Impact of rapid urbanization on water quality index in groundwater fed Gomati River, Lucknow, India

Pooja Goel[1], **Abhishek Saxena**[2,*], **Dhruv Sen Singh**[1] **and Deepti Verma**[2]

[1]Centre of Advanced Study in Geology, University of Lucknow, Lucknow 226 007, India
[2]Faculty of Civil Engineering, Shri Ramswaroop Memorial University, Barabanki 225 003, India

The present communication deals with the impact of rapid urbanization of Lucknow City on Gomati River. The lower values of water quality index (WQI < 50) at upstream of the city confirm the presence of good quality water. When it leaves the city downstream the value of WQI raises to >75, indicating that the water quality has deteriorated considerably and has become unfit for human consumption. The groundwater is also polluted due to urbanization and requires immediate attention for improving the water quality of Gomati river.

Keywords: Gomati river, groundwater, Lucknow, surface water, water quality index.

THE Gomati river passes through Lucknow city, the capital of Uttar Pradesh, India (Figure 1). It forms part of the Central Ganga Plain[1]. The climate of Lucknow is semi-arid to subtropical monsoon type with average annual rainfall of 963 mm. Gomati river is a groundwater fed river that originates in Pilibhit district at Madho-Tanda, a tributary of Ganga. Foster and Chaudhary[2] prepared a hydro-geological cross-section of Lucknow district (Figure 2). The section suggests that near Lucknow, due to excessive withdrawal of groundwater, groundwater is being replenished by the river. This situation appeared after 2005 due to rapid increase in Lucknow city's population.

According to census 2011, the population of Lucknow was 2,902,920 (http://www.census2011.co.in/census/city/127-lucknow.html). Comparison with previous census data shows that the population increased by about 38% between 2001 and 2011. This rapid urbanization has resulted in an increase in demand for water. As a consequence, sewage discharge also increased. At present, 415 MLD of water is required for drinking and other domestic purposes. Of this, 245 MLD is obtained from Gomati river and 170 MLD from groundwater sources (http://www.saiindia.gov.in/english/home/our_products/audit_report/government_wise/state_audit/recent_reports/Uttar_Pradesh/2011/CITY/CITY.html). According to the CAG report[3], the sewage of the town mostly flows through 25 main open drains and cannot be conveyed into trunk sewers due to level problems. This results in direct inflow of sewage into the river resulting in the pollution of Gomati.

Mirzai[4] stated that WQI method is an accepted tool worldwide for analysing the suitability of the surface water source for various purposes. Asadi *et al.*[5] and Buchanan[6] also claimed that WQI is a useful tool for communicating information on overall quality of water to the concerned citizens and policy makers. The present communication deals with the WQI of Gomati river

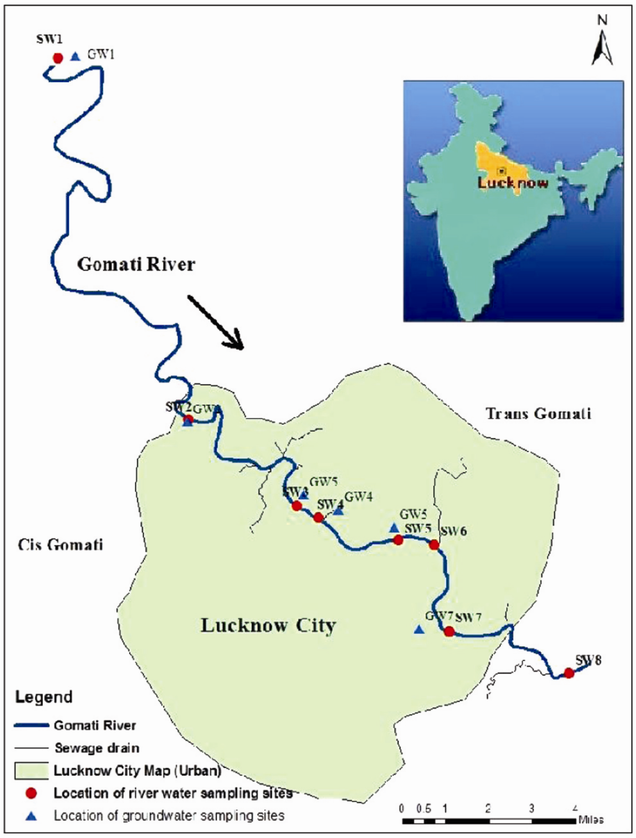

Figure 1. Location map of surface water and groundwater sampling site at Gomati River in Lucknow city.

