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Evaluation of Fluoride Contamination Using GIS in Thirukkazhukundram Block, Tamil Nadu, India

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ABSTRACT

The presence of fluoride in the groundwater in the Thirukkazhukundram Block in south India is now becoming an increasingly alarming issue. With the semi-arid climatic conditions, charnockite and gneiss rocks form the basement, contributing to the geology of the study area. The pre-monsoon (August 2016) and post-monsoon (February 2017) fluoride concentrations have an average output of 1.3 $mg.L^{-1}$ and 0.72 $mg.L^{-1}$ respectively. As of date, only in Neikuppi, the fluoride contamination is found to be 2 $mg.L^{-1}$ in pre-monsoon which is beyond the accepted limit as per the WHO standards. Other 29 locations taken up for study have fluoride value fluctuation from 1 $mg.L^{-1}$ to 2 $mg.L^{-1}$ in the pre-monsoon and from 0 to 1.5 $mg.L^{-1}$ in the post-monsoon. The main factor responsible for this fluoride contamination lies in the study area's hydro-geological condition which must be attended to immediately to prevent a public health problem in the future.

INTRODUCTION

All developing countries across the world depend upon the subsurface lithology water to meet up their consumption needs. The quality of the groundwater has been steadily deteriorating due to normal or anthropogenic means, as it happened in cases of worldwide groundwater fluoride contamination and even in our South Indian Thirukkazhukundram block. Fluorine reacting with rock minerals yield fluoride, which though found as a minor trace element in water are very noxious when their concentration is beyond the acceptable limit. Even when the fluoride concentration is very low below the normal limit, the latent effects disturb the public's health after prolonged intake. Thapa et al. (2009) showed the occurrence of high fluoride in drinking water of the study area, maximum mobilization of fluoride associated with na-hco_3 water type, chemical weathering along with ion-exchange bearing the blueprint of fluoride release, inverse geochemical modeling indicating under-saturation of fluoride, and alkaline aquifer condition accelerates the F-accumulation in groundwater. Kalpana et al. (2018) developed a Fluoride Index for mitigation of geogenic contamination by Managed Aquifer Recharge (FIMAR). Groundwater fluoride contamination could be judged by taking into account the temperature, pH, fluorine-containing minerals solubility, anion exchangeability of the minerals present in the aquifer, the geological and geomorphological texture of the study area through which the water is drained, and also the time of contact with a specific lithological unit (Thapa et al. 2009). To avoid dental cavities and mineralization of bone and formation of teeth enamel, a small amount of fluoride is always required. (Thapa et al. 2009). Overconsumption of fluoride causes dental fluorosis, skeletal fluorosis, and nonskeletal fluorosis in humans (WHO 2006). As per WHO, 0.5 $mg.L^{-1}$ is apt to stop dental fluorosis. Fluoride's desirable limit is 1 $mg.L^{-1}$ and the allowed limit is 1.5 $mg.L^{-1}$ as per BIS (1991) and ICMR. High fluoride concentrations in groundwater cause fluorosis in rural, dry, and semi-arid regions, areas with granite and gneiss, and advanced stages of groundwater development (Handa 1988, Balkema et al. 2013, Handa 1975, Narasayya 1970, CSME 1997, Garg et al. 2008, Tchobanoglous & Burton 1995, Saha 2015, Jothivenkatachalam et al. 2010, Ramesh & Soorta 2012, Dar et al. 2011, Balakrishnan et al. 2008, Kamalanandhini et al. 2016, Senthilkumar & Elango 2013, Mondal et al. 2008, Rao et al. 1997, Rama et al. 1982, Whitehead et al. 2009, PHED 2009, Ghazavi et al. 2012, Sinha 1986, Jadhav 2012, Mitharwal et al. 2009, Shrestha & Kazama 2007, Bharadwaj et al. 2011, Saxena & Ahmed 2001, WHO 2006, Chen Ching et al. 2015).

