Arab J Geosci (2015) 8:8039–8045
DOI 10.1007/s12517-015-1811-x

ORIGINAL PAPER

Impact of urban sprawl on groundwater quality: a case study of Faridabad city, National Capital Region of Delhi

S. C. Rai · A. K. Saha

Received: 18 September 2014 / Accepted: 20 January 2015 / Published online: 4 February 2015

Abstract The present study describes the urban sprawl and groundwater quality of Faridabad city of National Capital Region of Delhi. Urban sprawl was analyzed using remote sensing techniques. It was observed that since 2000, the city has experienced pronounced urban sprawl, which resulted in a substantial impact on water quality. The growth of urban areas has resulted in land use/cover changes. The analysis of the results shows the major increase (149 %) of barren land and built-up area (65 %) at the cost of vegetation and fallow land. Groundwater samples were analyzed for chemical parameters. The physico-chemical parameters (total hardness, F, TDS, Ca, Mn, Alkalinity and NO_3) of the groundwater varied significantly between seasons and sites. Groundwater quality of site II (industrial area) is highly polluted in comparison of other sites. The impact of urban sprawl on water quality is attributed to the population growth, urbanization, rapid industrialization, and blooming of residential colonies.

Keywords Urban sprawl · Land use/cover · Object-based remote sensing · Groundwater · Faridabad · National Capital Region

Introduction

An unprecedented population growth and migration, rapid urbanization, industrialization, and economic development are inadvertent. More and more towns and cities bloomed with a change in the land use along the highways and the immediate vicinity of the city. At least five cities viz. Noida, Gurgaon, Sonipat, Ghaziabad, and Faridabad have been developed around Delhi in the last four decades. The phenomenon of sprawling urban development is one of the major forces driving land use/cover change in developed and developing nations. Sprawl generally infers to some type of development with impacts such as loss of agricultural land, open space, and ecologically sensitive habitats. In other words, as population increases in an area or a city, the boundary of the city expands to accommodate the growth, this expansion is considered as sprawl (Heimlich and Anderson 2001; Interlandi and Crockett 2003; Hasse and Lathrop 2003; Wilson et al. 2003; Robinson et al. 2005; Tu et al. 2007; Stone 2008). Urban sprawl, as implied by its name, is an inherently dynamic spatial phenomenon. There is a great need to understand the spatial and temporal patterns of urban land use/cover change.

The lowering of ground water quality in the study area may be attributed to unabated population growth and changing land use/land cover (Rai 2011; Rai and Kumari 2012). Problems with water quality are often as severe as problems with water availability. Water pollution is a serious problem in India as about 70 % of its surface water resources and a growing number of its groundwater reserves are already contaminated (Rao and Mamatha 2004; Magesh et al. 2013; Alam 2014; Saba et al. 2014). The quality of water is depleting rapidly with massive industrialization, construction activities, and utilization of agricultural land and forest land for other developmental purposes. The rapid industrialization and expansion of cities pose high pressure on groundwater resources resulting into their depletion and contamination. Therefore, this study has been conducted to analyze the urban sprawl pattern (spatially and temporally) through remote sensing techniques. The study also examines the relationship between urban sprawl and water quality over space and time in different land use/cover categories.

The Faridabad city and its surrounding areas were selected for this study, which consists of 35 wards within a198.75 km^2

S. C. Rai · A. K. Saha (✉)
Department of Geography, Delhi School of Economics, University of Delhi, Delhi 110007, India
e-mail: ashisksaha@gmail.com

buffer around the city of Faridabad. Faridabad is situated on the Delhi-Mathura National Highway No. 2 at a distance of 32 km from Delhi having coordinates 28° 25′ 16″ N and 77° 18′ 28″ E (Fig. 1). The population of the city in 2011 was about 1.4 million. This area is more densely populated, urbanized, and industrialized than most parts of the National Capital Region of Delhi. Two geological units of Proterozoic and Quaternary age occur in the Faridabad area (Sett 1964). The major part of the Faridabad city is underlain by quaternary alluvium consisting of sand, clay, and silt. In the western and north-western part of the city, the quartzite ridges of the Delhi system can be observed. The soil varies from sandy to sandy loam. Thin veneer of fine- to medium-grained eolian sands overlies the alluvium at places. The area has semi-arid climate. The average annual rainfall is 350.4 mm.

