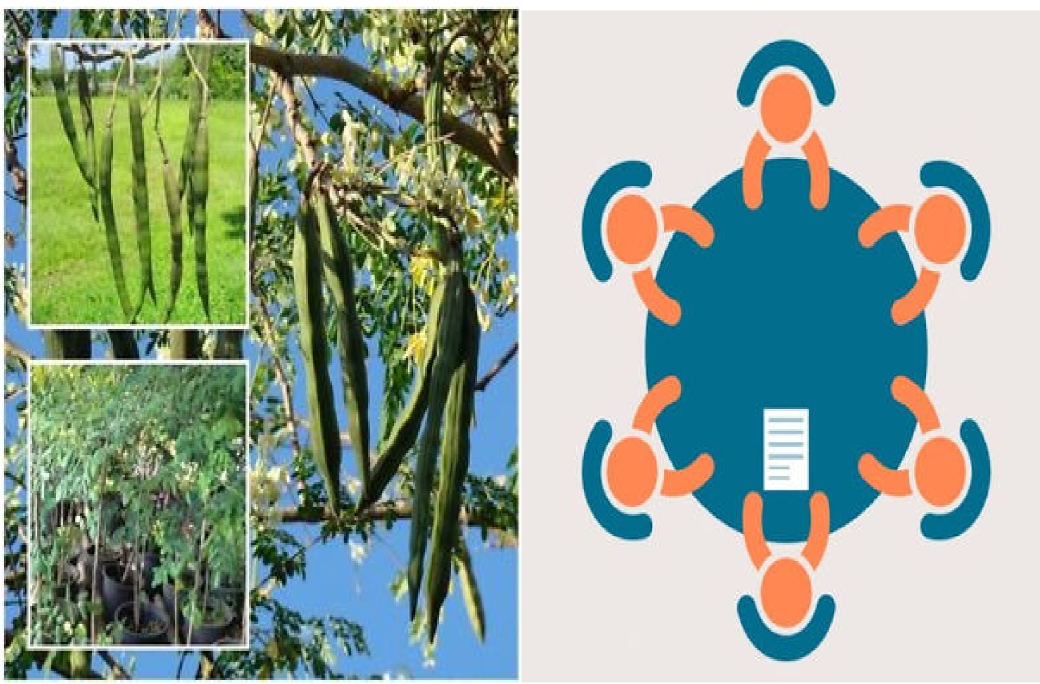
CHAPTER 3



RESULTS AND DISCUSSION

3 RESULTS AND DISCUSSION

3.1 Survey and selection of groundwater samples from North Gujarat and Saurashtra

3.1.1 Mapping Fluoride concentration in Districts

The study aimed at mapping average Fluoride concentration of North Gujarat and Saurashtra from tubewell and well (Plate 1) in five main districts of North Gujarat (two districts) and Saurashtra (three districts) during the year 2009-12. These were Mehsana, Patan, Jamnagar, Amreli and Rajkot. This selection was based on the data obtained from GWSSB on Fluoride concentration in groundwater for the district. The results on average Fluoride content for each district have been described in detail as under:

3.1.1.1 North Gujarat

- **Mehsana District :**

  To map average Fluoride concentration of the district, seven talukas (Table 2) were selected. These were Mehsana, Visnagar, Vadnagar, Kheralu, Unjha, Kadi and Satlasana. Groundwater samples from 30 villages of each taluka were collected and analysed. The samples were collected from bore well, tube wells and village wells during the study period.

  In Mehsana taluka, maximum concentration of Fluoride was recorded in the bore well sample of village Charadu (Fig. 8) (1.17 ppm) whereas the minimum from village Gojhariya (0.29 ppm). Fluoride concentration in the villages of Visnagar taluka was found (Fig. 9) to be ranged from 0.84 (Gothva) to 1.81 ppm (Valam). Maximum Fluoride concentration was recorded in the village Sultanpur (2.14 ppm) and the minimum in Molipur (0.94 ppm) in Vadnagar taluka (Fig. 10). In Kheralu taluka (Fig. 11), maximum concentration of Fluoride was recorded in the well sample of village Dabhoda (4.48ppm) whereas the minimum was in village Lunva (0.46 ppm). In Unjha taluka (Fig. 12), concentration of Fluoride was maximum in the bore well sample of village Upera (2.1 ppm) whereas minimum in village

PLATE 1

Kantharavi (0.65 ppm). In the villages of taluka Kadi (Fig. 13), the Fluoride concentration ranged from 2.35 (Dangarva) to 0.89 ppm (Nandasan). It was Maximum in village Nana Kothasana (4.6 ppm) and the minimum in village Isakpura (0.45ppm) of Satlasana taluka.

Out of total 30 villages surveyed, Nana Kothasana of Satlasna taluka recorded the highest Fluoride content i.e. 4. 6 ppm while Gojhariya of Mehsana takuka showed the minimum (0.29 ppm). In the remaining 28 villages, the level of Fluoride was recorded within 0.29-4.6 ppm range. From the data obtained, it is clear that Fluoride content in 10 villages (33.33%) was found beyond permissible limit. i.e. 1.5 ppm and in 17 villages (56.66%) it was within the range (0.5-1.5). There were 3 villages (10%) in which the level of Flouride remained even below the required Fluoride concentration i.e. 0.5 ppm

- **Patan District :**

Fluoride concentration in groundwater samples from 30 villages that belonged to seven talukas (Table 3) of Patan District was estimated. These were Chanasma, Harij, Patan, Radhanpur, Sami, Santalpur and Sidhpur.

In Chanasma taluka (Fig.15), maximum concentration of Fluoride was recorded in the bore well sample of village Sunsar (1.23 ppm) whereas the minimum in the village Palasar (0.86 ppm). In the villages of Taluka Harij (Fig. 16), Fluoride content ranged from 0.46 (Govna) to 1.83 ppm (Boratvada). It was Maximum in village Balisana (2.13 ppm) and minimum in village Kharivavdi (0.74 ppm) of Patan taluka (Fig. 17). In Radhanpur (Fig. 18) taluka, maximum concentration of Fluoride was recorded in the well sample of village Gulabpura (2.1 ppm) whereas the minimum was recorded for village Nanapura (0.63 ppm). In Sami taluka (Fig. 19), the bore well sample of village Mujpur (1.47 ppm) estimated maximum concentration of Fluoride whereas minimum in village Kathi (0.69 ppm). The content of Fluoride in the villages of Taluka Santalpur (Fig. 20) was found ranging from 0.82 (Babra) to 1.84 ppm (Korda). Maximum Fluoride concentration was recorded in village Chandravati (1.39 ppm) and the minimum in village Metrana (0.75 ppm) in Sidhpur taluka (Fig.21).

Out of total 30 villages surveyed, Gulabpura of Radhanpur taluka showed the highest Fluoride content i.e. 2.1 ppm while Nanapura of showed the minimum (0.63 ppm). In the remaining 28 villages, the level of Fluoride was recorded within 0.63-2.1 ppm range. From the data obtained it is depicted that Fluoride concentration in 7 villages (23.33%) was found beyond permissible limit. i.e. 1.5 ppm and in 22 villages (73.33%) it was within the range (0.5-1.5). There was 1 village (3.33%) in which the concentration of fluoride was recorded even less than 0.5 ppm.

Table 2 : Average Fluoride Concentration in Mehsana

Sr. No.	Taluka	Village	Fluoride mg/l
1	Mehsana	Ambasan	0.7
2	Mehsana	Boriavi	1.2
3	Mehsana	Charadu	1.17
4	Mehsana	Gojhariya	0.29
5	Visnagar	Basana	1.6
6	Visnagar	Gothva	0.84
7	Visnagar	Kamalpur	1.76
8	Visnagar	Udalpur	0.96
9	Visnagar	Valam	1.81
10	Vadnagar	Badarpur	1.43
11	Vadnagar	Sultanpur	2.14
12	Vadnagar	Sundhiya	1.47
13	Vadnagar	Molipur	0.94
14	Kheralu	Dabhoda	4.48
15	Kheralu	Chansol	1.2
16	Kheralu	Kuda	0.58
17	Kheralu	Lunva	0.46
18	Kheralu	Samoja	1.3
19	Unjha	Kanthravi	0.65
20	Unjha	Upera	2.1
21	Unjha	Dasaj	1.26
22	Kadi	Ankhol	0.93
23	Kadi	Dangarva	2.35
24	Kadi	Ghumasan	1.73
25	Kadi	Nandasan	0.89
26	Satlasana	Nana Kothasana	4.6
27	Satlasana	Isakpura	0.45
28	Satlasana	Santola	0.82
29	Satlasana	Vaghar	0.92
30	Satlasana	Timba	1.6

Table 3 : Average Fluoride Concentration in Patan

Sr. No.	Taluka	Village	Fluoride mg/l
1	Chanasma	Vadavli	0.93
2	Chanasma	Sunsar	1.23
3	Chanasma	Palasar	0.86
4	Chanasma	Khokhla	1.12
5	Harij	Govna	0.46
6	Harij	Sarer	1.32
7	Harij	Tharod	0.67
8	Harij	Boratvada	1.83
9	Patan	Aghar	0.94
10	Patan	Charup	1.57
11	Patan	Balisana	2.13
12	Patan	Ganeshpura	1.94
13	Patan	Kharivavdi	0.74
14	Radhanpur	Vadnagar	1.28
15	Radhanpur	Nanapura	0.63
16	Radhanpur	Lotiya	0.82
17	Radhanpur	Sardarpura	1.78
18	Radhanpur	Gulabpura	2.1
19	Sami	Biliya	0.72
20	Sami	Godhana	0.83
21	Sami	Kathi	0.69
22	Sami	Mujpur	1.47
23	Santalpur	Babra	0.82
24	Santalpur	Jakhotra	0.93
25	Santalpur	Sherpura	1.37
26	Santalpur	Korda	1.84
27	Sidhpur	Chandravati	1.39
28	Sidhpur	Kalyana	1.15
29	Sidhpur	Metrana	0.75
30	Sidhpur	Nedra	0.84

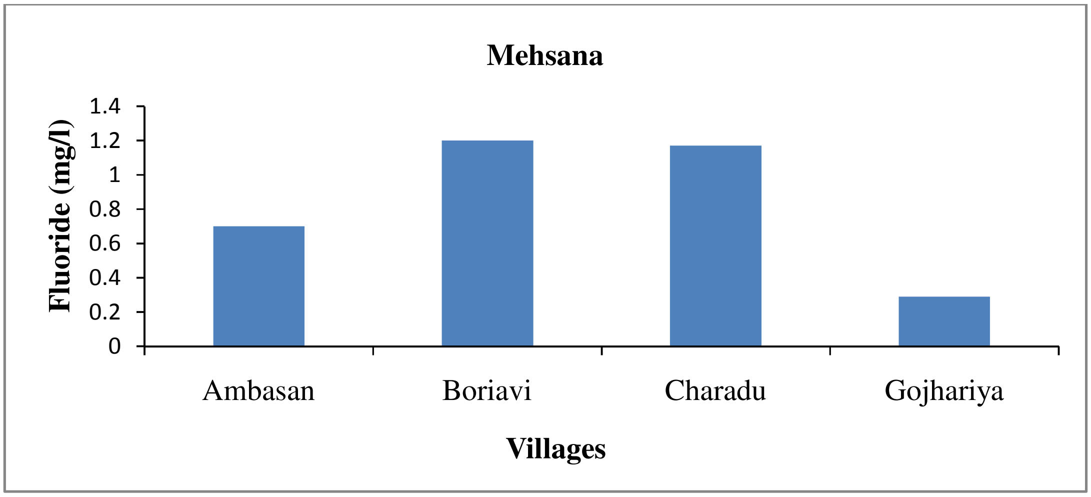


Figure 8 : Fluoride Content in Villages of Mehsana Taluka

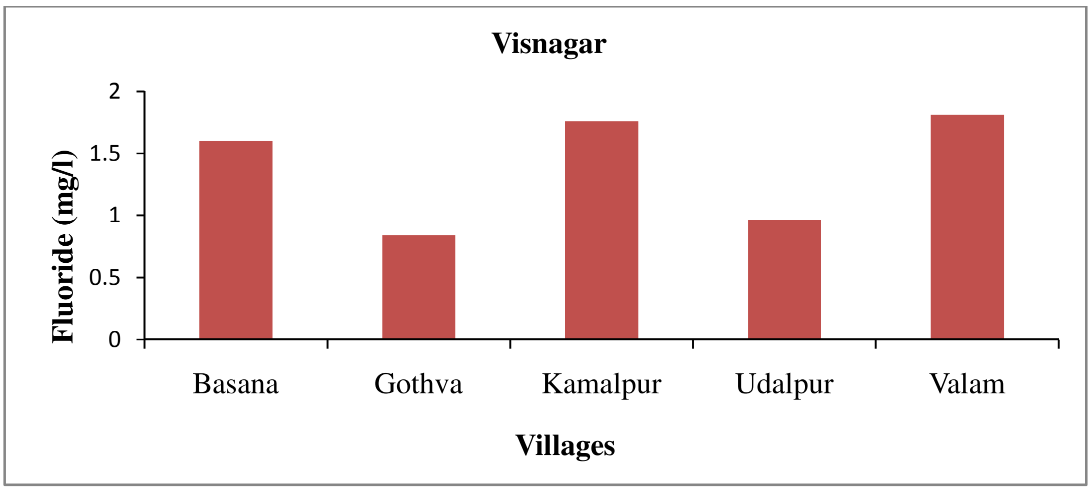


Figure 9 : Fluoride Content in Villages of Visnagar Taluka

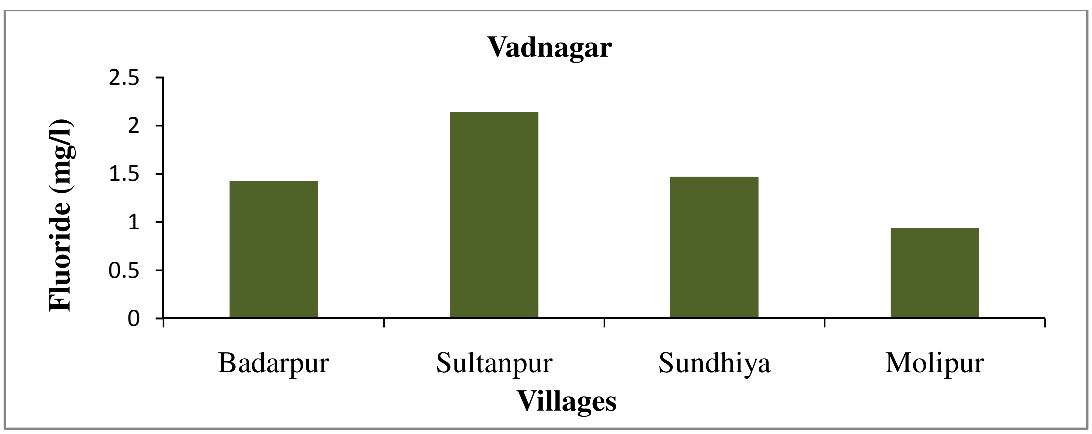


Figure 10 : Fluoride Content in Villages of Vadnagar Taluka

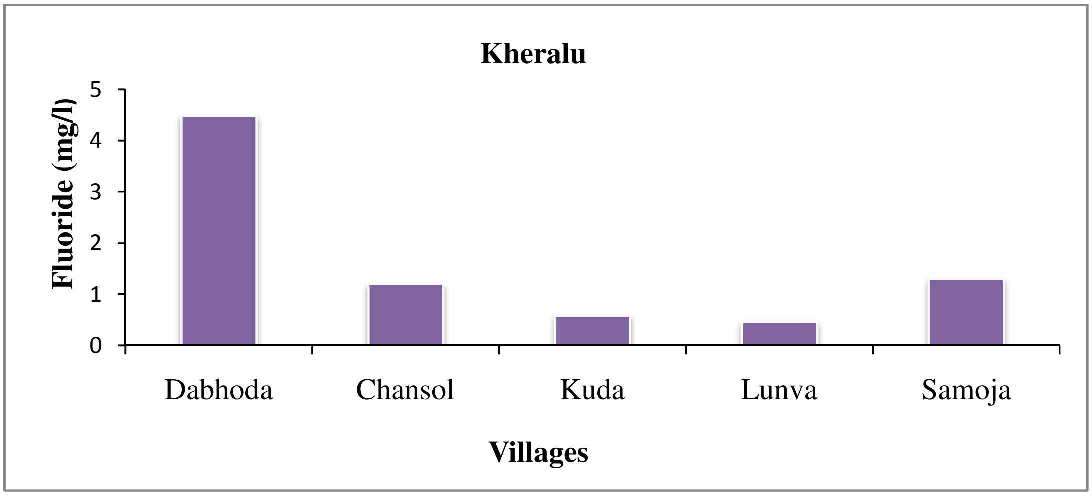


Figure 11 : Fluoride Content in Villages of Kheralu Taluka

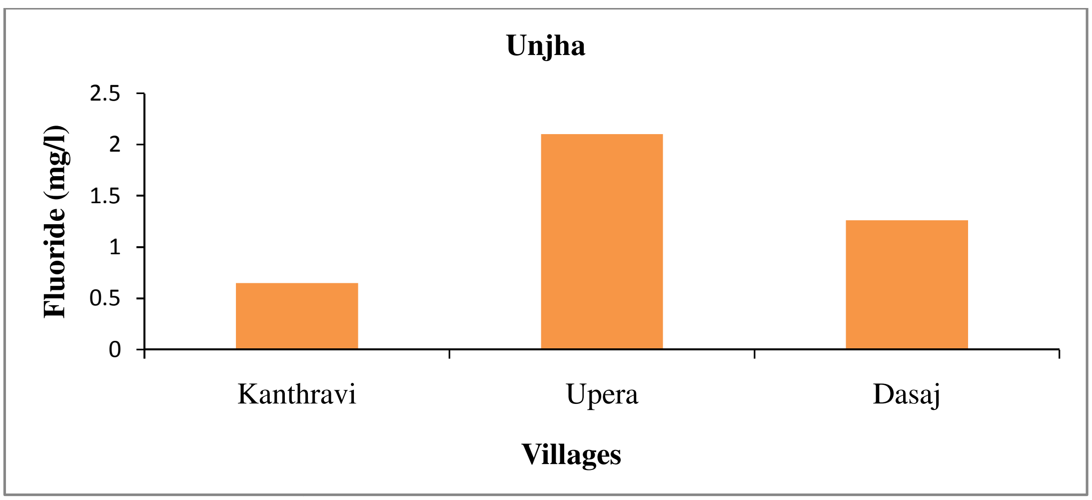


Figure 12 : Fluoride Content in Villages of Unjha Taluka

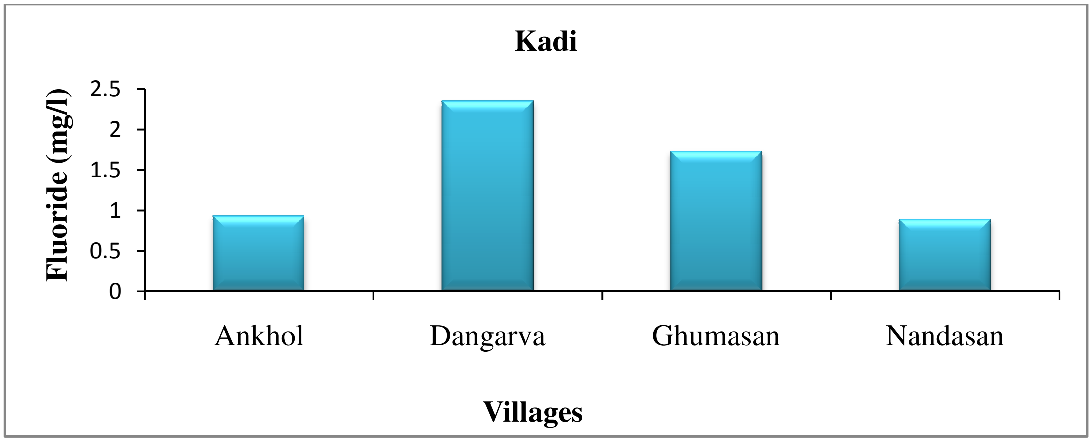


Figure 13 : Fluoride Content in Villages of Kadi Taluka

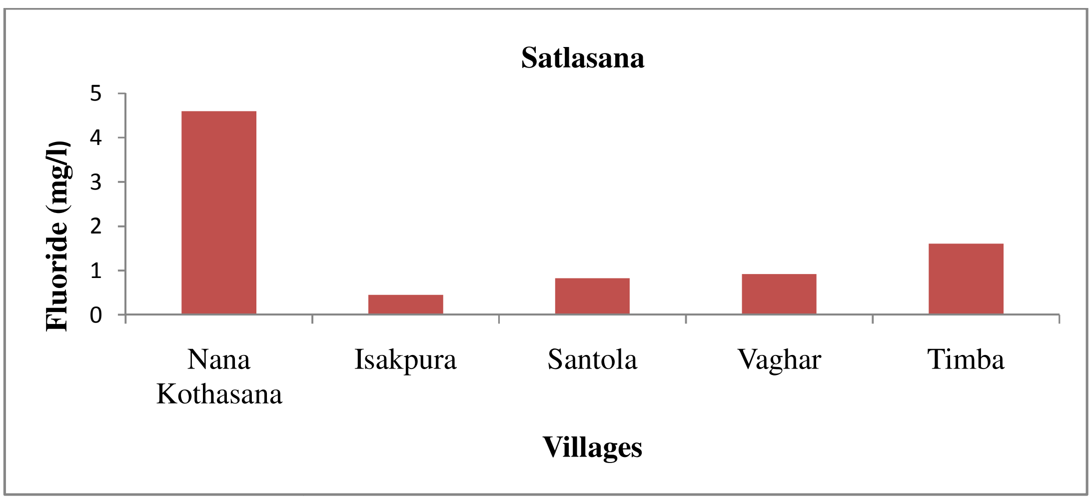


Figure 14: Fluoride Content in Villages of Satlasana Taluka

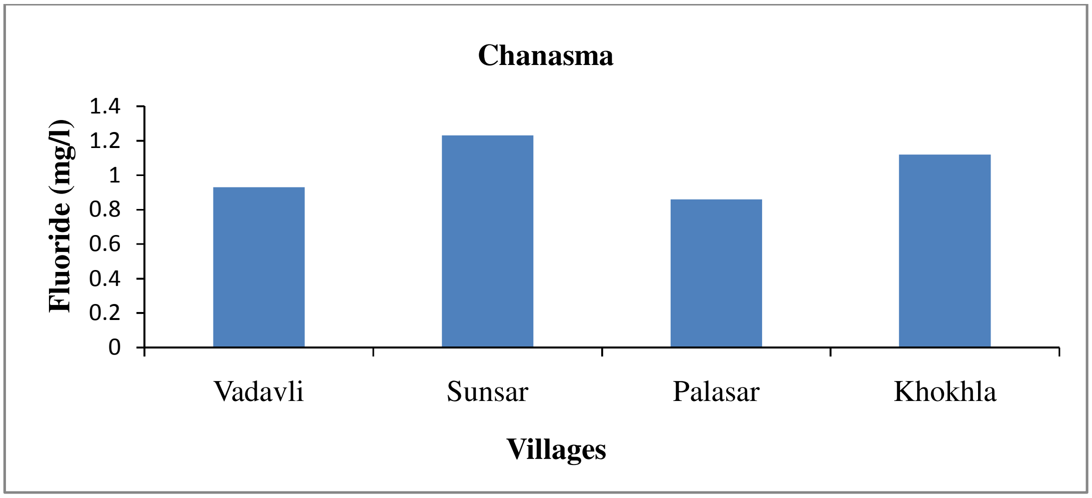


Figure 15: Fluoride Content in Villages of Chanasma Taluka

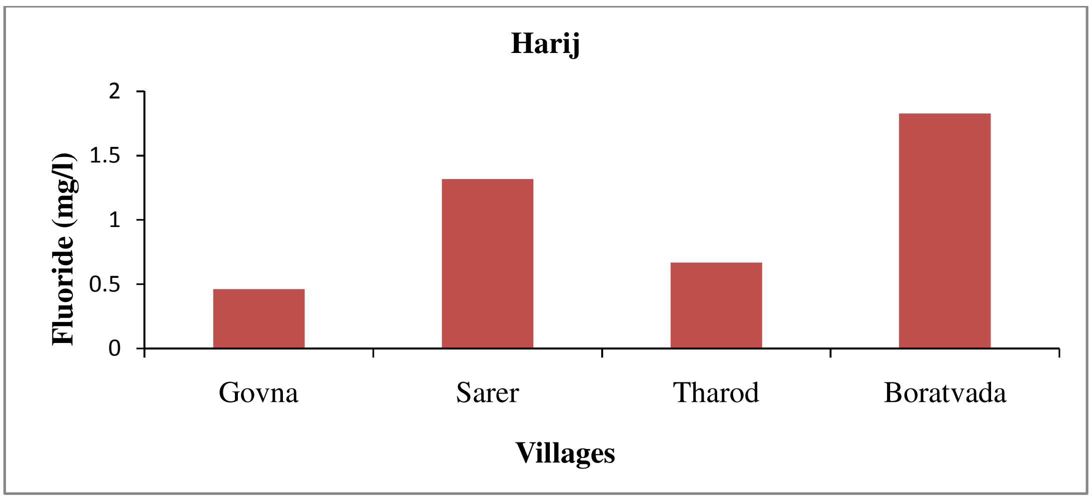


Figure 16: Fluoride Content in Villages of Harij Taluka

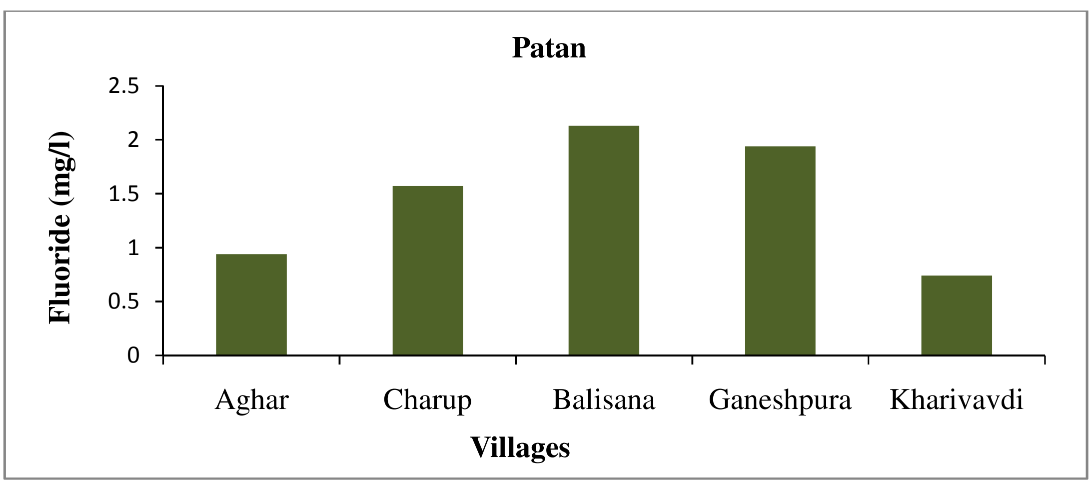


Figure 17: Fluoride Content in Villages of Patan Taluka

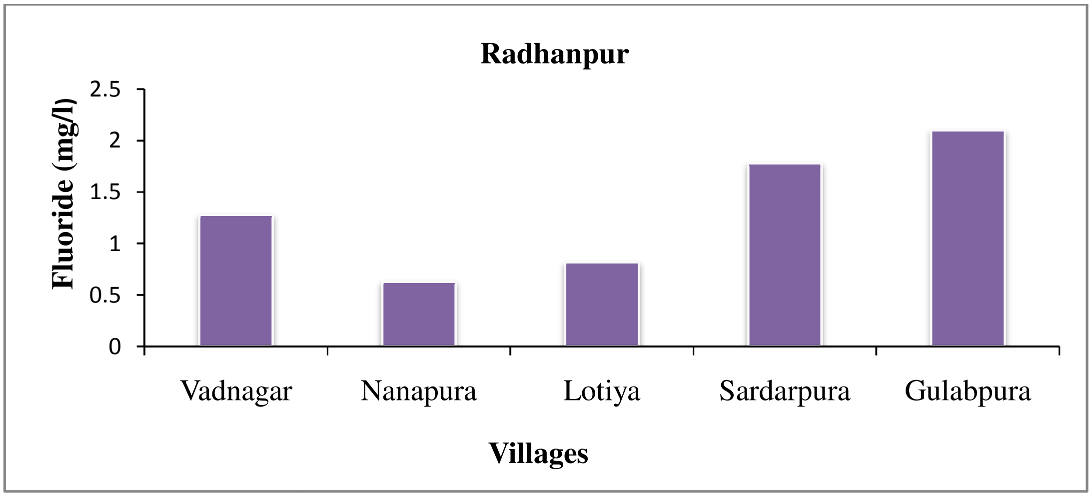


Figure 18: Fluoride Content in Villages of Radhanpur Taluka

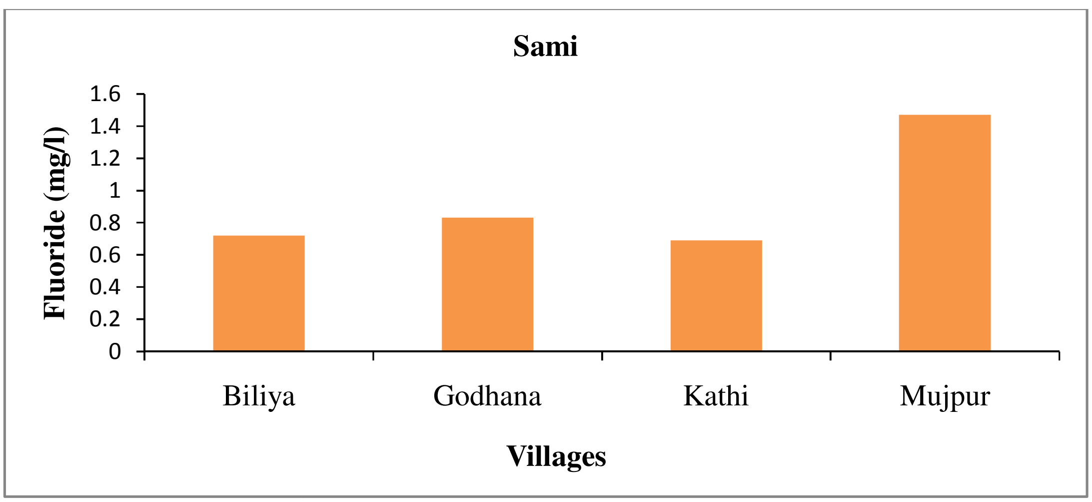


Figure 19: Fluoride Content in Villages of Sami Taluka

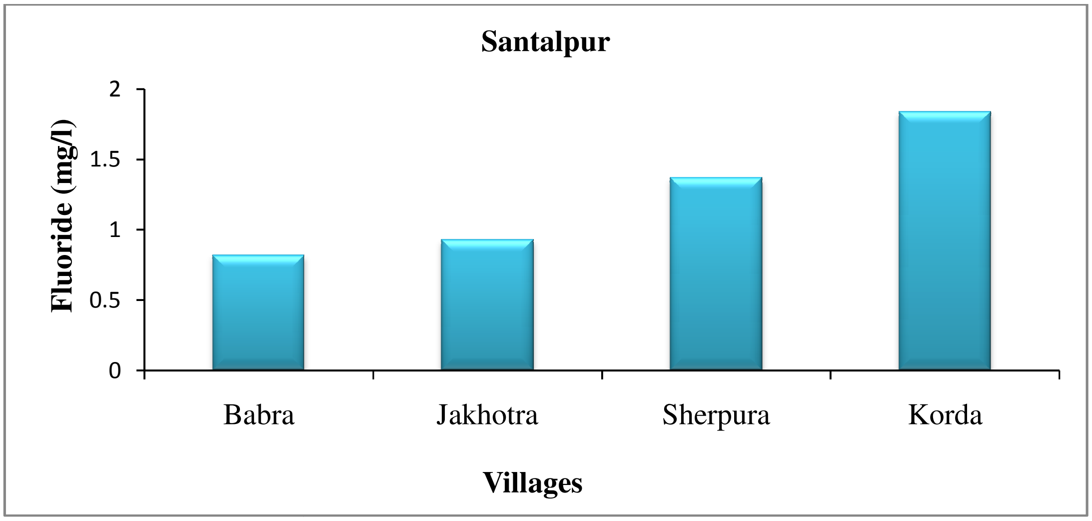


Figure 20: Fluoride Content in Villages of Santalpur Taluka

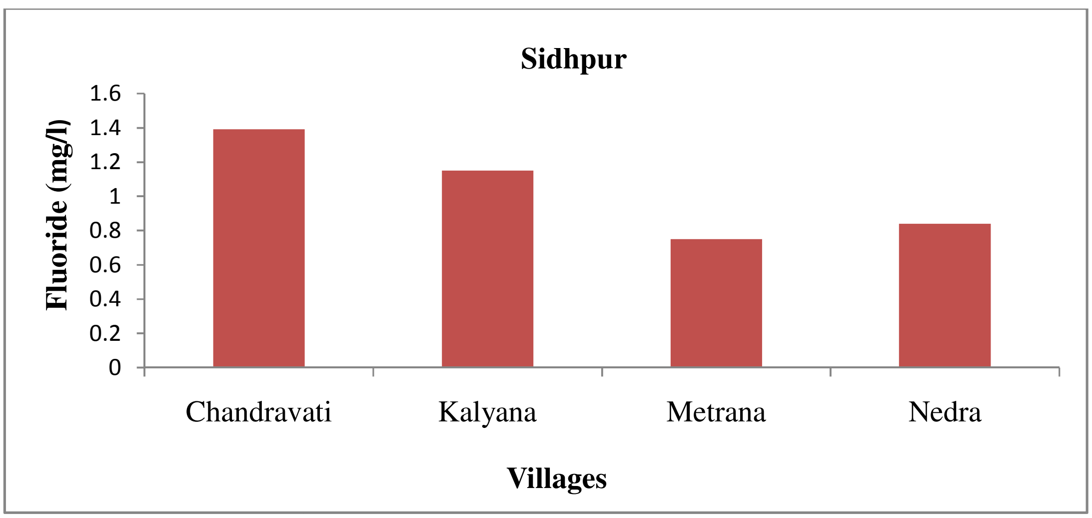


Figure 21: Fluoride Content in Villages of Sidhpur Taluka

3.1.1.2 Saurashtra

- **Jamnagar District :**

In this district, groundwater samples from 30 villages belonging to eight talukas (Table 4) were analysed for Fluoride content. These talukas were Jamnagar, Khambhalia, Lalpur, Kalavad, Okhamandal, Jamjodhpur, Bhanvad and Dhrol.

In Jamnagar taluka (Fig.22), maximum concentration of Fluoride was recorded in the bore well sample of village Dhandha (1.4 ppm) whereas the minimum in village Naghedi (0.48 ppm). In the villages of taluka Khambhalia (Fig. 23), the content was found ranging from 0.79 (Movan) to 1.4 ppm (Kuvadiya). Maximum concentration of Fluoride was recorded in village Modpar (1.2 ppm) and the minimum in village Meghpar (0.68 ppm) in Lalpur taluka (Fig. 24). In Kalavad taluka (Fig.25), concentration of Fluoride was maximum in the well sample of village Dudhala (1.67 ppm) whereas the minimum in village Umrala (0.86 ppm). In Okhamandal taluka (Fig.26) Fluoride content was maximum in the bore well sample of village Positra (1.32 ppm) whereas the minimum in village Goriyali (1.2 ppm). Fluoride content in the villages of taluka Jamjodhpur (Fig. 27) ranged from 1.24 (Satapar) to 1.41 ppm (Kotda). Maximum Fluoride concentration was recorded in village chandvad (1.3 ppm) and the minimum in village Mevasa (1.1 ppm) in Bhanvad taluka (Fig 28). In Dhrol taluka (Fig. 29), the well sample of village Vankiya (1.27 ppm) showed maximum concentration whereas minimum in the sample from village Hamapar (0.83 ppm).