Study Area

Groundwater samples collected from 30 locations of the Thirukkazhukundram Block were tested for fluoride contamination in the field itself using the color indicator method. This study area belongs to the Kanchipuram district of Tamil Nadu (Fig. 1). The geology of the study area (Fig. 2) has three segregations viz. coastal aeolian deposits, sand, and silt followed by basement charnockite in certain regions and gneiss in certain other parts. Ultrabasic intrusives of the archaean age and charnockites mainly comprise biotite and hornblende and are intruded by amphibolite, dykes of dolorite, and alluvial deposits are the youngest formation consisting of sands and clays and have deposits of quartz and pegmatites. The shale and clay of the Gondwana age occur on the bank of the Palar river. The Palar alluvium comprises coarse sands and gravels. The average thickness of alluvium is about 10 m to 30 m. The general trend of the gneiss is NE-SW direction. During the Jurassic period, Gondwana rocks, sedimentary rocks, faulted troughs, and rugged topography of crystalline 6 rocks, were deposited. The in-situ soils, laterites, and alluvial deposits were deposited along the Palar river during the quarternary period. The geomorphology of the study area (Fig. 3) also provides a clear picture of the subsurface lithology, which helps us understand the underlying soil's water-holding and yielding capacity, as well as their chemical environment and interaction, which plays a vital role in the presence or absence of fluoride and other contaminants. Fig. 4 shows the transport network of the study area.

Groundwater occurs mostly under water table or phreatic conditions in weathered, fractured, jointed, and faulted portions of granitic rocks and under artesian conditions in fractured zones located below impervious hard rocks. The pore spaces developed in the weathered mantle acts as shallow granular aquifers and forms the potential water-bearing zones. The water table is shallow in ayacut regions whereas it is relatively deeper in other regions. The groundwater of the charnockite type is found in shallow depths only when weathering is intense, and it develops much more slowly than gneissic formations.

The alluvium is the most important formation that carries a significant amount of groundwater. Groundwater is found below the water table or in semi-confined areas. The best aquifer is alluvium, which is primarily made up of stones, gravel, or coarse sand with little or no silt or clay. While silt or clay with a little or no boulders gravel or sand is a very poor aquifer. The thickness of these aquifers ranges from 10 m to nearly 80 m. One another mode of occurrence of groundwater in the alluvium is in the form of perched aquifers. Groundwater is met in these perched aquifers at a depth of 10 m from the ground level. In the Gondwana formation area, the groundwater yield is very poor. Groundwater is available under perched water table conditions along the coast. This is quite precious, and it should be used sparingly, as overlapping causes seawater intrusion in the area. The occurrence and movement of groundwater in hard rock formations are restricted to weathered and jointed portions. The intensity of weathering is not uniform and varies from place to place. Generally weathering and fractures are common at shallow depth. The sub-surface conditions can be studied by open-well inventories and by geophysical investigation.

In difficult situations, exploratory boreholes can be used to determine the subsurface conditions. Aquifer test or yield test can also be tried where ever large quantity of groundwater is needed. The SG & SWRDC has drilled 190 boreholes for investigation purposes throughout the entire district to get a comprehensive idea of the subsurface conditions. The complexity of the geological formations in this district is very well determined by drilling a series of bore wells all along the Palar river course. The thickness of alluvium is about 10 m near the confluence of the Cheyyar and Palar rivers. The maximum thickness of alluvium (30 m -40 m in flood plain area) is noted near Panakattucheri village of Thirukkazhukundram block. Based on the field study carried out and interpretations made from aerial photographs and satellite imageries, favorable

