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Research Article

DETECTION OF GEOSPATIAL VARIABILITY OF FLUORIDE CONCENTRATION IN MAHI-NARMADA INTER-STREAM AREA

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ABSTRACT
The large population of the study area depends mostly on groundwater for their agriculture and drinking water need, especially in the eastern and central part. The western part being close to Gulf of Cambay is inherently saline and groundwater occurs at shallow depth. In some part of the coastal areas groundwater occurs in form of brine and that is being used for making salt. A large no of groundwater samples were analyzed for their potability for agricultural and drinking purpose. Most of the water samples in the study area do not meet the water quality standard due to presence of high ionic concentration. Poor water quality can be observed dominantly in central and western part. The study indicates that occurrence, distribution and sustainability of groundwater reserves largely depend upon the geological environment. i.e. fluvial, marine and aeolian and accordingly groundwater facies also varies. The present study also focuses on fluoride concentration and its lateral distribution. Fluoride above the guideline value of BSI has been found in groundwater of the central alluvial plains of the study area. The fluoride indicates positive correlation with pH, Alkalinity, Na, SO4 and boron while it has negative correlation with other ions. The study indicates that the source of fluoride and nitrate above the permissible limits is attributed mainly to geogenic processes and also due to rapid depletion of ground water table. Geospatial variability (high and low fluoride containing areas) map was generated with the help of Geographic Information System. The spatial distribution maps generated for fluoride (physicochemical parameter) using GIS techniques could be useful for planners and decision makers for initiating groundwater quality development in the area.

Key Words: *Fluoride, Groundwater, Geospatial, GIS, Inter-stream Area*

INTRODUCTION
Development of any area to a large extent depends upon the utilizable water resources present and its development potential. Rapid pace of industrial and agricultural development coupled with population growth has necessitated looking into the intricacies of hydrogeological regime with a view to re-examine the role of natural processes that affect the natural water resources in terms of both quality and quantity. Broadly the quality of groundwater dependent upon factors like mineral composition of the water bearing formations/host rock, residue time in aquifer, recharge and discharge within the basin and salinity ingress which can be grouped in contamination caused by natural processes. There are anthropogenic contaminations caused by different types of pollutants like industrial, agricultural and sewerage. Ground water quality in the study area is highly diverse and complex due to influence of sea water intrusion (coastal salinity), inherent sediments' salinity, quality deterioration due to overexploitation and pollution.

The Study Area
The area lies between 72º 30' E and 73º 43' E longitudes and 21º 40' N and 22º 53' N latitudes, falling in 46/ B, C, F, G, J & k topographic sheets of the Survey of India. The study area constitutes a part of Mahi - Narmada interstream (Doab) region of Gujarat state (Figure 1). The study area is characterized by diverse lithologies having varied chemical composition and physical properties. As a result there is variation in its

water bearing properties both in quality and quantity. The study indicates that this variation is both lateral and vertical, owing to hydrogeological conditions.

It has a distinct physiographic boundary and is bordered by the Gulf of Cambay in the West, the rocky uplands in the East, Mahi River in the North and Narmada River in the South and sprawl in about 11,000 sq km. The study area inhabitates sizable population and as per 2001 Census, population of the 18 Talukas falling within 03 districts was 25.61 lakh. Population density for this area is 243person/km². The study area is characterized by poor land use pattern with almost 50% of the land fall under un-irrigated area and less than 7% area as forest land. Only 19% area is benefited by irrigation facility (Census 2001).

The study area receives rainfall due to SW monsoon and is limited to the period between June to September. The period is further extended upto November month due to retreating monsoon. The rainfall data for 42 years i.e. from 1961 to 2003 from 18 rain gauge stations located within the study area have been used. The average rainfall for the study area stands at 858.99 mm. The mean annual rainfall gradually increases from west to the east. The highest rainfall recorded in the study area is at Savli station in the year 1976 with 2688.7 mm precipitation and lowest was recorded during 1968 with 101 mm at Kawant station. The observed highest average rainfall in last 42 years is 1720mm and rainfall probability of this magnitude is expected to occur once in 44 years. While in every 3 years the area receives rainfall above 1000mm. The 75% dependable annual rainfall is (the value of annual rainfall at the station that can be expected to be equal or exceed 75% times) i.e. 653mm./1.33 years (Dabral, 2009).

