High fluoride incidence in groundwater and its potential health effects in parts of Raigarh District, Chhattisgarh, India

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High concentrations of fluoride (F^-) in drinking water are harmful to human health. Knowledge of spatio-temporal distribution of F^- content in groundwater is thus a prerequisite for taking preventive measures. This communication reports F^- incidence in groundwater and its relation with the prevalence of fluorosis in Tamnar area, Raigarh District, Chhattisgarh, India. Nearly 18% of the sampled wells had F^- concentrations above the desirable limit (> 1.0 mg/l), the highest value being 8.8 mg/l. High F^- concentrations primarily occurred in coal-bearing Barakar Formation of the Gondwana Supergroup. Prevalence of dental fluorosis was observed in five villages, viz. Dholnara, Kunjhemura, Muragaon, Pata and Saraitola; whereas skeletal fluorosis was found to occur only in Muragaon. The spatial distribution of F^- in groundwater, as indicated by hydrogeochemical analyses, corroborated well with the prevalence of dental and skeletal fluorosis. It is envisaged that, in addition to the people already affected, a large fraction of the population in the area is at potential risk, especially considering that the region falls in the coal mining and industrial belt. The health-risk map prepared using a Geographic Information System provides baseline information in taking mitigation measures.

Keywords: Fluoride, groundwater, health-risk, preventive measures.

THE occurrence of high fluoride (F^-) in groundwater has drawn considerable attention the world over, since groundwater is the main source of F^- intake[1]. F^- in drinking water has both beneficial and harmful effects on human health[2–8]. According to the Indian standards for drinking water[9], the acceptable (or desirable) limit of F^- in drinking water is 1.0 mg/l; however, in the absence of any alternate source, maximum permissible limit is 1.5 mg/l. Whereas low F^- content (< 0.60 mg/l) in drinking water can cause dental caries and poor development of bones[10], high F^- content (> 1.0 mg/l) can lead to dental and skeletal fluorosis[6]. The source of F^- in groundwater is primarily geogenic, i.e. from dissolution of fluorine-bearing minerals in the rocks transmitting groundwater, and occasionally anthropogenic[2,10–12].

India is among the 23 nations wherein a large population suffers from dental and skeletal fluorosis due to high F^- concentration in groundwater[13–15]. Since groundwater forms the main source of drinking water supply[16], generation of a reliable database on quality parameters and scientific study towards understanding the spatio-temporal distribution of F^- concentration in groundwater vis-à-vis plausible cause(s) are essential for taking preventive measures[17,18].

This communication embodies the findings of a detailed study[19] carried out in a part of Raigarh District, Chhattisgarh, India, especially dealing with spatio-temporal distribution of F^- concentration in groundwater and its effects on human health. The area studied forms a part of the Pahaj River watershed in Tamnar Block, Raigarh District (Figure 1). It lies between lat. 22°05′N and 22°15′N, and long. 83°20′E and 83°30′E, covering about 240 sq. km area. Pahaj is a tributary of the Kelo River, which in turn is a tributary of the Mahanadi River.

High F^- content in groundwater in the study area was reported for the first time in 2004 by the Public Health Engineering Department of the State Government. Incidences of dental and skeletal fluorosis are shown in Figure 2. The area is likely to be developed for coal mining and related industries and, hence a considerable population might be at potential risk due to consumption of water with high F^- content. This fact provided a motivation to carry out the present study. To the best of our knowledge, prior to the study by Beg[19], no systematic study on the geogenic source of F^- in groundwater has been carried out in the area.

The area is covered by the rocks of Barakar, Barren Measure, Raniganj and Kamthi formations of Gondwana Supergroup, consisting of a thick sequence of sandstones, shales, carbonaceous shales, clays and coal seams. The rocks have primary as well as secondary porosity and permeability. Physiographically, most of the area is occupied by flat to gently sloping land (about 260–300 m amsl) with soil cover and occasional outcrops of low-dipping sandstones. The northeastern and extreme southwestern parts are occupied by NW–SE running low hills and ridges (about 300–580 m amsl), formed by Raniganj and Kamthi formations. Groundwater occurs under phreatic to semi-confined conditions in shallow aquifers, and under confined conditions in deeper aquifers giving rise to artesian wells. The depth to groundwater level in the area during pre-monsoon period (early June 2008) ranges from about 12 m to more than 34 m below ground level. The groundwater-level fluctuation between pre-monsoon and post-monsoon periods (i.e. between early June and early November) is generally between 5 and 10 m. The overall groundwater movement direction is southwards; however, it varies locally depending on the

