the Central Pollution Control Board (CPCB) India, the fecal coliform concentration in domestic water sources shall be within the range of 500 MPN/100 mL (CPCB, 2000). The Bureau of Indian standards IS:10500, 2012, specifies nil value for the presence of coliform bacteria in drinking water (BIS, 2012).

Estuarine islands witness constant variation in the quality of groundwater due to tidal effects. Seawater intrusion influences the salinity of well water on the islands, with peaks in summers (Yan et al., 2015) and low during monsoons (Valiela et al., 2012). The soil in the island is mostly unconsolidated sediments which may easily allow contaminants to percolate and affect the aquifers through soil or surface runoff directly. Anthropogenic activities like waste management and planning of water sources should be considered to avoid contamination of the well water. The quality of well water is influenced by the physical characteristics of a well such as well lining, wellhead above or below ground level, and well housing. The proximity of wells to contamination sources like livestock and sewage pits can greatly impact the quality of the water sources.

The study aimed to investigate the factors leading to bacterial contamination of domestic water sources. Microbial analysis of well water samples was conducted during the pre-monsoon and monsoon to understand the seasonality of coliform presence in well water, due to precipitation and increase in the water table on the island (Atherholt et al., 2017). Selection criteria for identification of wells were based on the presence of well lining, wellhead, well housing, and distance of well from sewage pits, and livestock. (Gonzales, 2008) The wells having >500 MPN/100 mL, were correlated with other factors to arrive at the major contributor to the contamination of the wells.

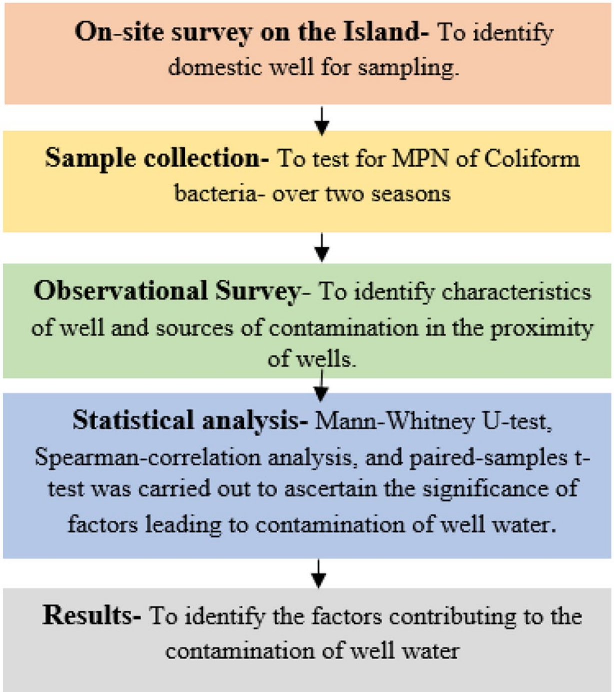

Figure 1. Outline of methods followed for the study.

Materials and Methods

Figure 1 shows the flow chart of methods followed for analyzing the factors contributing to bacterial contamination of domestic water sources on the island.

Study area

Mudukudru (13°24″21.46″ N, 74°43″35.01″ E), is a river island located in the estuary of the Swarna-Sita composite river system (Figure 2), where river Swarna meets the Arabian Sea. The island is the largest among the 15 islands in the estuary, having a total area of 632,523.659 sqm. and a perimeter of 4.75 km. (Satyaprakash Das, 2020). The island is administered by the Kallianpur Grama Panchayat of the Udupi District. It is 2.5 km from the sea and is located in Coastal Regulation Zone-III (CRZ-III). The region experiences two seasons, that is, Summer from February to May, and Monsoon from June to September (Kumar, 2012). The island has 112 dwelling units and a total population of 296 people, with the majority of the residents being fishermen. Public water supplies and wells are among the island's domestic water sources. During the summers, public water supply from the mainland is meager and intermittent, resulting in a scarcity of domestic water on the island. This forces the residents to rely on the well water.

Method of analysis

A survey was conducted on the island to identify the households with wells used for domestic purposes. The field wells used for agriculture or fishing activities were not included in the study. Out of 112 dwellings, 43 wells (Figure 3) were selected for the study based on the selection criteria.