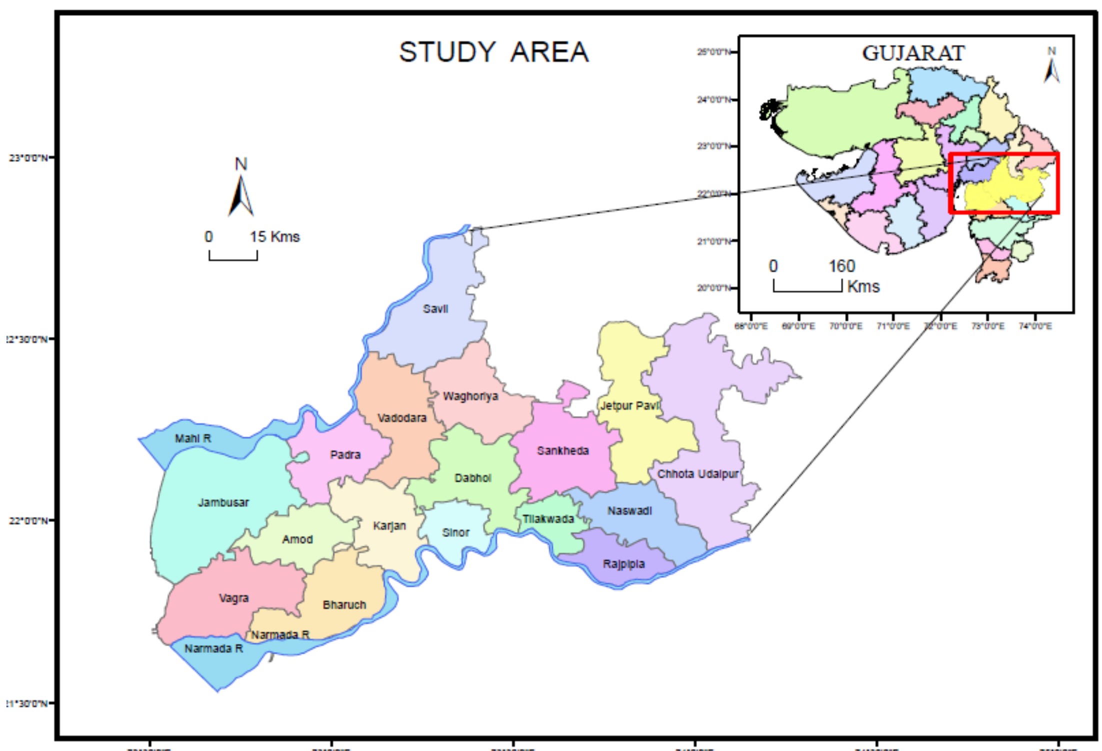

Figure1: Location Map of the Study Area

Geology of Study Area

The Cambay basin in Gujarat between latitudes 21º N & 24º N and longitudes 71º 31' E & 73º 30' E, is an intracratonic rift basin formed by discontinuous normal faults (*Biswas*, *1987*). The study area lies in southern part of Cambay basin which is a half graben. It is known to be a Cenozoic basin with basic lava flows forming the basement of the overlying Paleogene, Neogene and Quaternary sediments. The study area is a part of Mainland Gujarat and its geology is represented by Precambrain Crystallines, sedimentary rocks of Mesozoic (Cretaceous), Tertiary and Quaternary periods and the Deccan trap (Merh, 1995). The eastern part of the study area is exposed with basement gneissic complex, phyllite, schist, quartzite and post Delhi granites belonging to Precambrian Formation. The Precambrian rocks are unconformably overlained by the rocks of Bagh sedimentary sequence consisting of sandstone, shale and limestone of Cretaceous age. These are further intruded by extensive Deccan trap volcanics of Cretaceo-Eocene age (Figure 2). The western part lies in Jambusar-Bharuch alluvial tract of Cambay basin and that being part of 'Gujarat Alluvium Plains' comprises huge thickness of marine, fluvial and aeolian sediments predominantly alluvial phase, deposited during the Quaternary period (Merh and Chamyal, 1997). Subsurface water occurs in all the geological formations from porous media (consolidated and unconsolidated sedimentaries and alluvium) to hard rock formation (mainly metamorphics, intrusives and volcanics). The groundwater water in unconsolidated formation occurs in semi-confined to confined type of aquifers while in hard rock it is mainly confined to fractures and zone of weathering. Development of groundwater is mainly in unconfined conditions. The different conditions of groundwater occurrence in the state have led to divergent situations within different geological setup (CGWB, 2002). In alluvium area sand, gravel and Kankar represents ideal aquifers. In the alluvium domain, CGWB has identified five different aquifer zones. Though all five aquifers are not present throughout and not forming regional aquifers, but in eastern parts of the study area top three aquifers are seen hydraulically interconnected. The thickness of these aquifers also varies spatially and marked with distinct hydraulic properties (Table 1).

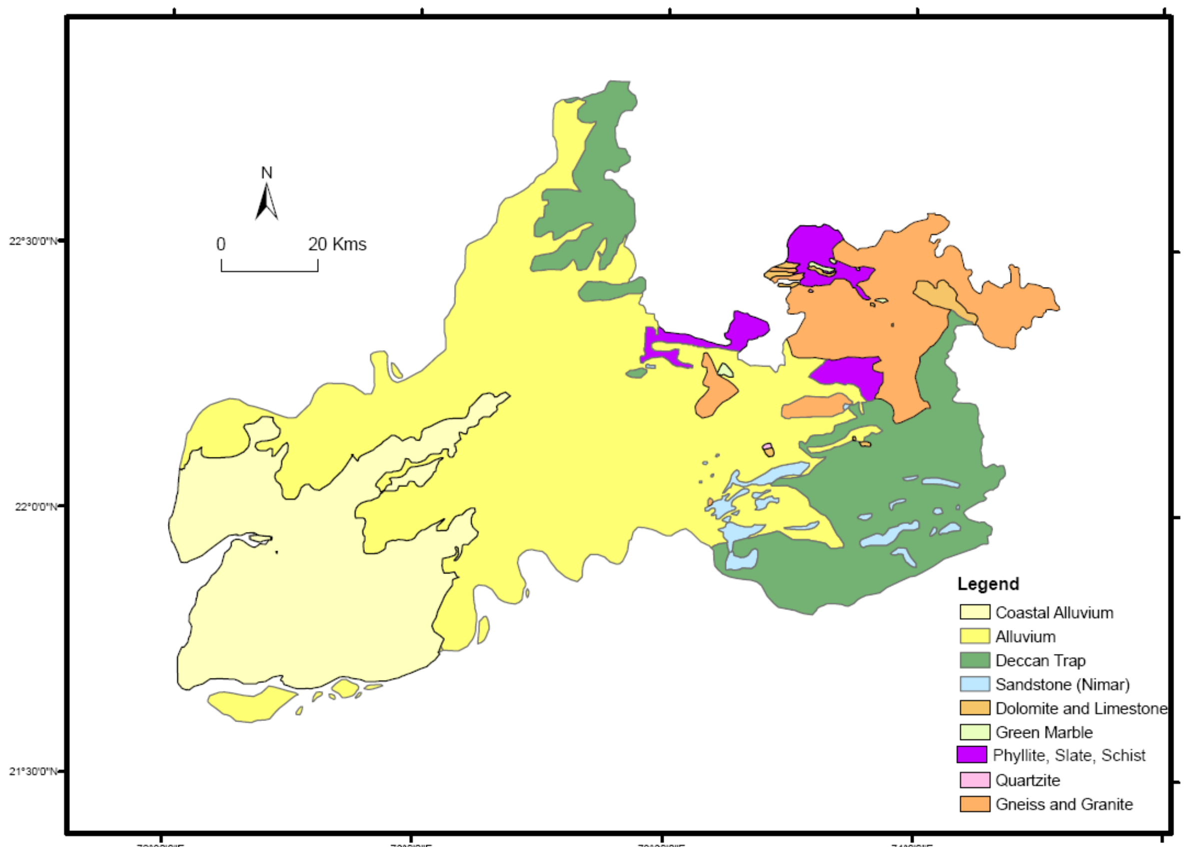

Figure 2: Geological Map of the Study Area (Complied After GSI)

Physiography and Geomorphology

Geomorphologically, the study area may be divided into four geomorphic zones viz.

a) The eastern uplands zone,

b) The intermediate pediment zone,
c) The central alluvial zone and
d) The low coastal zone.