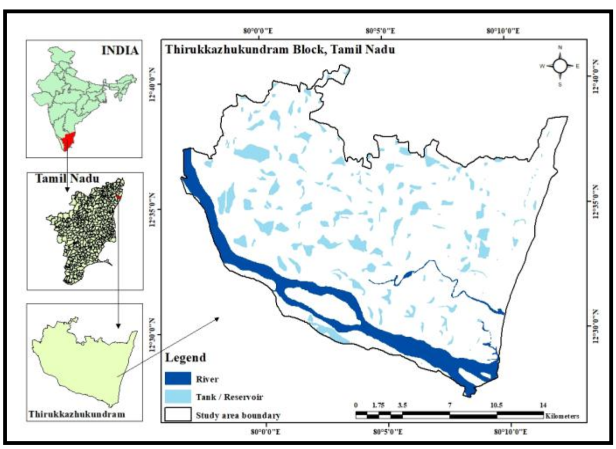

Fig. 1: Location of the study area.

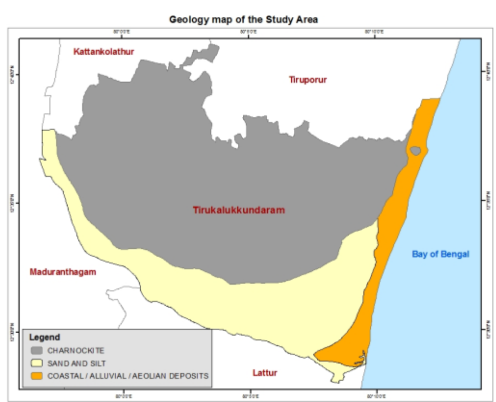

Fig. 2: Geology map of the study area.

locations are selected for exploratory boreholes. Subsurface hydrogeological characteristics are determined to evaluate the groundwater potential of the area. More than 46 boreholes have been handed over to user agencies like Municipality, TWAD Board and Panchayat Unions, etc., for drinking water purposes. The main aim of this study is to check out the existence and spatial fluctuation of fluoride contagion in pre-monsoon and post-monsoon under surface water, to thoroughly look into the nature of the fluoride concentration and hence to assess the resulting effect on human health on account of fluoride contaminated drinking water.

MATERIALS AND METHODS

To have clear knowledge regarding the fluoride concentration in groundwater, 30 samples from dug wells and bore wells were collected for examination and were tested in the field using the color indicator method both for pre-monsoon and post-monsoon from the research area, Thirukkazhukundram Block. The outputs were compared with drinking water quality standards as specified in the World health organization (WHO 2006). For every location, before and after the monsoon period, the comparison with the WHO standards was done and the respective spatial maps were prepared. As per WHO standards, fluoride concentration range in groundwater fluoride lies between 1 mg.L^{-1} (acceptable limit) and 1.5 mg.L^{-1} (permissible limit). The majority of the study area is unaffected by groundwater fluoride concentration contamination, but in a few areas, contamination has started, posing a serious threat to society.

RESULTS AND DISCUSSION

Fluoride, pH, EC, and total hardness were keenly studied. The final mean value of fluoride, pH, EC, and total hardness is provided in Table 1. The groundwater specimen data shows significant variations. Table 1 and Table 2 exhibits the pre-monsoon and post-monsoon period's fluoride distribution and limit of occurrence. Pre-monsoon fluoride varies from 1 to 2 mg.L^{-1} with a mean value of 1.3 mg.L^{-1} and post-monsoon fluoride concentration fluctuates from 0 to 1.5 mg.L^{-1} with a mean value of 0.72 mg.L^{-1}. pH varies from 7.2 to 8.2 in the pre-monsoon with a mean value of 7.7 and from 7 to 8.1 in the post-monsoon with a mean value of 7.6. EC varies from 616.9 to 2766.5 mg.L^{-1} in the pre-monsoon with an average of 1310.7 mg.L^{-1} and from 100.8 to 1219.4 mg.L^{-1} in the post-monsoon with a mean value of 525.1 mg.L^{-1}. TH varies from 134.541 to 890.1 mg.L^{-1} in the pre-monsoon with an average limit of 379.1 mg.L^{-1} and from 25.5 to 344.4 mg.L^{-1} in the post-monsoon with a mean value of 144 mg.L^{-1}. The samples were classified into five classes for depicting the frequency distribution (Fig. 5). During the post-monsoon period alone, 17% of the samples are below the detectable level (<0.25 mg.L^{-1}). Taking the level 0.25-0.5 mg.L^{-1}, 33% of the samples are observed only during the post-monsoon season. When it comes to the 0.75 mg.L^{-1}, 37% and 40% of the samples are observed during pre- and post-monsoon respectively. Then, for the level 1.25-1.5 mg.L^{-1}, 60% samples are observed during pre-monsoon and 10% are observed during post-monsoon. Between the two categories, there appears to be a positive trend with fluoride concentration, implying higher pre-monsoon fluoride content in the groundwater of the study area (Fig. 6 and Fig. 7). Also, we found that for value 1.5 mg.L^{-1}, we only observed 3% of the samples during the pre-monsoon period and nil observation during the post-monsoon period. Up to 0.5- 0.75 mg.L^{-1} level and between 1-1.25 mg.L^{-1} level, pre-monsoon observations are nil. Only, in Neikuppi, we find fluoride concentration

