Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 10	No. 4	pp. 567-572	2011

Original Research Paper

Groundwater Quality of Deeper Aquifers from Watersheds PGK1, PGK3 and PGK4, Yavatmal District (Maharashtra) in Central India

Y. A. Murkute and P. P. Badhan*
P. G. Department of Geology, R. T. M. Nagpur University, Nagpur-440 001, Maharashtra, India
*R&D Cell, Directorate, Groundwater Surveys and Development Agency, Pune-411 005, Maharashtra, India

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 17/3/2011
Accepted: 30/4/2011

Key Words:
Groundwater quality
Deeper aquifers
Neoproterozoic limestones
Fluorides

ABSTRACT

The groundwater quality from the watersheds PGK1, PGK3 and PGK4, Yavatmal District (Maharashtra), Central India, has been assessed and results are presented in the paper. Fifty samples collected from deeper aquifers have been analysed for various parameters like pH, EC, TDS, Ca^{++}, Mg^{++}, Na^+, K^+, HCO_3^-, CO_3^{-2}, Cl^-, SO_4^{-2}, and F^-. The interrelationship between F^- with pH, Na^+, SO_4^{-2}, and Cl^- has resulted into positive correlation, while inverse relationship is noted for Ca^{++} and HCO_3^-. In the area of study, the F^- content ranges from 0.2 to 15.6 mg/L, and 64% of groundwater samples from deeper aquifer have F^- concentration more than 1.0 mg/L. The higher concentration of F^- in Neoproterozoic limestones has been ascribed to the presence of fluoride bearing minerals like fluorite and apatite. In such limestones of chemical origin, co-precipitation of CaF_2 and $CaCO_3$ is the major process which controls the fluorine distribution in the rocks. The leaching of F^- containing minerals from the weathered zone to deeper depth has contributed the high F^- concentration in basaltic aquifers. Amongst the analysed samples, 58% of groundwater is suitable for irrigation.

INTRODUCTION

The disease fluorosis is observable in geographic areas with high content of fluorine in water and thus the disease resides largely endemic (Deshkar & Deshmukh 1998, UNICEF 1999). Accordingly, the intake of excessive fluoride through groundwater is solitary source of fluorosis (WHO 1984, Dev Burman et al. 1995, Subba Rao 2003). According to Kharb & Susheela (1994) and Susheela (2001) fluorosis is manifested in three main categories *viz*., i. dental fluorosis, ii. skeletal fluorosis and iii. non-skeletal fluorosis. With increase in severity of skeletal fluorosis pain becomes associated with rigidity and restricts movement of cervical and lumbar spine, shoulder joints as well as knee and pelvic joints (WHO 1984, 1994, Teotia & Teotia 1988, Susheela 2001). Such non-skeletal fluorosis represents neurological, muscular, allergic, gastrointestinal ailments as well as headache and urinary tract infections (Ozha & Mathur 2001). Various defluoridation methods are in vogue. Vali (1998) urged use of *Eleucine coracona* (ragi) as a source of calcium enrichment of habitual diets in fluorosis endemic areas to cope up with fluoride problems. The Nalgonda technique, which involves addition of lime and alum powder to the water, also proved to be effective; however, instead of lime the bleaching powder can also be added to disinfect the water (Madhnure & Malpe 2007). The artificial recharge to groundwater is, perhaps, the better remedial measure to control the fluorosis (Gupta & Deshpande 2003). In the present paper the observations on the study of hydrochemical composition of groundwater as well as F^- concentration in deeper aquifers are presented.

STUDY AREA

Location and climate: The study area covers the fifty villages from the watersheds PGK1, PGK3 and PGK4, Kelapur Tehsil (Lat. 19°47’03’- 20°14’26’N and Long. 78°23' 48-78°42’15’E), Yawatmal District, Maharashtra. The area experiences tropical dry subhumid climate. The summer months are much hot (max. temp. ~ 44°C) while, winter is mild (min. temp. ~ 15.1°C). The area receives the average rainfall of 1137.17 mm by south-west monsoon (June to September) with relative humidity of 68 % during monsoon season.