Consent for the collection of water samples was obtained from local authorities and individual households. Samples were collected (Figures 4 and 5) over two seasons, that is Pre-monsoon and Monsoon for better reliability of data and to understand the influence of anthropogenic and physiological changes happening due to seasonal variations.

Groundwater samples from 43 wells were collected in 200 mL sterilized bottles from various locations on the island adhering to the prescribed methods in IS 1622 & IS 3025 (Part-1). The bottles were labeled with the well number and GPS coordinates for identification purposes. The samples were sent to the laboratory within 2 hours of collection and stored at 4°C adhering to the standard operating procedures entailed by Scientific Engineering Response and Analytical Services (SERAS). The total coliform concentration in the samples was tested using, Multiple tube most probable number (MPN) fermentation techniques, with the enzyme β-D-galactosidase (APHA, 2005).

Parameters for protection of well water such as well depth (above 3 m = 1; below 3 m = 2) well lining (sanitary protection present = 1; absent = 2), wellhead (above ground level = 1; below ground level = 2), and contamination sources such as distance from sewage pits (above 10 m = 1; below 10 m = 2) and presence of livestock in close proximity to well (present = 1; absent = 2) were investigated and quantified (Ye et al., 2013).

To explore the relationship between well depth and bacterial contamination, paired-samples *t*-test and Spearman correlation analysis was used and to test the differences between the explanatory groups (well lining, wellhead, wellhead housing, and sources of contamination) Mann-Whitney U-test was used.

Results and Analysis

Bacterial contamination in domestic water

The concentration of total coliform in the water samples collected ranged from 49 MPN/100 mL to >2,400 MPN/100 mL. It was found that during the pre-monsoon period 22 out of 43 wells were contaminated with higher MPN count whereas, during the monsoons, the number of contaminated wells raised to 32 (Table 1). Figures 4 and 5 illustrate the distribution of bacterial contamination of well water samples during pre-monsoon and monsoon respectively. As per WHO, the total coliform bacteria count in public drinking water must not be detectable in any 100 mL sample (WHO, 2008). The Central Pollution Control Board, India recommends that the permissible limit of Total Coliform (TC) per 100 mL shall not exceed 500 MPN in water used for domestic purposes like bathing, washing clothes, and bathing cattle. (CPCB, 2000).

Influence of well characteristics

Well characteristics like well lining present with sanitary protection or not, wellhead above or below ground level, presence, or absence of well housing, and well depth was chosen to investigate