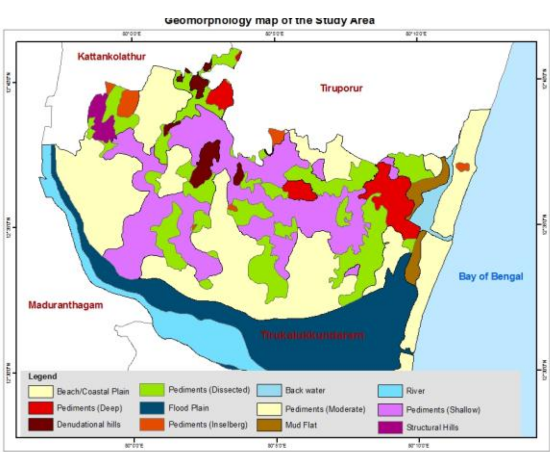

Fig. 3: Geomorphology map of the study area.

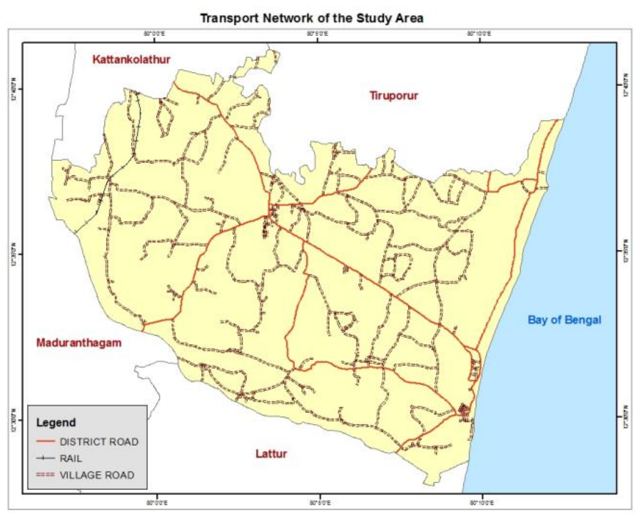

Fig. 4: Transport network of the study area.

Table 1: Pre-monsoon and post-monsoon concentrations of fluoride ($mg.L^{-1}$), pH, EC ($mg.L^{-1}$), and total hardness ($mg.L^{-1}$) in thirty places of groundwater in Thirukkazhukundram block.

