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High mobility of aluminium in Gomati River Basin: implications to human health

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Aluminium (Al), an environmentally abundant and immobile element, has been studied for its mobility in the Gomati River Basin, a part of the Ganga Alluvial Plain, northern India. The dissolved Al concentrations in the Gomati River water and the Lucknow groundwater range over three orders of magnitude, from 14 to 77,861 ppb. In the Gomati River water, Al is classified as a moderately mobile element. Nearly 19% of Lucknow groundwater samples and all the Gomati River water samples have Al values above the permissible limit (200 ppb) recommended by the World Health Organization. Systematic multi-disciplinary study is urgently required to understand the geological association of high Al mobility with human health in the Ganga Alluvial Plain, one of the densely populated regions of the world.

Keywords: Aluminium mobility, Ganga Alluvial Plain, groundwater, human health.

ALUMINIUM (Al) is the third most abundant element in the Earth's crust. Generally, the chemical weathering of

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rocks leads to a quick removal of alkali and alkaline earth elements; whereas Si, Fe and Al are retained as a residual deposit. Aluminium is considered as an immobile element and occurs in soils as bauxite[1]. In natural water, the most commonly found Al compounds have very low solubility and, therefore, their dissolved forms rarely occur in concentrations greater than 100 ppb (ref. 2). In this communication, we have discussed the dissolved concentrations of Al in water resources of the Gomati River Basin.

The Gomati River Basin (30,437 sq. km area) is located between 25–29°N and 80–84°E in the interfluve region of the Ganga (Ganges) and Ghaghara rivers of the Ganga Alluvial Plain in the northern part of India (Figure 1). It has high population density (>500 persons/sq. km) and houses nearly 40 million people[3]. The basin has low relief and encompasses an altitude range 60–190 m amsl (ref. 4). The river basin has humid subtropical climate, characterized by four distinct seasons – the summer season (March–May), monsoon season (June–September) of heavy precipitation, post-monsoon season (October–November) and winter season (December–February). The temperature varies from 44°C in summer to 4°C in winter and the average annual precipitation is around 100 cm. The Gomati River Basin has been selected for the present study mainly due to the fact that it receives no water or sediments directly from the Himalayan region at present. The water and sediments are derived from within the alluvial plain. Thus, the water chemistry represents the geochemical processes operating within the alluvial plain. The geological, hydro-chemical and environmental aspects of the river basin are presented in Table 1 (refs 4–8).

A total of 36 river water samples were collected from mid-channel of the Gomati River at Chandwak, at an interval of ten days for one year, covering all the seasons between June 2009 and May 2010. Chandwak is located at the distal end of the Gomati River, before it meets the Ganga River. All the important tributaries of the Gomati River meet it before Chandwak. Thus, the collected water samples at Chandwak give an average of the entire Gomati River Basin. Hundred groundwater samples were collected from India Mark-II hand pumps located in Lucknow area during May–June 2010. All river water

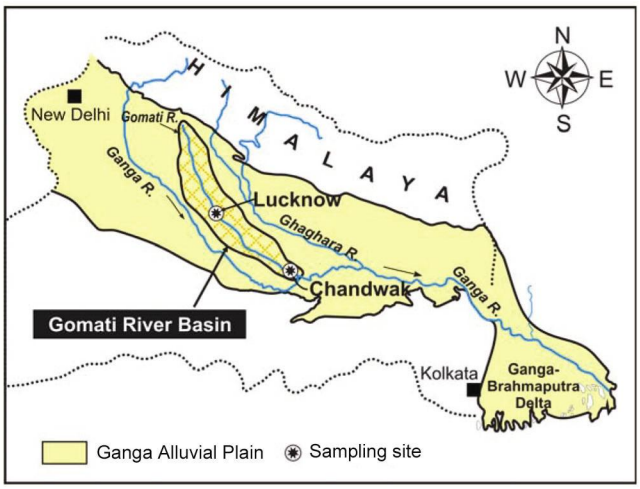

Figure 1. Location map of the Gomati River Basin showing sampling sites Lucknow for groundwater and Chandwak for river water.

