Asian Journal of Water, Environment and Pollution, Vol. 10, No. 2 (2013), pp. 51–58.

Spatial and Temporal Assessment of Groundwater Quality in Puri City, India: A Statistical Analysis

Ritesh Vijay*, S.S. Ramya, P.R. Pujari and P.K. Mohapatra
ESDM Division, National Environmental Engineering Research Institute, Nagpur – 440020, India
✉ r_vijay@neeri.res.in

Received May 4, 2011; revised and accepted March 18, 2013

Abstract: Puri city is situated near Bay of Bengal where there is a balanced interface of sea water and fresh water near the coast line. The city receives water from the groundwater sources and the quality of ground water is being maintained. The main objective of the paper is to assess the quality of ground water using statistical techniques and the suitability of this water for its utility was verified using Indian drinking water standards. Groundwater samples were collected from various specific areas during post and pre- monsoon seasons and analyzed for physico-chemical and bacteriological parameters and compared with standards. The ground water is mainly polluted due to the domestic effluent, which contains detergents, human and animal excreta, industrial waste and cremation of human and animal bodies. The study showed that concentration of quality parameters were more in the city area as compared to the water fields due to the various anthropogenic activities taking place in the city. Based on the spatial and temporal assessment of groundwater quality, various mitigation measures were suggested for improving the groundwater quality of the Puri city.

Key words: Groundwater quality, drinking water standards, statistical analysis, anthropogenic activities.

Introduction

In arid and semi-arid areas, ground water is often the only water resource, which is available round the year. The use of groundwater resources is increasing in many parts of the world due to population growth and declining rainfall that may be associated with regional climate change. As a consequence of these factors, it is becoming increasingly important to understand what level of groundwater use is sustainable in any given aquifer and what the environmental consequences of excessive groundwater use are likely to be (Appleyard, 2009). Ground water is not only a resource in itself but a long-term storage reservoirs. Ground water is highly valued because of certain properties not possessed by surface water (Goel, 2000).

Ground water in the coastal area is relatively vulnerable to the salinization by the natural sea water, which makes ground water unsuitable for drinking or for agricultural water. Also, heavy pumping and excessive use of ground water near the coastal area can increase the groundwater salinization (Barker et al., 1998; Bear et al., 1999, Cruz and Silva, 2000; Gimenez and Morell, 1997). The definition of water quality is very much depending on the desired use of water. Therefore different uses require different criteria of water quality as well as standard methods for reporting and comparing results of water analysis (Babiker, 2007). Puri city is situated on the shoreline of the Bay of Bengal and ground water is the only source available for water supply. It is a religious town having great national and international significance in the history of India. The main practise in the city is agriculture which greatly affects the groundwater quality.

The main objective of this study is to evaluate the influences of human activities on groundwater quality of

*Corresponding Author

Puri city. To accomplish this purpose, physico-chemical properties of ground water have been examined. Also, based on the analyzed data, statistical method has been used to characterize the groundwater quality.

Study Area

Puri city, as shown in Figure 1, lies between 19° 47′ to 19° 50′ N latitudes and 85° 48′ to 85° 52′ E longitudes and falls in the Survey of India Toposheet No. 74E13 covering an area of about 16.84 km^2. The ground elevation ranges from sea level to 18.8 m above mean sea level (MSL) within the municipal limits. It is situated on sandy terrain with sand dunes. The climate of Puri is warm-humid with the maximum and minimum temperatures as 37.5°C and 27°C in the summer while 28.2°C and 15.2°C in winter respectively. The mean annual rainfall is about 1517 mm from the southwest monsoon (Vijay et al., 2010). The population density, excluding undeveloped areas and vacant water fields/open land, is about 18,160 persons per square kilometre. River water is not sufficient and suitable for water supply due to non-perennial nature and salinity due to backwater of sea. Therefore, the city receives water supply of about 20.44 million litres per day (mld) from Chakratirtha water field (CTWF) on the eastern side and Balia Panda water field (BWF) on the western side of the city.

Methodology

Methodology of the study area is divided into two parts. Part I includes data collection and analysis while part II includes statistical analysis of groundwater quality for data interpretation and further utilization for planning and management.