No. of samples	Locations	Pre-monsoon				Post-monsoon			
		F	pH	EC	TH	F	pH	EC	TH
1	Nenmeli	1.00	8.1	746.21	224.52	0.00	7.96	272.06	98.36
2	Thirumani	1.00	7.6	650.85	214.92	0.00	7.69	215.89	70.09
3	Alagusamudram	1.00	7.6	773.97	178.18	0.50	7.92	200.39	59.99
4	Keerapakkam	1.00	7.8	2402.5	787.56	0.50	7.83	883.3	191.9
5	Mosivakkam	1.00	7.5	1086.2	330.87	0.50	7.03	509.15	152.2
6	Thazhambedu	1.00	7.8	1617.4	357.13	1.00	7.42	367.1	120.1
7	Manapakkam	1.50	7.8	2740.2	734.32	1.00	7.84	1098.3	295.4
8	Kuzhipanthandalam	1.50	7.9	1108.2	340.05	1.00	7.29	241.38	58.01
9	Pulikundram	1.50	7.8	2126.2	667.88	1.50	7.84	1219.4	344.4
10	Mamallapuram	1.00	8.2	748.04	200.27	0.00	7.33	100.79	25.54
11	Ponvilayanthakalathur	1.50	7.2	2036.5	579.61	1.00	7.65	670.08	205.8
12	Thirukazhukundram	1.50	7.7	2766.5	890.13	1.00	7.45	1104.8	321.8
13	Igai	1.00	7.7	1084.6	316.14	0.50	7.29	512.06	149.7
14	Navalur	1.00	7.6	922.92	242.33	0.50	7.5	332.03	96.81
15	Kadambadi	1.50	7.8	676	166.99	1.00	7.61	236.99	79.16
16	Salur	1.50	7.7	1011.1	260.06	1.00	7.55	373.94	109.1
17	Pattikadu	1.50	7.7	1127	338.7	1.50	8.09	312.34	102.1
18	Thathalur	1.50	7.8	977.59	273.43	0.50	7.54	466.08	130.3
19	Amaipakkam	1.50	7.7	935.27	201.94	1.00	7.61	368	116.9
20	Kunnathur	1.50	7.9	1363.2	416.48	1.00	7.84	495.89	149.2
21	Veerapuram	1.00	7.7	1260.7	335.67	0.50	7.33	523.38	160
22	Kilapakkam	1.50	7.7	2647.1	882.7	0.50	7.48	1079.7	270.1
23	Neikuppi	2.00	7.8	830.55	245.27	1.50	7.35	227.18	32.89
24	Vilagam	1.50	7.9	1797.1	639.23	1.00	7.05	617.01	227.5
25	Pandur	1.50	7.6	729.48	179.48	1.00	7.94	458.73	102.6
26	Sadurangapatnam	1.50	7.5	1186.8	282.02	0.50	7.33	621.89	121.5
27	Lathur	1.50	7.6	1523.1	431.56	0.50	7.7	551.41	108.8
28	Irumbilicheri	1.50	7.9	1158.9	347.82	1.00	7.57	682.96	200.4
29	Nallathur	1.50	7.3	671.01	134.48	0.00	7.34	796.62	146.3
30	Voyalur	1.00	7.3	616.94	172.57	0.00	7.53	213.83	72.98

Table 2: Pre-monsoon and post-monsoon concentrations of fluoride(mg/L) pH, EC (mg/L) and total hardness (mg/L) (maximum and mean) in the study place groundwater.

	Pre-monsoon		Post-monsoon	
	Max	Mean	Max	Mean
F	2	1.3	1.5	0.72
pH	8.2	7.7	8.1	7.6
EC	2767	1311	1219.4	525.1
TH	890.1	379.1	344.4	144

in groundwater to be above the permissible level and that particular value is 2 $mg.L^{-1}$.