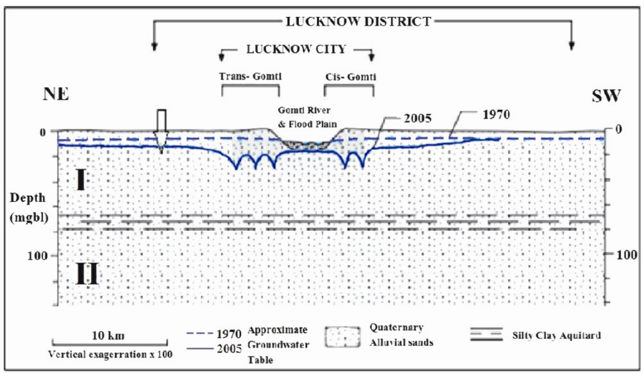

Figure 2. Simplified hydrogeological cross-section of Lucknow district (modified after Foster and Chaudhary, 2009).

*For correspondence. (e-mail: abhisheksaxena79@gmail.com)

water in the vicinity of Lucknow city and its comparison with the WQI of nearby groundwater samples.

In the present study, the water samples from the river were collected in January 2015. The sampling sites are in the entire 15 km stretch of the river between Chandrika Devi (SW1), upstream of the city to Shaheed Path (SW8), downstream of the city. In all, eight water samples were taken from the river mostly at the confluence of major drains (nala) into the river. It is important to know the impact of these drains on the river as Jal Sansthan uses this water after treatment for drinking water supply to the old city. In addition to the river water samples, six groundwater samples from shallow aquifers were collected from bore wells fitted with India Mark II hand pumps installed for drinking water and other domestic purposes. Groundwater sampling of sites near the Gomati river was carried out to see if there was any correlation between the surface and groundwater quality parameters. The surface and groundwater samples were analysed for different physical and chemical parameters to determine if the quality of water is suitable for domestic use. Figure 1 gives the location map of surface and groundwater sampling sites.

After collecting samples at regular intervals of the river stretch, the surface water samples were analysed for pH, conductivity, nitrate, fluoride, dissolved oxygen (DO), biochemical oxygen demand (BOD), phosphate and total coliform bacteria. The groundwater samples were also analysed for the same parameters except for DO, BOD and total coliform bacterial content. The main focus of the analysis was to find out the probability of contaminants in the surface adversely affecting the health of local people. The pH and conductivity were respectively measured using a pH meter (Toshniwal Model No. CL a 46) and EC meter (Toshniwal model TCM 15). Ca, Na and K were analysed using flame photometer (Systronics model 128). Fluoride and nitrate were determined using spectrophotometer (Perkin Elmer LAMBADA 40); DO was determined using digital DO meter (Labtronics Model LT 88) and BOD was calculated using the traditional incubation method.

Water quality refers to physical, chemical and biological characteristics of water. According to the Water Quality Index Protocol, the following criteria are essential for calculating the water quality index – BOD, DO, nitrate, pH, conductivity, phosphate and coliform bacteria. WQI is a unique number which represents the overall water quality by applying various water quality parameters and normalizing them into a single parameter. This method helps in rating the water quality at various sites. Communicating these water quality trends to the public and the policy makers help in better management of water quality issues. In this study WQI is estimated with special reference to water for drinking purposes. Lucknow Jal Sansthan uses this water for domestic water supply after treatment; therefore BIS norms (IS 10500–2012)[7] for water quality for drinking purposes are used.

WQI was calculated using weighted arithmetic index method[8]. Brown[9] and Kumari and Chaurasia[10] have given the following method for calculation of WQI – Let there be n water quality parameters and quality rating (Q_n) corresponding to the nth term parameter is a number reflecting relative value of this parameter in polluted water with respect to its standard permissible limit.