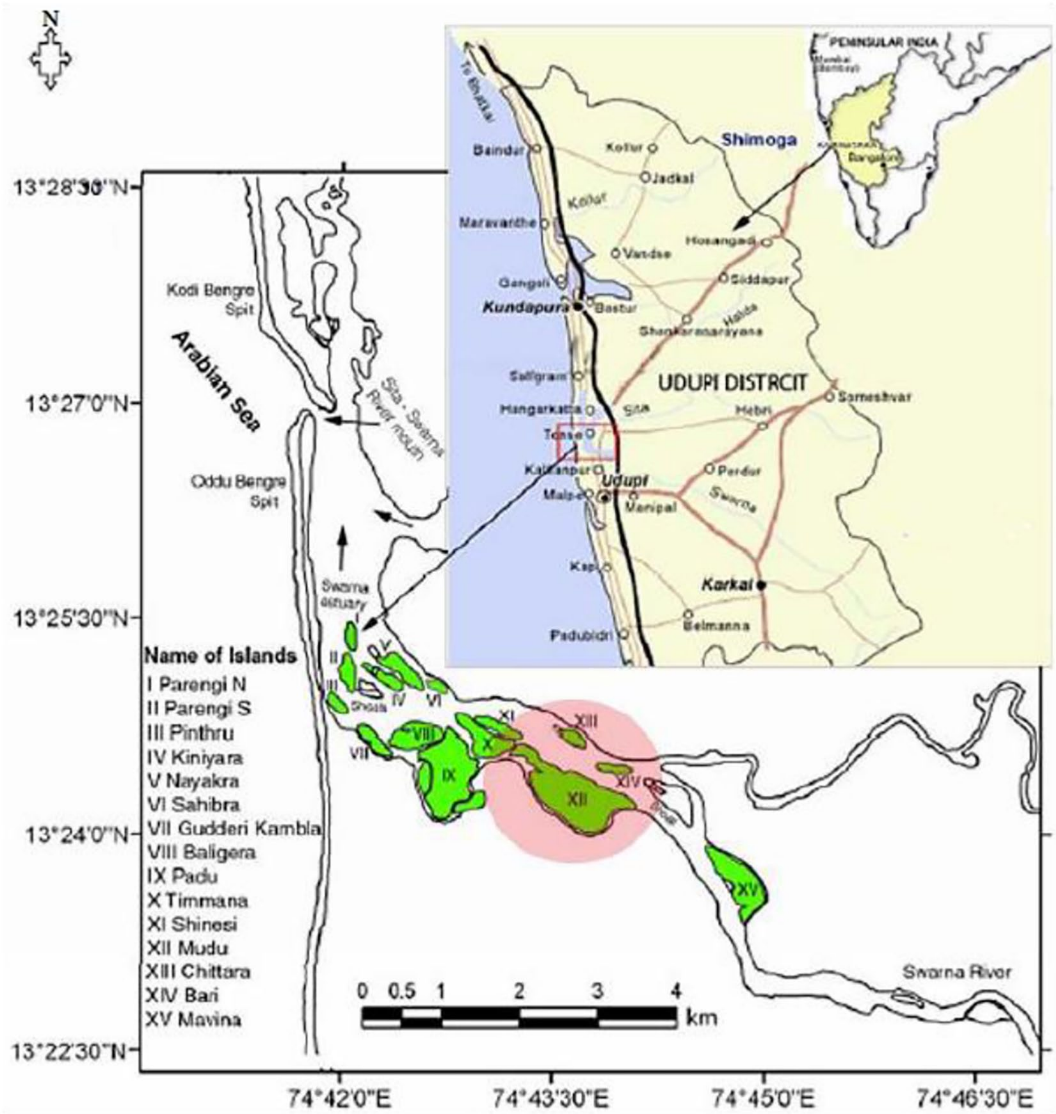

Figure 2. Showing the location of Mudukudru (XII), along with all the 15 Islands of the Estuary of Swarna-Sita composite river system.

bacterial contamination caused due to well characteristics (Nayebare et al., 2022). The results of the Mann-Whitney U-test, Spearman-correlation analysis, and paired-samples t-test, of the well characteristics and bacterial contamination, recorded over two seasons are shown in (Table 2).

As mentioned in (Table 2), the Mann-Whitney U test illustrates that the type of well lining, that is, whether the well is having sanitary protection or not, has significantly influenced the bacterial contamination with p-value .00 ($p \leqslant .05$) during pre-monsoon and monsoon seasons. It was observed, 44% of wells without sanitary protection had bacterial contamination in the water. Well lining or well protection wit sanitary lining, is an important factor that acts as a barrier to the leaching of contaminants around the wells.

Wellhead protection is another important factor as it does not allow the surface run-off water to enter into the wells. The results show there is no significance having (p-value = .203) with this aspect as the observation says that 98% of the wells on the island had a wellhead above the ground, however well housing has no significance during pre-monsoon but has shown significance during monsoon season with p-value .002 ($p \leqslant .05$). The result obtained from the paired-sample *t-test* for the depth of the well with the bacterial concentration shows that it has significance having p-value = .00 ($p \leqslant .05$) during both seasons (Ye et al., 2013).

Influence of contamination sources around wells

In a setting like an Island, contamination sources like the presence of sewage pits or livestock can affect the water quality of wells. Contamination sources like sewage pits and the presence of livestock were explored. As shown in (Table 3) the Mann-Whitney U test shows a strong significance for the presence of sewage pits over the MPN concentration during both seasons recording p-value = .001 during pre-monsoon and p-value = .007 during monsoon. The distance of livestock shows significance only during monsoon season recording p-value = .003. During monsoon, it was observed that the wells that were near the

