Environ Monit Assess (2011) 177:409–418
DOI 10.1007/s10661-010-1643-9

Assessment of groundwater quality in Puri City, India: an impact of anthropogenic activities

Ritesh Vijay · Puja Khobragade · P. K. Mohapatra

Received: 26 February 2010 / Accepted: 29 July 2010 / Published online: 17 August 2010

Abstract Puri City is situated on the east coast of India and receives water supply only from the groundwater sources demarcated as water fields. The objective of this paper is to assess and evaluate the groundwater quality due to impact of anthropogenic activities in the city. Groundwater samples were collected from the water fields, hand pumps, open wells, and open water bodies during post-monsoon 2006 and summer 2007. Groundwater quality was evaluated with drinking water standards as prescribed by Bureau of Indian Standards and Environmental Protection Agency to assess the suitability. The study indicated seasonal variation of water-quality parameters within the water fields and city area. Groundwater in the water fields was found to be suitable for drinking after disinfection. While in city area, groundwater quality was impacted by onsite sanitary conditions. The study revealed that groundwater quality was deteriorated due to the discharge of effluent from septic tanks, soak pits, pit latrines, discharges of domestic wastewater in leaky drains, and leachate from solid waste dumpsite. Based on observed groundwater quality, various mitigation measures were suggested to protect the water fields and further groundwater contamination in the city.

R. Vijay (✉) · P. Khobragade
ESDM Division, National Environmental Engineering Research Institute, Nehru Marg, Nagpur, 440020, Maharashtra, India
e-mail: r_vijay@neeri.res.in

P. K. Mohapatra
Orissa Water Supply & Sewerage Board, Water Works Road, Puri, 752002, Orissa, India

Keywords Groundwater quality · Anthropogenic activities · Contamination · Drinking water standards

Introduction

Groundwater is an important source of drinking water due to its high-quality, small seasonal variations, storage, easy exploitation, and socioeconomic development. Presently, 85% of the water requirement for domestic use in rural areas, 55% for irrigation, and over 50% for industrial and urban uses is met from groundwater (Ghosh and Sharma 2006). Due to rapid growth of population, urbanization, industrialization, and agriculture activities, groundwater resources are under stress. There is growing concern on the deterioration of groundwater quality due to geogenic and anthropogenic activities (CGWB 2010). The suitability of groundwater for drinking purposes is generally assessed by comparing its quality with drinking water standards established by national and international bodies. The water-quality parameters beyond the prescribed limits in the standards can render the water non-potable and may cause adverse health effects (Shankar et al. 2008). In many countries, waterborne diseases were linked to contaminated groundwater (Jones and Watkins 1985; Craun et al. 1997; Lamrani et al. 2008). Domestic sewage, effluent from septic tanks and soak pits, are the major sources contributing to groundwater pollution (Canter 1996; Dwivedi et al. 2007; De Andrade et al. 2008; Ozler and Aydin 2008). Salt water intrusion is one of the major problems in the coastal area. Heavy pumping and excessive uses of coastal groundwater, anthropogenic activities, and salt water intrusion were main causes for depletion of water table (Barker et al. 1998; Bear et al. 1999; Cruz and Silva 2000) and deterioration of groundwater quality (Kumar Swamy et al. 1997; Laluraj et al. 2005).

Puri City is located on the east coast of India. It is an internationally acclaimed tourist spot and has high religious importance for Lord Jagannath temple for which a large number of pilgrims visit the city throughout the year. Center of the city is highly populated and congested by narrow streets. Population density along the coast is also increasing due to development of hotels and residential houses in the last two decades. Groundwater is the only source available to meet the domestic water needs of the city. Groundwater is being deteriorated due to discharges of wastewater in leaky drains, leaching of effluents from septic tanks, soak pits, and pit latrines from on-site sanitation in residential areas, open defecation, etc. (Vijay and Mohapatra 2010). There is no industrial activity as such in the city, and agriculture is the main practice around the city which may also affect the groundwater quality of Puri. It is thus essential to safeguard these resources from anthropogenic activities and saltwater intrusion.

