Environ Monit Assess (2015) 187: 614
DOI 10.1007/s10661-015-4797-7

Impact assessment of on-site sanitation system on groundwater quality in alluvial settings: A case study from Lucknow city in North India

Chandrakant Jangam · S. Ramya Sanam · M. K. Chaturvedi · C. Padmakar · Paras R. Pujari · Pawan K. Labhasetwar

Received: 13 December 2014 / Accepted: 12 August 2015 / Published online: 6 September 2015

Abstract The present case study has been undertaken to investigate the impact of on-site sanitation on groundwater quality in alluvial settings in Lucknow City in India. The groundwater samples have been collected in the areas of Lucknow City where the on-site sanitation systems have been implemented. The groundwater samples have been analyzed for the major physicochemical parameters and fecal coliform. The results of analysis reveal that none of the groundwater samples exceeded the Bureau of Indian Standards (BIS) limits for all the parameters. Fecal coliform was not found in majority of the samples including those samples which were very close to the septic tank. The study area has a thick alluvium cover as a top layer which acts as a natural barrier for groundwater contamination from the on-site sanitation system. The *t* test has been performed to assess the seasonal effect on groundwater quality. The statistical *t* test implies that there is a significant effect of season on groundwater quality in the study area.

Keywords Alluvium soil · Fecal coliform · Groundwater pollution · Natural barrier · On-site sanitation

C. Jangam · S. Ramya Sanam · M. K. Chaturvedi · C. Padmakar · P. R. Pujari (✉) · P. K. Labhasetwar
Water Technology and Management Division, CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur 440020, India
e-mail: pr_pujari@neeri.res.in

Introduction

The growing population and the consequent need for proper sanitation practices have led to the adoption of on-site sanitation systems in view of their low cost and ease of implementation as compared to conventional sewerage. The contamination of groundwater sources due to on-site sanitation systems is a subject of research (Brown et al. 1979; Dewalle and Schaff 1980; Lewis et al. 1980; Hagedon 1984; Canter and Knox 1985; Andrews 1988; Lawrence et al. 2001; Pujari et al. 2007; Heng et al. 2010; Pujari et al. 2011) internationally. The vulnerability of groundwater from sources near on-site sanitation systems has been highlighted by the WHO (World Health Organization 1993). Studies indicate that the expansion of domestic settlements in urban and rural areas has a major effect on groundwater pollution due to poor sanitation systems (Mallard et al. 1994; Chidavaenzi et al. 2000; Nsubuga et al. 2004; NEERI 2005; Dzwairo et al. 2006; Pujari et al. 2007; Lu et al. 2008; Heng et al. 2010; Pujari et al. 2011; Gunawardana and Galagedara 2013, Shivendra and Ramaraju 2015).

The need for research on the impact of on-site sanitation systems on groundwater quality assumes significant importance in India, considering the fact that urbanization is on the rise and it is not possible to bring the entire city under a 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. Besides, the absence of a centralized water supply leads people to depend on groundwater sources like bore wells, hand pumps, and open wells to meet their drinking and

Fig. 1 Schematic map of India showing the study area (Lucknow City)

domestic requirements. In view of the ground water being used for potable purposes, it is desirable that the impact of on-site sanitation systems on groundwater quality and the maintenance of their quality be assessed through proper interventions be ensured.

The groundwater contamination from on-site sanitation systems vis-à-vis geological settings has been dealt with by different researchers since the 1980s. The hydrogeological factors, i.e., depth to water table, nature of the soil matrix, permeability of the formations, presence of fractures, redox conditions, and lateral separation between the on-site sanitation and groundwater sources, are the key parameters affecting groundwater pollution (Lewis et al. 1980; Lawrence et al. 2001). Dzwairo et al. (2006) reported that groundwater samples collected within a 25-m distance from pit latrines in Kamangira village in Zimbabwe were affected. The parameters affected were total and fecal coliform and nitrate. Similar findings have been reported recently by Pujari et al (2007) and Pujari et al. (2011). Pujari et al (2007) highlighted the vulnerability of the unconfined aquifer to the on-site sanitation systems in the fractured hard rocks belonging to the Deccan traps. Studies carried out by Pujari et al. (2011) indicate that the contamination in alluvial settings in Kolkata, India, is minimal as compared to the hard-rock areas in Indore.

The present study is attempted to study the groundwater quality vis-à-vis the on-site sanitation systems in the alluvial settings in Lucknow City, India, which is seated in the Indo-Gangetic plain like Kolkata. The study has been undertaken during two seasons, namely summer (May 2001) and post-monsoon (October 2001) to investigate the temporal variations of groundwater quality vis-à-vis the impact of on-site sanitation systems. In the present study, nitrate, chloride, and fecal coliform are considered as the key parameters to assess the impact of on-site sanitation on groundwater (ARGOSS 2001).

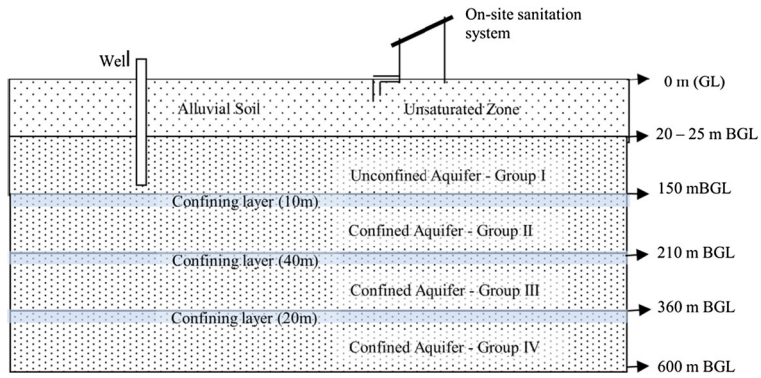

Fig. 2 Schematic section for alluvial settings with a moderate water table

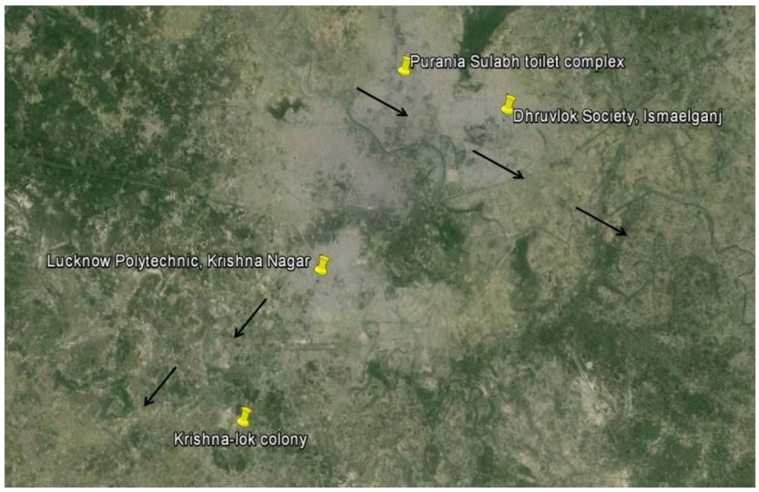

Fig. 3 Map depicting the sampling locations of the on-site sanitation system indicating the groundwater flow direction

Study area

The study is carried out in Lucknow City (23° 55′ N and 80° 59′ E) in India (Fig. 1). The city has a population of 2,815,601 as per the 2011 census. The estimated present population density is 6700 persons/km^2 (www.uhi-india.org). It stands at an elevation of 125.45 m above sea level. The city has a warm, humid subtropical climate and receives annual average rainfall of 1019 mm spread over 47 rainy days (www.cgwb.gov.in/NR). The rainfall is mostly from southwest monsoon and the rainy season extends from the months of June to September (Arun Kumar 2008). Physiographically, the study area is a part of the Indo-Gangetic plain. The city is drained by the Gomti River and its tributary Sai which are perennial in nature.