The eastern upland zone is marked by the Aravalli and Shyadri range having steep gradient. The Pediment zone is characterized by colluvial deposits overlying basement rock. The landscape of the pediment zone is marked by both erosional (e.g. cliffs, scarps, residual bedrock terraces, cascades, rapids etc) and depositional features (valley fills, low terraces, badland etc).

Table 1: Hydrogeological Characteristic of Various Lithologies and Structures in Study Area

Lithology		**Hydrostructure**	***Hydraulic characteristic**	**Remarks**
Alluvium	Coastal Plain	--	High porosity but low permeability	Mainly present in coastal area consisting of fine clay. Groundwater is saline at shallow and deeper level.
	Central Plains	--	Average Q-1000, k-15.58 to 277.47, T-189 to 4716,	Because of presence of primary porosity and permeability these are the best sites for groundwater development.
Sandstone		Fractures and weathered zone	Q-100, k-0.37, T-39.61, c-0.06, S-0.88	Sandstone lacks primary porosity due to high cementing and compaction, groundwater is mainly available through joints and fractures.
Dolomite and Limestone		Jointed & Fractured	Q-600, k- 5 to 10, T-25 to 50	Due to lack of primary porosity and permeability they do not form good aquifers.
Deccan Trap		Intersected by joints and fractures, at places highly weathered	Q-600, k-4.89 to 12.60, T-42 to 78, S-0.13 to 0.28	Hard rock lacks primary porosity but water is present through joints, fractures, veins & vesicles etc.
Green Marble		Jointed & Fractured	Q-100, k-5 to 10, T-25 to50	The areal extent is not much hence do not form good aquifers.
Quartzite		Sheared, shattered jointed	Q-259, k-0.06, T-16.09, c-0.06, S-0.0179	Secondary porosity having moderate yield.
Phyllite, Slate, Schist		Jointed, Fractured, Folded & faulted	Q-90, k-0.624, T-91.33, c-0.033, S-0.019	Lack of permeability poor yield. However, localized aquifer may be of moderate potential.
Gneiss and Granite		Jointed, fractured & sheared	Q-442, k-3.71, T-26.13, c-0.106, S-0.0179	Secondary porosity, localized aquifers with moderate potential.

**source [GWRDC & CGWB]*
Q- Discharge (l/m), k-Hydraulic Conductivity (m/day), T- Transmissivityy (m^2/day), S-Storage Coefficient, c- Dimensionless coefficient

The central Alluvium zone comprises predominantly Quaternary deposit and forms the major part of the study area. Important features of the alluvial plains are flood plains, ravines, natural levees, point bars, buried channels, gullies, cliffs and scarps etc.

Table 2: Physiographic Controlling the Hydrogeological Conditions in the Study Area

Hydrogeological Attributes	**Physiographic units**			
	Highland Zone	**Piedmont Zone**	**Central Alluvium Plain Zone**	**Coastal Plain Zone**
Hydromorphology It includes geomorphic features favouring availability of groundwater occurrence.	Ground slope >24˚, Steep hilly terrain, shallow weathered zone, thin soil cover, high runoff, radial drainage pattern, mainly erosional features, dissected plateaus & hills, pediplains, residual hills, valley fills etc.	Ground slope 9-24˚, this zone is marked by landforms formed due to prolonged erosion and later filled up by deposition of sediments by various processes	Ground slope 3-9˚, gentle terrain, low lying plains, flood plains, river terraces, thick soil cover, sandy and influent river bed, buried river channels thick weathered profile.	Ground slope upto 3˚, flat monotonous land with little or no undulation. Major geomorphic features are mud flats, old mud flats, river mouth bars, plains and coastal sand dunes.
Hydrolithology: Variation of rock types their composition and texture in response to groundwater occurrence, distribution and total potential.	The consolidated formation lacks inherent porosity as a result water is present in secondary porosity as well as in weathered zone which is the important source of occurrence and distribution of groundwater.	Here also weathering is important source of groundwater movement. Shallower aquifers are unconfined in valley fills deposits and weathered zone. While deeper aquifers are semi-confined.	It comprises mainly of coarse sand and clay with subordinate proportion of gravel, kankar & silt. Because of intercalation of permeable and impermeable layer groundwater occurrence is in unconfined to semi-confined state.	The sediments comprises mainly of sand, silt and clay. Aquifer occurs mainly in semiconfined and unconfined state but the quality is very poor hence not much useful.
Hydrostructure: The effect of the joints, fractures, faults, folds, foliation, bedding & unconformity etc	Lineations, deep fracture & fault, fracture zone, fault & shear zone, lithologic contracts, interflow surfaces, dykes & master joints, bedding planes, foliations, columnar joints, vesicular cavities, redbole layers and local fractures.	The secondary porosity like fractures, lineaments, bedding planes etc offer conduits for groundwater movement	Because of soft sediments only primary porosity is responsible for groundwater movement and occurrence.	Groundwater is confined in primary porosity of soft sediments, structural secondary porosity is absent.

The western Coastal zone is characterized by flat terrain inhibiting recent mudflats, river mouth bars, beach sand ridges, raised mudflats, older alluvial plains, and bets that are formed under fluvial marine environment. The coastal belt also shows development of ravines which also continues along the banks of Mahi and Narmada rivers in upper reaches. The general trend of slope in the study area is due WSW. A detail about the various geomorphic zones and its affinity for groundwater is given in Table-2.

MATERIALS AND METHODS

Groundwater Hydro-Geochemistry in Study Area

A total of 101 samples were collected from study area in a well spaced grid pattern for geochemical analysis. Samples were collected from borewell (BW) as samples of deeper depth, handpump (HP) samples of intermediate depth and few open wells (OW) as shallow subsurface samples. The American Public Health Association (APHA) has prescribed standard analytical techniques for determining the dissolved chemical content in groundwater. The water analysis was carried out using standard methods given in "Standard methods for the examination of water and waste water". Geospatial variability (high and low fluoride containing areas) map was generated with the help of Geographic Information System. Fluoride contamination in the study was delineated using IDW spatial interpolation in GIS platform. Details in ionic content of groundwater are given in Table 3 wherein comparison is also shown with respect to drinking standard. And Piper's Trilinear plot is done for determining the genetic classification of the water.