Physiography and drainage: The area exhibits moderately dissected topography with a few isolated hills. It forms the part of the Penganga sub-basin (Deshpande 1998, Duraiswami 2007, GSI 2008) with general slope towards south and southeast directions. The River Penganga and its tributary River Khuni drain the area. The drainage network is dendritic to sub dendritic with ephemeral drainages. Based on drainage analysis, Groundwater Surveys and Development Agency (GSDA) has delineated three watersheds, namely, i. PGK1, ii. PGK3 and iii. PGK4. The component-wise groundwater status has been given in Table 1.

Hydrogeological setting: In the area, the Neoproterozoic Penganga beds form the base for the disposition of relatively younger rocks of the upper Cretaceous Lameta Formation and in turn, Deccan trap basalt flows (Upper Cretaceous to Palaeogene) cap the area. Occasionally, soil drapes and in some parts local alluvium covers up the area.

The Penganga limestones are pink and gray in colour, fine grained and non-crystalline in nature. The associated sandstones are yellowish brown to pink in colour, medium grained and moderately indurated. At places, red shale layers are noticed to alternate with sandstones. Though, the limestones, at places, are massive, but are generally bedded and exhibit vertical joints. Occasionally, karst topography is developed and geomorphological features such as sink holes, galleries as well as caverns are associated with such rock type imparting secondary porosity and permeability. The silicified sandstones, certified limestones and calcareous sandstones represent the Lameta Formation. The basaltic flows are 'aa' as well as 'pahoehoe' types and are mostly dark gray to black in colour, massive and fine to medium grained in nature. The porphyritic texture in basalts is seldom noticeable while sometime flows are vesicular in nature. The alluvium deposits consist of beds of sand, gravel and boulders, confined to river and minor streams courses.

In the area, the groundwater mainly occurs under phreatic conditions; however, the deeper confined aquifers are also too common. The dugwells penetrating Neoproterozoic limestones range in depth between 5 and 15 mbgl. The diameters of the dugwells grade ranges from 3 to 5 m. The deeper aquifers vary in depth from 25 to 40 mbgl upholding a discharge of 50 to 300 m^3/ day (GSDA 2005, 2009). In the area of present study, the Lameta rocks do not act as prolific aquifers. The Basaltic lava flows are vesicular in nature and possess high weathering zone-depth as well as joints. The average depth of dugwells varies from 9 to 15 mbgl and yield ranges from 75 to 100 m^3/day. The borewells penetrating deeper aquifers have good yields ranging from 150 to 250 m^3/day. The wells piercing deeper aquifers in alluvial areas have discharge between 100 and 300 m^3/day, though in a few cases higher yields are also observed (GSDA 2009).

MATERIALS AND METHODS

The hydrochemical survey in the study area has been carried out during pre-monsoon season (May-June) of 2010. The grids were plotted on the study area and the fifty samples from the borewells were collected for the comparative study. The chemical parameters were analysed using the standard hydrochemical analytical techniques (APHA 1998) and the results are presented in Table 2.

RESULTS AND DISCUSSION

The groundwaters from the borewells (pH: 5.98 to 9.27) are acidic to neutral to moderately alkaline. The values of electrical conductivity vary from 640 to 2140 µS/cm. The TDS content varies from 410 to 1370 mg/L. The Ca^{++} ranges between 8 and 212 mg/L, and Mg^{++} between 3 and 123 mg/L. The Na^+ and K^+ contents in deeper aquifers range from 13 to 353 mg/L, and 0.8 to 52.2 mg/L respectively. The HCO_3^- content grade from 11 to 578 mg/L, and CO_3^{-2} concentration is highest up to 31 mg/L. The Cl^- content ranges between 9 and 520 mg/L. For such deeper aquifer SO_4^{-2} content grades from 9 to 343 mg/L, and the F^- content from 0.2 to 15.6 mg/L. Of the collected samples, 64% have F^- content more than 1mg/L, which is unsuitable for drinking (BIS 2003).

In the study area, the F^- concentration is more in Penganga limestones. The higher concentration of F^- is ascribed to the presence of fluoride bearing minerals like fluorite and apatite in limestones or the clays, which absorb fluorine by F^- to OH^- replacement (Kodate et al. 2007). According to Dev Burman et al. (1995), the fluoride content in groundwater depends on the rocks through which it flows and increases along with the depth. The correlation plots of pH versus F^-

Table 1: Groundwater status of watersheds (after GSDA 2009).