Data Collection and Analysis

Various groundwater samples were collected based on their locations in the specific regions and aquifer property. Sampling locations were identified in the study area using global positioning system (GPS) and collected from Chakrathirtha and Balia Panda water fields, city area and open wells/open water bodies. The post and pre-monsoon samples were collected during November 2006 and June 2007 respectively.

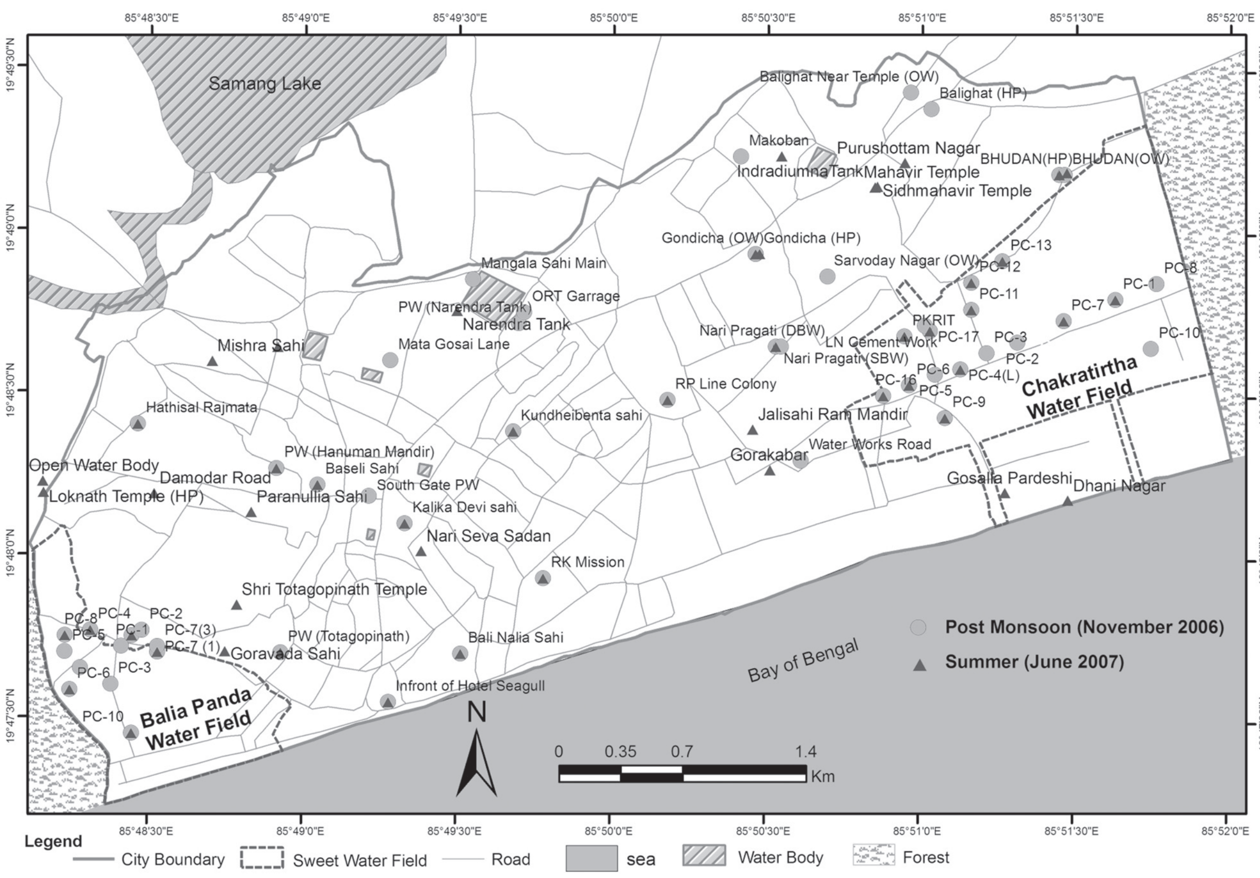

Figure 1. Study area of Puri city.

Groundwater samples were collected, preserved and analyzed as per the standard methods (APHA, 1998) and compared with Indian drinking water standards (BIS, 1991). In all 107 samples were collected and analyzed for the physico-chemical parameters such as pH, total dissolved solids (TDS), chloride (Cl), fluoride (F), nitrate (NO_3), sulphate (SO_4), calcium (Ca), magnesium (Mg), total hardness, total alkalinity, iron (Fe) and bacteriological parameters as total coliform (TC) and faecal coliform (FC). pH was analyzed on site and bacteriological parameters were analyzed immediately in the field laboratory and rest of the parameters being analyzed later in the institute laboratory.