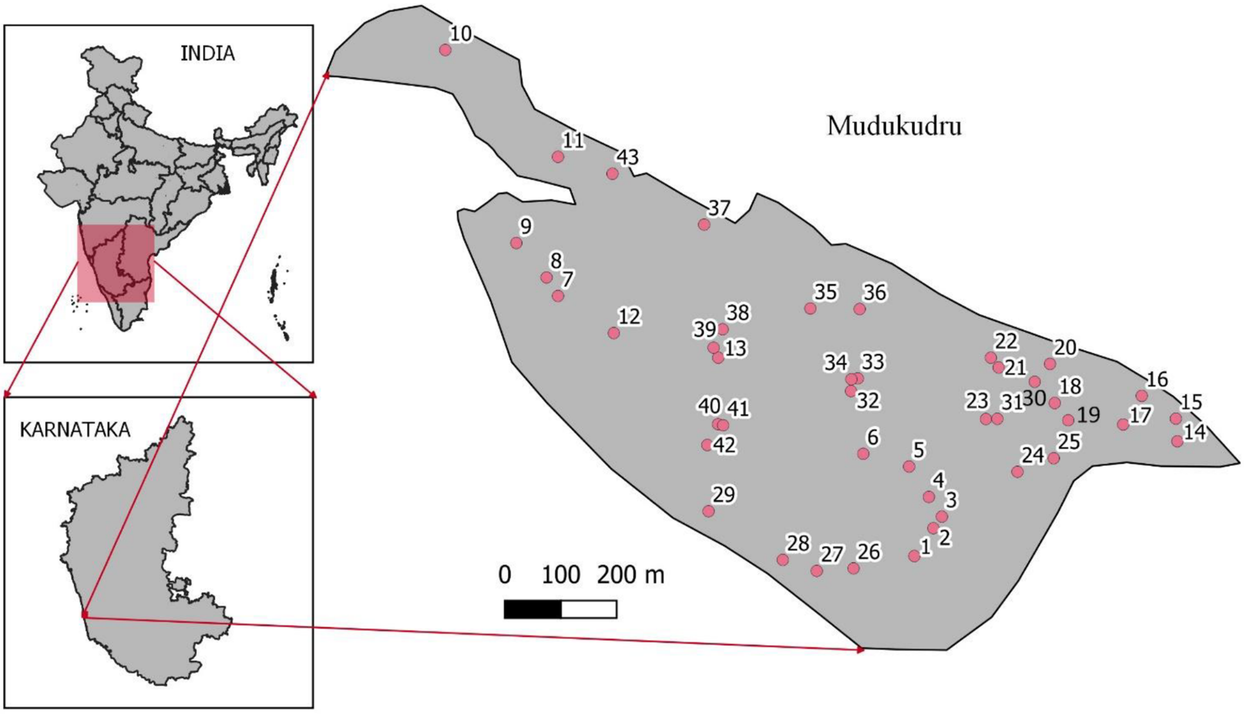

Figure 3. Map of sample sites.
Source: Author.