Table 3: Comparison of Groundwater Samples from Study Area with Drinking Water Quality Standards

Sr. No	Parameters	ICMR (1975)	ISI (1983)	WHO (1993)	Post Monsoon 2003
			PHYSICAL PROPERTIES		
1	Colour (Hazen)	5 (25)	10	5 (50)	NA
2	Odour	Not Desirable	Unobjectionable	Not Desirable	NA
3	Taste (JTU)	"	Agreeable	"	NA
4	Turbidity	5 (25)	10	5 (25)	NA
			CHEMICAL PROPERTIES		
5	pH	7.0-8.5 (6.5-9.2)	6.5-8.5	7-8 (6.5-9.2)	6.65-8.48
6	TDS (mg/l)	500 (1500)	2000	500 (1500)	168-81000
7	TH (mg/l)	300 (600)	300	300 (600)	70-16100
8	Calcium (mg/l)	75 (200)	75	75 (200)	10.1-6115
9	Magnesium (mg/l)	50 (150)	30	50 (150)	0-260.9
10	Chloride (mg/l)	200 (1000)	250	200 (600)	60-50000
11	Sulfate (mg/l)	200 (400)	150	200 (400)	19-59189
12	Fluoride (mg/l)	1.0 (1.5)	0.6 (1.2)	--(1.5)	0.1-13
13	Nitrate (mg/l)	20 (50)	45	--(50)	0.2-325
14	Copper (mg/l)	0.05 (1.5)	0.05	1.0 (1.5)	NA
15	Iron (mg/l)	0.3 (1.0)	0.3	0.3 (1.0)	NA
16	Manganese (mg/l)	0.1 (0.5)	0.1	0.1 (0.5)	0-2.9
17	Zinc (mg/l)	5.0	5.0	5.0	NA

NA - Not Analyzed

RESULTS AND DISCUSSION

Behaviour of Groundwater in the Study Area

Study of seasonal behavior of water table provides insight to examine aquifers response to groundwater recharge and utilization, a key factor of groundwater management. Groundwater storage is affected by rainfall recharge, incipient recharge from irrigation field and seepage from canal losses. Whereas groundwater draft, evaporation and subsurface flow are the key players in overall decline in the storage.

In study area, water levels from the year 1993-2003 for nearly 76 wells have been studied for its pre and post monsoon fluctuations. The fluctuation values were compared with the corresponding rainfall to deduce the sensitivity of the aquifer to rainfall. As the recharge to the aquifers is rainfall dependent, overall water levels are lowest in the month of May (Pre-monsoon) whereas higher in November (Post-monsoon). Further, the rainfall begins in the month of June and maximum water level is acquired in October, thereby infiltration is by and large poor especially in alluvium area. Overall characterization on groundwater behavior is given in Table 4.

Table 4: Groundwater Behaviour in Study Area

Sr. No.	Physiographic Zones	Sediment Characteristics	Groundwater Gradient	Groundwater Movement Direction
1	Eastern Hilly Zone	Precambrian Crystalline sedimentary and Deccan Traps	1 : 93 (SE) 1:154 (NE)	NW and WNW
2	Piedmont Zone	Colluviums followed by rock	1:352	WNW, WSW and West
3	Central Alluvium Plain Zone	Unconsolidated flood plain deposits	1 : 653	NW and SW overall Westerly
4	Western Coastal Zone	Unconsolidated mud dominated sediments	1 : 2542	Westerly

The coastal plain consists of thick pile of alluvium material comprising high percentage of clay sediments.

The average decadal pre-monsoon level is 10.8m while post monsoon level is 8.6m with a positive rise of 2.2m in storage having a standard deviation of 1.2.

However, the overall trend of hydrographs in most of the coastal village indicate a declining groundwater levels and that may be attributed to growing demand due to increase in population as well as rapid industrialization of the area (Dabral, 2009). The alluvial plain consists huge thickness of flood plain deposits that are extensively been utilized for agricultural purpose.

The average of last one decade indicates that the minimum and maximum pre-monsoon level is 8.05m & 30.11m while that of post-monsoon is 4.48m and 28.22m respectively. Therefore, average decadal fluctuation indicates a minimum of -0.4m while maximum average fluctuation is 11.16m with a standard deviation of 2.28m (Dabral, 2009).

The narrow piedmont zone demarcates transitional strip between highlands on the eastern side to alluvial plains on the western side. In last ten years average pre-monsoon groundwater level is minimum at 2m and maximum at 19m while during post monsoon minimum is at 1m and maximum at 18m. The average mean change in water level is 1.94m with a standard deviation of 1.5 (Dabral, 2009).