The objective of the paper is to evaluate and assess the groundwater quality based on anthropogenic activities in the city. For this, the criteria for selection of water-quality parameters are Bureau of Indian Standards (BIS) (IS Code 10500:1991) and United States Environmental Protection Agency (USEPA 2009) drinking water standards. The BIS has two limits: one is desirable and the other is permissible. The permissible limit applies to situation, where alternative water sources are absent. Since groundwater is the only source available in city, permissible limit was, therefore, considered for comparative assessment of groundwater quality. EPA standards were also considered for groundwater assessment due to its stringent water-quality limits.

Study area

The study area lies between 19°47′ to 19°50′ N latitudes and 85°48′ to 85°52′ E longitudes (Fig. 1) covering an area of about 16 km^2. Though there are several local slopes in all directions due to the presence of sand mounds and dunes, the general topography slopes smoothly towards southeastern side. The ground elevation varies from mean sea level (msl) to maximum 18.8 m. The groundwater aquifer is sandy unconfined which extends up to 40 m depth. The climate of Puri is warm and humid with maximum and minimum temperatures of 37.5°C and 15.2°C, respectively (Vijay et al. 2009a). The city receives most of the rainfall during June to October from the southwest monsoon. The average monthly and annual rainfall of the city was 126.4 and 1,517 mm, respectively, based on 2003 to 2008 rainfall data (IMD 2008). Population of the city was 157,610 as per 2001 census and has increased to 186,500 in the year 2008 (WSPT 2008). The population density, excluding undeveloped areas and vacant water fields/open land, is about 18,160 persons per square kilometer. River water is not sufficient and suitable for water supply due to nonperennial nature and salinity due to backwater of sea. Therefore, the city receives water supply of about 20.44 million liters per day (mld) from Chakratirtha water field (CWF) on the eastern side and Balia Panda water field (BPWF) on the western side of the city (Fig. 1). During field survey and sample collection, it was observed that most of the production wells directly supply groundwater without any treatment, and some of the production wells especially in CWF and BPWF supply groundwater after chlorination. Anthropogenic activities like encroachment by slum dwellers, bathing, parking and cleaning of vehicles, and dumping of domestic solid waste and

