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Fluoride concentration in river waters of south Asia

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Fluoride levels in various types of environmental samples show wide variations from a low of 1.2 µg/m^3 in the air samples over Delhi to a very high value of over 18,000 µg/l in a hot spring in the Western Ghats region, due to which the surface water samples in the mountain streams generally show higher F levels. Large rivers with large run-off show higher levels of fluoride and hence greater fluoride flux to the oceans. Higher fluoride exposures due to enhanced application of rock phosphates adversely affect the health of our aquatic environment, in addition to decreasing the per capita availability of safe drinking water.

WATER availability is a critical factor in socio-economic development, limiting progress in many areas such as south Asia and other arid and semi-arid zones. In most parts of the world, the finite supply of freshwater is put to heavy use[1]. Industrial wastes, sewage and agricultural run-off can overload rivers and lakes with chemicals, wastes and nutrients, and poison water supplies. At present, the annual freshwater consumption is around 4000 km^3 throughout the world with India's consumption being just 10% of this value[2,3]. But the quantity of freshwater demand does not reflect the problems associated with water quality parameters such as hardness, fluoride, bacterial count and toxic metal content. In India, the arsenic-related problem in drinking water is already well known[4–6]. An estimated 62 million people, including 6 million children suffer from fluorosis because of consuming fluoride-contaminated (> 1000 ppb) water[7].

Fluoride is ubiquitous in the environment and is always present in plants, soils and phosphatic fertilizers[8]. Various rock types contain fluoride at different levels: basalt, 360 µg/g; granites, 810 µg/g; limestone, 220 µg/g; sandstone and greywacke, 180 µg/g; shale, 800 µg/g; oceanic sediments, 730 µg/g; and soils, 285 µg/g (ref. 9). The F concentration in the upper continental crust is 611 ppm (ref. 10). It is an essential constituent in minerals such as fluorite, apatite, cryolite, and topaz[11]. Whereas minerals such as biotite, muscovite and hornblende may contain large per cent of F (ref. 12) and therefore, would seem to be the main source of F in surface waters. It appears, therefore, that the F content of surface water is largely dependent on the mineralogical composition of the inorganic fraction in surface soils and sediments. Apatite may perhaps exchange some of its hydroxyl ions for fluoride following reaction of the type:

$$Ca_{10}(PO_4)_6(OH)_2 + 2F^{-1} = Ca_{10}(PO_4)_6F_2 + 2OH^{-1} \quad (1)$$

$$K = a^2OH^{-1}/a^2F^{-1} = 10^{6.6} \quad (2)$$

i.e. the process converts the hydroxyl apatite of bones and calcium phosphate into fluorapatite, where K is equilibrium constant and a is activity[13]. With increasing use of fertilizers[14] containing fluoride, the fluoride content of surface water also increases. Approximately 20 to 400 g F per hectare is annually leached from soils, about the same amount that is added to the soil from the atmosphere, but fertilizing adds another 5 to 30 kg F per hectare annually[15]. This fluoride accumulates in the soils. The main part of fluoride in rainwater may originate in sea aerosols: K_2SiF_6 (hieratite) and Na_2SiF_6 (malladrite), where tiny droplets of foam are caught up by the wind[16] and may be carried far from the ocean to continental areas. The F content of various continental precipitations shows a range of 4–89 ppb and in the vicinity of cities and industrial areas, an average of 290 ppb can be found[17]. The order of magnitude of the normal fluoride content in the air is < 0.01–0.4 µg/m^3 and in industrial areas up to 5–111 µg/m^3 from chemical

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plants producing HF, aluminium, super phosphate, brickwork and burning of low quality coal[17]. The aim of this paper is to analyse the natural freshwater quality deterioration with regard to fluoride and related constituents, phosphate and calcium; and the dissolved flux and rate of denudation of those parameters to the ocean.

For the major river basins in south Asia, water samples were collected at a number of stations. For each basin, one station in the watershed and the other in the river mouth (except for river Indus) were chosen. A 100 ml of water sample was collected in a polypropylene bottle and pH was measured immediately by a calibrated field pH meter. Another 100 ml duplicate sample was filtered through Millipore 0.45-micron membrane filter and the sample was preserved with $HgCl_2$ for phosphate analysis, sealed tight and sent to the laboratory. Water samples were collected during the monsoon and non-monsoon, 1998–99. In addition to 165 samples collected in this period, data from other sources for many systems (almost all the data are from our laboratory) that followed the same analytical technique were also used, thereby ensuring compatibility for comparison purposes. Calcium was analysed using GBC-902 double beam atomic absorption spectrophotometer (AAS). Fluoride concentration was determined by fluoride ion selective electrode method (Corning P602) using TISAB (total ionic strength adjustment buffer). Phosphate was determined by Cecil spectrophotometer (ascorbic acid method)[18]. Chemical standards and blanks were run and replicate analysis of each sample was done for each parameter and the variation was ± 5–10%. Blank (milli Q water) levels were below detectable limits. The fluoride in air was measured following the methodology of Khare *et al.*[19].