Sr. No.	Component	PGK1		PGK3		PGK4	
		Command	Non-Command	Command	Non-Command	Command	Non-Command
1	Total Watershed area (ha)	4424.93	19189.30	9322.59	14071.86	5926.11	18078.54
2	Area suitable for groundwater recharge (ha)	4424.93	19189.30	9322.59	14071.86	5926.11	18078.54
3	Total annual groundwater recharge (ham)	426.94	1858.32	1339.59	1826.46	819.42	2384.10
4	Natural discharge (ham)	21.35	92.92	66.98	91.32	40.97	119.20
5	Net groundwater availability (ham)	405.60	1765.40	1272.61	1735.13	778.45	2264.89
6	Gross draft (ham)	55.10	489.02	419.88	412.78	167.47	420.94
7	Stage of development (%)	25.06	27.68	19.33			
8	Premonsoon water table trend	Rising	Rising	Rising			
9	Post monsoon water table trend	Rising	Rising	Rising			
10	Category of watershed	Safe	Safe	Safe			
11	Recharge from rain fall (ham)	403.17	1665.73	1115.41	1683.64	710.71	2168.13
12	Recharge from conservation structures (ham)	0	79.04	0	40.73	1.75	117.26

Table 2. Analytical data of groundwater samples from the study area.

Sample No.	Aquifer Type	pH	EC (µS/cm)	TDS (mg/L)	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	SO_4^{-2}	Cl^{-}	F^{-}
PG 1	BS, SS	7.44	740	474	199	21	13	7.2	0	347	63	72	1.4
PG 2	BS, SS	7.03	680	435	40	66	16	1.6	0	356	17	19	0.9
PG 3	BS, SS	7.17	720	461	76	39	20	2.5	0	245	12	24	0.7
PG 4	BS	5.98	790	506	130	46	25	13.4	28	358	35	88	0.5
PG 5	BS	7.03	970	621	130	45	26	1.4	0	401	44	46	1
PG 6	BS	6.58	640	410	51	59	20	11.4	0	324	13	35	0.9
PG 7	BS	7.57	880	563	51	69	26	27.4	0	324	24	66	1.4
PG 8	BS, SS	7.08	720	461	45	73	26	1.4	0	358	13	28	0.7
PG 9	BS, SS	6.78	830	531	47	66	26	1.4	0	460	15	35	1
PG 10	BS	6.79	830	531	135	31	35	1.4	0	241	54	70	0.9
PG 11	BS	7.35	860	550	91	54	37	2.1	0	385	14	47	1
PG 12	BS, SS	7.13	830	531	69	34	34	1.4	0	397	22	15	1
PG 13	BS	6.69	800	512	63	41	34	17.4	0	400	14	36	1.2
PG 14	BS	7.23	920	589	125	73	42	33.4	0	410	125	125	1.2
PG 15	BS, SS	7.37	1020	653	79	58	35	1.3	0	465	17	51	1.2
PG 16	BS	7.56	1020	653	160	58	49	1.2	4	443	58	153	1.5
PG 17	BS	7.4	1470	941	212	40	62	55.2	0	407	124	280	1.9
PG 18	BS	6.89	830	531	76	77	47	1.7	0	421	23	67	0.3
PG 19	BS, SS	7.42	1070	685	44	97	42	2.4	0	350	25	90	0.2
PG 20	BS, SS	9.15	1090	698	130	49	64	1.2	0	501	11	75	3.5
PG 21	BS	7.05	860	550	75	36	51	55.2	4	401	27	59	0.2
PG 22	BS	7.29	740.0	474	49.0	41.0	44.0	2.4	0	404.0	12.0	15.0	0.8
PG 23	BS	8.93	870	557	37	41	43	3.1	0	202	48	49	2.6
PG 24	BS, SS	8.93	840	538	49	63	56	3	0	537	24	9	1.4
PG 25	BS	8.04	1410	902	66	123	76	2.4	0	447	70	137	1
PG 26	SS	7.99	820	525	65	19	71	16.8	6	401	22	50	1.7
PG 27	BS	7.62	920	589	57	100	91	1.3	0	462	142	114	1.3
PG 28	BS	7.53	950	608	60	52	83	0.8	0	230	79	102	2.7
PG 29	BS, SS	9.18	800	512	15	43	54	2.2	0	274	32	26	3.2
PG 30	BS, SS	8.73	870	557	48	43	89	6.8	0	498	10	26	1.3
PG 31	BS	8.67	920	589	40	19	78	1.8	0	164	42	61	4.3
PG 32	BS	8.03	910	582	126	16	135	2.1	0	283	52	88	1.6
PG 33	BS	9.27	1160	742	24	43	79	1.6	13	176	20	67	4.4
PG 34	BS, SS	8.79	1040	666	105	62	176	2.6	0	433	75	164	1.8
PG 35	BS	7.98	940	602	45	64	135	6.8	0	168	343	111	2
PG 36	BS	8.71	1060	678	68	5	148	0.8	0	277	31	55	4.1
PG 37	BS	9.24	1140	730	31	22	125	1.2	0	98	67	167	4.7
PG 38	BS, SS	9.21	1130	723	8	55	123	2.4	20	179	25	177	5.5
PG 39	BS	8.6	1010	646	11	49	124	1.1	31	145	65	133	4.5
PG 40	BS	8.59	750	480	22	18	118	1.1	10	133	65	89	3.1
PG 41	BS	8.74	970	621	44	30	168	1.1	0	578	12	11	1.7
PG 42	BS	8.01	1270	813	47	24	200	2	4	288	9	232	3.4
PG 43	BS, SS	7.85	1010	646	45	23	204	1.1	5	508	34	65	1.2
PG 44	BS	8.64	1010	646	19	22	160	18.1	29	324	55	54	3.1
PG 45	BS	7.12	900	576	13	13	138	1.7	0	344	22	37	0.9
PG 46	BS	8.32	920	589	22	3	179	12.1	5	96	77	199	5.8
PG 47	BS	8.51	730	467	13	5	143	1.1	21	86	53	143	2.1
PG 48	BS	8.77	1910	1222	19	46	322	1.3	14	43	133	497	7.6
PG 49	BS	8.51	1540	986	10	21	244	1.6	19	41	133	253	15.6
PG 50	BS	9.25	2140	1370	20	24	353	1.9	18	11	177	520	11.1