Geologically, the area has a thick cover of Quaternary sediments overlying the basement of Bundelkhand granitoids and sedimentary rocks of the Vindhyan Supergroup. The borehole data of the Central Ground Water Board (CGWB) indicate the presence of bedrock at depths exceeding 298 and 445 m in the southern and western parts of the study area (Geological Survey of India (GSI) 2001). The area is underlain by a Quaternary alluvium consisting of clays, occasional kankar, and sand of various grades in different proportions. The sand horizons are at different depths from the different aquifers in the area. The surface deposits are mainly older alluvium and estimated to be in the range of 250 to 400 m deep. The results of exploratory boreholes drilled by the CGWB range in depth of 100 to 753 m bgl (below ground level). These boreholes reveal that the following four aquifer groups exist in the district (Fig. 2).

Group I: aquifer group 00–150 m bgl
Group II: aquifer group 160–210 m bgl
Group III: aquifer group 250–360 m bgl

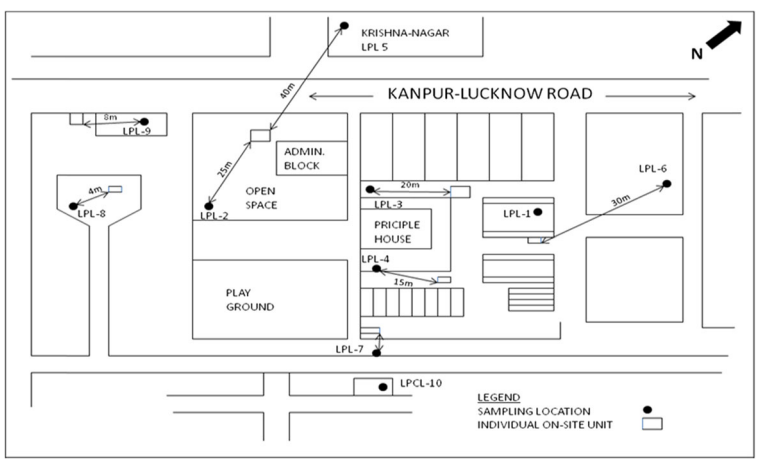

Fig. 4 Schematic map of the sampling locations in Lucknow Polytechnic, Krishna Nagar, Lucknow

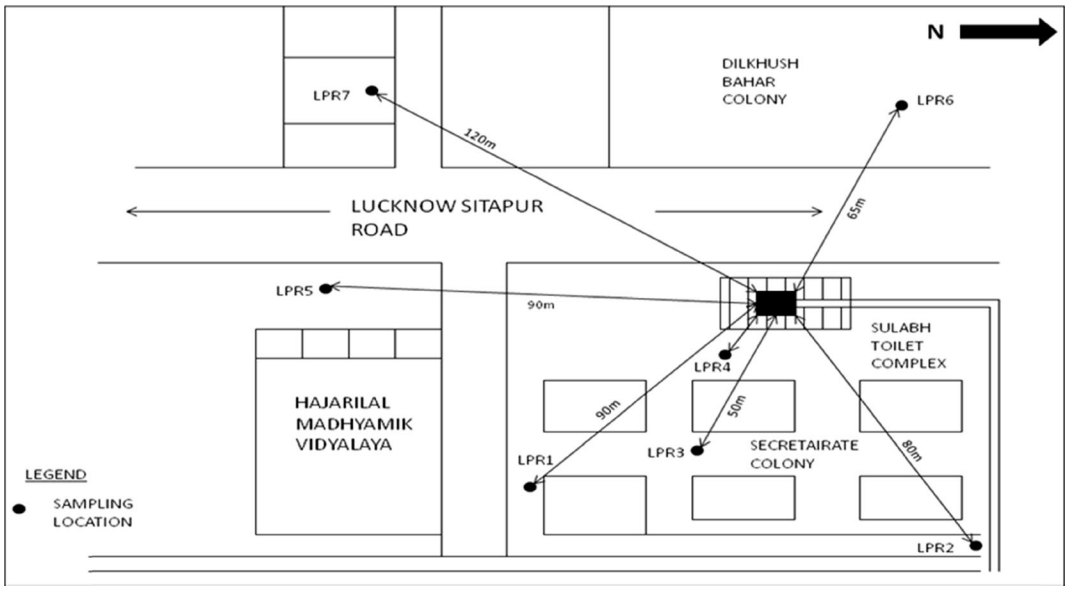

Fig. 5 Schematic map of the sampling locations in the Purania Sulabh toilet complex, Lucknow

Group IV: aquifer group 380–600 m bgl

The aquifers are characterized by primary porosity. All the municipality drinking water sources tap the top aquifer (0–150 m bgl) which is of unconfined type. The aquifer is characterized by sand with an admixture of clay. The drinking water wells are mostly drilled up to a depth of 40–50 m, and hence, the water is mostly drawn from a depth 20 to 30 m. The groundwater stage development is 50.1 % (http://cgwb.gov.in/nr/hydro/dist37.pdf).

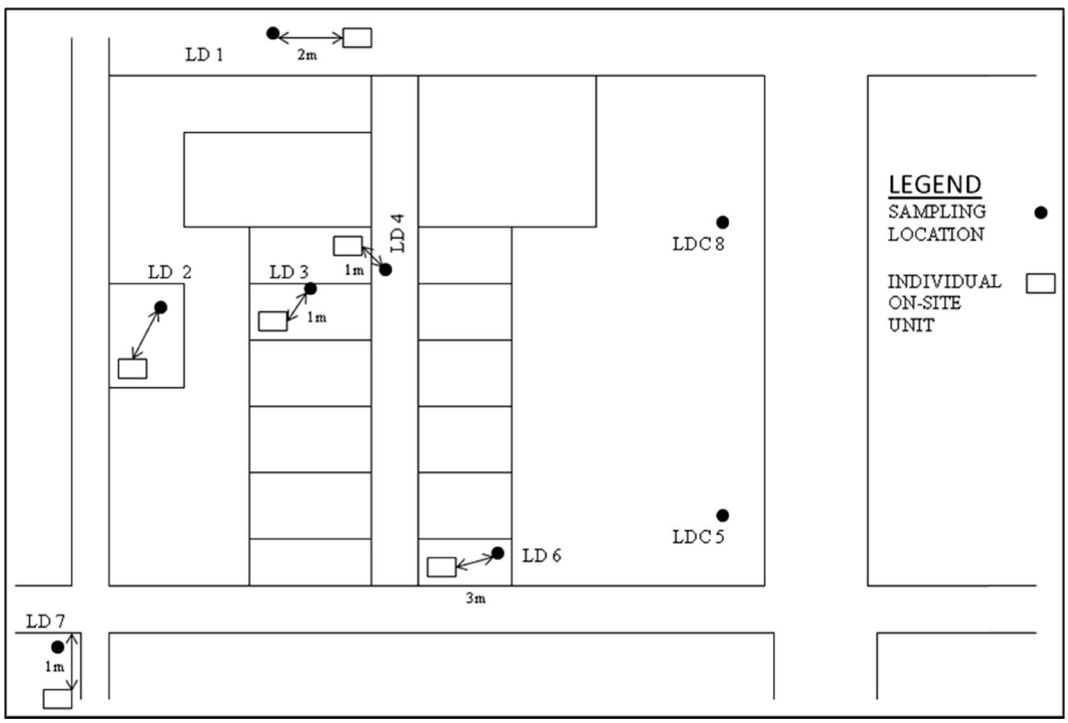

Fig. 6 Schematic map of the sampling locations in Dhruvlok society, Ismaelganj, Lucknow