The mean fluoride concentration given in Table 1 varies from a low value of 1 $\mu g/m^3$ in air through 13 ppb in glaciers, 34 ppb in snow, 63 ppb in rain, 248 ppb in rivers, 310 ppb in lakes, 605 ppb in estuaries and to a high value of 7119 ppb for hot springs. Previous estimate of F level in Indian rivers shows high values[20,21] compared to the present study based on F ion selective electrode. The river water F concentration also varies with lithology of basin, from basaltic 156 ± 120 ppb to recent alluvium 177 ± 141 ppb to granite gneiss 244 ± 278 ppb F. Contributions of dissolved $P–PO_4$ from the Himalayan rivers show very high values (67 ppb) compared to east- and west-flowing rivers (45 and 19 ppb $P–PO_4$). The average dissolved $P–PO_4$ level in south Asian rivers is about 49 ppb and this is substantially greater than Meybeck's estimated dissolved $P–PO_4$ in world rivers, i.e. 25 ppb. Similarly, for the south Asian rivers the average Ca was 26 ppm, and the Himalayan rivers show 31 ppm Ca. The east- and west-flowing rivers show 26 and 14 ppm Ca. Khari, a non-perennial tributary to River Banas in Rajasthan shows 118 ppm Ca. In River Hooghly, Ca value is higher than the normal freshwater concentration, 13 ppm (ref. 22). A maximum of 115 ppm Ca, 0.5 ppm F and 0.6 ppm $PO_4–P$ was observed in River Hooghly (at Howrah) and a minimum of 55 ppm Ca, 0.3 ppm F and 0.2 ppm $PO_4–P$ was found at Kukrahati, downstream. This may be due to urban population and their domestic sewage. The river water fluoride, dissolved $P–PO_4$ and Ca concentration also vary on the basis of area catchment size, from major river basin through (271 ppb F, 55 ppb dissolved $P–PO_4$ and 30 ppm of Ca), medium river basin (189 ppb F, 26 ppb dissolved $P–PO_4$ and 10 ppm of Ca) to minor river basin (100 ppb F, 14 ppb dissolved $P–PO_4$ and 13 ppm of Ca). Whereas the analysis of estuarine water samples shows (salinity 3–34‰) an average of 605 ppb F, 381 ppb dissolved $P–PO_4$ and 276 ppm Ca, and a sample from the Indian Ocean (latitude 10°N: longitude 77°5'E) shows 771 ppb F and 537 ppm of Ca. The inconsistency of F (0.03–1.7 ppm) and Ca (49–550 ppm) concentration in estuaries was due to varying salinity. The minor and major dissolved components of seawater show (for a salinity of 35‰) 1000–1600 ppb F and 412 ppm Ca ion[22].

Based on the predicted solubility model for fluorite[23] (K = –10.41) the observed results show that the freshwater is not saturated with respect to the mineral fluorite. A hot spring (Unai near Surat) in the Western Ghats region shows super saturation with respect to the mineral fluorite (IAP/K = 1.6). There are a number of springs (e.g. Sahastradhara near Dehra Dun, IAP/K = –1.4) draining into several Himalayan rivers that could be the major source of dissolved fluoride in the (285 ppb F) Himalayan rivers.

The south Asian rivers with an annual discharge of 2108 km^3 transport 0.5×10^6 t flux of dissolved F, ~ 0.1×10^6 t flux of dissolved $P–PO_4$ and ~ 5×10^6 t flux of dissolved Ca per year to the ocean, with a solute erosion rate of 0.2 t F km^{-2} yr^{-1}, 0.04 t $P–PO_4$ km^{-2} yr^{-1} and 21 t Ca km^{-2} yr^{-1}. The maximum rate of F transport (~ 0.3 t km^{-2} yr^{-1}) was observed for the Himalayan rivers, which can be understood in terms of high discharge[24,25]. The major river basins transport ~0.3×10^6 t flux of dissolved F yr^{-1} at a flux rate of ~0.1 t km^{-2} yr^{-1}. Similarly, the medium and minor river basins transport ~ 2000 to 1000 t flux of dissolved F yr^{-1} at the flux rate of ~ 0.01 t km^{-2} yr^{-1}. The dissolved flux rate of transportation for the east- and west-flowing rivers is ~ 0.1 t km^{-2} yr^{-1}. The annual F loss per unit area of catchment correlates ($r^2 = 0.3$) with the catchment runoff (Figure 1). Table 2 summarizes F, $P–PO_4$ and Ca dissolved flux and solute erosion rate for the individual river basins of south Asia. Discharge plays an important role in regulating the river water chemistry. Generally, rivers with large areas have large discharge[26–34]. Hence, discharge also has a positive effect on dissolved flux, similar to catchment area (Figure 2). The variation in

