Fluoride and other inorganic constituents in groundwater of Guwahati, Assam, India

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Groundwater quality in Guwahati has been studied with special reference to the presence of fluoride. The Brahmaputra river in the north, hills to the east and south, and alluvial soil to the west surround the city. Fluoride, above the guideline values of WHO, has been found in groundwater of the eastern and southern plains of the city. The fluoride contents have positive correlation with Na^+, K^+, total alkalinity and depth of source, and negative correlation with Mg^{2+}, Ca^{2+} and total hardness. Negative correlation of fluoride with hardness and absence of any correlation with chloride indicate recharge of the aquifer by the Brahmaputra and/or rain. A few of the samples showed high nitrate and sulphate contents. The sources of fluoride and nitrate are suspected to be minerals from the Precambrian granite, which forms the basement of the city and also outcrops at several places in the city.

PRESENCE of fluoride in groundwater poses a great problem in most of the states of India[1,2]. Severe contamination of fluoride in groundwater of Karbi Anglong and Nagaon districts of Assam and its manifestation in the form of fluorosis have been reported recently[2,3]. Subsequently, some reports in the newspapers about fluoride in groundwater in certain parts of Guwahati, the capital city of Assam and the gateway to northeastern India, has created confusion among the residents of the concerned areas in the city[4]. Guwahati is bounded by north latitudes 26°05′–26°15′ and east longitudes 91°35′–91°55′. It is sandwiched between the Brahmaputra river to the north, flowing from east to west, and Meghalaya hills to the south. The Precambrian metamorphic rock complex forms the basement of the city area and is also exposed sporadically in the form of iselbergs and denudational hills, with varying topography ranging from 49.5 to 300 m above msl towards south and southeast[5,6]. The city receives an annual rainfall of 152 to 324 cm, with fairly heavy rainfall during May–October[5]. There are two small streams, Basistha and Bharalu, originating from the southern hills; the former joins the Dipar Bil and the latter, the Brahmaputra. The city, with its geographical location, where the groundwater is likely to be recharged and diluted by the Brahmaputra, is not apparently expected to have fluoride in its groundwater. Guwahati is a fast-growing city with a present population of about a million, with inadequate municipal water supply. The presence of fluoride in groundwater can be attributed to geological reasons[1]. Considering the confusion among its residents regarding the use of groundwater, it was thought worthwhile to conduct a survey of fluoride contamination in groundwater and to understand its coexistence with minerals and the hydro-geological conditions.

Water samples were collected in PET bottles of half-litre size and closed tightly. A total of 235 groundwater samples were collected. Fluoride contents in all the samples have been determined. However, determinations of other ions and parameters have been carried out on twenty-four representative samples with varying fluoride concentrations.

Fluoride contents were determined by SPADNS method[7]. SPADNS (2-(*p*-sulphophenylazo)-1,8-dihydroxy-3,6-naphthalein disulphonate) was obtained from E-Merck and SRL. Nitrate contents were determined by spectrophotometric method[8]. Sulphate and chloride were determined by turbidimetric method and argentometric titrametric method, respectively[9]. Phosphate was determined by molybdenum blue method[10]. For all spectrophotometric determinations, a Hitachi U2001 UV-vis spectrophotometer fitted with thermostated cell holders was used.

All metal ions were determined using a Chemito AA 203 atomic absorption spectrophotometer. Total hardness was calculated from concentrations of Ca^{2+} and Mg^{2+} ions[9]. Doubly-distilled water was used for all purposes. Samples were collected in separate bottles for determination of iron. Iron was determined by AAS after dissolving the precipitated iron by adding known amount of nitric acid.