Methods

Land use/cover analysis

High- to very high-spatial-resolution satellite data are required to adequately characterize the heterogeneity of urban land cover. In this study, urban land use data were obtained from 5-m resolution IRS-1D pan-sharpened LISS-III data (for 2000) and IRS-ResourceSat-2 LISS-IV data (for 2008). Initially, the data sets were geometrically rectified and co-registered within sub-pixel accuracy. Considering high-variability and detailed information from high-resolution data (5 m), advanced object-based image classification (Lang 2008) technique in eCognitionDeveloper software was adopted. A multi-resolution segmentation based on color,

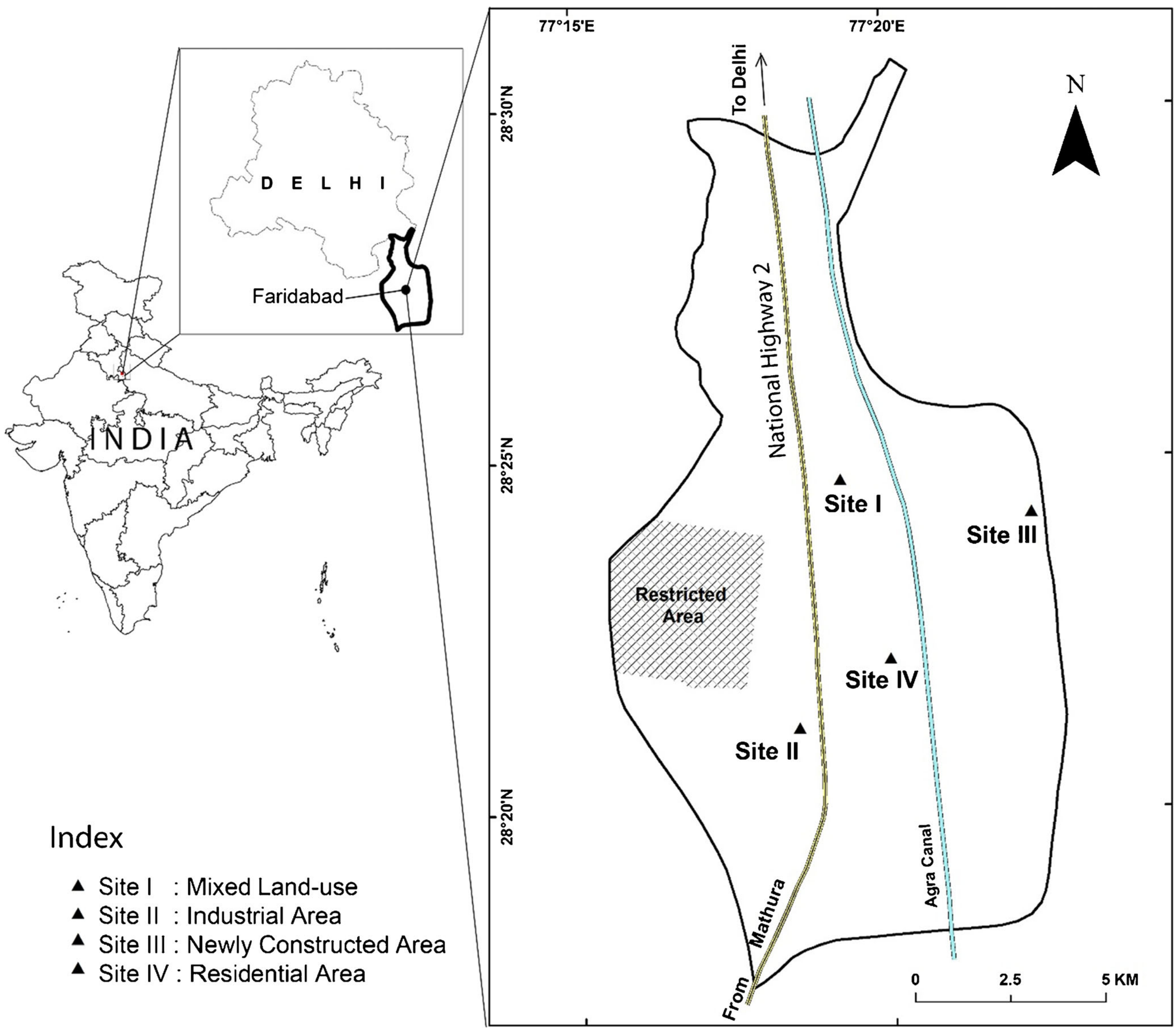

Fig. 1 Location map of Faridabad city indicating sampling sites

shape, and compactness was performed to convert digital images into homogeneous individual objects. These objects are then classified (Zhou and Troy 2008) using supervised nearest neighbor decision rules based on parameters consisting of spectral as well as contextual elements (e.g., size, shape, adjacency, texture, etc.). The following land use/cover has been obtained: built-up land, agriculture, vegetation, fallow land, barren land, and water bodies. Further, a change detection matrix has been prepared from rasterized classified maps of two dates (2000 and 2008) for analysis of land use cover change.

Monitoring stations and sampling design

The city of Faridabad has grown as one of the largest industrial estates, which houses a large number of manufacturing industries. The area has experienced rapid urbanization; hence, fallow land has been converted to residential land. In this background, four sampling sites viz. mixed land-use (site I), industrial area (site II), newly constructed area including agriculture (Site-III), and built-up area (site IV) were selected for groundwater quality analysis. Samples were collected in sterilized polyethylene bottles of 5 l and rinsed three to four times with the water sample and then labeled accordingly and brought to well-equipped laboratory for various chemical analyses (e.g., digital pH meter, atomic absorption spectrometer). Samples were collected in each site during monsoon and post-monsoon season for 2008–2010 for chemical analysis. The samples were collected seasonally, i.e., rainy season and post rainy season. All parameter analyses were completed within 15 days following standard method (Eaton et al. 1995). Before collecting water samples, hand pumps and tube wells were run continuously for about 15 min to avoid purging of stagnant water.

Statistical analyses were conducted using SPSS version 6.0. Statistical analysis between sites, seasons, and their interactions was based on analysis of variance (ANOVA).