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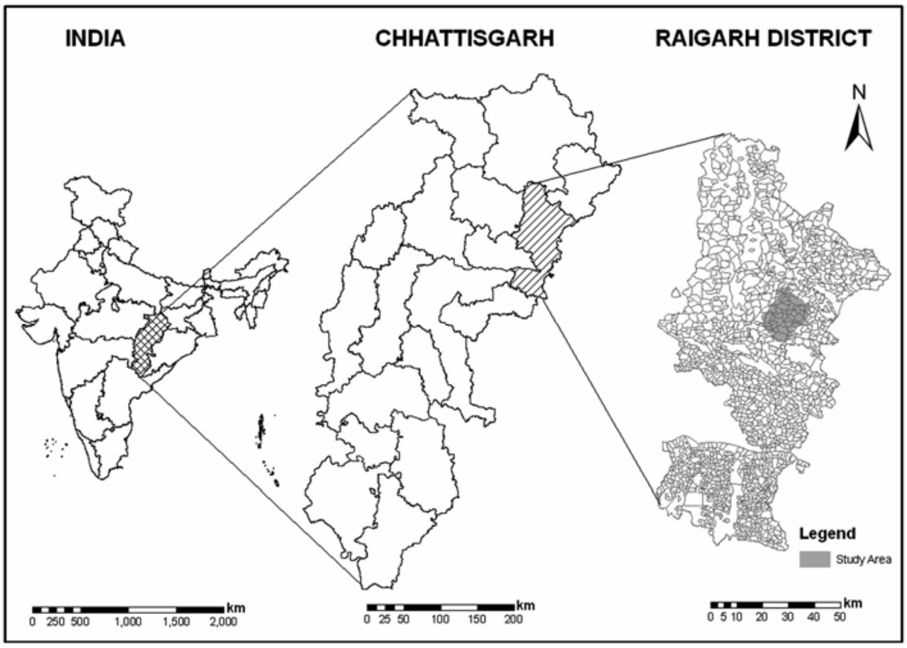

Figure 1. Location map of the study area.

Figure 2. Dental and skeletal fluorosis in the study area.

physiography. Groundwater is the sole source of drinking water in the area.

For hydrochemical analysis, groundwater samples were collected from hand pumps during pre-monsoon ($N = 83$) and post-monsoon ($N = 81$) periods of 2008. Water samples could not be collected from two locations during the post-monsoon period due to mechanical problem in the hand pumps. The temperature, pH and electrical conductivity (EC) were measured in the field using portable pH meter (model-pH tester 30 Eutech) and EC meter (Corning, model 831). Cations and anions were analysed using ion chromatograph (Metrohm, 861, Advanced Compact IC) and standard titration methods, following standard procedures[20]. The ion balance was within ± 10% for most of the samples; two samples of pre-monsoon and three samples of post-monsoon were found to have ion balance beyond ± 10% limit, possibly because of inaccurate analysis of HCO_3^-. The hydrochemical data were analysed and interpreted using univariate and multivariate methods. X-ray diffraction and petrographic analysis of rock samples collected from the high-F^- incidence zone were carried out for identification of minerals constituting the host rock. Geographic Information System (GIS) was used for spatial analysis of geological and hydrochemical data. The inverse distance weighting (IDW) method was used for interpolating the point hydrogeochemical data to depict the spatial distribution of F^- abundance in groundwater into different classes.