Table 1. Average concentration of fluoride (ppb), phosphorous (ppb) and calcium (ppm) in river, estuary, glacier, lake, spring, rain water and air

Name	Major lithology	Rainfall, mm	pH	F	SD	P–PO$_4$	SD	Ca	SD	IAP/K	*n*
Dokriani stream[P]	Shale – gneisses	–	7.2	131	71	–	–	0.1	0.02	–5.5	6
River Alakannanda[P]	Shale – gneisses	1500	7.2	140	–	1	–	31	–	–3.0	1[#]
River Bhagirathi[P]	Shale – gneisses	1500	7.0	287	–	3	–	18	–	–2.6	1[#]
River Bandal (Song)[47,48]	Phosphorite	1500	8.1	1352	217	63	9	48	24	–1.0	23
River Ramganga[49,50]	Recent alluvium	1000	7.9	247	77	106	26	58	31	–2.4	19
River Yamuna[20,50]	Recent alluvium	750	7.6	183	29	111		35	4	–2.7	3
River Yamuna[P]	Recent alluvium	750	8.4	574	157	155	79	43	14	–1.6	11
Najafgarh canal (Yamuna)[51]	Recent alluvium	750	6.7	670	–	2155	–	28	–	–1.6	–
Shahdara canal (Yamuna)[51]	Recent alluvium	750	6.8	510	–	698	–	27	–	–1.9	–
River Banas (Khari Tributary)[P]	Calc shist	500	8.7	600	–	24	–	118	–	–1.1	1[#]
River Chambal[P]	Shale – gneisses	750	8.4	114	–	88	–	33	–	–3.1	3
River Gomti[49,52]	Recent alluvium	1000	8.3	269	35	97	64	30	5	–2.4	11
Gomti tributaries[52]	Recent alluvium	1000	8.4	332	43	46	18	29	3	–2.3	5
River Ghaghra[P]	Recent alluvium	1250	7.8	195	–	1	–	46	–	–2.5	1[#]
River Ghaghra[49]	Recent alluvium	1250	8.0	100	–	3	–	50	–	–3.1	–
River Sone[P]	Shale – gneisses	1000	7.6	284	–	35	–	26	–	–2.4	1[#]
River Sone[20,49,53]	Shale – gneisses	1000	7.6	60	87	52	47	22	13	–4.8	8
River Gandak[P]	Recent alluvium	1750	7.9	99	–	1	–	44	–	–3.1	1[#]
River Gandak[49,53]	Recent alluvium	1750	7.7	31	30	38	4	30	6	–4.6	9
River Kosi[53]	Recent alluvium	2500	7.6	18	5	35	9	19	4	–5.0	6
River Mahananda[20]	Recent alluvium	2500	7.1	212	38	–	–	17	6	–2.9	5
River Ganges[P]	Recent alluvium	1250	7.5	199	57	6	6	34	11	–2.7	6
River Ganges[20,49,53]	Recent alluvium	1250	7.7	151	85	27	8	31	9	–3.2	47
River Hoogly[54]	Recent alluvium	1500	8.5	383	87	12	4	103	27	–1.6	5
River Padma[55,56]	Recent alluvium	1500	7.9	157	67	–	–	28	8	–3.0	5
River Padma[P]	Recent alluvium	1500	7.9	217	–	2	–	59	–	–2.3	1[#]
River Brahhmaputra[57]	Recent alluvium	2250	7.6	116	41	22	10	21	10	–3.4	49
G-B conf.[P]	Recent alluvium	2500	8.0	113	–	7	–	42	–	–3.0	1[#]
River Jamuna[P]	Recent alluvium	2000	8.1	67	–	3	–	26	–	–3.7	1[#]