Statistical Analysis

This paper mainly aimed at analyzing these groundwater quality parameters through box plot which is a clear visual representation of variation of each parameter. Box plots are the most powerful and useful tool in assessing the groundwater quality. It is a simple visual method to interpret the data. They provide much useful information regarding the various aspects of groundwater such as the area best for sampling and how much spread each parameter is and other main aspects like the range of the values of each parameter suitable for various purposes. The size of the box provides an estimation of the kurtosis—the peakedness of the distribution. Box plots display differences between samples without making any assumptions of the underlying statistical distribution: they are non-parametric (Hoaglin et al., 2003). The box plot was constructed using the R-package (Avner et al., 2006) which is a user-friendly and a simple coded package. All these parameters were taken as input into the R-package which resulted in the box plot showing the spread of each parameter over the different seasons. In this way, an effective visual analysis was carried out.

Results and Discussions

Groundwater Quality

Groundwater quality analysis based on physico-chemical characteristics during post and pre- monsoon are represented in Tables 1 and 2 respectively. Bacteriological data is presented for post and pre-monsoon in Table 3 with positive samples of FC. Groundwater quality was categorised in specific areas namely Chakrathirtha water field, Balia Panda water field, city production wells, city hand pumps and open wells/open water bodies in the city. Each parameter in the specific areas is represented as minimum, maximum, average and standard deviation amongst samples collected in that area. Water quality parameters were more in the city area as compared to water fields due to density habitat, water supply, insanitary conditions, domestic waste discharges in sand and leaky drains, soak pits, septic tanks etc.

Contamination was also found in water fields which are practically open lands but occupied with anthropogenic activities like slum encroachment, open defecation, clearing of vehicles etc. Contaminants may also be moved towards the water fields from surrounding geogenic habitats in the direction of flow due to continuous withdrawal from the water fields (Emmanuel et al., 2009). The groundwater quality was assessed with Indian drinking water standards and found within the desirable and permissible limits for most of the parameters except for F, NO_3, Fe, and FC in some areas. Each parameter is defined statistically through box plots with more details in the next section. The presence of Fe indicates the deteriorating groundwater due to the various anthropogenic activities. Fe was found more in the pre monsoon samples as compared to post monsoon samples even beyond the permissible limits (1.0 mg/L).

Statistical Analysis

Box plots are drawn for physico-chemical and bacteriological parameters of groundwater during post and pre-monsoon as presented in Figure 2 for (a) pH, (b) TDS, (c) chloride, (d) fluoride, (e) NO_3, (f) SO_4, (g) Ca, (h) Mg, (i) total hardness, (j) total alkalinity, (k) Fe, and (l) FC. Each plot indicated minimum, maximum and mean values in the specific areas and the nature of variation. Post and pre-monsoon values are plotted together to compare the groundwater quality seasonally. Plots are also highlighted with desirable and permissible limits of Indian drinking water standards.

pH in all the regions was well within the permissible limit except at production well (PC-3) in CTWF during post monsoon (Figure 2a). TDS was also found in the limits of the standards except at Gosalla Pardesi during summer (Figure 2b). The high concentration of TDS at this location may be due to its close vicinity with sea water. Box plot indicates average concentration of TDS more in post monsoon rather than in pre-monsoon. TDS was more in the city area as compared to other areas in both the seasons. This was due to the leaching of salt as well as percolation of sewage and waste water from leaky drains and anthropogenic activities (Palanisamy et al., 2007). Similarly plot of chloride indicates that all the samples were well within the limits of drinking water standards except at Gosalla Pardesi due to its location near the coast (Figure 2c). Fluoride was also within the standards except at one location (PC-7) on CTWF and two locations in city area (Figure 2d).