Results

General spatial patterns of urban sprawl

A detailed land use/cover inventory of the study is developed and presented in Table 1 and Fig. 2. General land use categories viz. built-up land, water bodies, vegetation, agriculture, fallow, and barren land are considered for classification for 2000 and 2008 years of satellite images. The area of each land use is obtained using class statistics option available in the software. The urban part of study area includes built-up area, industrial land use, mixed land use, and newly constructed areas within the city limit. The classified land use/cover map is verified with field data. Steady growth of built-up area showed about 29 and 48 % of the total area under this category in 2000 and 2008, respectively. Fallow land and barren land in the area was about 41 and 6 % in 2000 and 16 and 15 % in 2008, respectively. The agriculture land covered about 18 and 19 % in 2000 and 2008, respectively. Area under vegetation was 4 and 1 % and water bodies about 2 and 1 % in 2000 and 2008, respectively. Most of the urban expansion has been taken place towards the western side of the canal from north to south part of the city (Fig. 2) and fallow land has been lost for increased urbanization.

Table 1 Areas under different land use/cover and change detection of Faridabad city, 2000–2008

Land-use/cover	Year				Variations
	2000		2008		(2000–2008)
	(ha)	(%)	(ha)	(%)	(%)
Built-up land	4496.23	28.79	7438.11	47.63	65.43
Agriculture	2776.69	17.78	3020.62	19.34	8.78
Vegetation	699.25	4.48	172.09	1.10	−75.39
Fallow land	6449.52	41.30	2483.74	15.91	−61.49
Barren land	927.71	5.94	2309.11	14.79	148.90
Water bodies	266.48	1.71	192.21	1.23	−27.87

During the 8-year period, the area under built-up land has increased (65 %), while water bodies, vegetation, and fallow land decreased by 28, 75, and 61 % in the area. About 149 and 9 % increase was recorded in barren land and agriculture land (Table 1). The analysis of change detection matrix (Table 2) reveals that built-up area in 2008 (48 %) is a result of massive conversion of agricultural land (4 %), fallow land (18 %), and barren land (3 %) as existed in 2000. The reduction of vegetation may be accounted for conversion to built-up area (1 %) and barren land (1 %). Conversion to agricultural land (1 %) has also contributed to the overall reduction of vegetation in 2008.

Groundwater quality analysis

The data analyses revealed that the area is severally affected and has also become considerably vulnerable to pollution with a wide range of contaminations at concentrations ranging as follows (mg/l): total hardness (302–1121), Cl (91–1111), F (0.59–1.70), TDS (643–3522), Mg (33–191), Ca (67–132), SO_4 (78–711), NO_3(9–36), and alkalinity (309–465).