The results of analysis of various ions and other parameters of some selected samples (mostly having high fluoride concentrations) of groundwater in Guwahati are given in Table 1. The concentrations of various ions, except that of fluoride in some samples, NO_3^- in three samples and SO_4^{2-} in one sample, are either low or moderate and within the guideline values of WHO[11]. The distribution of fluoride in groundwater of the city is shown in Figure 1. Out of a total of 235 samples, 10.7% has fluoride concentration above 1.5 ppm, the guideline value of WHO, whereas 45.5% of the samples are deficient (below 0.6 ppm) in fluoride (Table 2). High fluoride concentration has been found in the southeastern plains of the city. The eastern part of the southeastern plains has highest fluoride concentration, as can be seen from Figure 1. This fluoride-affected area has an average elevation of 55 m R.L. and is made up of horizontal beds of clay and sand[6]. The area has a narrow link with the Brahmaputra in the northeastern corner of the city and a relatively wider opening towards Dipar Bil (a lake formed out of an abandoned course or meander of the Brahmaputra) and the Brahmaputra. It

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Table 1. Results of analysis of selected groundwater samples in Guwahati city

Sample no.	Sample location	Source	Ca^{2+} (ppm)	Mg^{2+} (ppm)	Na^{+} (ppm)	K^{+} (ppm)	Fe^{2+} (ppm)	Zn^{2+} (ppm)	F^{-} (ppm)	Cl^{-} (ppm)	SO_4^{2-} (ppm)	NO_3^{-} (ppm)	Ortho-phosphate (ppm)	TH (ppm)	Total alka-linity (ppm)
001	Chandmari colony	HT (PH)	10.4	7.2	29.2	7.3	0.15	0.02	2.67	7	120	1.1	6.15	55.7	244
018	Hatigarh Chariali	DTW	3.5	8.1	24.3	6.6	1.48	–	1.13	5	170	1.1	6.86	42.1	224
022	Narengi	DTW	26.5	26.1	32.8	12.0	0.05	0.09	1.07	106	155	112.3	6.44	173.6	154
023	Birkuchi	HT	2.4	0.2	84.2	6.2	0.32	0.08	6.88	9	265	2.4	4.63	7.0	176
025	Narengi	HT	4.1	2.2	99.9	6.6	0.78	0.01	4.67	7	245	4.7	5.44	19.1	220
040	Saatgaon	HT	1.5	2.5	63.2	6.6	2.16	0.01	2.75	7	155	13.3	7.24	13.8	249
041	Saatgaon	DTW	9.4	5.0	74.4	6.1	0.12	0.03	2.25	52	1610	1.1	5.72	43.8	205
044	Kalyan kuchi	HT (PH)	6.3	5.7	82.0	7.1	3.09	0.05	2.00	5	205	8.0	5.20	39.0	259
076	Kalapahar	HT (PH)	8.3	12.8	65.2	3.1	0.37	0.03	0.35	120	530	113.5	5.87	73.6	56
084	Lalganesh	HT	11.0	13.0	33.5	3.6	0.49	0.08	0.90	9	160	5.0	8.34	81.1	317
089	Saukuchi	DTW	6.9	5.7	56.4	6.2	0.16	0.06	3.75	7	215	1.0	8.76	40.7	215
103	Beltola Chariali	HT	6.3	6.8	31.2	3.3	3.16	–	1.00	5	175	6.0	7.19	43.7	171
124	Sixmile	HT	16.9	10.6	36.6	4.1	–	1.97	2.20	–	120	210.3	4.68	85.9	34
131	Sixmile	DTW	5.9	4.1	42.8	10.9	0.17	0.44	4.31	8	130	10.3	4.39	31.7	215
197	Birkuchi	HT (PH)	7.9	8.4	31.9	5.7	4.23	0.04	1.11	9	275	1.0	6.96	54.4	259
198	Birkuchi	HT	9.2	10.6	30.6	5.9	0.75	0.23	1.50	9	325	0.8	6.63	66.4	268
200	Saatgaon	DTW	8.0	7.0	97.0	6.1	0.17	0.05	2.50	7	150	1.1	7.30	48.6	322
202	Saatgaon	DTW	6.5	3.2	54.3	4.5	1.49	0.32	4.40	9	150	2.5	9.07	29.3	317
204	Bagharbari	DTW	5.9	5.7	41.7	6.7	0.04	0.04	1.50	7	125	1.3	4.82	38.3	229
209	Rukminigaon	HT (PH)	6.9	5.4	40.8	5.2	1.70	0.05	1.65	7	150	3.6	6.39	39.7	220
217	Hatigaon	HT (PH)	8.3	7.4	32.9	3.5	0.01	0.04	1.13	5	135	3.0	7.26	51.2	229
219	Hatigaon	DTW	9.0	7.3	37.2	4.8	0.02	0.06	1.08	9	130	4.0	6.00	52.3	244
234	Dipar Bil	Lake	10.0	7.3	28.6	10.4	0.72	–	0.42	31	370	2.2	3.78	55.2	151
235	Brahmaputra	River	10.4	5.7	4.5	1.2	0.25	–	0.18	3	175	1.2	4.45	49.6	88
WHO guideline values[11]			–	–	200	–	0.3	5	1.5	250	400	45	–	500	–

HT, Hand tube well; PH, Provided by Public Health Engineering Department; DTW, Deep tube well.