Table 1. General characteristics of the Gomati River and its drainage basin in the Ganga Alluvial Plain, northern India

Gomati River Basin
Drainage area, 30,437 sq. km; climate type, humid subtropical climate; annual rainfall, 81–125 cm; maximum and minimum elevation, 186 m and 61 m amsl; maximum and minimum temperature, 44°C and 4°C; maximum relief, 25 m; sub- and micro-basins, Sai River Basin and 33 micro-basins; land-use pattern, agriculture 67%, settlement 13%, barren land 14%, forest 4%, water bodies 2%; human population, ~40 million in 2010; basin groundwater pH, 7.6; basin groundwater hydro-geochemical facies, Ca–Mg–HCO_3; basin groundwater dissolved solid, 160 mg/l.
Gomati River water
Active channel length, 900 km; pH, 7.5–8.4; temperature, 15°C in winter and 35°C in summer; conductivity, 320–750 µS/cm; total dissolved solid in post-monsoon, 400 mg/l; total hardness, 300 mg/l; dissolved oxygen, 1–3 mg/l in urban stretch and 5–15 mg/l in non-urban stretch; low flow during summer season, 2–5 m^3/s; high flow during monsoon season, 500–900 m^3/s; total annual discharge, 5.9×10^9 m^3 in 2010; seasonal discharge contributions, monsoon 48%, post-monsoon 30%, winter 16% and summer 6%.
Gomati River sediments
Bedload sediments – mean grain size, very fine sand; minerals composition, quartz, muscovite, biotite, rock fragments, K-feldspar, plagioclase.
Suspended load sediments – mean grainsize, medium silt; clay minerals composition, mica – 33%.

Data source: refs 4–8.

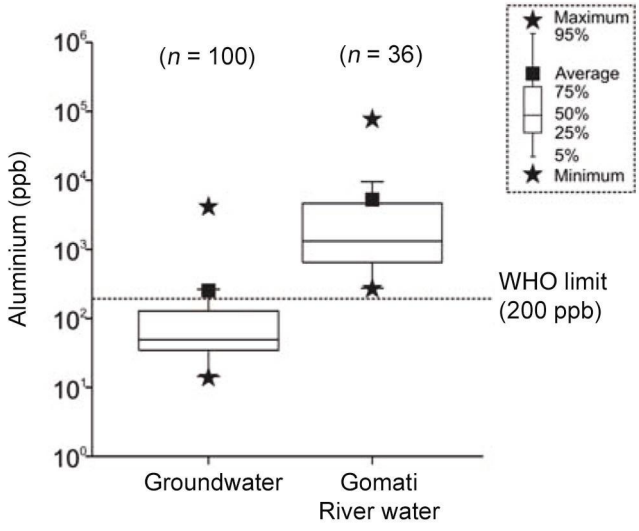

Figure 2. Box and whisker diagram showing distribution of dissolved Al concentrations in the Lucknow groundwater and the Gomati River water. All values of the Gomati River water and 19% values of the Lucknow groundwater are above the WHO permissible limit (200 ppb).

and groundwater samples were collected in wide mouth 250 ml polypropylene bottles (© Tarsons) with airtight caps and were acidified in the field with HNO_3 (5 ml/l). Each sample bottle was tagged with appropriate label and was carefully transported to the laboratory for chemical analysis. The samples were filtered through Millipore filtering assembly using <0.45 µm membrane filter and analysed by Inductively Coupled Plasma-Mass Spectrophotometer (ELAN DRC II Perkin Elmer SCIEX Instrument) at Indian Institute of Technology Roorkee, Roorkee. Each sample was analysed in triplicate and mean value was taken as the result. All the samples were analysed in the laboratory following the standard protocols[9]. The overall precision of the analytical method is about ± 3%.

Figure 2 displays box and whisker diagram showing the distribution of dissolved Al concentration in the Lucknow groundwater and the Gomati River water. In the groundwater, the dissolved Al ranges from 14 to 6596 ppb with an average value of 247 ppb. In the Gomati River water, the Al concentration varies from 273 to 77,861 ppb with an average value of 5289 ppb. The maximum permissible limit, recommended by WHO, for the presence of Al in drinking water is 200 µg/l (ref. 10). About 19% of the Lucknow groundwater samples and all the Gomati River water samples contain Al concentration above the permissible limit.

The spatial distribution of dissolved Al concentrations in the drinking groundwater of Lucknow area shows that high Al values are distributed in an isolated concentric pattern (Figure 3 *a*). The seasonal variation of Al concentration in the Gomati River water shows that during the monsoon season there is nearly 200 times increase in dissolved Al concentration compared to other seasons (Figure 3 *b*). The average value for the Gomati River is about 165 times higher than the world average value of Al in river water (32 ppb)[11]. The maximum Al concentration (77,861 ppb) coincides with first flood discharge peak (612 m^3/s) occurring in the middle of July during the monsoon season.

