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Significance of silica analysis in groundwater in parts of Central Ganga Plain, Uttar Pradesh, India

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A study on variation in silica values in groundwater from a small part of the Central Ganga Plain has yielded valuable information on relative roles of geogenic and anthropogenic solute acquisition processes and depth to the deep aquifer system in the area. It is recommended that silica analysis should be a mandatory component of all systematic hydrogeochemical studies.

Keywords: Central Ganga Plain, groundwater, silica.

THIS work is based on detailed hydrogeochemical study of groundwater samples collected twice a year for a period of two years at 45 locations, in a small part of the Central Ganga Plain[1].

Conventional and routine chemical analyses performed as part of hydrogeochemical studies of groundwater systems normally do not include silica. This is in spite of the fact that relatively rich literature exists on the relationship of silica with parameters, such as water–rock interaction[2,3], temperature conditions at the time of silica acquisition[3,4], regional heat flow values[5,6] and depth to aquifer. This study is an attempt to highlight the significance of silica analysis in groundwater studies.

Silica released as a result of chemical breakdown of silicate minerals in rocks and sediments by chemical weathering is acquired by circulating groundwater and therefore the source of silica (SiO_2) in groundwater is almost exclusively and unequivocally a result of water–rock interaction[7]. Concentration of SiO_2 in groundwater varies from 1 to 30 mg/l, the median value being 17 mg/l (ref. 8). Another study[2] demonstrates that silica content of groundwater increases due to increased contact with silicate rocks and that the silica content is directly proportional to the residence time of water underground. They also showed that water ascending from deeper reservoirs had higher silica values than in groundwater of shallow origin.

Relatively high silica content in groundwater, therefore, implies more intense water–rock interaction, which, in turn, may be related to various aquifer-related parameters, such as permeability, residence time and lithology.

On the other hand, solubility of silica in water is directly proportional to temperature[3]. This temperature–solubility relationship of silica is so consistent, at least to a temperature of about 300°C, that it is used as a geothermometer in the studies of deep groundwater and geothermal systems[3,9]. The application of silica geothermometry is vindicated by the fact that silica-equilibrium temperatures have been encountered in all the explored geothermal systems[10]. This silica–temperature relationship has also been widely used in thermal gradient/heat flow mapping[6].

Silica geothermometer has been applied to over 70,000 non-thermal groundwater samples of USA[5] and a strong correlation between silica geotemperatures and regional heat flow has been demonstrated and defined by the relationship:

Silica temperature in groundwater (t in °C) = $mq + b$,

where q is the regional heat flow in mWm^{-2} and m and b are constants with values of 0.67°C m^2 mW^{-1} and 13.2°C respectively. Constant b is related to the mean air temperature and m is related to the depth to which water descends. The study[2] further demonstrated that the estimated depth of the occurrence of groundwater in deep steady state is 1400–2000 m.

In another study of the Morgan County, West Virginia, USA[4], it has been shown that a relationship exists

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between observed temperatures of groundwater discharges and their silica content.

Hydrochemical geothermometers (based on silica and cation abundances) were used to determine source–reservoir temperature of water samples from 34 springs in a part of Himalayan foreland basin. A pronounced positive co-relation is obtained for SiO_2 indicating that high temperature water dissolved more silica while circulating in deeper formation[11]. In another study, silica concentration is used to distinguish rainfall, short residence time shallow groundwater from longer residence time deeper groundwater[12].

A number of silica geothermometers have been proposed. The one which seems to be appropriate for groundwater systems is given by Fournier[3]. This equation takes into account the solubility of chalcedony and is given here:

$$t°C = [(1032)/(4.69 - \log SiO_2)] - 273.15$$
$$(SiO_2 \text{ concentration in mg/l}).$$

By virtue of these characteristics of silica, a groundwater sample with higher silica content would represent more water–rock interaction at a relatively high temperature level than a sample with lower silica content. Translating silica values to aquifer temperature provides an estimate to the depth of aquifer assuming normal terrestrial thermal gradient of 30°C/km (refs 6 and 9).

The study area measuring 650 km² (29°05′–29°30′N, 77°20′–77°32′E) lies in the western part of Muzaffarnagar district in the state of Uttar Pradesh, India, bounded by Hindon and Krishni rivers. The two rivers are tributaries of Yamuna and are perennial, mature and meandering (Figure 1). Subsurface data available from shallow boreholes indicate that the top clay layer is persistent throughout the area and is underlain by a more porous and thicker granular zone intervened by several clay lenses[1]. The aquifer tends to behave as a monostratum to depth of about 120 m (Figure 2). As revealed by deep drilling data[13], thickness of Quaternary Alluvium is more than 1000 m and it is underlain by quartzite of Delhi Supergroup.

Out of 45 locations from which samples were collected for the detailed hydrogeochemical study[1], 12 were selected (Figure 1) based on various hydrological considerations and ground conditions, for determination of silica concentration. The hydrological condition considered in selection of sampling wells includes silica variation with depth and for this, wells in depth range of 18–86 m were sampled. There is also variation in TDS values from 559 to 1427 mg/l of the wells sampled. Moreover, the sampling wells were selected in such a way that minimum number of samples cover the entire area. The sampling for silica was carried out in June 2007.