Table 1: Statistical analysis for physico-chemical parameters of groundwater samples (post monsoon)

Parameters	*CTWF*			*BWF*			*CPW*			*CHP*			*COW*			*Sample higher than permissible limits*	*Indian drinking water standards*
	Min	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*		
pH	6.6	8.6	7.4	6.8	8.1	0	6.9	7.4	7.1	6.7	8.2	7.3	6.9	8.0	7.2	0	6.5 - 8.5
TDS	87	370	227	84	619	0	212	810	461	87	1572	611	184	645	394	0	500 - 2000
Hardness	76	263	167	12	200	0	142	336	240	52	480	222	56	354	194	0	300 - 600
Alkalinity	40	148	75	42	200	0	54	280	185	48	432	181	68	170	109	0	200 - 600
Ca	0	63	27	9	48	0	16	83	50	6	77	34	14	65	36	0	75 - 200
Mg	8.8	42	23.9	0.6	41.3	1(2)	14.6	61.7	44	9.3	115.2	40.5	10.1	46.5	26.3	1(2)	30 - 100
SO_4	0.9	32.7	10	4	42.3	0	3	51	24.8	1	144	39	2	35.2	17.3	0	200 - 400
NO_3	0.3	9.7	2	0.2	102	2(4)	0.3	12.8	3.8	0.2	155	11	0.4	8.9	2.3	2(4)	45
Cl	14	56	38	22	110	0	62	130	96	16	464	138	36	128	74	0	250 - 1000
F	0.04	1.8	0.3	0.04	0.8	2(4)	0.08	0.5	0.3	0.04	1.7	0.5	0.2	0.8	0.5	2(4)	1.0 - 1.5
Fe	0.1	0.3	0.2	0.2	1	1(2)	ND	0.6	-	0.8	1.1	0.9	-	-	-	1(2)	0.3 - 1

CTWF = Chakratirtha water field, BWF = Balia Panda Water Field, CPW = City production well, CHP = City hand pump, COW = City open well, Min = minimum, Max = maximum, Avg = average, SD = standard deviation

Units mg/L for all parameters except for pH

Table 2: Statistical analysis for physico-chemical parameters of groundwater samples (summer)

Parameters	*CTWF*			*BWF*			*CPW*			*CHP*			*COW*			*Sample higher than permissible limits*	*Indian drinking water standards*
	Min	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*		
pH	7.4	7.9	7.6	6.7	7.4	7	6.8	7.4	7	6.8	8.1	7.6	7.2	7.3	7.6	0	6.5-8.5
TDS	55	346	215	79	372	198	247	431	340	93	2208	505	587	675	631	1(2)	500-2000
Hardness	52	164	114	40	180	101	120	136	128	24	520	162	160	220	190	0	300-600
Alkalinity	12	148	90	20	200	93	112	152	132	52	288	151	140	388	264	0	200-600
Ca	9.6	22.4	15.5	6.4	27.2	16.3	17.6	27.3	22.4	6.4	54.4	14.8	16	27.6	21.6	0	75-200
Mg	3.9	30	18.4	1	30.1	14.7	12.6	22.4	17.5	0	93.2	30.4	22.4	43.7	33.1	0	30-100
SO_4	10	56	31	7	37	17	18	44	31	8	320	52	25	116	71	0	200-400
NO_3	0.9	49.3	15.8	1.4	61.1	14.4	7.3	21.7	14.5	1.9	148	30.5	5.5	37.7	21.6	10(19)	45
Cl	27	82	51	37	60	49	72	77	75	22	1122	147	87	205	146	1(2)	250-1000
F	0.06	0.14	0.9	0.09	0.31	0.16	0.1	0.12	0.11	0.05	2.04	0.43	0.17	0.31	0.24	3(7)	1.0-1.5
Fe	0.18	1.7	0.8	0.12	1.2	0.6	1.1	1.4	1.2	0.04	3.5	1.5	1.2	2.3	1.7	30(57)	0.3-1

CTWF = Chakratirtha water field, BWF = Balia Panda Water Field, CPW = City production well, CHP = City hand pump, COW = City open well, Min = minimum, Max = maximum, Avg = average, SD = standard deviation

Units mg/L for all parameters except for pH

Table 3: Bacteriological analysis (positive samples)

Sampling area/samples	*CTWF*		*BWF*		*CPW*		*CHP*		*COW*	
	PM	*S*	*PM*	*S*	*PM*	*S*	*PM*	*S*	*PM*	*S*
Total Number	15	10	11	6	4	2	21	25	5	8
FC	–	1	–	1	–	–	1	1	1	6

CTWF = Chakratirtha water field, BWF = Balia Panda Water Field, CPW = City production well, CHP = City hand pump, COW = City open well, PM = post monsoon, S = summer

Chloride was found very less than the desirable limits but at one location it was found higher than the permissible limits where the location is closer to the sea. The leaching of the marine sedimentary deposits and the domestic sewage is the main reason for chloride in ground water. The one nearer to the sea has high percolation of deposits into the ground water which contaminates it further more (Figure 2e).