The Hydro-Chemical Environment of Thirukkazhukundram's Relation with Groundwater Fluoride

The relation between environment hydrochemistry and groundwater fluoride is well analyzed. The scatter diagrams in Fig. 8 explain the pre-monsoon and post-monsoon pH, EC, and TH's relation with fluoride. PH, EC, and total hardness (TH) administer the correlated plotting. The pH and fluoride levels have a negative correlation. The main source of fluoride in groundwater is natural contamination, however, the dissolution process is still not well understood (Handa 1975, Saxena & Ahmed 2001). Fluoride is present in fluorite, granite, gneisses, and pegmatite (Rama 1982), all of which include fluoride. Granite, gneisses, basalts, dolerites, quartzites, pegmatites, hornblende, syenites, biotite, muscovite, fluorite, fluoromica, cryolite, villanite, etc., (Saxena & Ahmed 2001) are rock varieties that have high fluoride contagion in hard rock terrain. The study area is characterized by three to four layers namely basement gneiss or charnockite hard rock overlain by fractured charnockite or gneissic rocks sedimentary subsurface and on the top we have alluvium. According to Thapa et al. (2009), water level variations, as well as fluoride contamination of groundwater in alluvial zones, are unusual. The majority of the dug wells along with sub-surface water

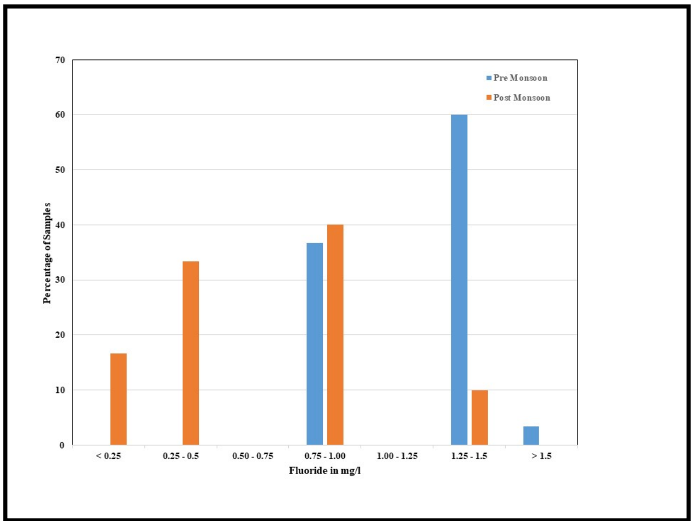

Fig. 5: Frequency distribution of fluoride during pre-monsoon season (August 2016) and post-monsoon season (February 2017).

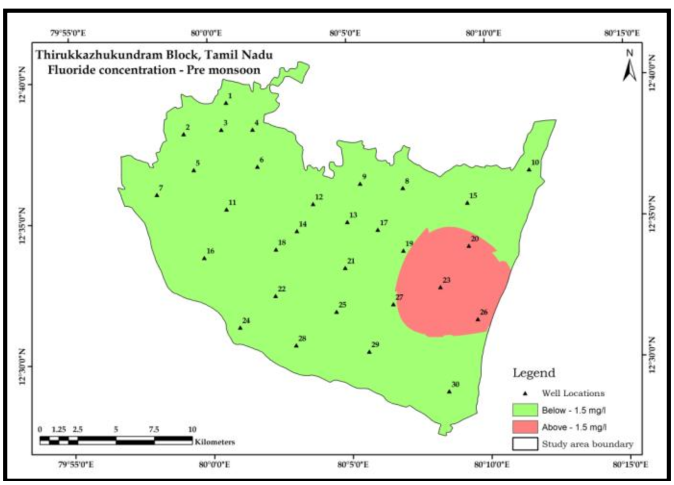

Fig. 6: Spatial map of pre-monsoon groundwater fluoride concentration of the study area.