Seasonal variation in groundwater quality characteristics of the study area have been analyzed in detail and presented in Table 3. Most of the selected parameters reflected the seasonal

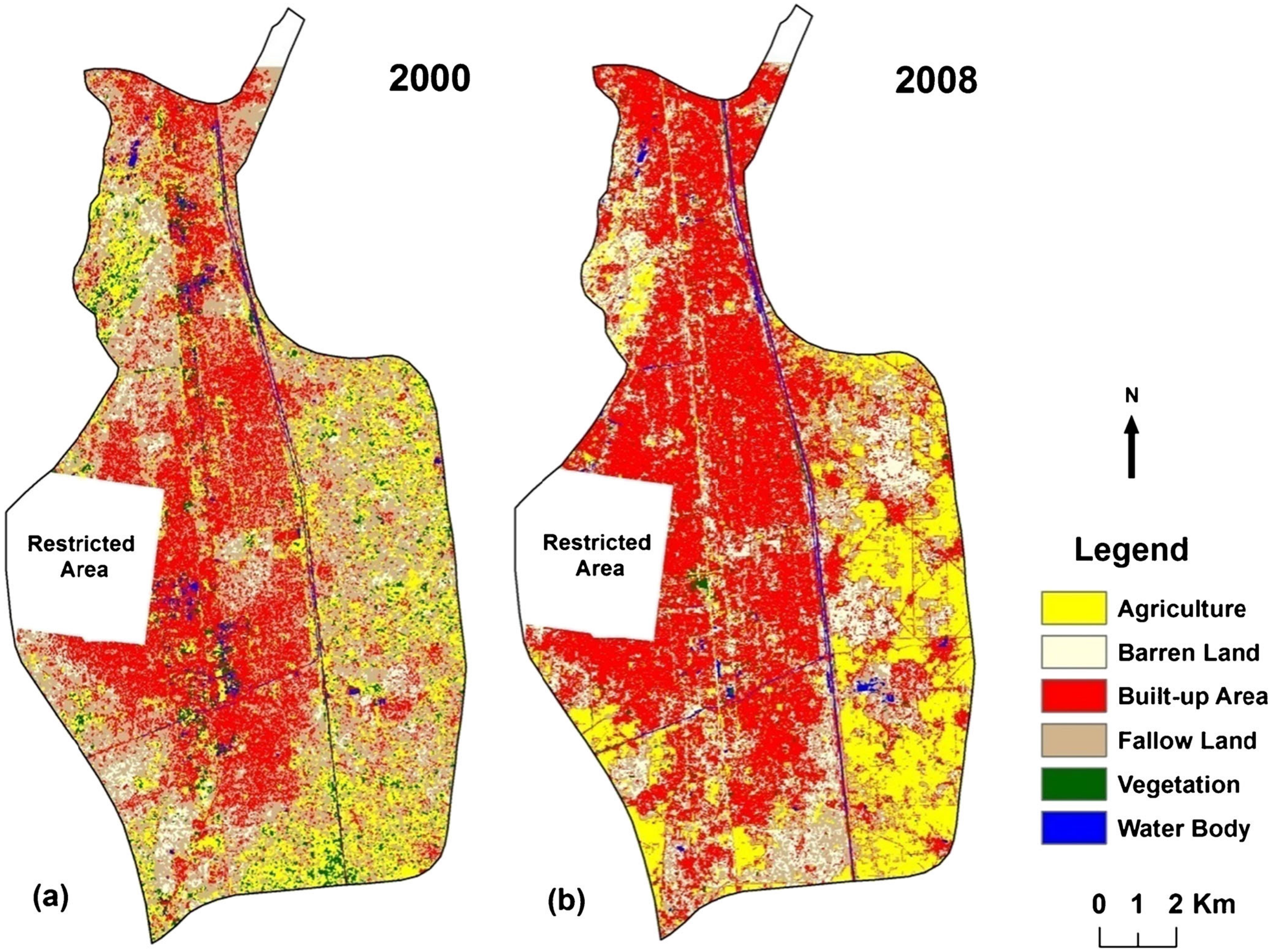

Fig. 2 Land use/cover classification of Faridabad city

pattern showing higher values in the monsoon season. The average value of pH is 7.5 to 7.6 during monsoon season and 7.15 to 7.5 during post-monsoon season. Analysis of variance showed that the pH varied significantly at seasons but their interaction was not significant (Table 3). TDS varied significantly among sites and seasons and their interaction was significant. Alkalinity was lowest during post-monsoon seasons at all sites. The total alkalinity varied significantly among sites and seasons and their interaction was also significant. Total hardness of groundwater varied between 268 and 1251 mg/l as $CaCO_3$ during the monsoon period and 295 to 991 mg/l as $CaCO_3$ during post-monsoon period. The total hardness varied significantly among the sites and seasons and their interaction was also significant (Table 3).