Out of total 30 villages surveyed, Dudhala of Kalavad taluka showed the highest Fluoride content i.e. 1.67 ppm while Naghedi of Jamnagar taluka showed the minimum (0.48 ppm). In the remaining 28 villages, the level of Fluoride was recorded within 0.48-1.67 ppm range. From the data obtained, it is depicted that Fluoride content in 01 village (3.33%) was found to be beyond permissible limit. i.e. 1.5 ppm and in 28 villages (93.33%) it was found within the range (0.5-1.5). The concentration of Fluoride in 1 village (3.33%) was estimated which was even less than the prescribed limit recommended by WHO.

- **Amreli District :**

The study reported Fluoride content of groundwater samples from 30 villages that belonged to five talukas (Table 5) of Amreli District. These were Amreli, Rajula, Lilia, Jafrabad and Lathi talukas.

In Amreli taluka (Fig.30) maximum concentration of Fluoride was recorded in the bore well sample of village Pithavajal (1.70 ppm) whereas the minimum in sample from village Chital (0.59 ppm). Fluoride content in the villages of taluka Rajula (Fig. 31) ranged from 1.3 (Sajanvav) to 2.40 ppm (Kadiyali). Maximum Fluoride concentration was recorded in village Gundaran (3.0 ppm) and the minimum in village Godhavadar (1.60 ppm) of Lilia taluka (Fig. 32) In Jafrabad taluka (Fig. 33) the well sample of village Kadiyali (2.3 ppm) recorded maximum Fluoride concentration whereas the minimum was from village Nageshri (1.14 ppm). In Lathi taluka (Fig.34) the content was found maximum in the bore well sample of village Matirala (2.0 ppm) whereas minimum from village Suvagadh (0.97 ppm).

Out of total 30 villages surveyed, Gundaran of Lilia taluka recorded the highest Fluoride content i.e. 3.00 ppm while Chital of Amreli taluka showed the minimum (0.59 ppm). In remaining 28 villages, the level of Fluoride ranged from 0.59-3.00 ppm. This data revealed that Fluoride content in 20 villages (66.66%) was found to be beyond permissible limit. i.e. 1.5 ppm and in 10 villages (33.33%) it was found within the permissible range (0.5-1.5 ppm).

- **Rajkot District :**

For estimation of average Fluoride content in the groundwater samples of the district, five talukas (Table 6) were selected and the samples from 30 villages of these talukas were analyzed. These were Gondal, KotdaSangani, Wankaner, Morbi and Rajkot talukas. The samples were collected from borewell, tubewells and village wells during the study period.

In Gondal taluka (Fig. 35) maximum concentration of Fluoride was recorded in the bore well sample of village Padavala (1.68 ppm) whereas the minimum in the sample of village Daiya (0.47 ppm). Fluoride content in the villages of taluka KotdaSangani (Fig.36) was found ranging from 0.83 (Bhadva) to 1.68 ppm (Padavala). In village Samadhiyala (3.37ppm) Fluoride concentration was found maximum and the minimum in village Rangpar (0.86 ppm) in Wankaner taluka (Fig.37). In Morbi taluka (Fig.38) maximum concentration of Fluoride was recorded in the well sample of village UnchiMandal (2.78ppm) whereas the minimum in village Nagalpar (0.8 ppm). In Rajkot taluka (Fig. 39) the concentration of Fluoride was maximum in the bore well sample of village Pipaliya (2.1 ppm) whereas the minimum in the sample from village Vadali (0.84 ppm).

Out of total 30 villages surveyed, Samadhiyala of Wankaner taluka showed the highest Fluoride content i.e. 3.37 ppm while Daiya of Gondal taluka showed the minimum (0.47 ppm). In the remaining 28 villages, the level of Fluoride was recorded within 0.47-3.37 ppm range. From the data obtained, it is clear that the content of Fluoride in 11 villages (36.66%) was found beyond permissible limit. i.e. 1.5 ppm and in 18 villages (60.0%) it was within the prescribed range (0.5-1.5). There was 1 village (3.33%) in which the level of Fluoride remained below 0.5 ppm.

Table 4 : Average Fluoride Concentration in Jamnagar

Sr. No.	Taluka	Village	Fluoride mg/l
1	Jamnagar	Chavda	0.95
2	Jamnagar	Naghedi	0.48
3	Jamnagar	Rampar	1.24
4	Jamnagar	Dhandha	1.4
5	Khambhalia	Bajana	0.94
6	Khambhalia	Lalparda	1.17
7	Khambhalia	Movan	0.79
8	Khambhalia	Kuvadiya	1.4
9	Lalpur	Meghpar	0.68
10	Lalpur	Haripar	1.1
11	Lalpur	Khatiya	0.82
12	Lalpur	Modpar	1.2
13	Kalavad	Jashapar	1.36
14	Kalavad	Dudhala	1.67
15	Kalavad	Nana vadala	1.1
16	Kalavad	Umrala	0.86
17	Okhamandal	Goriyali	1.2
18	Okhamandal	Rajpara	1.3
19	Okhamandal	Shivrajpur	1.24
20	Okhamandal	Positra	1.32
21	Jamjodhpur	Satapar	1.24
22	Jamjodhpur	Vansjalia	1.34
23	Jamjodhpur	Kotda	1.41
24	Bhanvad	chandvad	1.3
25	Bhanvad	Hathla	1.2
26	Bhanvad	Mevasa	1.1
27	Dhrol	Kharva	1.1
28	Dhrol	Nathuvadla	0.92
29	Dhrol	Vankiya	1.27
30	Dhrol	Hamapar	0.83

Table 5: Average Fluoride Concentration in Amreli

Sr. No.	Taluka	Village	Fluoride mg/l
1	Amreli	Giriya	0.74
2	Amreli	Chital	0.59
3	Amreli	Ishvariya	1.35
4	Amreli	Pithavajal	1.70
5	Amreli	Rajasthali	0.89
6	Amreli	Keriyachad	1.30
7	Rajula	Masundra Nana	1.60
8	Rajula	Kalyanpar	1.60
9	Rajula	Kadiyali	2.40
10	Rajula	Kundaliyala	1.80
11	Rajula	Sajanvav	1.3
12	Rajula	Dungar	1.41
13	Lilia	Gundaran	3.0
14	Lilia	Punjapadar	2.0
15	Lilia	Jatroda	2.20
16	Lilia	Nana Lilia	2.32
17	Lilia	Godhavadar	1.60
18	Lilia	Ingorala	1.74
19	Jafrabad	Timbi	2.0
20	Jafrabad	Rohisa	2.0
21	Jafrabad	Lothpur	1.80
22	Jafrabad	Mitiyala	1.80
23	Jafrabad	Kadiyali	2.3
24	Jafrabad	Nageshri	1.14
25	Lathi	Bhingrad	1.93
26	Lathi	Luvariya	1.30
27	Lathi	Matirala	2.00
28	Lathi	Chhabhadiya	1.80
29	Lathi	Suvagadh	0.97
30	Lathi	Narangadh	1.65

Table 6: Average Fluoride Concentration in Rajkot

Sr. No.	Taluka	Village	Fluoride mg/l
1	Gondal	Daiya	0.47
2	Gondal	Moviya	1.24
3	Gondal	Padavala	1.68
4	Gondal	Bandhiya	1.29
5	Gondal	Chordi	0.73
6	Gondal	Vanthali	1.38
7	KotdaSangani	Bhadva	0.83
8	KotdaSangani	Navi Mengani	0.94
9	KotdaSangani	Satapar	1.38
10	KotdaSangani	Padavala	1.68
11	KotdaSangani	Naranka	1.48
12	KotdaSangani	Devaliya	1.29
13	Wankaner	Rangpar	0.86
14	Wankaner	Sindhavadar	1.87
15	Wankaner	Samadhiyala	3.37
16	Wankaner	Vardusar	0.94
17	Wankaner	Lunasar	1.3
18	Wankaner	Pipardi	2.4
19	Morbi	Paneli	2.0
20	Morbi	Ghuntu	2.00
21	Morbi	Rajpar	1.67
22	Morbi	UnchiMandal	2.78
23	Morbi	Nagalpar	0.8
24	Morbi	Panchasar	2.0
25	Rajkot	Maliyasan	0.93
26	Rajkot	Ronki	1.46
27	Rajkot	Pipaliya	2.1
28	Rajkot	Rampara	1.4
29	Rajkot	Vadali	0.84
30	Rajkot	Lodhida	1.27

(* Earlier Wankaner was under Rajkot district before 2014 which has now been Shifted to Morbi District)

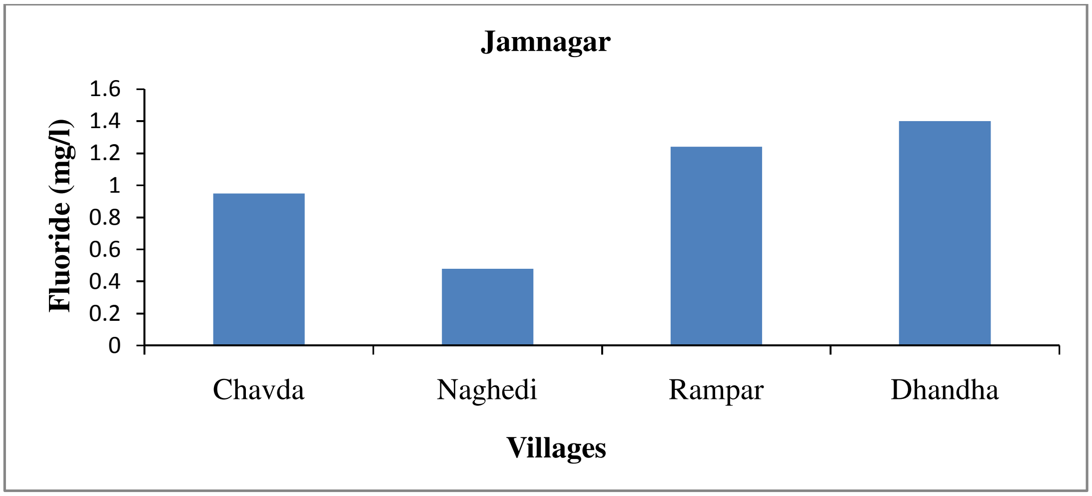


Figure 22: Fluoride Content in Villages of Jamnagar Taluka

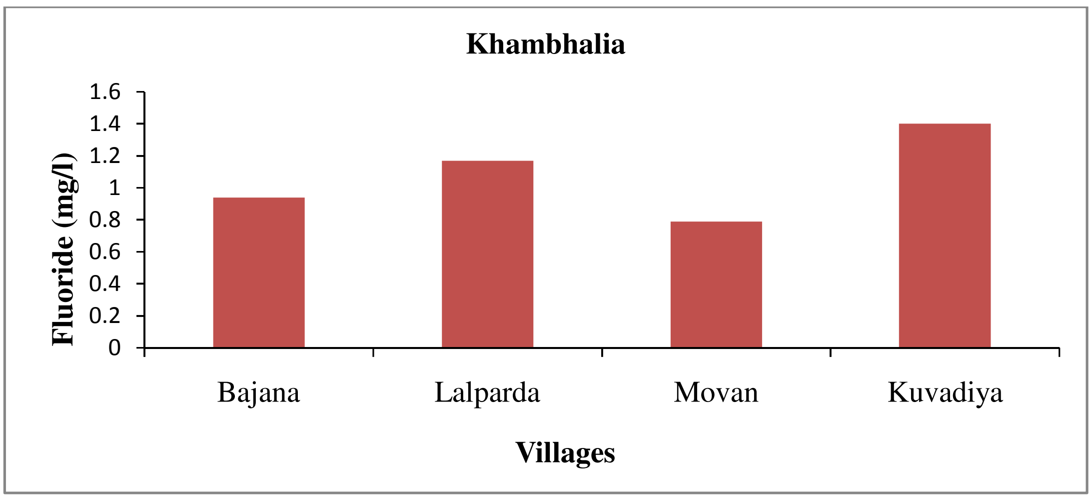


Figure 23: Fluoride Content in Villages of Khambhalia Taluka

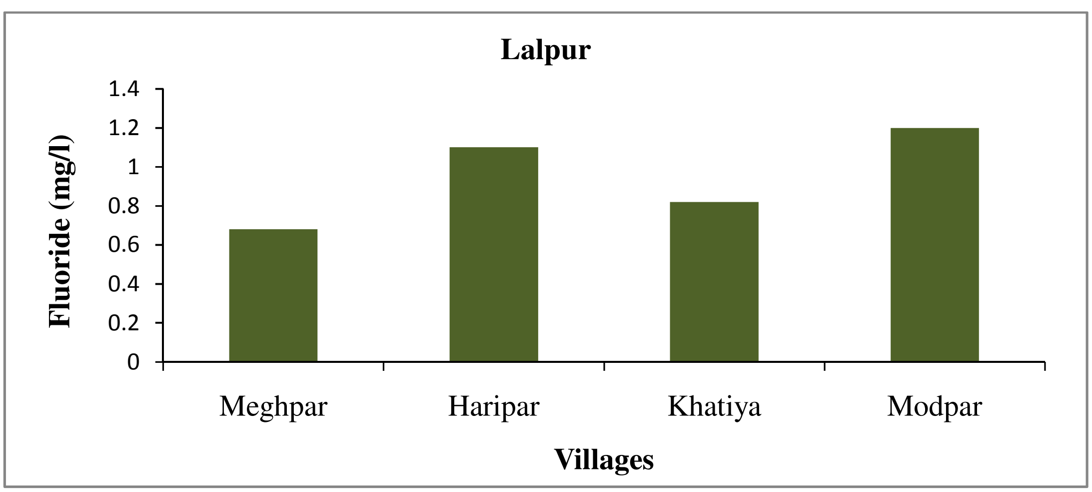


Figure 24: Fluoride Content in Villages of Lalpur Taluka

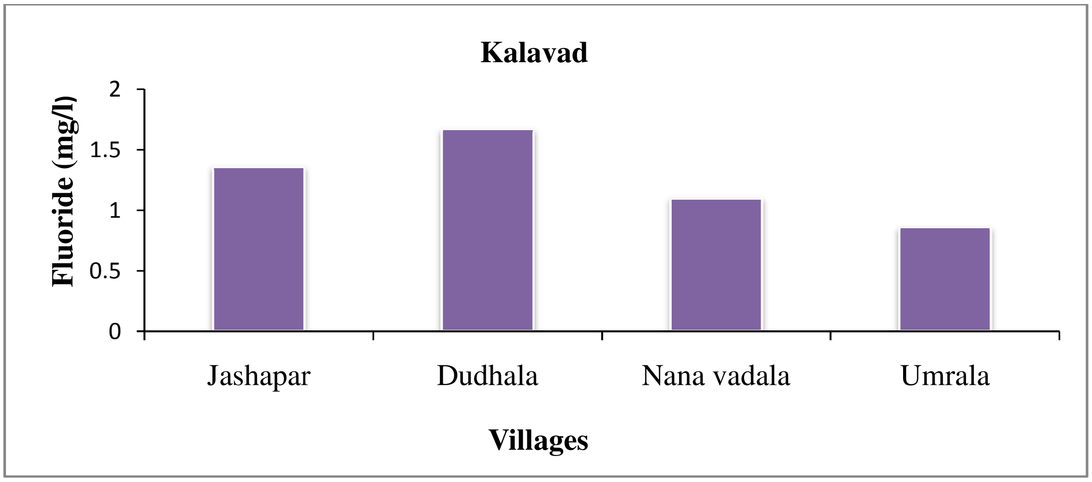


Figure 25: Fluoride Content in Villages of Kalavad Taluka

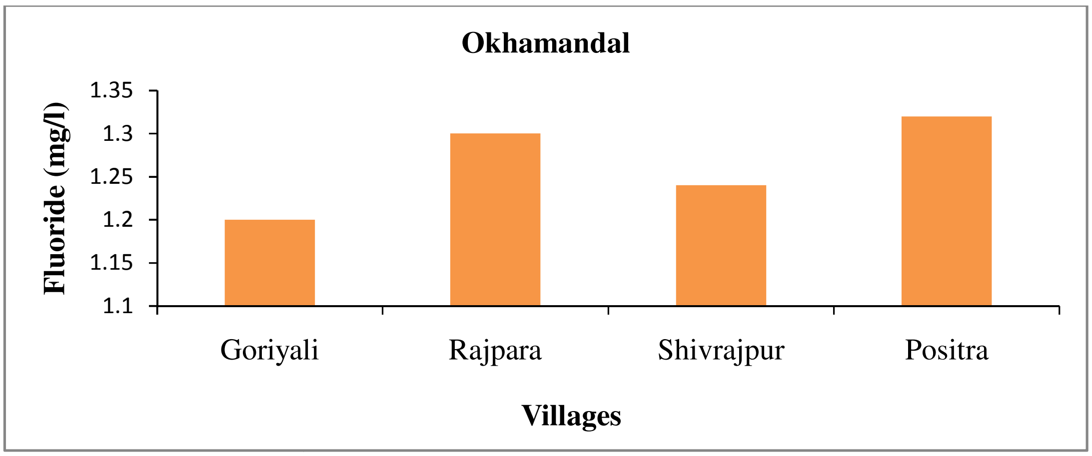


Figure 26: Fluoride Content in Villages of Okhamandal Taluka

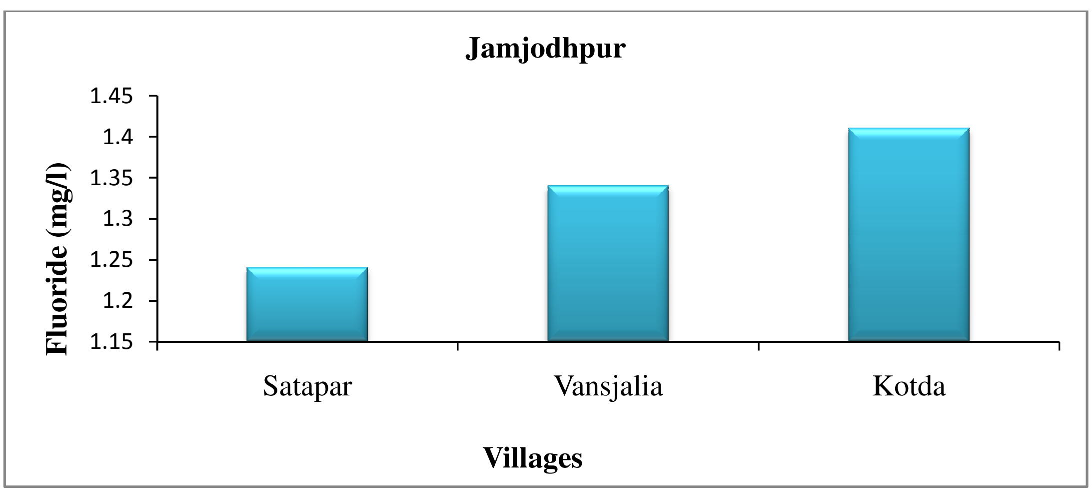


Figure 27: Fluoride Content in Villages of Jamjodhpur Taluka

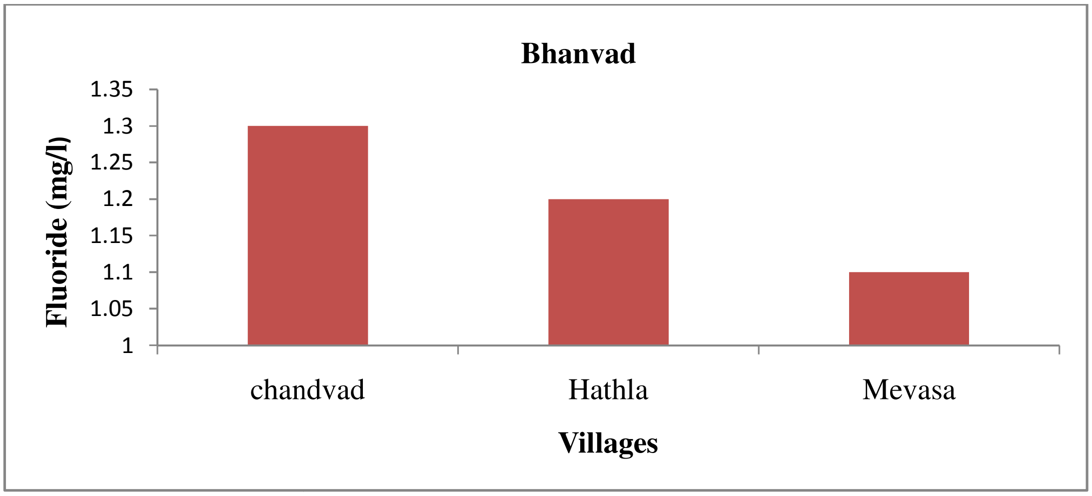


Figure 28: Fluoride Content in Villages of Bhanvad Taluka

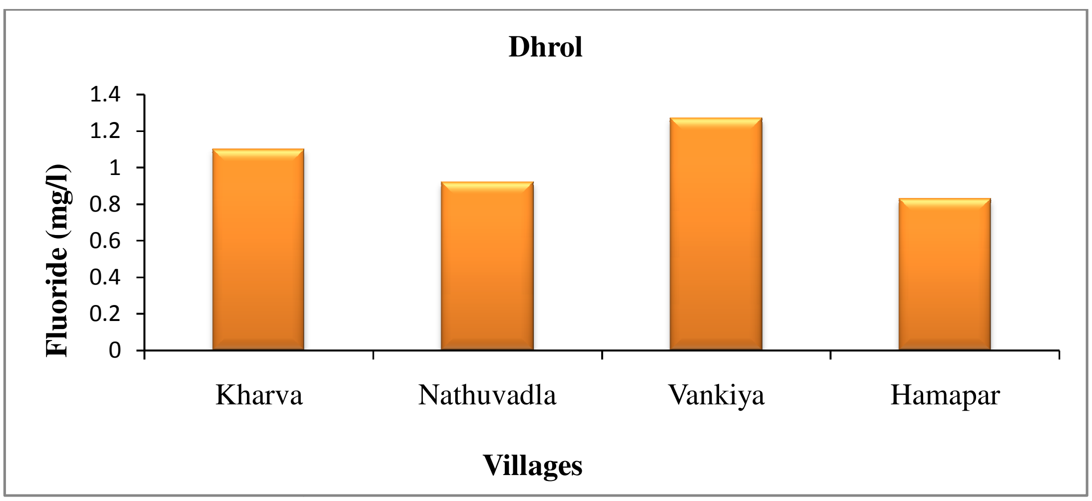


Figure 29: Fluoride Content in Villages of Dhrol Taluka

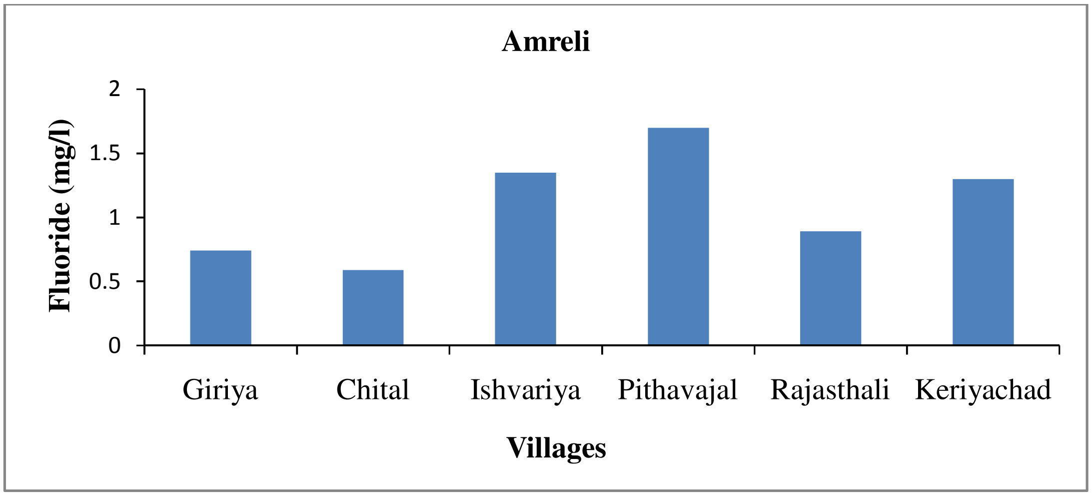


Figure 30: Fluoride Content in Villages of Amreli Taluka

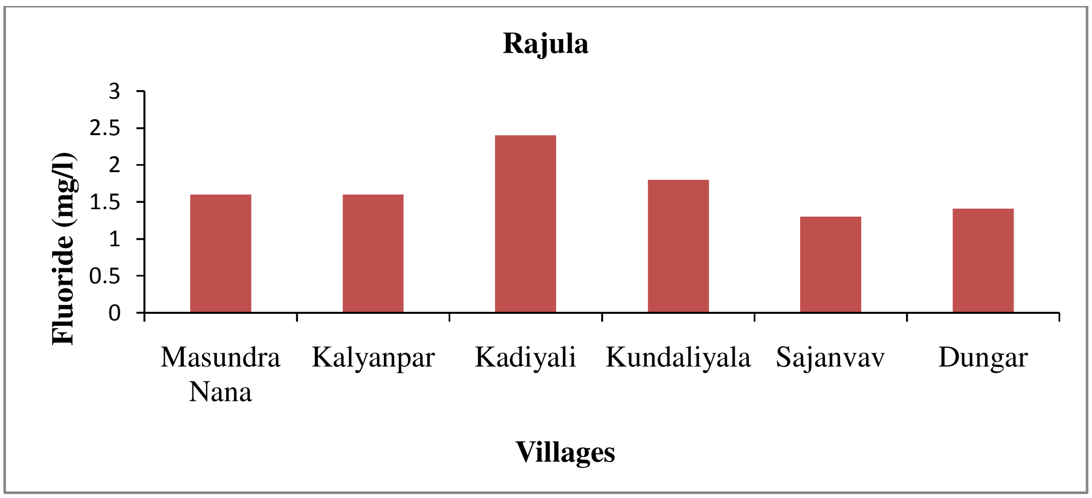


Figure 31: Fluoride Content in Villages of Rajula Taluka

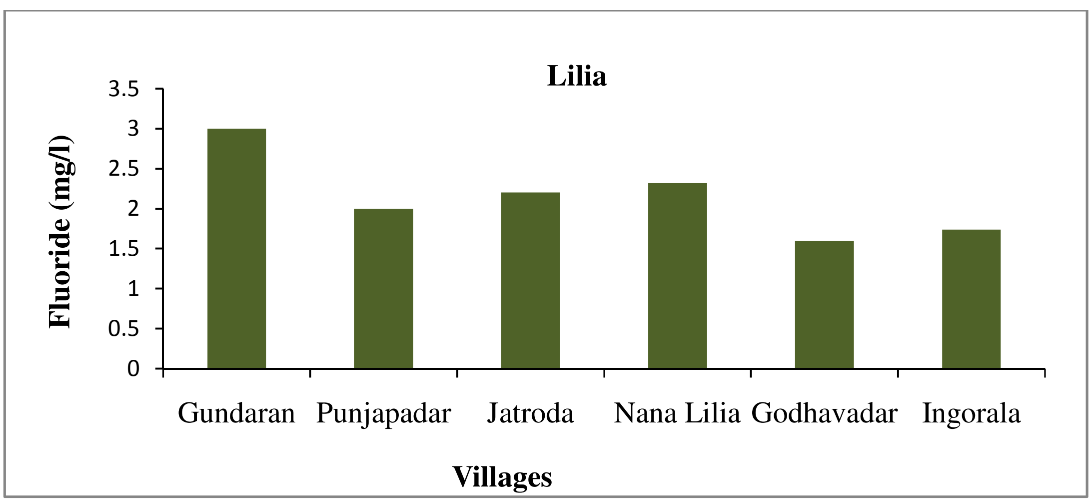


Figure 32: Fluoride Content in Villages of Lilia Taluka

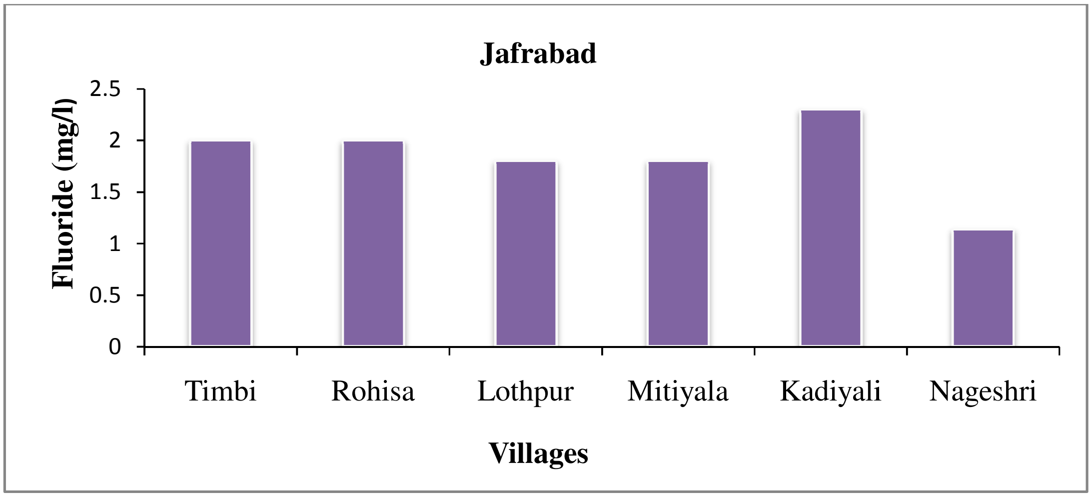


Figure 33: Fluoride Content in Villages of Jafrabad Taluka

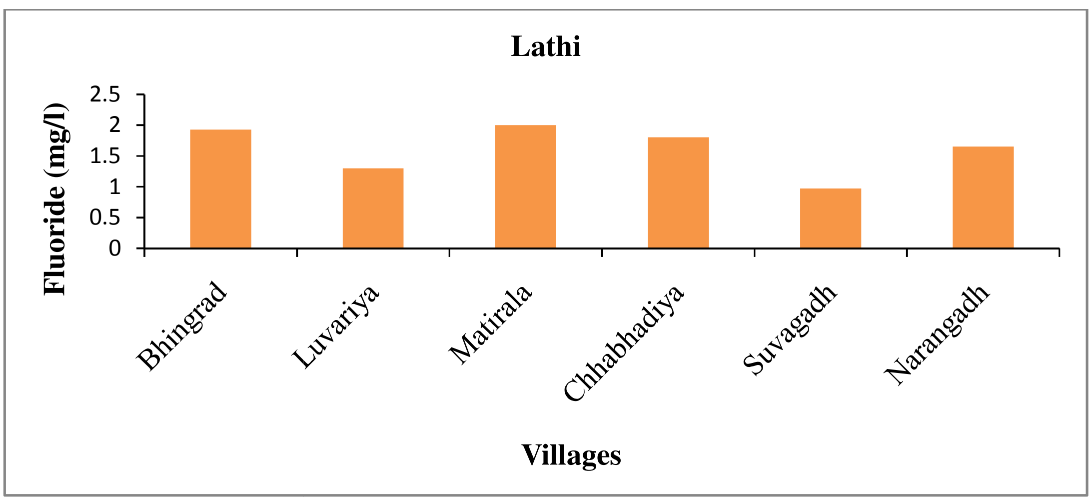


Figure 34: Fluoride Content in Villages of Lathi Taluka

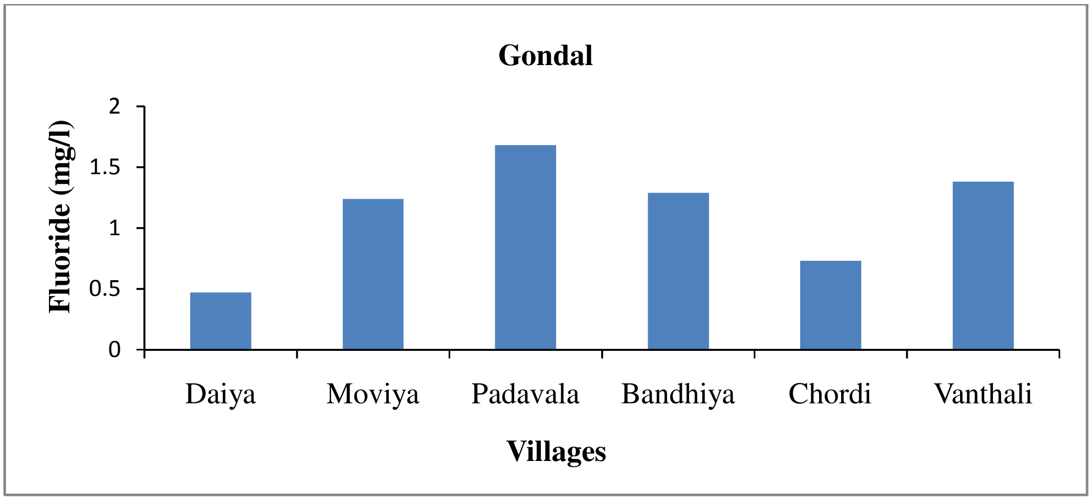


Figure 35: Fluoride Content in Villages of Gondal Taluka

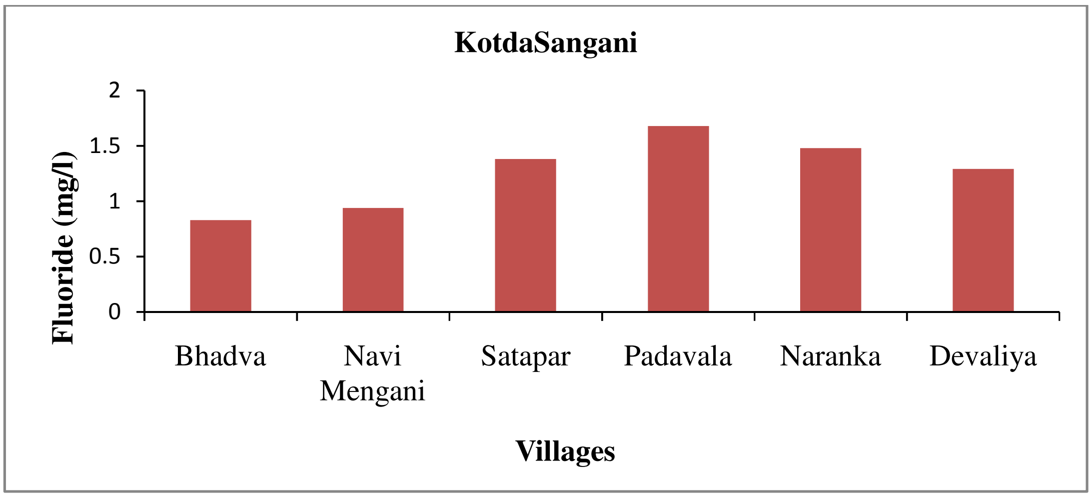


Figure 36: Fluoride Content in Villages of KotdaSangani Taluka

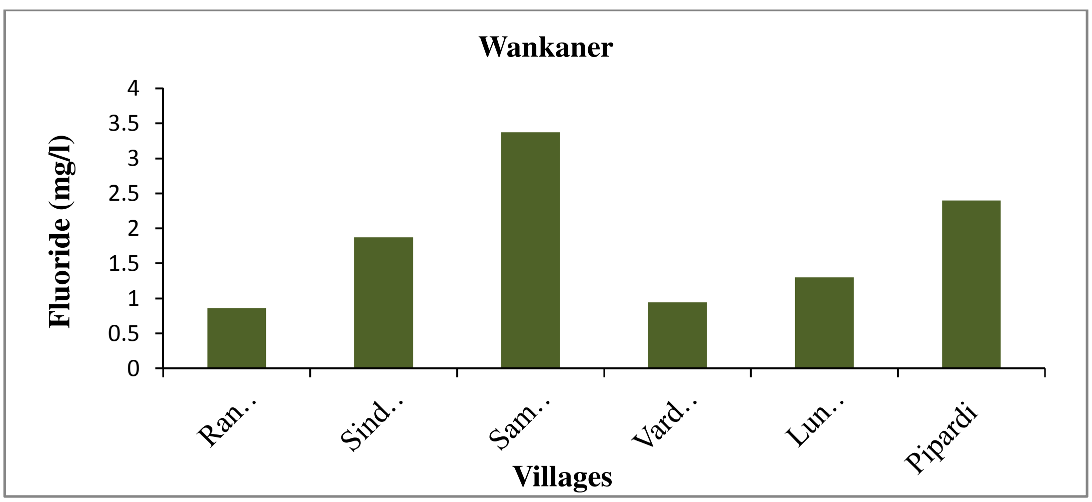


Figure 37: Fluoride Content in Villages of Wakaner Taluka

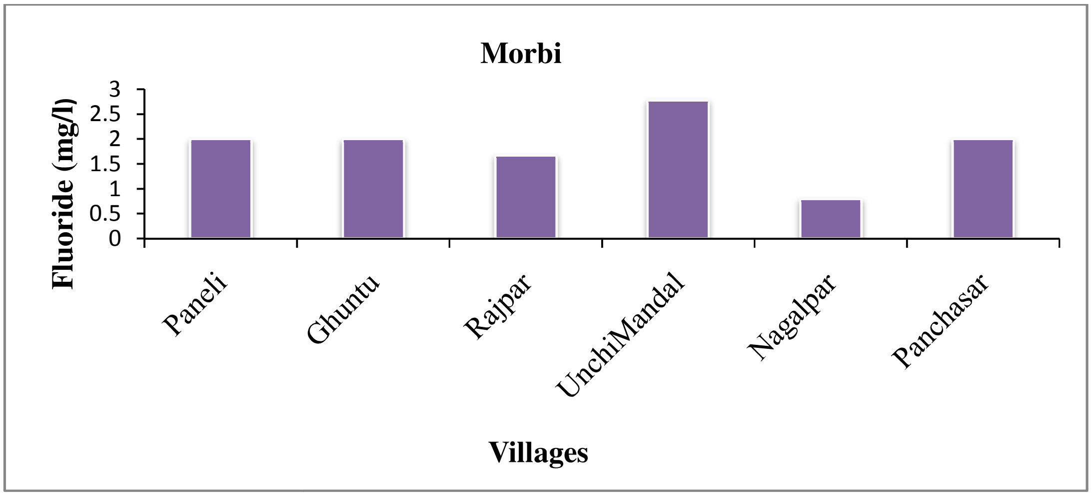


Figure 38: Fluoride Content in Villages of Morbi Taluka

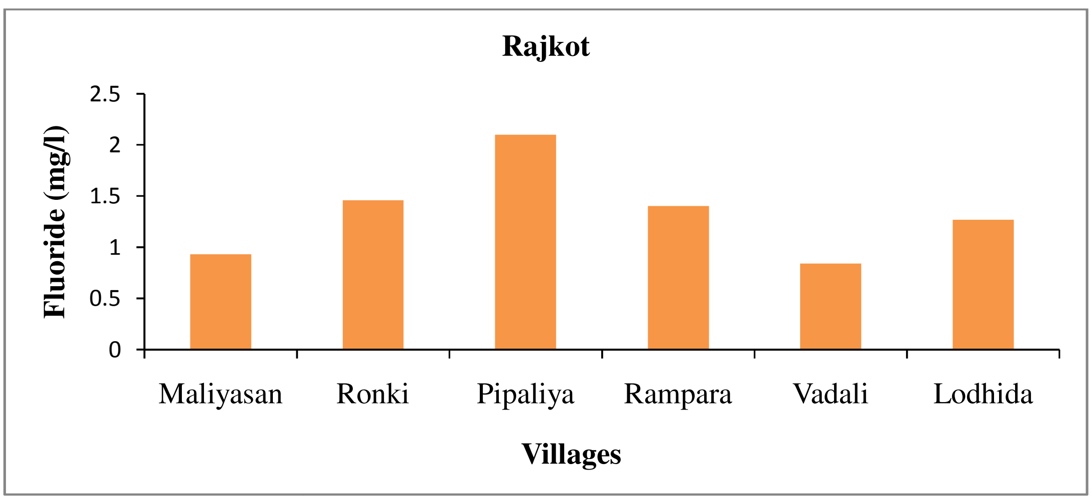


Figure 39: Fluoride Content in Villages of Rajkot Taluka

From the results obtained on mapping of Fluoride concentration in groundwaters of Mehsana, Amreli and Rajkot districts, the highest Fluoride concentration was recorded in taluka Satlasana followed Lilia and Wankaner respectively and therefore they were selected for further study.

