tsunami wave in December 2004, the subsided and submerged part of the township got exposed for a while. This rare sight has been witnessed by the local fishermen community. The local inhabitants believed that coastal erosion was the main causative factor for the destruction and subsidence of the township in mid-twentieth century. The present marine geo-scientific observations, however, confirm a vertical movement parallel to the coastline with a displacement of ~5 m in the offshore segment (Figures 2 and 3), which actually led to the subsidence of the southern part of the township.

Such neo-tectonic movements at various places along the east coast of India have been reported[3–6]. Normally, neo-tectonic movements in the coastal zone may be discerned by the study of palaeo-strandlines. However, the area of study does not show any indication of such strandline positions, except a wide Aeolian belt along the coast. Under this scenario, other critical sets of data pertaining to near-shore bathymetry, side scan, sampling and underwater videography have provided valuable clues in support of the subsidence phenomenon through neo-tectonic activity. Usually it is not an easy task to confirm the evidence of Holocene faulting within the unconsolidated sediments. The present evidence of faulting off erstwhile Dhanushkodi township is documented with geo-scientific clues from offshore field evidences, and hence stands out as a unique study. The fault throw of ~5 m discerned in the study area may be only a surficial manifestation of a deep-seated and major faulting at depth, whose actual and destructive effect has not reached the surface. The faulting has understandably caused severe loss to the coastal zone, its inhabitants and their properties.

This event of subsidence along with field evidence of faulting does not warrant any dating method to prove the age of this faulting, because according to eyewitnesses and land-survey records, this geological event occurred during AD 1948–49. Most likely, this Dhanushkodi fault is the latest neo-tectonic movement ever recorded along the east coast of India.

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Occurrence of fluoride in the groundwaters of Pandharkawada area, Yavatmal district, Maharashtra, India

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Hydrogeological investigations have been carried out in the rural parts of Yavatmal district, Maharashtra, where agriculture is the main occupation. The area is mainly occupied by Deccan basalts, except in the southern part, where limestone and shale belonging to the Penganga Group occur. Groundwater occurs under unconfined conditions in the weathered and fractured portions of rocks, and semi-confined to confined conditions in fractured rocks. The groundwater of the area is of bicarbonate (HCO_3^-)-type and high fluoride (F^-) concentration is observed in deeper aquifers compared to shallow aquifers. Physicochemical conditions like decomposition, dissociation and subsequent dissolution along with long residence time might be responsible for leaching of F^- into the groundwater.

Keywords: Deccan basalts, groundwater, fluoride, rocks.

SOME elements are essential in trace amounts for human beings, while higher concentration of these elements causes toxic effects, and fluoride (F^-) is one of them[1]. Concentration of F^- between 0.6 to 1.0 mg/l in potable water protects tooth decay and enhances bone development[2,3]. Indian drinking water standards have suggested[3] permissible limit of F^- in drinking water at 1.0 mg/l, which is lower than the maximum tolerance limit (1.5 mg/l) of F^- in drinking

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water specified by WHO[4]. Ingestion of water with F^- concentration above 1.5 mg/l results in fluorosis.

The first case of fluorosis was detected[5] from Andhra Pradesh during early 1930s. Maharashtra is one among the States affected by endemic fluorosis[1]. In the present communicaton, we report high concentration of F^- (up to 13.41 mg/l) in the groundwaters of rural parts of Yavatmal district, Maharashtra (Figure 1).

Hydrogeochemical survey of the study area has been carried out during pre-monsoon of 2001. The area is of undulatory dissected plateau, with isolated hills having elevation of 220 to 340 m amsl. The general slope of the area is from north to south. River Penganga and its tributory Khuni drain the area. The drainage is sub-dendritic to dendritic and is ephemeral in nature. The Saikheda and Wai are the two irrigation projects located in the area.

Geologically, the study area is dominated by basaltic lava flows of Deccan Volcanic Province, except in the southern part, where limestone, sandstone and shale belonging to the Neoproterozoic Penganga Group occur. Penganga rocks are overlained by Upper Cretaceous Lameta Formation comprising cherty limestone, variegated sandstone and clay bands. Basaltic lava flows (Upper Cretaceous to Palaeogene) belonging to the Ajanta and Chikhli Formations of Sahyadri Group overlie the older formations. The flows are simple 'aa' and compound 'pahoehoe' types[6]. Quaternary alluvium and black cotton soils overlie the basalts.