Q_n values are given by the relationship

$$Q_n = 100\ (V_n - V_i)/(V_s - V_i),$$

where V_s is the standard value; V_i is the ideal value; in most cases $V_i = 0$ except in certain parameters like pH, dissolved oxygen, etc. calculation of quality rating for pH and DO (where V_i was not zero)

$$Q_{\mathrm{pH}} = 100\ (V_{\mathrm{pH}} - 7.0)/(8.5–7.0) \text{ and}$$

$$Q_{\mathrm{DO}} = 100(V_{\mathrm{DO}} - 14.6)/(6.0–14.6).$$

Calculation of unit weight: The unit weight (W_n) for various water quality parameters is inversely proportional to the recommended standards for the corresponding parameters

$$W_n = k/S_n$$

where W_n is the unit weight for the nth parameter, S_n the standards permissible value for nth parameter and k is the proportionality constant. The unit weight (W_n) values in the present study are taken from Krishnan[11].

$$k = \sum 1/S_n,$$

Calculation of WQI: WQI = $\sum Q_n W_n / \sum W_n$.

The suitability of WQI values for human consumption after Mishra and Patel[12] are

0–25 = Excellent, 26–50 = Good, 51–75 = Bad,

76–100 = Very bad and above 100 = Unfit.

Table 1 gives the analytical results of various surface water quality parameters for the selected sites of river Gomati. The analysis of water quality shows that the quality of water becomes deteriorated near Lucknow as one goes downstream. As expected, at places where the drains/nalas discharge effluents into the river, the quality of water becomes poor. This shows that the existing sewage system is not effective and the river water flow is also not sufficient to carry the discharges of domestic sewage. The continuously increasing value of nitrate from upstream to downstream sections of the river, points to increased domestic wastewater in the downstream segment of the river. The Central Pollution Control Board

Table 1. Surface water quality parameters at the selected sampling sites (SW1–SW8)

Parameters	Unit	Std.	SW 1 (Chandrika Devi)	SW 2 (IIM Road)	SW 3 (Kudia Ghat)	SW 4 (Daliganj)	SW 5 (Lakshaman Mela)	SW 6 (Bhaisakund)	SW 7 (Dilkusha)	SW 8 (Shaheed Path)
pH		8.5	8.25	8.35	7.51	7.09	7.1	6.95	6.9	6.9
DO	mg/l	6	11	10.7	9.3	5	3.7	2.2	1.5	1
BOD	mg/l	5	2.8	3.2	3.7	5	6.5	8.5	9.5	12
Total coliform	MPN/100 ml	1,000	1,700	2,400	5,400	16,000	49,000	94,000	110,000	130,000
Conductivity	mS/cm	0.78	0.420	0.504	0.630	0.950	0.725	0.700	1.28	1.1
Nitrate	ppm	45	1.1	0.85	2.3	2.22	2.48	1.68	2.26	3.1
Phosphate	ppm	6	0.11	0.05	0.49	0.55	0.25	0.63	1.39	1.2
Fluoride	ppm	1	0.42	0.414	0.455	0.445	0.494	0.445	0.472	0.52
Potassium	ppm	12	4.57	4.65	6.28	6.48	5.89	6.09	7.28	8.1
Calcium	ppm	75	18.59	10.86	23.24	22.31	22.71	23.34	25.11	26

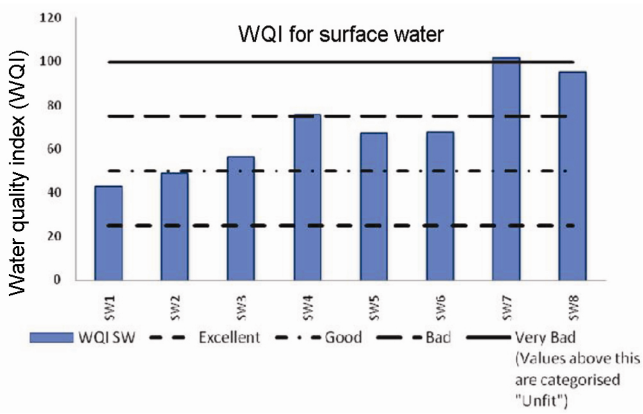

Figure 3. WQI standard categories versus actual WQI at various selected surface water sampling sites.

(CPCB) has classified the waters into five categories A–E according to 'best designated use of stream water'. The water at upstream of Lucknow city was categorized under 'B' category which classifies the water as suitable for bathing purposes. Downstream, i.e. SW4 onwards, the water does not fall under any category (A to E), suggesting that it is unsuitable for any use. This implies that water is more domestic sewage than normal river water.

The pH of surface water ranges from 6.9 to 8.35 which is almost within the range of BIS. However, from upstream to downstream, the water becomes more acidic due to discharge of effluents. In the upstream section of river Gomati, water is characterized by higher value of DO and is complemented by rich aquatic life but after sampling station SW3, it starts decreasing, ultimately making the water at station SW8 not suitable for aquatic life.