BS - Basalt, SS - Sandstones, LS - Limestones

have depicted the positive correlation (Fig. 1a), indicating that higher alkalinity of the water promotes leaching of F^- thus increasing the F- concentration (Saxsena & Ahmed 2001, Madhnure & Malpe 2007). An inverse relationship has been found between F^- and Ca^{++} concentration (Fig. 1b). The positive relationship is also observed between F^- and Na^+ (Fig.1c), indicating that Na^+ is released in that supports dissolution of F^- (Kodate et al. 2007). The F^- and HCO_3^{-2} show inverse relationship (Fig. 1d) as also observed by Apambire et al. (1997). This inverse correlation is

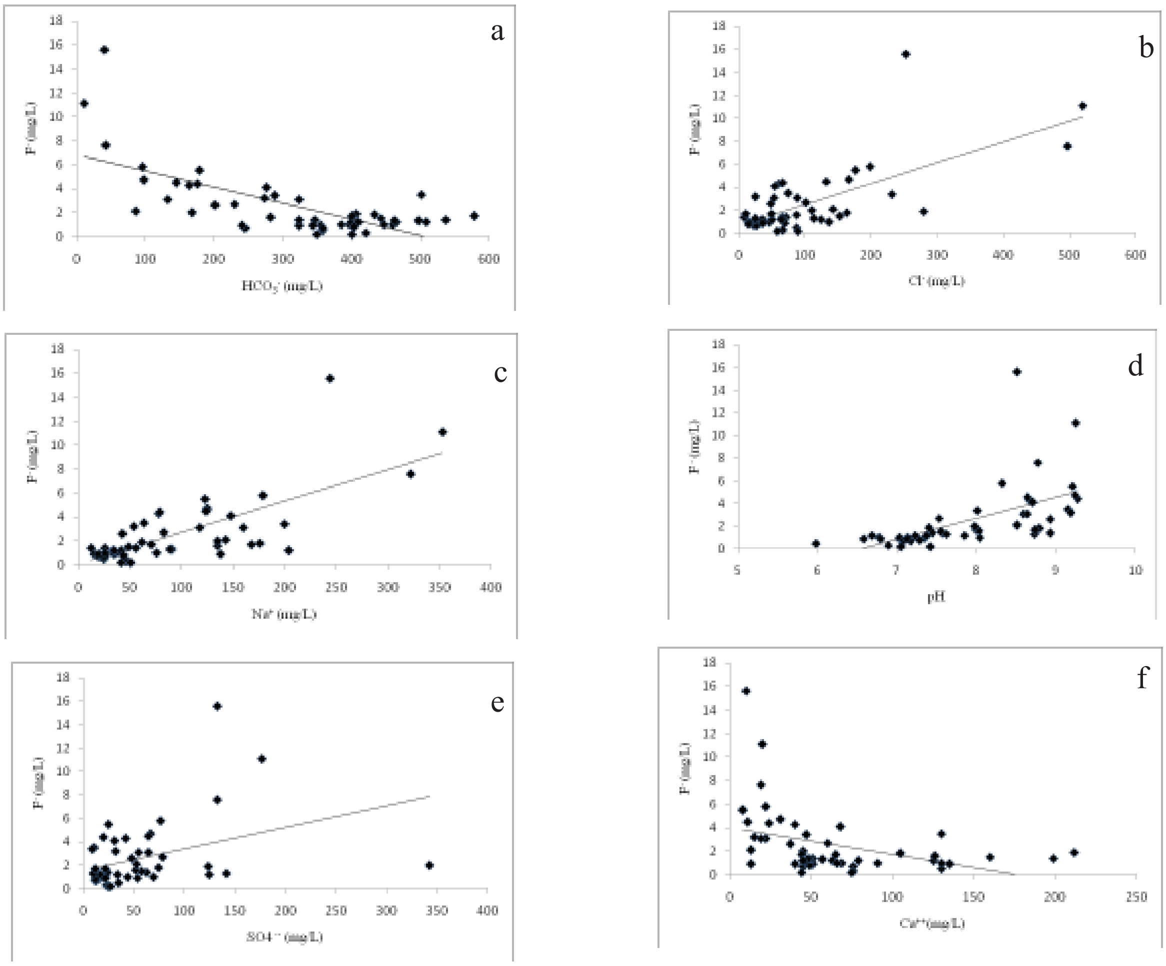

Fig. 1: Correlation of F^- with other chemical parameters.

attributed to alkaline nature of water, where carbonates and hydroxyl ions are dominant as compared to HCO_3^- (Hem 1991, Karanth 1997, Shivanna et al. 2003). The F^- shows positive correlation with SO_4^{-2} and Cl^- (Fig. 1e,f). The