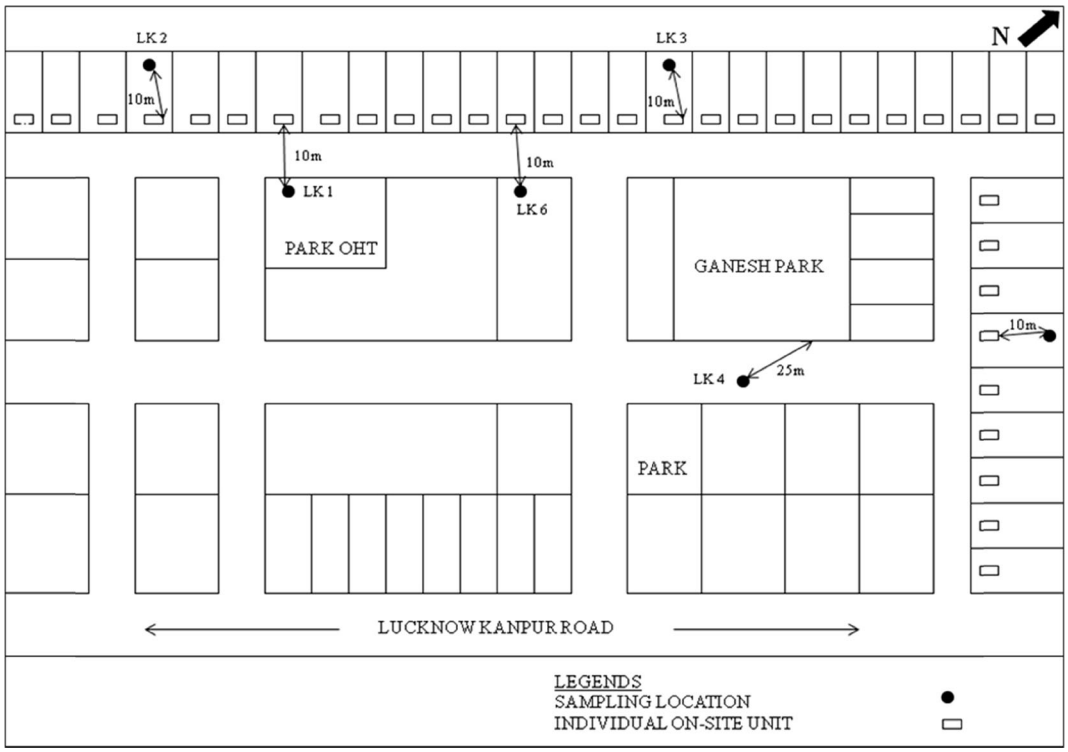

Fig. 7 Schematic map of the sampling locations in Krishna Lok Colony, Shankar Balram Type, Lucknow

The present study was carried out at four sites in Lucknow City, viz., Lucknow Polytechnic, Krishna Nagar (site 1), Sulabh toilet complex near Purania (site 2), Dhruvlok society (site 3), and Krishna Lok Colony (site 4) where an on-site sanitation system has been in practice for more than 10 years (Fig. 3). Site 1 (Lucknow Polytechnic) is located at Krishna Nagar in Lucknow—Kanpur road (Fig. 4). The site is an academic institution occupied by student hostels, staff quarters, and academic departments. The site has two septic tanks and 25 individual units for disposed excreta which are within the premises. Ten samples have been collected for analysis from Lucknow Polytechnic. Site 2 in Purania near Sulabh toilet complex is occupied by different housing colonies and Hajarilal Madhyamik Vidyalaya. The Sulabh toilet complex has an on-site sanitation system for disposal of excreta (Fig. 5). This site is densely populated than Krishna Nagar Polytechnic. Groundwater sources (hand pump) are

Table 1 Observed major parameters of samples from Lucknow Polytechnic, Krishna Nagar, Lucknow

Parameter	Season	Samples										
		LPL1	LPL2	LPL3	LPL4	LPL5	LPL6	LPL7	LPL8	LPL9	LPL10	Avg
NO_3 (mg/l)	Summer	0.3	0.4	0.4	0.4	0.4	0.1	0.2	0.1	0.3	0.1	0.27
	Post-monsoon	0.2	0.4	0.3	0.4	0.5	0.5	0.3	0.3	0.2	0.3	0.34
Cl (mg/l)	Summer	14	30	16	24	43	11	21	16	59	52	28.6
	Post-monsoon	20	22	18	22	37	12	19	20	16	18	20.4
FC (CFU/100 ml)	Summer	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Post-monsoon	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TDS (mg/l)	Summer	382	410	410	360	460	390	360	335	285	560	395.2
	Post-monsoon	278	288	335	334	415	515	275	500	325	290	355.5

ND not detected

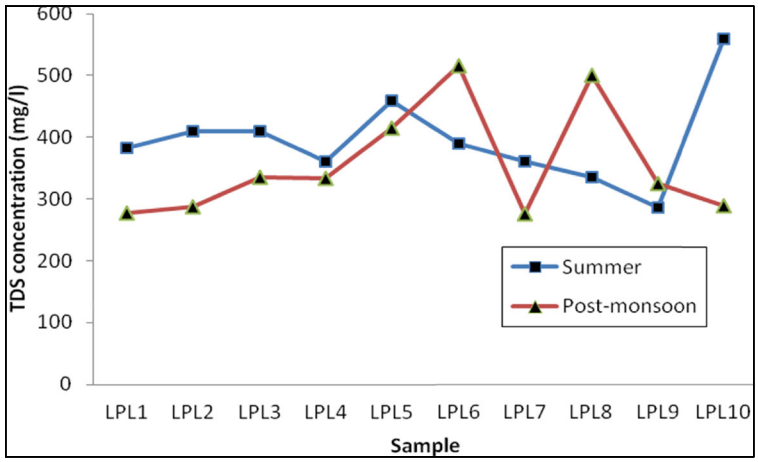

Fig. 8 TDS concentration in samples from Lucknow Polytechnic

scattered in all the directions around the septic tank. Groundwater is being used by localities to meet their daily requirements. Seven samples have been collected from Purania for analysis. In Dhruvlok society (site 3), the samples are scattered close to the on-site sanitation systems (Fig. 6). Eight samples have been collected from Dhruvlok society. Krishna Lok Colony (site 4) has more individual on-site sanitation systems (Shankar-Balram type) than any other site. Six samples were collected from Krishna Lok Colony where collection sources were present in a 10- to 25-m range within the on-site sanitation (Fig. 7).

Methodology

Grab sampling has been adopted to collect the groundwater samples at the four sites. For physicochemical parameters, the samples were collected in pre-cleaned 1000-ml polyethylene bottles. Double-distilled water was used for cleaning the polyethylene bottles before sampling. For bacteriological parameters, groundwater samples were collected in pre-cleaned and sterilized 300-ml glass bottles. The samples collected for bacteriological analysis were transported to a laboratory in cool condition (4 °C). Temperature, pH, and electrical conductivity (EC) were measured on-site using a portable sensor of Eutech Make. Whatman filter paper (No. 4) was used to filter the groundwater samples before analysis in the laboratory as some of the sources were from rusted wells. The purpose was to filter any suspended particles present in the samples; a finer filtration size was not considered for the principal parameters investigated: chloride and nitrate. The physiochemical parameters were analyzed by following the standard protocols (APHA 1998). The NO_3 analysis was performed on UV-visible spectrophotometer 118 (Make: systronic). The bacteriological parameter fecal coliform (FC) was analyzed by membrane filter technique (APHA 1998). Colony formations are carried out by using a 50-mm sample. For FC, the processed sample is kept in the incubator and was maintained at 45.5 °C for 24 h. The bacterial contamination is measured in colony-forming units (CFU) per 100 ml.