Aluminium presents only one oxidation state (III) and a range of species in natural waters. The important Al species are Al^{3+}, $AlOH^{2+}$, $Al(OH)_2^+$, $Al(OH)_3^0$ and $Al(OH)_4^-$. Aluminium mainly occurs as Al^{3+} under acidic conditions and as $Al(OH)_4^-$ under neutral to alkaline conditions[12]. It displays solubility as a function of pH. It increases at low (pH < 6) and high (pH > 8) pH values, which is relative to low solubility at near neutral pH[12] (Figure 4). The element mobility index is the ratio of sodium-normalized dissolved elements concentration to that of the Upper Continental Crust[11]. Globally, the mobility index of Al is 100 times lower than that of Na and therefore, Al is classified as an immobile element[11]. In the Gomati River water, the average concentration of dissolved elements is Al, 5,289 µg/l; V, 8.21 µg/l; Cr, 4.76 µg/l; Mn, 115 µg/l; Fe, 2,080 µg/l; Ni, 7 µg/l; Co, 2 µg/l; Cu, 7.34 µg/l; Zn,

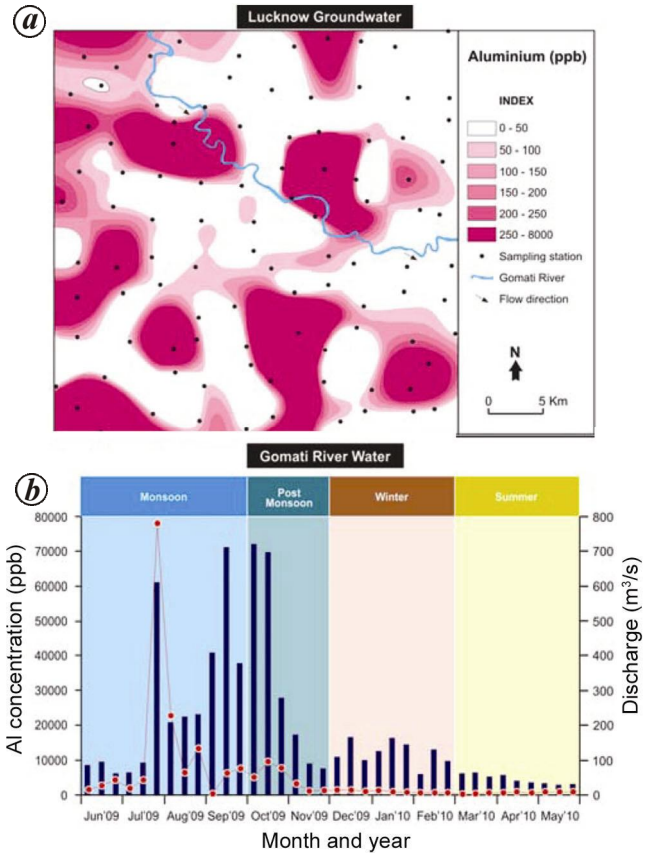

Figure 3. ***a***, Spatial distribution of dissolved Al concentrations in the Lucknow groundwater; ***b***, Seasonal distribution of dissolved Al concentrations along with discharge in the Gomati River water at Chandwak. The maximum Al concentration coincides with first flood discharge peak occurring in the middle of July during the monsoon season (refer to Figure 1 for sampling locations).

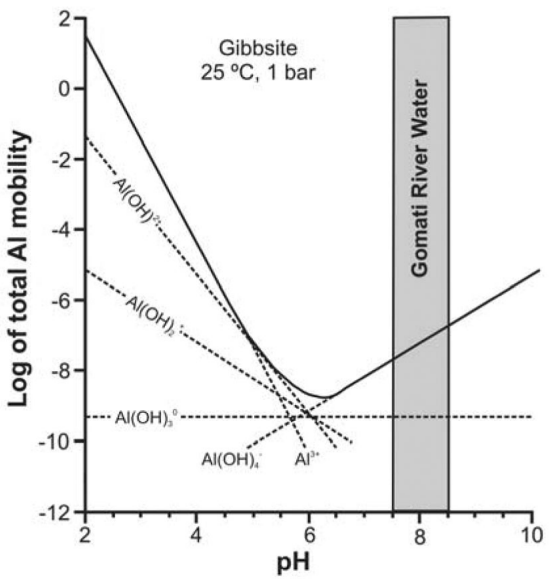

Figure 4. Solubility of Al as a function of pH (modified after Walther[12]). The solubility is high at low (<6) and high (>8) pH. The pH of the Gomati River water is also shown.