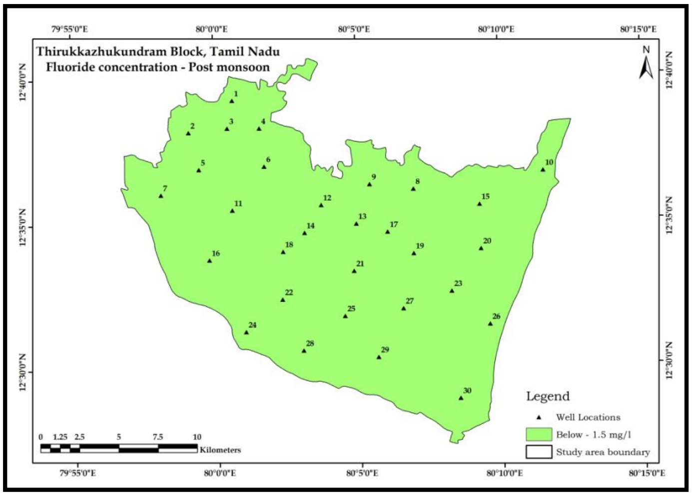

Fig. 7: Spatial map of post-monsoon groundwater fluoride concentration of the study area.

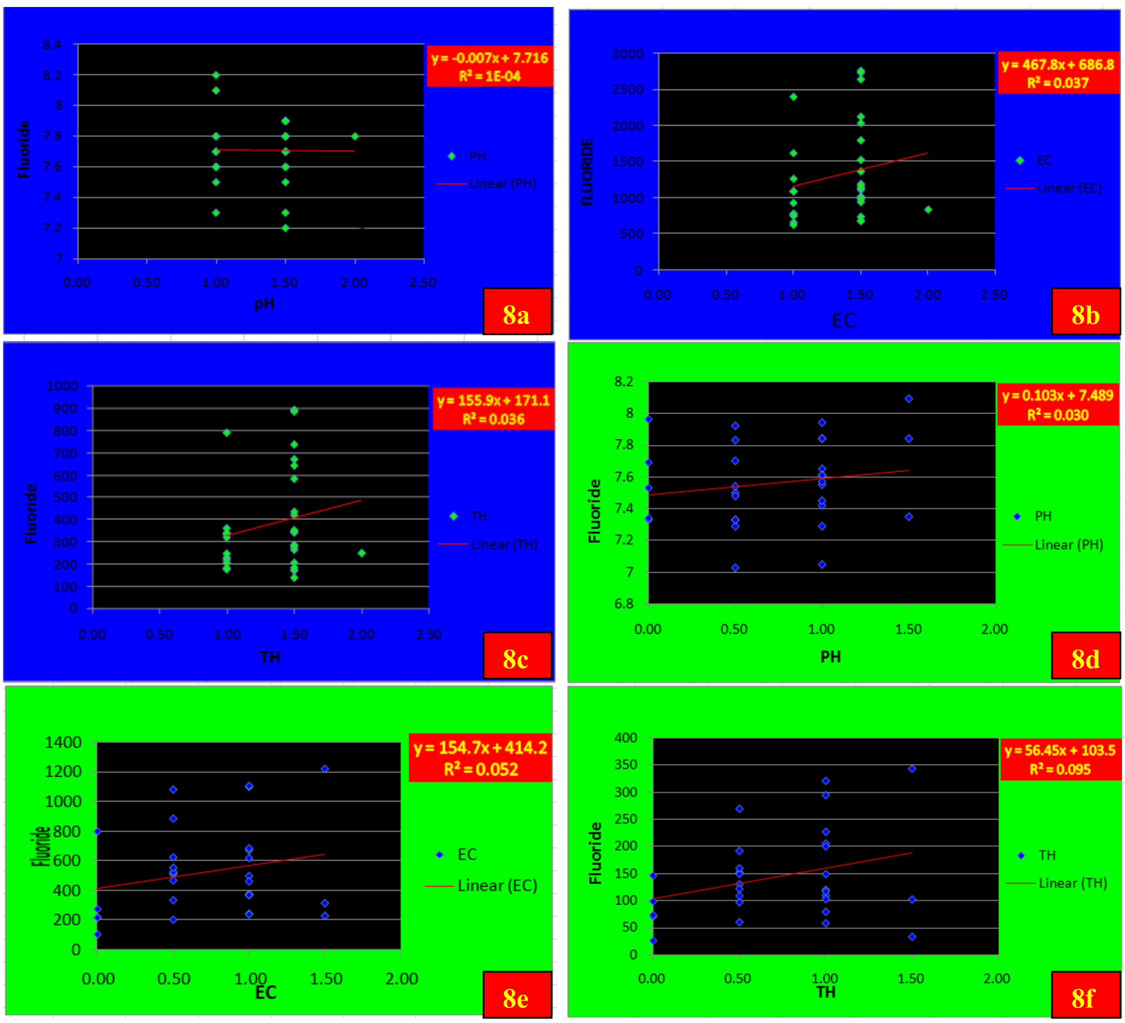

Fig. 8 (a to f): Scatter diagrams showing the relationship of the study area groundwater fluoride and pH, EC and total hardness.

bodies get depleted. The enrichment process, as well as the rapid decline of the water table, are made more effective by the soil and water reaction, and the gradual and steady casual leaching of fluoride into subterranean flowing water is aided by regional groundwater over-pumping. Because groundwater serves all of the public's domestic needs in the study area, special attention must be paid to fluoride contamination in the groundwater, which could eventually lead to all types of dental and skeletal fluorosis, posing a serious threat to future generations (Kamalanandhini et al. 2016).

Fluoride's Impact on Health Factor

In terms of the reproductive system (Naseem et al. 2016), there is a decrease in female fertility rates, as well as testosterone reduction, follicle stimulating hormones, and inhibin B quantity reduction in males (OrtizPérez et al. 2003). Fluoride also influences the shape and mobility of sperm in males (Chinoy & Narayana 1994). When it comes to neurobehavior (Trivedi et al. 2007), intellectual quotient (IQ) and thinking capacity loss occur. Children's mental abilities are impaired. Children's developing brain is subjected to neurotoxicity. (Grandjean & Landrigan 2006). The central nervous system's energy needs are met by interrupting the glycolysis cycle (ValdezJiménez et al. 2011). Fluoride has an effect on enzyme function, protein structure, brain functioning, hence, defective cognition and memory occurs (Spittle 1994). When it comes to the cardiovascular system, excessive fluoride intake causes oxidative stress, which leads to inflammatory mechanisms, atherosclerosis, vascular stiffness, myocardial cell damage, Bradycardia, abnormal heart