In our study, Satlasana (Mehsana) fall under North Gujarat region. Fluoride enhancement in groundwater in these regions might be due to two possible reasons. Its geochemistry that comprises of country rock as charnokites, calc-granites and calc-gneiss formation which enrich Fluoride in the groundwaters and anthropogenic activities for eg. Intensive agricultural practices and use of phosphate based fertilizers which also contribute significantly towards rise in Fluoride level in groundwater.

Lilia and Wankaner (Amreli and Rajkot) belong to Saurashtra, where also we have estimated Fluoride level in the groundwater beyond permissible limit. This is probably due to geological set up of the area that comprises of Basaltic rock, sandstone, Deccan trap lava flows, supra trappeans, Gaj beds, and Miliolite limestone leading to enhancement in the level of Fluoride.

The results on mapping Fluoride concentration in 30 villages of Mehsana, Amreli and Rajkot districts revealed that in Mehsana, Satlasana taluka (village Nana Kothasana 4.6 ppm), in Amreli, Lilia taluka(village Gundaran 3.0ppm), and in Rajkot, Wankaner taluka (village Samadhiyala 3.37 ppm) showed high concentration of Fluoride in groundwater.

Discussion:

High Fluoride concentration in Groundwater of Gujarat was reported by Deshpande and Gupta (2003). They recorded high Fluoride in a regional alluvial aquifer system under water stress in the North Gujarat-Cambay (NGC) region in western India. They discovered some high fluoride pockets in the region and suggested that it might be probably due to preferential dissolution of high Fluoride bearing minerals.

In four districts of North Gujarat, Patel and Bhatt (2007) had documented that Fluoride level in Groundwater was above permissible limit in 80% villages of Sabarkantha District, 95% villages in Patan District, 92% villages in Banaskantha District and 95% villages in Mehsana District. They investigated that Na^{+} content in the GW samples was more than that of Ca^{+2} and Mg^{+2} ions. This rise might be due to deposition of $CaCO_3$ and $MgCO_3$ which in turn might have enhanced the formation of NaF in the water. This favors enrichment of Fluoride in the unconfined water. Intensive and long-term irrigation practices in the district was probablly another factor that causes weathering and leaching of Fluoride from the soil/weathered rocks. Thus easy accessibility and continuous contact of circulating water to the weathered products during irrigation dissolves and leaches the minerals, including fluorine, contributing Fluoride to the surface water and groundwater (Subbarao and Rao, 2003 and Sarma and Rao, 1997).

In Kadi tehsil of Mehsana District, 40% GW samples were reported for high Fluoride level and were above permissible limit (Salve *et al.*2008).

Bhavnagar district of Saurashtra region was worked out for Fluoride content in groundwater samples at twelve different locations in three different seasons (winter, Summer and post monsoon) by Mishra *et al.* (2009). They reported that all the location under study had high Fluoride concentration that was beyond permissible limit.

Elevated level of Fluoride in Groundwater of Nalgonda District,Andhra Pradesh was reported by Brindha *et al.* (2011). They collected Groundwater samples from 45 wells once every two months and reported that 52% of the samples were suitable for human consumption. However, 18% of the samples from the study area had less than the required limit and contradictorily, 30% of the samples possessed high concentration of Fluoride, i.e., above 1.5 mg/l. Weathering of rocks and leaching of Fluoride bearing minerals were found to be the major causes which contribute to rise in concentration of Fluoride in Groundwater in this region. The other important natural phenomenon that contributes to high Fluoride is rapid evaporation rate in the area.

In Chithar river basin, Tamil Nadu, Fluoride as one of the main trace element in Groundwater was documented by Subramani *et al.* (2005). They collected Groundwater samples from 24 representative open wells in July 2001 and 18 samples in July 2002. The concentration of Fluoride in Groundwater of the basin varies between 0.07 mg/l and 0.94 mg/l during July 2001 and concentration was slightly higher during July 2002, ranging between 0.19 mg/l and 1.3 mg/l. All samples examined exhibit suitability for drinking.

Bedrock containing Fluoride minerals is generally responsible for high concentration of Fluoride ion in Groundwater. This was investigated Handa 1975; Wenzel and Blum 1992 and Bardsen *et al.* 1996.

Fluoride Contamination in six different GW samples of Tonk district, Rajasthan was recorded by Yadav *et al.* (2009).. They reported that 110 villages of Deoli Tehsil had high Fluoride concentration in water. 58.19% villages of this Tehsil had Fluoride in the range of 1.5-3.0 mg/l and 30% village had 3.0-6.0 mg/l of Fluoride while 12% village had more than 6.0 mg/l of Fluoride. In Newai Tehsil, almost 240 villages (out of 269 villages) had Fluoride concentration in the range of 1.5-6.0 mg/l in groundwater.

Fluoride concentration ranged from 1.5-6.0 mg/l in 134 villages of Malpura Tehsil. 42 villages had more than 6 mg/l. In Todaraisingh Tehsil, 70 villages, out of 79 had Fluoride concentration ranging from 1.5-6.0 mg/l. About 82 villages of Uniyara Tehsil were reported to have high concentration of Fluoride (> 1.5 mg/l) in Groundwater. 330 villages of Tonk Tehsil of Tonk District had more than1.5 mg/l Fluoride concentration in Groundwater. 280 of them had 1.5-6.0 mg/l and 50 had more than 6.0 mg/l Fluoride concentration. They envisaged that 44.93% area of Tonk district was affected by high Fluoride level of 1.5-3.0 ppm and 40.63% area was affected because the concentration ranged from 3-6 ppm. 7.55% area affected due to elevated Fluoride level of 6-8 ppm and 3.63% area affected because Fluoride concentration ranged from 8-10 ppm. 3.25% area of Tonk district was affected by Fluorosis because of more than 10 ppm fluoride concentration in the groundwater. This contamination seemed to occur naturally by Fluoride rich rock salt system.

Hydrogeochemical investigation had been carried out in the granitic terrain of Siddipet area, Medak district, Telangana State by Narsimha and Sudarshan (2017). They collected 104 groundwater samples from 39 villages of Siddipet region in the month of July 2014. Hydrogeochemical investigation revealed that the concentration of Fluoride in groundwater ranged from 0.2-2.2 mg/l. 22 % of Groundwater samples in the villages of Nanchrpalli, Ponnala, Silanagar, Ganpur, Venkatapuram, Irkod, Rampur, Appannapalli, Pullur, Ankampet, Raghapuram, Randampalli, Narsapur, Mittapalli, Boggolonibanda, and Nancharpalli exceed the drinking water standard of 1.5 mg/l set by WHO. The area was occupied by granitic/granitic genesis of the Archean age. The Fluoride bearing minerals apatite, muscovite, and biotite are present in these rocks which were found responsible for high concentration of Fluoride in the groundwater due to rock–water interaction. It was suggested that silicate weathering domination and rock–water interaction were the primary factors in increasing the major ion concentration in the groundwater. The high Na^+ concentration in groundwater might be related to the cation exchange mechanism in the aquifers as investigated by Kangjoo Kim and Seong-Taekyun (2005).

High Fluoride contamination in Groundwater of Agra district, Uttar Pradesh reported by Sharma *et al.* (2011). Groundwater samples were collected during the months of April, June, August, and December 2010 from 45 sampling wells selected. A total of 180 groundwater samples were collected from Fluoride affected region of Baroli–Aheer at villages Panchgai, Khera and Baroli–Aheer near Agra. The Fluoride concentration in groundwater of this region ranged from 0.1 to 14.8 mg/l. In this, 71% samples were found exceeding permissible limit. In the study area, Fluoride contamination was mainly a natural process, i.e. leaching of fluorine-bearing minerals, since no man-made pollution had been noticed. Since fluorite, apatite, mica and various other minerals take part during rock–water interaction, and liberate fluoride into the Groundwater. It was found that the Fluoride concentration in groundwater increases along the groundwater flow direction and also with increasing depth. Fluoride in groundwater of this region was mainly due to dissolution from Fluoride bearing minerals like Fluorspar, Fluorite etc.

Singaraja *et al.* (2014) reported high Fluoride concentration in Groundwater of Thoothukudi district of Tamilnadu. Analysis of Fluoride in 100 water samples from entire district during pre-monsoon (May) and postmonsoon (February) was carried out. Higher concentration of fluoride was observed during pre-monsoon (3.3 mg/l) as compared to the postmonsoon (2.4 mg/l) might be due to the dilution effect. The spatial distribution of Fluoride in both the seasons revealed that highest Fluoride concentrations was shown in the north and central part of the study area. This region is chiefly composed of the alluvial plain followed by charnockite, which aids as one of the main source for Fluoride in the study area. It is also interesting to note that that alluvial plain groundwater had high fluoride levels due to alteration of mud and clay layers in the subsurface lithology which had very low hydrologic conductivity. The southern, western and the eastern parts of the study area do not suffer from Fluoride contamination.

3.2 Bioremoval of Fluoride

The study involves screening of different plant materials to check their removal capacity of Fluoride in synthetic Fluoride solution and selection of plant materials with maximum Fluoride adsorption/absorption capacity. It also incorporates Optimization of dose, time and volume of the selected bioadsorbent, Physicochemical characterization of groundwater samples with special reference to Fluoride concentration, selection of groundwater samples and In-vivo experiment on defluoridation capacity of the selected bioadsorbent.

3.2.1 Screening of plant materials, checking Fluoride removal capacity and selection of suitable bioadsorbent

In the present study, experiments were carried out in vitro for the selection of suitable bioadsorbent for Fluoride removal. For this, plants like *Moringa oleifera* L., *Cocos nucifera* L. and *Oryza sativa* L. were tried. For *Moringa oleifera* - Bark, *Moringa oleifera* – Seed, *Cocos nucifera* - Shell, *Cocos nucifera* - Mature Fruit Fiber and *Oryza sativa* - Husk were used . Initial Fluoride concentration was kept constant; i.e. 1.5 mg/l and final concentration was determined after administration of plant material. Volume of the solution for each experiment was kept constant; 1.e.150 ml. Standard dose of each plant part was kept constant i.e. 0.75 g. The experiments were carried out for 4 hours of time duration. From the difference, % removal of fluoride by each of the bioadsorbent (plant material) was calculated (Table 7).The results indicated that, *Moringa oleifera* sun dried bark powder of 0.15 mm particle size removed 16% Fluoride whereas oven dried and sun dried bark powder with 0.25 mm particle size showed 8% and 12 % Fluoride removal respectively. *M. oleifera* bark pieces sun dried and oven dried had given 5.33% and 3.33% Fluoride removal. *Moringa oleifera* seed powder with 0.15mm and 0.25mm particle size removed 13.33% and 12% Fluoride respectively whereas seed coat powder removed 4.67% Fluoride.

Sun dried and oven dried shell pieces of *Cocos nucifera* were found to remove 1.33% and 2.67% Fluoride respectively. Oven dried shell powder with 0.25mm particle size removed 3.33% and mature fruit fiber powder with 0.25 mm particle size had 2.0% Fluoride removal capacity. Rice husk as a whole, in the form of pieces, oven dried and sun dried lowered down 0.67%, 1.33%, 2.0% and 0.67% of Fluoride concentration respectively. Husk powder with 0.25 mm particle size reduced Fluoride level to 2.67%.

From the results obtained, it is clear that among different plant parts used, *Moringa oleifera* bark and seed powder (PLATE 2) with 0.15 mm particle size showed maximum Fluoride removal efficiency. So these were selected for further batch adsorption study.

PLATE 2

Table 7: % Fluoride removal capacity of selected plant materials

Plant Name	Part used as Bioadsorbent	Ovendried/ Sundried/ Air dried	I.Fc. mg/l	F.Fc. mg/l	% Fluoride Removal
Moringa oleifera L.					
BARK	Bark Pieces	Sun dried	1.5	1.42	5.33
	Bark Pieces	Oven dried	1.5	1.45	3.33
	Bark Powder - 0.25 mm particle size	Sun dried	1.5	1.32	12.00
	Bark Powder - 0.15 mm particle size	Sun dried	1.5	1.26	16.00
	Bark Powder - 0.25 mm particle size	Oven dried	1.5	1.38	8.00
SEED	Seed powder - 0.25 mm particle size	Air dried	1.5	1.32	12.00
	Seed Powder - 0.15 mm particle size	Air dried	1.5	1.3	13.33
	Seed Coat Powder	Air dried	1.5	1.43	4.67
Cocos nucifera L.					
SHELL	Shell Pieces	Sun dried	1.5	1.48	1.33
	Shell Pieces	Oven dried	1.5	1.46	2.67
	Shell Powder - 0.25 mm particle size	Oven dried	1.5	1.45	3.33
FIBRES	Mature Fruit Fiber Powder - 0.25 mm particle size	Oven dried	1.5	1.47	2.00
Oryza sativa L.					
HUSK	Husk (whole)	Air dried	1.5	1.49	0.67
	Husk Pieces	Air dried	1.5	1.48	1.33
	Husk	Oven dried	1.5	1.47	2.00
	Husk	Sun dried	1.5	1.49	0.67
	Husk Powder - 0.25 mm particle size	Air dried	1.5	1.46	2.67

I.Fc. = Initial Fluoride Concentration

F.Fc. = Final Fluoride Concentration

3.2.2 In-vitro Optimization Study

Batch optimization study using *Moringa oleifera* bark powder (MBP)

Batch optimization study using *M. oleifera* L. bark powder was studied to check adsorption of Fluoride ion through batch mode, considering different parameters such as dosage, agitation time and an initial concentration of Fluoride ions. Experiments were conducted by keeping one test parameter varied and remaining parameters constant.

Effect of initial Fluoride concentration

For a strictly adsorptive reaction, in the optimized period of contact, the rate varied directly with the concentration of adsorbate. The capacity of the MBP materials decreased sharply (Fig.40) with increase in initial Fluoride ion concentration. The adsorption capacity of biosorbent was systematically studied by varying the initial concentration of Fluoride ions between 1 and 5 mg/l. Maximum Fluoride ion removal occurred at 1 ppm level.

Effect of contact time

It was found that the removal of Fluoride ions increased with increase in contact time to some extent. Further increase in contact time didn't increase the uptake. This might be due to deposition of Fluoride ions on the available adsorption sites on MBP material. 92.75 % of the adsorption occurred (Fig.41) within eight hours of the contact for Fluoride ions with an initial concentration of 1 ppm and adsorbent dose of 5 g/l.

Effect of adsorbent dose

It was observed that the removal of Fluoride ions increased with an increase in the amount of adsorbent. For all these runs, initial Fluoride ion concentration and contact time was fixed at 1 mg/l and eight hour respectively. The amount of dose was varied between 1.2 and 5 g/l in aqueous solution. Results showed that MBP was efficient for 71.35% removal of Fluoride ions at 5 g/l and 67.2% at 1.2 g/l (Fig.42).

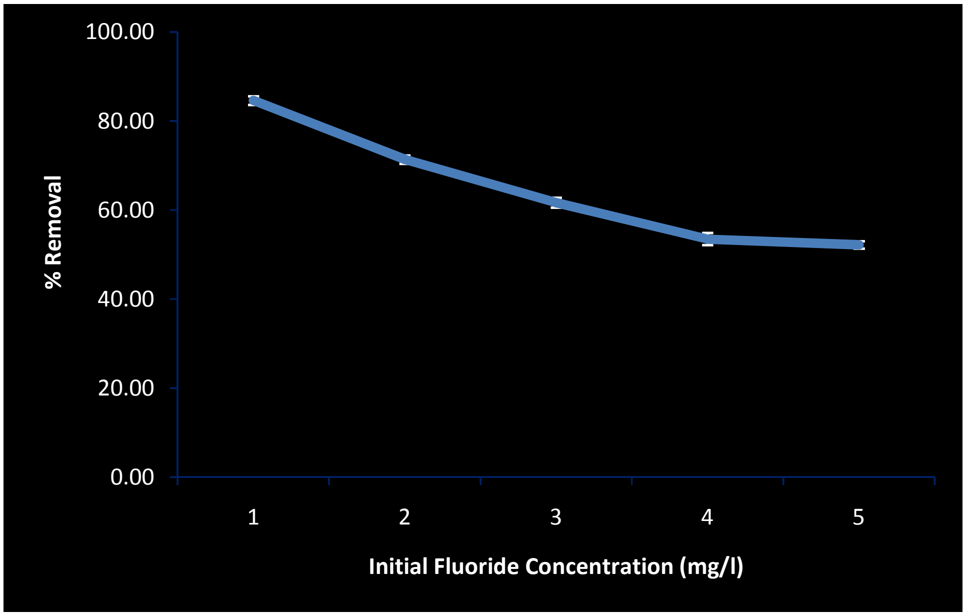


Figure 40: Effect of Initial Fluoride Concentration on Fluoride ion removal by MBP

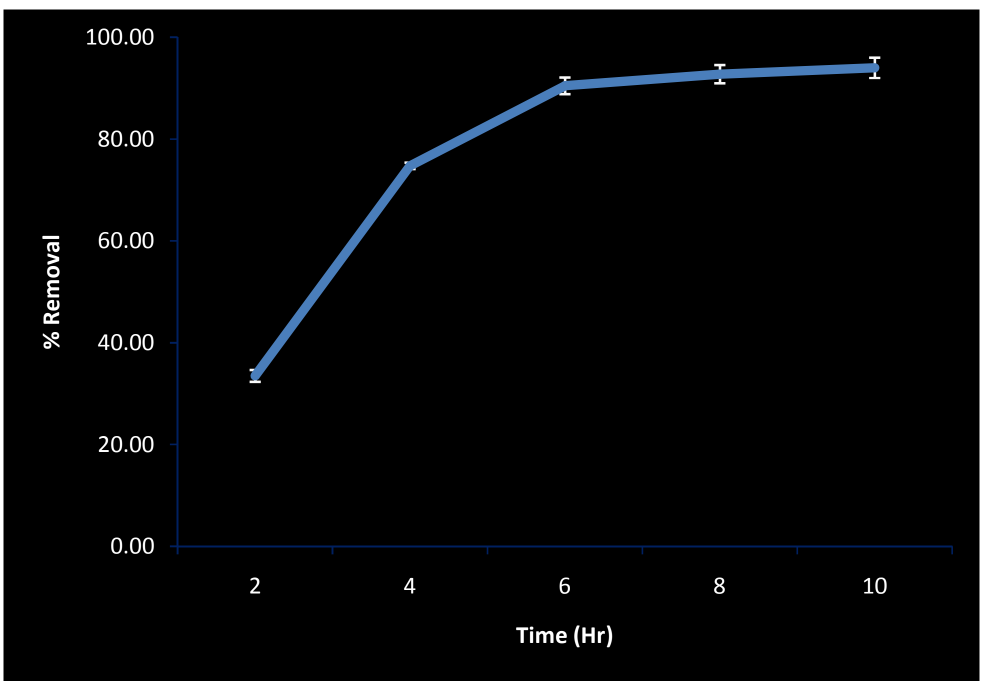


Figure 41 : Effect of Time on Fluoride ion removal by MBP

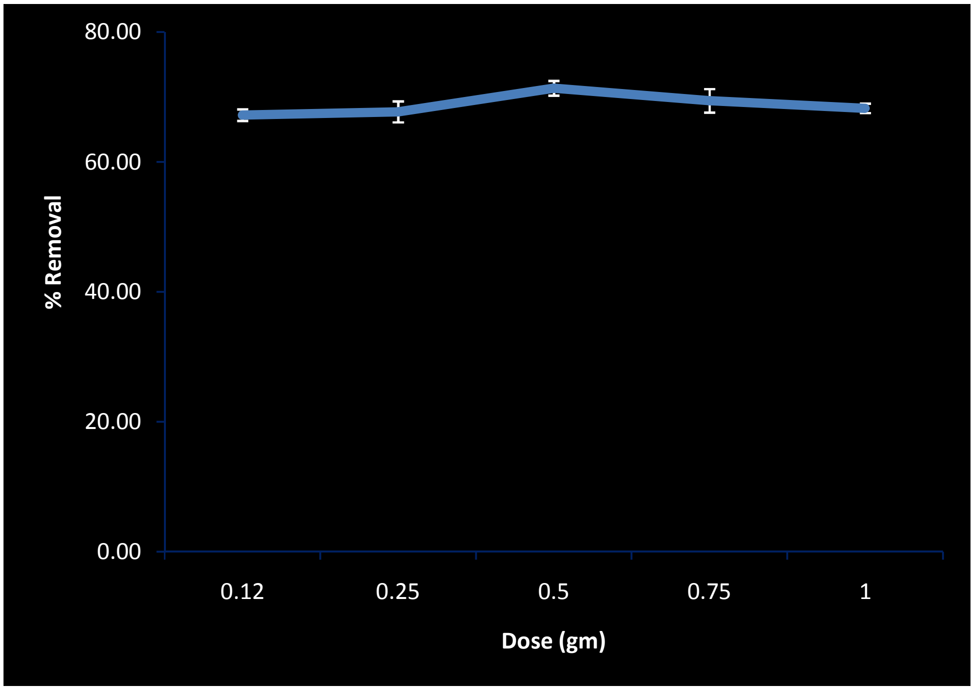


Figure 42: Effect of dose on Fluoride ion removal by MBP

Batch optimization study using *Moringa oleifera* seed powder (MSP)

Batch optimization study was carried out through batch mode to check adsorption of Fluoride ion using *M. oleifera* L. seed powder. For the study parameters which were taken into consideration were: dosage, agitation time and an initial concentration of Fluoride ions. Experiments were performed keeping one test parameter varied and remaining parameters constant.

Effect of initial Fluoride concentration

For adsorption process of Fluoride ion in the optimized period of contact, the rate varied directly with the concentration of adsorbate. The efficiency of the MSP materials decreased (Fig.43) with increase in initial Fluoride ion concentration. The adsorption capacity of biosorbent was systematically studied by taking various initial concentration of Fluoride ions ranged between 1 and 5 mg/l. MSP was found to remove Fluoride ion at a maximum rate at 1 ppm level.

Effect of contact time

The experiment was conducted on performance of MSP towards removal of Fluoride at varying contact time i.e 2,4,6,8, and 10 hrs. A positive correlation between Fluoride ion removal and contact time for initial four hours had been established. Results showed that with the increase in contact time from 2 to 4 hours the rate of removal also increased. Further increase in contact time did not show any increase in the Fluoride removal (Fig.44). At initial concentration of 1 ppm and MSP dose of 5 g/l, maximum adsorption, 32.5% occurred within four hours of contact time.

Effect of adsorbent dose

It was observed that the removal of Fluoride ions increased with an increase in the amount of adsorbent. For all these runs, initial Fluoride ion concentration and contact time was fixed at 1 mg/l and four hour respectively. The amount of dose was varied between 1.2 and 10 g/l in aqueous solution. Results showed that MSP was efficient for 32.5% removal of Fluoride ions at 5 g/l and 18.7% at 1.2 g/l (Fig. 45).

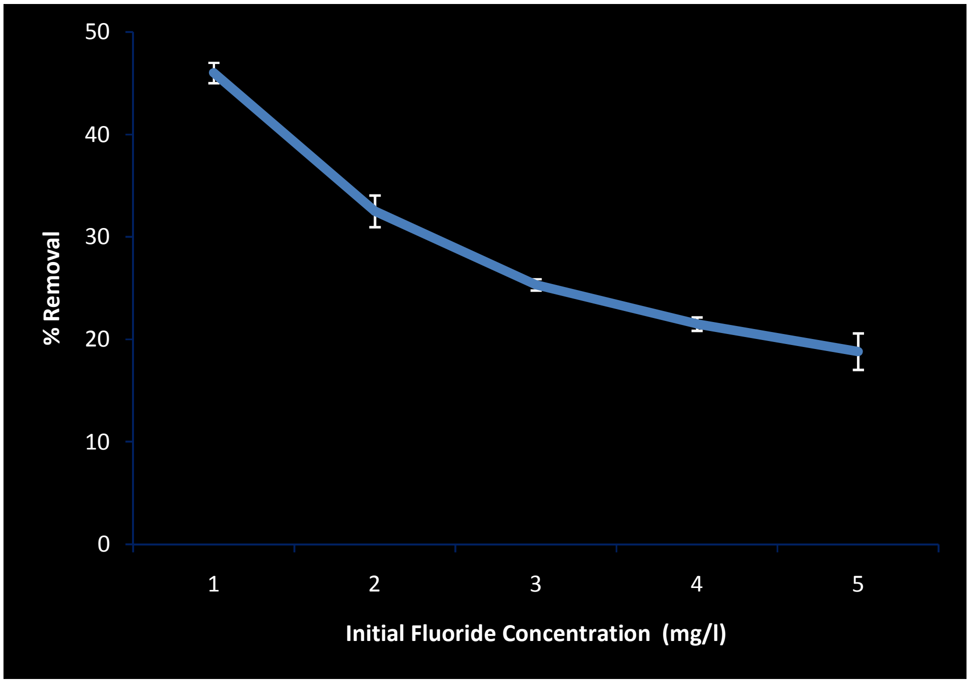


Figure 43 : Effect of Initial Fluoride Concentration on Fluoride ion removal by MSP

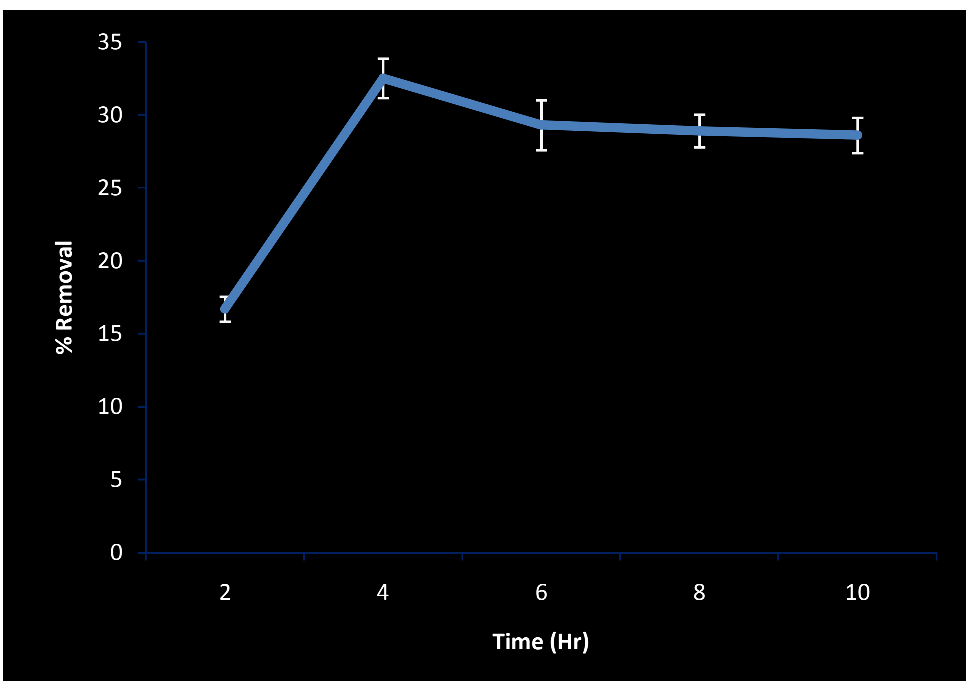


Figure 44 : Effect of Time on Fluoride ion removal by MSP

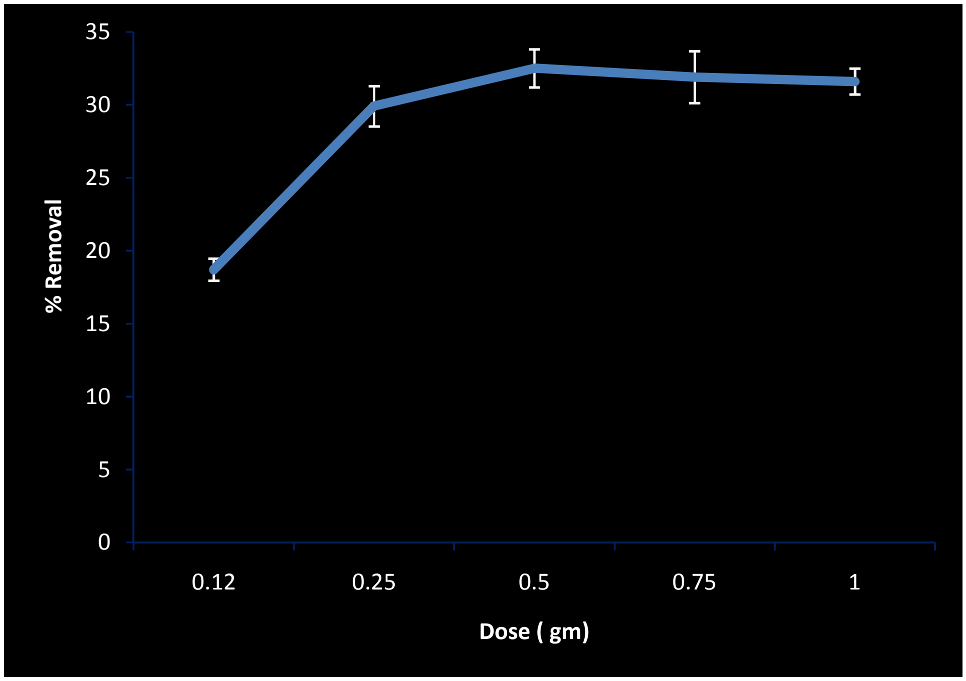


Figure 45: Effect of dose on Fluoride ion removal by MSP

In-vitro Fluoride removal efficiency of *Moringa oleifera* bark powder (MBP), was 92.75% within 8 hours of contact time at 5 g/l dose with initial concentration of 1 ppm as measured in optimized study whereas for *Moringa oleifera* seed powder (MSP), the reduction was 32.5% within 4 hours of contact time at 5 g/l dose and 1 ppm initial concentration of Fluoride.

Adsorption isotherms

Adsorption isotherm is a functional expression that correlates the amount of solute adsorbed per unit weight of the adsorbent and the concentration of an adsorbate in bulk solution at a given temperature under equilibrium conditions. It is important to establish the appropriate relationship for the batch equilibrium data using empirical or theoretical equations as it may help in modeling, analyzing and designing adsorption systems. The adsorption isotherms are one of the most useful data to understand the mechanism of the adsorption and the characteristics of isotherms are needed before the interpretation of the kinetics of the adsorption process. Various Adsorption isotherms were applied as follows:

Langmuir isotherm for *Moringa oleifera* bark powder (MBP) and *Moringa oleifera* seed powder (MSP)

A plot of $\frac{1}{q_e}$ vs $\frac{1}{c_e}$ was drawn (Fig. 46 and 47) from the linear quation of Langmuir. The result obtained from the regression correlation was fairly well (R^2= 0.96 and 0.98 for MBP and MSP) at temperature 298 K . The value of K_L and q_m (as shown in Table 8) obtained from the slope as well as intercept for MBP 3.36 and 0.49 while for MSP it was 1.47 and 0.21. In addition to above the value of dimensionless constant separation factor R_L ranged from 0.23 to 0.06 for 1 – 5 ppm for MBP whereas for MSP it was 0.40 to 0.12 for 1-5 ppm at 298 K temperature.