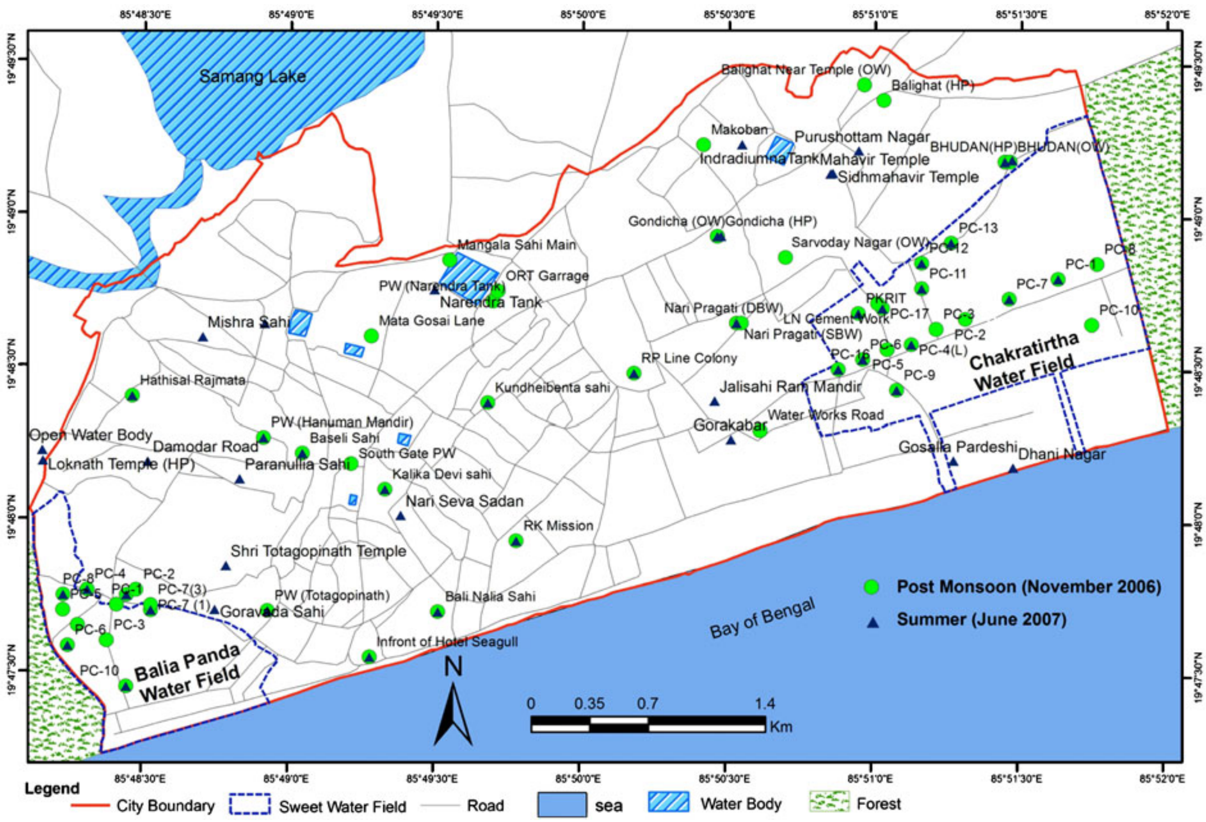

Fig. 1 Study area and details of groundwater sampling

open defecation were observed in the water fields (Vijay et al. 2009b).

Methodology

Data collection

The water table and quality are influenced by recharge and excessive withdrawal of groundwater. Therefore, groundwater levels were measured with reference to ground elevation and samples were collected in post-monsoon (November 2006) and summer (June 2007) to assess water level fluctuation and groundwater quality. Samples were collected from water fields (CWF and BPWF) and city areas including production wells, hand pumps, open wells, and open water bodies (tanks) as shown in Fig. 1. The details of samples were also collected and located in the physical space by global positioning system. Ideally, number of samples should be equal during post-monsoon and summer. During field work, difficulty was experienced to measure water levels and collection of samples from some of the production wells due to continuous pumping for city water supply, and as a result, water samples were left out unintentionally. Open wells and water bodies play an important role in groundwater recharge and quality; therefore, samples were also collected from these sources. These large water bodies were constructed hundred of years ago to meet domestic water requirement, but nowadays, water bodies are used for bathing and other activities due to its high religious importance except for drinking.

Water-quality analysis

Groundwater samples were collected, preserved, and analyzed as per standard methods (APHA 1998; Table 1). A total of 107 samples were

Table 1 Sample preservation and analysis techniques

Sr. no.	Parameters	Preservation	Technique/Method
Physicochemical			
1	pH	Analyzed immediately	pH meter
2	TDS	Refrigeration	Gravimetric method
3	Total hardness		Titrimetric method
4	Alkalinity		
5	Ca		
6	Mg		
7	SO_4		Spectrophotometeric method
8	NO_3		
9	Cl	Not required	Argentometric method
10	F	Not required	Ion selective electrode method (Fluoride meter)
11	Fe	Filtered immediately and added HNO_3 to pH < 2	ICP (Induced coupled plasma membrane technique)
Bacteriological			
12	TC	Refrigeration	Membrane filter technique
13	FC		

collected during post-monsoon and summer as summarized in Table 2. Grab sample of groundwater with 1 l volume was collected at each location. Collected samples were analyzed for physicochemical parameters as pH, total dissolved solid (TDS), total hardness, alkalinity, calcium (Ca), magnesium (Mg), sulfate (SO_4), nitrate (NO_3), chloride (Cl), fluoride (F), iron (Fe), and bacteriological parameters such as total coliform (TC) and fecal coliform (FC). pH was analyzed immediately after sampling at each site, whereas TC and FC were analyzed immediately in the field laboratory. Other parameters were analyzed in the institute laboratory after completion of the sampling.

Results and discussion

Groundwater levels were transferred to msl to estimate water table fluctuation, and samples were analyzed to assess the water quality.