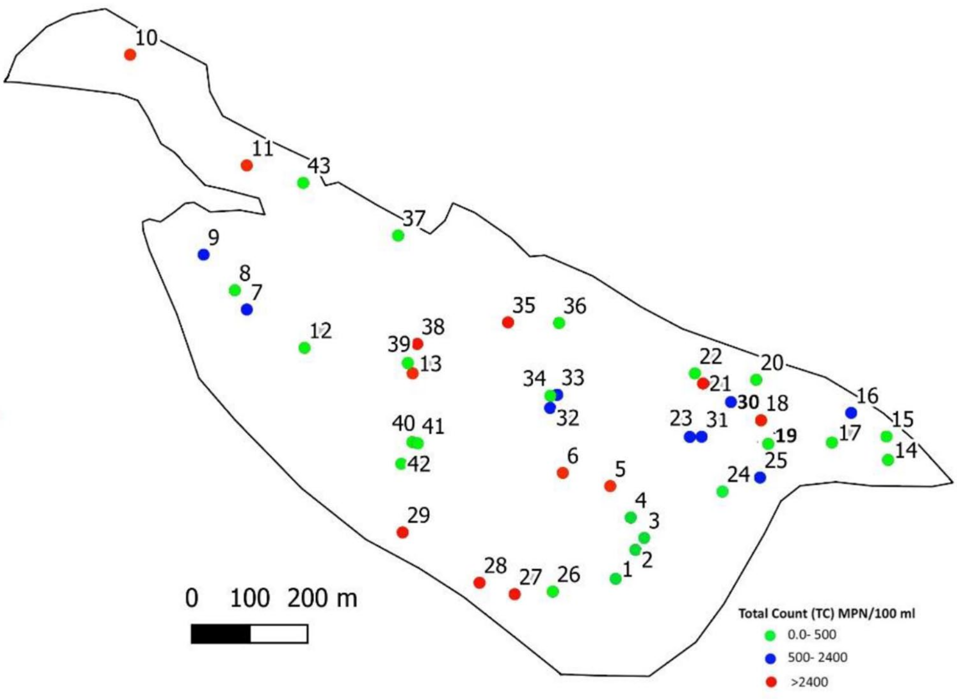

Figure 4. Bacterial contamination in well water samples during Pre-Monsoon.

sewage pits (<10.0 m) indicated a higher concentration of coliform bacteria.

The well water samples collected indicated the presence of bacterial contamination both during, pre-monsoon and monsoon seasons. The total coliform recorded during pre-monsoon ranged between 49 MPN/100 mL and >2,400 MPN/100 mL, similarly during monsoon, the range varied between 180 MPN/100 mL and >2,400 MPN/100 mL.

Well characteristics such as well lining, depth of well, and presence of sewage pits were the major contributors to bacterial contamination of the wells. From the study, it was observed that the prevalence of bacterial contamination during monsoon

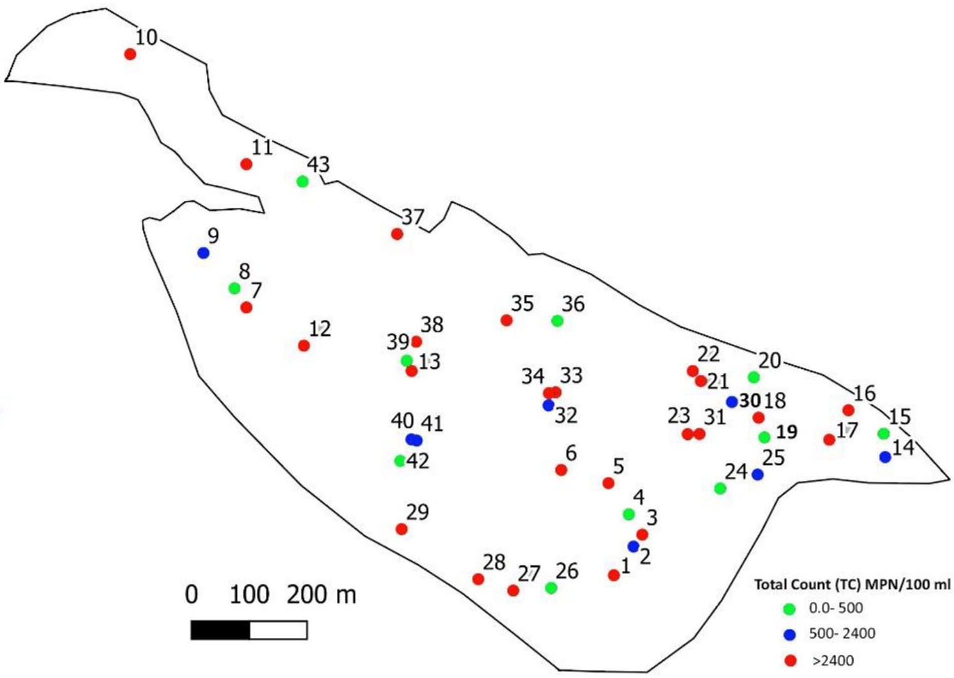

Figure 5. Bacterial contamination in well water samples during Monsoon.

is significantly higher compared to the pre-monsoon season. From the study, it was observed that 27 out of the 43 wells, did not have sanitary protection out of which 89% were found to have bacterial contamination. Eighteen wells were found to be in close proximity (<10.0 m) to sewage pits out of which 94% were found to have bacterial contamination. This shows that the distance of the sewage pit has a major influence on coliform bacterial contamination.

Discussion

The study in the context of the estuarine Islands is one of its kind where the phenomenon of bacterial contamination of domestic water sources has been investigated. Contaminated water poses health risks and has a detrimental impact on the growth of a community. The physical environment has a major influence on the quality of water, therefore the water sources must be protected and conserved.