The fluoride concentration was more than the permissible limits in the ground water which deteriorates its quality. The higher concentrations were found more during the post monsoon season at PC-7 in Chakratirtha water field and at hotel sea gull which is nearer to the sea. The PKRIT colony near the sweet water field showed the highest concentration in the summer season (Figure 2f). The main contributor of fluoride in that area is the alluvium containing mica and the use of phosphotic fertilizers in the area. The excessive concentration of fluoride leads to fluorosis and dental carries (Meenakshi and Maheshwari, 2006). As there is less concentration of fluoride in the city area, there are fewer chances of dental carries and the other diseases by fluoride.

Nitrate was found in all the areas due to geogenic and anthropogenic activities. Nitrate was more in the city samples as compared to the water fields. Even both the water fields were found more than 45 mg/L (Figure 2e). NO_3 concentration was the highest at the Hathisal Rajmata land. CTWF is surrounded by habitat and BWF is influenced by upstream located solid waste dumping ground. Presence of nitrate indicated percolation of sewage in the ground water (MacQuarrie et al., 2001). SO_4 in ground water was within the limits of standards (200-400 mg/L) and comparatively more in city area (Figure 2f) but the highest was obtained at Gosalla Pardesi Baraf which is closer to the sea.

Calcium and magnesium were well within the limits of standards and were more in post monsoon as compared to pre-monsoon due to leaching of salts by groundwater recharge (Figures 2g and 2h).

Total hardness of all the samples was found within the desirable limits but some were above the desirable limits and within the permissible limits as depicted in the box plot (Figure 2i). Hardness in the water field samples was in the range of 25-200 mg/L which may be considered as soft to moderately hard water as per Sawyer and Mc Crathy (1994) classification and ranges. 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 ground water of water fields varied within soft to moderately hard water while hard to very hard water in city samples. Average concentration of hardness was more in post monsoon as compared to pre-monsoon due to leaching of bicarbonate ions. The total hardness was more in the city samples. Similarly, alkalinity was more in the city area as compared to water fields and well within the standards.

The major reason for the alkalinity in ground water is its pH. The pH contributes much to the alkalinity of groundwater at most of the areas. All the samples collected were within the desirable limits. At some other locations it was above the desirable limits but within the permissible limits hence it can be safely used for various purposes.

Iron is one of the most important parameters of groundwater quality. It was found above the permissible limits in many of the samples in summer and in two samples during the post monsoon but the maximum limit was found in the city hand pumps. This is mainly due to the iron bacteria present in the water due to the anthropogenic geogenic activities (Das et al., 2007). Fe was more in summer samples due to less water column availability as compared to post monsoon. This high concentration doesn't affect the people consuming the ground water through hand pumps.

FC was found only during pre-monsoon except at Dhani Nagar during post monsoon that too in the city open wells. This was due to the poor sanitary conditions and the disposal of sewage from soak pits and septic tanks etc. FC was also found in water fields due to its sewage travel through sandy strata and movement towards water fields due to continuous pumping. Therefore, water supply of the city must be chlorinated to minimize health hazards. The major contamination is mainly in the city open wells which are clearly indicated by the box plot by its spread (Figure 2l).