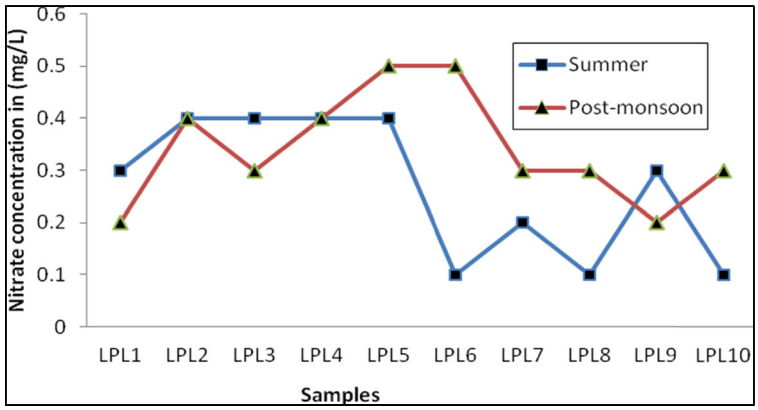

Fig. 9 Nitrate concentration in samples from Lucknow Polytechnic

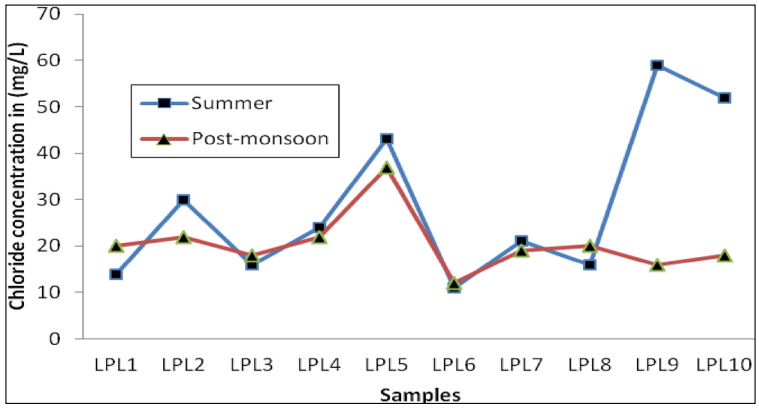

Fig. 10 Chloride concentration in samples from Lucknow Polytechnic

Student's *t* test was carried out for testing the significant difference between means of factors for summer and post-monsoon seasons against a left-sided alternative hypothesis, i.e., the mean of pre-monsoon is less than that of the other. The test statistic, which follows *t* distribution with ($n1 + n2 - 2$) degrees of freedom, is given by

$$t = \frac{\bar{x1} - \bar{x2}}{\sqrt{s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where $\bar{x1}$ is the mean of variable of summer, $\bar{x2}$ is the mean of variable of post-monsoon, s^2 is the variance of the combined sample, n_1 is the number of observations on variable of summer, and n_2 is the number of observations on variable of post-monsoon. If the computed value is greater than the critical value (right-sided alternative), then there is a significant effect of season on the groundwater quality; otherwise, there is no significant effect of season on the groundwater quality.

Results and discussions

The chemical and microbiological contamination of groundwater systems due to on-site sanitation systems has been dealt with by different workers (Lewis et al. 1980; Indra Raj 2000; Lawrence et al. 2001; NEERI 2005; Dzwairo et al. 2006; Pujari et al. 2007; Pujari et al. 2011). The chemical parameters of concern due to on-site sanitation systems are nitrate and chloride, whereas the microbiological parameters of concern are bacteria, viruses, and protozoa. Hence, groundwater samples in the vicinity of such sites are expected to have higher concentrations of nitrate, chloride, and microbiological organisms. It is reported that (ARGOSS 2001) 4 kg of nitrogen per person is released per year and each person

Table 2 Observed major parameters of samples from the Purania Sulabh toilet complex, Lucknow

Parameter	Season	Samples							
		LPR1	LPR2	LPR3	LPR4	LPR5	LPR6	LPR7	Avg
NO_3 (mg/l)	Summer	0.2	0.3	0.1	0.4	0.2	0.1	0.2	0.2
	Post-monsoon	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.2
Cl (mg/l)	Summer	10	10	7	30	70	64	37	32.6
	Post-monsoon	9	10	8	36	58	45	33	28.4
FC (CFU/100 ml)	Summer	ND	ND	ND	ND	ND	ND	ND	ND
	Post-monsoon	ND	ND	ND	ND	ND	ND	ND	ND
TDS (mg/l)	Summer	236	235	240	292	315	510	555	340.4
	Post-monsoon	188	235	260	200	325	440	210	265.4

ND not detected

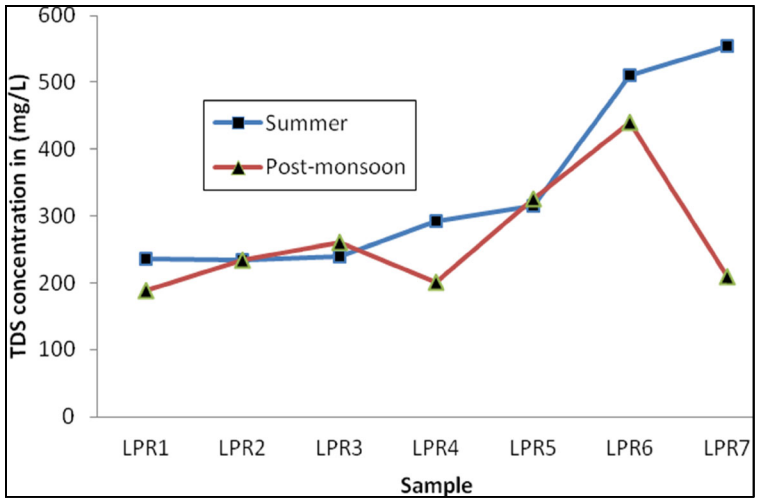

Fig. 11 TDS concentration in samples from Purania

loses 4 g of chloride per day through urine, feces, and sweat. In view of this, only chloride and nitrate are considered in addition to TC and FC to assess the likely impact of the on-site sanitation systems on groundwater quality.

Lucknow Polytechnic (site 1)

In Lucknow Polytechnic, total dissolved solids (TDS), nitrate, and chloride are presented in Table 1 (Figs. 8, 9, and 10). TDS concentration varied between 285 and 560 mg/l in summer and 275–515 mg/l in post-monsoon (Fig. 8). It is observed that the TDS concentration was reduced in post-monsoon as compared to summer, except for the samples namely LPL6, LPL8, and LPL9. The concentration of TDS at all locations is within the permissible limit of the Bureau of Indian Standards (BIS) (1991). The average TDS concentration in summer (395.2 mg/l) was more than that in post-monsoon (355.5 mg/l). The nitrate concentration (Fig. 9) was within the BIS (1991) limit (45 mg/l) for both seasons. The average nitrate concentration in summer is less as compared to that in the post-monsoon season. The highest average concentration was found in monsoon (0.50 mg/l). It is also observed that the chloride concentration (Fig. 10) is within the BIS limit (1000 mg/l). The average concentration in summer (28.6 mg/l) is more than that in post-monsoon (20.4 mg/l). However the fecal coliform was not detected in any sample in any season (Table 1). As discussed, all the municipality groundwater sources are tapping the top unconfined aquifer which is 0–150 m bgl. As the water level is at a depth varying between 30 and 40 m, there is a significant reduction in the contaminants