Freundlich isotherm for *Moringa oleifera* bark powder (MBP) and *Moringa oleifera* seed powder (MSP)

In contrast to the isotherm model for homogenous adsorption on the monolayer, the Freundlich model provides a model for the heterogenous adsorption. The plot of $\ln q_e$ vs $\ln C_e$ was drawn (Fig. 48 and 49). The results were best fit to the experimental data for temperature 298 K. The value of K_F was 0.35 for MBP and 0.12 for MSP at 298 K. In addition to this the value of heterogeneity factor “n” was 2.54 and 2.84 (Table 9) for MBP and MSP respectively.

In our study, from Langmuir isotherm values of R_L ($0 < R_L < 1$) for MBP and MSP showed favorable adsorption system. However, Freundlich isotherm model, based on multilayer adsorption, described results were best fit to the experimental data as Freundlich coefficient $n > 1$ for MBP and MSP, and that supports the favorable physical process of adsorption of Fluoride onto the adsorbent.

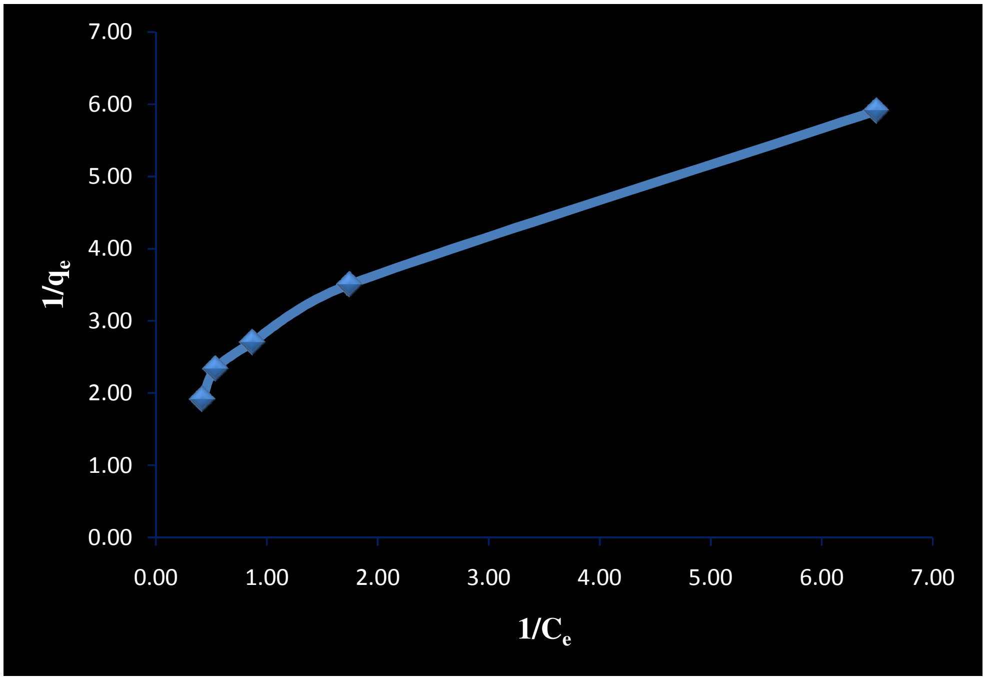


Figure 46 : Langmuir adsorption isotherm for MBP

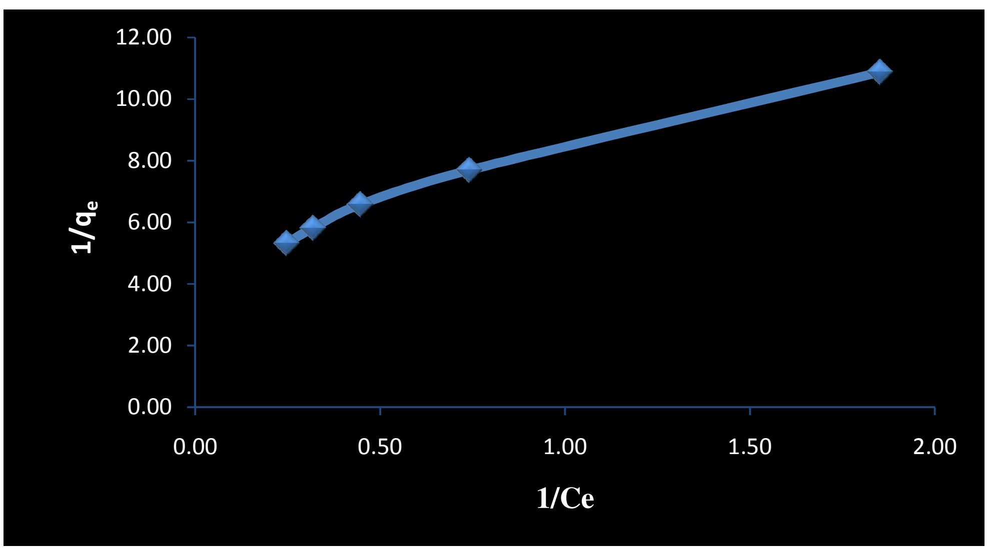


Figure 47 : Langmuir adsorption isotherm for MSP

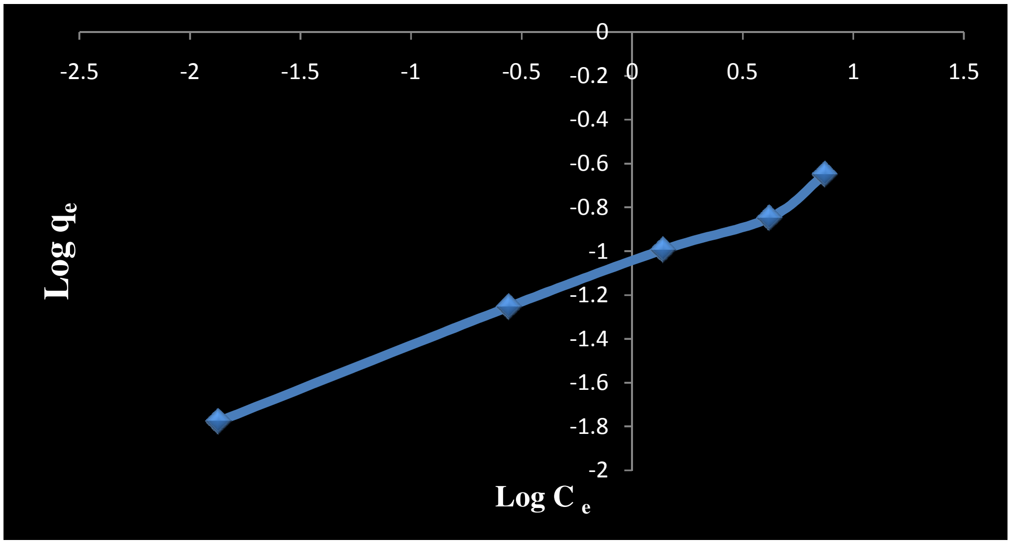


Figure 48 : Freundlich adsorption isotherm for MBP

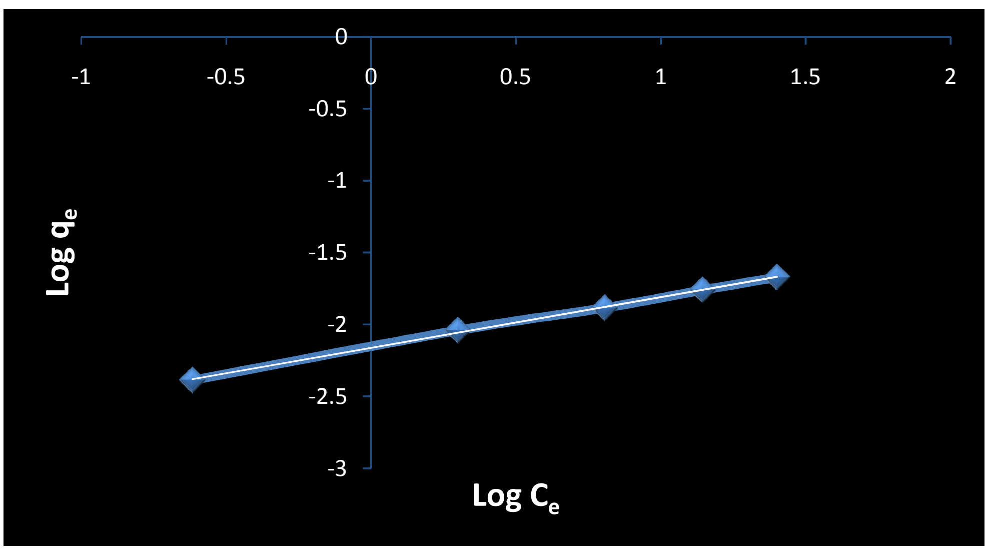


Figure 49 : Freundlich adsorption isotherm for MSP

Table 8: Langmuir variables for MBP and MSP

Sr. No.	Adsorbent Name	Temperature (K)	q_m	K_L	R_L					R^2
					1	2	3	4	5	
1	MBP	**298**	**0.49**	**3.36**	**0.23**	**0.13**	**0.09**	**0.07**	**0.06**	**0.96**
2	MSP	**298**	**0.21**	**1.47**	**0.40**	**0.25**	**0.18**	**0.15**	**0.12**	**0.98**

Table 9: Freundlich variables for MBP and MSP

Sr. No.	Adsorbent Name	Temperature(K)	K_F (mg/g)	n	R^2
1	MBP	298	0.35	2.54	0.99
2	MSP	298	0.12	2.84	0.99

Discussion :

The results illustrated decreased Fluoride removal efficiency with increasing initial concentration. Lower concentration causes more interaction of Fluoride ions with the binding sites and at higher concentration, increase in the number of ions is responsible for competition in availability of binding sites on the adsorbent surface (Murugan and Subramanian, 2006). Moreover, for fixed adsorbent dose, the total available adsorption sites were limited, which became saturated at high concentration. Due to increasing concentration gradient, Fluoride acts as increasing driving force to overcome all mass transfer resistances of the Fluoride between the aqueous and solid phase, leading to an increasing uptake capacity until sorbent saturation is achieved. Similar result had reported for Fluoride removal by Sujana *et al.*(2009).

Alagumuthu *et al.* (2011) recorded that initially there were large number of vacant active binding sites in adsorbent, and consequently large amount of Fluoride ions was bound rapidly onto the adsorbent. The binding site shortly become limited and the remaining vacant surface sites are difficult to be occupied by Fluoride ions due to the formation of repulsive forces between the adsorbate on the solid surface and the liquid phase (Bhaumik *et al*. 2012).

Killedar and Bhargava (1993) reported that no further increase in adsorption after a certain amount of adsorbent was added. This might be due to overlapping of adsorption sites as a result of overcrowding of adsorption particles, reducing the net surface area.

3.2.3 Physicochemical characterization of groundwater samples with special

reference to Fluoride

For in vivo bioremoval study, 30 groundwater samples from 30 villages from each taluka i.e. Satlasana, Lilia and Wankaner were collected in pre and post monsoon and were analyzed for potable parameters as well as Fluoride content. Out of these 30 groundwater samples, five samples were selected randomly from each taluka for correlation analysis and piper diagram.

The villages selected from Satlasana taluka were Dharoi, Mota Kothasana, Dharavania, Dholu and Vajapur. From Lilia taluka, Punjapadar, Putaliya, Sanaliya, Eklera and Timbri were selected and Satapar, Jodhapar, Garida, Shekharadi and Amarsar were selected from Wankanere Taluka.

Physicochemical Analysis of groundwater samples

To assess drinking water quality of the collected groundwater samples, following parameters were taken into consideration i.e. Fluoride, pH, Total alkalinity, Total dissolved solids, Calcium, Magnesium, Carbonate, Bicarbonate, Sulphate and Sodium. Average values (pre and post monsoon) of each physicohemical parameter were taken into consideration.

Satlasana Taluka

pH

pH is an important piece of information used as first measure to evaluated the applicability of groundwater for drinking purpose. From the data obtained it is depicted that pH value ranged from 7.82 to 8.93. pH value of only one village (3.33%) was found to be beyond permissible limit. i.e. 8.5 (Table: 12)

Total Alkalinity

Alkalinity is due to various ionic species of bicarbonate, hydroxide, phosphate, borate and organic acids. Minimum value of alkalinity recorded was 77 and maximum was 412.0.

Total Dissolved Solids

Total dissolved solids are the concentrations of all dissolved minerals mainly inorganic salts in water which indicate the general nature of salinity of water. TDS value ranged from minimum of 155 to maximum of 805 mg/l.

Calcium

Calcium in this taluka ranged from 7.70 to 117.20 mg/l.

Magnesium

The range of Magnesium was found to be 9.12-29.28 mg/l.

Sulphate

Sulphate mg/l ranged from 2.86 to 37.20.

Sodium

Sodium is one of the major inorganic cation of water. It is the sixth most abundant element in the earth's curst. Minimum value of sodium recorded was 13 while maximum was 112 mg/l .

Fluoride

Fluoride value ranged from 1.08 to 5.70 mg/l . 25 samples (83.33 %) in this taluke were found to be beyond permissible limit i.e. 1.5 ppm.

Except for pH and Fluoride all the other parameters were found within the permissible limit of BIS.

Table 10: Physicochemical parameters of groundwater samples of Satlasana taluka

Premonsoon

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Bhanavas	7.88	92.80	150.00	21.60	14.40	14.00	93.00	28.60	20.00	2.68
2	Santola	7.83	414.00	390.00	38.40	26.90	18.00	82.00	25.78	36.00	2.81
3	Sheshpur	7.90	92.00	240.00	24.80	14.40	12.00	92.00	28.60	23.00	2.80
4	Samrapur	7.85	90.80	370.00	41.60	25.44	14.00	90.00	28.60	23.00	2.44
5	Nana Kothasana	8.00	102.40	200.00	18.40	17.76	17.00	101.00	2.02	20.00	3.76
6	Dholu	8.40	111.60	200.00	16.00	15.84	22.00	109.00	17.16	20.00	4.04
7	Dharoi	7.90	86.00	240.00	28.80	16.32	24.00	88.00	22.88	20.00	1.10
8	Kanedia	7.96	96.00	184.00	17.80	16.36	28.00	92.00	14.70	18.00	1.30
9	Nedardi	8.00	104.00	260.00	17.60	12.48	22.00	106.00	28.60	37.00	3.30
10	Ajabapur	7.98	118.00	180.00	20.80	11.52	19.00	112.00	2.86	20.00	1.39
11	Radhupura	7.92	94.80	175.00	21.60	18.24	14.00	94.00	2.86	13.00	2.64
12	Mumanvas	8.00	76.00	560.00	16.00	24.60	48.00	87.00	34.32	100.00	5.52
13	Vaghar	8.01	148.00	380.00	20.00	25.92	14.00	145.00	31.46	50.00	1.35
14	Jaspur	8.01	104.00	270.00	24.00	17.76	14.00	107.00	20.02	23.00	2.68
15	Khodamali	8.03	136.00	280.00	18.40	20.16	12.00	134.00	28.60	30.00	2.30

(Contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Hadol	8.04	110.00	220.00	26.00	26.00	20.00	110.00	11.46	24.00	2.60
17	Vav	8.02	106.80	180.00	16.00	15.36	19.00	94.00	5.72	20.00	2.42
18	Mota Kothasana	7.98	98.00	250.00	28.80	13.92	22.00	88.00	28.60	20.00	2.68
19	Isakpura	8.00	91.20	300.00	28.00	17.76	24.00	92.00	22.88	30.00	1.15
20	Dharavania	8.10	92.00	235.00	24.80	15.36	24.00	93.00	17.16	22.00	3.68
21	Bedasma	8.20	99.40	297.00	34.00	13.96	18.00	97.00	31.66	33.00	3.80
22	Shahpura	8.02	94.00	310.00	34.40	25.44	22.00	85.00	11.44	23.00	2.60
23	Kesarpura	8.03	74.80	260.00	19.20	18.72	24.00	116.00	17.16	25.00	4.04
24	Rajpur	8.00	112.00	170.00	24.00	11.52	24.00	121.00	5.72	15.00	3.70
25	Aankaliyara	8.02	107.20	200.00	24.80	15.36	26.00	121.00	8.58	20.00	3.52
26	Timba	8.00	104.40	170.00	20.80	12.00	22.00	117.00	17.16	23.00	4.04
27	Vajapur	8.94	124.00	810.00	7.80	13.40	31.00	114.00	37.22	36.00	5.80
28	Gothada	8.02	110.00	420.00	49.60	29.28	29.00	95.00	20.02	43.00	3.30
29	Sartanpur	8.20	120.00	370.00	14.40	12.96	48.00	209.00	28.60	112.00	2.04
30	Bhimpur	8.15	108.40	165.00	22.40	9.12	14.00	102.00	5.72	23.00	1.98

Table 11: Physicochemical parameters of groundwater samples of Satlasana taluka

Postmonsoon

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Bhanavas	7.87	92.00	160.00	20.00	14.40	12.00	92.00	28.60	20.00	2.68
2	Santola	7.81	410.00	395.00	38.80	26.90	12.00	78.00	25.74	30.00	2.76
3	Sheshpur	7.92	92.80	250.00	24.00	14.40	12.00	93.00	31.46	23.00	2.80
4	Samrapur	7.83	90.00	370.00	40.00	25.44	14.00	90.00	28.60	23.00	2.44
5	Nana Kothasana	7.95	101.20	200.00	19.20	17.76	19.00	101.00	22.88	20.00	3.76
6	Dholu	8.00	110.00	210.00	17.60	15.84	24.00	110.00	20.02	20.00	4.00
7	Dharoi	7.91	87.20	235.00	26.40	16.32	22.00	87.00	28.60	20.00	1.06
8	Kanedia	7.94	90.00	180.00	17.60	16.36	24.00	90.00	14.30	15.00	1.24
9	Nedardi	8.02	102.00	280.00	17.60	12.48	24.00	102.00	25.74	37.00	3.63
10	Ajabapur	7.96	116.00	185.00	21.60	11.52	19.00	116.00	2.86	20.00	1.34
11	Radhupura	7.92	94.00	170.00	22.40	18.24	12.00	94.00	2.86	13.00	2.68
12	Mumanvas	8.00	78.00	550.00	17.60	24.60	48.00	87.00	37.18	100.00	5.60
13	Vaghar	8.03	149.20	385.00	22.40	25.92	12.00	149.00	34.22	50.00	1.35
14	Jaspur	8.01	106.00	275.00	28.00	17.76	14.00	106.00	22.88	23.00	2.64
15	Khodamali	8.03	137.20	270.00	20.00	20.16	14.00	137.00	31.46	30.00	2.36

(Contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Hadol	8.01	106.00	210.00	20.00	26.00	17.00	106.00	11.44	20.00	2.20
17	Vav	8.02	96.00	170.00	17.60	15.36	19.00	96.00	8.58	20.00	2.48
18	Mota Kothasana	7.98	89.60	240.00	26.40	13.92	17.00	89.00	31.46	20.00	3.68
19	Isakpura	8.00	95.20	290.00	26.40	17.76	24.00	95.00	28.60	30.00	1.04
20	Dharavania	7.61	95.20	235.00	24.00	15.36	24.00	96.00	20.02	22.00	3.64
21	Bedasma	8.00	99.20	295.00	32.00	13.96	14.00	99.00	31.46	30.00	3.60
22	Shahpura	7.94	73.20	310.00	33.60	25.44	19.00	73.00	14.30	23.00	2.68
23	Kesarpura	8.03	113.20	250.00	16.00	18.72	24.00	113.00	20.02	25.00	4.08
24	Rajpur	8.03	107.20	185.00	22.40	11.52	29.00	107.00	5.72	15.00	3.76
25	Aankaliyara	8.02	106.80	205.00	24.80	15.36	29.00	107.00	8.58	20.00	3.52
26	Timba	8.05	108.80	195.00	213.60	12.00	24.00	109.00	17.16	23.00	4.24
27	Vajapur	8.92	122.00	800.00	7.60	13.40	29.00	116.00	37.18	32.00	5.60
28	Gothada	8.02	81.20	405.00	48.80	29.28	36.00	81.00	22.88	43.00	3.96
29	Sartanpur	8.24	216.00	390.00	14.40	12.96	46.00	216.00	28.60	112.00	2.04
30	Bhimpur	8.18	108.80	160.00	23.20	9.12	14.00	109.00	8.58	23.00	1.94

Table 12: Average values of Physicochemical parameters (pre and post) of Satlasana taluka

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Bhanavas	7.88	92.40	155.00	20.80	14.40	13.00	92.50	28.60	20.00	2.68
2	Santola	7.82	412.00	392.50	38.60	26.90	15.00	80.00	25.76	33.00	2.79
3	Sheshpur	7.91	92.40	245.00	24.40	14.40	12.00	92.50	30.03	23.00	2.80
4	Samrapur	7.84	90.40	370.00	40.80	25.44	14.00	90.00	28.60	23.00	2.44
5	Nana Kothasana	7.98	101.80	200.00	18.80	17.76	18.00	101.00	12.45	20.00	3.76
6	Dholu	8.20	110.80	205.00	16.80	15.84	23.00	109.50	18.59	20.00	4.02
7	Dharoi	7.91	86.60	237.50	27.60	16.32	23.00	87.50	25.74	20.00	1.08
8	Kanedia	7.95	93.00	182.00	17.70	16.36	26.00	91.00	14.50	16.50	1.27
9	Nedardi	8.01	103.00	270.00	17.60	12.48	23.00	104.00	27.17	37.00	3.47
10	Ajabapur	7.97	117.00	182.50	21.20	11.52	19.00	114.00	2.86	20.00	1.37
11	Radhupura	7.92	94.40	172.50	22.00	18.24	13.00	94.00	2.86	13.00	2.66
12	Mumanvas	8.00	77.00	555.00	16.80	24.60	48.00	87.00	35.75	100.00	5.56
13	Vaghar	8.02	148.60	382.50	21.20	25.92	13.00	147.00	32.84	50.00	1.35
14	Jaspur	8.01	105.00	272.50	26.00	17.76	14.00	106.50	21.45	23.00	2.66
15	Khodamali	8.03	136.60	275.00	19.20	20.16	13.00	135.50	30.03	30.00	2.33

(Contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Hadol	8.03	108.00	215.00	23.00	26.00	18.50	108.00	11.45	22.00	2.40
17	Vav	8.02	101.40	175.00	16.80	15.36	19.00	95.00	7.15	20.00	2.45
18	Mota Kothasana	7.98	93.80	245.00	27.60	13.92	19.50	88.50	30.03	20.00	3.18
19	Isakpura	8.00	93.20	295.00	27.20	17.76	24.00	93.50	25.74	30.00	1.10
20	Dharavania	7.86	93.60	235.00	24.40	15.36	24.00	94.50	18.59	22.00	3.66
21	Bedasma	8.10	99.30	296.00	33.00	13.96	16.00	98.00	31.56	31.50	3.70
22	Shahpura	7.98	83.60	310.00	34.00	25.44	20.50	79.00	12.87	23.00	2.64
23	Kesarpura	8.03	94.00	255.00	17.60	18.72	24.00	114.50	18.59	25.00	4.06
24	Rajpur	8.02	109.60	177.50	23.20	11.52	26.50	114.00	5.72	15.00	3.73
25	Aankaliyara	8.02	107.00	202.50	24.80	15.36	27.50	114.00	8.58	20.00	3.52
26	Timba	8.03	106.60	182.50	117.20	12.00	23.00	113.00	17.16	23.00	4.14
27	Vajapur	8.93	123.00	805.00	7.70	13.40	30.00	115.00	37.20	34.00	5.70
28	Gothada	8.02	95.60	412.50	49.20	29.28	32.50	88.00	21.45	43.00	3.63
29	Surtanpura	8.22	168.00	380.00	14.40	12.96	47.00	212.50	28.60	112.00	2.04
30	Bhimpur	8.17	108.60	162.50	22.80	9.12	14.00	105.50	7.15	23.00	1.96

Lilia Taluka :

pH

From the data obtained it is depicted that pH value ranged from 7.82 to 8.72. pH value of 10 villages (33.33%) was found to be beyond permissible limit. i.e. 8.5 (Table :15).

Total Alkalinity

Minimum value of alkalinity recorded was 102 and maximum was 588.0.

Total Dissolved Solids

TDS value ranged from minimum of 455 to maximum of 5096 mg/l. TDS value of 12 villages (40.0%) was found to be beyond permissible limit.

Calcium

Calcium in this taluka ranged from 8.40 to 313.20 mg/l. Calcium value of 3 villages (10.0%) was found to be beyond permissible limit.

Magnesium

The range of Magnesium was found to be 4.32- 236.16 mg/l.

Sulphate

Sulphate mg/l ranged from 17.16 to 493.35 mg/l.Calcium value of 2 villages (6.67%) was found to be beyond permissible limit.

Sodium

Minimum value of sodium recorded was 153 while maximum was 1110 mg/l. Calcium value of 25 villages (25%) was found to be beyond permissible limit.

Fluoride

Fluoride value ranged from 1.19 to 3.56 mg/l. 28 samples (93.33 %) in this taluke were found to be beyond permissible limit i.e. 1.5 ppm.

Table 13: Physicochemical parameters of groundwater samples of Lilia taluka

Premonsoon

Sr. No.	Village	pH	TA mg/l	TDS mg/l	Ca mg/l	Mg mg/l	CO_3 mg/l	HCO_3 mg/l	SO_4 mg/l	Na mg/l	F mg/l
1	Lonki	8.55	649.20	1140.00	7.20	10.08	149.00	649.00	31.46	490.00	2.76
2	Timbri	7.95	122.00	2501.00	84.00	130.08	96.00	122.00	99.00	650.00	2.80
3	Nana Lilia	8.74	354.00	3010.00	12.00	33.60	432.00	354.00	198.00	1020.00	1.38
4	Godavadar	8.69	386.00	1240.00	14.40	12.96	108.00	386.00	66.00	457.00	2.48
5	Bhesan	7.91	153.20	5002.00	146.40	188.16	96.00	153.00	396.00	1060.00	2.48
6	Vaghaniya	8.42	232.00	1980.00	20.00	50.40	216.00	232.00	330.00	670.00	2.36
7	Putaliya	8.50	216.00	505.00	17.60	13.44	48.00	216.00	37.18	140.00	1.38
8	Eklera	8.48	409.20	1670.00	13.60	22.08	228.00	409.00	66.00	615.00	2.38
9	Khara	8.56	620.00	1440.00	15.20	12.00	161.00	620.00	14.30	550.00	2.74
10	Shedhavadar	8.05	153.20	3005.00	108.00	171.36	108.00	153.00	297.00	785.00	2.60
11	Kalyanpur	8.66	543.20	1860.00	14.40	18.24	348.00	543.00	264.00	730.00	2.44
12	Kankot Mota	8.50	157.20	605.00	18.40	21.12	53.00	157.00	28.60	148.00	1.90
13	Krankach	7.93	128.00	1390.00	134.40	89.28	108.00	128.00	82.50	275.00	1.79
14	Haripar	8.40	351.20	620.00	11.20	5.28	96.00	351.00	20.02	230.00	1.60
15	Bhensavadi	8.35	201.20	1480.00	8.00	49.44	144.00	201.00	14.30	425.00	1.82

(Contd.)

Sr. No.	Village	pH	TA mg/l	TDS mg/l	Ca mg/l	Mg mg/l	CO_3 mg/l	HCO_3 mg/l	SO_4 mg/l	Na mg/l	F mg/l
16	Piplva	7.73	104.00	1350.00	208.00	95.04	84.00	104.00	72.60	194.00	2.56
17	Bhoringda	7.85	110.00	1500.00	144.00	88.32	60.00	110.00	132.00	250.00	0.88
18	Amba	7.82	55.20	1450.00	136.00	94.08	120.00	55.00	99.00	275.00	2.56
19	Saladi	8.50	226.00	710.00	14.40	28.32	86.00	226.00	8.58	220.00	1.42
20	Sanaliya	8.73	311.20	1960.00	14.40	40.32	264.00	311.00	82.50	705.00	1.86
21	Hathigadh	8.48	232.00	1690.00	24.00	39.36	180.00	232.00	165.00	600.00	1.44
22	Punjapadar	8.69	370.00	490.00	11.20	3.36	94.00	370.00	28.60	186.00	1.20
23	Rajkot nana	8.45	166.00	295.00	19.20	16.32	46.00	166.00	20.02	70.00	1.96
24	Antaliya	8.57	405.20	720.00	12.00	9.12	108.00	405.00	14.30	237.00	2.40
25	Dhangala	8.28	220.00	2910.00	20.80	49.44	168.00	220.00	264.00	1000.00	2.48
26	Sajantimba	8.17	128.00	1455.00	63.20	42.24	96.00	128.00	165.00	425.00	1.38
27	Jatroda	8.53	260.00	630.00	10.40	21.12	82.00	261.00	495.00	210.00	2.80
28	Bodiya	7.97	262.40	4990.00	100.00	123.36	96.00	262.00	544.50	1056.00	2.70
29	Kuntana	8.21	214.00	4500.00	48.00	124.32	108.00	214.00	330.00	1020.00	2.20
30	Gundaran	8.77	406.00	980.00	14.40	14.40	151.00	406.00	66.00	373.00	2.30

Table 14: Physicochemical parameters of groundwater samples of Lilia taluka

Postmonsoon

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Lonki	8.61	528.00	805.00	9.60	9.12	166.00	528.00	82.50	400.00	3.28
2	Timbri	7.70	171.20	6005.00	542.40	342.24	96.00	471.00	455.40	1167.00	4.32
3	Nana Lilia	8.54	534.00	980.00	5.60	11.04	142.00	534.00	297.00	440.00	3.54
4	Godavadar	8.24	489.20	700.00	9.60	7.20	106.00	489.00	72.60	340.00	2.20
5	Bhesan	7.74	92.00	5190.00	115.20	237.12	108.00	92.00	415.00	1160.00	3.60
6	Vaghaniya	8.32	164.80	1540.00	27.20	93.12	26.00	163.00	237.60	580.00	0.82
7	Putaliya	8.20	223.20	390.00	9.60	9.12	50.00	223.00	66.00	167.00	1.82
8	Eklera	8.73	443.60	850.00	22.40	12.00	166.00	433.00	171.30	425.00	2.68
9	Khara	8.87	526.00	1480.00	10.40	21.60	187.00	526.00	330.00	785.00	4.32
10	Shedhavadar	8.50	157.20	605.00	18.40	21.12	53.00	157.00	28.60	148.00	1.90
11	Kalyanpur	8.48	600.00	1150.00	10.40	14.40	151.00	600.00	238.04	635.00	3.60
12	Kankot Mota	7.57	159.20	2980.00	420.00	234.24	60.00	159.00	396.00	600.00	1.28
13	Krankach	8.17	120.00	710.00	74.40	62.40	24.00	120.00	198.00	140.00	0.59
14	Haripar	8.51	265.60	295.00	7.20	4.32	65.00	265.00	28.60	148.00	4.96
15	Bhensavadi	8.14	201.20	1980.00	70.40	117.12	72.00	201.00	330.00	730.00	1.82

(Contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Piplva	8.44	367.60	430.00	10.40	9.12	86.00	367.00	66.00	194.00	2.74
17	Bhoringda	8.66	263.20	870.00	17.60	13.44	110.00	264.00	330.00	505.00	2.80
18	Amba	7.82	149.20	1520.00	159.20	104.16	20.00	150.00	363.00	410.00	1.22
19	Saladi	8.38	246.00	600.00	8.00	30.24	70.00	246.00	214.50	263.00	1.22
20	Sanaliya	7.54	164.80	4200.00	417.60	89.28	96.00	165.00	389.40	1060.00	3.86
21	Hathigadh	8.66	263.20	870.00	17.60	13.44	110.00	264.00	330.00	505.00	2.80
22	Punjapadar	8.50	370.00	400.00	7.20	5.28	106.00	370.00	37.18	202.00	2.78
23	Rajkot nana	8.57	405.20	720.00	12.00	9.12	108.00	405.00	14.30	237.00	2.40
24	Antaliya	8.73	488.00	940.00	11.20	13.44	151.00	488.00	79.20	350.00	2.36
25	Dhangala	8.62	532.80	870.00	20.00	2.40	110.00	533.00	392.70	550.00	2.68
26	Sajantimba	8.52	267.20	1230.00	12.00	37.44	77.00	267.00	297.00	664.00	3.20
27	Jatroda	8.20	276.00	690.00	16.00	41.28	65.00	276.00	168.30	310.00	1.44
28	Bodiya	7.90	195.20	4510.00	115.20	330.24	120.00	195.00	442.20	1080.00	2.80
29	Kuntana	8.25	232.00	1680.00	37.60	44.16	84.00	232.00	330.00	850.00	1.46
30	Gundaran	8.36	586.00	910.00	7.20	13.44	139.00	586.00	99.00	425.00	2.80

Table 15: Average values of Physicochemical parameters (pre and post) of Lilia taluka

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Lonki	8.58	588.60	972.50	8.40	9.60	157.50	588.50	56.98	445.00	3.02
2	Timbri	7.83	146.60	4253.00	313.20	236.16	96.00	296.50	277.20	908.50	3.56
3	Nana Lilia	8.64	444.00	1995.00	8.80	22.32	287.00	444.00	247.50	730.00	2.46
4	Godavadar	8.47	437.60	970.00	12.00	10.08	107.00	437.50	69.30	398.50	2.34
5	Bhesan	7.83	122.60	5096.00	130.80	212.64	102.00	122.50	405.50	1110.00	3.04
6	Vaghaniya	8.37	198.40	1760.00	23.60	71.76	121.00	197.50	283.80	625.00	1.59
7	Putaliya	8.35	219.60	447.50	13.60	11.28	49.00	219.50	51.59	153.50	1.60
8	Eklera	8.61	426.40	1260.00	18.00	17.04	197.00	421.00	118.65	520.00	2.53
9	Khara	8.72	573.00	1460.00	12.80	16.80	174.00	573.00	172.15	667.50	3.53
10	Shedhavadar	8.28	155.20	1805.00	63.20	96.24	80.50	155.00	162.80	466.50	2.25
11	Kalyanpur	8.57	571.60	1505.00	12.40	16.32	249.50	571.50	251.02	682.50	3.02
12	Kankot Mota	8.04	158.20	1792.50	219.20	127.68	56.50	158.00	212.30	374.00	1.59
13	Krankach	8.05	124.00	1050.00	104.40	75.84	66.00	124.00	140.25	207.50	1.19
14	Haripar	8.46	308.40	457.50	9.20	4.80	80.50	308.00	24.31	189.00	3.28
15	Bhensavadi	8.25	201.20	1730.00	39.20	83.28	108.00	201.00	172.15	577.50	1.82

(contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Piplva	8.09	235.80	890.00	109.20	52.08	85.00	235.50	69.30	194.00	2.65
17	Bhoringda	8.26	186.60	1185.00	80.80	50.88	85.00	187.00	231.00	377.50	1.84
18	Amba	7.82	102.20	1485.00	147.60	99.12	70.00	102.50	231.00	342.50	1.89
19	Saladi	8.44	236.00	655.00	11.20	29.28	78.00	236.00	111.54	241.50	1.32
20	Sanaliya	8.14	238.00	3080.00	216.00	64.80	180.00	238.00	235.95	882.50	2.86
21	Hathigadh	8.57	247.60	1280.00	20.80	26.40	145.00	248.00	247.50	552.50	2.12
22	Punjapadar	8.60	370.00	445.00	9.20	4.32	100.00	370.00	32.89	194.00	1.99
23	Rajkot nana	8.51	285.60	507.50	15.60	12.72	77.00	285.50	17.16	153.50	2.18
24	Antaliya	8.65	446.60	830.00	11.60	11.28	129.50	446.50	46.75	293.50	2.38
25	Dhangala	8.45	376.40	1890.00	20.40	25.92	139.00	376.50	328.35	775.00	2.58
26	Sajantimba	8.35	197.60	1342.50	37.60	39.84	86.50	197.50	231.00	544.50	2.29
27	Jatroda	8.37	268.00	660.00	13.20	31.20	73.50	268.50	331.65	260.00	2.12
28	Bodiya	7.94	228.80	4750.00	107.60	226.80	108.00	228.50	493.35	1068.00	2.75
29	Kuntana	8.23	223.00	3090.00	42.80	84.24	96.00	223.00	330.00	935.00	1.83
30	Gundaran	8.57	496.00	945.00	10.80	13.92	145.00	496.00	82.50	399.00	2.55

Wankaner Taluka :

pH

From the data obtained it is depicted that pH value ranged from 7.72 to 8.62. pH value of 3 villages (10.0%) was found to be beyond permissible limit. i.e. 8.5 (Table :18).