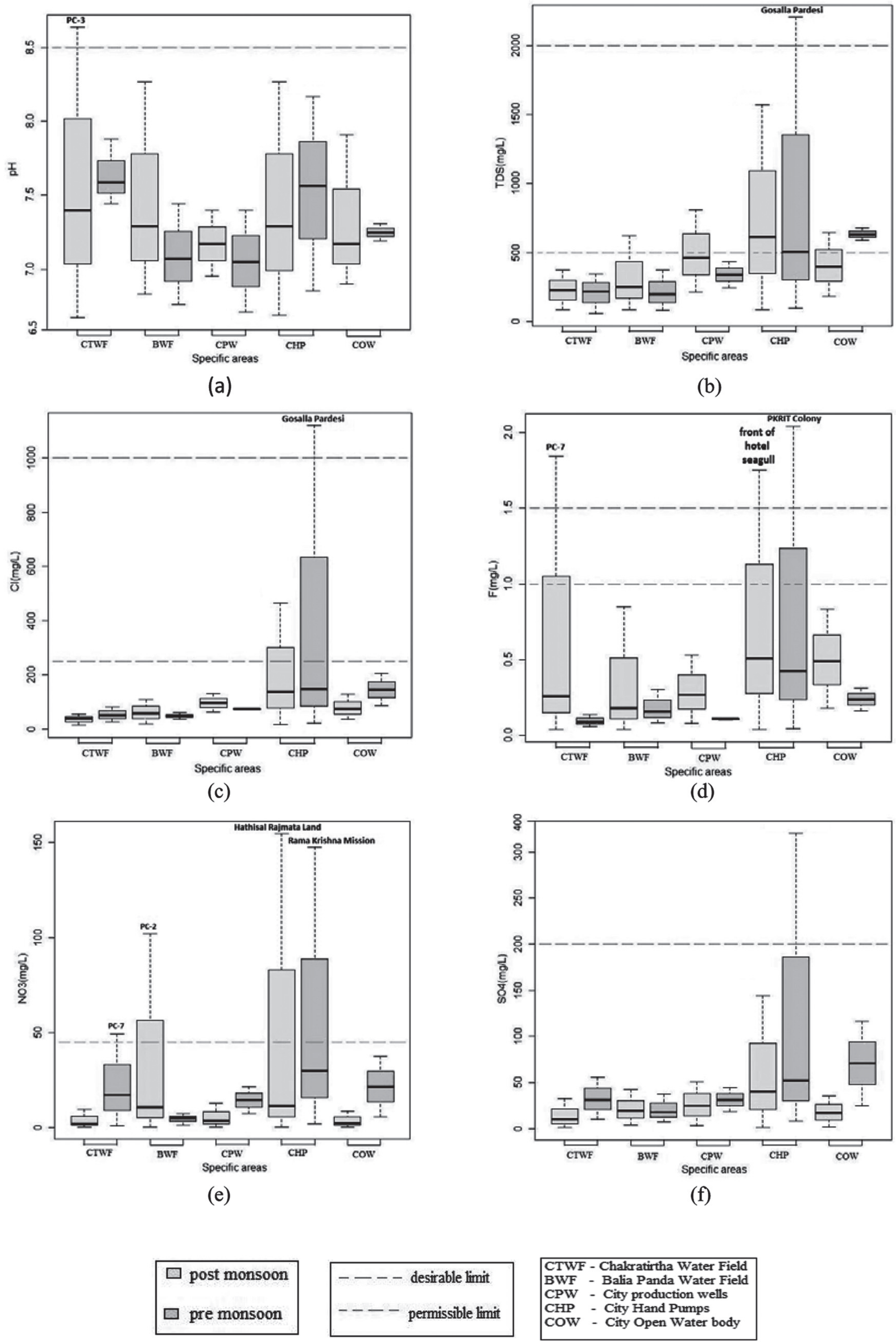

Figure 2: (*Contd.*)