Results of silica analysis are given in Table 1. Also given in the table are reservoir temperatures estimated using chalcedony thermometry and concentration levels of Cl and TDS.

Silica values have been related to Cl (Figure 3 a) and TDS (Figure 3 b). On SiO_2–Cl plot, samples 1, 2, 3, 4 and
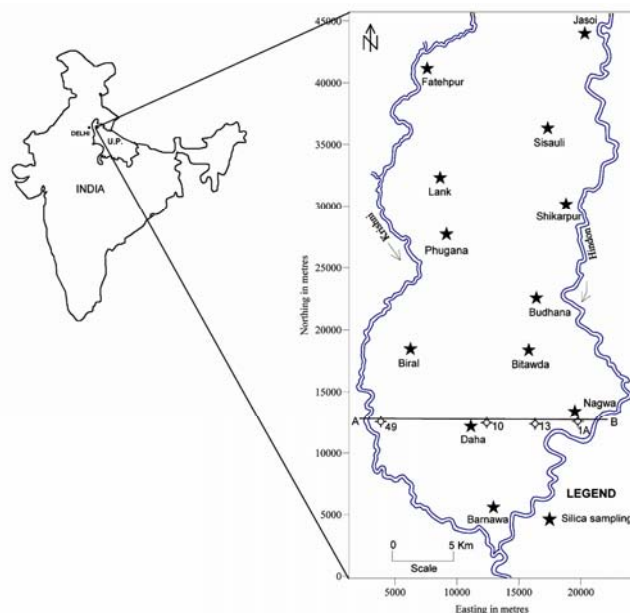

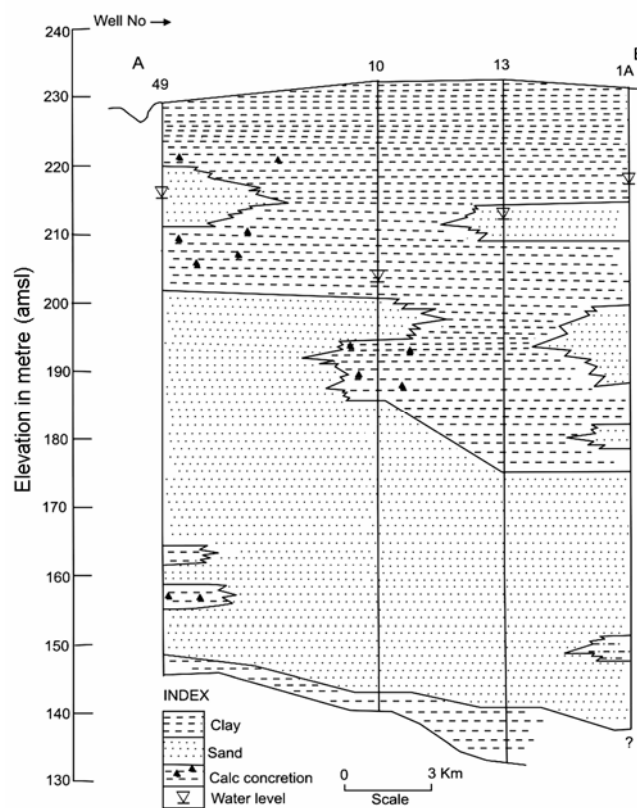**Figure 1.** Location of sampling wells in the study area.

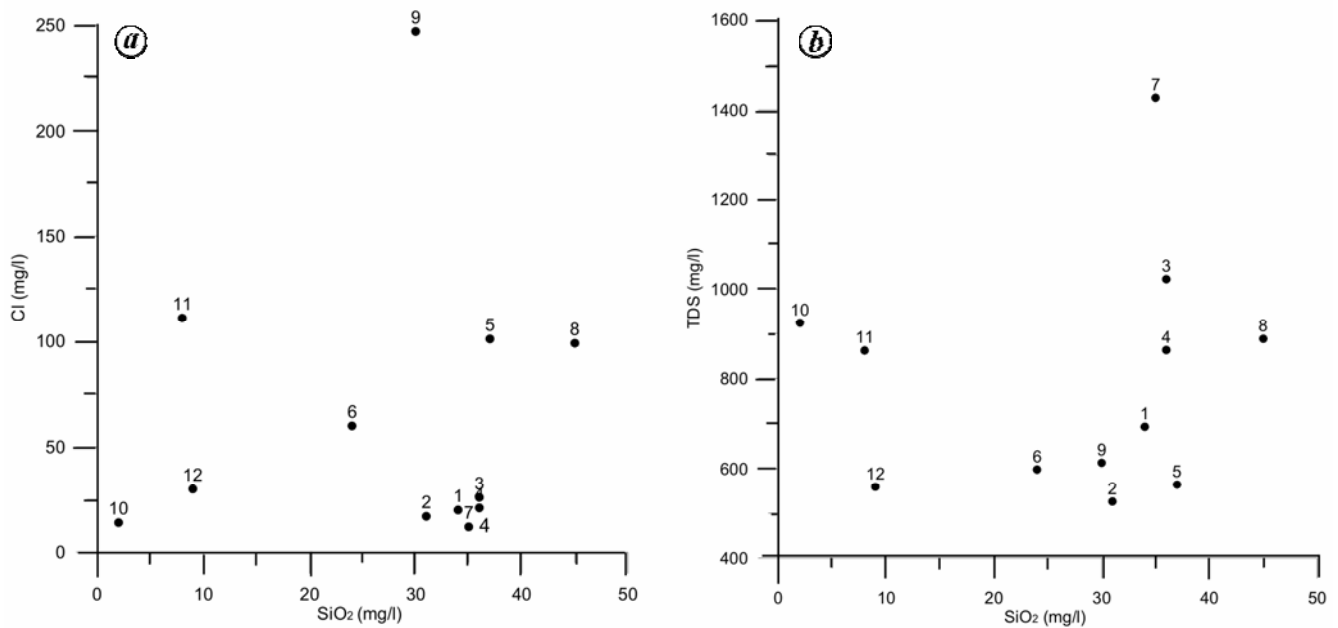**Figure 2.** Hydrogeological cross-section along line A–B.

