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Assessment of the impact of on-site sanitation systems on groundwater pollution in two diverse geological settings—a case study from India

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Abstract On-site sanitation has emerged as a preferred mode of sanitation in cities experiencing rapid urbanization due to the high cost involved in off-site sanitation which requires conventional sewerages. However, this practice has put severe stress on groundwater especially its quality. Under the above backdrop, a study has been undertaken to investigate the impact of on-site sanitation on quality of groundwater sources in two mega cities namely Indore and Kolkata which are situated in two different geological settings. The parameters for the studies are distance of groundwater source from place of sanitation, effect of summer and monsoon seasons, local hydro-geological conditions, and physico-chemical parameters. NO_3 and fecal coliform concentrations are considered as main indexes of pollution in water. Out of many conclusions which can be made from this studies, one major conclusion is about the influence of on-site sanitation on groundwater quality is minimal in Kolkata, whereas it is significant in Indore. This difference is due to the difference in hydrogeological parameters of these two cities, Kolkata being on alluvium quaternary and Indore being on Deccan trap of Cretaceous to Paleogene age.

Keywords Groundwater · On-site sanitation systems · Pollution · TDS · Nitrate · Fecal coliforms

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Introduction

Groundwater constitutes one of the principal sources of freshwater. On a global scale, it constitutes about 22.6% of the freshwater available in the earth. Groundwater is a principal source for irrigation and drinking in the rural India. It continues to be a reliable source for drinking and domestic use even in urban and peri-urban areas where there is no centralized water supply by the civic authorities. In view of the groundwater being used for potable purpose, it is desirable that the quality is maintained safe as per the recommended guidelines (BIS 1991). The groundwater quality is deteriorated due to geogenic as well as anthropogenic factors. Among the anthropogenic factors, the impact of on-site sanitation on groundwater quality has been a subject of much concern. The contamination of groundwater due to on-site sanitation systems has been reported by different authors since the 1980s (Lu et al. 2008; Pujari et al. 2007; Dzwairo et al. 2006; NEERI report 2005; Nsubuga et al. 2004; Lawrence et al. 2001;

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Chidavaenzi et al. 2000; Mallard et al. 1994; Andrews 1988; Canter and Knox 1985; Hagedon 1984; Dewalle and Schaff 1980; Lewis et al. 1980; Brown et al. 1979). It is reported that 25% of all housing units in the USA have on-site sanitation systems (Bunnels et al. 1999) and they are reported to be source of local and regional groundwater contamination in USA and elsewhere (Bunnels et al. 1999; Clawges and Vowinkel 1996).

Studies pertaining to impact of on-site sanitation systems on groundwater assume significant importance in India considering the fact that urbanization is on the rise and it is not possible to bring the entire city under centralized water supply and sewerage system. The high cost involved in providing conventional sewerage has led to increasing adoption of on-site sanitation especially in the peri-urban areas of big cities in India. The absence of centralized water supply leads people to depend on groundwater sources like bore-well, hand-pumps, and open wells to meet their drinking and domestic requirements. In view of the water being used for potable purpose, it is desirable that the impact of on-site sanitation system on groundwater quality be assessed and ensure the maintenance of its quality through proper intervention.

The groundwater contamination from on-site sanitation system vis-à-vis geological settings has been dealt by different workers since the 1980s. The hydrogeological factors, i.e., depth to water table, nature of the soil matrix, and lateral separation between the on-site sanitation and groundwater source are the key parameters affecting groundwater pollution (Lawrence et al. 2001; Lewis et al. 1980). Dzwairo et al. (2006) reported that groundwater samples collected within 25 m distance from pit latrines in Kamangira village in Zimbabwe were affected by the pit latrine. The parameters affected were the total and fecal coliforms, and nitrate. Similar findings have been reported recently by Pujari et al. (2007) and Lu

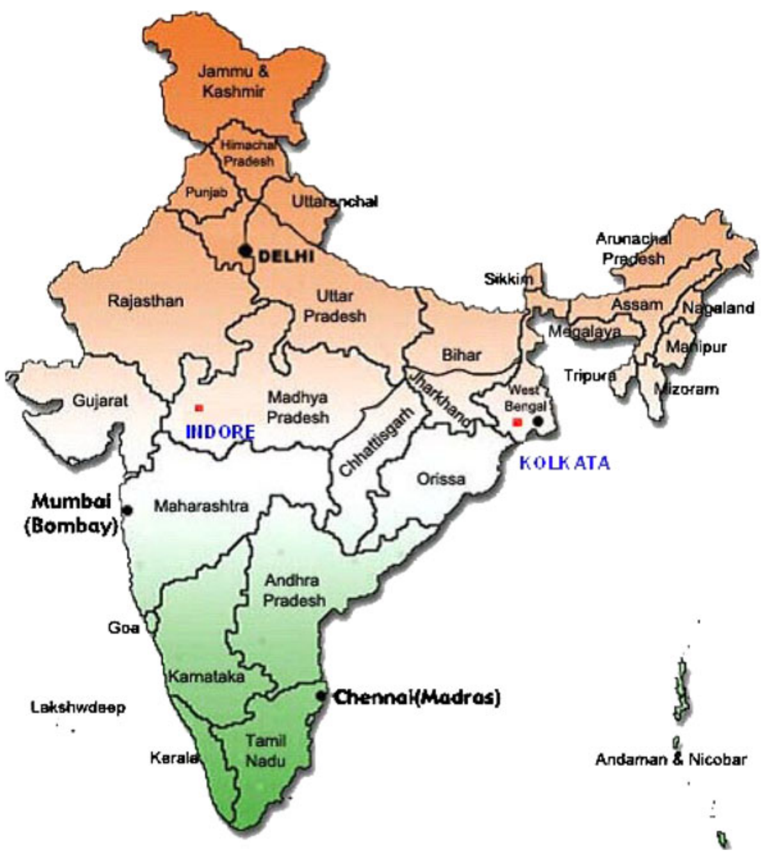

Fig. 1 Schematic map of India with the study areas (Indore and Kolkata)