The BOD is maximum in SW8 and decreases in the upstream waters, confirming that sewage drains directly discharge into the river, pointing to inefficiency of the wastewater treatment plant. This is also indicated by high values of coliform bacteria in the downstream waters of the river.

Conductivity also increases with increase in the number of drains discharging effluents into the river. The values of nitrate, fluoride, calcium, phosphate and potassium are well within the limits of BIS for drinking water. However, slight increase in nitrate for the samples SW4, SW5, SW6, SW7 and SW8 could be mainly due to open defecation on the river bank near these sampling sites. With the above parameters water quality index was calculated (Figure 3).

Table 2 gives the analytical values for various physicochemical parameters in the shallow aquifer near the river Gomati. The various groundwater quality parameters, viz. pH, conductivity, nitrate, fluoride, calcium, phosphate and potassium of groundwater samples were also within the permissible limits. However, higher values of nitrate were observed near sampling station GW3, which was mainly due to leaching of unauthorized solid waste dump in the vicinity of this sampling site. Water quality index parameters for groundwater samples were also calculated considering the parameters, viz. pH, conductivity, phosphate, fluoride, calcium, nitrate and potassium.

Figure 3 gives comparison of water quality index at various intervals of river Gomati across the city. It is seen that the samples collected from the upstream of the river, i.e. at SW1 and SW2 can be categorized under good quality with a WQI of 42.9 and 48.7 respectively, indicating that the river water of Gomati before entering the city is fairly good. Water quality in the downstream starts deteriorating with the inflow of effluents from sewage drains directly into the river. The WQI of water samples at SW3, SW4 and SW5 are categorized as bad with values of 56.6, 67.2 and 67.5 respectively. The WQI value at SW4, which is in the mid of the river stretch, showed a high value of 75.9 and is categorized under very bad quality. This is mainly due to more number of drains discharging their effluents close to this place. The WQI is 101.9 at SW7 in the stretch of the river after confluence of almost all the sewage drains into the river. This proves that the current system of sewage treatment plant of the city is not capable of treating the current amount of

Table 2. Groundwater quality parameters at the selected sampling sites (GW1–GW8)

Parameters	Unit	Std.	GW1 (Chandrika Devi)	GW2 (IIM Road)	GW3 (Kudia Ghat)	GW4 (Daliganj)	GW5 (Lakshaman Mela)	GW7 (Dilkusha)
pH		8.5	7.150	7.070	7.190	7.480	7.770	7.090
Conductivity	mS/cm	0.78	0.390	0.345	0.442	0.382	0.374	0.456
Nitrate	ppm	45	1.300	0.840	40.800	14.800	1.330	39.500
Phosphate	ppm	6	0.430	0.310	0.080	5.100	0.090	0.080
Fluoride	ppm	1	0.431	0.567	0.476	0.379	0.575	1.460
Potassium	ppm	12	5.510	5.520	6.340	5.570	4.530	6.410
Calcium	ppm	75	20.220	11.010	22.970	33.750	15.230	37.350

Groundwater samples GW6 (Baisakund) and GW8 (Shaheed path) were not available,

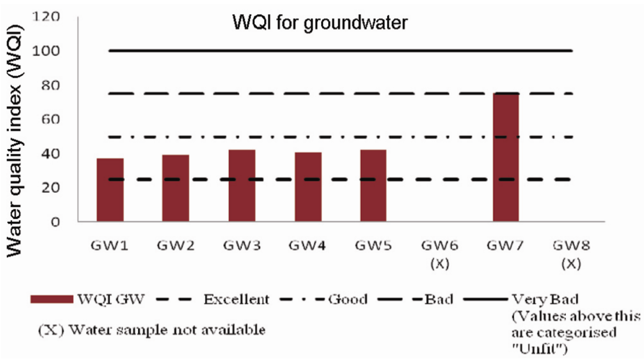

Figure 4. WQI standard categories versus actual WQI at various selected groundwater sampling sites.

sewage generated in the city, resulting in adverse pollution of the river. SW8 sample is from the downstream-most point of the river after which it leaves the city. Here the river water shows a WQI of 95.34 which is just a little less than WQI 100 which renders the river water unfit for any use. The slightly lower WQI could mainly be due to two reasons: (a) by the time river water reaches this stretch, part of the pollutants that had entered the river would had settled down and (b) a new treatment plant – Bharwara STP, set up upstream of this sampling station must have effectively removed some pollutants. The average value of WQI of Gomati River water at Lucknow is 69.5 which catergorizes this water as ‘bad’ quality of river water.