Table 2 Land-use/cover change detection matrix (in percent)

2000	2008 [A]	[B]	[C]	[D]	[E]	[F]	Total (2000)
[A] Agriculture	5.49	0.21	0.23	4.22	4.41	3.21	17.78
[B] Water Bodies	0.07	0.63	0.18	0.16	0.46	0.20	1.71
[C] Vegetation	1.36	0.09	0.09	1.07	0.96	0.91	4.48
[D] Fallow land	9.25	0.08	0.26	7.04	18.20	6.47	41.30
[E] Built-up land	2.14	0.22	0.32	2.29	21.09	2.73	28.79
[F] Barren land	1.04	0.00	0.02	1.11	2.51	1.25	5.59
Total (2008)	19.34	1.23	1.10	15.91	47.63	14.79	

Table 3 Seasonal variations in groundwater quality in Faridabad city

Water quality parameter	Sites (monsoon season)				Sites (post-monsoon season)			
	I	II	III	IV	I	II	III	IV
pH	7.4	7.5	7.5	7.4	7.2	7.4	7.2	7.3
TH	391	1251	308	268	390	977	293	328
Fe	0.08	0.18	1.31	0.12	0.07	0.05	0.81	3.05
Cl	260	1080	84	260	244	1094	94	280
F	1.0	1.0	1.8	1.4	0.53	0.08	1.5	0.9
TDS	1194	3500	680	1375	1127	3540	592	1307
Mg	32	210	20	16	48	170	46	64
Ca	104	151	93	104	71	111	37	35
Cu	0.01	0.01	0.28	0.01	0.01	0.01	0.01	0.02
Mn	0.05	0.06	0.02	0.01	0.01	0.04	0.02	0.02
SO_4	174	735	84	185	149	710	68	222
NO_3	6	30	5	14	42	40	11	24
Pb	0.02	0.05	0.02	0.02	0.02	0.03	0.02	0.02
Zn	0.04	0.12	0.56	0.12	0.03	0.21	0.29	0.08
Alkalinity	395	484	325	495	340	448	286	419

ANOVA: pH site $F_{3,16}$=1.465, P=NS. Season $F_{1,16}$=15.187, P<0.001; site×season $F_{3,16}$=0.465, P=NS. TH site $F_{3,16}$=512, P<0.001; season $F_{1,16}$=10.473, P<0.05; site×season $F_{3,16}$=18.103, P<0.001. Fe site $F_{3,16}$=1.461, P=NS; season $F_{1,16}$=0.872, P=*NS*; site×season $F_{3,16}$=1.671, P=NS. Cl site $F_{3,16}$=747.8, P<0.001; season $F_{1,16}$=0.177, P=NS; site×season $F_{3,16}$=0.227, P=NS. F site $F_{3,16}$=54.768, P<0.001; season $F_{1,16}$=73.730, P<0.001; site×season $F_{3,16}$=3.830, P<0.05. TDS site $F_{3,16}$=9183, P<0.001; season $F_{1,16}$=11.9, P<0.05; site×season $F_{3,16}$=4.777, P<0.05. Mg site $F_{3,16}$=248.2, P<0.001; season $F_{1,16}$=6.766, P<0.05; site×season $F_{3,16}$=15.003, P<0.001. Ca site $F_{3,16}$=69.23, P<0.001; season $F_{1,16}$=185.1, P<0.001; site×season $F_{3,16}$=4.97, P<0.05. Cu site $F_{3,16}$=1323, P<0.001. Season $F_{1,16}$=1216, P<0.001; site×season $F_{3,16}$=1302, P<0.001. Mn site $F_{3,16}$=15.0, P<0.001; season $F_{1,16}$=10.667, P<0.05; site×season $F_{3,16}$=6.556, P<0.05. SO_4 site $F_{3,16}$=340.2, P<0.001. Season $F_{1,16}$=0.250, P=NS; site×season $F_{3,16}$=0.9, P=NS. NO_3 site $F_{3,16}$=29.9, P<0.001; season $F_{1,16}$=19.501, P<0.001; site×season $F_{3,16}$=0.444, P=NS. Pb site $F_{3,16}$=5.708, P<0.001; season $F_{1,16}$=3.375 P=NS; site×season $F_{3,16}$=1.708, P=NS. Zn site $F_{3,16}$=19.636, P<0.001; season $F_{1,16}$=1.972, P=NS; site×season $F_{3,16}$=3.890, P<0.05. Alkalinity site $F_{3,16}$=437.9, P<0.001; season $F_{1,16}$=185.16, P<0.001; site×season $F_{3,16}$=6.090, P<0.05