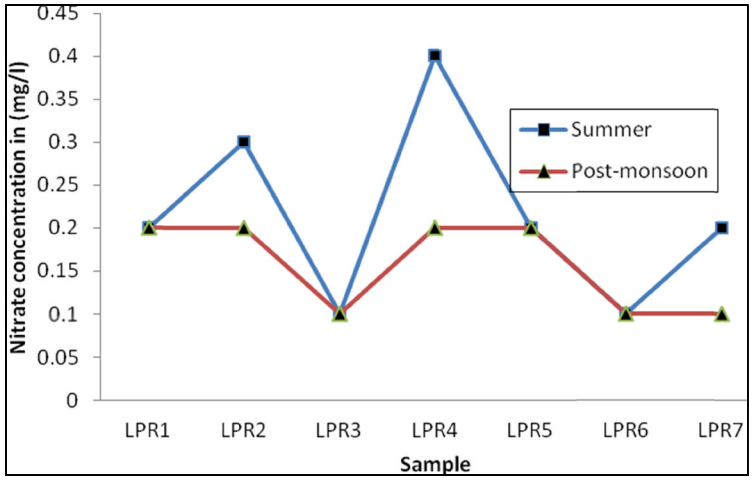

Fig. 12 Nitrate concentration in samples from Purania

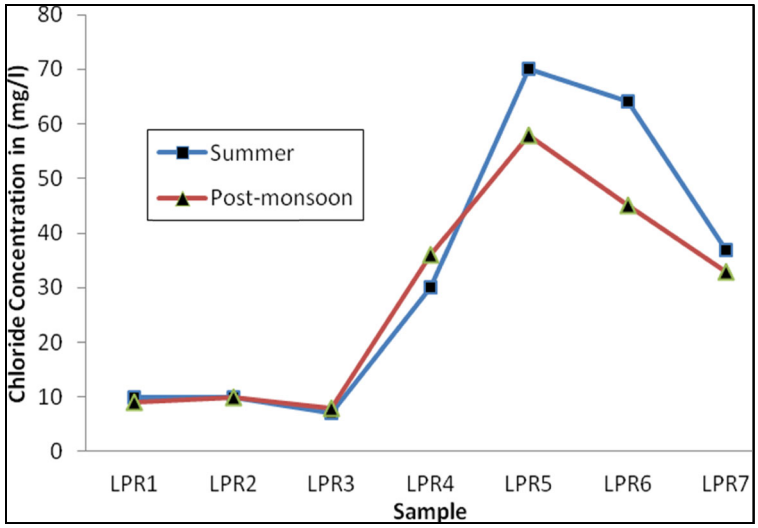

Fig. 13 Chloride concentration in samples from Purania

(microbial and chemical) reaching the aquifer. Most of the contaminants are likely to be get absorbed or retarded in this thick vadose zone (up to 25–30 m) layer before reaching the aquifer. The low nitrate concentration can be attributed to the anaerobic conditions in the aquifer as evident by the low dissolved oxygen (DO) (1.2–3.2 mg/l) in the groundwater samples (NEERI 2005). Low nitrate concentration (ND–0.9 mg/l) in the similar hydrogeological settings is also reported in the alluvial setup at Kolkata (Pujari et al. 2011). Denitrification has been reported at DO <4 mg/l and redox potential <300 mV (Paul and Ladd 1981; Rissmann 2011). Tiwari et al. (1983) reported a decreasing trend in organic carbon with respect to depth in the central UP region which may be responsible for denitrification. The denitrification process is supported by the low to moderate redox potential reported by Singh et al. (2014) for selected sites close to Lucknow in the Indo-Gangetic plain.

Purania (site 2)

In the Purania site, on an average, the concentrations of chloride and nitrate were less in post-monsoon as compared to those in the summer season. However, the TDS concentration at LPR3 and LPR5 in the post-monsoon season was observed to be more as compared to that in summer (Table 2). The TDS concentration (Fig. 11) was found to be within the BIS (1991) permissible limit (2000 mg/l) in all samples. As observed at Lucknow Polytechnic, fecal coliform was not detected in any sample in both summer and post-monsoon seasons.

Table 3 Observed major parameters of samples from Dhruvlok society, Ismaelganj, Lucknow

Parameters	Season	Samples								
		LD1	LD2	LD3	LD4	LD5	LD6	LD7	LD8	Avg
NO_3 (mg/l)	Summer	0.5	0.9	0.6	0.2	0.8	0.4	0.3	0.6	0.54
	Post-monsoon	0.2	0.2	0.2	0.1	0.2	0.3	0.3	0.1	0.2
Cl (mg/l)	Summer	10	16	6	9	17	11	16	13	12.25
	Post-monsoon	8	13	8	12	15	10	13	11	11.25
FC (CFU/100 ml)	Summer	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Post-monsoon	ND	ND	ND	ND	ND	ND	ND	ND	ND
TDS (mg/l)	Summer	375	410	316	295	495	368	345	337	367.63
	Post-monsoon	350	222	312	204	260	388	294	292	290.25

ND not detected

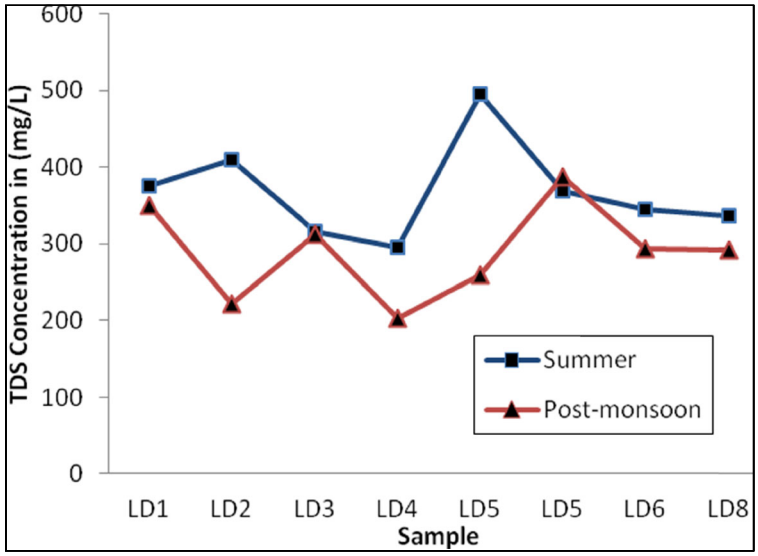

Fig. 14 TDS concentration in samples from Dhruvlok society

The average nitrate concentration (0.21 mg/l) was observed during both seasons (Fig. 12), which was within the BIS (1991) limit (45 mg/l). Chloride concentration varied in the range 7 to 70 mg/l in all seasons (Fig. 13). The highest chloride concentration (70 mg/l) was observed at LPR5 in the summer season with high average (32.57 mg/l) than post-monsoon (28.43 mg/l). However, the chloride concentration at the Purania site was within the BIS (1991) limit (1000 mg/l).

Dhruvlok society (site 3)

The parameters, namely TDS, nitrate, chloride, and FC, at Dhruvlok society show a similar pattern range as in the case of Lucknow Polytechnic (Table 3). The TDS concentration varied in the range 204 mg/l (in post-monsoon)–495 mg/l (in summer) at Dhruvlok society. The average TDS concentration in summer (367.63 mg/l) was observed to be more than the average concentration in post-monsoon. All the samples have TDS concentration within the BIS (1991) limit (Fig. 14). As in the case in Dhruvlok society, Lucknow Polytechnic, and Purania site, fecal coliform contamination was not observed in both summer and post-monsoon seasons. The nitrate concentration varied from 0.2 to 0.9 mg/l in summer and 0.1 to 0.3 mg/l in the post-monsoon season. None of the samples in both seasons exceeds the BIS (1991) limit (45 mg/l) for nitrate concentration (Fig. 15). The chloride concentration at Dhruvlok society was observed to be in the range of 6 to 17 mg/l in summer