Figure 3. *a*, SiO$_2$ versus Cl plot. *b*, SiO$_2$ versus TDS plot.

Table 1. Silica values and temperatures derived

Location	Depth (m)	SiO$_2$ (mg/l)	Cl (mg/l)	TDS (mg/l)	Temperature (°C) chalcedony
Fatehpur	50	34	20	693	54
Jasoi	40	31	17	526	50
Sisauli	40	36	26	1022	56
Budhana	74	36	21	863	56
Lank	83	37	101	564	57
Bitawada	28	24	60	598	40
Nagwa	15	35	12	1427	55
Daha	70	45	99	888	66
Barnawa	50	30	247	613	47
Phughana	86	2	14	924	–38
Biral	30	8	111	862	–0.6
Shikarpur	18	9	30	559	3.09

7 occupy a small cluster defined by higher SiO$_2$ values of 31–37 mg/l and relatively low Cl values of 12–25 mg/l. These may be termed as groundwaters that have attained their silica values through interaction with the solid phase at temperatures averaging around 55°C. Samples 5, 6, 8, 10 and 12 suggest normal SiO$_2$–Cl relationship which may suggest dominant role of water–rock interaction. Samples 9 and 11 from Barnawa and Biral (Figure 1) are peripheral to river Krishni and are anomalously enriched in Cl probably due to inflow from highly contaminated river.

On SiO$_2$–TDS plot (Figure 3 *b*), on the other hand, these samples plot in nearly a straight vertical line indicating that silica values have no explicit relationship with TDS values and any TDS value of 500 to >1400 mg/l may be possible for nearly identical SiO$_2$ concentration.

If the bulk of solute acquisition (TDS) would have resulted from water–rock interaction, a positive correlation between SiO$_2$ and TDS would have been logically expected. It may therefore be inferred that relatively high concentration levels of TDS are related to anthropogenic rather than geogenic phenomenon.

Silica values > 30 mg/l are seen in the northern and the southern parts of the area. These coincide with TDS values of 500–850 mg/l. On the other hand, SiO$_2$ values < 30 mg/l tend to occur in zones with higher TDS values of 850–1200 mg/l. This implies that relatively lower TDS samples have a larger proportion of groundwater of deeper origin and those with higher TDS have a substantial component of low-silica water derived from the surface. The low-silica water may either be from the rivers or may be contamination-enriched rain water descending underground.

Temperatures likely to exist at deeper reservoir conditions, as estimated by the chalcedony equation, are highest for Daha, i.e. 66°C. For Fatehpur, Jasoi, Sisauli, Budhana, Lank and Nagwa, it ranges between 50°C and 57°C, averaging 55°C. Inferred temperature is lower at 39°C for Bitawada. Since samples were collected in June 2007, when the ambient temperature was in excess of 30°C, a silica temperature of 66°C at Daha would mean a temperature of about 35°C over and above the average air temperature which, in turn, would correspond to a depth of about 1000 m taking into account an average heat flow value of 30°C/km (ref. 8). Other samples, characterized by silica values > 30 mg/l and temperature averaging around 55°C would, by the same token, correspond to a depth of about 800 m.

Thermometry is not applicable to samples 10, 11 and 12 from Phughana, Biral and Shikarpur as these are far too smaller than the values normally found in ground-waters[1,4]. As a matter of fact, the values of 2–9 mg/l tend to characterize river water rather than subsurface water. The only hypothesis that may be offered is that these three wells discharge water that has reached aquifers as a result of the influent nature of the two rivers. Further, it would mean that this water has relatively shorter residence time which has precluded rock–water interaction.

This study has revealed that SiO_2 values are of great significance in understanding the level of origin of groundwater and hydrogeochemical processes, geogenic or anthropogenic, that may influence the distribution of major ions in groundwater. Silica values, when related to a rather conservative ion Cl or total solute concentration may provide valuable information which not only can help in identifying source of chemical species but may also play a major role in managing and conserving precious groundwater resources. It is therefore strongly recommended that silica determinations should be taken up in all groundwater investigations.

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