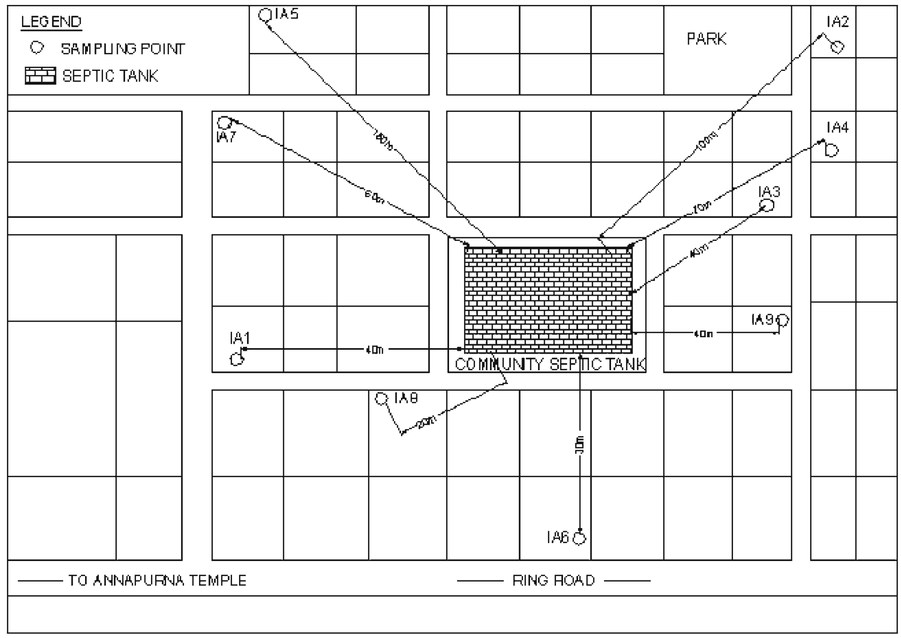

Fig. 2 Schematic map of sampling locations in Ahilya Nagar, Indore

et al. (2008) in studies carried out in China and India, respectively. Lu et al. (2008) reported elevated concentration of nitrate due to leaking septic tanks in China.

The present work is a comprehensive attempt to study the impact of on-site sanitation systems on groundwater quality in two different geological settings in India. The two cities, namely Indore and Kolkata are located in the hard rock basaltic region and Indo-Gangetic plains, respectively. The study was undertaken in summer (April 2002) and monsoon (August 2002) seasons to investigate the temporal variations in the concentration of contaminants in groundwater. The key objective was to find out if the groundwater quality is affected by the installation of on-site sanitation

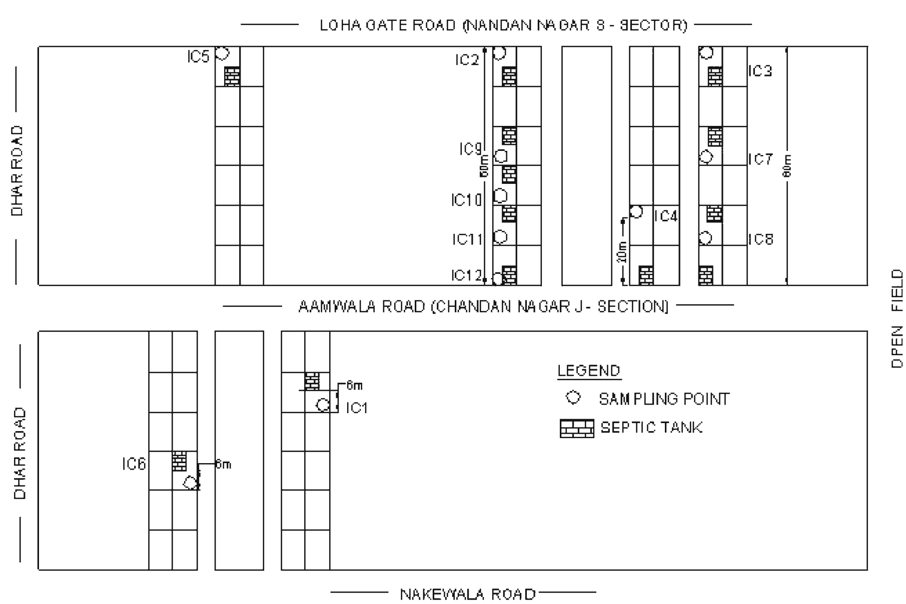

Fig. 3 Schematic map of sampling locations in Chandan Nagar Indore

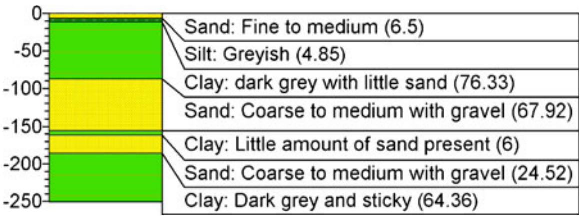

Fig. 4 Litholog from Bhatpara near the study area (Source: CGWB Eastern region 2001). The depth unit is meter

systems and whether the pollution level is affected by the underlying geology. Studies (Lawrence et al. 2001; Lewis et al. 1980) have indicated that chloride, nitrate, and fecal coliforms are the parameters affected by installation of on-site sanitation systems. The parameters considered as impact indicators were nitrate (NO_3) and fecal coliforms (FC). The incidence of water-borne disease was discussed with the inhabitants in the study areas during the sampling as well.

Study area

The study was undertaken in Indore and Kolkata cities (Fig. 1). Indore is located at latitude 22°44′ N and longitude 75°50′ E. It is one of the most important cities in Central India. The city has lot of commercial importance. The city experiences sub-humid tropical climate and receives well-spread rainfall (mean annual rainfall, 1,050 mm approximately) during the south-west monsoon. Geologically, the city is characterized by Indore formation belonging to the Deccan trap of Cretaceous to Paleogene age (68–62 my). The basalt flows underlie the black cotton soil, which has a thickness of 2.00 to 3.00 m. The region has ‘Aa’ and compound ‘pahoehoe’ basaltic lava flows. The upper portion of each flow is vesicular basalt whereas the lower portion is massive basalt (GSI 2002). Besides, fractures are present in the lava flows. Hydrogeologically, the depth to water table varies from 10–20 m below ground level (bgl) in summer (April 2002) to 5–10 m (bgl) in monsoon (August