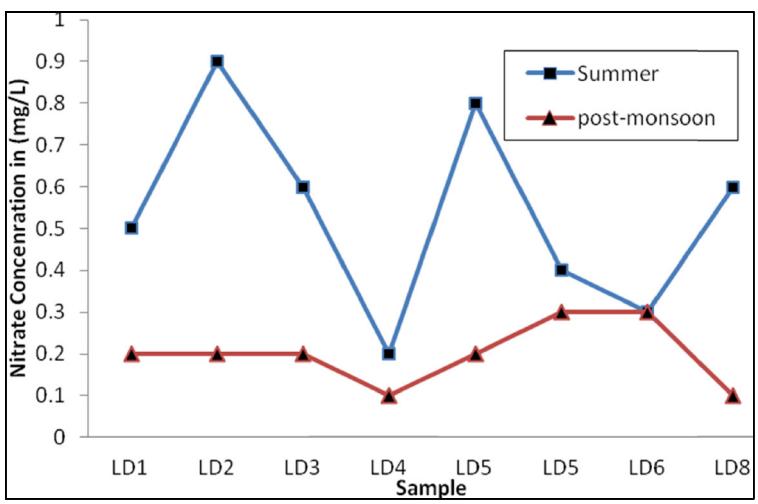

Fig. 15 Nitrate concentration in samples from Dhruvlok society

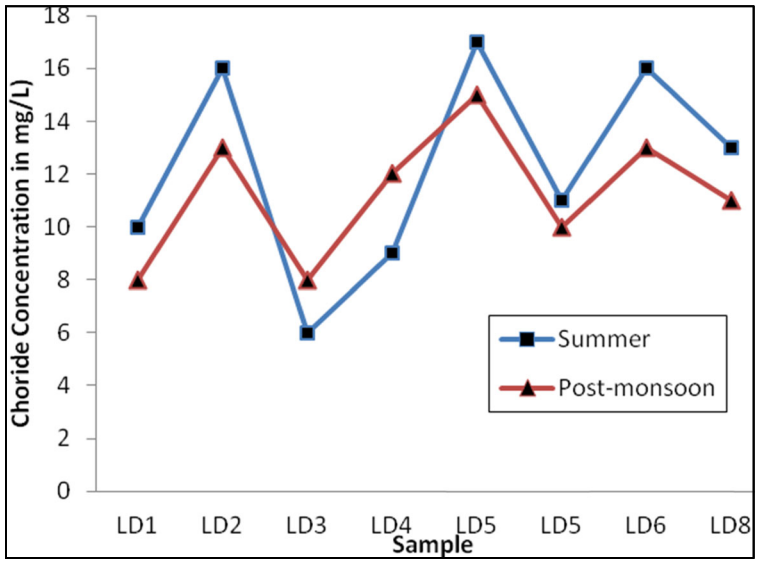

Fig. 16 Chloride concentration in samples from Dhruvlok society

and 8 to 15 mg/l in post-monsoon. In the sample namely LD4, chloride concentration in post-monsoon (12 mg/l) is found to be more than that in the summer (9 mg/l) season. The average chloride concentration of 12.35 mg/l was observed during the summer season (Fig. 16). The average concentration of all key parameters in summer was found to be more than that in the post-monsoon season (Table 3). All the parameters from Dhruvlok society are within the BIS (1991) limit.

Krishna Lok Colony (site 4)

The distance between the on-site sanitation system and groundwater sources (hand pump/dug well) is minimal in Krishna Lok Colony than in any other site in the study area. The TDS concentration ranged between 210 and 385 mg/l (Fig. 17). The highest average concentration was observed during summer (352.83 mg/l); hence, the TDS concentrations in all samples from Krishna Lok Colony are within the BIS (1991) limits. A look at nitrate and chloride concentrations at this site reveals that they are more similar to the concentration levels at Dhruvlok society. The average nitrate concentration was found to be the same in both the seasons (0.28 mg/l) which is within the BIS (1991) limit. In the summer season, the nitrate concentration is not detected at the sample namely LK5 (Fig. 18). At this site, the average chloride concentration in post-monsoon (9.67 mg/l) is

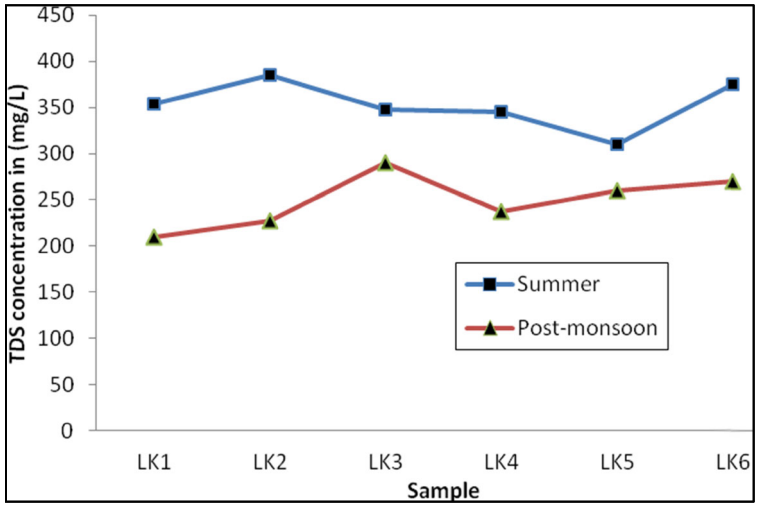

Fig. 17 TDS concentration in samples from Krishna Lok Colony

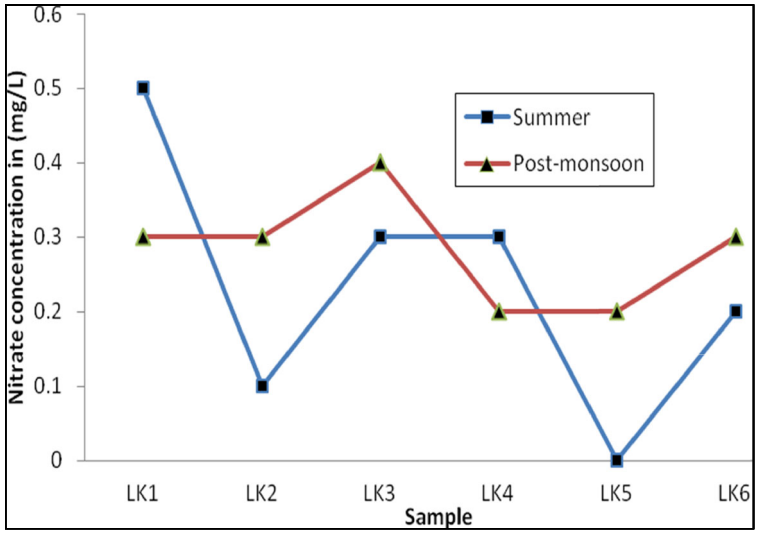

Fig. 18 Nitrate concentration in samples from Krishna Lok Colony

found to be slightly more than that in the summer season (9.5 mg/l) (Fig. 19). As for fecal coliform, sampling site LK1 is the only place where equal fecal coliform concentration (2 CFU/100 ml) is found in both the seasons. In the monsoon season, the movement of pathogens in the vadose zone is relatively fast due to the infiltration and recharge rate. Infiltration causes an increase in the water table and aerobic conditions which leads to the survival rate of coliform (Table 4).