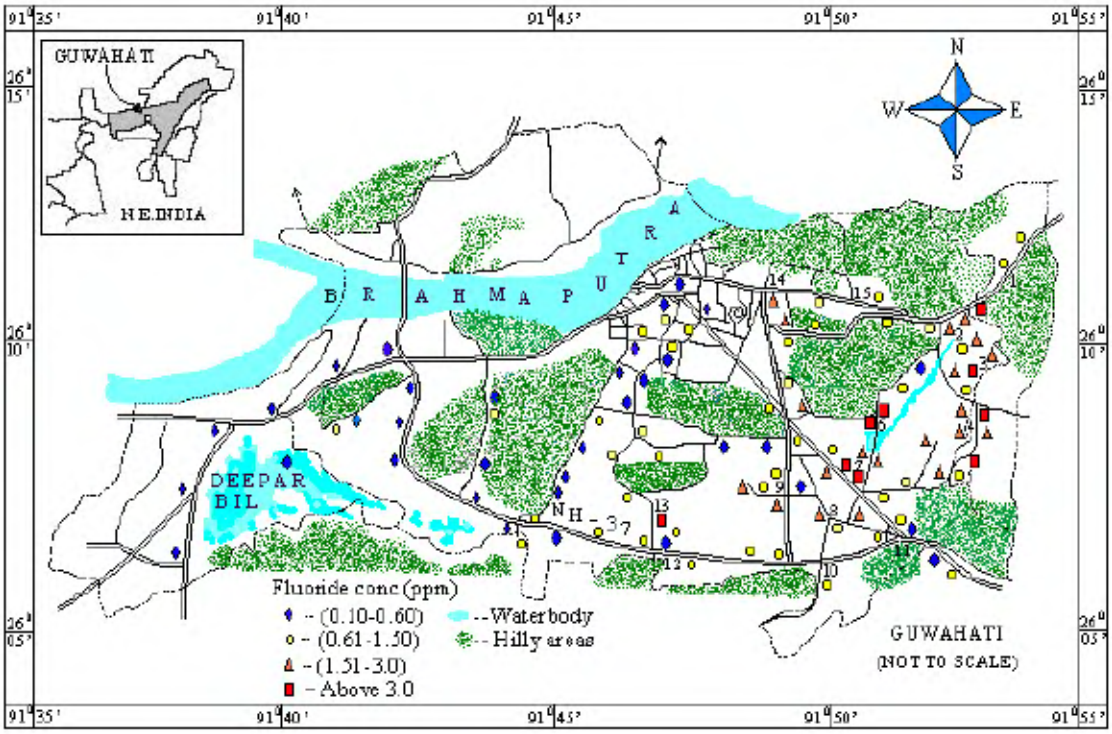

Figure 1. Map showing the distribution of fluoride in Guwahati. Location of fluoride-affected areas: 1, Bonda; 2, Narengi; 3, Birkuchi; 4, Saatgaon; 5, Boidangbori; 6, Hengerabari; 7, Sixmile; 8, Beltola; 9, Hatigaon; 10, Bashistha; 11, Khanapara; 12, Lokhra Chariali; 13, Saukuchi; 14, Chandmari; 15, Noonmati and 16, Mathgharia.