The study explores the correlation of well characteristics and contamination sources with the total coliform levels observed in the samples. The higher values of coliform during the monsoon season indicate a higher rate of leaching of contaminants through the ground resulting in contamination of wells (Custodio, 2000). A study testing the "microbial quality of well water" in rural and urban areas of the Udupi district revealed the presence of fecal contamination in the well water samples. It entails further research to identify the sources of contamination (Mukhopadhyay et al., 2012). Another study conducted in Beijing, China indicated high contamination due to the presence of dry toilets in the vicinity of the wells. The absence of well protection and well housing also contributed to contamination levels (Ye et al., 2013). Another similar study conducted in rural villages of Mohale Basin, Lesotho, showed bacterial contamination of drinking water sources due to lack of well protection, livestock in close proximity to the source, unhygienic practices, and poor waste management, which had a significant impact on the health status of the population (Gwimbi, 2019).

The study is significant in the broader context of planning and management of water sources in river islands. Efficient management of water resources is crucial to the ecosystem which helps in building resilience for a sustainable future. In the study, the microbial analysis of samples was limited to arriving at the total coliform (TC) value. Although fecal coliform like Escherichia coli was not tested in the samples, the total coliform value was considered to be useful to determine the microbial value of well water. Other factors like, well water pH, water temperature, soil type, vegetation, socio-economic cultural background, and agricultural practices of the population was not studied in this research, which can be further examined for justifying the contamination levels. The study's scope was limited to the collection of samples from only one island. Therefore, samples from neighboring islands can be investigated further to determine the degree of bacterial contamination of water sources.

Conclusions

It was observed that improper sewage waste management on the island led to the contamination of water sources, affecting the health and hygiene of the inhabitants residing on the island. Regular monitoring of well water at the source, along with community-driven programs focusing on creating awareness for hygiene education and strategies for waste management and treatment methods for the protection of water sources on the island is suggested.

Table 1. Descriptive Statistics of Bacterial Contamination (Total Coliform) in Well Water Samples Over Two Seasons.

WELL NO.	PRE-MONSOON	MONSOON	CO-ORDINATES
	TOTAL COLIFORM MPN/100 ML	TOTAL COLIFORM MPN/100 ML	
Well-1	140	>**2,400**	13.4026820, 74.7287203
Well-2	350	**920**	13.4031321, 74.7290341
Well-3	**540**	>**2,400**	13.4033187, 74.7291736
Well-4	280	350	13.4036363, 74.7289593
Well-5	>**2,400**	>**2,400**	13.4041259, 74.7286324
Well-6	>**2,400**	>**2,400**	13.4043304, 74.7278757
Well-7	**920**	>**2,400**	13.4068704, 74.7228365
Well-8	180	180	13.4071694, 74.7226471
Well-9	**920**	**1,600**	13.4077242, 74.7221475
Well-10	>**2,400**	>**2,400**	13.4108368, 74.7209724
Well-11	>**2,400**	>**2,400**	13.4091158, 74.7228335
Well-12	240	>**2,400**	13.4062735, 74.7237572
Well-13	>**2,400**	>**2,400**	13.4058789, 74.7254815
Well-14	240	**920**	13.4045381, 74.7330587
Well-15	220	350	13.4049034, 74.7330336
Well-16	**540**	>**2,400**	13.4052706, 74.7324700
Well-17	350	>**2,400**	13.4048082, 74.7321639
Well-18	>**2,400**	>**2,400**	13.4051529, 74.7310337
Well-19	350	350	13.4042798, 74.7306360
Well-20	240	240	13.4057846, 74.7309555
Well-21	>**2,400**	>**2,400**	13.4057259, 74.7301083
Well-22	350	>**2,400**	13.4058828, 74.7299792
Well-23	**920**	>**2,400**	13.4048936, 74.7298994
Well-24	350	350	13.4040427, 74.7304208
Well-25	**1,600**	**1,600**	13.4042619, 74.7310186
Well-26	240	350	13.4024821, 74.7277175
Well-27	>**2,400**	>**2,400**	13.4024404, 74.7271106
Well-28	>**2,400**	>**2,400**	13.4026181, 74.7265504
Well-29	>**2,400**	>**2,400**	13.4034012, 74.7253239
Well-30	**920**	**1,600**	13.4056203, 74. 7,308,972
Well-31	**920**	>**2,400**	13.4048969, 74.7300872
Well-32	**920**	**1,600**	13.4053420, 74.7276730
Well-33	**920**	>**2,400**	13.4055472, 74.7277845
Well-34	350	>**2,400**	13.4055329, 74.7276776