River Megna[55,56]	Recent alluvium	2500	7.5	66	32	–	–	7	2	–4.4	6
Megna tributaries[55,56]	Recent alluvium	2500	7.6	64	40	–	–	7	2	–4.5	5
River Damodar[P]	Granite gneisses	1500	7.9	216	91	31	30	17	9	–3.0	9
River Subarnareka[P]	Granite gneisses	1500	8.3	393	–	155	–	20	–	–2.3	3
River Brahmani[58]	Granite gneisses	1500	6.9	159	114	15	9	7	2	–3.7	8
River Mahanadi[59,60]	Shale – gneisses	1750	7.7	13	4	2	1	20	5	–5.3	16
Mahanadi tributaries[59,60]	Shale – gneisses	1750	7.5	13	5	3	1	26	9	–5.2	8
River Manjira[P]	Basalt and gneisses	750	8.7	110	27	73	12	39	–	–3.6	2
River Pranhita[P]	Granite gneisses	1000	8.4	184	112	99	25	28	10	–3.0	14
River Godavari[P]	Basalt and gneisses	1000	8.6	175	194	68	37	20	5	–3.4	16
River Thungabhadra[61]	Granite gneisses	875	8.1	238	23	32	31	20	7	–2.7	11
River Krishna[62,63]	Granite gneisses	875	7.6	324	114	25	7	31	6	–2.3	10
Krishna tributaries[62]	Basalt	875	7.5	393	148	28	4	25	6	–2.2	6
River Pennar[P]	Granite gneisses	875	8.3	345	33	32	14	15	3	–2.5	2
Stream Kaleru (Pulicat)[P]	Granite gneisses	1000	7.6	212	4	9	–	23	–	–2.7	2[#]
Stream Araniar (Pulicat)[P]	Granite gneisses	1000	6.8	62	22	14	–	66	–	–3.4	2[#]
Stream Kalangi (Pulicat)[P]	Granite gneisses	1000	7.1	109	64	16	–	36	–	–3.2	2[#]
River Cauvery[64]	Granite gneisses	875	7.6	239	166	50	34	26	8	–2.8	21
Cavery tributaries[64]	Granite gneisses	750	7.8	351	340	69	57	26	12	–2.7	10
River Vaigai[P]	Granite gneisses	750	7.7	1364	953	60	–	27	7	–1.2	3
River Tamirabarani[P]	Granite gneisses	750	8.0	108	69	18	–	12	–	–3.7	4
River Kallada[65]	Granite gneisses	2500	6.9	72	7	12	20	5	21	–4.7	6
River Achenkovil[65]	Granite gneisses	2500	7.2	75	21	26	16	3	1	–4.6	4
River Pamba[65]	Granite gneisses	2500	7.1	89	52	19	18	2	1	–4.7	8
River Manimala[65]	Granite gneisses	2500	7.0	84	50	18	1	2	1	–4.8	5
River Muvatupuzha[65]	Granite gneisses	2500	7.4	50	14	15	7	3	0.2	–4.9	2
River Periyar[65]	Granite gneisses	2500	7.6	110	64	20	12	2	1	–4.5	7
River Chalakudi[65]	Granite gneisses	2500	7.0	120	28	13	–	2	0.5	–4.3	2
River Bharatpuzha[65]	Granite gneisses	2500	7.7	208	103	27	21	13	6	–3.1	6
River Kadalundi[65]	Granite gneisses	2500	7.7	70	–	10	–	3	–	–4.6	1
River Chaliyar[65]	Granite gneisses	2500	7.5	114	49	25	10	5	4	–4.1	9
River Kalinadi[P]	Granite gneisses	2500	6.9	18	–	1	–	6	–	–5.5	1