During monsoon, the concentration of Ca^{2+} and Mg^{2+} ranged from 93 to 151 and 14 to 210 mg/l, and during post-monsoon, it ranged from 35 to 112 and 47 to 171 mg/l, respectively. Both the parameters varied significantly among the sites and seasons and their interaction was also significant. In the case of anions, Cl^-, SO_4^{2-}, NO_3^-, and F^- ranged from

Table 4 Pearson's correlation coefficient for physico-chemical characteristic of (n=24, df=8)

Parameters	pH	Th	Fe	Cl	F	TDS	MG	Ca	Cu	Mn	SO4	N03	PB	Zn	Alkalinity
pH	–	0.252	0.089	0.210	0.374	0.221	0.140	0.544	0.396	0.343	0.196	0.106	0.448	0.420	0.354
Th		–	−0.255	0.960	−0.482	0.946	0.967	0.696	−0.245	0.687	0.950	0.736	0.702	−0.100	0.532
Fe			–	−0.203	0.183	−0.221	−0.211	−0.330	0.166	−0.163	−0.230	−0.301	−0.133	0.138	0.136
Cl				–	−0.614	0.993	0.949	0.668	−0.338	0.624	0.978	0.814	0.616	−0.163	0.664
F					–	−0.611	−0.528	−0.153	0.564	−0.246	−0.584	−0.721	−0.121	0.510	−0.307
DS						–	0.933	0.684	−0.347	0.633	0.990	0.822	0.607	−0.217	0.695
MG							–	0.535	−0.312	0.599	0.943	0.825	0.652	−0.125	0.497
Ca								–	0.025	0.660	0.663	0.237	0.566	−0.025	0.614
Cu									–	−0.235	−0.310	−0.419	−0.123	0.785	−0.404
MN										–	0.669	0.245	0.560	−0.259	0.364
SO4											–	0.820	0.615	−0.218	0.645
NO3												–	0.367	−0.250	0.534
PB													–	−0.045	0.384
Zn														–	−0.396
Alkalinity															–

84 to 1080, 86 to 736, 6 to 30, and 1.0 to 1.9 during monsoon season and 98 to 1141, 70 to 685, 11 to 51, and 0.09 to 1.5 mg, respectively during post-monsoon season. All the parameters varied significantly among the sites but their interaction in season, site and season was not significant (Table 3).

Correlation analysis

Table 4 shows the correlation matrix for all the analyzed data. A high and significant positive correlation was observed between all selected parameters except few. pH showed a positive correlation with all parameters. Total hardness is negatively correlated with Fe, F, Cu, and Zn. Fe is positively correlated with only F, Cu, Zn, and alkalinity. Chloride is negatively correlated with F, Cu, and Zn, whereas fluoride is negatively correlated with dissolved solids, Mg, Ca, Mn, SO_4, NO_3, and alkalinity. Dissolved solid and Mg are positively correlated with all parameters except Cu and Zn. Cu is negatively correlated with all parameters except Zn. Other parameters such as Mn, SO_4, NO_3, Pb, and Zn are negatively correlated with Zn only.