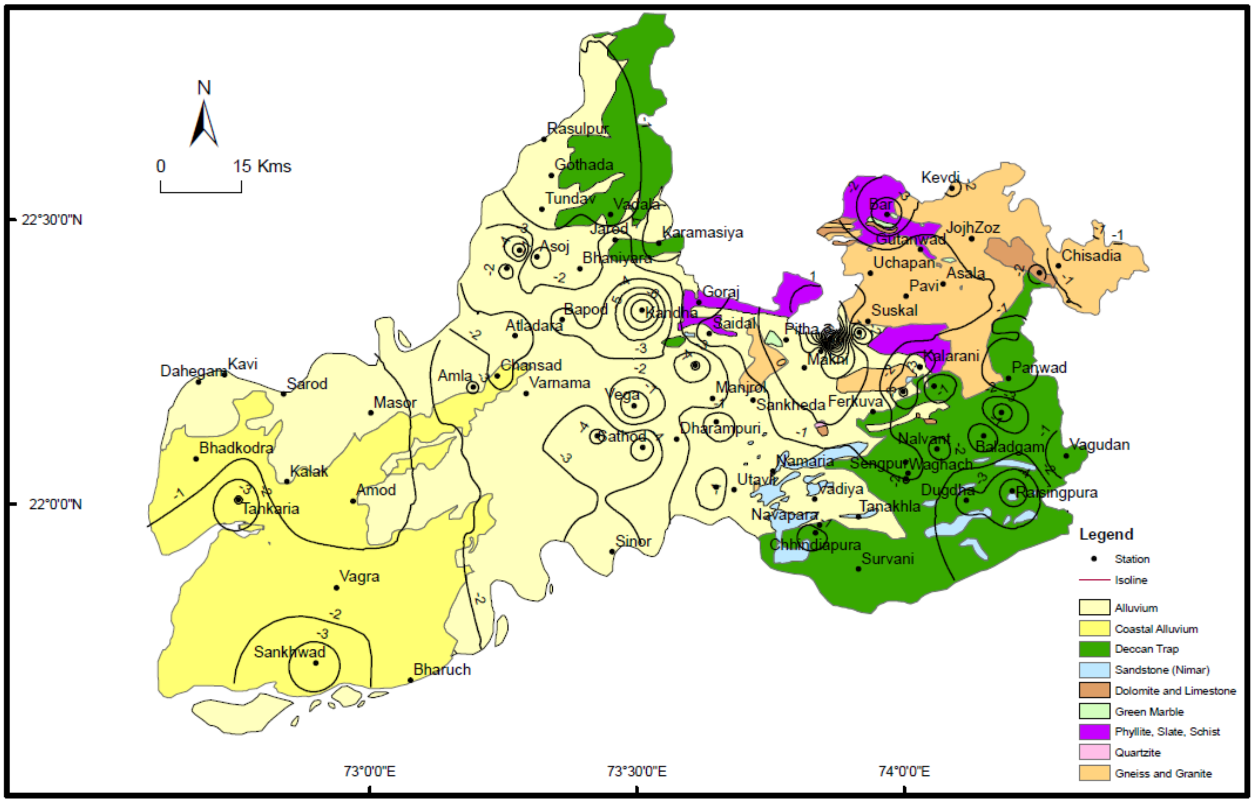

Figure 3: Decadal Changes in Water Level of the Study Area

The eastern highland zone is characterized by hard rock terrain signifying less population density, sporadic settlements and patchy agricultural land compared to alluvial plains of the study area. The decadal average pre-monsoon minimum and maximum water level stand at 4.7m and 12.55m respectively. While that of post-monsoon period is 3.5 and 10.8m respectively. However, in general there is declining trend in most of the areas (Dabral, 2009).

The decadal change in water levels of pre and post-monsoon depicts average water level fluctuation is ranging between 0.5 to 3.0m in low lying areas whereas 0.5 to 4.5m in high topographic regions.

The central part (west of Gorej village) shows maximum positive fluctuation upto 6m. Maximum decline of -3.1m has been observed in Tilakwada Taluka with minor decline in Sankheda and Padra Taluka (Figure 3.).

The observed negative change in Tilakwada and Padra Taluka may be attributed to excessive withdrawal (i.e. Demand > Recharge) due to population growth and industrialization of the area. Other areas show normal behavior on groundwater storage and at places show surplus resources.

Piper's Trilinear plot of the study area determining the genetic classification of the water indicates mean dominant cation in the order of $Na^{+} > Ca^{++} > Mg^{++} > K^{+}$, while anions shows $SO_4^{2-} > Cl^{-} > HCO_3^{-}$. Most of the coastal samples fall in NaCl domain while few in CaCl and Ca-Mg-HCO_3 domain.

Samples from shallow aquifers (including open well) of the coastal plain falls in NaCl > CaCl > Na-HCO_3 domain. Overall groundwater facies is Na^{+} - Ca^{++} - Mg^{++} - K^{+}: SO_4^{2-} - Cl^{-} - HCO_3^{-} type (Figure 4). Genetic classification of groundwater samples based on Piper's Trilinear plot is given in Table 5.

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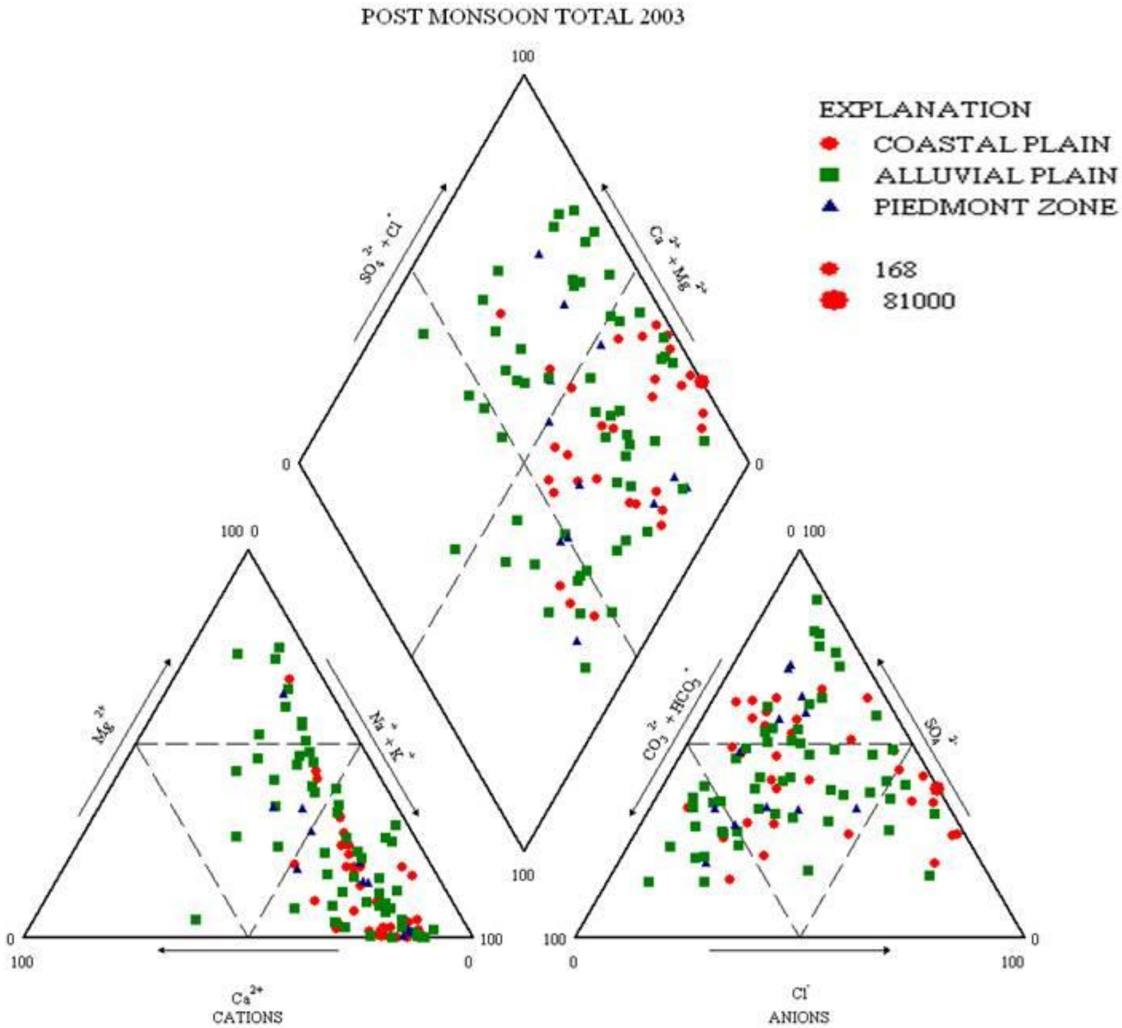