SO_4^{-2}/Ca^{++} ratio ranging from 0.05 to 3.5 indicates dissolution of sulphate bearing minerals in groundwater (Saini et al. 2006). Pophare & Dewalkar (2007), while working in sedimentary terrain have established the relationship between TDS content and the fluoride concentration. They have pointed out that when TDS is lower, the fluoride content is also low. This is in agreement with the observation in the present investigation. Due to high concentration of fluoride, 64% of the samples were found to be not suitable for drinking purpose. The major cations-anions have been plotted in the Piper's trilinear diagram (Piper 1944). The groundwater of the study area is mostly Mg-Ca-HCO_3-Cl, Na-Mg-Cl-HCO_3, Mg-Ca-HCO_3 and HCO_3-Cl-SO_4 types (Fig. 2). The suitability of groundwater has also been checked for irrigation purpose using Sodium Adsorption Ratio (SAR)

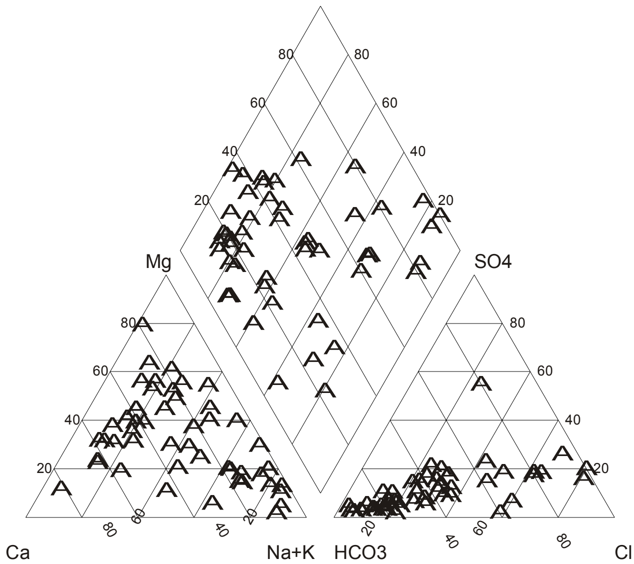

Fig. 2: Piper diagram of groundwater of the study area.