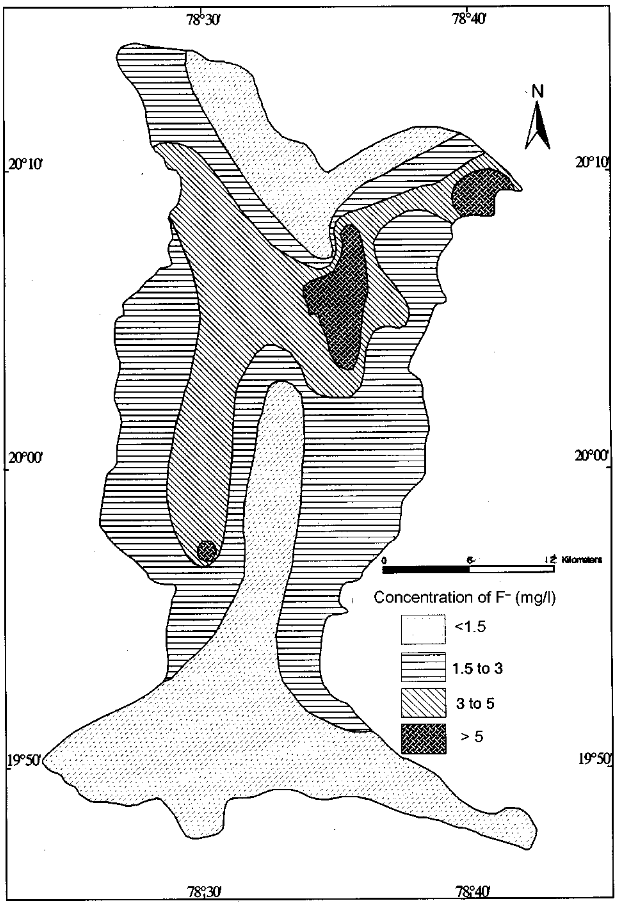

Figure 1. Distribution of F^- in groundwaters of the study area.

Groundwater occurs under phreatic conditions in the weathered zone, fractured and vesicular basalts (shallow aquifer) and under semi-confined to confined conditions in the fractured zone (deep aquifer). The depth to water level varies from 2 to 10.2 m below ground level (bgl) in shallow aquifers and from 21 to 50.50 m bgl in deeper aquifers. Rainfall is the main source of groundwater recharge.

Forty-four water samples from dug wells and bore wells in close proximity were collected for comparative study. Fluoride concentration along with other chemical parameters were analysed, using the standard chemical analytical techniques[7], and the results are presented in Table 1.

Groundwater from dug wells is neutral to moderately alkaline (pH 7.18–8.01), while that from bore wells is moderately alkaline to alkaline (pH 7.23–9.24; Table 1). The samples have electrical conductivity (EC) values in the range of 197 to 1780 μS/cm in shallow aquifers and 460 to 1740 μS/cm in deeper aquifers. The average calcium (Ca^{+2}) concentration from shallow and deep aquifers is in the range 24–206 and 6–96 mg/l respectively. Similarly, sodium (Na^+) concentration ranges from 12 to 128 and 21 to 353 mg/l in shallow and deep aquifers respectively. The concentration of chloride (Cl^-) in shallow and deep aquifers is within the permissible limits[3]. The F^- concentration ranges from 0.30 to 1.77 mg/l in shallow aquifers and from 0.90 to 13.41 mg/l in deeper aquifers. Groundwaters of the study area are of bicarbonate-type[8].

A comparison of F^- concentration of groundwaters between shallow aquifers (depth less than 20 m) and deeper aquifers (depth more than 40 m) from the same location has indicated that deeper aquifers have higher F^- concentration than shallow aquifers. This is in aggrement with earlier observations[9–11]. F^- concentration is within permissible limits in 95% of the samples collected from shallow aquifers compared to only 25% from deeper aquifers. Similarly, pH of groundwater from deeper aquifers is high compared to shallow aquifers, and increases with increase in F^- concentration (Figure 2 *a*). Fluoride and pH pair has positive correlation, indicating that higher alkalinity of the water promotes leaching of F^- and thus affects the concentration of F^- in the groundwaters[12].