Water table fluctuation

Groundwater levels in water fields and city area during post-monsoon and summer are presented in Fig. 2. The average water table above msl in post-monsoon and summer were 3.9 and 1.5 m, respectively. Water table reached the ground in many places in the city due to excessive recharge during monsoon and post-monsoon. During

Table 2 Sampling details and bacteriological analysis (CFU/100ml)

Sampling area/	Chakratirtha WF		Balia Panda WF		City PW		City HP		City OW/OWB		Drinking Water Standards	
samples	PM	S	PM	S	PM	S	PM	S	PM	S	BIS	EPA
Total	15	10	11	6	4	2	21	25	5	8		
Bacteriological analysis (positive samples and %)												
TC	1 (7)	4 (40)	1 (9)	1 (17)	0	0	2 (9)	3 (12)	3 (60)	7 (87)	0	5%[a]
FC	0	1 (10)	0	1 (17)	0	0	1 (5)	1 (4)	1 (20)	6 (75)	0	0

WF water field, *PW* production well, *HP* hand pump, *OW* open well, *OWB* open water body, *PM* post-monsoon, *S* summer, *BIS* Bureau of Indian Standards, *EPA* Environmental Protection Agency

[a]More than 5% samples TC positive in a month. Every sample that has TC must be analyzed for either FC or *Escherichia coli*. If two consecutive samples show TC positive and one is also positive for FC or *E. coli*, system has an acute maximum concentration level violation

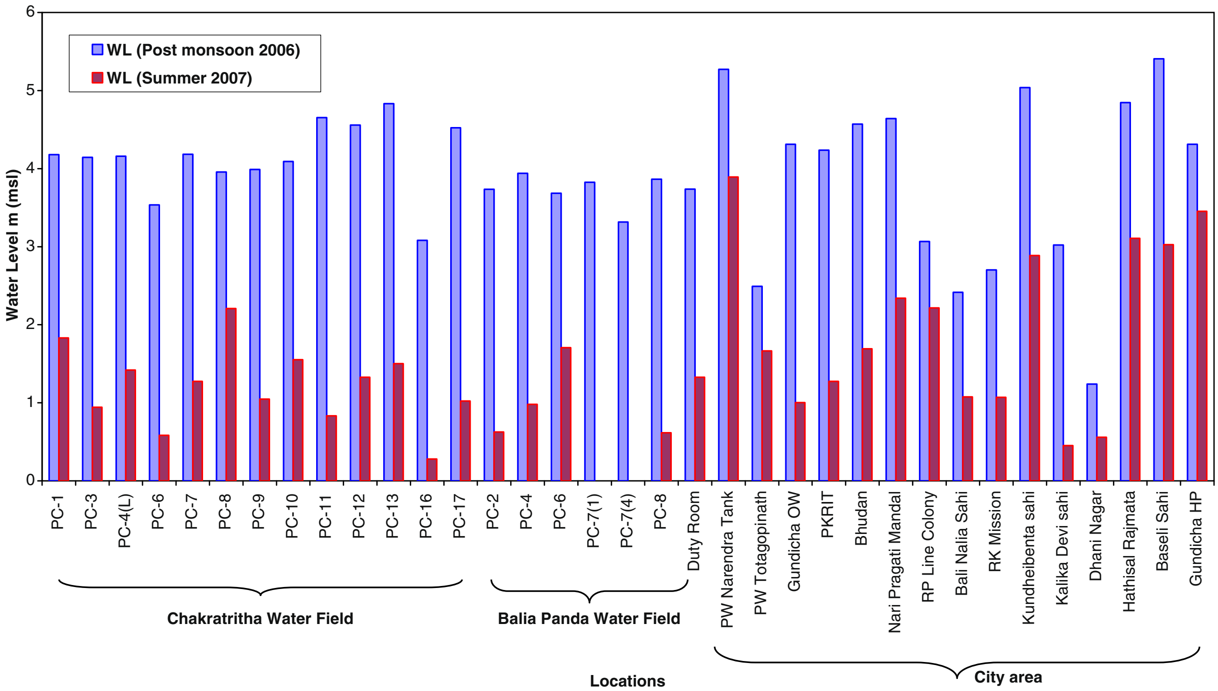

Fig. 2 Fluctuation in groundwater levels

summer, it was found that water table declined more in water fields with an average of 2.97 m due to continuous withdrawal as compared to city area with an average of 1.86 m. The minimum fluctuation was observed in hand pump at Dhani Nagar (0.68 m) near the shoreline, and maximum fluctuation was observed at production well PC-7(1) at BPWF (4.31 m). The water table was observed at msl or even below msl in the production wells PC-7 (BPWF) due to continuous withdrawal during summer.