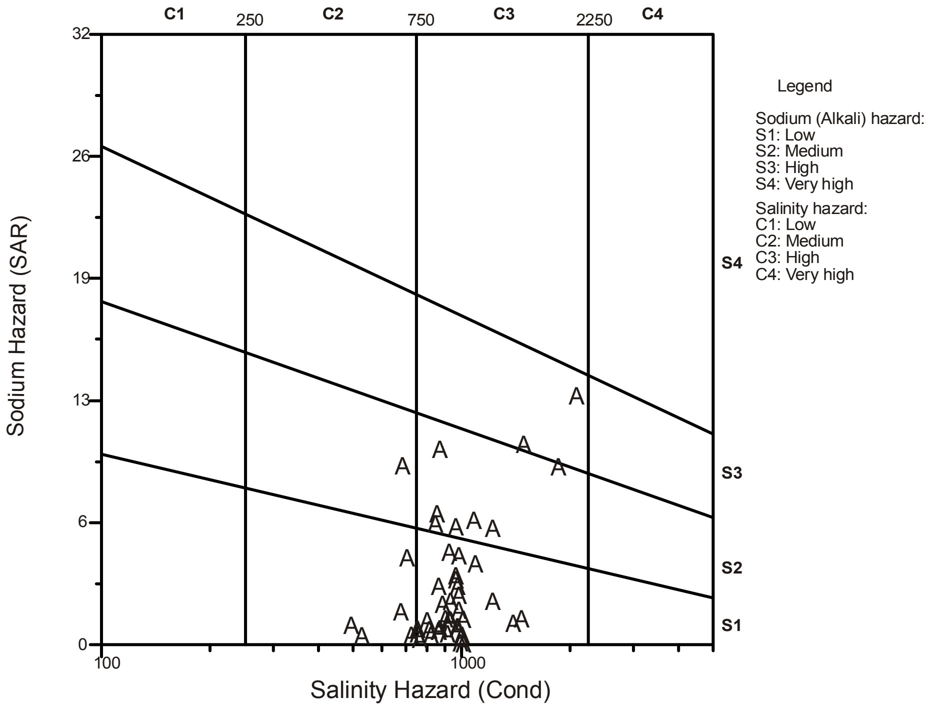

Fig.3. SAR vs. conductivity diagram of the samples (After U.S. Salinity Laboratory Staff 1954)

and U.S. Salinity Laboratory Staff (1954). Most of the samples fall in C3-S1 category; however, samples also fall in C_2- S_1, C_3-S_2, C_2-S_2 and C3-S3 categories (Fig. 3). Accordingly, 58% of groundwater from deeper aquifer is of excellent quality, 14% is of good, 12% is fair and 16% is unsuitable for irrigation purpose.

The higher concentration of F^- in Neoproterozoic limestones has been ascribed to the presence of fluoride bearing minerals like fluorite and apatite (Deshmukh et al. 1995). In such limestones of chemical origin, co-precipitation of CaF_2 and $CaCO_3$ is the major process which controls the fluorine distribution in rocks. The leaching of F^- containing minerals from the weathered zone to deeper depth has contributed to the high F^- concentration in basaltic aquifers. Besides, the source of F^- is expected to be the amphibolites and biotite (Madhnure & Malpe 2007).