Figure 4 shows the water quality index for groundwater samples collected from selected groundwater sampling sites. It is clearly seen that groundwater samples collected from the proximity of the river in the upstream section, i.e. GW1 and GW2 are categorized under good quality with a WQI of 37.38 and 39.07 respectively. This indicates good quality groundwater in the shallow aquifer. Although the WQI of groundwater samples show marginal increase from GW1 to GW5, the water can still be categorized under ‘good’ quality. However, at GW7, WQI reaches a value of 76, which makes the groundwater quality ‘very bad’. In this section, the polluted river water may seep into the ground and pollute the shallow aquifer.

In the case of river Gomati, the positive correlation between WQI of river water and groundwater (Figure 5) strongly suggests that the surface water quality of the river adversely affects the quality of groundwater which is a matter of great concern. Pollution of aquifers to a large extent may adversely affect drinking water quality of many adjoining villages. Therefore there is a need for urgent intervention by the state government to ensure zero-tolerance for any polluted effluents being discharged into the river. There are many other examples of groundwater/spring water fed rivers in India facing problems of pollution as they flow through the urban areas. Shah and Joshi[13] stated that when River Sabarmati in Gujarat passes through Ahemdabad it gets highly polluted. The main cause of deterioration in water quality is attributed to anthropogenic activities such as illegal discharge of sewage and industrial effluents, lack of proper sanitation, unprotected river sites and urban runoff. The WQI studies on Sabarmati River suggest that the river water is much cleaner in the segment upstream of Ahmedabad City, but gets polluted by the time it exits the city. Their studies convey that improper disposal of waste in rivers could have serious implications on our ecosystem. Although Sabarmati is lined throughout Ahmedabad, it has not succeeded in preventing seepage of pollutants into the groundwater. The river water is not even fit for recreation purposes and other social activities[14]. Malviya *et al.*[15] reported greater impact of urban activity on ground and river water quality in Hoshangabad as most of the river water at the sampling sites in Hoshangabad are polluted with discharged wastes. Bhardwaj *et al.*[16] suggested through principal component analysis, that besides the geogenic processes, the anthropogenic processes play a very important role in the pollution of Chhoti Ghandak River (groundwater fed river) which could in turn adversely affect the groundwater system of the area in future.

The WQI of the Gomati River flowing through Lucknow city indicates that good quality river water that reaches the city, gets severely polluted by unsatisfactorily treated or untreated sewage. Seepage into river water also affects groundwater quality especially in the downstream

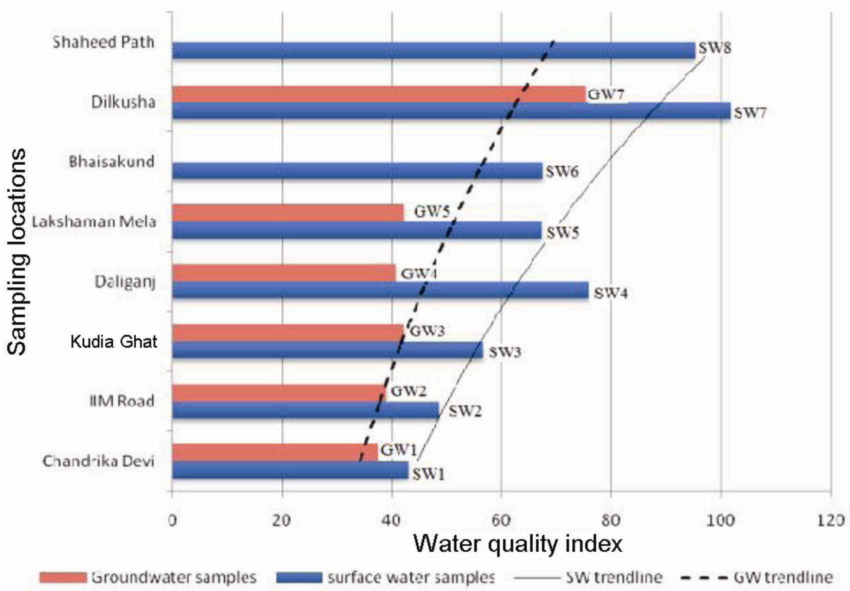

Figure 5. Positive correlation between WQI of surface and groundwater.

segment near Lucknow. It can be concluded that the present sewage treatment system for Lucknow city is ineffective. Similar situations are seen in the river and groundwaters near other major cities. Urgent intervention by Government agencies and proper treatment of wastewater is called for to protect the health of river and ground water systems near the cities.