Total Alkalinity

Minimum value of alkalinity recorded was 119 and maximum was 530.0.

Total Dissolved Solids

TDS value ranged from minimum of 315 to maximum of 3045 mg/l. TDS value of 4 villages (13.33%) was found to be beyond permissible limit.

Calcium

Calcium in this taluka ranged from 8.0 to 276 mg/l. Calcium value of 2 villages (6.67%) was found to be beyond permissible limit.

Magnesium

The range of Magnesium was found to be 8.64- 181.68 mg/l.

Sulphate

Sulphate mg/l ranged from 12.87 to 268.95mg/l.

Sodium

Minimum value of sodium recorded was 68 while maximum was 596 mg/l. Sodium value of 14 villages (46.67%) was found to be beyond permissible limit.

Fluoride

Fluoride value ranged from 1.10 to 4.07 mg/l. 24 samples (80.0 %) in this taluke were found to be beyond permissible limit i.e. 1.5 ppm.

Table 16: Physicochemical parameters of groundwater samples of Wankaner taluka

Premonsoon

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Mesariya	8.00	115.20	1102.00	135.20	89.28	12.00	115.00	44.00	180.00	1.90
2	Samadhiyala	7.70	171.20	6005.00	542.40	342.24	96.00	171.00	455.40	1167.00	4.32
3	Gundakhada	8.13	163.20	615.00	26.40	49.44	19.00	163.00	28.60	148.00	2.78
4	Ratadiya	8.26	185.20	590.00	24.00	44.16	43.00	185.00	20.02	148.00	1.82
5	Satapar	8.36	204.00	310.00	23.60	39.20	43.00	204.00	14.30	75.00	0.74
6	Vinayagadh	8.36	332.00	500.00	10.40	9.12	91.00	332.00	8.58	186.00	2.42
7	Jalida	8.14	137.20	210.00	20.00	12.00	31.00	137.00	14.30	40.00	2.20
8	Rangapar	8.23	215.20	305.00	19.20	6.24	34.00	215.00	5.72	80.00	2.36
9	Garida	8.15	151.20	230.00	18.40	16.32	31.00	151.00	8.58	47.00	2.60
10	Rupavati	8.30	229.20	530.00	9.61	8.16	55.00	229.00	44.00	173.00	1.84
11	Jepur	8.31	470.00	1750.00	28.00	20.16	276.00	470.00	82.50	550.00	2.80
12	Mahika	8.21	171.20	640.00	25.60	45.12	38.00	171.00	31.46	154.00	2.60
13	Kherava	8.60	362.40	590.00	11.20	10.08	101.00	362.00	28.60	132.00	2.40
14	Khijadiya	8.30	156.00	230.00	17.60	11.04	34.00	156.00	5.72	53.00	2.42
15	Kothi	8.14	272.00	870.00	15.20	37.44	62.00	272.00	66.00	230.00	1.84

(Contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Jodhapar	8.02	149.20	650.00	24.00	49.44	34.00	149.00	54.00	140.00	1.84
17	Gariya	8.11	184.00	610.00	30.40	45.12	48.00	184.00	54.00	132.00	1.76
18	Limbada	8.20	160.00	580.00	18.40	48.00	38.00	160.00	50.00	132.00	1.54
19	Kanapar	8.08	116.00	510.00	42.40	33.12	22.00	116.00	44.00	80.00	2.60
20	Shekharadi	8.54	534.00	980.00	15.60	11.04	142.00	534.00	297.00	440.00	3.54
21	Lalpar	8.05	107.20	405.00	43.20	24.00	29.00	107.00	34.32	56.00	1.38
22	Tarakiya	8.16	146.00	215.00	26.40	13.44	31.00	146.00	14.30	37.00	1.30
23	Daladi	8.44	367.60	430.00	10.40	9.12	86.00	367.00	66.00	194.00	2.74
24	Chandrapur	8.01	157.20	190.00	24.00	13.44	24.00	157.00	14.30	33.00	2.80
25	Sindhavadar	7.74	92.00	5190.00	115.20	237.12	108.00	92.00	415.00	1160.00	3.60
26	Pratapghadh	8.50	157.20	605.00	18.40	21.12	53.00	157.00	28.60	148.00	1.90
27	kanakot	7.86	153.20	2480.00	82.40	129.12	144.00	153.00	99.00	550.00	2.36
28	Pipardi	8.41	207.20	405.00	14.40	14.40	46.00	207.00	44.00	112.00	2.44
29	Amarsar	8.70	526.00	870.00	10.40	6.24	185.00	526.00	25.74	340.00	4.60
30	Vaghashiya	7.88	102.00	1470.00	134.40	97.44	17.00	102.00	82.50	250.00	2.40

Table 17: Physicochemical parameters of groundwater samples of Wankaner taluka

Postmonsoon

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Mesariya	8.34	124.00	300.00	22.40	16.32	38.00	124.00	25.74	56.00	1.72
2	Samadhiyala	8.61	528.00	805.00	9.60	9.12	166.00	528.00	82.50	400.00	3.28
3	Gundakhada	8.23	215.20	305.00	19.20	6.24	34.00	215.00	5.72	80.00	2.36
4	Ratadiya	8.91	821.40	1680.00	18.40	20.16	358.00	821.00	201.30	965.00	2.44
5	Satapar	8.06	181.20	320.00	14.40	14.40	41.00	181.00	11.44	85.00	2.78
6	Vinayagadh	8.26	261.20	580.00	14.40	11.04	53.00	261.00	66.00	148.00	2.64
7	Jalida	8.50	157.20	605.00	18.40	21.12	53.00	157.00	28.60	148.00	1.90
8	Rangapar	8.05	107.20	405.00	43.20	24.00	29.00	107.00	34.32	56.00	1.38
9	Garida	8.14	202.00	870.00	15.20	37.44	62.00	202.00	66.00	230.00	1.84
10	Rupavati	8.36	204.00	310.00	13.60	19.20	43.00	204.00	14.30	75.00	0.74
11	Jepur	8.24	167.20	1150.00	29.60	68.16	96.00	177.00	72.60	440.00	1.76
12	Mahika	8.15	112.00	810.00	59.20	50.40	24.00	122.00	31.46	160.00	2.26
13	Kherava	8.20	223.20	390.00	9.60	9.12	50.00	223.00	66.00	167.00	1.82
14	Khijadiya	8.38	246.00	600.00	8.00	30.24	70.00	246.00	214.50	263.00	1.22
15	Kothi	8.17	120.00	710.00	74.40	62.40	24.00	120.00	198.00	140.00	0.59

(Contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Jodhapar	7.82	149.20	520.00	159.20	104.16	20.00	150.00	363.00	410.00	1.22
17	Gariya	8.38	246.00	600.00	8.00	30.24	70.00	246.00	214.50	263.00	1.22
18	Limbada	8.32	164.80	1540.00	27.20	93.12	26.00	163.00	237.60	580.00	0.82
19	Kanapar	8.24	489.20	700.00	9.60	7.20	106.00	489.00	72.60	340.00	2.20
20	Shekharadi	8.13	183.20	615.00	26.40	49.44	19.00	183.20	28.60	148.00	2.78
21	Lalpar	8.32	164.80	1540.00	27.20	93.12	26.00	163.00	237.60	580.00	0.82
22	Tarakiya	8.38	246.00	600.00	8.00	30.24	70.00	246.00	214.50	263.00	1.22
23	Daladi	8.73	488.00	940.00	11.20	13.44	151.00	488.00	79.20	350.00	2.36
24	Chandrapur	8.20	276.00	690.00	16.00	41.28	65.00	276.00	168.30	310.00	1.44
25	Sindhavadar	8.01	157.20	190.00	24.00	13.44	24.00	157.00	14.30	33.00	2.80
26	Pratapghadh	7.70	177.20	1980.00	198.40	132.00	62.00	167.00	300.30	275.00	2.80
27	kanakot	7.57	159.20	2980.00	420.00	234.24	60.00	159.00	396.00	600.00	1.28
28	Pipardi	8.20	223.20	390.00	9.60	9.12	50.00	223.00	66.00	167.00	1.82
29	Amarsar	8.54	534.00	980.00	5.60	11.04	142.00	534.00	297.00	440.00	3.54
30	Vaghashiya	8.25	232.00	1680.00	37.60	44.16	84.00	232.00	330.00	850.00	1.46

Table 18: Average values of Physicochemical parameters (pre and post) of Wankaner taluka

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Mesariya	8.17	119.60	701.00	78.80	52.80	25.00	119.50	34.87	118.00	1.81
2	Samadhiyala	8.16	349.60	3405.00	276.00	175.68	131.00	349.50	268.95	783.50	3.80
3	Gundakhada	8.18	189.20	460.00	22.80	27.84	26.50	189.00	17.16	114.00	2.57
4	Ratadiya	8.59	503.30	1135.00	21.20	32.16	200.50	503.00	110.66	556.50	2.13
5	Satapar	8.21	192.60	315.00	19.00	26.80	42.00	192.50	12.87	80.00	1.76
6	Vinayagadh	8.31	296.60	540.00	12.40	10.08	72.00	296.50	37.29	167.00	2.53
7	Jalida	8.32	147.20	407.50	19.20	16.56	42.00	147.00	21.45	94.00	2.05
8	Rangapar	8.14	161.20	355.00	31.20	15.12	31.50	161.00	20.02	68.00	1.87
9	Garida	8.15	176.60	550.00	16.80	26.88	46.50	176.50	37.29	138.50	2.22
10	Rupavati	8.33	216.60	420.00	11.61	13.68	49.00	216.50	29.15	124.00	1.29
11	Jepur	8.28	318.60	1450.00	28.80	44.16	186.00	323.50	77.55	495.00	2.28
12	Mahika	8.18	141.60	725.00	42.40	47.76	31.00	146.50	31.46	157.00	2.43
13	Kherava	8.40	292.80	490.00	10.40	9.60	75.50	292.50	47.30	149.50	2.11
14	Khijadiya	8.34	201.00	415.00	12.80	20.64	52.00	201.00	110.11	158.00	1.82
15	Kothi	8.16	196.00	790.00	44.80	49.92	43.00	196.00	132.00	185.00	1.22

(Contd.)

Sr. No.	Village	pH	TA	TDS	Ca	Mg	CO_3	HCO_3	SO_4	Na	F
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
16	Jodhapar	7.92	149.20	585.00	91.60	76.80	27.00	149.50	208.50	275.00	1.53
17	Gariya	8.25	215.00	605.00	19.20	37.68	59.00	215.00	134.25	197.50	1.49
18	Limbada	8.26	162.40	1060.00	22.80	70.56	32.00	161.50	143.80	356.00	1.18
19	Kanapar	8.16	302.60	605.00	26.00	20.16	64.00	302.50	58.30	210.00	2.40
20	Shekharadi	8.34	358.60	797.50	21.00	30.24	80.50	358.60	162.80	294.00	3.16
21	Lalpar	8.19	136.00	972.50	35.20	58.56	27.50	135.00	135.96	318.00	1.10
22	Tarakiya	8.27	196.00	407.50	17.20	21.84	50.50	196.00	114.40	150.00	1.26
23	Daladi	8.59	427.80	685.00	10.80	11.28	118.50	427.50	72.60	272.00	2.55
24	Chandrapur	8.11	216.60	440.00	20.00	27.36	44.50	216.50	91.30	171.50	2.12
25	Sindhavadar	7.88	124.60	2690.00	69.60	125.28	66.00	124.50	214.65	596.50	3.20
26	Pratapghadh	8.10	167.20	1292.50	108.40	76.56	57.50	162.00	164.45	211.50	2.35
27	kanakot	7.72	156.20	2730.00	251.20	181.68	102.00	156.00	247.50	575.00	1.82
28	Pipardi	8.31	215.20	397.50	12.00	11.76	48.00	215.00	55.00	139.50	2.13
29	Amarsar	8.62	530.00	925.00	8.00	8.64	163.50	530.00	161.37	390.00	4.07
30	Vaghashiya	8.07	167.00	1575.00	86.00	70.80	50.50	167.00	206.25	550.00	1.93

In Lilia, pH, Fluoride, sodium, sulphate and TDS estimated were found beyond the limit whereas Total alkalinity, Calcium and Magnesium were within the limit. pH, Fluoride, TDS, sodium and calcium were recorded beyond limit and Total alkalinity, Magnesium, and Sulphate were found within the limit in Wankaner taluka.

Discussion :

The study was carried out to assess the ground water quality and its suitability for drinking purpose in most rural habitations of Bassi tehsil of district Jaipur, Rajasthan by Saxena and Saxena (2015). For this purpose, groundwater samples from hand pumps, open wells and bore wells of a total of 50 villages in Bassi Tehsil of Jaipur district were collected and analyzed for different physico-chemical parameters. They investigated that groundwater pH was positively correlated with electrical conductivity, total hardness, calcium hardness, magnesium hardness, chloride, nitrate, and total dissolved solids and was negatively correlated with total alkalinity and Fluoride. EC had been found to show negative correlations with Fluoride whereas all other parameters were found to be positively correlated with EC. Out of 55 correlation coefficients, value of 6 correlation coefficients (r) lies between the TDS and EC, Cl- and EC (0.9356), Ca H and TH (0.9960), Mg H and TH (0.9967), Ca H and Mg H (0.9856), Cl- and TDS (0.9356) were found to be at highly significant levels ($0.8< r < 1.0$). Value of one correlation coefficient had given the significant level of r values. They investigated that there were 11 values of r showing moderate significant coefficient levels ($0.6< r < 0.8$). They also reported that 56% of groundwater samples had Fluoride content within the permissible limit (> 1.5 mg/l, WHO) and remaining 44% of villages with very high Fluoride concentrations. The favorable factor which contributes to rise of Fluoride level in groundwater is the presence of fluoride rich rock salt system. The nitrate ion concentration of 14% of total samples was more than 45 mg/l. In some samples it went beyond concentration of 380 mg/l. The increased nitrate level in the groundwater samples might be due to the consumption of large quantity of nitrogenous fertilizers like urea, NPK and cattle-shed along with municipal wastes. 24% of ground water samples had TDS more than 2000 mg/l (relaxed permissible limit as per BIS standards) and 42% groundwater samples recorded the Chloride level more than 200 mg/l.

Bishnoi and Arora (2007) had carried out study in ten villages of Rohtak district, Haryana. Total 63 water samples were collected from different sources, such as shallow handpumps, dug wells and public health water supply taps and analyzed. At 30 locations, Fluoride concentration was higher than the permissible limit. All locations of village Baniyani, had Fluoride concentration within the permissible limit except one; at Masoodpur and Lahli, only one location in each village had Fluoride concentration within the acceptable range. At Kalanaur, two locations had Fluoride concentration within the acceptable range. The remaining villages (about 50%) water sources had Fluoride content higher than permissible limit.
The Fluoride content in the groundwater is a function of many factors such as availability and solubility of fluoride minerals, velocity of flowing water, temperature, pH, concentration of calcium and bicarbonate ions in water, etc. (Khaiwal and Garg, 2006). These researchers had observed uneven distribution of Fluoride in the groundwater of Hisar city which was due to uneven distribution of Fluoride containing minerals in the rocks. Meenakshi *et al.*(2004) had reported the Fluoride contamination in the ground water of some villages in Jind district. The results showed that more than 50% water sources had Fluoride concentrations higher than permissible limits. A study conducted by Yadav and Lata (2003) in the Jhajjar district of Haryana have reported that Fluoride content was higher than 2 mg/l in all the locations of this district.

Correlation analysis was carried out for different parameters. Highly significant and positive correlation had been observed between TDS-TH ($r = 0.583$, $p <0.01$), TDS-Ca ($r = 0.820$, $p < 0.01$), TDS-Na ($r = 0.753$, $p < 0.01$), TDS-K ($r = 0.651$, $p < 0.01$), TDS-Cl ($r = 0.803$, $p < 0.01$), and TDS Sulphate ($r = 0.716$, $p < 0.01$). This suggested that presence of TH, calcium, sodium, potassium, chloride and sulphate in the study area greatly influence the TDS and EC. Total hardness was positively and significantly correlated with Ca ($r = 0.778$, $p <0.01$), Mg ($r = 0.575$, $p < 0.01$), Cl ($r = 0.547$, $p < 0.01$) and sulphate ($r = 0.759$, $p < 0.01$). This showed that there was great dependence of hardness on calcium, magnesium, chloride and sulphate. Total alkalinity was significantly and positively correlated with bicarbonate content ($r = 0.989$, $p < 0.01$) indicating that alkalinity was mainly of bicarbonate type. Sodium was significantly correlated with chloride ($r = 0.864$, $p < 0.01$) and sulphate ($r =0.578$, $p < 0.01$). Chloride content was significantly and positively correlated with sulphate ($r = 0.624$, $p < 0.01$). pH was significantly but negatively correlated with EC, TDS, TA, calcium, sodium and chloride. In contrast, Fluoride was not significantly correlated with any of the analyzed water quality parameter.

Statistical Study on Physicochemical Characteristics of groundwater in and around Namakkal, Tamilnadu was carried out by Karunakaran *et al.* (2009). Total 30 samples were collected from ten locations using spot sampling procedure and studied for every two month for the period June-2007 to December-2007. The results were:pH of test samples was within the permissible limits that had ranged from 6.90 to 8.33. Total hardness of collected samples was found to be in the range from 380 to 1050 mg/l. Total hardness values for samples collected from Thillaipurum, Nallipalayam, and Valayapatty were high due to the high concentration of calcium and magnesium salts. Hardness leads to heart diseases and kidney stone formation. These samples were not much suitable for drinking, washing, cleaning and laundering (Lalitha *et al*., 2004). The chloride content of water samples collected lies in the range from 142 to 888 mg/l. Sample collected from Anbu nagar, Thillaipuram and Nallipalayam had high concentration of chloride content and found to exceed the permissible limit proposed by BIS and WHO.High chloride content in water bodies harms metallic pipes and structure as well as agricultural crops (Shukla *et al*., 1992). Total alkalinity of water samples ranged from 300 to 935 mg/l. Samples from Thillaipuram and Velagoundampatty had high concentration of alkalinity and exceed the permissible limit proposed by BIS. High alkalinity in water bodies leads to sour taste and salinity. Sulphates of test samples ranged from 70 to 240 mg/l. Samples collected from Anbu nagar, Thillaipuram and Nallipalayam had moderately high values of sulphate and was found to be exceed the permissible limit.. Sulphate concentrations around 1000 mg/l, has laxative effect and causes gastro intestinal irritation (Bhatia, 2000). Nitrate of water samples ranged from 23 to 55 mg/l. Samples from Anbu nagar and Nallipalayam had moderately high values of nitrate and beyond the permissible limit proposed by BIS. High nitrate concentration in water bodies leads to organic pollution causes blue baby syndrome and it can be removed by desalination (Xanthoulis and

Wallender,1991). Sodium in the water samples ranged from 20 to 67 mg/l. Sodium in all the samples were found to be within the permissible limit.

Fluoride of water samples ranged from 0.1 to 1.4 mg/l. Samples collected from Anbu nagar, Thillaipuram and Nallipalayam had slightly high values of Fluoride and beyond the permissible limit proposed by BIS. High Fluoride values may be causes fluorosis, which is characterized by mottling of teeth enamel, nervous and skeletal disorder. The correlation coefficients (r) among various water quality parameters indicated the strong positive correlation between sulphate and Fluoride (0.977), nitrate and fluoride (0.976), conductivity and chloride (0.954). The correlation coefficients between conductivity and dissolved oxygen (0.777), total solids and fluoride (0.754), total solids and sulphate (0.732) were found to be moderately correlated. Sulphate and dissolved oxygen showed negative correlation with other parameters. Total hardness, pH, sodium, potassium and total alkalinity were showing weak correlation with the other parameters. Results of correlation analysis shown that sulphate and fluoride, nitrate and fluoride, conductivity and chloride were having high correlation with most of the other parameters.

Fluoride concentrations in surface and ground water samples were determined in eight villages of Prakasham district in India by Ramanaiah *et. al.* (2006). Thirty-eight samples were collected and analysed for Fluoride content along with physico-chemical parameters. In order to study the possible relation between the Fluoride concentration and other physicochemical parameters, correlation studies were performed. TDS showed good correlation (R2 - 0.61) with Fluoride concentration compared to other physicochemical parameters studied. EC had good correlation (R2 - 0.36) followed by nitrate (R2 - 0.24), total hardness (R2 - 0.12), chloride (R2 - 0.06) and sulfate (R2 - 4 x 10-5). The principal ion contributing TDS are carbonate, bicarbonate, chlorides, fluorides, sulphates, nitrates,sodium, potassium, calcium and magnesium. In this study, low values of hardness were observed for all the samples. Generally water with Fluoride more than 1.5 mg/l had hardness less than 200 mg/l, which was found true in their study. The phenomenon of decrease in hardness concentration contributing to higher Fluoride concentration might be attributed to calcium complexing effect. Fluoride complexes are formed more readily in mineralized water than in dilute water. Where Fluoride and TDS are high, the chance of substitution by Fluoride is less. Another factor significantly contributing to excess Fluoride concentration in the ground water samples may be attributed to the depletion in water table in this area. On an average, about 4 feet reduction in ground water level was observed in the area in a four year's period. This phenomenon may be attributed to the concentration of ionic composition effect.

Valenzuela-Vásquez *et al.* (2006) reported high Fluoride concentration up to 7.59 mg/l was found in groundwater from "La Victoria" area. This water was supplied to Hermosillo City, Sonora, Mexico. In the study, geochemistry of groundwater, hydrogeology, relationship between physicochemical parameters, and geologic setting were correlated to define the origin and the geochemical mechanisms of groundwater fluorine enrichment. High Fluoride concentration was found to get associated with pH, high bicarbonates and temperature, and it decreased towards the west and south of the study area. They analysed that Fluoride showed negative correlation with calcium concentration. Sodium sulphate facies of regional deep water flow were related to high Fluoride concentration. High electric resistivity rocks associated with granites from the Sierra Bachoco basement might be the deep source of Fluoride.

Chandio *et al.* (2015) had conducted a study to assess Fluoride estimation and its correlation with other physicochemical parameters in drinking water in some areas of Balochistan, Pakistan. Total 150 samples were taken from open wells, tube wells, and karezes of Mastung, Mangochar, and Pringabad areas of Balochistan province. 96 drinking water samples out of 150 were found unfit for human consumption. The highest concentration of Fluoride was recorded; 14 mg/l in Mastung. Correlation analysis showed that fluoride solubility in drinking water is pH dependent; and the salts of Ca^{+2}, Na^{+}, K^{+}, Cl^{-}, and SO_4^{-2} were found to contribute to attain the favorable pH for dissolution of Fluoride compounds in drinking water. Principal component analysis shown that the geochemical composition of the rocks was only responsible for groundwater contamination. Area-wise analysis in their study reflected that the samples from 39 sites from Mastung, 12 from Mangochar, and 13 from Pringabad were found in the risk of dental fluorosis of mild to severe nature. However, 12 sampling sites from Mastung, 8 from Mangochar, and 2 from Pringabad were identified as the risks of mottling and skeletal fluorosis or other bone abnormalities.

Kumar and Seema (2016) performed a study to monitor Fluoride contamination and correlation with physicochemical parameters of surface soil and groundwater near tea-garden of Thakurganj block of Kishanganj, Bihar. They found that Fluoride concentration in surface soil varied from 1.11-4.9 mg/l and in groundwater varied from 0.21-3.9 mg/l.

Correlation Analysis

Correlation analysis was performed between Fluoride concentration in selected groundwater samples and only those physicochemical parameters which affect enhancement/reduction of Fluoride in natural waters. .These parameters were pH, Total alkalinity, TDS, Carbonate, Bicarbonate, Sodium, Calcium and Magnesium.

In selected villages of Satlasana, pre monsoon Fluoride value ranged from 1.1 to 5.8 mg/l whereas post monsoon ranged from 1.06 to 5.6 mg/l.

In pre monsoon season, Fluoride showed positive correlation (Table :19) with pH ($r = 0.92$, $p < 0.05$), Total alkalinity ($r = 0.9$, $p < 0.05$), TDS ($r = 0.72$, $p < 0.05$), Carbonate ($r = 0.65$, $p < 0.05$), Bicarbonate ($r = 0.87$, $p < 0.05$) and Sodium ($r = 0.78$, $p < 0.05$) whereas in post monsoon season (Table :20), positive correlation was shown by Fluoride with pH ($r = 0.64$, $p < 0.05$), Total alkalinity ($r = 0.82$, $p < 0.05$), TDS ($r = 0.67$, $p < 0.05$), Carbonate ($r = 0.51$, $p < 0.05$), Bicarbonate ($r = 0.81$, $p < 0.05$) and Sodium ($r = 0.71$, $p < 0.05$).

In pre and post monsoon correlation analysis, Fluoride showed positive correlation with pH, Total alkalinity, TDS, Carbonate, Bicarbonate, and Sodium while negative correlation with Calcium and Magnessium.

Samples selected from Lilia taluka recorded 1.2 to 2.8 mg/l Fluoride value in pre monsoon season while in post monsoon season it ranged from 2.78 to 4.32 mg/l.

In pre monsoon (Table : 21), Fluoride showed positive correlation with TDS (r = 0.91, p <0.05), Carbonate(r = 0.3, p <0.05), Sodium(r = 0.0.81, p <0.05), Calcium (r = 0.73, p <0.05) and Magnesium (r = 0.81, p <0.05) while in post monsoon season (Table :22), positive correlation of Fluoride was found with Total alkalinity (r = 0.23, p <0.05), TDS (r = 0.93, p <0.05), Calcium (r = 0.93, p <0.05), Magnesium (r = 0.82, p <0.05), Carbonate (r = 0.16, p <0.05), Bicarbonate (r = 0.24, p <0.05) and Sodium (r = 0.94, p <0.05).

Correlation analysis on data obtained in pre monsoon, Fluoride was found positively correlated with TDS, Carbonate, Sodium, Calcium and Magnesium while negative correlation with pH, Total alkalinity and bicarbonate. In post monsoon correlation analysis, Fluoride showed positive correlation with all parameters under investigation except pH.

In the villages of Wankaner taluka, for pre monsoon season, Fluoride value ranged from 0.74 to 4.6 mg/l while post monsoon season, the value ranged from 2.78 to 3.54 mg/l.

In this taluka,Fluoride showed positive correlation with pH(r = 0.67, p <0.05), Total alkalinity (r = 0.81, p <0.05), TDS(r = 0.71, p <0.05), Carbonate (r = 0.87, p <0.05), Bicarbonate (r = 0.81, p <0.05) and Sodium(r = 0.76, p <0.05) in pre monsoon season (Table :23)while in post monsoon season (Table 24), positive correlation was obtained with pH(r = 0.85, p <0.05), Total alkalinity(r = 0.72, p <0.05), TDS, (r = 0.28, p <0.05) Carbonate(r = 0.64, p <0.05) and Bicarbonate (r = 0.72, p <0.05).

Thus, in pre monsoon Fluoride was found positively correlated with pH, Total alkalinity, TDS, Carbonate, Bicarbonate and Sodium while it was negatively correlated with Calcium and Magnesium. For post monsoon season, Fluoride showed positive correlation with all parameters except Calcium, Magnesium and Sodium.

Table 19: Correlation analysis of Satlasana Taluka for Pre-monsoon

	pH	Total Alkalinity	Total Dissolved Solids	Calcium	Magnesium	Carbonate	Bicarbonate	Sodium	Fluoride
pH	1	0.95	0.86	-0.99	-0.57	0.8	0.95	0.89	0.92
Total Alkalinity		1	0.75	-0.95	-0.61	0.62	0.94	0.76	0.9
Total Dissolved Solids			1	-0.78	-0.72	0.97	0.66	0.99	0.72
Calcium				1	0.44	-0.73	-0.98	-0.81	-0.9
Magnesium					1	-0.57	-0.33	-0.69	-0.63
Carbonate						1	0.6	0.97	0.65
Bicarbonate							1	0.7	0.87
Sodium								1	0.78
Fluoride									1

Table 20: Correlation analysis of Satlasana Taluke for Post-monsoon

	pH	Total Alkalinity	Total Dissolved Solids	Calcium	Magnesium	Carbonate	Bicarbonate	Sodium	Fluoride
pH	1	0.79	0.94	-0.88	-0.69	0.62	0.7	0.88	0.64
Total Alkalinity		1	0.77	-0.98	-0.46	0.83	0.99	0.79	0.82
Total Dissolved Solids			1	-0.87	-0.71	0.73	0.68	0.99	0.67
Calcium				1	0.52	-0.85	-0.95	-0.88	-0.79
Magnesium					1	-0.15	-0.37	-0.69	-0.77
Carbonate						1	0.82	0.79	0.51
Bicarbonate							1	0.71	0.81
Sodium								1	0.71
Fluoride									1

Table 21: Correlation analysis of Lilia Taluka for Pre-monsoon

	pH	Total Alkalinity	Total Dissolved Solids	Calcium	Magnesium	Carbonate	Bicarbonate	Sodium	Fluoride
pH	1	0.41	-0.84	-0.88	-0.65	0.5	0.39	-0.82	-0.71
Total Alkalinity		1	0.12	0.03	0.41	0.58	1	0.06	0.23
Total Dissolved Solids			1	1	0.91	-0.08	0.14	0.98	0.93
Calcium				1	0.88	-0.13	0.05	0.98	0.93
Magnesium					1	-0.11	0.43	0.82	0.82
Carbonate						1	0.56	0.04	0.16
Bicarbonate							1	0.06	0.24
Sodium								1	0.94
Fluoride									1

Table 22: Correlation analysis of Lilia Taluka for Post-monsoon

	pH	Total Alkalinity	Total Dissolved Solids	Calcium	Magnesium	Carbonate	Bicarbonate	Sodium	Fluoride
pH	1	0.75	-0.58	-0.94	-0.88	0.37	0.75	-0.3	-0.77
Total Alkalinity		1	-0.35	-0.82	-0.76	0.54	1	-0.05	-0.36
Total Dissolved Solids			1	0.66	0.82	0.5	-0.35	0.94	0.91
Calcium				1	0.97	-0.31	-0.82	0.38	0.73
Magnesium					1	-0.07	-0.76	0.59	0.81
Carbonate						1	0.54	0.76	0.3
Bicarbonate							1	-0.05	-0.36
Sodium								1	0.81
Fluoride									1

Table 23: Correlation analysis of Wankaner Taluka for Pre-monsoon

	pH	Total Alkalinity	Total Dissolved Solids	Calcium	Magnesium	Carbonate	Bicarbonate	Sodium	Fluoride
pH	1	0.91	0.6	-0.81	-0.74	0.92	0.91	0.75	0.67
Total Alkalinity		1	0.85	-0.84	-0.75	0.97	1	0.95	0.81
Total Dissolved Solids			1	-0.59	-0.4	0.82	0.85	0.95	0.71
Calcium				1	0.93	-0.9	-0.84	-0.7	-0.96
Magnesium					1	-0.75	-0.75	-0.6	-0.85
Carbonate						1	0.97	0.89	0.87
Bicarbonate							1	0.95	0.81
Sodium								1	0.76
Fluoride									1

Table 24: Correlation analysis of Wankaner Taluke for Post-monsoon

	pH	Total Alkalinity	Total Dissolved Solids	Calcium	Magnesium	Carbonate	Bicarbonate	Sodium	Fluoride
pH	1	0.92	0.73	-0.74	-0.77	0.9	0.92	0.24	0.85
Total Alkalinity		1	0.71	-0.43	-0.56	0.96	1	0.57	0.72
Total Dissolved Solids			1	-0.34	-0.26	0.75	0.71	0.57	0.28
Calcium				1	0.94	-0.5	-0.43	0.45	-0.77
Magnesium					1	-0.63	-0.56	0.33	-0.84
Carbonate						1	0.96	0.52	0.64
Bicarbonate							1	0.57	0.72
Sodium								1	-0.11
Fluoride									1

Piper Diagram :

Piper Diagram is generally used for inferring hydrogeochemical facies of groundwater. This concept helps to elucidate mechanisms of flow and transporting groundwater systems and unlock an archive of pale environmental information (Vasanthavigar *et al.*, 2010). According to this, the piper diagram can be separated in hydrochemical facies. In this context, piper diagram were generated for selected groundwater samples of Satlasana, Liliya and Wankaner taluka for both pre and post monsoon season.

In Satlasana, it is seen that the alkaline earth metal (Ca^{+2} + Mg^{+2}) exceed alkali (Na^{+}+ K^{+}) and weak acids (HCO_3^{-} + CO_3^{-2}) over strong acids (Cl^{-} + SO_4^{-2}) in both the seasons (Figure 50 & 51). Also these diagrams indicated that the groundwater in this area is of magnesium bicarbonate type in both the seasons.

In groundwater of Liliya taluka (Figure 52 & 53), the alkali (Na^{+}+ K^{+}) were found dominant over alkaline earth metal (Ca^{+2} + Mg^{+2}) and weak acids (HCO_3^{-} + CO_3^{-2}) exceed strong acids (Cl^{-} + SO_4^{-2}) in both the seasons. Groundwater of pre-monsoon season is of sodium chloride type and sodium bicarbonate type and in post monsoon season is of only bicarbonate type.

Groundwater type of Wankaner taluka (Figure 54 & 55), is investigated in which in pre-monsoon season, alkaline earth metal (Ca^{+2} + Mg^{+2}) exceed alkali (Na^{+}+ K^{+}) and weak acids (HCO_3^{-} + CO_3^{-2}) exceed strong acids (Cl^{-} + SO_4^{-2}). In post-monsoon season alkali (Na^{+} + K^{+}) dominant over alkaline earth metal (Ca^{+2} + Mg^{+2}) and strong acids (Cl^{-} + SO_4^{-2}) exceed weak acids (HCO_3^{-}, CO_3^{-2}). Groundwater is of sodium bicarbonate and mixed type in both the seasons while sodium chloride type in only post monsoon season.