Remedial measures: The defluoridation, nutritional supplementation and artificial recharge are the common practices for prevention and control of the fluorosis. According to Sriram et al. (1998), the use of bauxite for defluoridation appears to be the uncomplicated. The supplementation by calcium rich, vitamin C and antioxidants to the diet may be beneficial for prevention of fluorosis. Vali (1998) propounded the use of *Eleucine coracana* (ragi) as a source of calcium enrichment of habitual diets in fluorosis endemic areas. Adsorption is another method of defluoridation in which water is passed through a column packed with strong adsorbent like activated alumina (Al_2O_3), the F- ions are adsorbed on the surface of adsorbent and water is relatively free from F^- (Singh 2004). Other low cost adsorbents are fresh leaves of *Acacia catechu* (Khair), *Ficus regalia* (Pipal), *Azardichta indica* (Neem), bone char, synthetic tricalcium phosphate, florex, activated carbon, etc. (Rao 2003). The artificial recharge to groundwater, perhaps, is the better remedial measure to control fluorosis (Deshmukh et al. 1995, Gupta & Deshpande 2003, Jacks et al. 2005). Though, these defluoridation methods are known, the indigenous methods pertaining to locale should be more emphasized. In addition, awareness regarding prevention of fluorosis should be given much attention and the community involvement in defluoridation operation and maintenance is recommended.

CONCLUSIONS

The higher concentration of F^- in Neoproterozoic limestones is related to the presence of fluoride bearing minerals like fluorite and apatite. The co-precipitation of CaF_2 and $CaCO_3$ has controlled the fluorine distribution in these limestones of chemical origin. The leaching of F^- containing minerals from the weathered zone to deeper depth has contributed to the higher F^- concentration in basaltic aquifers.

ACKNOWLEDGEMENT

The author PPB thanks Director, Groundwater Surveys and

Development Agency, Pune for granting the permission to publish the paper.

REFERENCES

Apambire, W.M., Boyle, D.R. and Michel, F.A. 1997. Geochemistry, genesis and health implications of fluoroferrous groundwater in upper regions of Ghana. Environ. Geol., 33: 13-24.

APHA 1998. Standard Methods for the Examination of Water and Wastewater. 20th edition, American Public Health Association, Washington D.C.

BIS 2003. Drinking Water Specification, IS: 10500, 1991. Bureau of Indian Standards, New Delhi.

Deshkar, S.M. and Deshmukh, A.N. 1998. Safe limits of fluoride content in drinking water for populations inhabiting semiarid tropical regions of the world, suffering from endemic calcium malnutrition. Gond. Geo. Mag., Spl. Vol. 3, pp. 11-26.

Deshmukh, A.N., Wadaskar, P.M. and Malpe, D. B. 1995. Fluorine in environment: A review. Gond. Geo. Magz., 9: 1-20.

Deshpande, G.G. 1998. Geology of Maharashtra. Geol. Soc., India, pp. 221.

Dev Burman, G.K., Singh, B. and Khatri, P. 1995. Fluoride in environment: Hydrogeochemical studies of groundwater having high fluoride contents in Chandrapur district. Gond. Geol. Magz., 9: 71-80.

Duraiswami, R.A. 2007. Groundwater conditions in eastern Maharashtra: Emerging Challenges. In: A. M. Pophare and D.B. Malpe (Eds.). Recent Developments in Groundwater Resources of Central India, Gond. Geol. Publication, 11: 69-76.

GSDA 2005. Report on Dynamic Groundwater Resources of Maharashtra as on March 2004. Groundwater Surveys and Development Agency, Water Supply and Sanitation Department, Government of Maharashtra and Central Ground Water Board, Central Region, Nagpur, pp. 332.

GSDA 2009. Dynamic Groundwater Resources of Maharashtra Detailed Report (as on 2007-08). Groundwater Surveys and Development Agency, Water Supply and Sanitation Department, Government of Maharashtra and Central Ground Water Board, Central Region, Nagpur, pp. 228.

GSI 2008. Geology and mineral resources of Maharashtra. Geol. Surv. India, Miscellaneous Publication, 30(II) pp. 120.

Gupta, S.K. and Deshpande, R.D. 2003. High fluoride of north Gujrath-Cambay region: Origin, community perception and remediation. In: V.P. Singh and R.N. Yadava (Eds.), Groundwater Pollution. Allied Pub. Pvt. Ltd., New Delhi, pp. 368-388.

Hem, J.D. 1991. Study and interpretation of the chemical characteristics of natural waters. USGS, Water Supply Paper No. 1473.

Jacks, G. and Bhattachrya, P., Chaudhary, V. and Singh, K.P. 2005. Controls on the genesis of high-fluoride groundwaters in India. Appl. Geochem., 20: 221-228.

Karanth, K.R. 1997. Groundwater Assessment, Development and Management. Tata McGraw Hill, New Delhi, pp. 720.