1. Kumar, A., Ground water brochure of Lucknow district, Uttar Pradesh. In *Report by Central Ground Water Board* (*India*), 2010, p. 7.
2. Foster, S. and Choudhary, N. K., Lucknow City – India: Groundwater Resource Use and Strategic Planning Needs; The World Bank Report (Sustainable Groundwater Management: Lessons from Practice); GW-MATE, 2009, Case Profile Collection No. 23 (51828), pp. 1–8.
3. CAG Report. Performance Audit on Compliance with Environmental Laws in Lucknow City, Uttar Pradesh For the Year 2010-11, Comptroller and Auditor General of India (under Article 151 (2) of the Constitution of India), 2012.
4. Mirzai, M., Application of the water quality index as simple indicator of watershed pollution. *Adv. Water Resour. Protect.*, 2014, **2**, 42–46.
5. Asadi, S. S., Vuppala, P. and Anji, R. M., Remote sensing and GIS techniques for evaluation of groundwater quality in Municipal Corporation of Hyderabad (Zone-V), India. *Int. J. Environ. Res. Publ. Health*, 2007, **4**(1), 45–52.
6. Buchanan, S. and Triantafilis, J., Mapping water table depth using geophysical and environmental variables. *Groundwater*, 2009, **47**(1), 80–96.
7. IS 10500:2012. Indian Standard Drinking Water Specification (Second Revision). Bureau of Indian Standard, Government of India, 2012.
8. Behmanesh, A. and Feizabadi, Y., Water Quality Index of Babolrood River in Mazandaran, Iran. *Int. J. Agric. Crop Sci.*, 2013, **5**(19), 2285–2292.
9. Brown, R. M., McClelland, N. I., Deininger, R. A. and Tozer, R. G., Water quality index-do we dare? *Water Sew. Works*, 1970, **117**(10), 339–343.
10. Kumari, V. and Chaurasia, G. L., Study of water quality status of Sai River in Uttar-Pradesh with Reference to Water Quality Index assessment. *Int. J. Innov. Res. Sci., Eng. Technol.*, 2015, **4**(1), 18614–18623.
11. Krishnan, J. S. R., Rambabu, K. and Rambabu, C., Studies on water quality parameters of bore waters of Reddigudum Mandal. *Ind. J. Environ. Proct.*, 1995, **16**(4), 91–98.
12. Mishra, P. C. and Patel, R. K., Quality of drinking water in Rourkela, outside steel town ship. *J. Environ. Pollut.*, 2001, **8**(920), 165–169.
13. Shah, K. A. and Joshi, G. S., Evaluation of water quality index for river Sabarmati, Gujrat, India. *Appl Water Sci, Publ.*, 2015.
14. Patel, B., Development of Water Quality Index: A case of Sabarmati River front development project. In proceedings of International Journal of Academic Conference, 2011, p. 1(1).
15. Malviya, A., Diwakar, S. K., Sunanda, and Choubey, O. N., Chemical assessment of Narmada river water at Hoshangabad city and Nemawar as navel of river in Central India. *Oriental J. Chem.*, 2010, **26**(1), 319–323.
16. Bhardwaj, V., Singh, D. S. and Singh, A. K., Water quality of the Chhoti Gandak River using principal component analysis, Ganga Plain, India. *J. Earth Syst. Sci.*, 2010, **119**(1), 117–127.

ACKNOWLEDGEMENTS. P.G. thanks DST, New Delhi for funding the project entitled 'Quality assessment of surface and subsurface water in Gomati River Basin in Lucknow region and its management through surface and groundwater modelling techniques' (SR/WOS-A/ES-01/2013(G)). The authors thank the Head, Department of Geology, Lucknow University for providing facilities. They also thank Prof. Surendra Kumar and Dr Purnima Bali, Geology Department, Lucknow University for their valuable suggestions.

Received 18 February 2016; accepted 23 August 2017

doi: 10.18520/cs/v114/i03/650-654