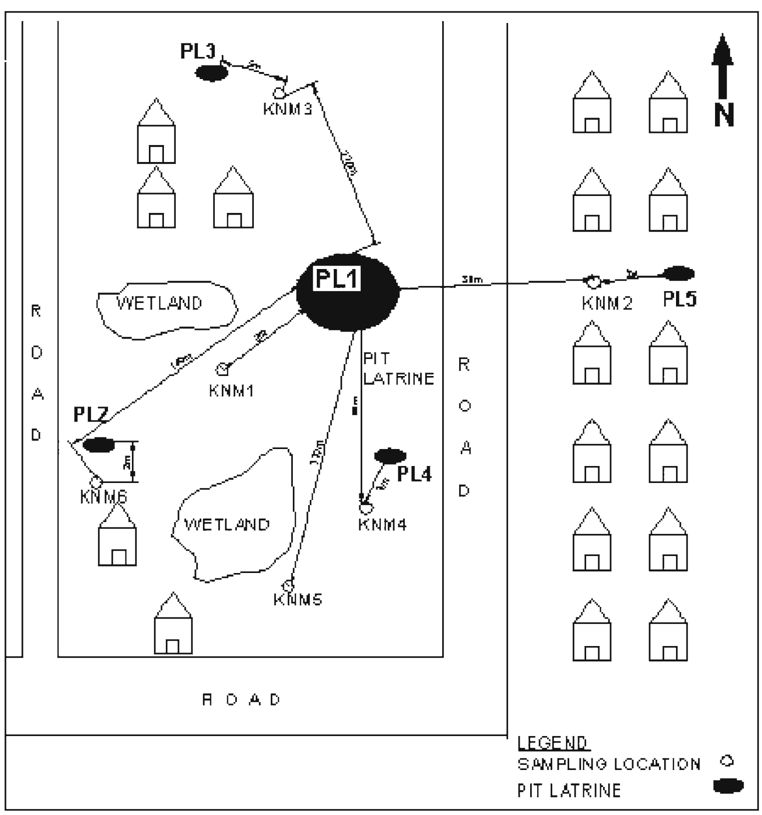

Fig. 5 Schematic map of sampling locations in Mathpara, Barrackpore, Kolkata

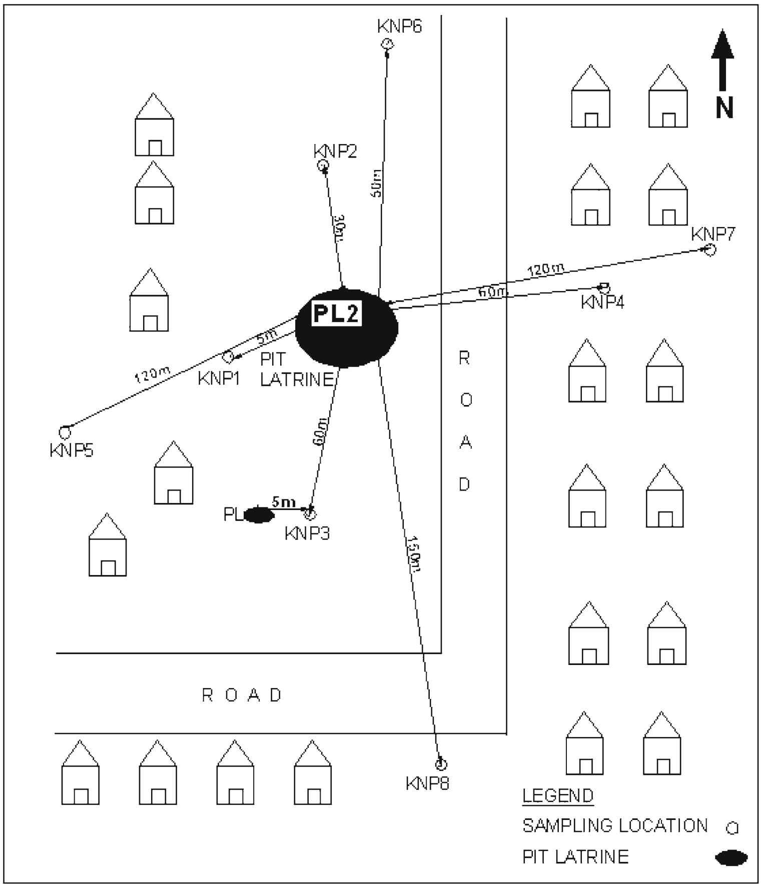

Fig. 6 Schematic map of sampling locations in Mathpara, Barrackpore, Kolkata

2002). The aquifer is of unconfined type. The aquifer has mostly secondary porosity in the form of fractures and the disposition of fractures and vesicular units govern the movement of groundwater flow. The region has moderate groundwater potential (GSI 2002).

Two sites, namely Ahilya Nagar and Chandan Nagar were selected in the city for analysis of groundwater quality. The site at Ahilya Nagar is