Contd…

Table 1. (*Contd…*)

River Kalinadi[20]	Granite gneisses	2500	7.0	176	60	–	–	21	8	–3.0	7[#]
River Mandavi[P]	Granite gneisses	2500	7.6	26	–	1	–	7	–	–5.1	1[#]
River Zuari[P]	Granite gneisses	2500	7.1	30	7	1	–	5	–	–5.1	2[#]
River Purna[P]	Basalt	875	8.0	155	64	22	14	40	26	–2.9	3
Tapti triputaries[P]	Basalt	1000	8.1	265	74	3	1	37	6	–2.4	4
River Tapti[P]	Basalt	1250	7.9	204	54	12	1	25	11	–2.8	6
River Narmada[P]	Basalt	1250	8.2	119	41	3	3	27	9	–3.2	5
Narmata tributaries[P]	Basalt	1000	7.7	256	223	3	1	33	11	–2.7	7
River Mahi[66]	Shale – gneisses	875	8.0	396	97	7	2	19	1	–2.3	5
River Sabarmati[P]	Shale – gneisses	875	8.4	363	6	179	21	23	14	–2.3	5
River Sutlej[20]	Recent alluvium	1000	7.5	120	–	–	–	43	–	–3.0	–
River Beas[20]	Recent alluvium	1000	7.3	110	–	–	–	22	–	–3.3	–
River Ravi[20]	Granite gneisses	1500	7.4	100	–	–	–	40	–	–3.1	–
River Indus[20]	Granite	600	7.6	150	–	49	–	29	–	–2.9	–
Dokriani snow[P]	–	–	7.2	34	3	–	–	0.1	0.01	–6.6	2
Dokriani glacier[P]	–	–	7.0	21	6	–	–	0.1	0.02	–7.2	2
Chhota-Shigri glacier[67]	–	–	–	5	1	–	–	0.1	0.03	–8.2	37
Sahastradhara (spring)[P]	Older alluvium	1500	7.3	294	–	0.5	–	258	–	–1.4	1
Gundala hotspring[21]	Granite gneisses	–	–	3000	–	(near to river Godavari)		–	–	–	–
Unai hotspring[P]	Granite gneisses	1500	7.4	18063	9414	1	1	95	14	1.6	4
Hoogly estuary (13‰)[54,68]	Recent alluvium	1500	8.2	498	191	15	2	175	108	–1.2	8
Mahanadi estuary (27‰)[59]	Coastal alluvium	1500	8.1	33	1	1	–	389	35	–3.1	2
Godavari estuary (34‰)[P]	Coastal alluvium	1000	8.3	1700	–	85	–	460	–	0.4	1[#]
Krishna estuary (5‰)[63]	Coastal alluvium	1000	8.3	889	405	4	2	49	34	–1.7	14
Ennore estuary (34‰)[P]	Coastal alluvium	750	6.8	830	12	9	–	318	–	–0.4	2
Adyar estuary (3‰)[69]	Granite gneisses	750	7.5	431	64	3204	1974	423	386	–1.0	7
Cavery estuary (5‰)[70]	Recent alluvium	1000	8.0	496	323	72	51	149	131	–1.6	26
Pichavaram mangrove (27‰)[71]	Recent alluvium	1000	7.8	333	–	91	–	208	–	–1.4	17
Vellar estuary (29‰)[71]	Recent alluvium	1000	7.7	324	–	75	–	550	–	–1.0	5
Coleroon estuary (14‰)[71]	Recent alluvium	1000	7.9	230	–	98	–	182	–	–1.8	3
Cochin backwater (8‰)[72]	Coastal alluvium	2500	7.4	365	71	83	68	274	25	–1.2	3
Kalinadi estuary (18‰)[P]	Coastal alluvium	2500	7.8	356	66	2	1	281	72	–1.2	6[#]
Mandavi estuary (30‰)[P]	Coastal alluvium	2500	7.7	471	182	7	1	319	115	–1.0	5[#]
Zuari estuary (32‰)[P]	Coastal alluvium	2500	7.7	604	155	23	5	437	89	–0.6	4[#]
Kelambakkam[73,74]	Salt farm water	–	7.9	309	39	132	–	1201	622	–1.3	53
Vedaranyam[73,74]	Salt farm water	–	7.9	146	92	137	–	609	209	–1.9	11
Lake Pulicat (33‰)[P]	Recent alluvium	1000	7.1	470	16	2	–	396	–	–0.8	2[#]
Indian Ocean[P]	–	–	7.4	771	–	9	–	537	–	–0.2	1
Lake Kolleru[75,76]	Recent alluvium	1000	7.8	758	195	1145	792	262	161	–0.7	40
Lake Vembanad[72]	Recent alluvium	2500	6.4	45	6	37	23	3	1	–4.9	4
Lake Puskar[P]	Recent alluvium	600	7.8	400	346	169	27	59	33	–2.0	3
Arain pond (Rajasthan)[P]	Recent alluvium	600	7.9	200	–	106	–	21	–	–2.8	–
Kekri pond (Rajasthan)[P]	Recent alluvium	600	8.2	400	–	168	–	59	–	–1.8	–
Jorhat, Assam (lake)[P]	Shale – gneisses	2500	8.5	55	–	10	–	18	–	–4.0	–
New Delhi (air) (μg/m^3)[P]	–	–	–	0.3	–	–	–	0.01	–	–	–
Agra air (μg/m^3)[19]	–	–	–	1.2	–	–	–	0.01	4	–	–
Agra (rainwater)[77]	–	750	6.8	63	54	–	–	0.4	0.2	–5.8	16
Himalayan rivers[P]	Shale – gneisses	1500	7.8	285	371	67	176	31	31	–3.0	250
East-flowing rivers[P]	Granite gneisses	875	7.9	244	278	45	79	26	12	–3.2	164
West-flowing rivers[P]	Basalt	2000	7.5	156	120	19	36	14	14	–3.7	97
Major river basin[P]	Various lithology	–	7.8	271	319	55	140	30	25	–3.0	408
Medium river basin[P]	Various lithology	–	7.6	189	331	26	22	10	10	–3.8	65
Minor river basin[P]	Various lithology	–	7.1	100	65	14	10	13	17	–4.2	38
South Asian rivers[P]	Various lithology	–	7.8	248	312	49	128	26	24	–3.2	511
World average for rivers[35,36]	Various lithology	–	6.1	152	–	8	–	15	–	–3.2	–
Indian estuaries[P]	Coastal alluvium	–	7.9	605	702	381	1179	276	181	–1.1	64
Mean glacier	–	–	7.0	13	4	–	–	0.1	–	–7.7	39
Mean hot spring	–	–	7.4	7119	–	1	–	176	–	0.1	–
Mean lake	–	–	7.8	310	–	273	–	70	–	–2.7	–
Mean air	–	–	–	1	–	–	–	0.01	–	–	–

*P, present study; ‰, Salinity; #, Sampled monsoon only.