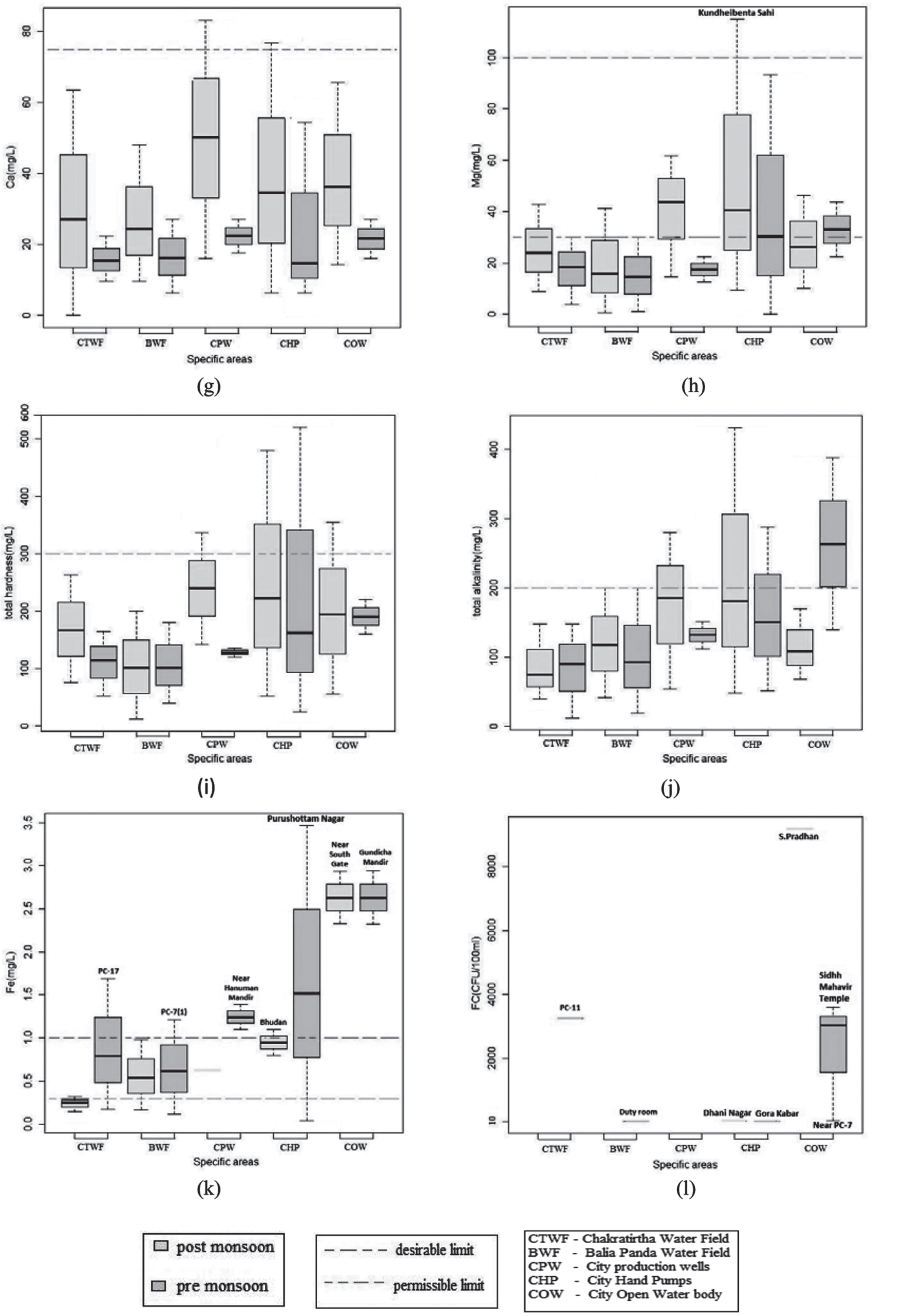

Figure 2: Box plots for the physico-chemical and bacteriological parameters: (a) pH, (b) TDS, (c) Cl, (d) F, (e) NO_3, (f) SO_4. (g) Ca, (h) Mg, (i) total hardness, (j) total alkalinity, (k) Fe, and (l) FC.

Conclusions

Puri city is dependent on groundwater resources which appear to be the only alternative in the absence of surface water sources. The groundwater quality assessment of Puri city revealed that most of the parameters were within the standards. Parameters were more in the city areas as compared to the other sampling regions especially the water fields. Since, city sewerage system and water plant are under construction, chances of groundwater contamination will be minimized. The groundwater quality of water fields was found safe except for NO_3 and bacteriological contamination due to solids waste dump and various man-made activities in and around water field. Therefore, water field should be protected from anthropogenic activities and well connected with city sewerage system. The storm water drains need to be strengthened by separating the sanitation, sewerage and drainage aspects, which are currently intermixed.