Bacteriological analysis

Bacteriological analysis of groundwater samples during post-monsoon and summer is summarized in Table 2. FC should be absent in the drinking water as per Indian and USEPA standards because it indicates presence of pathogens due to fecal contamination (Schmoll et al. 2006). Even TC should be absent as per Indian standards while USEPA's legal limit for TC was set at 5% for public water system which means TC should not be present in more than 5% of water samples. Both the water fields were found to be affected with FC and TC. Production wells were affected with TC (PC6, PC11, PC13, and PC16) and FC (PC11) in CWF and production well (Duty room) at BPWF was affected with TC and FC in summer. The presence of FC and TC in the production wells indicated that bacteria move in the direction of continuous withdrawal through sandy strata due to disposal of sewage and wastewater from septic tanks and soak pits from the nearby residential areas. TC and FC were also found in the city area both in post-monsoon and summer. FC was found in the samples at Dhani Nagar fisherman area and at Gora Kabar due to poor sanitary conditions, lack of drainage, stagnant wastewater, and slum habitation. Production wells in the city were unaffected by coliform. Open wells and open water bodies were affected with high count of TC and FC.

Physicochemical analysis

Physicochemical characteristics and statistical analysis of groundwater samples of post-monsoon and summer along with limits of BIS and EPA standards for drinking water are presented in Tables 3 and 4, respectively. The values of individual water quality parameter are given as minimum, maximum, average, and standard deviation of the collected samples in the specific area. The limit for NO_3–N is 10 mg/L, equivalent to 44.3 mg/L as NO_3 as per EPA standards. EPA limits are more stringent compared to BIS for drinking water standards except for fluoride (BIS = 1.5 mg/L and EPA = 2.0 mg/L). Groundwater quality was within the limits as per Indian drinking water standards for pH, total hardness, alkalinity, Ca, Mg, and SO_4. Limits for these parameters are not mentioned in the EPA standards except for pH and SO_4. pH was within limits except at PC3 in CWF during post-monsoon. As per Sawyer et al. (1994), hardness was classified as soft (<75 mg/L), moderately hard (75–150 mg/L), hard (150–300 mg/L), and very hard water (>300 mg/L). As per this classification, the groundwater of water fields varied within soft to moderately hard water while hard to very hard water in city samples. Variation in hardness was more in post-monsoon samples as compared to summer season due to leaching of calcium and magnesium bicarbonate through recharge. Similarly, Ca and Mg in the groundwater were more in the city samples as compared to the water fields. As observed, slightly alkaline nature of the groundwater and hardness in most of the samples contribute to major form of alkalinity. Alkalinity was more in city samples and less in water fields. Parameters like NO_3, Cl, F, TDS, and Fe exceeded the limits of BIS and EPA in both the seasons. The number of samples (percentage of samples) exceeding the drinking water standards are given in Table 5 and discussed in following sections.

Nitrate

The presence of nitrate in groundwater is an indication of very recent sewage contamination (Schmoll et al. 2006). Previous studies indicated that source of non-agricultural nitrate in groundwater is due to discharge of wastewater, effluent from on-site sanitation, leachate from solid waste dump sites, and reuse of wastewater for irrigation (Wakida and Lerner 2005; Chanakya

Table 3 Statistical analysis for physicochemical parameters of groundwater (post-monsoon)