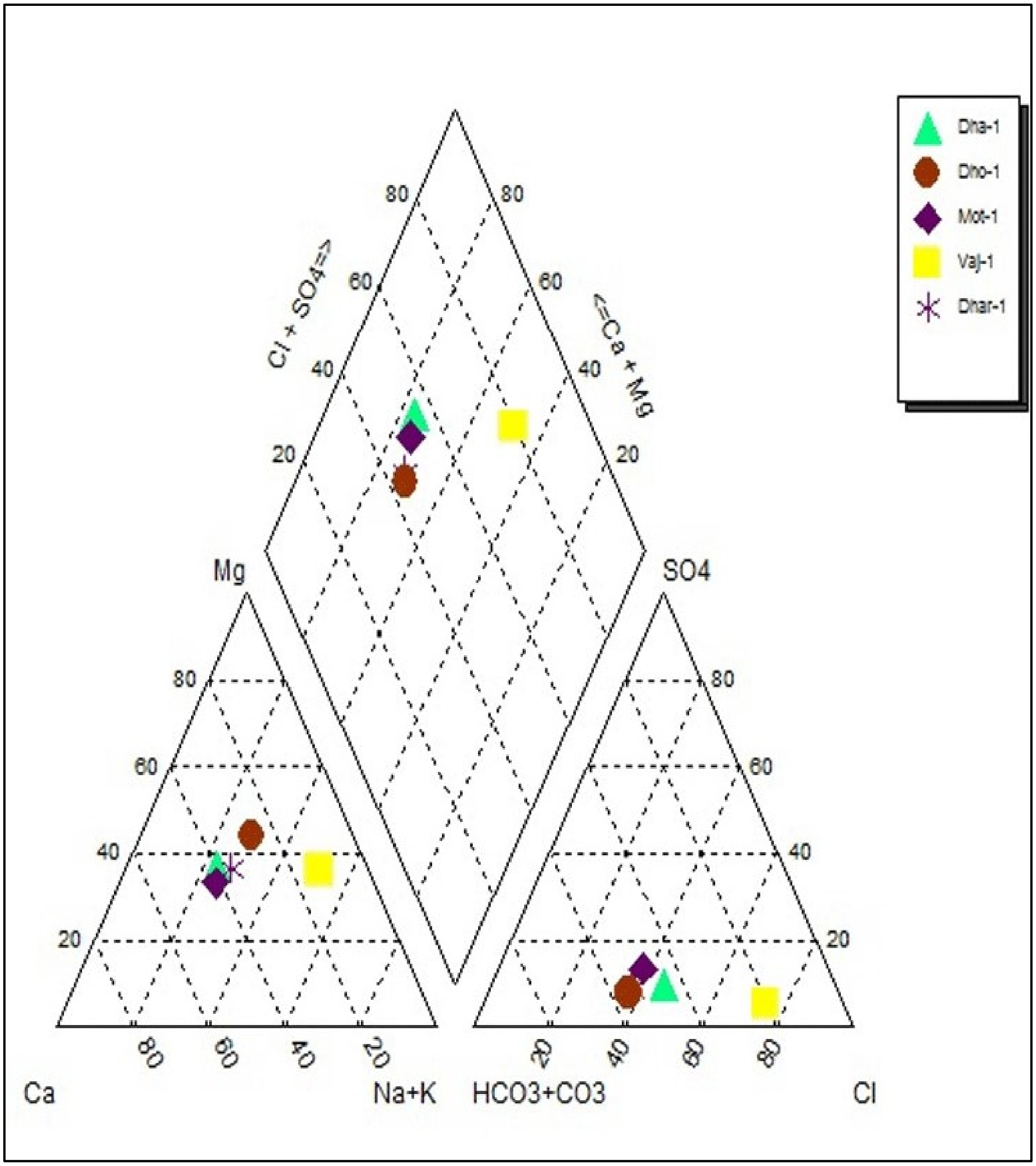
Discussion

Sujatha (2003) in her study on Ranga Reddy district, Andhrapradesh had reported that the groundwater of the area was mainly of bicarbonate type and hydrochemical type comprised of calcium chloride (CaCl), calcium bicarbonate chloride (Ca-HCO_3-Cl), calcium bicarbonate (Ca-HCO_3) and calcium sodium bicarbonate chloride (Ca-Na-

HCO_3-Cl). Because of this, concentration of Fluoride in groundwater of the study was low. She concluded that high Fluoride in groundwater is generally associated with low calcium content and high bicarbonate content.

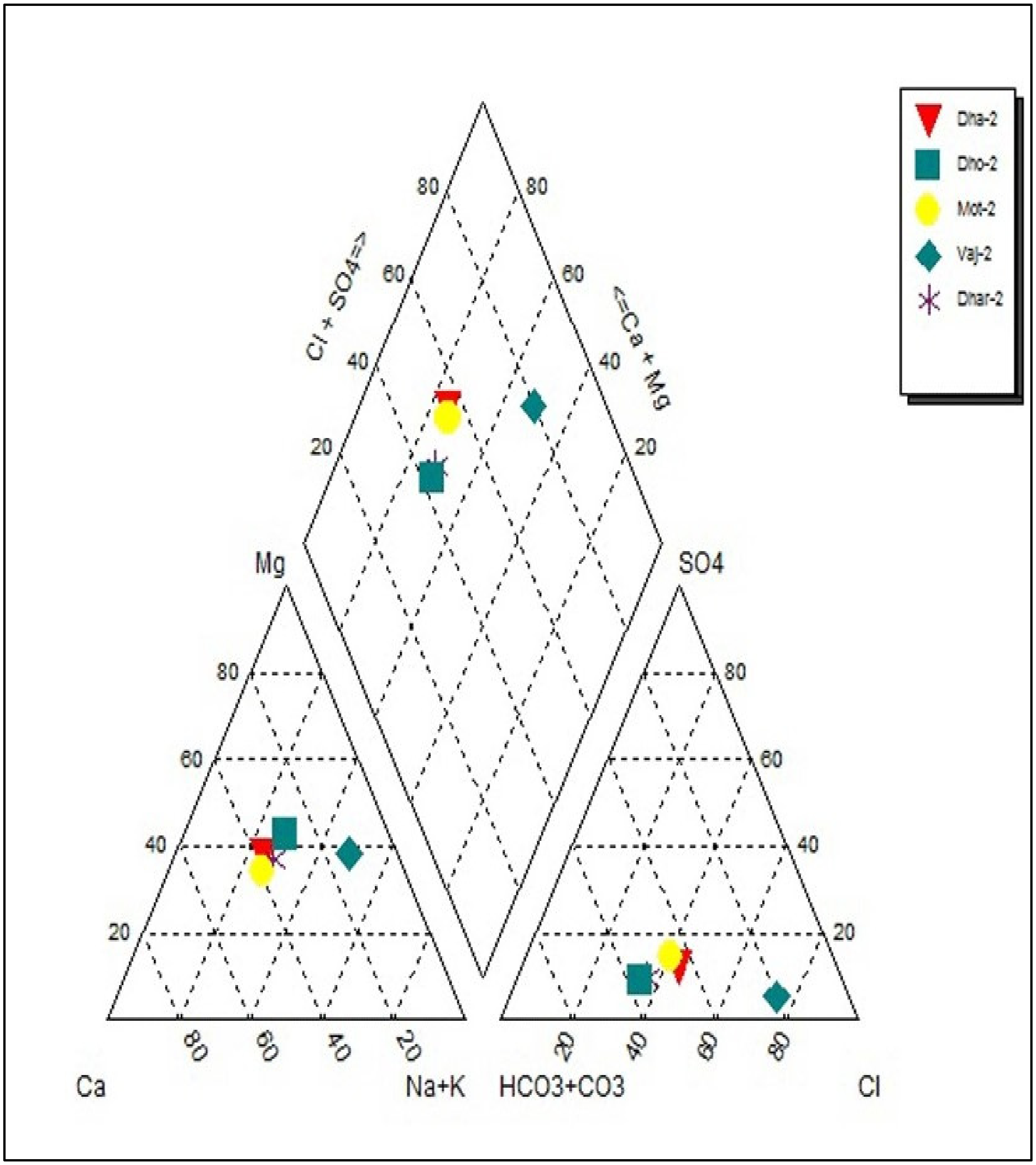
Li *et al.* (2012) had worked on groundwater quality of Shizuishan city, northwest of China. They investigated that the major chemical types of tested groundwater samples fall into categaries of HCO_3·Cl-Na·Ca type, HCO_3·-Na·Ca type and some mixed HCO3·SO_4·Cl-Na·Ca type.

In our study,Vajapur village of Satlasana taluka, Timbri village of Liliya taluka and Amarsar village of Wankaner taluka showed high bicarbonate content and it showed direct positive correlation with the Fluoride concentration in groundwaters.



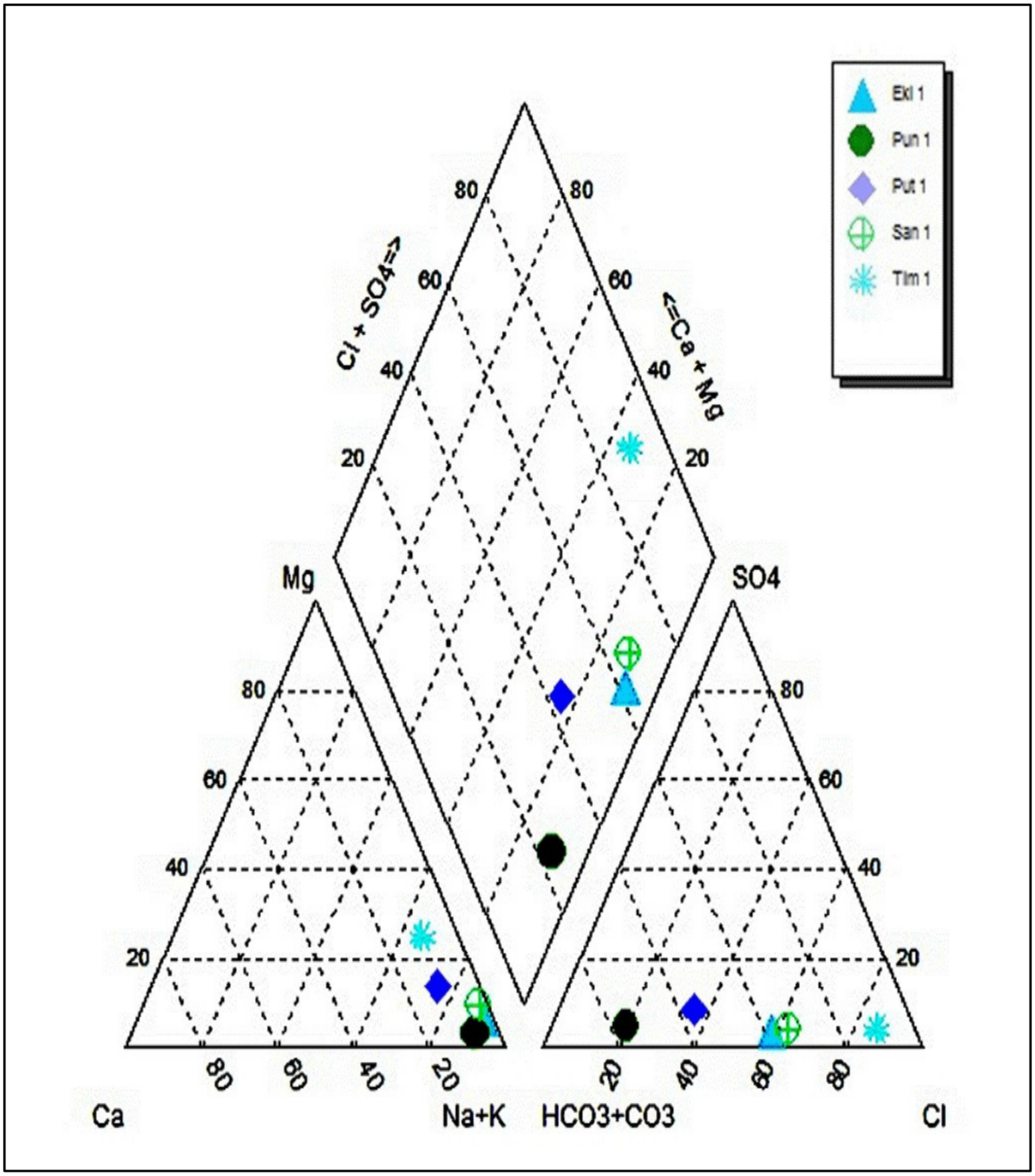
(Dha : Dharoi, Dho : Dholu, Mot : Mota Kothasana, Vaj : Vajapur, Dhar : Dharavania)

Figure 50 : Piper Diagram for Pre Monsoon Season of Satlasana Taluka



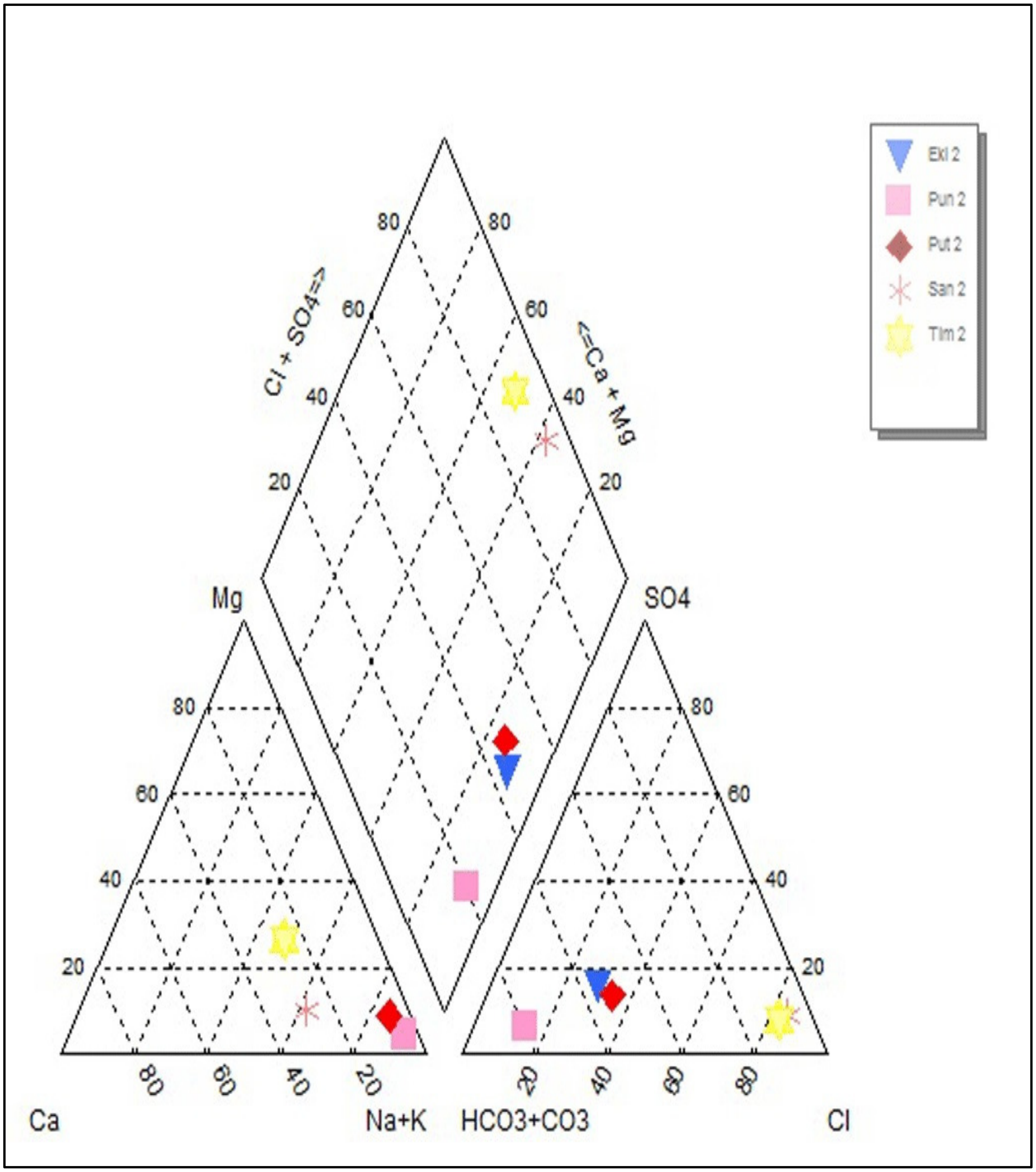
(Dha : Dharoi, Dho : Dholu, Mot : Mota Kothasana, Vaj : Vajapur,
Dhar : Dharavania)

Figure 51: Piper Diagram for Post Monsoon Season of Satlasana Taluka



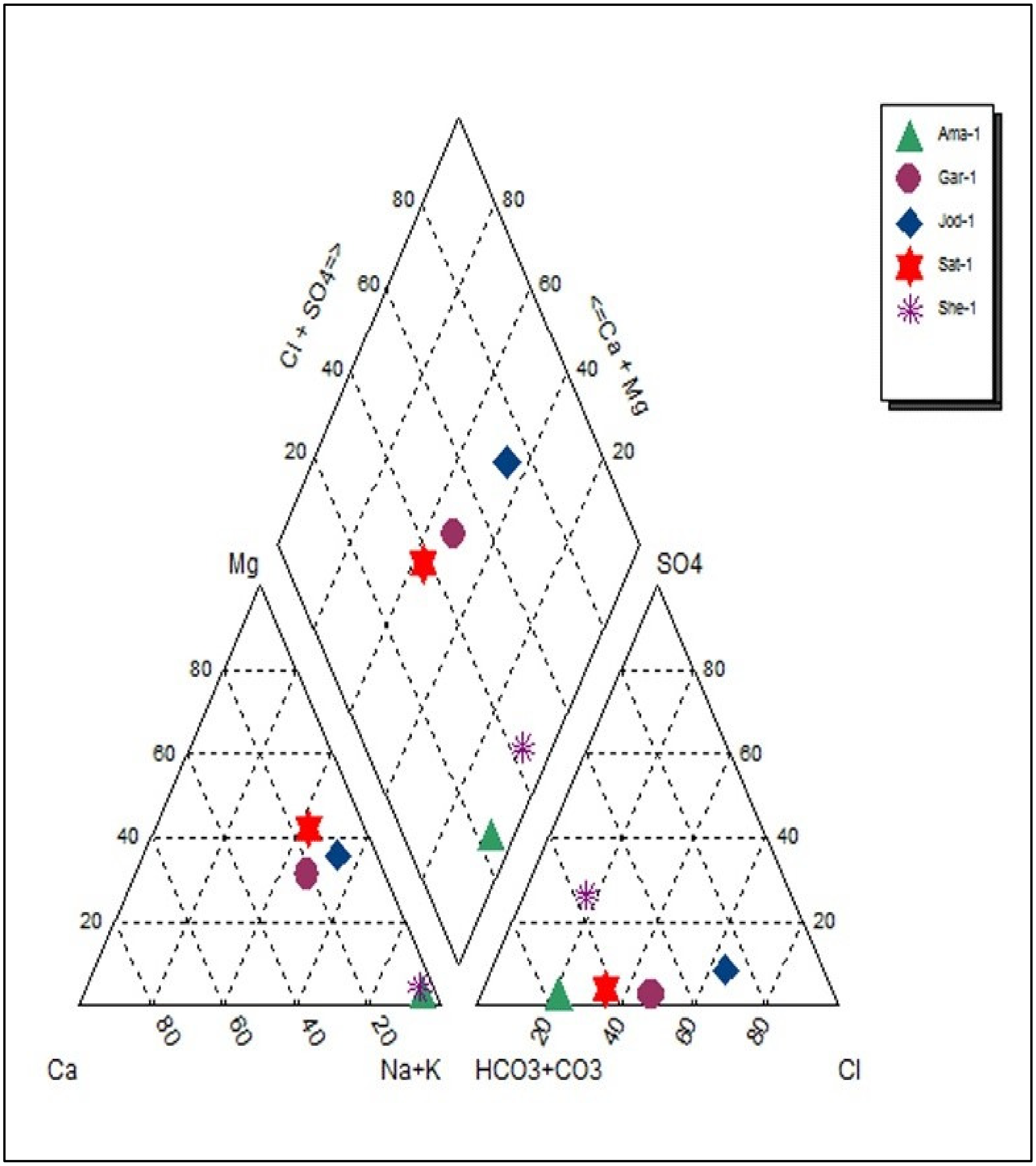
(Ekl : Eklera, Pun : Punjapadar, Put : Putaliya, San : Sanaliya, Tim : Timbri)

Figure 52: Piper Diagram for Pre Monsoon Season of Lilia Taluka



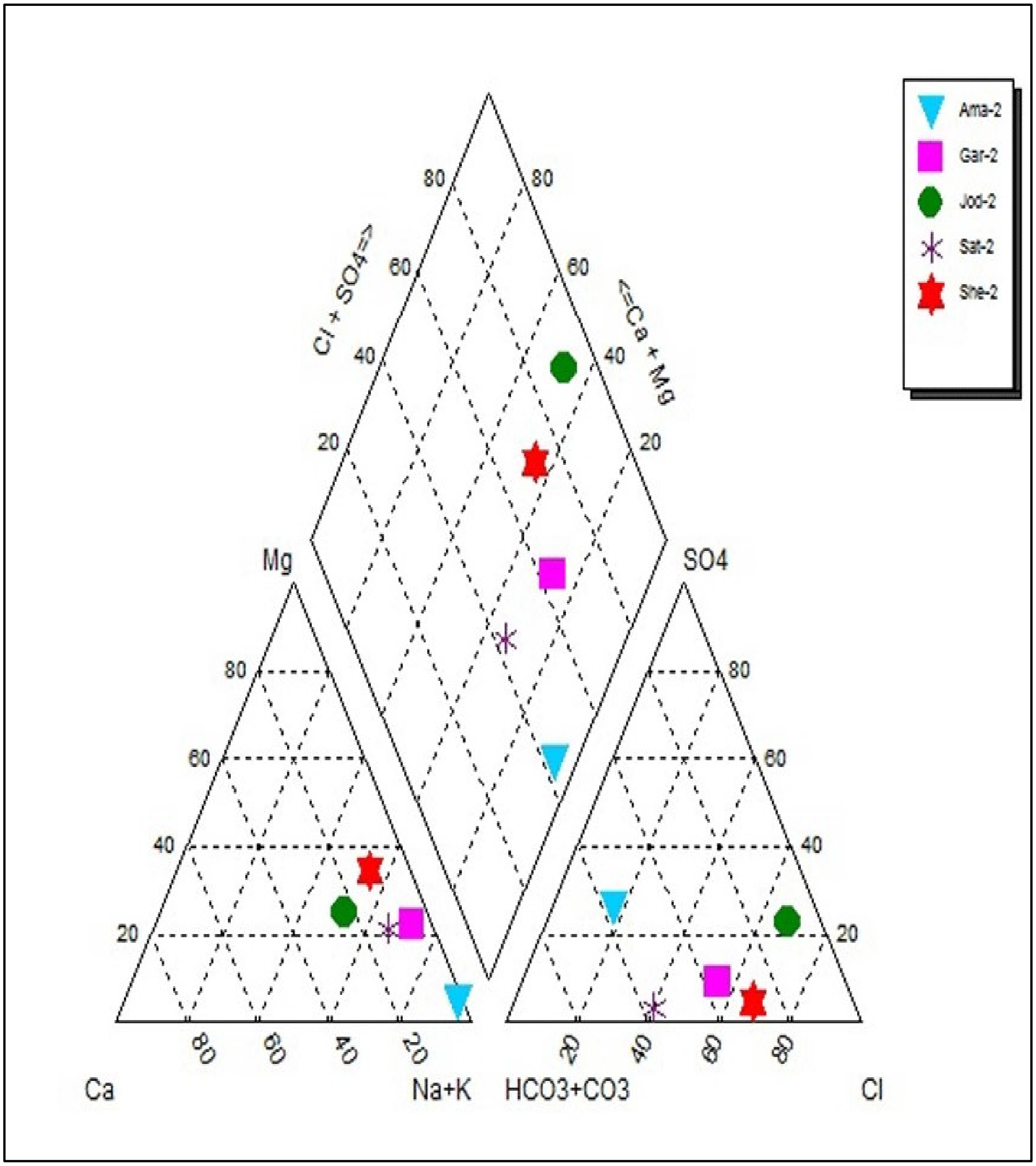
(Ekl : Eklera, Pun : Punjapadar, Put : Putaliya, San : Sanaliya, Tim : Timbri)

Figure 53: Piper Diagram for Post Monsoon Season of Lilia Taluka



(Ama : Amarsar, Gar : Garida, Jod : Jodhapar, Sat : Satapar, She : Shekhardi)

Figure 54: Piper Diagram for Pre Monsoon Season of Wankaner Taluka



(Ama : Amarsar, Gar : Garida, Jod : Jodhapar, Sat : Satapar, She : Shekhardi)

Figure 55: Piper Diagram for Post Monsoon Season of Wankaner Taluka

3.2.4 In-vivo experiment for Bioremoval study for defluoridation capacity of the MBP and MSP

In vivo defluoridation experiments were conducted using standard dose of the adsorbent (*Moringa oleifera* L. bark and seed powder) in the selected groundwater samples of Satlasana, Liliya and Wankaner taluka. The results of in-vivo were then compared with in-vitro experiments. It revealed that Fluoride adsorption capacity of the adsorbent was found to be less in in-vitro as compared to in-vivo condition. The removal efficiency of *Moringa oleifera* L. bark powder (Table : 25) in the range of 30.65% to 45.45. *M. oleifera* L. seed powder (Table : 26) reduced the concentration of Fluoride in the range of 7.41% to 29.09%. Highest defluoridation capacity of the adsorbent was recorded in the groundwater sample of Dharoi village of Satlasana taluka (45.45%) and the lowest in Amarsar village of Wankaner taluka (30.65%) by bark. *M. oleifera* seed showed highest defluoridation capacity in the groundwater sample of Dharoi village of Satlasana taluka (29.09%) and lowest in Vajapur village of Satalasana taluka (7.41%).

Table 25 : In-vivo defluoridation by *M. oleifera* bark

Taluka	Villages	I. F.	F.F.	% removal
Lilia	Putaliya	1.82	1.03	43.41
	Eklera	2.68	1.59	40.67
	Punjapadar	2.78	1.74	37.41
	Sanaliya	3.86	2.56	33.68
	Timbri	4.32	2.91	32.64
Satlasana	Dharoi	1.10	0.60	45.45
	Mota Kothasana	3.68	2.14	41.85
	Dharavania	3.68	2.33	36.68
	Dholu	4.04	2.74	32.18
	Vajapur	5.80	3.97	31.55
Wankaner	Jodhapar	1.84	1.05	42.93
	Garida	2.60	1.57	39.62
	Satapar	2.78	1.72	38.13
	Shekharadi	3.54	2.31	34.75
	Amarsar	4.60	3.19	30.65

Table 26: In-vivo defluoridation by *M. oleifera* Seed

Taluka	Villages	I. F.	F.F.	% removal
Liliya	Putaliya	1.82	1.32	27.47
	Eklera	2.68	1.99	25.75
	Punjapadar	2.78	2.30	17.27
	Sanaliya	3.86	3.32	13.99
	Timbri	4.32	3.94	8.80
Satlasana	Dharoi	1.10	0.78	29.09
	Mota Kothasana	3.68	2.92	20.65
	Dharavania	3.68	3.24	11.96
	Dholu	4.04	3.64	9.90
	Vajapur	5.80	5.37	7.41
Wankaner	Jodhapar	1.84	1.37	25.54
	Garida	2.60	2.14	17.69
	Satapar	2.78	2.36	15.11
	Shekharadi	3.54	3.18	10.17
	Amarsar	4.60	4.17	9.35

3.3 Estimation of biochemical parameters in the test plants

To study biochemical changes induced by Fluoride ion, grains of *Triticum aestivum* L. var. GW 496 and *Pennisetum glaucum* R.Br. var. proagro 9444 were collected from fields of the study area, (PLATE 3) and were allowed to grow.Initial concentration of Fluoride in soil samples was measured and it was found to be nil. After sowing the seeds, they were watered with synthetic NaF solution to get desired concentration of 1,2,3,4 and 5 mg/l (Treated plants). Seeds watered with no Fluoride concentration. served as control (control plants). At the mature stage of the plant (PLATE 4) biochemical parameters like Chlorophyll, Carbohydrate, Protein and Proline were estimated from root, stem and leaves of the treated and control plants.

3.3.1 Pigment contents:

For Chlorophyll estimation leaves of *Triticum aestivum* L. and *Pennisetum glaucum* R.Br. were analyzed whereas Carbohydrate, Protein and Proline estimation were carried out in the root, stem and leaves of the test plants.

Chlorophyll a (mg/g) in leaves of *Triticum aestivum* L. was estimated to be 0.17, 0.15, 0.13, 0.22, 0.13 and 0.23 in the control and 1-5 mg/l range of Fluoride concentration (Fig. 56)respectively. Chlorophyll b and total Chlorophyll (mg/g) was found to be 0.09, 0.08, 0.08, 0.05, 0.15 and 0.09 and 0.26, 0.23, 0.21, 0.27, 0.28 and 0.32 in control and plants treated with 1-5 mg/l Fluoride concentration respectively.

Chlorophyll a (mg/g) in leaves of *Pennisetum glaucum* R.Br. was 0.12, 0.12, 0.13, 0.16, 0.18, and 0.20 for control and 1-5 mg/l Fluoride concentration (Fig. 57) respectively; Chlorophyll b was 052, 0.63, 0.47, 0.62, 0.22 and 0.13 and total Chlorophyll was estimated to be 0.63, 0.75, 0.60, 0.78, 0.40 and 0.33 respectively.

The results of Chlorophyll content of both the test plant suggested that there was no definite pattern of increase or decrease in the pigment contents in treated plant and therefore no correlation was established between effect of Fluoride ion on pigment contents of the experimental plants.

PLATE 3

PLATE 4

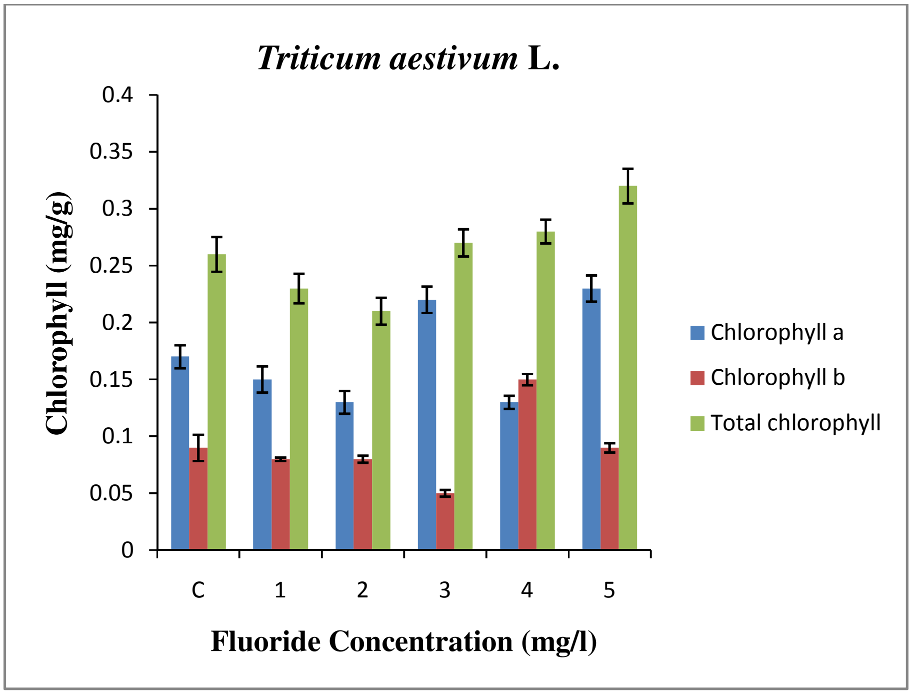


Figure 56: Chlorophyll content in Fluoride treated and untreated plants

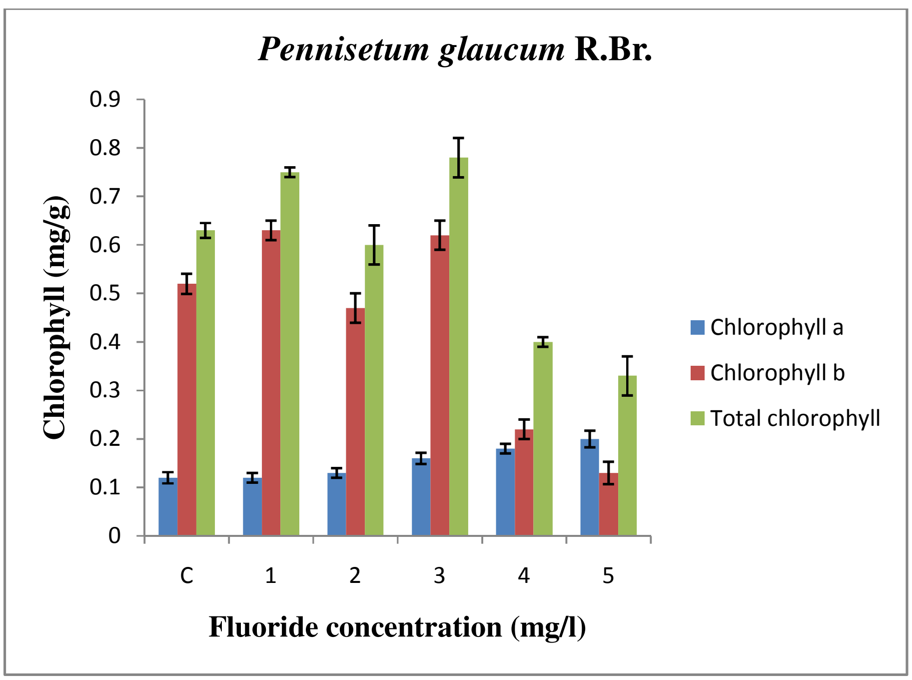


Figure 57: Chlorophyll content in Fluoride treated and untreated plants

Discussion:

To study effect of Fluoride on growth parameters and its accumulation in *Triticum aestivum* L. var. Raj 3675, Joshi and Bhardwaj (2012) had conducted a study in which they reported that total Chlorophyll content was higher during early stages of growth after treatment with Fluoride but it gradually decreased at late stage of development along with increasing chlorosis and necrosis. Moreover, Fluoride was shown to had little effect on Chlorophyll b but Chlorophyll a was significantly reduced with increasing Fluoride concentration in the irrigation water. Similar results were obtained by Tomar and Aery, 2000. Decreased growth and pigment content had been observed by them at higher concentration of waterborne Fluoride in two crops, namely cowpea (*Vigna unguiculata* L. var. walp. gota) and wheat (*Triticum aestivum* L. var. PDW-215). Bhargava and Bhardwaj (2010) had carried out study to observe effect of sodium Fluoride on seed germination and seedling growth of *Triticum aestivum* L. var. Raj. 4083. As per their results, total Chlorophyll was affected by Fluoride toxicity. At 20 mg/l NAF concentration it was 0.074 mg/g which was reduced by 27.45% compared to control (0.102 mg/g).

Fluoride toxicity in potato (*Solanum tuberosum* L.) plant was studied by Das *et al.* (2015). Plants were grown in contaminated soils with graded concentration i.e. 0, 11.05, 22.11 ,44.21, 110.53 and 221.05 mg NaF/ kg soil to the pots and biochemical analysis was performed in which potato leaves showed gradual decrease of total chlorophyll with increasing Fluoride concentration. In addition to that Chlorophyll 'a' to 'b' ratio as well as total Chlorophyll showed linear decremented trend with applied Fluoride dose. This was probably due to higher accumulation of Fluoride in leaves of the test plant and subsequently readily bind with Mg^{+2}, forming an MgF complex. This kind of complexation may destroy the photosynthetic pigments, particularly the Chlorophylls, thereby significantly declining the concentration of pigments. Their results clearly indicated that Chlorophyll 'b' was more sensitive to Fluoride that disrupt the balance between energy trapping in photosystem II and cause a decrease in electron transport. The inhibition of Chlorophyll content due to Fluoride might be a consequence of inhibition by fluoride of incorporation of γ-aminolevulinic acid into chlorophyll synthetic pathway (Wallis *et al.* 1974).