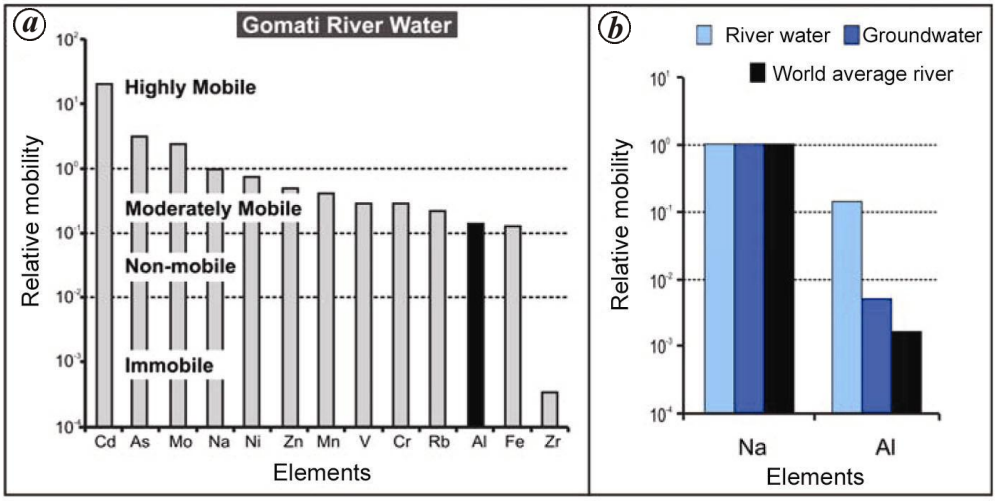

Figure 5. Sodium normalization bar diagram showing relative elemental mobility in the Gomati River Basin. ***a***, Aluminium and other trace elements (Rb, Cr, V, Mn, Zn and Ni) are classified as moderately mobile elements in the Gomati River water. ***b***, Relative mobility of Al and Na in the Gomati River water, Lucknow groundwater and world average river water.

16.9 µg/l; As, 2.25 µg/l; Se, 100 µg/l; Rb, 11.6 µg/l; Sr, 230 µg/l; Zr, 0.03 µg/l; Mo, 1.7 µg/l; Cd, 0.96 µg/l; Ba, 93.4 µg/l and Pb, 4.3 µg/l. Figure 5 *a* shows the Na-normalized relative mobility of Al and other elements in the Gomati River water. The mobility index of Al is between 1.0 and 0.1; hence it is classified as a moderately mobile element in the Gomati River Basin. This is in total variance with the immobile nature of Al in other river basins of the world[11]. Some other trace elements like Ni, Cu, Zn, Pb, Mn, V, Cr and Rb are also classified as moderately mobile elements in the Gomati River water. The relative mobility of Al in the Gomati River water is about 30 times higher than the Lucknow groundwater and about 90 times higher than the world average river water (Figure 5 *b*).

Aluminium is predominantly transported in water of the Gomati River Basin by the weathering processes of the alluvial sediments (parent material). On release from mineral, Al chemistry controls its mobility. Dissolved Al shows high significant correlation coefficient ($r^2 = 0.99$) with dissolved Fe in the Gomati River water. This indicates a common source present in the alluvial sediments. Dissolution and weathering of biotite is important to provide Al and other trace elements in the Gomati River water[13]. Some contributions from muscovite and feldspar are also considered important.

Aluminium, a potent neurotoxicant, is associated with age-related neurodegenerative disorders (including Alzheimer's disease) in humans[14–19]. These human-health disorders have been recently reported in India[20–23]. Future studies should emphasize the possible role of high dissolved Al concentration in the Gomati River Basin (the Ganga Alluvial Plain) and its effect on the human health of this region.

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Errata

Oxyhalide disinfection by-products in packaged drinking water and their associated risk

I. V. Saradhi, S. Sharma, P. Prathibha and G. G. Pandit
[*Curr. Sci.*, 2015, **108**, 80–85]

1. Page 80, Column 1, Para 1 (Abstract), Line 11

   The following sentence
   'Bromate in 27% samples was found to be higher than the World Health Organization (WHO) guideline values of 10 μg/l…'

   Should be replaced by

   'Bromate level in 27% of brands (i.e. five brands out of 18 brands) and 5.6% of samples (i.e. five samples out of 90 samples) analysed exceeded the WHO recommended guideline[1] value of 10 μg/l.'

2. Page 81, Column 2, Para 2, Line 39

   The following sentence
   'Bromate level in 27% (five nos) of drinking water samples exceeded the WHO recommended guideline value[1] of 10 μg/l.'

   should be replaced by

   'Bromate level in 27% of brands (i.e. five brands out of 18 brands) and 5.6% of samples (i.e. five samples out of 90 samples) analysed exceeded the WHO recommended guideline[1] value of 10 μg/l.'

3. Page 84, Column 2, Para 2, Line 3

   The sentence 'The results showed that bromate, chlorite and chlorate were detected in a number of samples and bromate in 27% of samples analysed was more than the guideline value recommended by WHO.'

   should be replaced by

   'The results showed that bromate, chlorite and chlorate levels were detected in samples and bromate level in 27% of brands (i.e. five brands out of 18 brands) and 5.6% of samples (five samples out of 90 samples) analysed exceeded the WHO recommended guideline value of 10 μg/l.'