An inverse relationship is found between F^- and Ca^{+2} (Figure 2 *b*). Decreasing Ca^{+2} concentrations are found under alkaline conditions, when Na^+ increases. This has also been observed by Handa[13] and Jacks *et al.*[14] in high F^- groundwaters from some parts of India. In the process of chemical weathering, as the mineral changes to montmorillonite phase, Na^+ is released into the groundwater that is supported by positive correlation between Na^+ and F^- (Figure 2 *c*). Positive relationship between F^- and HCO_3^-

Table 1. Chemical composition of groundwaters in the study area

Sample location	Source	pH	EC (µS/cm at 25°C)	TDS	Ca^{+2}	Na^{+}	CO_3^{-2}	HCO_3^-	Cl^-	F^-
				mg/l						
Chikhaldara	DW	7.33	197	128	206	70	–	421	301	0.48
	BW	7.94	750	488	28	105	–	403	35	1.21
Mohadari	DW	7.32	860	559	86	15	–	476	10.6	0.34
	BW	7.23	1440	936	96	27	–	506	128	0.95
Runjha	DW	7.59	1070	696	90	54	–	476	85	0.61
	BW	8.51	670	436	6	131	24	110	124	4.81
Khatara	DW	7.18	800	520	50	22	–	445	18	0.88
	BW	7.92	1270	826	34	220	–	250	227	3.03
Sonurli	DW	8.01	980	637	52	50	–	531	71	0.56
	BW	8.64	1520	988	14	300	12	37	415	7.22
Karanji (Phul Pod)	DW	7.70	590	384	64	22	–	372	18	0.56
	BW	8.60	700	455	6	139	18	116	131	2.45
Wadhona (Bk)	DW	7.76	900	585	42	22	–	506	14	0.58
	BW	8.39	910	592	16	177	6	92	195	5.76
Wadhona (Kh)	BW	8.54	830	540	10	163	12	73	170	5.75
Sakhi (Bk)	DW	7.60	800	520	54	20	–	458	14	0.64
	BW	7.45	800	520	22	21	–	476	11	0.98
Dharna	DW	7.60	840	546	48	19	–	464	28	0.58
	BW	9.13	1250	813	12	250	30	37	301	13.41
Sakhra	BW	9.24	1740	1131	22	353	18	18	574	11.9
Nilzai	DW	7.63	640	416	38	26	–	409	32	0.45
	BW	8.4	820	533	8	156	30	354	46	3.50
Ganeshpur	DW	7.70	610	397	34	20	–	433	14	0.78
	BW	7.38	860	559	48	62	–	317	92	2.84
Wai	DW	7.71	1320	858	60	33	–	525	81.5	0.47
	BW	8.1	740	481	10	124	–	293	67	3.02
Datpari	BW	7.72	930	605	46	127	–	262	124	2.91
Pimpri	DW	7.65	1780	1157	72	74	–	531	206	0.86
	BW	7.55	890	579	38	36	–	470	39	0.90
Gevrai Munch	DW	7.75	620	403	28	18	–	366	10.6	0.66
	BW	8.34	520	338	10	100	12	165	64	4.81
Marathwakdi	DW	7.8	950	618	36	53	–	512	60	0.72
	BW	7.85	1110	722	32	198	–	555	70	1.0
Dhoki	DW	7.50	1380	897	56	128	–	647	74	1.77
	BW	7.58	1060	689	64	104	–	610	17.7	1.09
Shushri	DW	7.76	800	520	24	18	–	451	10.6	0.55
	BW	8.54	880	572	10	157	24	110	149	5.95
Pendhari	BW	8.06	460	299	14	94	–	275	21	2.88
Tembhi	BW	7.48	950	618	16	46	–	567	7.09	1.58
Warha	BW	7.50	1380	897	56	128	–	647	74	1.77
Arli (Bk)	DW	7.65	640	416	30	38	–	323	32	0.61
Pimpershenda	DW	7.54	900	585	56	14	–	531	14	0.47
	BW	7.30	970	631	28	70	–	555	21.2	1.01
Karegaon	DW	7.59	700	455	28	12	–	390	18	0.30