Kharb, P. and Susheela, A.K. 1994. Fluoride ingestion in excess and its effects on organic and certain inorganic constituents of soft tissues. Med. Sci. Res., 22: 43-44.

Kodate, J.K., Pophare, A.M., Gajbhiye, R. and Meshram, Y. 2007. Hydrochemistry of groundwater from Bhadravati tehsil, Chandrapur District, Maharashtra with reference to fluoride contamination. In: A.M. Pophare and D.B. Malpe (Eds.), Recent Developments in Groundwater Resources of Central India. Gond. Geol. Publication, Spl. Vol. 11: 113-118.

Madhnure, P. and Malpe, D.B. 2007. Fluoride contamination of groundwaters in rural parts of Yawatmal District, Maharashtra: Causes and Remedies. In: A.M. Pophare and D.B. Malpe (Eds.). Recent Developments in Groundwater Resources of Central India. Gond. Geol. Publication, 11: 127-135.

Ozha, D.D. and Mathur, S.B. 2001. Socio-economic losses to human and livestock health in Rajasthan due to high fluoride bearing groundwater and its mitigation. International Workshop on Fluoride in Drinking Water: Strategies, Management and Mitigation, Bhopal, pp. 162-170.

Pophare, A.M. and Dewalkar, S.M. 2007. Groundwater quality in eastern and southeastern parts of Rajura tehsil, Chandrapur District, Maharashtra. In: A.M. Pophare and D.B. Malpe (Eds.). Recent Developments in Groundwater Resources of Central India. Gond. Geol. Publication, 11: 119-126.

Rao, N.C.R. 2003. Fluoride and environment - A review. In: M.J. Bunch, V.M. Suresh and T. Vasnt Kumar (Eds.), Proc. Third International Conference on Environment and Health, Chennai, India, pp. 386-399.

Saini, R.K., Chakrapani, G.J. and Sen, A.K. 2006. Geochemical studies of groundwater in Shanpur, Uttar Pradesh. J. Geol. Soc., India, 68: 50-58.

Saxsena, V.K. and Ahmed, S. 2001. Inferring of chemical parameters for the dissolution of fluoride in groundwater. Environ. Geol. 43: 731-736.

Sriram, A., Bhale, S.A., Nagmote, A. and Deshmukh. A.N. 1998. Bauxite as a cheap natural medium for domestic defluoridation units: A case study of selected bauxite occurrences in India. Gond. Geo. Mag., Spl. Vol. 3, pp. 57-80.

Shivanna, K.T. and Mohoakr, H.V. 2003. Isotope chemical approach to study the fluoride contamination in groundwater of Ilkal area, Bagalkot District, Karnataka. Proc. of Int. Conference on Water and Environment, Bhopal, India. Allied Pub. Pvt. Ltd., pp. 332-346.

Subba Rao, N. 2003. Groundwater quality: Focus on fluoride concentration in rural parts of Guntur district, Andhra Pradesh, India. Hydro. Sci. j., 48(5): 835-847.

Susheela, A.K. 2001. Sound planning and implementation of fluoride and fluorosis mitigation programme in an endemic village. International Workshop on Fluoride in Drinking Water: Strategies, Management and Mitigation, Bhopal, pp. 22-24.

Teotia, S.P.S. and Teotia, M. 1988. Endemic skeletal fluorosis: Clinical and radiological variants. Fluoride, 21: 39-44.

UNICEF 1999. State of the art report on the extent of fluoride in the drinking water and the resultant endemicityin India. UNICEF, New Delhi.

U.S. Salinity Laboratory Staff 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S. Deptt. of Agriculture Hand Book. No.60, pp.160.

Vali, S.A. 1998. Ragi (*Eleucine coracana*) as a source of calcium enrichment of habitual diets in fluorosis endemic areas. Gond. Geol. Mag., Spl. Vol. 3, pp. 81-90.

Wedepohl, K.H. 1974. Handbook of Geochemistry, Speger-Verlag, Berlin, Hedeilberg, New York.

WHO 1984. Guidelines for Drinking Water Quality, Vol. 2. Health Criteria and Other Supporting Information. World Health Organization, Geneva.

WHO 1994. Fluorosis and Oral Health. World Health Organization Technical Report Series, 846, pp. 37.