The F^- concentration in groundwater varied from 0.09 to 8.8 mg/l during pre-monsoon and from negligible

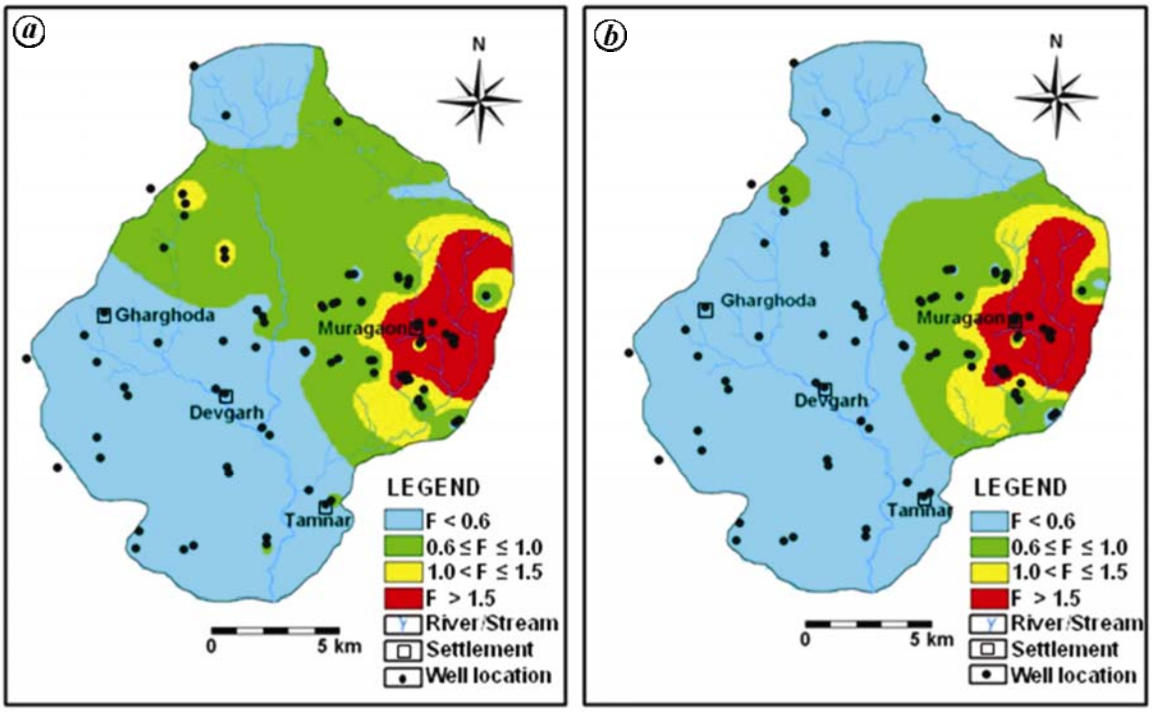

Figure 3. Spatial distribution of fluoride in groundwater during (***a***) pre-monsoon and (***b***) post-monsoon periods.

(non-detectable) to 7.1 mg/l during post-monsoon. The results of chemical analyses of F^- concentration during the pre-monsoon and post-monsoon periods showed the following. About 18% of all the samples in the eastern part of the area had F^- concentration above the desirable limit. About 57% of the total samples in the northern, southern and western parts of the area had F^- concentration below the minimum required level. The remaining 25% of all the samples in the eastern and central parts of the area had F^- concentration within the optimum range (i.e. 0.6–1.0 mg/l). Among the 36 villages for which hydrochemical analyses were carried out, F^- concentration in groundwater consistently exceeded the desirable and maximum permissible limits in three villages, viz. Muragaon, Pata and Saraitola. In Muragaon and Saraitola, F^- concentration exceeded 3 mg/l, indicating the population risk to skeletal fluorosis[21]. In addition, F^- concentration was found to be higher than the desirable limit in Auraimura and Patrapalli villages during pre-monsoon and in Dholnara village during post-monsoon. Maps of the spatial distribution of F^- concentration in groundwater during the pre-monsoon and post-monsoon periods were prepared by interpolating the point hydrogeochemical data in GIS (Figure 3). The areas having F^- concentration above the desirable and maximum permissible limits are depicted in yellow and red colours respectively.