(Continued)

Table 1. (Continued)

WELL NO.	PRE-MONSOON	MONSOON	CO-ORDINATES
	TOTAL COLIFORM MPN/100 ML	TOTAL COLIFORM MPN/100 ML	
Well-35	**>2,400**	**>2,400**	13.4066740, 74.7270003
Well-36	49	280	13.4066659, 74.7278133
Well-37	240	**>2,400**	13.4080249, 74.7252465
Well-38	**>2,400**	**>2,400**	13.4063371, 74.725553
Well-39	350	350	13.4060400, 74.7254037
Well-40	240	**1,600**	13.4048065, 74.7254791
Well-41	240	**920**	13.4047886, 74.7255633
Well-42	350	350	13.4044700, 74.7253028
Well-43	350	350	13.4088442, 74.7237337
Median	**540**	**2,400**	
Minimum	**49**	**180**	
Maximum	**2,400**	**2,400**	

The values in bold signifies, Total Coliform concentration in the water sample exceeds the standard value of 500 MPN/100 mL, as specified by CPCB, India.

Table 2. Mann-Whitney U test, paired-samples t-test, and Spearman-correlation analysis of well characteristics in relation to Total Coliform.

WELL CHARACTERISTICS	PRE-MONSOON DATA				MONSOON DATA			
	TC (TOTAL COLIFORM)				TC (TOTAL COLIFORM)			
	N	SUM OF RANKS	Z	*P*	N	SUM OF RANKS	Z	*P*
Sanitary protection present	16	189	−4.178	.00	16	139	−5.917	.00
No sanitary protection	27	757			27	807		
Well head above ground level	42	21.63	−1.274	.203	42	914.5	−0.846	.397
Well head below ground level	1	37.5			1	31.5		
Well housing present	15	260	−1.820	.069	15	218	−3.155	.002
No well housing	28	686			28	728		
Depth of well	43	-	−7.211	.00	43	-	−12.056	.00
		-	−0.101	0.52		-	0.069	.659

TC = Total Coliform; N = Number of samples; Z = Z value of Mann-Whitney U-Test; p = sig. (two-tailed); r = correlation coefficient of Spearman-correlation analysis; t = value of paired sample t-test.

Table 3. Mann-Whitney U test of the Sources of Contamination in the Proximity of Wells.

WELL CHARACTERISTICS	PRE- MONSOON DATA				MONSOON DATA			
	TC (TOTAL COLIFORM)				TC (TOTAL COLIFORM)			
	N	SUM OF RANKS	Z	*P*	N	SUM OF RANKS	Z	*P*
Distance of well from sewage pit $>$10 m	25	419	−3.290	.001	25	18.04	−2.694	.007
Distance of well from sewage pit $<$10 m	18	527			18	27.5		
Livestock	10	279	−1.73	.084	10	315	−3.016	.003
No livestock	33	667			33	631		

TC = Total Coliform; N = sample count; Z = Z value of Mann-Whitney U-Test; p = sig. (two-tailed).

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Author Contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Satyaprakash Das, Sanjana Shetty, and Rituka Kapur. The first draft of the manuscript was written by Satyaprakash Das and Dr. Nandineni Rama Devi, Dr. Suma Nair and Dr. Udaya Shankar H N have reviewed and commented at various stages of the manuscript writing. All authors read and approved the final manuscript.

Consent to Publish

I, the undersigned, give my consent for the publication of identifiable details, which can include photographs, and other details within the text to be published in the above Journal and Article.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval and Consent to Participate

Ethical clearance was taken from Kasturba Medical College and Kasturba Hospital Institutional Ethics Committee (Registra-tion No. ECR/146/Inst/KA/2013/RR-19) with certificate no.IEC:135/2021, for the collection of water samples from households and its microbial analysis. Informed consent was taken from local authorities as well as head members representing individual households, for the collection of water samples.

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