Table 2. Amount of dissolved flux and solute erosion of fluoride, phosphorous and calcium in south Asian rivers

River	Discharge#,** (km^3 yr^{-1})	Area#,** (km^2)	Run-off (mm yr^{-1})	Dissolved flux (t yr^{-1})			Solute erosion rate (t km^{-2} yr^{-1})		
				F	P–PO$_4$	Ca	F	P–PO$_4$	Ca
Vaigai	0.7	6348	110	955	42	19133	0.15	0.007	3
Tamirabarani	0.8	4761	168	87	14	9920	0.02	0.003	2
Manjira	4.1	21694	189	451	301	159900	0.02	0.014	7
Sabarmati	4.1	21674	189	1488	733	92696	0.07	0.034	4
Chambal	4.8	23025	208	547	421	157440	0.02	0.018	7
Indus	73.3	321289	228	10995	3584	2129960	0.03	0.011	7
Gomti	7.4	30437	243	1991	719	225364	0.07	0.024	7
Cauvery	21.4	87900	243	5105	1063	550286	0.06	0.012	6
Sutlej	14.6	57000	256	1752		629058	0.03		11
Krishna	67.8	258948	262	21967	1702	2122004	0.08	0.007	8
Tapti	18.4	65145	282	3754	227	453333	0.06	0.003	7
Thungabhadra	9.4	28180	334	2241	297	189624	0.08	0.011	7
Mahi	11.8	34842	339	4673	84	221887	0.13	0.002	6
Padma	350.5	980000	358	76059	788	20748955	0.08	0.001	21
Yamuna	131.7	366233	360	75617	20437	5706159	0.21	0.056	16
Subarnareka	10.8	29196	370	4240	1675	220320	0.15	0.057	8
Godavari	119.0	312812	380	20825	8074	2424625	0.07	0.026	8
Narmada	41.3	98796	418	4895	131	1113304	0.05	0.001	11
Pranhita	43.0	100000	430	7910	4259	1206270	0.08	0.043	12
Sone	31.8	71200	447	9031	1123	819532	0.13	0.016	12
Ramganga	15.2	32400	469	3760	1612	877772	0.12	0.050	27
Mahanadi	66.9	141589	472	836	156	1308731	0.01	0.001	9
Damodar	9.8	20000	490	2112	305	165184	0.11	0.015	8
Ravi	7.7	14442	533	770		308617	0.05		21
Ganges	525.0	861404	609	104475	3075	17812053	0.12	0.004	21
Hoogly	493.0	750000	657	188645	5786	50779000	0.25	0.008	68
Brahmani	36.2	51822	699	5747	561	240278	0.11	0.011	5
Beas	14.7	20303	724	1617		324048	0.08		16
Ghaghra	94.4	127000	743	18408	105	4328383	0.14	0.001	34
Gandok	52.2	64300	812	5168	58	2284656	0.08	0.001	36
Bharatpuzha	5.1	6186	824	1063	139	66555	0.17	0.022	11
Periyar	4.9	5398	908	539	96	11830	0.10	0.018	2
Kosi	57.2	62000	923	1039	1989	1105867	0.02	0.032	18
Chalakudi	1.6	1704	939	192	21	2960	0.11	0.012	2
Kadalundi	1.1	1122	980	77	11	3520	0.07	0.010	3
Kalinadi	3.7	3750	987	68	4	21748	0.02	0.001	6
Achenkovil	1.5	1484	1011	113	39	4125	0.08	0.026	3
Jamuna	654.5	580000	1128	43852	2217	17287125	0.08	0.004	30
Pennar	67.8	55213	1228	23419	2178	1049037	0.42	0.039	19
Pamba	3.4	2235	1521	302	65	6885	0.14	0.029	3
Manimala	1.6	847	1889	134	29	3040	0.16	0.034	4
Megna	151.5	80000	1894	10074		996840	0.13		12
Kallada	3.4	1699	2001	244	41	18360	0.14	0.024	11
Chaliyar	5.9	2923	2018	675	145	29762	0.23	0.050	10
Muvatupuzha	3.6	1554	2317	180	53	10980	0.12	0.034	7
Brahhmaputra	537.2	194413	2763	62352	11810	11279829	0.32	0.061	58
Himalayan rivers	1605.5	1457106	1102	457941	107259	49350136	0.31	0.07	34
East-flowing rivers	391.4	948589	413	95354	17522	10080248	0.10	0.02	11
West-flowing rivers	111.4	249359	447	17326	2078	1554975	0.07	0.01	6
Major river basins	1140.6	2580000	442	308570	62840	33800500	0.12	0.02	13
Medium river basins	11.2	240000	47	2121	294	115657	0.009	0.0012	0.5
Minor river basins	12.7	200000	64	1266	182	162313	0.006	0.0009	1
South Asian rivers	2108.3	2655054	794	522506	103426	54871582	0.20	0.04	21
World total	40856*	101000000*	405	6210112	332976	612840000	0.06	0.003	6