Figure 4: Piper Trilinear Plot of Groundwater Samples in Study Area (Post-monsoon 2003)

Table 5: Genetic Classification of Groundwater Samples based on Piper Trilinear Diagram

Field No.	Description based on piper fields	Total No. of Post-monsoon 2003 Samples
I	Alkaline earth exceeds alkalies	27
II	Alkalies exceed alkaline earth	74
III	Weak acid exceed strong acids	21
IV	Strong acids exceed weak acids	80
V	Carbonate hardness exceeds 50%	5
VI	Non-carbonate hardness exceeds 50%	7
VII	Non-carbonate alkali exceeds 50%	55
VIII	Carbonate alkali exceeds 50%	1
IX	No one cation anion pair exceeds 50%.	32

Geospatial Detection of Fluoride in Groundwater

Geographic Information System (GIS) can be a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment, and managing water resources on a local or regional scale (Collet, 1996). GIS based interpolation permits representation of point data in a continuous spatial domain and therefore helps in understanding the spatial variability of the phenomenon (Gao, 1995). Though there are a number of spatial interpolation techniques available in GIS, in the present study spatial interpolation technique using inverse distance weighted (IDW) approach were used to delineate the locational distribution of fluoride contamination in water sources. It is one of the standard spatial interpolation procedures in geographic information science (Burrough and McDonnell, 1998) which uses a defined or selected set of sample points for estimating the output grid cell value. It determines the cell values using a linearly weighted combination of a set of sample points. The method controls the significance of known points upon the interpolated values based upon their distance from the output point thereby generating a surface grid as well as thematic isolines. A similar approach is used to delineate ground water recharge zones superimposing TDS contour map to validate the qualitative suitability of groundwater development (Dabral and Sharma, 2013). To detect the fluoride in the study area the laboratory tested fluoride sample location were taken-up for IDW interpolation

Status of Fluoride in Study Area

In the study area high fluoride (F^-) concentration beyond permissible limit has been observed from ten locations. These sites includes Kaliari BW (2.1 mg/l), Nada BW (3.8 mg/l), Ambada BW (2.2 mg/l), Vadodara city BW (1.9 mg/l), Makarpura HP (3.8 mg/l), Khervadi BW (2.8 mg/l), Nariya BW (2.2 mg/l), Anguthan BW (7.0 mg/l) & HP (2.6 mg/l) and Bhimpura HP (13 mg/l). Fluoride concentration at different sampling site is shown in Figure 5, while spatial distribution pattern is given in Figure 6.