It was observed that high F^- concentration in groundwater mainly occurred in wells tapping the aquifers in Barakar Formation, which has a litho-assemblage of feldspathic sandstone/shale/coal. The positive correlation of F^- with Na^+ and SiO_2, the groundwater type, increase in $Na^+ : Ca^{2+}$ values with increase in F^- concentration, presence of Li^+ in the high-F^- zone, absence of PO_4^{3-}, and the results of mineralogical and petrographic analyses indicate that F^- in groundwater is geogenic. Micas and clay minerals occurring in the Barakar Formation appear to be the main source of high F^- in groundwater. It was also observed that high F^- generally occurred in deeper (> 110 m) wells. No relation was, however, apparent between F^- occurrence and physiography or the direction of groundwater movement. Detailed analysis of hydrochemical, geological and hydrogeological datasets for inferring the plausible source(s) and causes leading to high F^- in groundwater has been reported elsewhere[19].

Ground campaigns indicated that dental fluorosis was prevalent in five villages, viz. Dholnara, Kunjhemura, Muragaon, Pata and Saraitola. The occurrence of skeletal fluorosis was found only in Muragaon. The prevalence of dental fluorosis (i.e. ratio of number of people affected by the disease to the total population) was highest (6.03%) in Saraitola and lowest (1.26%) in Dholnara (Figure 4). Dental fluorosis is mainly found to occur among children of 10–15 years age group. The prevalence of skeletal fluorosis in Muragaon was 1.2%, where eight people were found to be affected. These data on dental and skeletal fluorosis corroborate well with the spatial distribution patterns of F^- in groundwater (Figures 3 and 4).

Based on the spatial distribution of F^- concentration in groundwater during the pre-monsoon and post-monsoon periods, a health-risk map[22] was prepared (Figure 5). The

Table 1. Villages affected and population at risk

Health-risk category	Number of villages prone to health risk	Population at risk*
Prone to dental caries and poor bone development	32	20,306
Prone to dental fluorosis	8	2,632
Prone to dental and skeletal fluorosis	12	4,228

*Based on Census–2001.

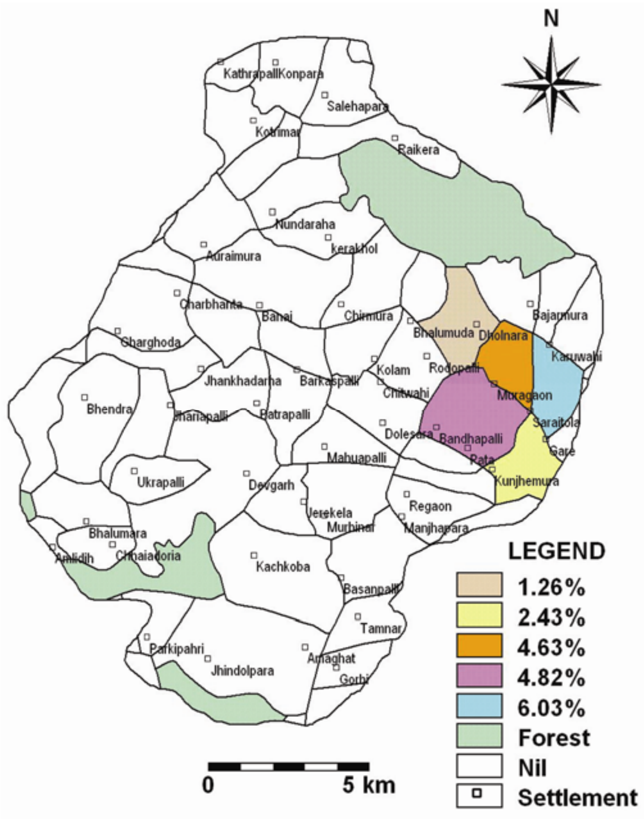

Figure 4. Prevalence of dental fluorosis. Solid black lines represent village boundaries.