is interesting to note that the fluoride concentration of the groundwater in this area gradually decreases from the east towards the west. The groundwater samples of the western part of Guwahati are mostly deficient in fluoride content. This indicates that the source of fluoride is present in the eastern part of the southeastern plains. The fluoride in the groundwater of the western part of the city is probably diluted by the Brahmaputra, where the fluoride concentration has been found to be 0.18 ppm (0.116 ppm, ref. 12). The approximate depth of the sources of the samples shows a positive correlation with the fluoride concentration (Figure 2). This indicates the source of fluoride to be fluorite or (and) apatite minerals present in the Precambrian granite or granitic-gneiss of the underground basement[13,14]. Occurrence of high fluoride in groundwater of other areas adjacent to Guwahati can be noted here[3,15]. High fluoride level in groundwater has been reported in Darrang[15] (to the northeast of the city), Nagaon[3] and Karbi Anglong districts[3] (both to the east of the city). It is also interesting to note that the entire fluoride-affected region is in the same geological set-up[13]. The municipal wastewater of the city, however, was reported to be free from fluoride contamination[16], which is probably due to dilution by rainwater and municipal water supplied from the Brahmaputra.

The correlation of some select ions and other parameters with fluoride is shown in Figure 3. The alkaline earth metal ions, viz. Mg^{2+} and Ca^{2+}, and the total hardness showed clear negative correlation with fluoride content. The correlation coefficients were – 0.548, – 0.391 and – 0.506, respectively. Negative correlation of fluoride with Mg^{2+} and Ca^{2+} is as expected due to low solubility of fluorides of these ions[14,17–19]. It can be noted here that the groundwater of the fluoride-contaminated area of Guwahati is known to be largely soft. However, Chakraborti *et al.*[3] reported positive correlation of fluoride with Ca^{2+} in groundwater in parts of Nagaon and Karbi Anglong districts of Assam. The positive correlation observed by these authors may be attributed to the presence of limestone in those areas[13]. The alkali metal ions, viz. Na^+, K^+ and total alkalinity showed positive correlation with fluoride content, with correlation coefficient (r) of 0.606, 0.229 and 0.214, respectively. A positive correlation of fluoride with Na^+ in groundwater of a nearby area, viz. parts of Nagaon and Karbi Anglong districts of Assam was also reported by Chakraborti *et al.*[3].

In most of the samples, the iron contents were much above the guideline value of WHO. The iron content did not show any correlation with fluoride. Similarly, three of the samples, one each from three different places, viz. Narengi, Kalapahar and Sixmile, were found to contain alarmingly high concentrations of nitrate and did not have any correlation with fluoride. In the absence of the possibility of nitrate contamination due to fertilizer in these locations, the same can be attributed to minerals from the basement[20]. These samples were moderately hard and had moderately high Cl^- content. Cl^- also did not show any correlation with fluoride content, ruling out evaporation as a reason for high fluoride content[21]. One sample drawn from Saatgaon and the one from Sixmile containing high nitrate showed high SO_4^{2-} content. The presence of fluoride in the groundwater of the area necessitates a study of the presence of other toxic elements, since certain toxic elements, like arsenic, boron, etc. have been reported to show positive correlation with fluoride[17].

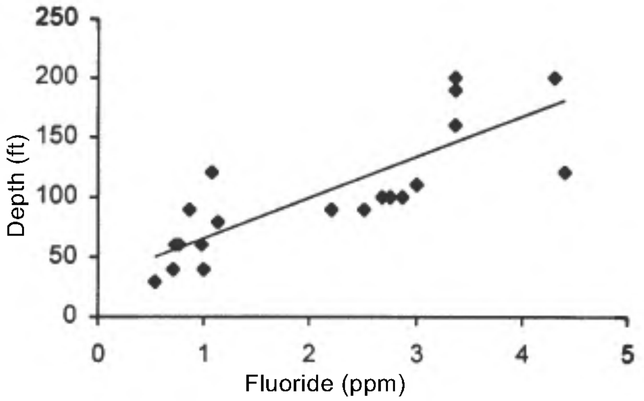

Figure 2. Correlation of depth of source with fluoride concentration in selected groundwater samples. Solid line indicates trend.