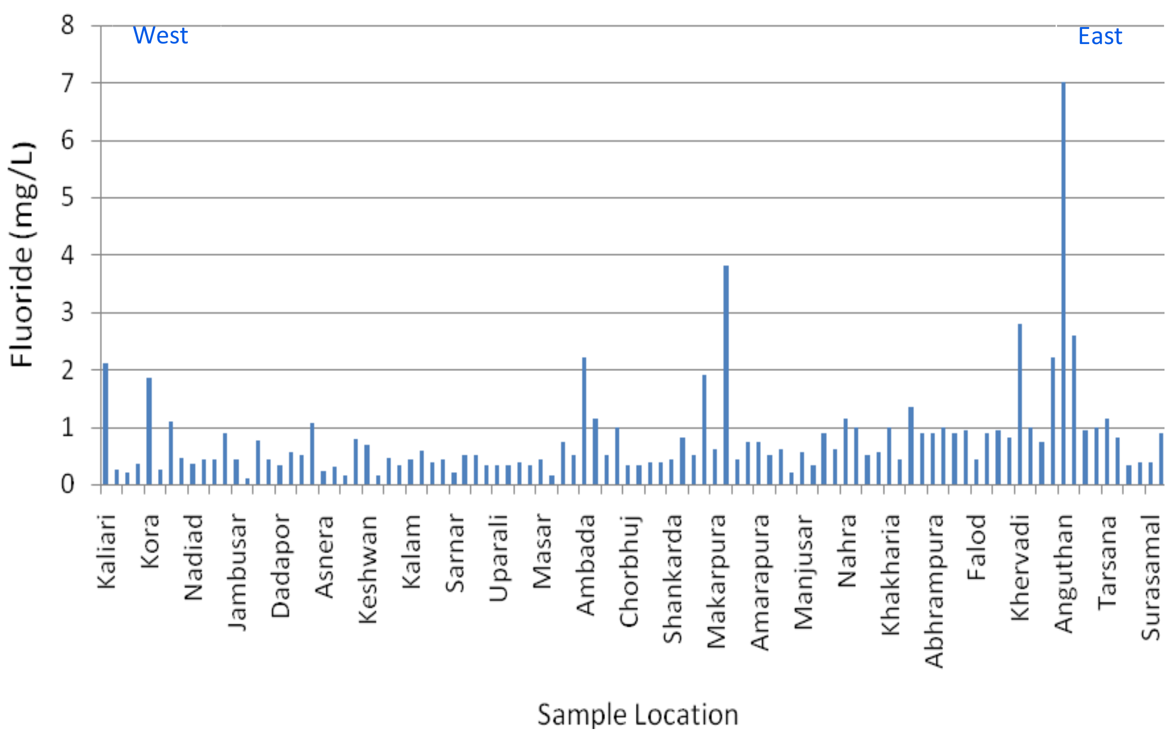

Figure 5: Post-monsoon Fluoride Concentrations in Groundwater of the Study Area

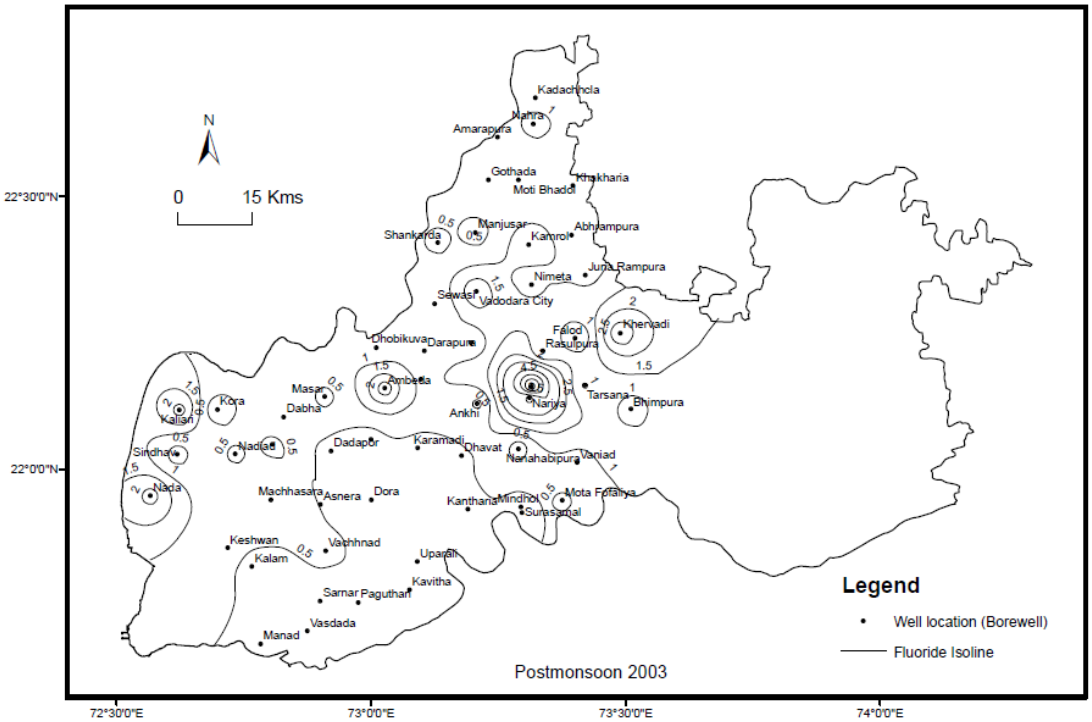

Figure 6: Iso-Fluoride Concentration Map of the Study Area (Post-monsoon 2003)

Fluoride is mainly derived from rock/mineral water interaction. The highlands are having basalt and carbonate rocks consisting fluorite mineral. Most of the rivers draining the area originate from these highlands and during the process, dissolution and precipitation of fluoride take place in lower reaches. As the water samples were mainly collected from wells utilized for the irrigation purpose therefore, no deleterious effect on human health is observed in the study area. Statistical analysis of fluoride in the study area is shown in Table 6.

Table 6: Statistical Analysis for Fluoride Distribution in Study Area

Sr. No.	Statistical Input	Post Monsoon 2003
1	Mean	0.94
2	Median	0.50
3	Minimum	0.10
4	Maximum	13
5	Standard Deviation	1.5

Correlation matrix has also been used to study the possible relationship between the fluoride concentration and other physico-chemical parameters. Mg, Si, Mn, total hardness, Cl, K, Ca, Sr, TDS, Ec and nitrate indicates correlation with fluoride concentration in an increasing order. Fluoride shows +ve correlation with sulphate, sodium, pH and boron whereas it has strong correlation with alkalinity while with other ions it shows –ve correlation. However, –ve correlation with magnesium and nitrate is expected due to low solubility of these ions (Hem, 1971; Das, 2003). Correlation of fluoride with some of the ions is shown in Figure 7.

The correlation coefficient among various chemical variable shows pH having –ve correlation with most of the parameters except alkalinity and potassium.

Table 7: Correlation Matrix for Water Quality Parameters in the groundwater for Post-monsoon 2003 season (N=101)

Variables	pH	EC	TDS	Na	Ca	Mg	K	Alkalinity	TH	SO_4	Cl	NO_3	F	B	Si	Sr	Mn
pH	1.00	-0.11	-0.11	-0.07	-0.17	-0.29	0.00	0.09	-0.29	-0.18	-0.17	-0.06	0.18	-0.01	-0.14	-0.21	-0.39
EC		1.00	0.98	0.83	0.90	0.23	0.04	-0.05	0.80	0.52	0.90	0.48	-0.02	0.37	-0.05	0.73	0.15
TDS			1.00	0.80	0.89	0.19	0.01	-0.05	0.77	0.49	0.87	0.51	-0.02	0.35	-0.04	0.73	0.15
Na				1.00	0.81	0.06	-0.03	0.08	0.64	0.62	0.90	0.51	0.06	0.45	-0.10	0.67	-0.07
Ca					1.00	0.14	0.09	-0.08	0.83	0.55	0.88	0.53	-0.06	0.38	-0.02	0.81	0.12
Mg						1.00	-0.01	-0.24	0.68	0.24	0.26	-0.03	-0.32	-0.01	0.35	0.23	0.47
K							1.00	0.15	0.06	0.07	-0.01	0.12	-0.08	-0.01	0.09	0.04	-0.25
Alkalinity								1.00	-0.20	0.17	-0.17	0.10	0.56	0.42	-0.12	-0.11	-0.28
TH									1.00	0.55	0.81	0.38	-0.23	0.28	0.18	0.74	0.33
SO_4										1.00	0.49	0.25	0.01	0.48	-0.07	0.35	0.00
Cl											1.00	0.47	-0.08	0.30	-0.01	0.75	0.19
NO_3												1.00	-0.01	0.15	0.08	0.39	-0.09
F													1.00	0.21	-0.31	-0.04	-0.23
B														1.00	-0.05	0.32	0.05
Si															1.00	-0.03	0.15
Sr																1.00	0.02
Mn																	1.00