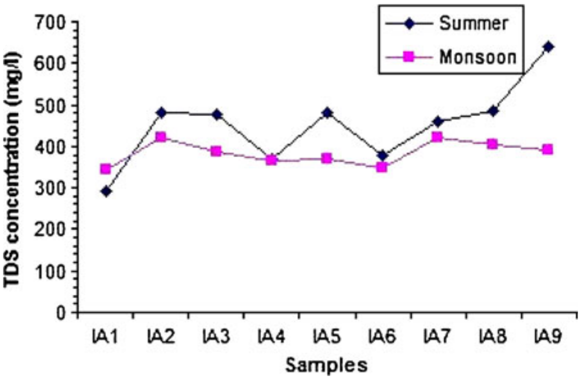

Fig. 7 TDS concentration in samples collected from Ahilya Nagar, Indore

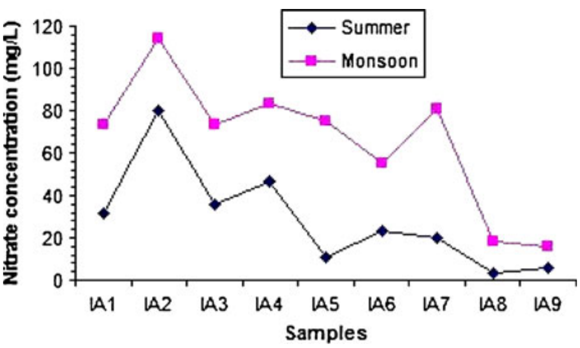

Fig. 8 NO_3 concentration in samples collected from Ahilya Nagar, Indore

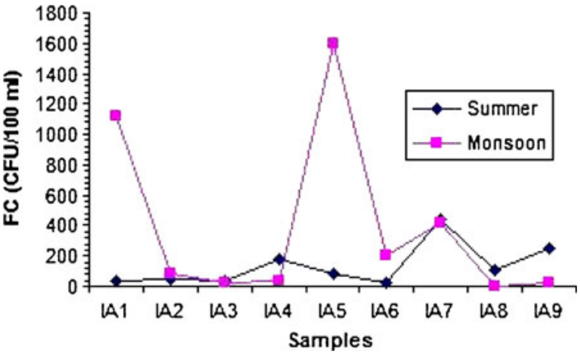

Fig. 9 FC concentration in samples collected from Ahilya Nagar, Indore

characterized by better sanitation and the area is inhabited by people from higher income group. The site has approximately 170 inhabitants. The domestic garbage is regularly transported from the community dustbins to the solid waste disposal site located in the outskirts of the city. The site has a community septic tank (Fig. 2) which is connected to the individual toilets. There are groundwater sources (open wells, hand-pumps) in the individual houses (Fig. 2). Groundwater is extracted from the unconfined aquifer to meet their drinking requirements. Nine (numbered 1–9) samples have been collected for analysis in Ahilya Nagar. In contrast, the site at Chandan Nagar (Fig. 3) is inhabited by people from the lower income group. The locality is densely populated as compared to Ahilya Nagar. The site has approximately 300 inhabitants. Besides, there is no proper sewerage system. The wastewater from houses is carried through open drains. The domestic solid waste are scattered in the locality in an unorganized way. Often, the effluent from the latrines is directly connected to the open drains. Six (numbered 1–6) samples were collected for analysis. The sampling points were close to the individual septic tanks. The locality is also supplied water by the civic authorities. However, the inhabitants are still dependent on the groundwater source for their drinking water requirements.

Kolkata is located at latitude 22°32′ N and longitude 88°22′ E. The city experiences a moderate climate with an average annual rainfall of 1,580 mm. It receives rainfall mostly from the southwest monsoon. Physiographically, the city forms the eastern flank of the Indo-gangetic plains. The surface deposits are mainly alluvium of quaternary to recent in age. It is underlain by clay lenses. The soil characteristics range from fine-loamy silt to sandy loam with intermittent clay lenses. Two sites (Mathpara and Palpara) have been selected for the study. Both the sites are part of Barrackpore Municipality of the North 24 Parganas district. The predominant form of sanitation is pit-latrines in the two selected localities. The aquifer occurs under both confined and unconfined conditions. A litholog (Fig. 4) collected near the area shows the continuation of alluvium up to approximately 250.0 m. The porosity is mainly of primary type as deciphered in the litholog (CGWB 2001). The study area has very good groundwater potential and the yield is of the order of 150 m^3/h. The un-confined aquifer is very shallow and thin (approximately 6.0 m) whereas the confined aquifer is deep and it extends from 90 to 150 m (Fig. 4). Interaction with the inhabitants indicated that the installed groundwater abstraction sources are tapping the deep aquifer in the zone (90 to 150 m depth) in the study area. Both the sites are inhabited by people from the lower income group.

There is no organized solid waste management at the site. Individual houses have pit latrines and there are open wells around the pit latrines (Figs. 5

Table 1 Critical parameters of samples from Ahilya Nagar, Indore

Parameters	Seasons	Samples									
		IA1	IA2	IA3	IA4	IA5	IA6	IA7	IA8	IA9	Avg
TDS (mg/L)	Summer	290	480	475	370	480	380	460	485	640	451.9
	Monsoon	345	420	385	365	370	350	420	405	390	356.7
NO_3 (mg/L)	Summer	32	80	36	47	11	23	20	3	6	28.66
	Monsoon	73	114	73	83	75	55	81	18	16	65.33
FC (CFU/100 mL)	Summer	40	45	36	180	80	26	440	112	250	134.3
	Monsoon	1,120	80	20	36	1,600	200	412	ND	24	388

Table 2 Critical parameters of samples from Chandan Nagar, Indore

Parameters	Seasons	Samples												
		IC1	IC2	IC3	IC4	IC5	IC6	IC7	IC8	IC9	IC10	IC11	IC12	Avg
TDS (mg/L)	Summer	670	485	790	720	805	770	590	880	750	700	700	720	715
	Monsoon	620	540	720	595	695	695	540	800	650	730	655	700	661.6
NO_3 (mg/L)	Summer	26	2	30	10	25	44	16	26	36	13	31	27	23.8
	Monsoon	52	12	50	158	31	57	35	54	45	50	18	43	50.4
FC (CFU/100 mL)	Summer	30	20	35	ND	420	ND	8	26	ND	20	4	2	47
	Monsoon	44	24	68	48	600	ND	24	20	48	200	20	ND	91

and 6). Fourteen samples (six from Mathpara and eight from Pal Para) were collected for analysis of groundwater quality. All the samples were in the vicinity of the pit latrines and hence they were representative from the pollution perspective.

Methodology

Study area has been selected in a city having on-site sanitation as the preferred mode of disposal of the excreta. It was also ensured that groundwater sources are available in the vicinity of the on-site sanitation systems. Sampling locations were identified in the vicinity of the septic tanks. For physico-chemical parameters, the samples were collected in pre-cleaned 500-ml polyethylene bottles. Groundwater samples were collected in 300-ml glass bottles for bacteriological parameters. The bottles were cleaned with double-distilled water before sampling. The samples were filtered by Whatman filter paper (No. 4) prior to their analysis in the laboratory. Temperature and pH were measured in the field itself using potable sensor from Eutech Instruments. NO_3 was measured using the UV visible spectrophotometer 118 (Make: Systronics). The physico-chemical parameters were analyzed by following the standard protocols (APHA 1998). The parameters namely Na, K, and Ca were analyzed by Flame Photometer (model—CL361). The detection limit for Na, K, and Ca are 0.5, 0.5, and 15 ppm, respectively. The bacteriological analysis was done by membrane filter technique. Fifty milliliters of the sample is used for colony formations. The analysis is done for both total coliforms (TC) and fecal coliforms. The bacterial contamination is measured in colony forming unit (CFU) per 100 mL. For TC, the processed sample is kept in the incubator, maintained at 37°C for 18 h, whereas for FC, it is maintained at 44.5°C in the incubator for 24 h.