Parameters	Chakratirtha WF				Balia Panda WF				City PW				City HP				City OW/OWB				Drinking water standards	
	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	BIS	EPA
pH	6.6	8.6	7.4	0.5	6.8	8.1	7.5	0.4	6.9	7.4	7.1	0.2	6.7	8.2	7.3	0.4	6.9	8.0	7.2	0.4	6.5–8.5	6.5–8.5
TDS	87	370	227	85	84	619	250	152	212	810	461	290	87	1,572	611	366	184	645	394	216	500–2,000	500
Hardness	76	263	167	55	12	200	101	47	142	336	240	91	52	480	222	132	56	354	194	115	300–600	NM
Alkalinity	40	148	75	26	42	200	118	54	54	280	185	110	48	432	181	104	68	170	109	40	200–600	NM
Ca	0	63	27	16	9	48	24	12	16	83	50	28	6	77	34	23	14	65	36	22	75–200	NM
Mg	8.8	42	23.9	9	0.6	41.3	16	10.2	14.6	61.7	44	21.6	9.3	115.2	40.5	30.4	10.1	46.5	26.3	13.5	30–100	NM
SO_4	0.9	32.7	10	8.7	4	42.3	19	11.5	3	51	24.8	19.8	1	144	39	36.8	2	35.2	17.3	12	200–400	250
NO_3	0.3	9.7	2	2.5	0.2	102	10	30.4	0.3	12.8	3.8	6	0.2	155	11	33	0.4	8.9	2.3	3.7	45	10[a]
Cl	14	56	38	10	22	110	58	26	62	130	96	38	16	464	138	99	36	128	74	44	250–1,000	250
F	0.04	1.8	0.3	0.5	0.04	0.8	0.2	0.2	0.08	0.5	0.3	0.2	0.04	1.7	0.5	0.5	0.2	0.8	0.5	0.3	1–1.5	2
Fe	0.1	0.3	0.2	0.1	0.2	1	0.5	0.4	ND	0.6	–	–	0.8	1.1	0.9	0.2	–	–	–	–	0.3–1	0.3

Unit mg/L for all parameters except for pH

WF water field, *PW* production well, *HP* hand pump, *OW* open well, *OWB* open water body, *PM* post-monsoon, *S* summer, *Min* minimum, *Max* maximum, *Avg* average, *SD* standard deviation, *BIS* Bureau of Indian Standards, *EPA* Environmental Protection Agency, *NM* not mentioned in standard

[a]Measured as nitrogen

Table 4 Statistical analysis for physicochemical parameters of groundwater (summer)

Parameters	Chakratirtha WF				Balia Panda WF				City PW				City HP				City OW/OWB				Drinking water standards	
	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	BIS	EPA
pH	7.4	7.9	7.6	0.1	6.7	7.4	7	0.2	6.8	7.4	7	0.4	6.8	8.1	7.6	0.3	7.2	7.3	7.6	0.1	6.5–8.5	6.5–8.5
TDS	55	346	215	104	79	372	198	104	247	431	340	131	93	2,208	505	419	587	675	631	62	500–2,000	500
Hardness	52	164	114	42	40	180	101	45	120	136	128	11	24	520	162	124	160	220	190	42	300–600	NM
Alkalinity	12	148	90	45	20	200	93	60	112	152	132	28	52	288	151	69	140	388	264	175	200–600	NM
Ca	9.6	22.4	15.5	4.5	6.4	27.2	16.3	7.4	17.6	27.3	22.4	6.8	6.4	54.4	14.8	9.5	16	27.6	21.6	7.9	75–200	NM
Mg	3.9	30	18.4	9	1	30.1	14.7	10.5	12.6	22.4	17.5	6.9	0	93.2	30.4	26.4	22.4	43.7	33.1	15.1	30–100	NM
SO_4	10	56	31	16	7	37	17	11	18	44	31	18	8	320	52	61	25	116	71	65	200–400	250
NO_3	0.9	49.3	15.8	15.9	1.4	61.1	14.4	22.9	7.3	21.7	14.5	10.2	1.9	148	30.5	41.1	5.5	37.7	21.6	22.7	45	10[a]
Cl	27	82	51	17	37	60	49	8	72	77	75	3	22	1,122	147	215	87	205	146	83	250–1,000	250
F	0.06	0.14	0.9	0.02	0.09	0.31	0.16	0.09	0.1	0.12	0.11	0.01	0.05	2.04	0.43	0.54	0.17	0.31	0.24	0.1	1–1.5	2
Fe	0.18	1.7	0.8	0.6	0.12	1.2	0.6	0.4	1.1	1.4	1.2	0.2	0.04	3.5	1.5	0.8	1.2	2.3	1.7	0.5	0.3–1	0.3