Table 2. Distribution of fluoride in groundwater in different areas of Guwahati

Area	Location	Total number of samples	Percentage of samples in different ranges of fluoride content (ppm) 0.1–0.6	0.6–1.5	1.5–3.0	> 3.0
Entire city	–	235	45.5	43.8	6.0	4.7
Southeast plains	Bonda, Birkuchi, Narengi, Chandmari, Mathgharia, Noonmati, Saatgaon, Hengerabari, Sixmile, Boidangbori, Khanapara, Beltola, Hatigaon, Bashishta, Saukuchi, Lokhra Chariali	127	27.5	52.8	11.0	8.7
Eastern part of southeast plains	Bonda, Birkuchi, Narengi, Chandmari, Saatgaon, Hengerabari, Sixmile, Panjabari	71	28.2	39.4	18.3	14.1

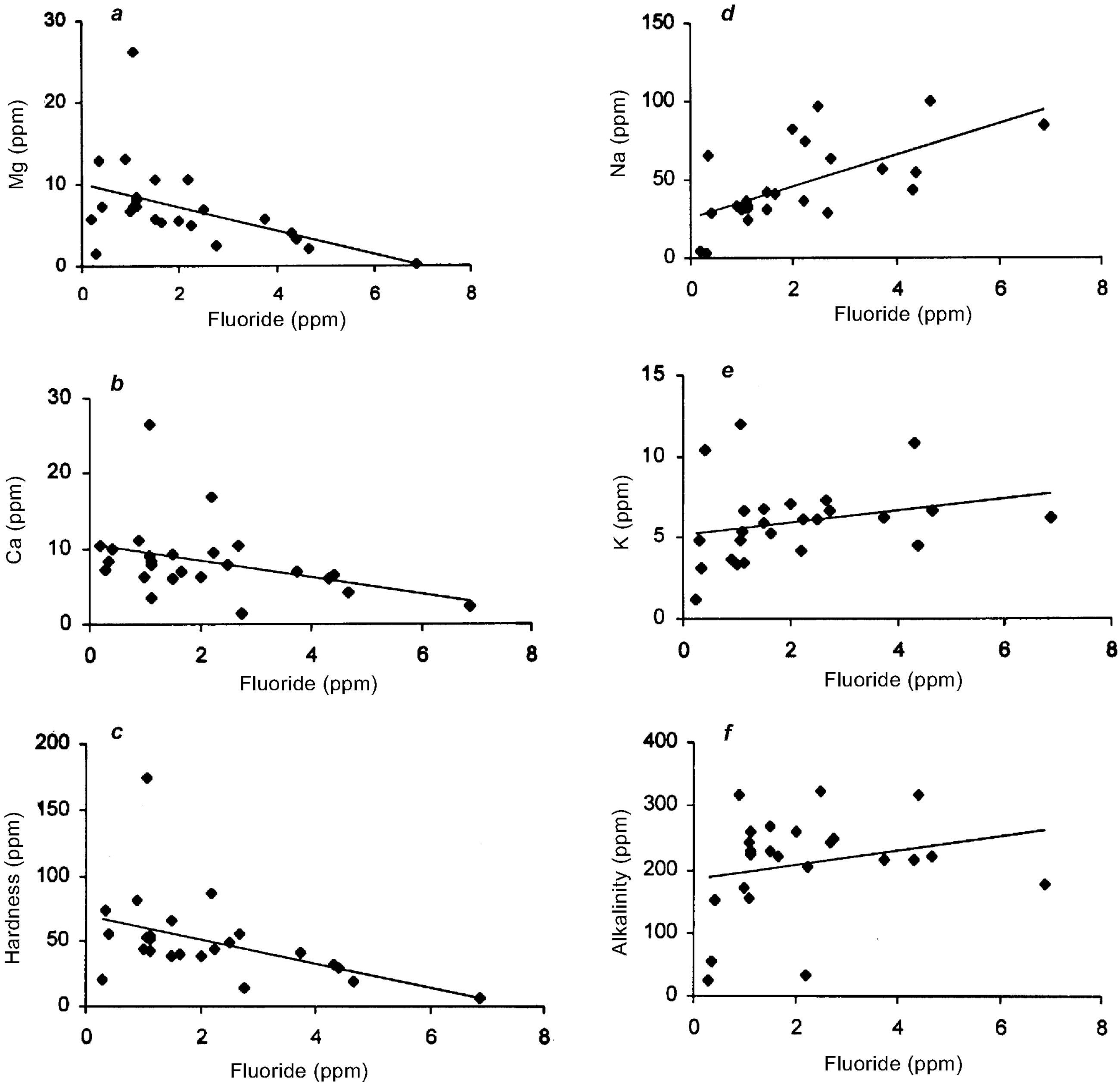

Figure 3. Variation/correlation of different ions and other parameters with fluoride concentration in selected groundwater samples: (***a***) Mg^{2+} vs F^-, (***b***) Ca^{2+} vs F^-, (***c***) Hardness vs F^-, (***d***) Na^+ vs F^-, (***e***) K^+ vs F^-, (***f***) Total alkalinity vs F^-. The solid lines indicate trends.