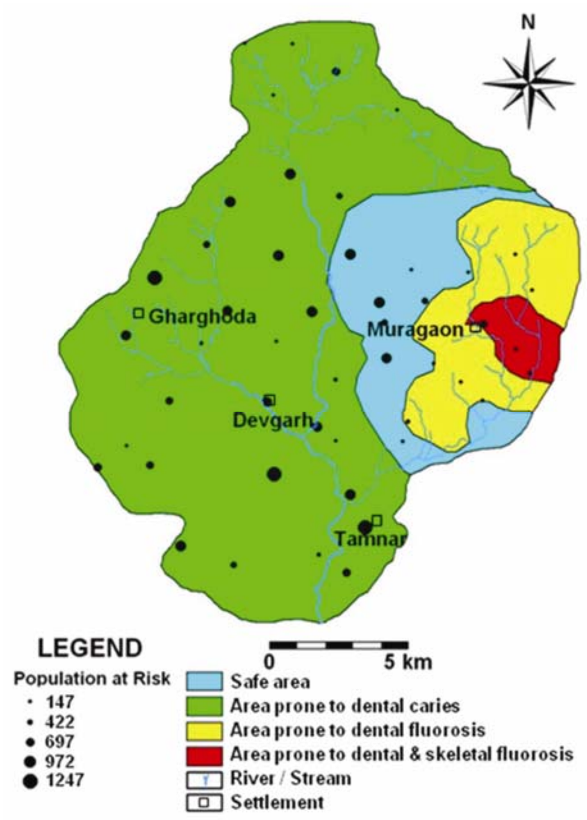

Figure 5. Map showing health risk and population at risk based on fluoride concentration in groundwater.

map divides the area into four categories – (1) safe area ($0.6 < F^- < 1.0$ mg/l), (2) area prone to dental caries and poor bone development ($F^- < 0.6$ mg/l), (3) area prone to dental fluorosis ($F^- > 1.0$ mg/l), and (4) area prone to dental and skeletal fluorosis ($F^- > 3.0$ mg/l). The lower limit for dental fluorosis has been taken as 1.0 mg/l, as incidences of dental fluorosis in the country have been reported beyond this level[6,22]; the lower limit for skeletal fluorosis was taken as 3.0 mg/l (ref. 21). The health-risk map (Figure 5) was prepared by overlaying the pre-monsoon and post-monsoon health-risk maps (both having four categories as mentioned above) in GIS domain, since there is a temporal change in F^- concentration in groundwater. The final health-risk map was prepared in such a way that if an unsafe zone was encountered in either of the pre-monsoon or post-monsoon periods, it was mapped as unsafe zone and its effect on human health was assigned. However, small polygons resulting due to interpolation error or occurring as small islands, and sliver polygons developed due to overlaying of pre-monsoon and post-monsoon health-risk maps have been removed and merged with the background. Population data (Census–2001) were also superimposed over the final health-risk map to estimate the population at risk due to high or low F^- concentration (Figure 5). The relevant details are summarized in Table 1. It is clear that in addition to the people already affected, a large fraction of the population in the area is at potential risk. Therefore, the health-risk map provides baseline information for taking mitigation measures.

The results presented here are based on a comprehensive study undertaken in the area on F^- occurrence in groundwater. The findings are significant as the area falls in the potential mining and industrial belt of Chhattisgarh, emphasizing a large population may be at potential risk. The rock and water interaction with accompanying ion exchange processes in micas and clay minerals appear to be the primary mechanism for high concentration of F^- in groundwater. Systematic study needs to be undertaken in the Gondwana rocks in the surrounding area, with an emphasis on the coal-bearing Barakar Formation, to delineate unsafe zones.

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Seismic site characterization using *Vs*30 and site amplification in Gandhinagar region, Gujarat, India

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Gujarat is prone to earthquake hazard of different levels from moderate to high, assigned as zones II–V in the seismic zoning map of India. Many multistorey buildings collapsed in Ahmedabad city at a distance of 225 km from the location of the 2001 Bhuj earthquake. Gandhinagar falls in zone III where an intensity of VII or VIII from the regional large earthquakes or local earthquakes of magnitude 6 can be expected; which can damage single and multistorey buildings. Thus, there is a need for site characterization and seismic hazard mapping of the area. Shear-wave velocities were measured using the MASW technique at 63 sites in and around Gandhinagar. Based on *Vs*30 in most of Gandhinagar the soils have been classified as D-type (180–360 m/s) in accordance with the NEHRP provision, except the northern part of the city (sites 27, 51, 53 and 54), where *Vs*30 values larger than 360 m/s qualify the area as a NEHRP class C-type soil (360–760 m/s). However, nearly the whole of Gandhi-

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