Unit mg/L for all parameters except for pH

WF water field, *PW* production well, *HP* hand pump, *OW* open well, *OWB* open water body, *PM* post-monsoon, *S* summer, *Min* minimum, *Max* maximum, *Avg* average, *SD* standard deviation, *BIS* Bureau of Indian Standards, *EPA* Environmental Protection Agency, *NM* not mentioned in standards

[a]Measured as nitrogen

Table 5 Evaluation of groundwater water quality

Parameters	Number of samples exceeding standards (% of samples)																			
	Chakratirtha WF				Balia Panda WF				City PW				City HP				City OW/OWB			
	PM		S		PM		S		PM		S		PM		S		PM		S	
	BIS	EPA	BIS	EPA	BIS	EPA	BIS	EPA	BIS	EPA	BIS	EPA	BIS	EPA	BIS	EPA	BIS	EPA	BIS	EPA
NO_3	–	–	2 (20)	2 (20)	1 (9)	1 (9)	1 (16)	1 (16)	–	–	–	–	1 (5)	1 (5)	8 (32)	8 (32)	–	–	–	–
Cl	–	–	–	–	–	–	–	–	–	–	–	–	–	2 (10)	1 (4)	2 (8)	–	–	–	–
F	1 (7)	–	–	–	–	–	–	–	–	–	–	–	1 (5)	–	2 (8)	1 (4)	–	–	1 (13)	1 (13)
TDS	–	–	–	–	–	1 (9)	–	–	–	2 (50)	–	–	–	12 (57)	1 (4)	11 (44)	–	2 (40)	–	3 (38)
Fe	–	1 (7)	3 (30)	6 (60)	–	3 (27)	2 (33)	4 (67)	–	1 (25)	2 (100)	2 (100)	1 (5)	1 (5)	19 (76)	24 (96)	–	–	5 (63)	5 (63)

WF water field, *PW* production well, *HP* hand pump, *OW* open well, *OWB* open water body, *PM* post-monsoon, *S* summer, *BIS* Bureau of Indian Standards, *EPA* Environmental Protection Agency

– Parameters within standards

and Sharatchandra 2008). Nitrate causes methemoglobinemia or blue baby disease in infants, disorders of alimentary canal, respiratory, and nervous system (Majumdar and Gupta 2000). Nitrate in groundwater samples shows variations in both the seasons. The average concentration of nitrate was more in summer as compared to post-monsoon. Nitrate exceeded the limits in three (PC-7 and PKRIT from CWF and PC-10 from BPWF) out of 16 samples from water fields during summer and only one (PC-2 from BPWF) out of 26 samples in post-monsoon. The presence of nitrate in the production wells indicated percolation of sewage from the residential area and its movement towards water fields by pumping. Even nitrate exceeded the limits in eight out of 25 city samples (hand pumps) in summer and one out of 21 samples in post-monsoon. Low concentration of nitrate in post-monsoon may be due to dilution by recharge.

Chloride

It is a good indicator of groundwater quality. The chloride concentration in groundwater will increase if it mixed with sewage or sea water. Chloride concentration of more than 250 mg/L causes salty taste. As per EPA standards, the chloride concentration was within the limit (250 mg/L) in all production wells and most of the city hand pumps except two samples in each post-monsoon (Mata Gosai and ORT garrage) and summer (RK Mission and Gosala Pardeshi). As per BIS, the chloride concentration was found well above limit (1,000 mg/L) at Gosala Pardeshi in summer.

Fluoride

Fluoride in small amount is necessary for good health for preventing dental carries but high concentration causes health risk such as dental fluorosis and skeletal fluorosis (Baskaradoss et al. 2008). Fluoride-bearing minerals in the rocks and their interaction with water and agricultural activities are considered to be the main cause for fluoride in groundwater (Saxena and Ahmed 2003). Fluoride in most of the groundwater samples was within the limit (1.5 mg/L) except at PC (7) in CWF and hand pump (in front of hotel Seagull) in city during post-monsoon. In summer, it exceeded the limit in city hand pumps (Gondicha mandir and PKRIT) and also in open water body (Indradiumna tank).