Although fluoride contents beyond the guideline values of WHO have been found in a large number of samples, no report of fluorosis from the area has been known till date. There may be two reasons for this. First, most of the residents of the area use shallow dug wells or hand tube wells. The number of users of deep tube well is relatively smaller, and they are economically well-off and healthier[2,3].

Keeping in view the unusual high concentrations of the harmful ions, viz. fluoride, nitrate, etc., it is advisable to test the potability of groundwater of at least the eastern part of Guwahati before using it for drinking. For the city of Guwahati, urban water supply from the adjacent river, the Brahmaputra, could be a better alternative than attempting high-cost and less-effective fluoride removal processes.

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Implications of transverse fault system on tectonic evolution of Mainland Kachchh, western India

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The tectonic evolution and seismic phenomenon of Kachchh region have been attributed to differential movement along the E-W trending master faults. However, a NW-SE to NE-SW transverse fault system also exists which cuts across the E-W tectonic fabric of Kachchh. The present study attempts to delineate the role of transverse faults in pre-Quaternary and Quaternary tectonic evolution of Mainland Kachchh based on a regional scale geomorphic study. Significance of these transverse faults in the tectonic evolution of Kachchh is obvious as they laterally displace the large E-W faults and the domal structures associated with them. The Kachchh Mainland Fault (KMF) and the Katrol Hill Fault (KHF) are the two major E-W trending master faults of Mainland Kachchh which show distinct offsets along transverse faults. Geomorphic evidences of strike slip movement along the transverse faults affecting the KMF and KHF are seen in the form of displacement of major fault scarps, beheaded/deflected or offset drainage, sags, shutter ridges and pressure ridges. The observed amount of offset along the transverse faults ranges from a few hundreds of metres to several kilometres, which includes a pre-Quaternary as well as a Quaternary component. It is suggested that a part of the stresses being accumulated on the E-W trending faults is being possibly transmitted to the NW-SE to NE-SW transverse faults, which may account for the present seismic phenomenon in Kachchh. However, detailed mapping of the transverse fault system, followed by detailed geomorphic and palaeoseismic studies are needed to understand the role of transverse faults in generating seismic activity in Mainland Kachchh.

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THE lack of understanding of the seismic phenomenon of the Kachchh region as a whole can partly be attributed to inadequate data on fault systems and Quaternary tectonic activity along them. In general, the seismic instability of the area has been attributed to the E-W trending fault system, which includes among others, the Kachchh Mainland Fault (KMF) and the Katrol Hill Fault (KHF; Figure 1 *a* and *b*). The KMF and the KHF are the two major E-W trending faults which control the present tectonic framework and overall geomorphic configuration of the Mainland Kachchh[1,2]. These faults are not continuous, but appear to be laterally displaced by several NNE-SSW to NNW-SSE trending transverse faults. The role of these transverse faults in the tectonic evolution of Mainland Kachchh is not yet known. Here, we present some evidence on the possible implications of the transverse faults on tectonic evolution and seismicity based on a regional-scale geomorphic study carried out along the KMF and the KHF. The study reveals that tectonic activity along the transverse faults is intricately linked with the tectonic evolutionary history of Mainland Kachchh in pre-Quaternary and Quaternary times as well.

The KMF is a significant tectonic feature with a long history of reactivation closely connected with the tectonic evolution of the Kachchh basin[1,2]. The general trend of the fault is E-W while in the western part, it trends in WNW-ESE direction (Figure 1 *a*). The fault forms a spectacular geomorphic feature with north-facing steep fault scarps that separate the Banni-Rann region to the north and a highly rugged topography of the Mainland Kachchh to