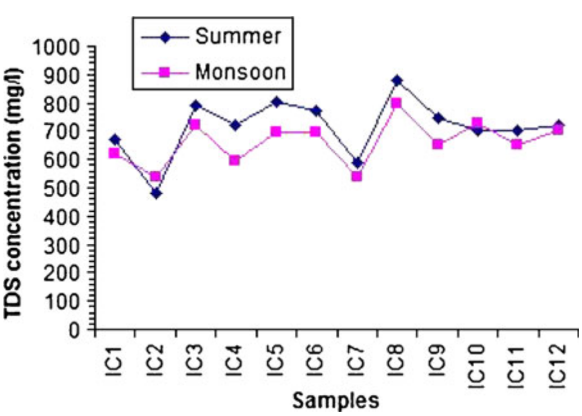

Fig. 10 TDS concentration in samples collected from Chandan Nagar, Indore

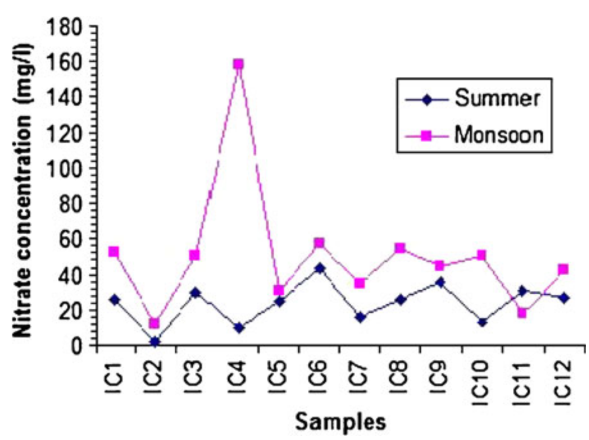

Fig. 11 NO_3 concentration in samples collected from Chandan Nagar, Indore

The samples collected are from the unconfined aquifer in Indore and the deep confined aquifer in Kolkata.

Results and discussions

Physico-chemical and bacteriological parameters were analyzed for all the samples in pre-monsoon and monsoon seasons. Studies (Lu et al. 2008; Dzwairo et al. 2006; Lawrence et al. 2001; Dewalle and Schaff 1980; Lewis et al. 1980) dealing with the assessment of on-site sanitation on groundwater quality indicate that the parameters likely to be affected are the nitrate, chloride, and fecal coliforms. Lawrence et al. (2001) reported that an estimated 4 kg/year of nitrogen is released per person and under aerobic conditions, a significant percentage of this nitrogen will be oxidized to form nitrate. It is also reported (Lawrence et al. 2001) that chloride (4 gm/day) is released per person through urine, feces, and sweat. Hence, groundwater source is vulnerable to nitrate contamination due to continuous loading of nitrate from on-site sanitation systems. Hence, any attempt to study the impact of on-site sanitation systems on groundwater should focus on critical parameters, namely, NO_3 and fecal coliforms. In the present study, the focus was only on parameters, namely, nitrate and fecal coliforms. The TDS were discussed to get an overall idea of the groundwater quality.

Indore

In Ahilya Nagar, the TDS, nitrate, and FC are presented in Figs. 7, 8, and 9, respectively. Regarding TDS, it can be noticed (Table 1, Fig. 7) that in general, the concentration is less in monsoon as compared to summer and it is within the permissible limit (2,000 mg/L) of BIS (1991). The average concentration in monsoon (356 mg/L) is less than that in summer (452 mg/L). The reduced concentration in monsoon can be attributed to the dilution taking place on account of recharge of the shallow aquifer due to the monsoon rains. However, the nitrate concentration (Fig. 8) presents a contrasting picture. The concentration level in monsoon (average 65 mg/L) is more as compared to summer (average 29 mg/L). This pattern has been observed in earlier studies also (Lawrence et al. 2001; NEERI report 2005; Pujari et al. 2007). It is evident that the nitrate concentration is with in the desirable BIS limit of 45 mg/L for all the samples in Ahilya Nagar except samples IA2 and IA4 during summer season. In Monsoon, all the samples exceed the desirable limit of BIS (1991) except samples IA8 and IA9. The decrease in summer season can be attributed to the lowering of the groundwater table wherein anaerobic condition is created and nitrate is partially converted to nitrogen (Lawrence et al. 2001). The fecal coliform concentration (Fig. 9) is in general more in monsoon as compared to summer. All the samples are contaminated by fecal coliforms in summer and monsoon except IA8, which is not contaminated in monsoon. The infiltration and recharge in the monsoon can lead to faster movement of the pathogens in the vadose zone, which is very thin (up to 4 m) and there are fractures in the rock matrix which serve as preferential pathways. As a result, they are likely to reach the water table at a faster rate in monsoon as compared to summer.

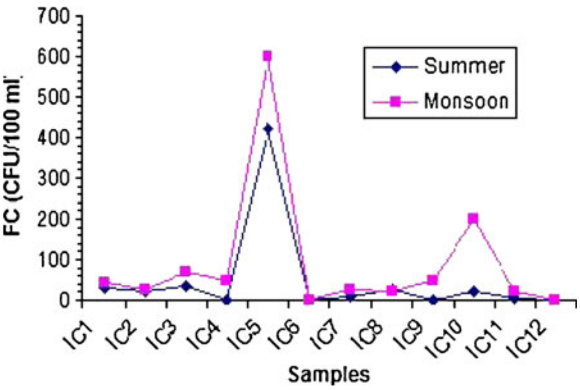

Fig. 12 FC concentration in samples collected from Chandan Nagar, Indore

Table 3 Statistical correlation of critical parameters in Ahilya Nagar

	Summer			Monsoon		
	Distance	Nitrate	FC	Distance	Nitrate	FC
Distance	1			1		
Nitrate	0.26	1		0.56	1	
FC	−0.051	−0.29	1	0.60	0.22	1

Table 4 Critical parameters of samples from Mathpara, Kolkata

Parameters	Seasons	Samples						
		KNM1	KNM2	KNM3	KNM4	KNM5	KNM6	Avg
TDS (mg/L)	Summer	512	524	533	524	540	528	526.8333
	Monsoon	345	336	354	324	367	394	353.3333
NO_3 (mg/L)	Summer	0.4	0.6	0.4	0.2	0.4	0.3	0.383333
	Monsoon	0.3	0.4	0.4	0.3	0.4	0.3	0.35
FC (mg/L)	Summer	4	5	1	1	1	2	2.333333
	Monsoon	1	ND	ND	ND	1	ND	0.333333

This can be responsible for increase in the survival rate of pathogens and thereby increasing the FC concentration in monsoon. The increase in water table leads to aerobic conditions and thereby increasing the survival rate of the coliforms.