A water treatment plant has to be set up in the city to account for the rapid contamination of the ground water and especially bacteria which were found in water fields. The number of domestic connections to each household has to be increased. There has to be improved sanitation keeping in mind the increasing population of the city. People are using low cost methods of disposal of sewer like soak pits and septic tanks. These methods some time increase NO_3 in the soil and bacterial contamination of ground water; therefore there is a need to make a planned sewer system and treat it before it gets percolated in the ground. Any development plan in the city as well as in the water fields needs to be carefully planned to prevent further groundwater contamination.

Acknowledgements

Authors are thankful to Director, NEERI, Nagpur for providing encouragement and necessary infrastructural support. The Orissa Water Supply and Sewerage Board, Bhubaneswar is acknowledged for providing the financial support to carry out this study.

References

APHA (1998). Standard methods for the examination of water and wastewater (American Public Health Association), Washington DC, 20th Edn.

Appleyard, S. and T. Cook (2009). Reassessing the management of groundwater use from sandy aquifers: Acidification and base cation depletion exacerbated by drought and groundwater withdrawal on the Gnangara Mound, Western Australia. *Hydrogeology Journal*, **17(3):** 579-588.

Avner Bar-Hen and Nicolas Picard (2006). Simulation study of dissimilarity between point process. *Computational Statistics*, **21(3-4):** 487-507.

Babiker, I.S., Mohamed, A.A. and T. Hiyama (2007). Assessing groundwater quality using GIS. *Water. Resources Management*, **21:** 699-715.

Barker, A.P., Newton, R.J. and S.H. Bottrell (1998). Processes affecting groundwater chemistry in a zone of saline intrusion into an urban sandstone aquifer. *Applied Geochemistry*, **13(6):** 735-749.

Bear, J., Cheng, A.H.-D., Sorek, S., Ouazar, D. and I. Herrera (1999). Seawater Intrusion in Coastal Aquifers Concepts, Methods and Practices. Kluwer, Academic Publishers, Dordrecht.

BIS Code 10500:1991. Drinking Water Standard. Manak Bhavan, New Delhi. http://bis.org.in/bis/html/10500.html.

Cruz, J.V. and M.O. Silva (2000). Groundwater salinization in Pico Island (Azores, Portugal): Origin and mechanisms. *Environmental Geology*, **39:** 1181-1189.

Das, B., Hazarika, P., Saikia, G., Kalita, H., Goswami, D.C., Das, H.B., Dube, S.N. and R.K. Dutta (2007). Removal of iron from groundwater by ash: A systematic study of a traditional method. *Journal of Hazardous Materials*, **141(3):** 834-841.

Emmanuel, E., Marie Gisèle Pierre and Y. Perrodin (2009). Groundwater contamination by microbiological and chemical substances released from hospital wastewater: Health risk assessment for drinking water consumers. *Environment International*, **35(4):** 718-726.

Gimenez, E. and I. Morell (1997). Hydrogeochemical analysis of salinization processes in the coastal aquifer of Oropesa (Castellón, Spain). *Environmental Geology*, **29:** 118-131.

Goel, P.K. (2000). Water Pollution – Causes, Effects and Control. New Age Int. (P) Ltd., New Delhi.

Hoaglin, D.C., Mosteller, F. and J.W. Tukey (2003). Understanding Robust and Exploratory Data Analysis. *Statistical Science*, **18(3):** 311-318.

MacQuarrie, K.T.B., Sudicky, E. and W.D. Robertson (2001). Numerical simulation of a fine-grained denitrification layer for removing septic system nitrate from shallow ground water. *Journal of Hydrology*, **52:** 29-55.

Meenakshi, R.C. and Maheshwari (2006). Fluoride in drinking water and its removal. *Journal of Hazardous Materials*, **137(1):** 456-463.

Palanisamy, P.N., Geetha, A., Sujatha, M., Sivakumar, P. and K. Karunakaran (2007). Assessment of Ground Water Quality in and around Gobichettipalayam Town Erode District, Tamilnadu. *E-journal of Chemistry*, **4(3):** 434-439.

Sawyer, C.N., McCarty, P.L. and Parking, G.F. (1994). Chemistry for environmental engineering (4th ed.), McGraw Hill, New York.

Vijay, R., Kobragade, P. and P.K. Mohapatra (2010). Assessment of groundwater quality in Puri City, India: An impact of anthropogenic activities. *Environmental Monitoring and Assessment*. Online DOI: 10.1007/s10661-010-1643-9.