Trace metals

The trace metal concentration variations (Cu, Pb, Zn, Ni, Cd, Cr, Mn, and Fe) in both monsoon and post-monsoon in groundwater of the area were analyzed. Cu values range from 0.01 to 0.29 mg/l during monsoon. However, during the post-monsoon, the values range from 0.01 to 0.02 mg/l. During both monsoon and post-monsoon, the concentration of Cu is well within the WHO permissible limit of 1.5 mg/l. In the case of iron, value ranges from 0.08 to 1.32 mg/l during monsoon and post-monsoon demonstrates 0.07 to 4.15 mg/l. Though there is a seasonal variation in the concentration of Fe values, the wells which are very close to the industries and the highest values recorded in sites 3 and 4 in both the seasons. Pb values during monsoon ranges from 0.01 to 0.05 mg/l, and the values during post-monsoon ranges from 0.02 to 0.04 mg/l. Mn values during monsoon ranges from 0.01 to 0.07 mg/l and the values during post-monsoon ranges from 0.01 to 0.04 mg/l. Zn values ranges from 0.04 to 0.57 mg/l during monsoon and from 0.09 to 0.32 mg/l during post-monsoon. Other trace metals, i.e., Hg, Cd, Se, As, Cn, Cr, Al, and boron have no significant variation between sites and seasons.

Discussion and conclusions

Urban sprawl had substantial impact on groundwater quality in the study area. The impact of urban sprawl on groundwater quality is attributed to the population growth and land use change. In the study area, all the water quality parameters showed a wide variation in space and time. The spatial variation of groundwater contamination is caused mainly by localized industrial activities and improper disposal of waste water and solid waste. Temporal variations were due to seasonal influences mainly the effect of rainfall. High correlation existed between concentrations of water quality and urban sprawl.

Alkalinity refers to the amount of carbonates, bicarbonates, and hydroxide ions and is commonly found in the form of carbonates of sodium, calcium, and magnesium (Zajic 1971). The higher concentration of alkalinity value is reported in the study area and exceeds the permissible limit in all the sites. Total hardness of all the water samples exceeds the highest desirable limit (300 mg/l). Total hardness of the groundwater varied between 302 to 1121 mg/l as $CaCO_3$. Classification of groundwater based on total hardness shows that a majority of groundwater samples fall in the hard water category. As per the TDS classification (Fetter 1990), most of the groundwater samples collected during monsoon and post-monsoon periods belong to brackish type (TDS>1000 mg/l). TDS more than 3000 mg/l was observed in site-II. TDS values when compared with WHO's permissible limit reveals that all sites samples were unfit for drinking and other domestic purposes. TDS is likely to be increased due to the disposal of untreated waste from the industries. During the post-monsoon period, nitrate concentration decreased in many sites, which are mostly in the residential and newly constructed area. However, it has increased in the mixed land use and industrial area which could be due to the leaching of nitrate from the open sewerage lines. This indicates that domestic waste leads to more nitrate problems. The WHO's health-based guideline values for nitrate in drinking water is 10 mg/l. These values are exceeding the WHO guideline except site III. Aggarwal (1999) reported that Maharashtra, Karnataka, and Tamilnadu states are worst affected by high nitrate inputs to aquifers, with average values in groundwater being 10.0, 10.6, and 5.9 mg/l, respectively. Handa (1975) reported very high concentrations of nitrate-N (up to 200 mg/l) in saline groundwater from Rajasthan, although these were taken to be high because of natural concentration of solutes by evaporation, rather than related directly to pollution. High concentrations of fluoride, often significantly above 1.5 mg/l, constitute a severe problem over large parts of India. Long-term use of groundwater for drinking has resulted widespread fluorosis symptoms, from mild forms of dental fluorosis to crippling skeletal fluorisis. In the absence of known major geological source of fluoride and nitrate in the study area, excessive application of agri-chemicals and discharge from steel, aluminum, brick and tile industries, and disposal of crop residues are major causes of pollution (Datta 2005).

All water samples were rich in chloride except site III and exceed the desirable limit (250 mg/l) as per Indian Standard Specification for drinking water. The same trend followed by sulfate. This could be due to the occurrence of more anthropogenic pollution. In the case of iron, there is a seasonal variation in the concentration of Fe values; the wells which are very close to the industries show higher values. At this site, the predominant industrial units are engineering industries, which involve cutting, milling, sizing, and producing different sizes and shapes of scrap metal chiefly iron. Hence, the high Fe concentration in these waters could be attributed mainly to the anthropogenic activities rather the soil-water interaction. Lead is usually found in low concentration in natural water because Pb-containing minerals are less soluble in water. All sample sites have shown beyond permissible limits as per the Indian Standards Specification limit of 0.01 mg/l. The study corroborates findings closer to the observations made by Ravichandran and Jayaprakash (2011). The presence of sizable quantity of lead in groundwater of the study area indicates that the industrialization and urbanization have resulted in severe contamination of groundwater. The Mg was at moderate level in all the sites except site III, but Ca is slightly high and exceeded the maximum permissible limit (75 mg/l). No occurrence of high arsenic concentration has been reported from groundwater in the study area.