BW, Bore well; DW, Dug well.

is observed in shallow aquifers, as the concentration of HCO_3^- is maximum, when the pH of water is less than 8.3 (Figure 2 *d*)[15–18]. Inverse relationship between F^- and HCO_3^- is noticed in deeper aquifers (Figure 2 *e*)[19,20]. This is because in highly alkaline water, carbonate (CO_3^{-2}) and hydroxyl (OH^-) ions are dominant compared to HCO_3^- ions (Table 1)[15,16]. About 50% of the deeper aquifer samples have pH in the range of 8.3 to 9.24. No definite relationship between F^- and EC has been found.

In general, aridity of climate is one of the primary reasons for the origin of high F^- in groundwater. Several processes, namely dissolution of F^- bearing minerals, ion exchange and evaporative concentration can locally account for high F^- concentration in groundwater[13,19,21–24]. Incidence of F^- in groundwater is mainly a natural phenomenon, influenced by the local and regional geological setting and hydrogeological conditions. The chief sources of F^- in natural waters are F^--bearing minerals (fluorite, fluorapatite, cryolite and apophyllite) as well as F^- replacing OH^- in the ferromagnesium silicates (amphiboles and micas), and soil consisting of clay minerals[17,23,25–27]. The degree of weathering and the leachable F^- in a terrain is more important in deciding F^- content in the water rather than the mere presence of F^--bearing minerals in the bulk rocks/soils[25,28]. According to Saxena and Ahmed[12], alkaline pH ranging from 7.6 to 8.6 with high HCO_3^- concentration (350–450 mg/l) and moderate EC are the favourable conditions for CaF_2 dissolution in the groundwaters.

Basalts are the major lithological units of the area and no mineral-bearing high F^- could be traced, excepting amphibole, biotite and fluorapatite. The source of F^- in the groundwater of this area appears to be these OH^- minerals. In the present area, bore wells tapping compound 'pahoehoe' flows have high concentration of F^- compared to dug wells tapping simple 'aa' flows. Comparative sluggish movement of groundwater in compound 'pahoehoe' flows provided more favourable hydrogeological conditions for dissolution of F^-, as these are more porous and less permeable (storage coefficient 0.00034–0.00052)[29]. Thus in turn provided more time for leaching of F^- bearing minerals under alkaline environment[10].