In Chandan Nagar site, the TDS concentration in monsoon is reduced as compared to summer level (Table 2, Fig. 10). All the samples have TDS with in the BIS (1991) limit of 2,000 mg/L. However, the concentration of nitrate and FC (Figs. 11 and 12) is more in monsoon as compared to summer. A close look at the nitrate concentration (Fig. 11) reveals that the concentration ranges from 2–44 mg/L (average 24 mg/L) in summer and 12–158 mg/L in monsoon (average 50 mg/L). All the samples have nitrate within the desirable limit in summer. However, all the samples excepting IC2, IC5, IC7, IC11, and IC12 have nitrate concentration exceeding the BIS (1991) limit in monsoon. The FC concentration in Chandan Nagar (Table 2) varies from not detectable (ND) to 400 CFU/100 mL in summer. In monsoon, it varies from ND to 600 CFU/100 mL. All the samples are contaminated by fecal coliforms in summer except samples IC4, IC6, and IC9. In monsoon, all the samples are contaminated except IC6. The analysis indicates that the highest concentration in Chandan Nagar is 600 CFU/100 ml whereas the highest in Ahilya Nagar is 1,600 CFU/100 ml. Though the overall sanitation scenario in Ahilya Nagar is definitely better as compared to Chandan Nagar, the concentration level of the contaminants suggests an adverse scenario.

A statistical correlation was attempted on parameters namely, the distance of the source from the community septic tank, the nitrate concentration, and the fecal coliform concentration for samples collected in Ahilya Nagar. The correlation in summer indicates that the distance has a positive correlation with the nitrate and a negative correlation with the fecal coliforms (Table 3). It is also observed that the nitrate and fecal coliforms have a negative correlation. However, in monsoon, the nitrate and fecal coliform have a positive correlation with the distance (Table 3) and a positive correlation (0.22) exists between nitrate and fecal coliforms. This indicates that there can be other

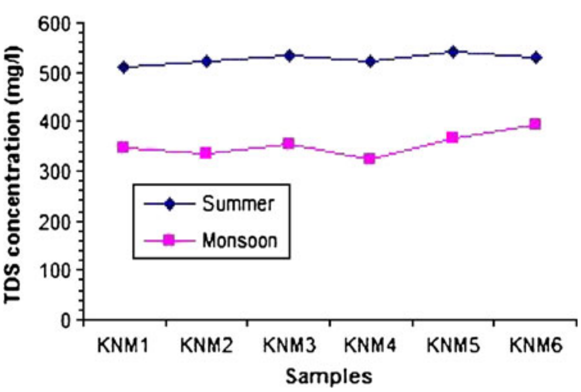

Fig. 13 TDS concentration in samples collected from Mathpara, Kolkata

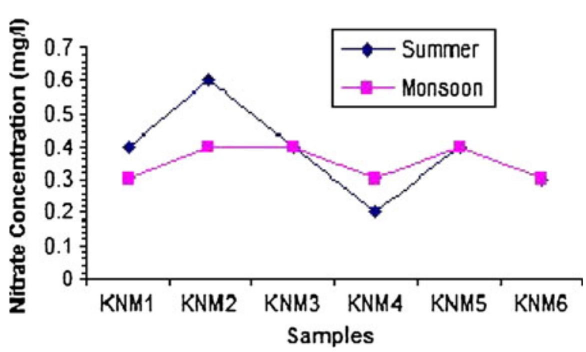

Fig. 14 NO_3 concentration in samples collected from Mathpara, Kolkata

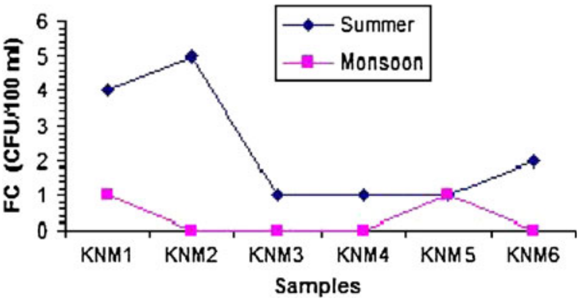

Fig. 15 FC concentration in samples collected from Mathpara, Kolkata

factors, apart from distance which are affecting the concentration of nitrate and fecal coliforms.

As the vadose zone is very thin (3 to 4 m) and the intervening medium is weathered basalt, the travel time between the source and receptor is very less. Hence, the chances of contaminants reaching the water table (3 to 4 m depth in monsoon and 10 to 12 m in summer) is very high. The shallow water table aided by presence of fractures can aggravate the pollution as the travel time from the source (septic tank) to the receptor (open well/hand-pump) is likely to be less. The statistical correlation for Ahilya Nagar (Table 3) indicates that in monsoon, the nitrate and FC can be attributed to the same source. The significant positive correlation of nitrate and FC with distance negates the view that concentration decreases with the distance.