**ref. 78; *ref. 35; #, ref. 26.

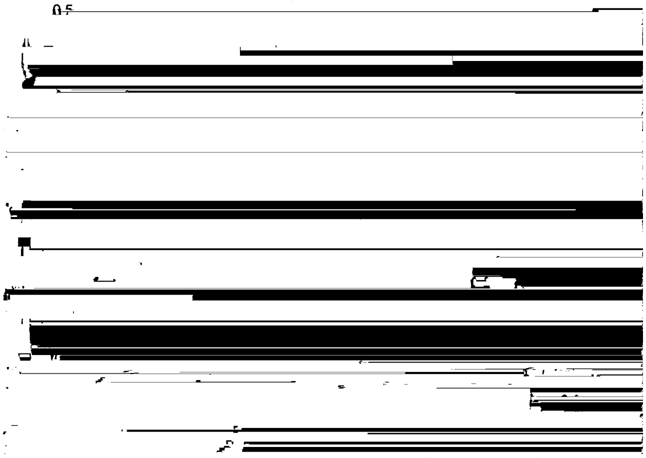

Figure 1. Relationship between area-specific annual fluoride exports by individual river basins in south Asia and their respective run-off.

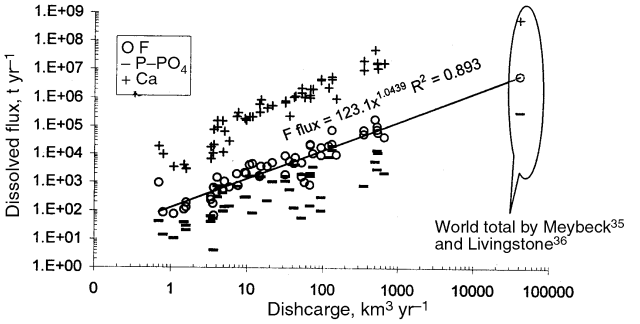

Figure 2. Relationship between discharge and dissolved flux in south Asia.

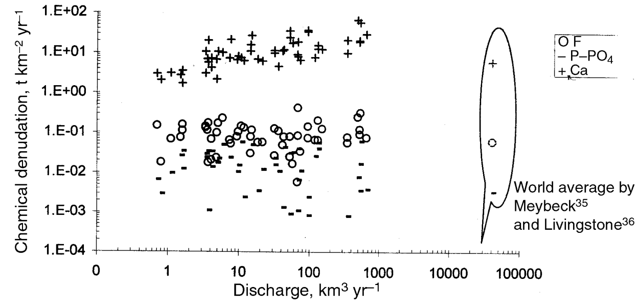

Figure 3. Variation in discharge vs solute erosion rate in south Asia.

discharge vs solute erosion for the individual river basins of south Asia is much similar than world average[35,36] for F and Ca, whereas dissolved P–PO$_4$ shows uneven distribution, perhaps may be due to the increase of non agricultural land use[37] (Figure 3). Estimated reserve of Indian rock phosphate[38] shows ~ 49×10^6 t P$_2$O$_5$ and the analysis of F content shows that rock phosphate carries an average of 1.8% shows ~ 7×10^6 t. The annual F exposure by consumption of rock phosphate in India[14] shows a growth rate of 2.7% and the annual mean dissolved oxygen (DO) in Indian rivers[2] declines at the growth rate of – 0.6% (Figure 4). The amount of DO present in water depends on the temperature, salinity and nutrients (N, P, Si)[39]. Nutrients and temperature stimulate algal blooms, which subsequently decompose, potentially robbing the bottom water of oxygen[40,41]. Depletion of DO in water supplies can encourage the microbial reduction of nitrate to nitrite and sulphate to sulphide, giving rise to hypoxia, a low oxygen condition that can be stressful or fatal to aquatic life[39]. Cities like Delhi drain enormous amounts of nutrient to River Yamuna, Najafgarh canal (2 ppm PO$_4$–P). The observed other eutrophicated rivers at downstream point are Sabarmati and Subarnareka (0.2 ppm PO$_4$–P). Agriculture run-off hastens the growth of wetland degradation and it was observed in Lake Kolleru (1 ppm PO$_4$–P). Similarly, untreated urban sewage degrading the estuarine environment was found in Chennai. The average concentration of PO$_4$–P at estuarine of Adyar shows 3 ppm. Therefore, freshwater and marine organisms are very sensitive to many human activities and dissolved nutrients can be used as good indicators of the state of water quality degradation[42]. The River Bandal (tributary) draining through Mussoorie phosphorite mine area to River Song shows 63 ppb PO$_4$–P. The observed results