The analysis results indicate that the concentration of TDS, NO_3, and Cl is well within the permissible limit of BIS at all the three sites. It is observed that the concentration in post-monsoon is less as compared to that in the summer season for parameters, namely TDS and chloride. However, the nitrate concentration is less in summer as compared to the post-monsoon level. Similar findings have been reported in previous studies (Pujari et al. 2007; Pujari et al. 2011). The recharge due to the rainfall (1000 mm) can lead to significant dilution of the chemical contaminants. As the groundwater development in the study area is approximately 50.10 % (http://cgwb.gov.in/nr/hydro/dist37.pdf), the recharge will be significant and that will lead to significant dilution of contaminants, namely chloride and TDS. However, the depletion of the water table in the summer season can lead to anaerobic conditions wherein conversion of nitrate to nitrogen gas takes place and leads to lesser nitrate in summer as compared

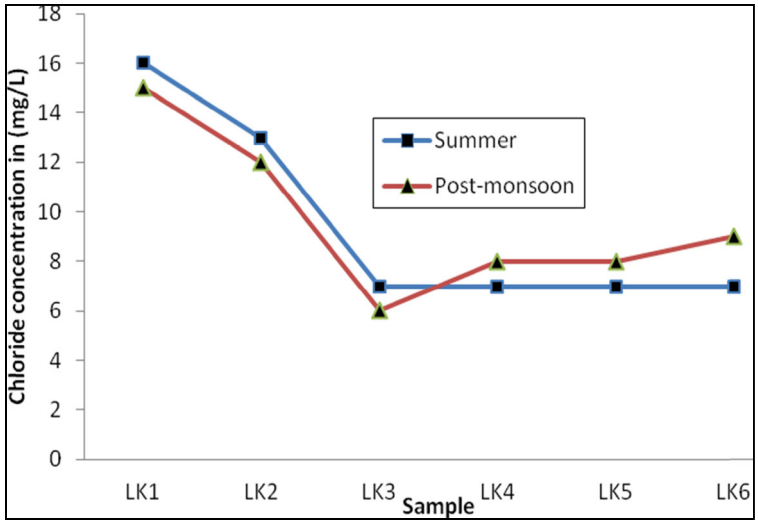

Fig. 19 Chloride concentration in samples from Krishna Lok Colony

Table 4 Observed major parameters of samples from Krishna Lok Colony, Shankar Balram Type, Lucknow

Parameter	Season	Samples						
		LK1	LK2	LK3	LK4	LK5	LK6	Avg
NO_3 (mg/l)	Summer	0.5	0.1	0.3	0.3	ND	0.2	0.28
	Post-monsoon	0.3	0.3	0.4	0.2	0.2	0.3	0.28
Cl (mg/l)	Summer	16	13	7	7	7	7	9.5
	Post-monsoon	15	12	6	8	8	9	9.67
FC (CFU/100 ml)	Summer	2	ND	ND	ND	ND	ND	2
	Post-monsoon	2	ND	ND	ND	ND	ND	2
TDS (mg/l)	Summer	354	385	348	345	310	375	352.83
	Post-monsoon	210	228	290	237	260	270	249.17

ND not detected

to post-monsoon. The fecal coliform concentration is conspicuously absent at site 1, site 2, and site 3. Similar findings have been reported from Kolkata in the alluvial settings (Pujari et al. 2011) wherein it was observed that the contamination was minimal. The findings are in contrast to the situation encountered in the hard-rock areas in Indore, where the site is characterized by a shallow water table, fractured rocks, and a thin unsaturated zone (Figs. 2 and 20). It is evident that the underlying geology, the characteristics, and factors like recharge play an important role in the retardation of the chemical and microbiological contaminants.

The range of water quality parameters at all study locations (27 nos.) is summarized in Table 5. It reveals that none of the samples exceeds the BIS limit for key parameters, except the LK1 sample from Krishna Lok Colony for fecal coliform. Fecal coliform is found in the LK1 sample in both seasons (2 CFU/100 ml) at Krishna Lok Colony. The highest TDS concentration range (275–560 mg/l) was observed at the Lucknow Polytechnic site.

The statistical significance (*t* test) of the seasonal variation of the key parameters (Table 6) has been attempted. The table value (critical value) is seen for

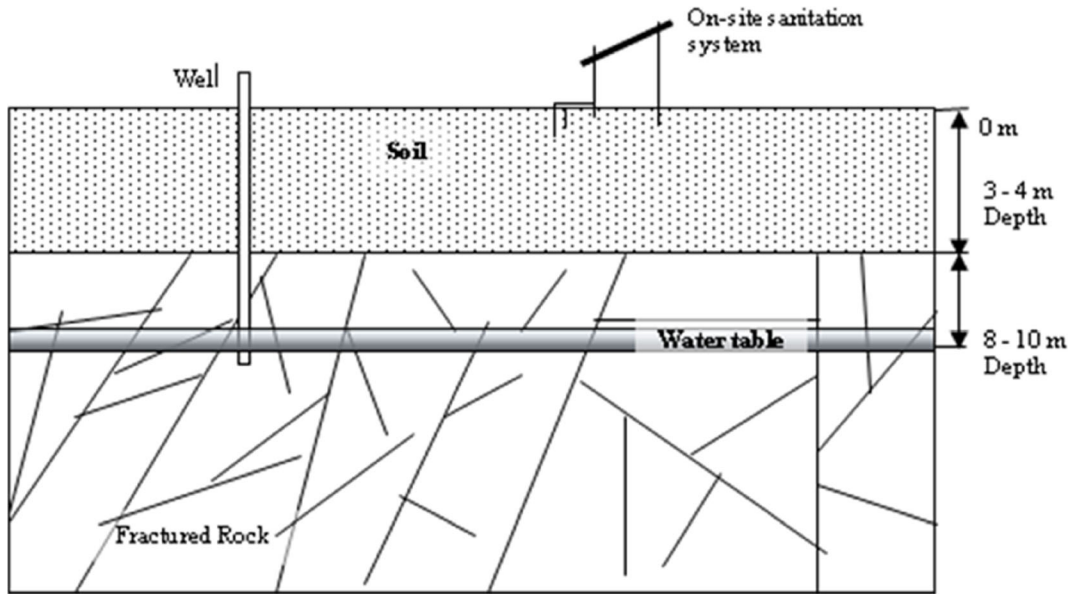

Fig. 20 Schematic sections for hard-rock areas having a shallow water table

Table 5 Summary of the water quality parameters at the sampling locations

Name of the location	pH		TDS		Nitrate		Chloride		Fecal coliform	
	Range	No. of samples exceeding the BIS limit (6.5–8.5)	Range (mg/l)	No. of samples exceeding the BIS limit (2000 mg/l)	Range	No. of samples exceeding the BIS limit (45 mg/l)	Range	No. of samples exceeding the BIS limit (1000 mg/l)	Range	No. of samples exceeding the BIS limit (0 in 100 ml)
Lucknow Polytechnic	6.9–7.7	NA	275–560	NA	0.1–0.5	NA	11–43	NA	ND	NA
Purania Sulabh toilet complex	7–7.9	NA	188–555	NA	0.1–0.4	NA	7–70	NA	ND	NA
Dhruvlok society	7–7.6	NA	204–495	NA	0.1–0.9	NA	6–16	NA	ND	NA
Krishna Lok Colony	7.2–7.5	NA	210–385	NA	ND–0.5	NA	6–16	NA	ND–2	1

NA no any, *ND* not detected

the respective degrees of freedom at 5 % significance level. The computed *t* values for Lucknow Polytechnic and the Purania Sulabh toilet complex are less than the critical value; hence, there is no significant effect of season on groundwater quality at these two locations. The *t* value at Dhruvlok society is more than the critical value of *t*; hence, there is a significant effect of season on TDS and NO_3. In Krishna Lok Colony, the seasonal variation of TDS is significant whereas there is no significant variation of NO_3 and Cl. Hence, the results clearly indicate that there is significant effect of season on the mean values of groundwater quality.

SD standard deviation, *CV* coefficient of variation, *t t* test value

Questionnaire survey

The users of the municipality drinking wells were interviewed in the course of the study period about their level of satisfaction and the prevalence of any waterborne disease. All the respondents were of the view that the water quality is satisfactory, and there has not been any outbreak of any waterborne disease in the localities.