Kolkata

As in the case of Ahilya Nagar and Chandan Nagar, the TDS level in Mathpara in Kolkata shows similar pattern (Table 4, Fig. 13). The TDS varies in the range 52–540 mg/L in summer and 324–394 mg/L in monsoon. All the samples have TDS within the BIS limit, i.e., 2,000 mg/L. As far as nitrate is concerned, it varies in the range 0.2–0.6 mg/L in summer and 0.3–0.4 mg/L in monsoon (Table 3, Fig. 14). The temporal variation of nitrate concentration is not following the trend observed in Indore city wherein the concentration increased in monsoon. The FC concentration is found in the range 1–5 CFU/100 mL in summer and ND–1 CFU/100 mL in monsoon (Fig. 15)

The parameters namely TDS, NO_3, and FC in respect of Palpara have similar range as in the case of Mathpara (Tables 4 and 5). The TDS varies in the range 398–518 mg/L in summer and 276–488 mg/L in monsoon (Fig. 16). As far as nitrate is concerned, it varies in the range 0.2–0.6 mg/L in summer and 0.3–0.4 mg/L in monsoon (Fig. 17). The FC concentration varies in the range ND–2 CFU/100 mL in summer and ND–1 CFU/100 mL in monsoon (Fig. 18). A close examination of the scenario in Mathpara (Figs. 13–15) and Palpara (Figs. 16, 17, and 18) reveals that the contamination is very less as compared to Ahilya Nagar (Figs. 7–9) and Chandan Nagar (Figs. 11–13). Besides, the nitrate concentration (Fig. 15) is very less and with in the recommended limit of BIS (1991) and WHO (1993). As mentioned above, the groundwater is extracted from the confined aquifer situated between 90 and 150 m (bgl). This layer underlies a thick clay layer (10 to 90 m). In view of the thick clay layer overlying the aquifer (Fig. 5), there is significant reduction of the contaminants (microbial as well as chemical) reaching the water table at a depth of 90 m. Most of the contaminants are likely to be retarded and

Table 5 Critical parameters of samples from Palpara, Kolkata

Parameters	Seasons	Samples								
		KNP1	KNP2	KNP3	KNP4	KNP5	KNP6	KNP7	KNP8	Avg
TDS (mg/L)	Summer	398	512	514	518	498	488	498	492	490
	Monsoon	276	350	362	329	348	390	488	326	359
NO_3 (mg/L)	Summer	0.5	0.4	0.4	0.4	0.6	0.4	0.2	0.5	0.4
	Monsoon	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3
FC (mg/L)	Summer	2	ND	1	ND	2	ND	2	1	1
	Monsoon	ND	ND	ND	1	ND	ND	ND	ND	–[a]

[a] Average is less than 1

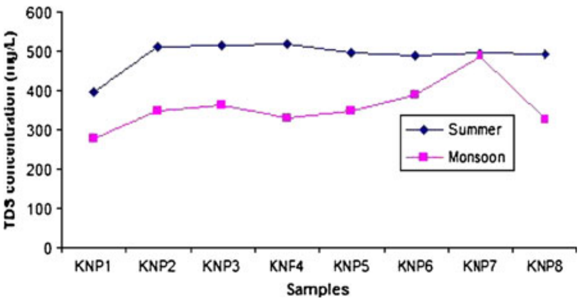

Fig. 16 TDS concentration in samples collected from Palpara, Kolkata

adsorbed before reaching the confined aquifer at 90 m depth.

Questionnaire survey

Opinion was sought from the owners of the wells regarding the use of water and prevalence of any water-borne disease in the area. Though the contamination in terms of nitrate and fecal coliforms was significant in Ahilya Nagar and Chandan Nagar, the respondents in Chandan Nagar mentioned about incidence of water-borne disease in the area. The residents in Ahilya Nagar mentioned that the well water was only used for domestic purpose other than drinking. They reported that there has not been any outbreak of water-borne disease. The respondents in Kolkata in general did not have any complaints about the groundwater quality. Incidence of water-borne disease was also not mentioned by them during the interviews.

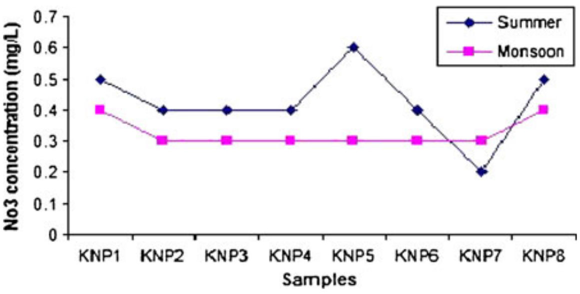

Fig. 17 NO_3 concentration in samples collected from Palpara, Kolkata

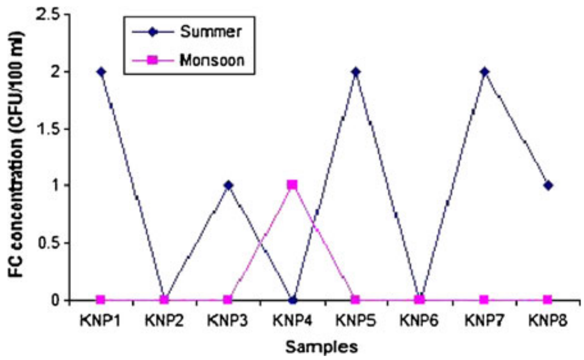

Fig. 18 FC concentration in samples collected from Palpara, Kolkata

Conclusions

1. The study areas at Indore which are characterized by hard rock show significant concentration of nitrate and fecal coliforms. The nitrate exceeds the desirable limit (45 mg/L) of BIS and hence the situation is alarming for both the localities, namely, Ahilya Nagar and Chandan Nagar. As far as fecal coliform is concerned, excepting three samples, the rest are contaminated by fecal coliforms in summer as well as monsoon. As per the BIS guidelines, fecal coliform should be absent in order that the water can be considered safe for drinking. There is health risk due to elevated nitrate concentration (exceeding BIS limit) in most of the samples.
2. The study areas at Kolkata, which are characterized by alluvial formations show minimal concentration of nitrate and fecal coliforms. The nitrate concentration is with in the desirable limit of BIS. The fecal coliform concentration is also less and it varied in the range ND to 5 CFU/100 mL.
3. The presence of shallow water table (10–20 m) in summer and 5–10 m in monsoon) in Indore and coupled with the presence of fractures in the underlying rocks renders the water source vulnerable to pollution from the on-site sanitation systems. It is also observed that at a lateral distance of 150 m (Fig. 3), the community septic tank does not render the source safe for drinking. It is likely that there are

preferential pathways in the form of fractures may be responsible for contamination at this distance.