3.3.2 Carbohydrate content:

Carbohydrate content (% mg) in the roots of *Triticum aestivum* L. was found to be 0.23, 0.24, 0.25, 0.25, 0.27 and 0.29 in the control and 1-5 mg/l Fluoride concentration (Fig. 58) respectively whereas stem and leaf showed the content of 0.36, 0.31, 0.34, 0.36, 0.43 and 0.48 and 0.19, 0.26, 0.31, 0.34, 0.42 and 0.49 % mg in control and plants treated with 1-5 mg/l Fluoride concentration respectively.

Carbohydrate content (% mg) in plants of *Pennisetum glaucum* R.Br. (Fig. 59) was 0.23, 0.25, 0.25, 0.28, 0.29 and 0.3 in roots for control and 1-5 mg/l Fluoride concentration respectively whereas in the stem it was 0.29, 0.34, 0.35, 0.37, 0.42 and 0.5 and in leaves it was 0.15, 0.17, 0.24, 0.36, 0.41 and 0.47 % mg respectively.

Results obtained from our study on effect of Fluoride ion on carbohydrate content clearly stated that with increase in Fluoride concentration in-vitro Carbohydrate content also showed rise in the level in both the test plant. Moreover, treated plants showed enhanced level of Carbohydrate than control plants.

Discussion:

Das *et al.*(2015) worked on Fluoride toxicity in potato (*Solanum tuberosum* L.). The plants were grown in contaminated soils with graded concentration i.e. 0, 11.05 , 22.11 ,44.21, 110.53 and 221.05 mg NaF/ kg soil by adding sodium fluoride (NaF) to the pots and measured sugar level in Fluoride treated and control plants. They investigated that sugar level in leaves initially increased up to F dose of 38 mg NaF per Kg soil and then drastically decreased at higher concentration. In general, all the treated plants decreased sugar content as compared to control. In contrast to this, Fluoride content in shoot was found to have positive influence on sugar ($r=0.887$, $p<0.05$) level. They also noticed no visible symptoms of phyto-toxicity of Fluoride ion in the range of 0-190 mg NaF per Kg soil. Reduction of sugar synthesis at elevated Fluoride level in *Cicer arietinum* L. was also reported by Dey *et al.* (2012).

Elloumi *et al.*(2005) had conducted a study on almond seedlings (*Amygdalis communis*) grown in nutrient solutions containing NaF concentrations ranged from 0 to 10 mM. They reported that reducing sugars and starch in the leaves decreased with increasing Fluoride concentration. They also stated that there might be Formation of reducing sugars such as glucose, fructose, and mannose in the leaves which were inhibited by Fluoride. This showed the tendency of plants exposed to Fluoride, decrease the concentrations of reducing sugars in their leaves indicated possible conversion of these sugars to non-reducing sugars, such as sucrose and raffinose or sugar alcohols. Under these conditions, increased levels of non-reducing sugars in tissues might be a mechanism adopted by plants to reduce F toxicity (Kim *et al.*2003). Our results on Carbohydrate are not in accordance with the results of these previous reports.

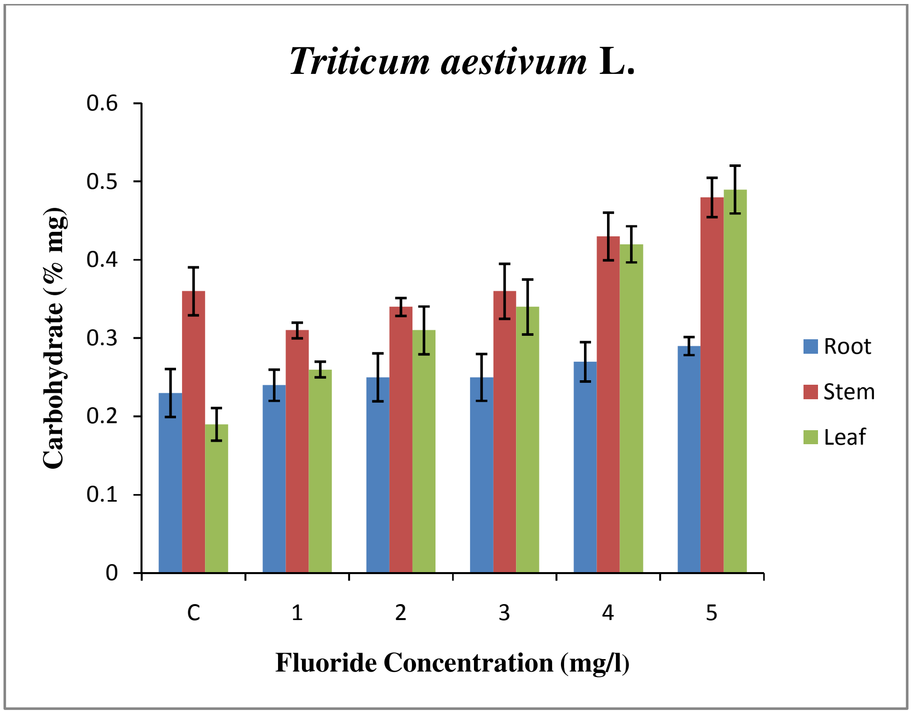


Figure 58: Carbohydrate content in Fluoride treated and untreated plants

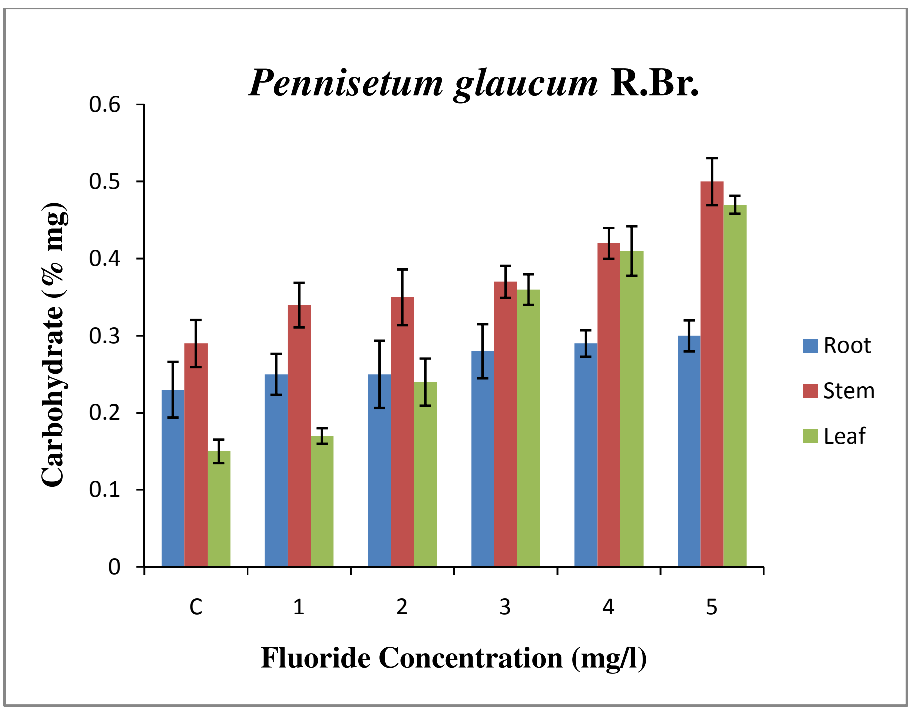


Figure 59: Carbohydrate content in Fluoride treated and untreated plants

3.3.3 Protein content:

Protein content (mg/g) in the roots of *Triticum aestivum* L. (Fig. 60) was 0.93, 1.56, 2.35, 3.37, 4.76, and 6.42 in the control and 1-5 mg/l Fluoride concentration respectively whereas stem and leaf showed 1.24, 1.93, 2.68, 3.14, 3.87 and 4.42 mg/g and 0.95, 1.28, 1.84, 2.68, 3.46 and 3.72 mg/g in the control and treated plants with 1-5 mg/l Fluoride concentration respectively.

Protein content (mg/g) in plants of *Pennisetum glaucum* R.Br. (Fig. 61) was 0.81, 1.48, 2.63, 3.64, 4.39 and 5.8 in roots for control and 1-5 mg/l Fluoride concentration respectively whereas in the stem it was 1.17, 1.83, 2.51, 2.97, 3.64 and 3.86 mg/g and in leaves it was 0.93, 1.49, 1.83, 2.41, 2.95 and 3.43 mg/g respectively.

Results obtained from our study on effect of Fluoride ion on Protein content clearly indicated that with increase in Fluoride concentration in-vitro Protein content also showed rise in both the test plants. Moreover, treated plants showed enhanced level of Protein than control plants.

Discussion:

To study effect of Fluoride on Protein Profiles in Two Cultivars of Mulberry V_1 and M_5 Rao *et al.* (2013) had conducted experiment on leaf of 45 days. Leaf pieces in petri dishes were supplemented with different concentrations of NaF i.e. 100, 200 and 300ppm and distilled water was alone served as control. It was observed that relative to controls, total protein was found significantly decreased in the V_1 and M_5. Further the results indicated that the leaf protein content in both cultivars declined and the magnitude of decrease was found to be concentration depended and the period of exposure. It was also observed that there existed a marked difference between the V_1 and M_5 cultivars. Fluoride treatments decreased total protein contents in the both cultivars of mulberry. These results suggest the suppression of protein synthesis and/ or utilization of proteins for energy purposes. This could be attributed to the ability of fluoride to modify the ratio of free nucleotides and that of RNA, to decrease of the rate of RNA synthesis and / or to enhance ribonuclease activity.

To investigate the effect of sodium Fluoride on two sunflower cultivars (*Helianthus annuus* (Fudek cv. and Earlyflower cv.) during germination and seedling growth stages, experiments were carried out by Saleh and Abder-Kadar (2003). Seeds of sunflower cultivars were germinated in the dark in 12-cm diameter petri-dishes on filter paper moistened with 0.0, 0.2, 0.5, 1.0 and 5.0 mM sodium fluoride. The germinating seeds were collected after 24, 48 and 72 hours post fluoride treatment. In other experiment, seeds were grown in plastic pots irrigated every two days with half-strength Hoagland solution containing 0.0, 0.2, 0.5, 1.0 and 5.0 mM NaF. Seedlings were harvested two-weeks after the beginning of NaF treatments. They reported that protein content at both; germination and seedling stages, for both cultivars was significantly decreased at all fluoride concentrations. Moreover, the decrease in protein content was time dependent and was negatively correlated with fluoride concentrations. This could be attributed to the ability of fluoride to modify the ratio of free nucleotides and that of RNA, to decrease the rate of RNA synthesis, and/or to enhance ribonuclease activity. As a result, it affects protein synthesis negatively (Bhatnager & Bhatnager 2000). Asthir et al. (1998) concluded that wheat grains respond to fluoride-mediated disruption of carbon metabolism by a compensatory effect on nitrogen metabolism.

Our results are not in agreement with the previous reports.

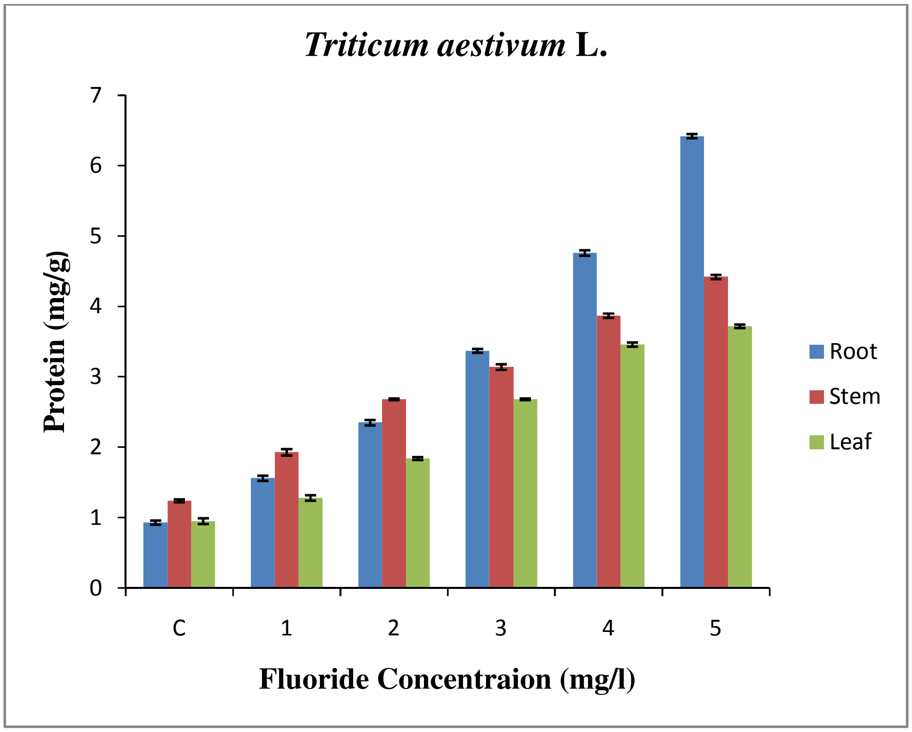


Figure 60: Protein content in Fluoride treated and untreated plants

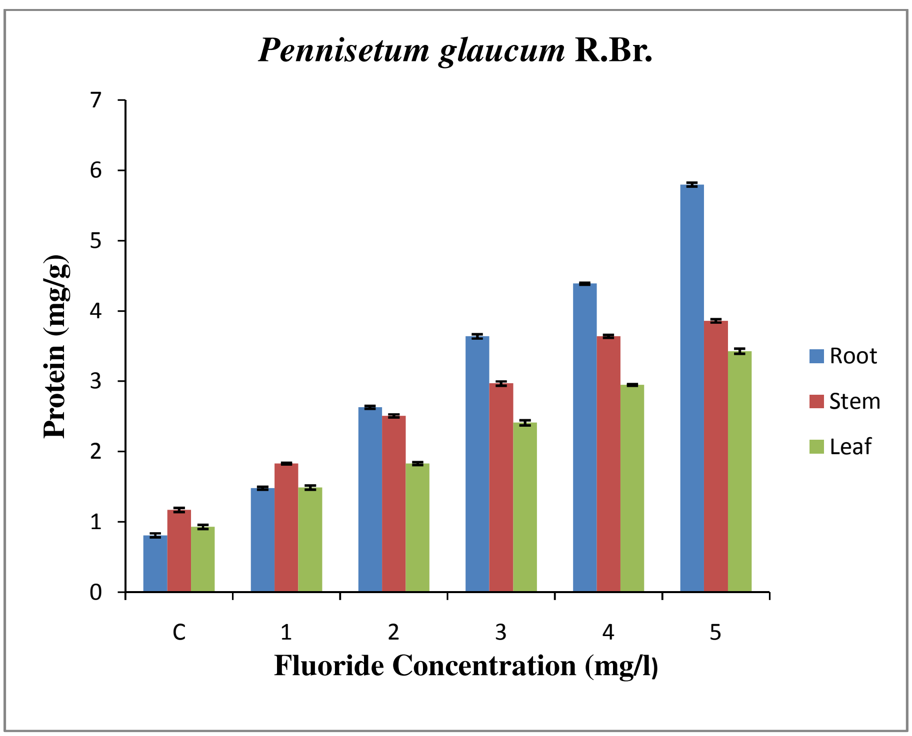


Figure 61: Protein content in Fluoride treated and untreated plants

3.3.4 Proline:

Proline content (mg/g) in the roots of *Triticum aestivum* L. (Fig. 62) was 2.82, 2.63, 2.9, 2.72, 2.51 and 2.71 in the control set up and 1-5 mg/l Fluoride concentration respectively whereas stem and leaf showed 23.89, 24.36, 23.57, 23.42, 24.44, and 24.5 and 8.69, 8.22, 8.12, 8.42, 8.37 and 8.61 mg/g in control and plants treated with 1-5 mg/l Fluoride concentration respectively.

Proline content (mg/g) in plants of *Pennisetum glaucum* R.Br. (Fig. 63) was 2.48, 2.44, 2.56, 2.54, 2.86 and 2.59 mg/g in roots for control and 1-5 mg/l Fluoride concentration respectively whereas in the stem it was 21.91, 21.89, 21.26, 21.53, 21.59 and 21.5 and in leaves it was 6.69, 6.7, 6.32, 6.39, 6.35 and 6.43 respectively.

The level of Proline was found highly fluctuating when both the test plants were subjected to 1-5 mg/l concentration of Fluoride. Therefore no comments were made on the effect of Fluoride concentration on Proline content of the test plants.

Discussion:

Gadi (2016) had conducted a study to investigate the effect of sodium fluoride (NaF) on pigments, metabolic patterns and nitrate reductase activity in in-vitro grown seedlings of *Ziziphus mauritiana* cv. Tikadi. Seeds were germinated in petriplates containing whatman No.1 filter paper and they were irrigated with distilled water (control), 1 and 10 mM NaF treatement. They reported that increase in NaF levels significantly reduced soluble Proline content.

Das *et al.*(2015) in their study on Fluoride toxicity in potato (*Solanum tuberosum* L.) tuber grown in contaminated soils with graded concentration to measure Proline level in the leaves. Also, the measured Proline level ($r = 0.775$, $p < 0.05$) in the tuber was found influenced by Fluoride content in shoot positively. Their findings suggested that Proline level in potato tuber is also significantly influenced by Fluoride content in leaf and sugar level in potato tuber.

Our results on effect of Fluoride ion on Carbohydrate, Protein and Proline content of both the test plants are not in accordance with the results obtained by many researchers. As per these reports, Fluoride exerts its toxic effects only when the accumulation by a particular plant species is high. If Fluoride accumulation capacity is low, it does not pause any negative impact on biochemical properties of a plant like chlorophyll, protein carbohydrate etc. In our results we reported very low accumulation of Fluoride in both the plants under study. This low concentration of Fluoride might be insufficient to exert any negative impact on biochemical properties of the test plants and simultaneously the plants did not reflect any morphological abnormalities.

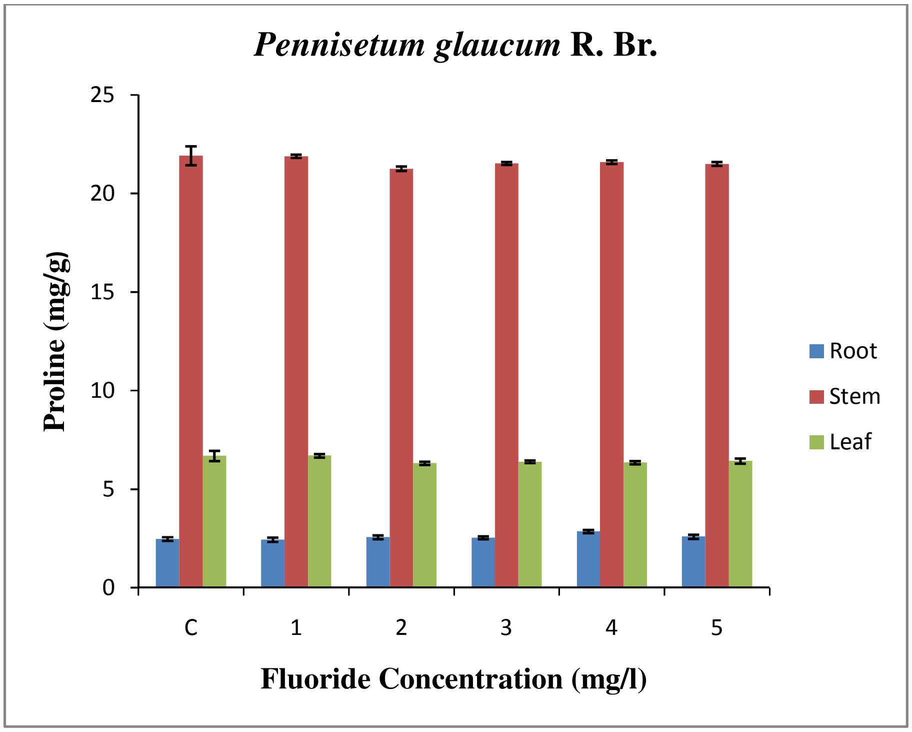


Figure 62: Proline content in Fluoride treated and untreated plants

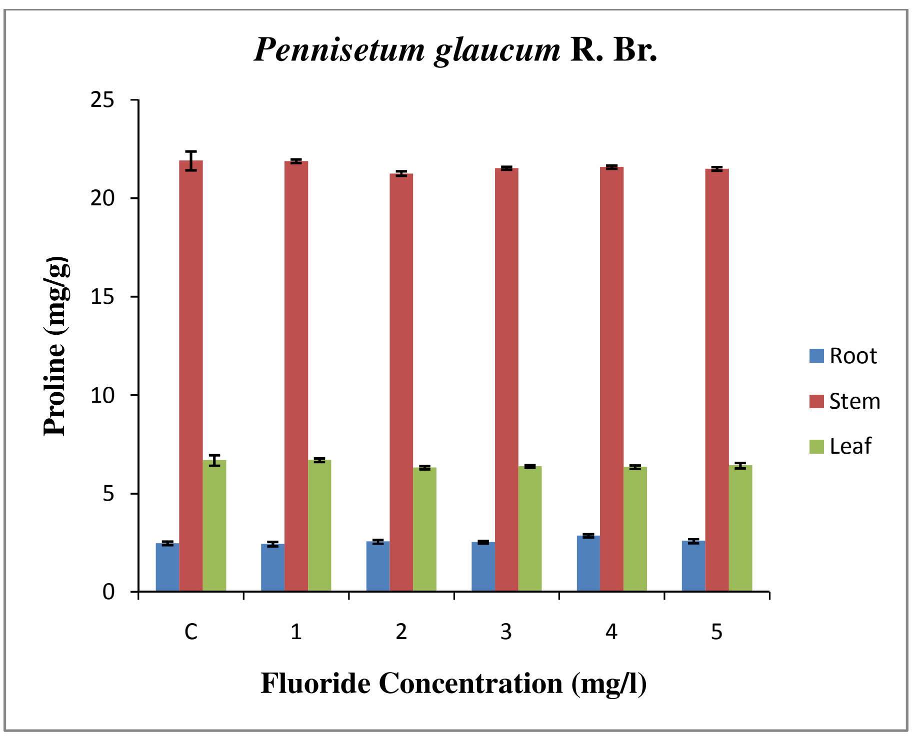


Figure 63 Proline content in Fluoride treated and untreated plants

3.4 Bioaccumulation of Fluoride in crop plants

Bioaccumulation of Fluoride was estimated in the grains of *Triticum aestivum* L. (PLATE 5) and *Pennisetum glaucum* R.Br.(PLATE 6) grown in in-vitro condition supplemented with Fluoride concentration in the range of 1-5 mg/l. The estimated value of Fluoride in grains of *Triticum aestivum* L. (Table: 6) was 0.076, 0.092, 0.128, 0.161 and 0.19 mg/g with the initial Fluoride concentration of 1, 2, 3 ,4 and 5mg/l respectively whereas in *Pennisetum glaucum* R.Br (Table:7) it was 0.069, 0.089, 0.114, 0.156 and 0.194 mg/g. Results showed that gradual rise in the Fluoride concentration increased Fluoride accumulation in the grains of both the test plants. There was negligible difference in the accumulation capacity of both the plants under study.

Discussion:

Jalgaon district of Maharashtra, state of India was investigated for Fluoride level in soil, water and grain of Jowar (Naik *et al*., 2017). In their study they recorded the level of soil Fluoride which was 2.6 ppm and in water it was 1.6 ppm and in grain, of the test plant it was lowest i.e. 1.4 ppm. They envisaged that the accumulation of Fluoride in Jowar grains might be attributed to uptake from the soil as well as from water that was used for irrigation.

Mustofa *et al.*(2014) had measured levels of Fluoride in cereals like Tef (Gonder), Wheat (wonji), corn (Arsi negele) and Barley (Wonji) grown in some areas of Ethiopia, They recorded that the range of accumulation of Fluoride was 3.7 mg/Kg in Corn to 10.98 mg/Kg in Tef. The order of accumulation of Fluoride in the tested cereals was found to be wheat (10.3 mg/Kg> Tef (8 mg/Kg) > Barley (6.07 mg/Kg) > corn (4.53 mg/Kg).They stated that Fluoride accumulation in grains might be added to soils from agriculture inputs like fertilizers as well as pesticides and the crop subjected to this contain/accumulate Fluoride in their edible parts. The level of Fluoride in Bajara, Chawla and Moth collected from Lohrana village (Nawa tehsil) was reported 3.84 µg/g, 14.44 µg/g and 13.06 µg/g respectively (Gautam *et al*. 2010).

Fluoride in plants primarily enters through stomata, passes into intercellular spaces, contacts the mesophyll and than absorb into the cell or dissolved in water from where

PLATE 5

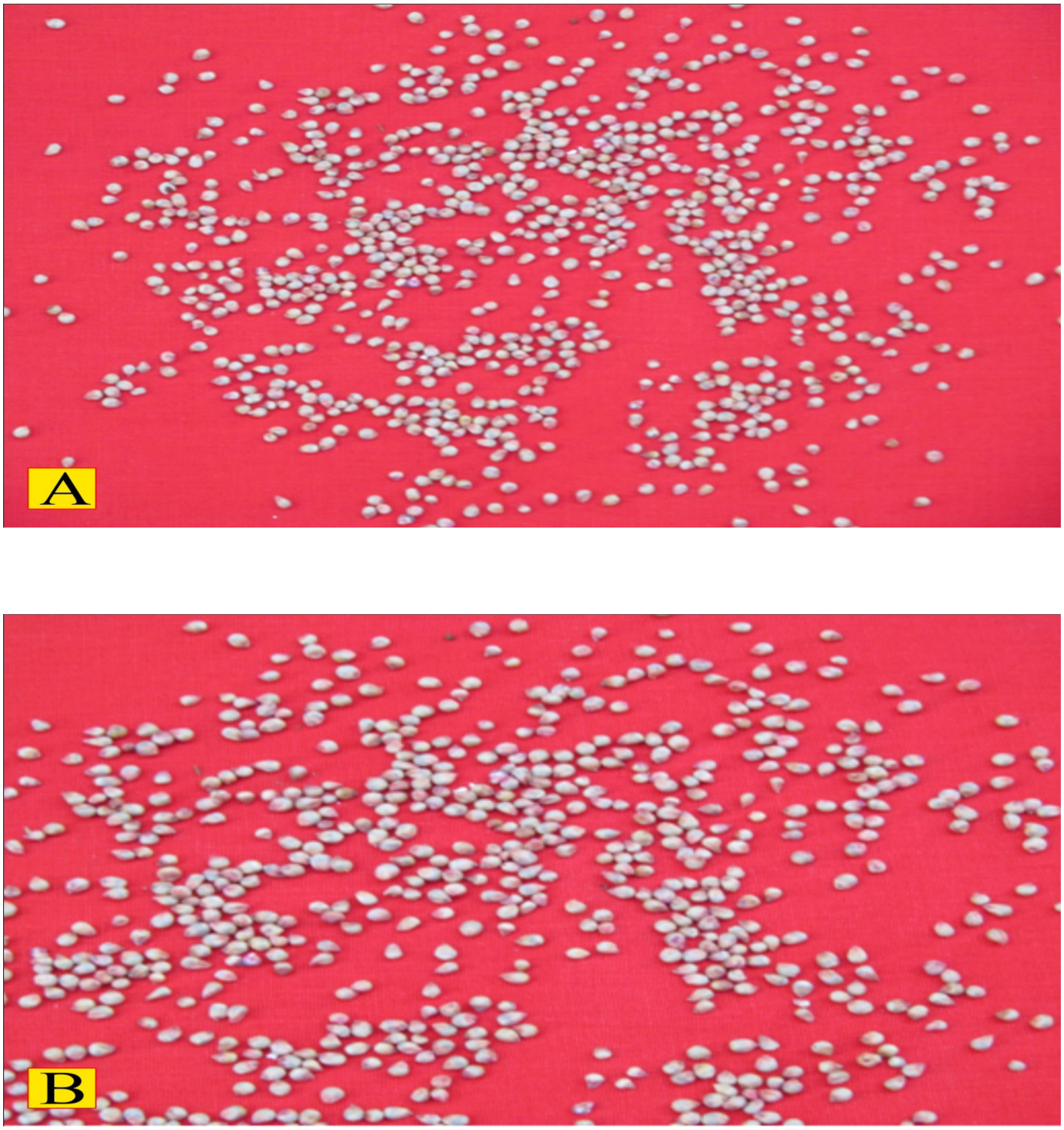


PLATE 6

it finally gets transported through the vascular tissue to the leaf tips and its margins. The airborne Fluoride along with other pollutants settles out of the atmosphere and tends to accumulate in the soil.

Thus, this soluble form of Fluoride is easily absorbed and accumulated by both leaves and roots. However, Fluoride accumulation largely depends on the duration of exposure, its concentration in soil, water and air and also the form of Fluoride (Treshow,1970). Its bioavailability is also influenced by presence of metal forming complexes, pH variation and precipitation.

Accumulation of Fluoride in different plant parts had been reported by several researchers. In general, from various studies conducted by different researchers had proved that concentration of Fluoride in grains/fruits of cereals as well as vegetable plants was much lesser than the vegetative parts. Maclean and Schneider (1981) had studied effects of gaseous hydrogen Fluoride on the yield of field grown wheat (*Triticum aestivum* L.). In our study, We observed that there was no significant difference in the concentration of Fluoride in treated and control grains *T. aestivum* L. The result indicated that Fluoride accumulated in the vegetative parts of treated plants might have not translocated up to the grains resulting into lower accumulation of Fluoride in grains of the test plants. These results were also supported by Singh et al. (1995). They conducted experiment on Fluoride treated plants of *Abelmorchus esculantus* and the estimated its level in root and Fruit of the test plant. They concluded that the root accumulated most of the Fluoride whereas the fruit accumulated the least. The reason for more accumulation in fruit might be due to Fluoride supplied through irrigation water.

Fluoride accumulation in crops and vegetables in Fluoride endemic area of West Bengal was studied by Gupta and Banergee (2011). In their research, Fluoride content in the leafy vegetables was found to be higher [transfer factor (TF)>1] than that of fruiting vegetables. High Fluoride translocation in the leafy vegetables might be attributed to the increased rate of metabolism (and/or photosynthetic rate) in leafy shoots in comparison to seeds/grains of the test plants. Higher metabolic activity in these plants could be associated with high intake of water resulting in increased Fluoride concentration in the leafy parts of the plants.

Table 27: Fluoride accumulation (mg/g) in *Triticum aestivum* L.Grains

I.Fc.	mg/g	% absorption
1	0.076±0.007	1.52
2	0.092±0.008	1.84
3	0.128±0.013	2.56
4	0.161±0.010	3.22
5	0.19±0.009	3.8

Table 28: Fluoride accumulation (mg/g) in *Pennisetum glaucum* R.Br. grains

I.Fc.	mg/g	% absorption
1	0.069±0.005	1.38
2	0.089±0.007	1.78
3	0.114±0.006	2.28
4	0.156±0.020	3.12
5	0.194±0.008	3.88

I.Fc. = Initial Fluoride concentraion

Bioconcentration of Fluoride in Lady's finger was studied by Jha *et al.* ((2013). Maximum accumulation of Fluoride was found in the roots of the experimental plants than leaf, shoots and fruits. Their findings were in agreement with Jha et al. (2009) and Patel and Vyas (2004). They stated that a soluble fraction of Fluoride of soil is taken up by roots passively and than subsequently transported in above ground parts like shoots and leaves. The transport of most of the Fluoride across the roots remains in the cell wall and intercellular spaces (apoplast) rather than through cell membrane because of low permeability of Fluoride ion to cell membrane which further limits its diffusion into the cell. (Takmaz-Nisaneiouglu and Davison, 1988).

In our study we reported low Fluoride concentration in the grains of *Triticum aestivum* L. and *Pennisetum glaucum* R.Br. as compared to these earlier reports. This was probably due to relatively low permeability of Fluoride ion through endodermis and retention of Fluoride ion in the cell wall and intercellular spaces of cells of vegetative parts than the fruiting parts like grain.

3.5 SEM-EDX study in the grains of the test plants

Energy-dispersive X-ray microanalysis (EDX) is a technique for analyzing elements at the microscopic level. For this purpose, scanning (SEM) or transmission electron microscopes (TEM) are equipped with an energy dispersive system for quantitative electron probe X-ray microanalysis. The TEM-EDX system requires embedded samples, which enable high spatial resolution. The SEM-EDX system can be applied to surfaces of untreated specimens and thus provides a rapid way of measuring elemental distributions in plant and animal materials. The most significant recent advance has been the development of cryo-SEM for in situ elemental quantification by EDX (Ryan *et al.*,2007 and McCully *et al.*,2010).

In this context, the mechanism of sorption is probed in the present study in order to establish theoretical grounds for the observed sorption phenomenon by making morphological studies and adopting such techniques like scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX).

3.5.1 SEM Analysis

Our observations on SEM and EDX of *Triticum aestivum* L.(PLATE 7-10) and *Pennisetum glaucum* R.Br.(PLATE 11-14) grain after treatment with Fluoride (5 mg/l concentration) indicated that surface morphology of control and treated plants was almost similar. These observations were correlated with low accumulation of Fluoride in the grains of both the test plants. Hence these results confirm that the percentage of Fluoride adherence was much less in Fluoride treated grains of *Triticum aestivum* L.(0.19±0.009 mg/g) and *Pennisetum glaucum* R.Br.(0.194±0.008 mg/g) because of which the seeds of the test plants did not reflected any alterations in the surface morphological features.

Discussion

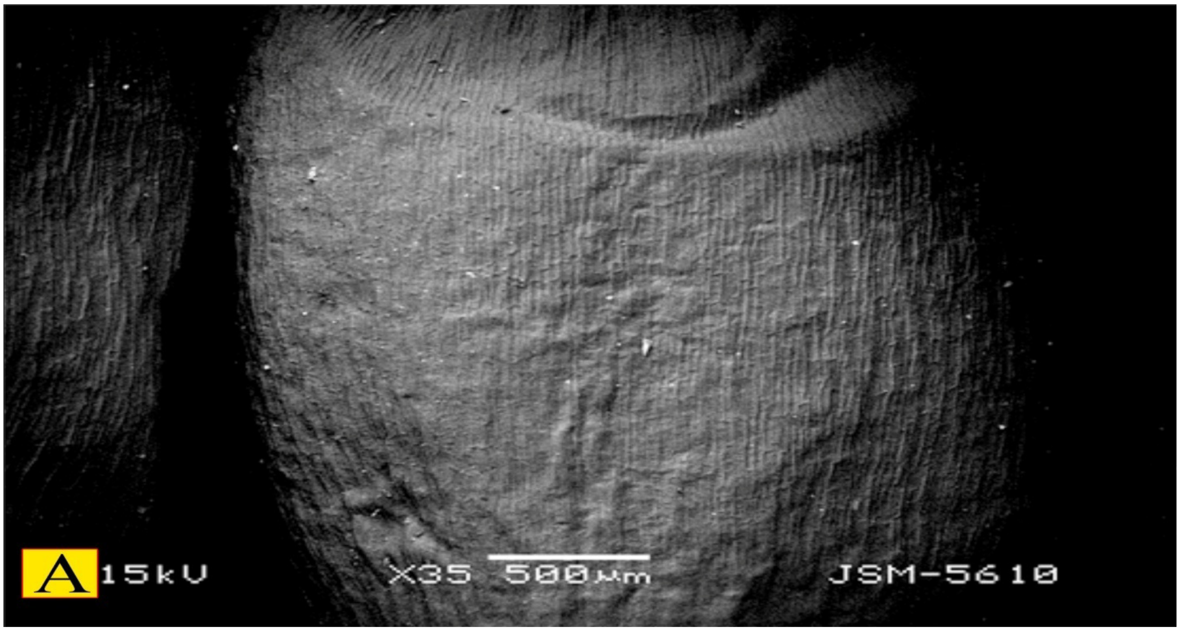
Earlier reports on SEM and EDX analysis had stated that different plant based adsorbent used for Fluoride removal reflected specific characteristics which are different from control samples. These characteristics of adsorbent include rough surface area, large pore size, and porous nature after treatment with Fluoride ion.