Table 6 Summary of season-wise chemical composition of groundwater samples collected from the study area

Location	Parameters	Summer			Post-monsoon			*t*	Remarks
		Mean	SD	CV	Mean	SD	CV		
Lucknow Polytechnic	TDS (mg/l)	395.2	74.7	0.19	355.5	90.07	0.25	1.07	Not significant
	NO_3 (mg/l)	0.27	0.13	0.49	0.34	0.18	0.32	−1.27	Not significant
	Cl (mg/l)	28.6	16.9	0.6	20.4	6.54	0.32	1.39	Not significant
	FC (CFU/100 ml)	0	0	0	0	0	0	–	–
Purania Sulabh toilet complex	TDS (mg/l)	340.4	135.3	0.39	265.43	89.75	0.34	0.73	Not significant
	NO_3 (mg/l)	0.21	0.11	0.49	0.16	0.053	0.34	1.24	Not significant
	Cl (mg/l)	32.6	26.1	0.80	28.43	19.84	0.69	0.35	Not significant
	FC (CFU/100 ml)	0	0	0	0	0	0	–	–
Dhruvlok society	TDS (mg/l)	367.6	62.6	0.17	290.25	61.68	0.21	2.15	Significant
	NO_3 (mg/l)	0.54	0.24	0.44	0.2	0.075	0.38	2.76	Significant
	Cl (mg/l)	12.3	3.9	0.32	11.25	2.49	0.22	0.62	Not significant
	FC (CFU/100 ml)	0	0	0	0	0	0	–	–
Krishna Lok Colony	TDS (mg/l)	352.8	26.3	0.07	249.17	29.49	0.12	2.98	Significant
	NO_3 (mg/l)	0.23	0.18	0.75	0.28	0.075	0.27	−0.66	Not significant
	Cl (mg/l)	9.5	3.99	0.42	9.66	3.27	0.34	−0.61	Not significant
	FC (CFU/100 ml)	0.33	0.82	2.45	0.33	0.82	2.45	–	–

Conclusion

The present study indicated that the parameters of concern from the implementation of on-site sanitation systems are well within the BIS limits for all the samples. The bacteriological parameter was conspicuously absent in majority of the samples. The study area which is characterized by alluvial settings indicates minimal contamination of nitrate and fecal coliform. It has been observed that fecal coliform at Krishna Lok Colony (LK1) was found to be higher (2 CFU/100 ml) as compared to that at the other locations. It is possible that the open pit which constitutes the on-site sanitation system in Krishna Lok Colony may be contributing to more leakage as compared to other systems. Besides, site-specific conditions may be considered in further research. The presence of a thick sand column and the presence of a slightly deeper water level (30–40 m in summer and 25–30 m in post-monsoon) lead to significant retardation of the chemical as well microbiological contaminants. As there is a thick sand column lying between the on-site sanitation system and the water table, it is likely that fecal coliform will die down before reaching the water table (Lawrence et al. 2001). The low nitrate concentration may be attributed to the anaerobic condition prevailing in the groundwater sources. The statistical *t* test also implies that there is a significant effect of season on groundwater quality in the study area. The present study indicates that the implementation of an on-site sanitation system in alluvial settings with moderate water table (30–40 m in summer and 20–30 m in post-monsoon) does not have any significant impact on the groundwater quality.

Recommendations

i. Implementation of an on-site sanitation system should be encouraged in the alluvial settings having a multiple-aquifer system as noticed in Lucknow. If off-site sanitation cannot be implemented totally, a low-cost on-site sanitation system can be preferred.
ii. In the alluvial settings with a multiple-aquifer system opting for a low-cost on-site sanitation system, the deeper confined aquifer should be used for drawing the groundwater instead of the shallow unconfined aquifer.
iii. Critical parameters like the depth to water table, nature of the soil matrix, and the rock strata need to be considered in any program on installation of on-site sanitation systems where groundwater is used for drinking. A thick unsaturated zone with partially clay soil to retard the transport of chemicals will be appropriate for the implementation of on-site sanitation systems.
iv. Mandatory monitoring of the groundwater sources should be carried out in areas served by on-site sanitation systems. The monitoring should be carried out for indicator parameters like nitrate, chloride, and fecal coliform.

Acknowledgments The authors thank the CPHEEO-WHO for supporting the research study. The authors also thank the Director, CSIR-NEERI, Nagpur, for providing the necessary infrastructure.

References

Andrews, E. E. (1988). Hydrogeologic case study of septic tank effluent discharge, Figure 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.

ARGOSS (2001). Guidelines for assessing the risk to groundwater from on-site sanitation. British Geological Survey CR/01/142.

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

Bureau of Indian Standards (BIS) (1991). *Drinking water specification: ISO 10500:1991*. India:New Delhi.

Canter, L. W., & Knox, R. C. (1985). Septic tank system effects on groundwater quality. Michigan: *Lewis Publishers*, Inc. p 136.

CGWB (Central Ground Water Board), Lucknow District profile. (http://cgwb.gov.in/nr/hydro/dist37.pdf)

Chidavaenzi, K., Bradley, M., Jere, M., & Nhandara, C. (2000). *Pit latrine effluent infiltration into groundwater: the Epworth study.* London:Water Sanitation and Health, IWA.

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.

Geological Survey of India (2001), District resource map of Lucknow district published by GSI (2001).

Gunawardana, I.P.P & Galagedara, L.W. (2013). A new approach to measure sanitation performance, *Journal of Water*,

Sanitation and Hygiene for Development, Vol 3 No 2 pp 269–282, IWA Publishing 2013, doi:10.2166/washdev.2013.046.

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.

Heng, S., Putra, D. P. E., & Wilopo, W. (2010). *The impact of sanitation on groundwater nitrate level in Bantul district, Bantul Regency*. Indonesia:Yogyakarta Special Province.

Arun Kumar (2008). Groundwater brochure of Lucknow District, Uttar Pradesh, Central Ground Water Board Report, (http://cgwb.gov.in/District_Profile/UP/Lucknow.pdf)

Lawrence, A. R., Macdonald, D. M. J., Howard, A. G., Barret, M. H., Pedley, S., Ahmed, K. M., (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 faecal 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.

Paul, E.A & Ladd, J.N. (Eds.), Soil biochemistry, Vol. 5Dekker, New York (1981), pp.415–471.

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.

Pujari P.R., C. Padmakar, Pawan K. Labhshetwar, Piyush Mahore, A.K. Ganguli (2011). Assessment of the impact of on-site sanitation systems on groundwater pollution in two diverse geological settings—a case study from India. *Environmental Monitoring and Assessment*, 10661–011–1965–2

Raj, I. (2000). *Issues and objectives in groundwater quality monitoring programme under hydrology project* (pp. 1–7). Bangalore:Proc. Natl. Symp. groundwater quality monitoring.

Rissmann, C. (2011). Regional mapping of groundwater denitrification potential and aquifer sensitivity—technical report. Publication No 2011–12.Environment Southland.

Shivendra, B. T., & Ramaraju, H. K. (2015). Impact of onsite sanitation system on groundwater in different geological settings of peri urban areas. *Aquatic Procedia*, *4*(2015), 1162–1172. doi:10.1016/j.aqpro.2015.02.148.

Singh, K. P., Gupta, S., & Rai, P. (2014). Investigating hydrochemistry of groundwater in Indo-Gangetic alluvial plain using multivariate chemometric approaches. *Environmental Science and Pollution Research*, *21*(9), 6001–6015.

Tiwari, K. N., Kumar, A., & Pathak, A. N. (1983). Characterisation of salt-affected soils in central alluvial region of Uttar Pradesh. *Journal of the Indian Society of Soil Science*, *31*, 272–280.

WHO (1993). *Guidelines for drinking water quality, recommendations (Vol. 1* (2nd ed.,). Geneva:World Health Organization.