4. The available litholog (Fig. 5) close to the study area indicates that there is a thick clay layer of approximately 76 m above the water-bearing sand horizon. The groundwater is extracted from the sand layer underlying the 76-m thick clay layer. The presence of this clay layer is likely to act as an adsorbant for the contaminants which percolate from the pit latrine. As there is a significant distance of 150 m from the source (pit latrine) to the receptor (groundwater source), the fecal coliforms are likely to die down before reaching the water table (Lawrence et al. 2001). The chemical contaminants, namely, nitrate are likely to be adsorbed on the intervening clay layer.
5. The study conclusively reveals that the impact of the on-site sanitation system has pronounced effect on shallow unconfined aquifer in hard rock region, i.e., Indore as compared to confined aquifer in the Indo-Gangetic plains, i.e., Kolkata. The effect will be same for both chemical and bacteriological contaminants. However, the bacteriological contaminants are minimally present in the deep aquifer underlying the thick clay layer in Kolkata. The distance of travel, nature of the soil matrix, and the depth of water table are affecting the concentration level of the chemical and bacteriological contaminants.

Recommendations

1. On-site sanitation program should be discouraged in hard rock areas with shallow water table. The results indicate that the nitrate level exceeds the desirable limit of BIS and almost all the samples are contaminated from fecal coliforms. The groundwater sources should not be used for drinking purpose. If off-site sanitation cannot be provided, best engineering design should be ensured and operation and maintenance (O&M) should be an integral part of the low-cost sanitation program.
2. The nitrate concentration is well within the desirable limits of BIS in Kolkata. The bacterial contamination is also insignificant (not detectable to 6 CFU/100 mL). This water will not pose any health risk as far as nitrate and fecal coliforms are concerned.
3. Critical parameters like the depth of the water table, soil characteristics, and rock strata need to be considered in any program on installation of on-site sanitations where groundwater is used for drinking purpose.
4. A systematic lithological mapping and hydrogeological mapping needs to be carried out in any area which is going to be served by on-site sanitation facilities. If a confined aquifer with sustainable yield exists in the study area, this may be preferred to the shallow aquifer.
5. Mandatory monitoring of groundwater sources needs to be carried out in areas served by on-site sanitation systems. The monitoring needs to be carried out for indicator parameters like nitrate, chloride, and fecal coliforms by agency responsible for water supply and sanitation.

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References

Andrews, E. E. (1988). Hydrogeologic case study of septic tank effluent discharge, Figureure eight Island, North Carolina. In *Coastal water resources, proc. symp. at Wilmington, North Carolina* (pp. 505–507). American Water Resources Association, Bethesda, Maryland.

APHA (1998). *Standard methods for the examination of water and wastewater* (20th ed.). Washington: American Public Health Association.

Brown, K. W., Wolf, H. W., Donnelly, K. C., & Slowey, J. F. (1979). The movement of faecel colliforms and coliphages below septic lines. *Journal of Environmental Quality, 17*, 401–408.

Bunnels, J. F., Zambella, R. A., Margon, M. D., & Gray, D. M. (1999). A comparison of nitrogen removal by subsurface dosing and standard septic systems in sandy soils. *Journal of Environmental Management, 56*, 209–219.

Bureau of Indian Standards (BIS) (1991). *Drinking water specification: IS 10500:1991*. New Delhi, India.
Canter, L. W., & Knox, R. C. (1985). *Septic tank system effects on groundwater quality*. Michigan: Lewis Publishers.
CGWB (2001). *Official communication from C.G.W.B*. Eastern region.
Chidavaenzi, K., Bradley, M., Jere, M., & Nhandara, C. (2000). *Pit latrine effluent infiltration into groundwater: The Epworth study*. London: Water sanitation and Health, IWA
Clawges, R. M., & Vowinkel, E. F. (1996). Variable indicating nitrate contamination in bedrock aquifers, Newark basin, New Jersey. *Water Resources Bulletin, 32*, 1055–1066.
Dewalle, F. B., & Schaff, R. M. (1980). Groundwater pollution by septic tank drain fields. *Journal of Environmental Engineering, 106*, 631–636.
Dzwairo, B., Hoko, Z., Love, D., & Guzha, E. (2006). Assessment of the impacts of pit latrines on groundwater quality in rural areas: A case study from Marondera district, Zimbabwe. *Physics and Chemistry of the Earth, 31*, 779–788.
GSI (2002). *District resource map of Indore district*. Published by GSI (2002).
Hagedon, C. (1984). Microbiological aspects of groundwater pollution due to septic tanks. In B. Britton, & C. P. Gerba (Eds.), *Groundwater pollution microbiology* (pp. 181–196). New York: Wiley.
Lawrence, A. R., Macdonald, D. M. J., Howard, A. G., Barret, M. H., Pedley, S., Ahmed, K. M., et al. (2001). *Guidelines for assessing the risk of groundwater from on-site sanitation*. Commissioned report (CR/01/142) of British Geological Survey.
Lewis, W. J., Fester, S., & Drasar, B. S. (1980). *Risk of groundwater pollution by on-site sanitation in developing countries*. A Literature Review, IRCWD Report No. 01/82.
Lu, Y., Tang, C., Chen, J., & Sakura, Y. (2008). Impact of septic tank systems on local groundwater quality and water supply in the Pearl River Delta, China: Case study. *Hydrological Processes, 22*, 443–450.
Mallard, F., Reygrobellet, J. L., & Soulie, M. (1994). Transport and retention of faecel bacteria at sewage-polluted fractured rock sites. *Journal of Environment Quality, 23*, 1352–1363.
NEERI (2005). *Impact of on-site sanitation systems on quality of groundwater and surface water sources submitted to CPHEEO-WHO*. New Delhi.
Nsubuga, F. B., Kanisiime, F., & Okot-Okumu, J. (2004). Pollution of protected springs in relation to high and low density settlements in Kampala-Uganda. *Physics and Chemistry of the Earth, 29*, 1153–1159.
Pujari, P. R., Nanoti, M. V., Nitnaware, V. C., Khare, L. A., Thacker, N. P., & Kelkar, P. S. (2007). Effect of on-site sanitation on groundwater contamination in a basaltic environment—A case study from India. *Environmental Monitoring and Assessment, 134*, 271–278.
WHO (1993). *Guidelines for drinking water quality, recommendations* (Vol. 1, 2nd ed.). Geneva: World Health Organization.