Acknowledgments The authors thank the University of Delhi for the financial support and Ms. Ankita Medhi for the assistance in land use classification. Thanks are also given to the Department of Science and Technology, Government of India, for providing eCognition Developer Software to the "second author."

References

Aggarwal GD (1999) Diffuse agricultural water pollution in India. Water Sci Technol 39:33–47

Alam F (2014) Evaluation of hydrogeochemical parameters of groundwater for suitability of domestic and irrigational purposes: a case study from central Ganga Plain, India. Arab J Geo 7(10):4121–4131

Datta PS (2005) Groundwater ethics for its sustainability. Curr Sci India 89(5):812–817

Eaton AD, Clesceriand LS, Greenberg AE (1995) Standard method for the examination of water and waste water, 19th edn. American Public Health Association, Eds, Washington, DC

Fetter CW (1990) Applied hydrology. CBS Publishers & Distributors, New Delhi

Handa BK (1975) Geochemistry and genesis of fluoride-containing groundwater in India. Ground Water 13:275–281

Hasse JE, Lathrop RG (2003) Land resource impact indicators of urban sprawl. Appl Geogr 23:159–175

Heimlich R, Anderson W (2001) Development at the urban fringe and beyond: impacts on agriculture and rural land. Agriculture Economic Report (AER803), United States Department of Agriculture

Interlandi S, Crockett CS (2003) Recent water quality trends in the Schuylkill River, Pennsylvania, USA: a preliminary assessment of the relative influences of climate, river discharge and suburban development. Water Res 37:1737–1748

Lang S (2008) Object-based image analysis for remote sensing applications: modeling reality—dealing with complexity. In: Blaschke T, Lang S, Hay GJ (eds) Object-based image analysis: spatial concepts for knowledge-driven remote sensing applications. Springer, Berlin Heidelberg

Magesh NS, Krishnakumar NS, Chandrasekar N, Soundranayagam JP (2013) Groundwater quality assessment using WQI and GIS techniques, Dindigul district, Tamil Nadu, India. Arab J Geo 6(11): 4179–4189

Rai SC (2011) Water management for megacity: National Capital Territory of Delhi. Water Resour Manage 25:2267–2278

Rai SC, Kumari P (2012) Assessment of groundwater contamination from land-use/cover change in rural–urban fringe of National Capital Territory of Delhi (India). Scientific Annals of Alexandru Ioancuza, University of Iasi – Geography series 58(1):31–46

Rao SM, Mamatha P (2004) Water quality in sustainable water management. Curr Sci India 87(7):942–947

Ravichandran K, Jayaprakash M (2011) Seasonal variation on physico-chemical parameters and trace metals in groundwater of an industrial area of north Chennai, India. Indian J Sci Technol 4(6):646–649

Robinson L, Newell JP, Marzluff JM (2005) Twenty-five years of sprawl in the Seattle region: growth management responses and implications for conservation. Landscape Urban Plan 71:51–72

Saba NU, Umar R, Khan A (2014) Evaluation of chemical and microbial quality of groundwater of Moradabad City. India Arab J Geo. doi: 10.1007/s12517-014-1473-0

Sett DN (1964) Groundwater geology of the Delhi region. Buss Geo Surv India, Series-Energy Geo and Groundwater 16(1):1–123

Stone B Jr (2008) Urban sprawl and air quality in large US cities. J Environ Manage 86:688–698

Tu J, Zong-Guo X, Clarke C, Allen F (2007) Impact of urban sprawl on water quality in Eastern Massachusetts, USA. Environ Manage 40: 183–200

Wilson EH, Hurd JD, Civco DL, Prisloe MP, Arnold C (2003) Development of a geospatial model to quantify describes and map urban growth. Remote Sens Environ 86:275–285

Zajic JE (1971) Water pollution disposal and reuse. Marcel Daker Inc., New York

Zhou W, Troy A (2008) An object-oriented approach for analysing and characterizing urban landscape at the parcel level. Int J Remote Sens 29(11):3119–3135