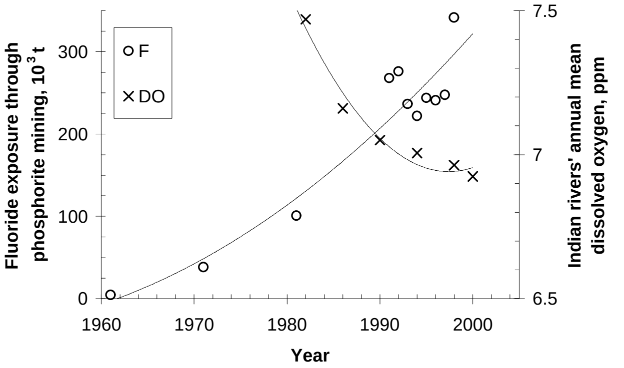

Figure 4. Relationship between year and F exposure to environment and river DO level in India.

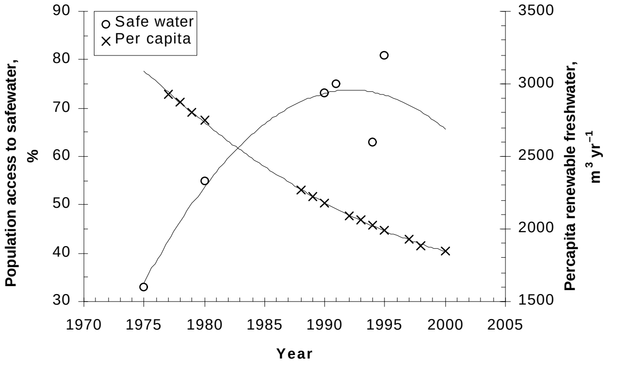

Figure 5. Relationship between year and Indian access to safe water and freshwater resources.

show that compared to PO_4–P, the F concentration was high, 1.4 ppm, because of the waste generated by the miners left near drains. Whereas the River Vaigai does not have any major fluorite deposit in catchment; a sample of monsoon at upstream shows 0.6 ppm F and a non-monsoon at downstream shows 2.4 ppm F, with an average of 1.4 ppm F. The normal rainfall over the region is 750 mm per year. Over 1 million people live at the downstream region (Madurai) and depend mainly on groundwater for domestic consumption. The waste water generated by them, is finally discharged through a number of canals, into the River Vaigai which is almost dry in the summer season. The majority of waste water is discharged into the recipients (rivers) without adequate treatment; the world total reaching to about 1500 $km^3 yr^{-1}$ (ref. 43). For efficient dilution of a cubic metre of untreated waste water, we need 8 to 10 m^3 of freshwater[44]. A simple calculation shows that the world freshwater resources are not sufficient to dilute the untreated waste water. Population access to safe water, with reference to F, As and microbial level is 73% in India[45], but the per capita annual renewable freshwater has been declining at the growth rate of – 2.0% (Figure 5). The total replenishable groundwater resource for India is about 431,884 M ha m per year, but the calculated average fluoride (2.8 ppm) comes well above the Indian prescribed limit of 1.0 ppm (ref. 46).

Most of the freshwater bodies in south Asia have no fluoride problems, except for specific locations in parts of Western Ghats region having enriched fluoride source. The annual fluoride loss due to soil erosion correlates well with run-off. Increasing fertilizer application also increases the fluoride availability to freshwater. This may adversely affect the health and availability of the renewable freshwater on per capita basis in the near future.

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Large scale Antarctic features captured by multi-frequency scanning microwave radiometer on-board OCEANSAT–1

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This paper discusses the features observed over the Antarctic in the passive microwave emission region by the multi-frequency scanning microwave radiometer (MSMR) instrument on-board the Indian remote sensing satellite IRS-P4, now called OCEANSAT–1. Brightness temperature images produced from MSMR show a clear distinction between open water and sea-ice-covered regions. It is also possible to differentiate several levels of ice concentration in the Antarctic Circumpolar Ocean. A number of land features like the Trans-Antarctic Mountain Ranges, part of Gamburtsev sub-glacial mountains, Wilkes and Aurora sub-glacial basins, etc. can be demarcated as well. The consistent quality and regular availability of MSMR data since June 1999 serve as a very useful tool in all-weather day-and-night monitoring of the Antarctic region. MSMR data used in continuation of ESMR, SMMR and SSM/I data, would prove valuable in the study of long-term changes in the polar cryosphere associated with global climate change.

ANTARCTICA, covering an area of 14 million km^2, with an average ice thickness of about 2–3 km, is an important component of the earth's climate system. The sea-ice extent over the Antarctic Circumpolar Ocean varies between 2 and 18 million km^2 from summer to winter, strongly influencing the Antarctic Ocean bottom water formation and thus modifying the physical, chemical and biological properties of the world's oceans[1,2].

The polar-ice plays an important role in the global climate system and is potentially a sensitive indicator of the effects of the global change. Both the land and the

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