rhythms, reduced myocardial function, hypothyroidism, diabetes mellitus, and obesity (Xu et al. 1997). Hypocalcemia and hypercalcemia are also caused by excessive fluoride6 (Nureddin 2018). Loss of mucus layer, hyperaemia, oedema, haemorrhage, and stomach lining rupture are all common gastrointestinal complications (Pratusha et al. 2011), also nausea, vomiting, and stomach pains occur (Nabavi et al. 2013). Thyroid gland structural changes and dysfunctions occur as endocrine system-based effects of abnormal fluoride intake (Kheradpisheh et al. 2018). There is an increase in parathyroid and calcitonin activity, as well as secondary hyperparathyroidism and impaired glucose tolerance (Doull et al. 2006). With respect to the renal system, fluoride concentration abnormality increases the kidney stone risks (Doull et al. 2006). Metabolic, histopathological, and pathological variations in the glomeruli are seen (Bouaziz et al. 2006).

CONCLUSION

Natural sources constitute the main site of groundwater fluoride in the study area, with a higher concentration during the pre-monsoon season than during the post-monsoon season. The geology, hydrology, and geochemistry of the environment, as well as the weathering of fluoride-containing rocks and significant ups and downs in the water table level, all contribute to the presence of fluoride. Fluoride in groundwater exceeds allowed limits, posing a reasonable concern that is slowly increasing due to delays in the implementation of water treatment schemes. Also, the public relies on groundwater for drinking and other household works. The majority of the public suffers from a lack of proper water supply. Due to the numerous health issues associated with fluoride concentration level abnormalities, care must be taken to ensure that fluoride content does not exceed the permissible limit, and necessary steps must be taken to protect the lives of those who live in this area.

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