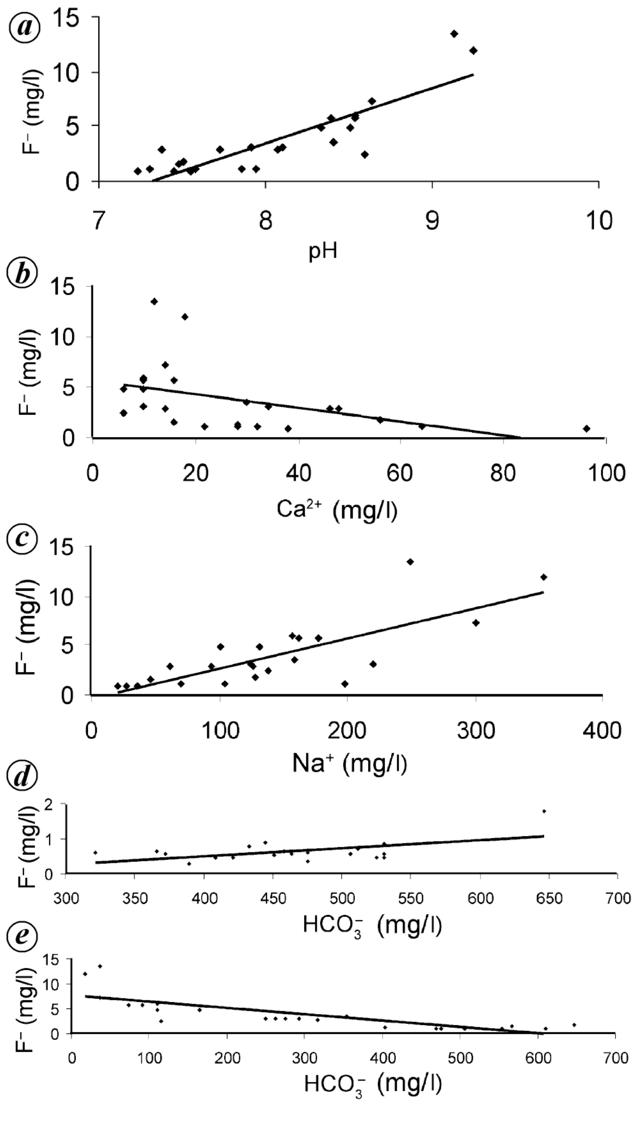

Figure 2. Plot of F^- vs pH (***a***), F^- vs Ca^{2+} (***b***), F^- vs Na^+ (***c***), F^- vs HCO_3^- in dug-well water and (***d***) F^- vs HCO_3^- in bore-well water (***e***).

We conclude that rock–water interaction is the main process in which F^--rich minerals are decomposed/dissociated from the source rock and F^- is dissolved in the groundwater by dissolution[24]. High concentration of F^- in deeper aquifers compared to shallow aquifers could be due to its high residence time in the aquifer system, thereby having longer contact time for dissolution of F^--bearing minerals present[30]. The influence of local lithology, aided by other factors like semi-arid climate of the region may be responsible for higher concentration of F^- in the groundwater of the region.

As recommendations, we suggest that the drinking water source from the affected area may be met from shallow dug wells. Bore-well water may be used for other domestic purposes. Villagers should be educated about the hazards of consumption of high F^--bearing water and use of simple methods of defluoridation. Defluoridation techniques (Nalgonda, activated alumina, low-cost adsorbants and ion exchange) may be adopted in the study area, where no alterantive source is available with community involvement in operation and maintenance. More emphasis may be given to calcium and phosphorous-rich food, as its intake helps in reduction in the absorption of F^- in the intestine. Rainwater harvesting and artificial recharge techniques should be implemented effectively to reduce F^- content in the water.

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Temporal and spatial variations in water flow and sediment load in the Narmada river

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Rivers are an integral part of the hydrologic cycle and are the major geologic agents which erode the continents and transport water and sediments to the oceans. Thus rivers constitute an important link between continents and oceans. A number of natural and anthropogenic factors influence the water and suspended sediment flux of a river basin along its pathway. Some important key factors are: area of drainage basin, relief, geology of basin, climate including rainfall and its intensity, run-off, vegetation, tectonics, land-use patterns and presence of reservoirs/dams. Any or all of these factors can be important in a particular river system. We recognize three key factors that influence water and suspended sediment load of the Narmada river, namely basin geology, rainfall and presence of reservoirs/dams. In the present study, water flow and suspended sediment load data in the Narmada river have been assessed based on 20 years of monitoring at various gauging stations. Most of the water flow in the river is during the monsoon season, except in some tributaries, where groundwater flow to the river during non-monsoon is significant. The suspended sediment flux is significantly lowered by the construction of dams and reservoirs along the river course.

Keywords: Narmada river, reservoirs/dams, sediment load, water flow.

THE Narmada river basin, lies in the central part of India, between 72°32′E–81°45′E long. and 21°20′N–23°45′N lat., with a drainage area of 98796 sq. km and a mean elevation of 760 m, higher than other peninsular rivers[1]. The total length of the river is 1312 km. The catchment area of the river extends in the administrative States of Madhya Pradesh (MP; 86.18%), Gujarat (11.6%), Maharashtra (1.5%) and Chhattisgarh (0.72%)[1]. In contrast to the other peninsular rivers in India, the Narmada along with the Tapti, drains westward into the Arabian Sea. The Narmada river has its origin at Amarkantak, on the eastern fringe of the Maikala plateau, of Satpura range, Anuppur District, MP and empties into the Arabian Sea near Bharuch (Figure 1). The basin is bounded in the north by the Vindhyans, in the east by the Maikala range, in the south by the Satpuras and in the west by the Arabian Sea. The river has 41 tributaries of which 22 are on the left bank (south) and 19 on the right bank (north)[1], although only Burhner,

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