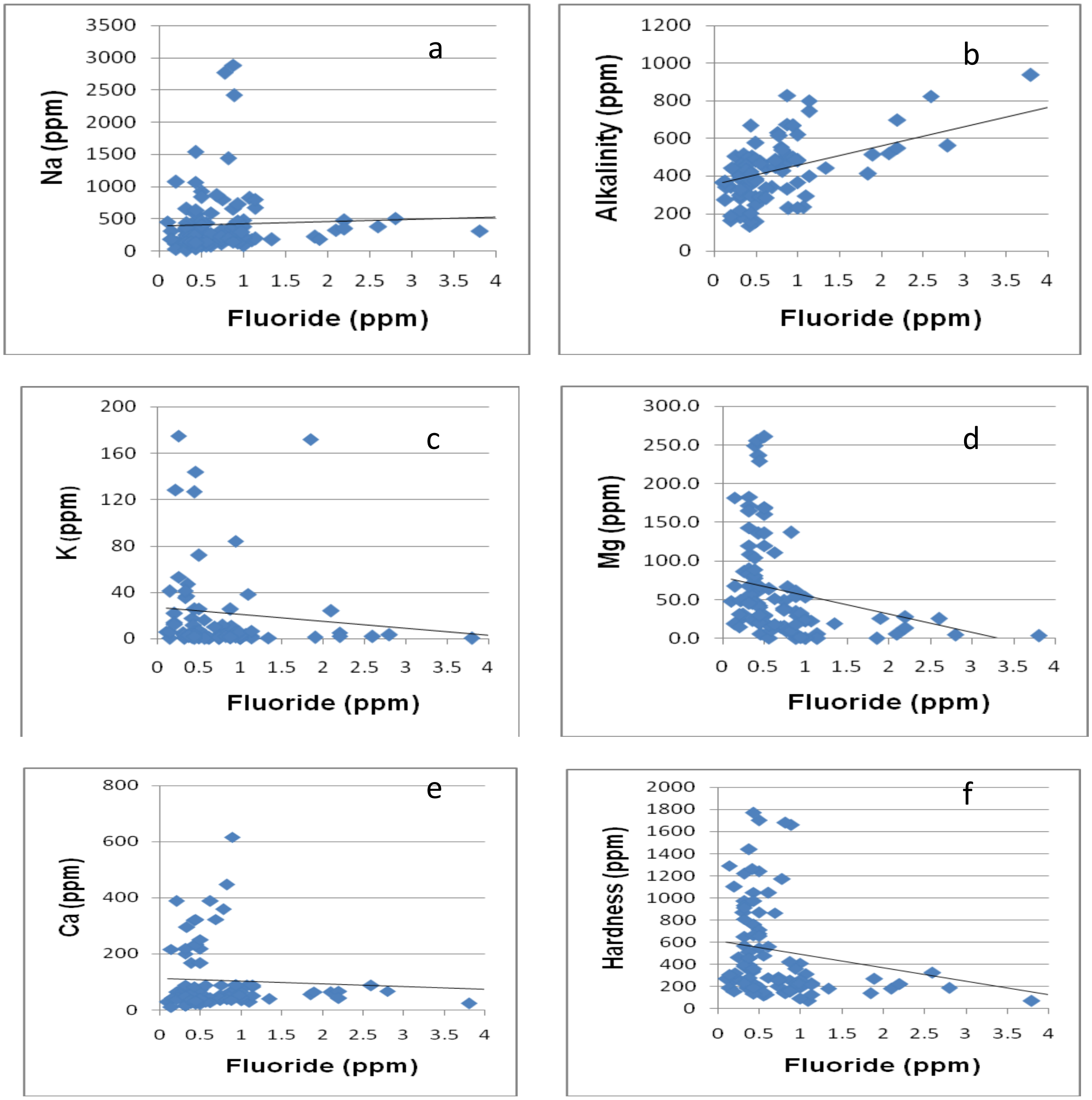

Figure 7: Graph showing Variation Correlation of fluoride with different ions (a) Na+ vs F-, (b) Total Alkalinity vs F-, (c) K+ Vs F-, (d) Mg++ Vs F-,(e) Ca++ vs F- and (f) Hardness vs F-. The solid lines indicate trends

The correlation of Ec with alkalinity & fluoride is –ve while with others ions it has +ve correlation. Sodium has –ve correlation with potassium, manganese and silica in an increasing order while shows +ve correlation with other ions. Calcium is strongly correlatable with Cl, total hardness, Sr, Sulphate, NO_3 and boron in a decreasing order. Manganese is strongly correlatable with Mg, TH, Cl, Ec, Si, TDS, Ca, B, Sr and SO_4 in a decreasing order. Strontium shows strong +ve correlation with Ca, chloride, TH, EC, TDS & Na in a decreasing order. Silica shows +ve correlation with Mg, TH, Mn, K and NO_3 in a decreasing order. Boron has –ve correlation with pH, Mg, K and Si (Table 7). Fluoride ions inhibit a variety of enzymes often by forming complexes with magnesium ions and other metal ions (Andezhath, 1999; Pillai, 2002).

Conclusion

Most of the water samples in the study area do not meet the water quality standard due to presence of high ionic concentration. The dominating ground water facies in the study area is Na-Mg-Ca-K: SO_4-Cl-4CO_3 type. Groundwater quality tends to deteriorate from eastern hilly zone to western coastal plains which follow the ground water gradient direction. The groundwater movement direction as evident from reduced water level map indicates that highlands act as a recharge zone to the shallow and deeper aquifers. Fluoride concentration beyond the permissible limit is found in limited number of samples while others are within the safe limit. Moreover, some of the inland groundwater samples show high fluoride concentration both for shallow and deeper aquifers. The excess fluoride concentration in the study area than the permissible limits is attributed to the geogenic processes and also due to rapid depletion of ground water. It has been observed that in high fluoride concentration area the samples were taken from the wells which were mainly utilized for the irrigation purpose hence so far the case of fluorosis has not been highlighted from the fluoride affected zone.

The study has demonstrated the utility of GIS technology along with laboratory analysis in assessing fluoride in groundwater. The spatial distribution maps generated for fluoride (physicochemical parameter) using GIS techniques could be useful for planners and decision makers for initiating groundwater quality development in the area.

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