Total dissolved solids

TDS in groundwater indicated decreasing trend from post-monsoon to summer in water fields and city area except open wells/water bodies. The open wells/water bodies registered increase in TDS in summer probably due to decrease in water volume by evaporation. The high concentration of TDS in groundwater in post-monsoon may be attributed due to leaching of salts from ground surface by recharge. TDS in water fields was less as compared to city areas, as water fields are open areas and less affected with anthropogenic activities as compared to city area. TDS was more in city area due to percolation of wastewater and sewage through porous media which contributes TDS in the groundwater. TDS exceeded the EPA limit (500 mg/L) in one out of 11 samples from BPWF (PC-1), two out of four samples in city production wells (near Narendra tank and south gate), 12 out of 21 in city hand pumps, and two out of five samples in city open wells during post-monsoon. Whereas in summer, TDS was found above limit at 11 out of 25 city hand pumps and three out of eight city open wells and water body samples. As per Indian standards, TDS was found within the limit (2,000 mg/L) in all the samples except at hand pump (Gosalla Pardeshi) in summer.

Iron

Iron is found in groundwater all over the world and its high concentration causes bad taste, discoloration, staining, turbidity, esthetic, and operational problems in water supply system (Vigneswaran and Visvanathan 1995). The presence of iron in groundwater is not anthropogenic and harmful to human health. The presence of iron may be due to iron bacteria in groundwater (Blarasin et al. 1999). Average concentration of iron was less in water fields as compared to city areas. Fe concentration was also less in post-monsoon in comparison to summer due to recharge. According to BIS standards, all samples except one (Bhudan) from city hand pump were within the limits (0.3–1.0 mg/L) during post-monsoon. While in summer, Fe was found above the limits in three out of 10 samples from CWF (PC-13, PC-16, PC-17), two out of six samples from BPWF (PC-4 and PC-7), 19 out of 25 city hand pumps, and five out of eight open wells/open water bodies. As per EPA standards, Fe exceeded the limit (0.3 mg/L) in most of the samples. Fe was found above the limit in one out of 15 samples from CWF (PC-8), three out of 11 samples from BPWF (PC-1, PC-6, PC-5), one out of four samples in city production wells (Hanuman mandir), and one out of 21 samples in city hand pumps (Bhudan and forest range office) during post-monsoon. While in summer, Fe exceeded the limit in six out of 10 samples from CWF (PC-1, PC-7, PC-11, PC-13, PC-16, and PC-17), four out of six samples from BPWF (PC-4, PC-7, Duty Room, and PC-8), 24 out of 25 hand pumps, and five out of eight open wells/water bodies from the city.

Conclusion and suggestions

Groundwater quality clearly indicated the variation in parameters between water fields and city areas due to effect of seasons, prevalent on-site sanitation, and solid waste dumping. Groundwater quality of Chakratirtha and Balia panda water fields was found to be overall safe for drinking purpose except in some of the production wells where nitrate, TC, and FC were observed. Therefore, water supply of the city must be chlorinated to reduce health risk. Some of the parameters like nitrate, chloride, sulfate, fluoride, and iron were more in city area as compared to water fields.

Both the water fields contribute high recharge due to its large area and act as a slow sand filter to improve the quality of groundwater. Therefore, both the water fields should be protected from anthropogenic activities. Any developmental activities in the water fields should be well planned and connected with city sewerage system. Although the city is implementing the sewerage system, full-scale wastewater collection and treatment will prevent further groundwater contamination. A management strategy to stop practicing of septic tanks, soak pits, open discharges of domestic waste, and uncontrolled solid waste dumping is also needed to protect groundwater resources.

Acknowledgements The study is a part of research project funded by the Orissa Water Supply and Sewerage Board (OWSSB), Bhubaneswar. Authors are thankful to Director, NEERI, Nagpur and Member Secretary, OWSSB for providing encouragement and necessary infrastructural support. The contributions of Mr. S. S. Nanda, Deputy Project Engineer, OWSSB, Puri is gratefully acknowledged. Authors are also thankful to reviewers for their suggestions and comments as well as Ms. Nitu D. Sharma and Ms. Ramya S. Sanam for editorial corrections.

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