SEM micrograph of nitric acid activated carbon made from *Vitex negundo* bark was studied by Suneetha *et al.* (2015). The examination of the SEM micrographs of the activated carbon material showed presence of dark and grey areas. The dark areas indicated pores and grey areas indicated the carbon matrix. Also, the micrographs showed rough surface of the adsorbent. It might be providing large surface area for adsorption. Overall, a well-developed porous surface was observed at higher magnification and further, randomly distributed pore size was observed in all micrographs. The grey surface area of every micrograph contained smaller micro particles (nm to μm) which might be indicative of activated sites or surface functional groups of the carbon. The adsorption of Fluoride might be due to the presence of pores and active groups on the surface. Thus, SEM micrographs proved adsorption of Fluoride.

Murugan and Subramanian (2006) had investigated SEM photographs of *Tamarind* seed treated with synthetic Fluoride solution. They observed that the spongy particles of free *Tamarind* seed after Fluoride binding were converted into large sized, rough surface particles. They suggested that the hydrogen bonding of Fluoride with the phenolic / hydroxyl groups of the seed samples was also a possibility of alterations in SEM micrograph of the seed. All these spectral shifts and SEM study lend evidence to electrostatic bonding of Fluoride ion.

Mondal (2017) had conducted a study on Natural Banana (*Musa acuminate*) Peel (NBP), an unconventional adsorbent for Fluoride removal; was treated with synthetic Fluoride solution. SEM photograph of NBP after loading of Fluoride showed that the surface of NBP had numerous micro-rough, porous structures which might be the area of Fluoride loading.

However, there are the reports which proved that surface morphological features of plant based bio adsorbent tend to change when the Fluoride ion accumulation is high and vice-versa. Boukhris *et al.* (2015) had investigated *Atractylis serratuloides* to understand physiological mechanisms of Fluoride tolerance at the Fluoride-contaminated sites of Tunisia. They recorded no fluorine accumulation in the tissues of root, stem and leaf of the test plant even in the most contaminated site at Gabes.



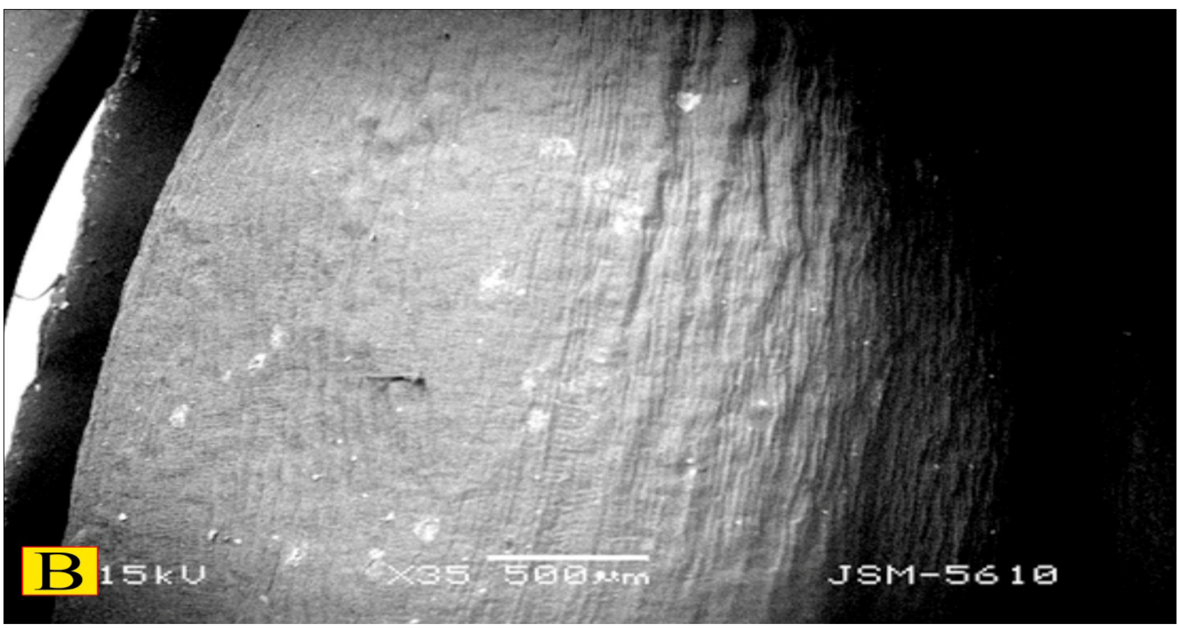
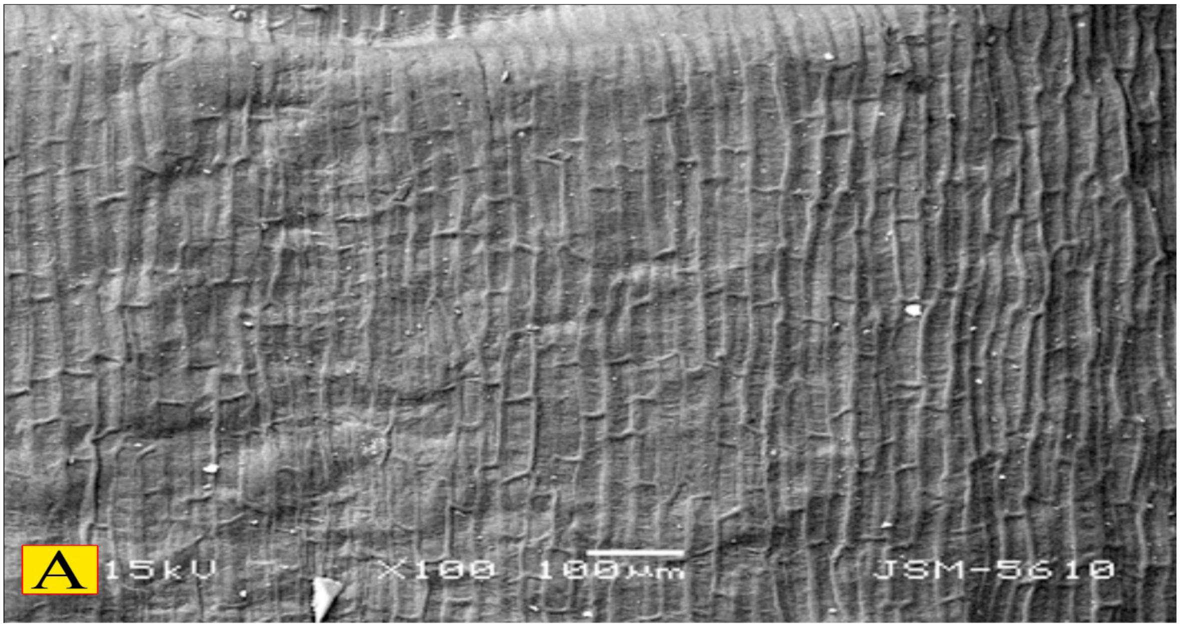


PLATE 7



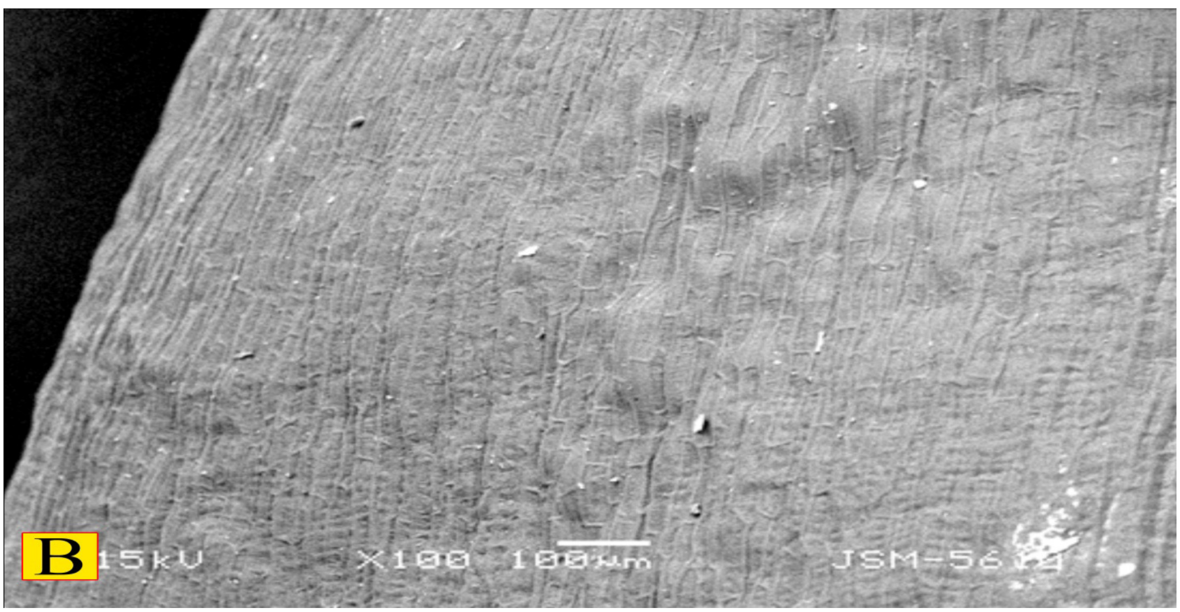
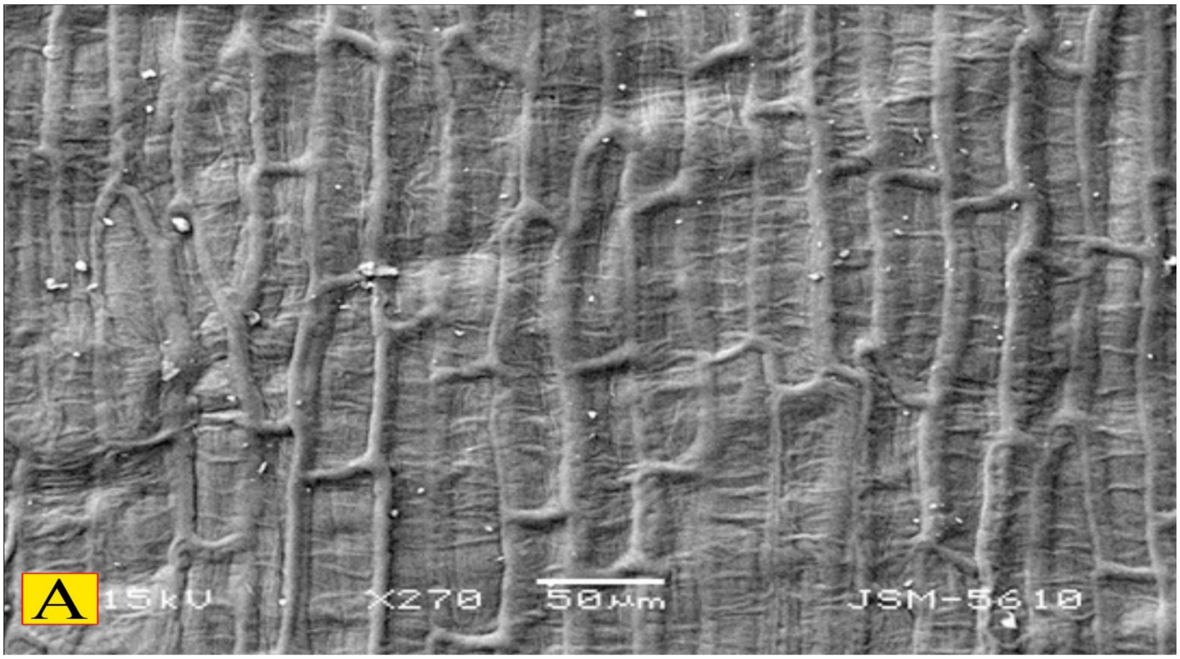


PLATE 8



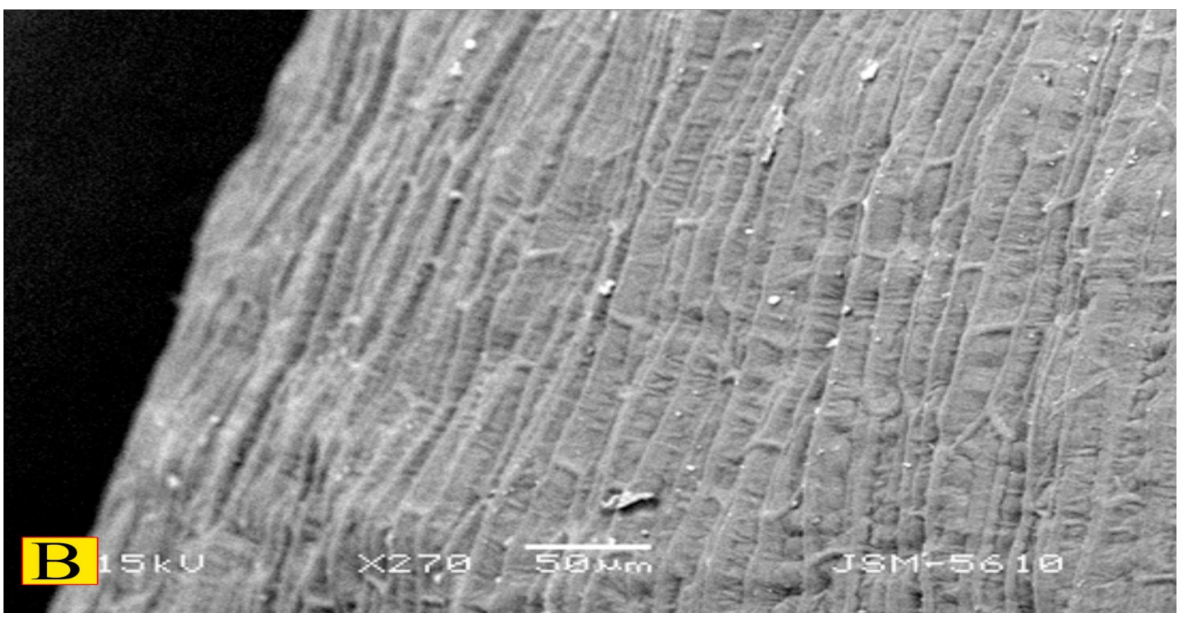
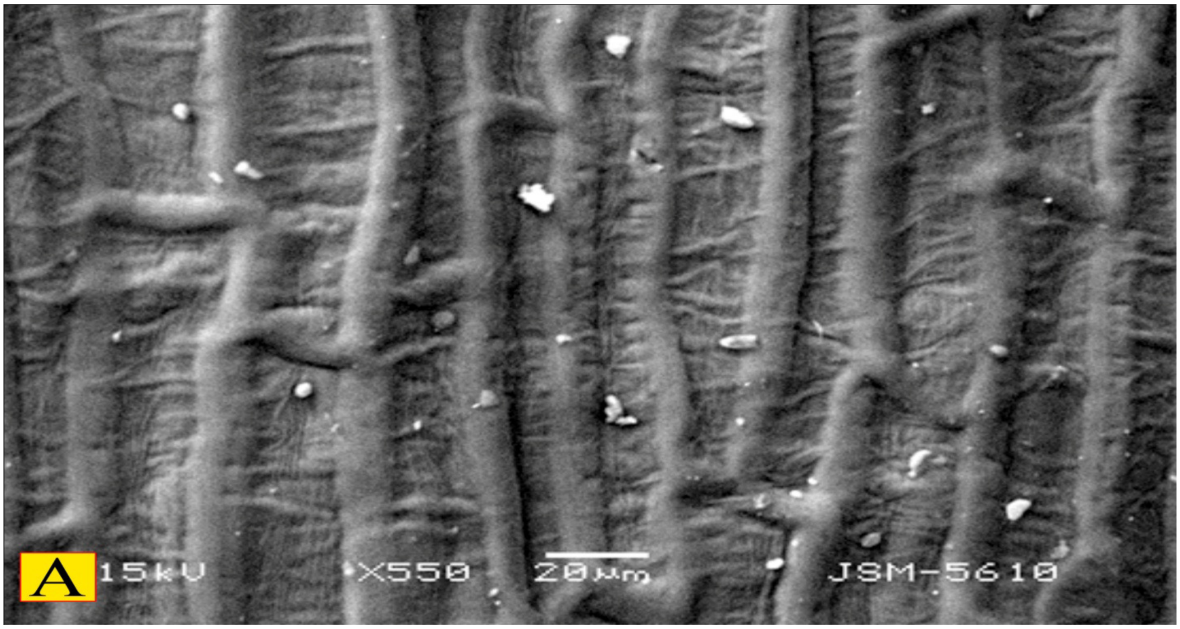


PLATE 9



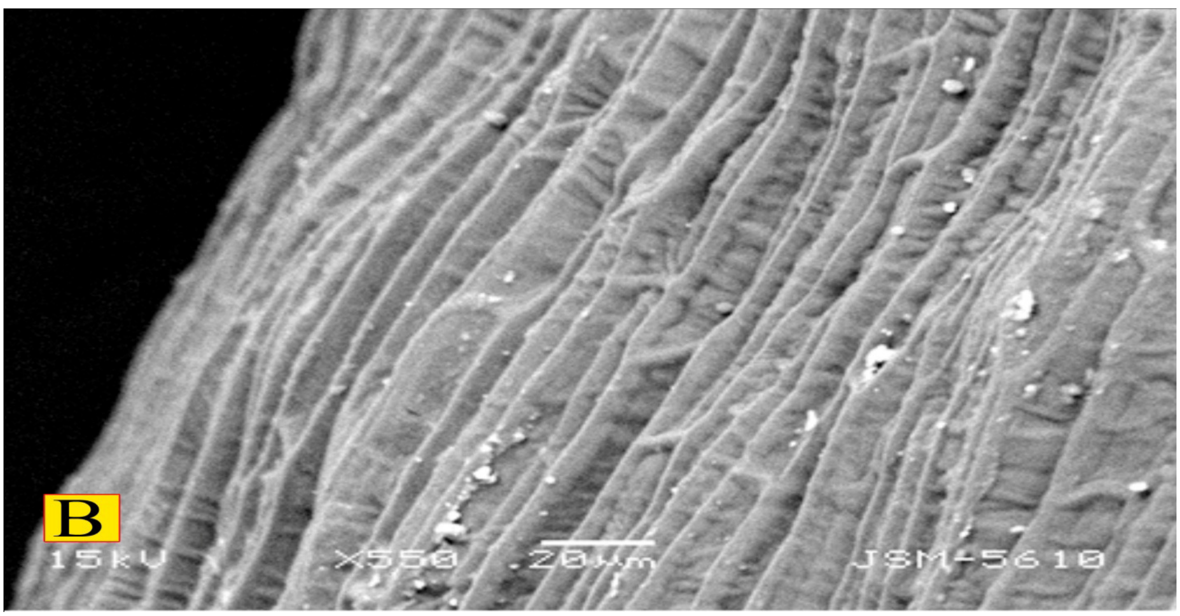
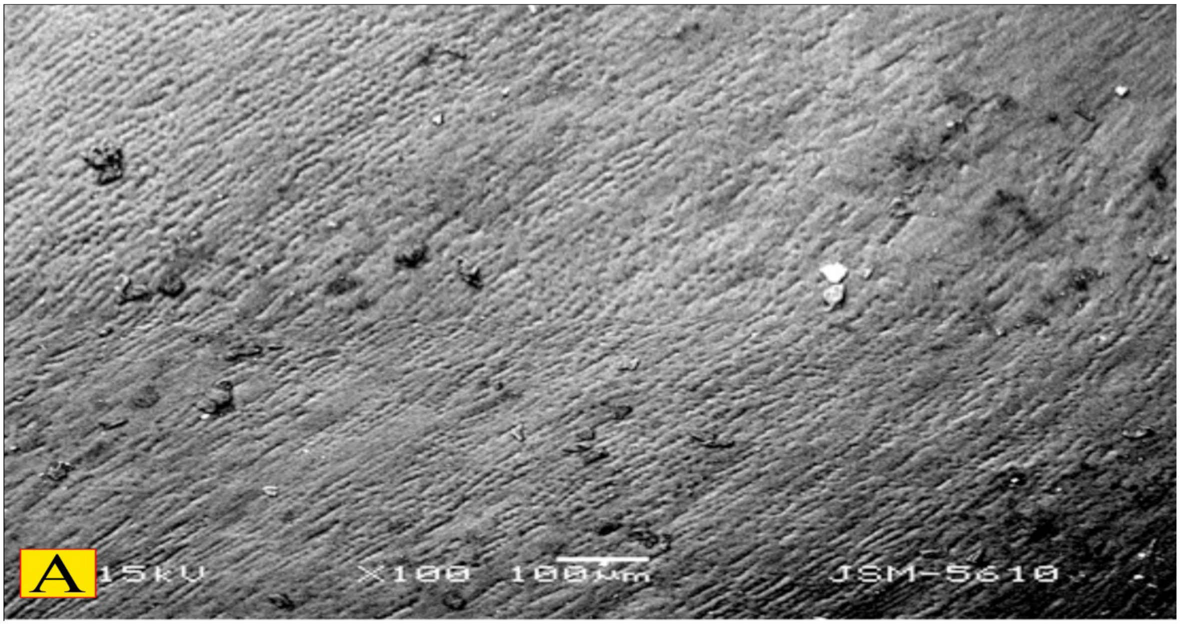


PLATE 10



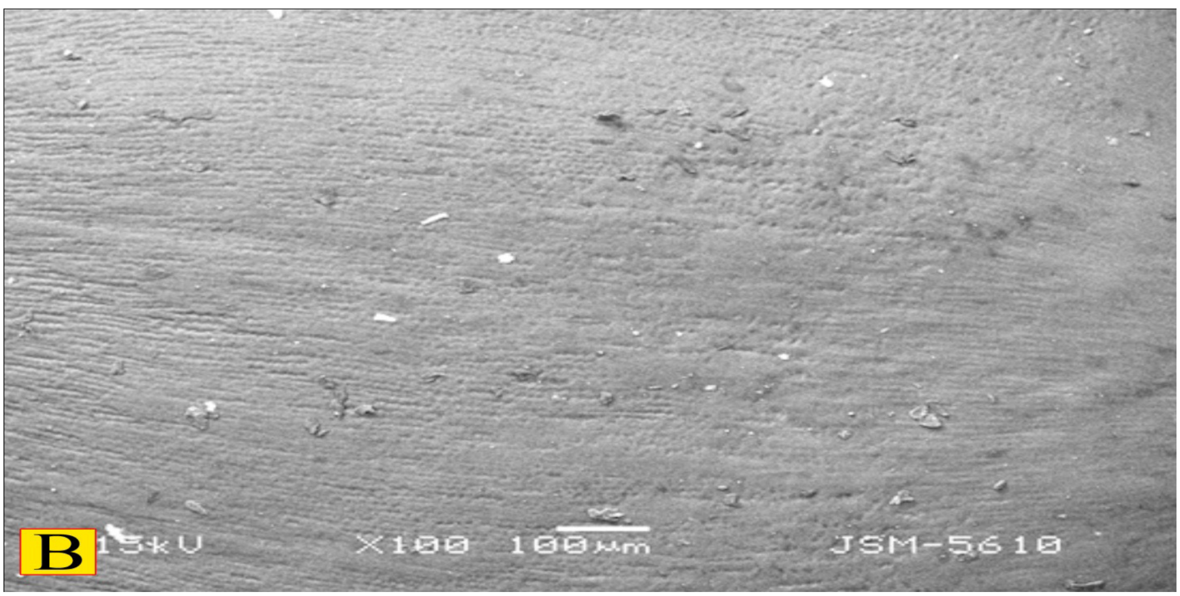
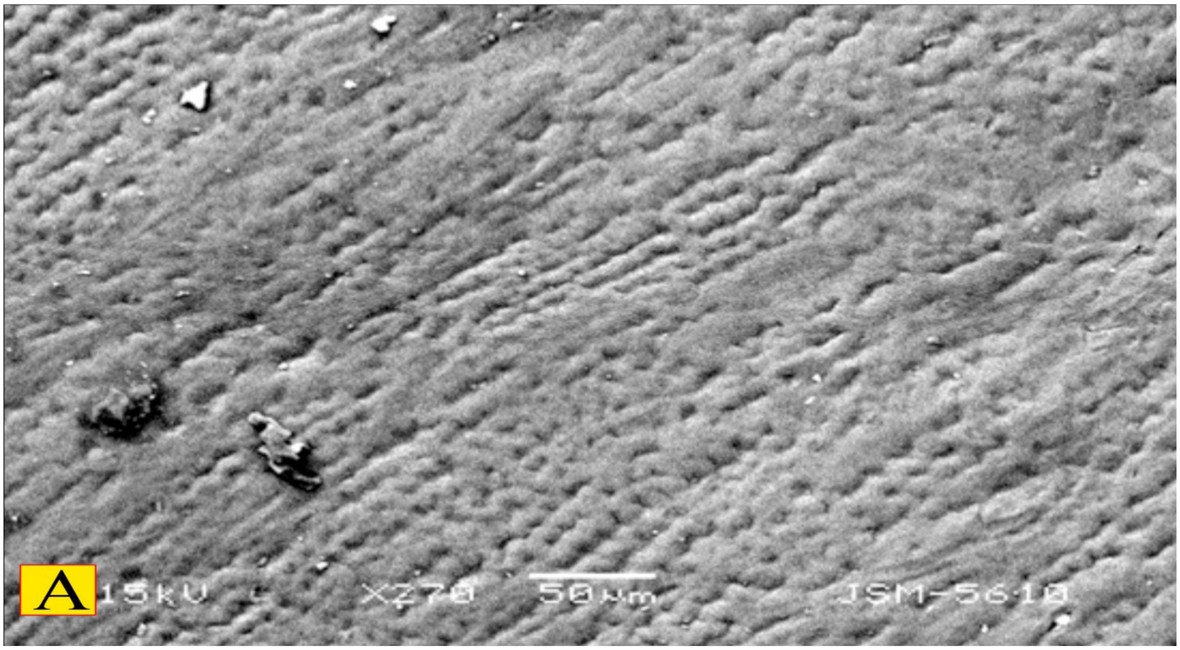


PLATE 11



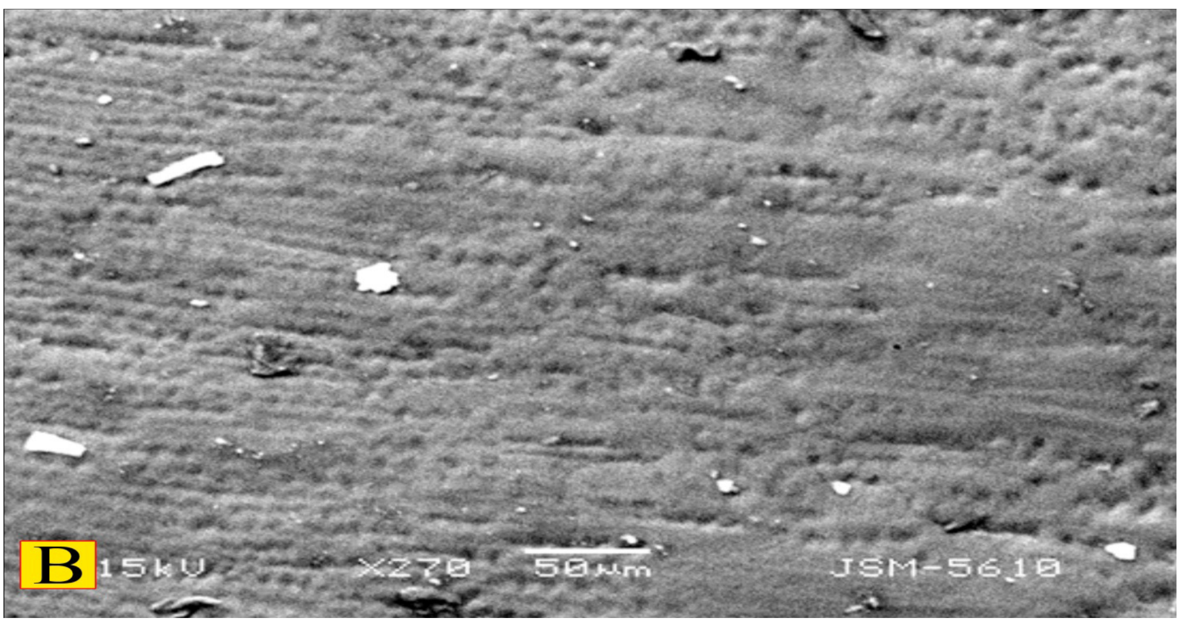
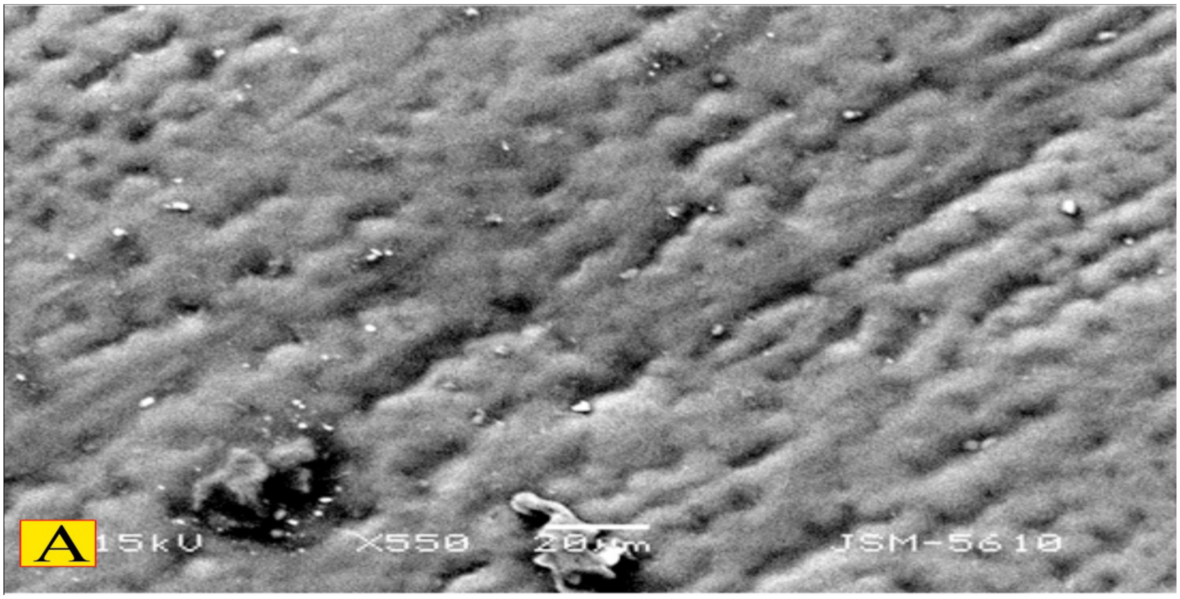


PLATE 12



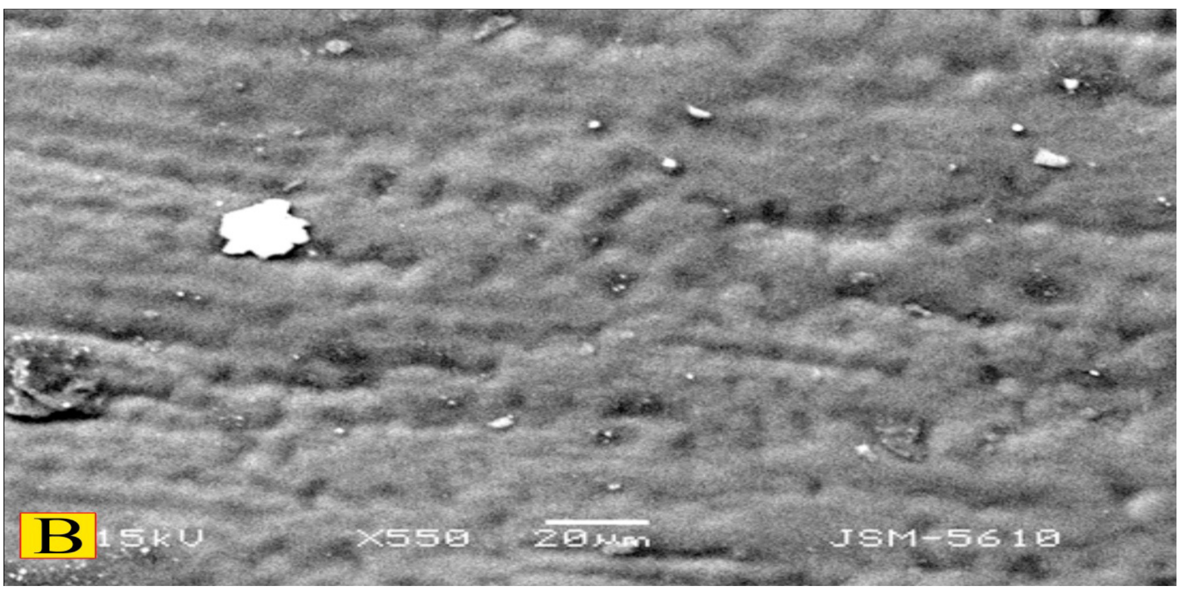
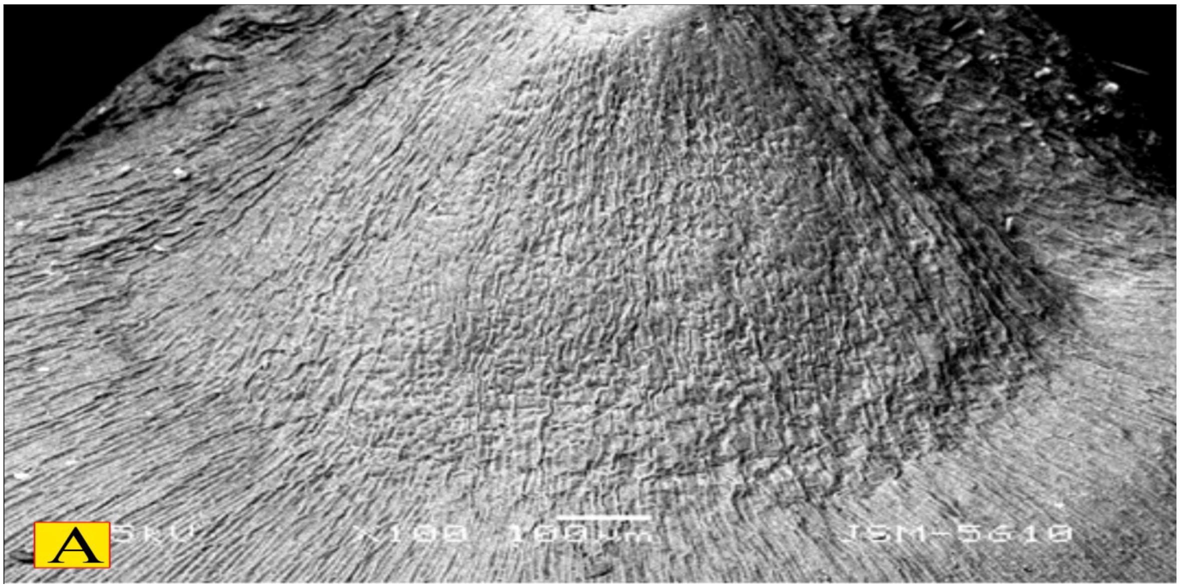


PLATE 13



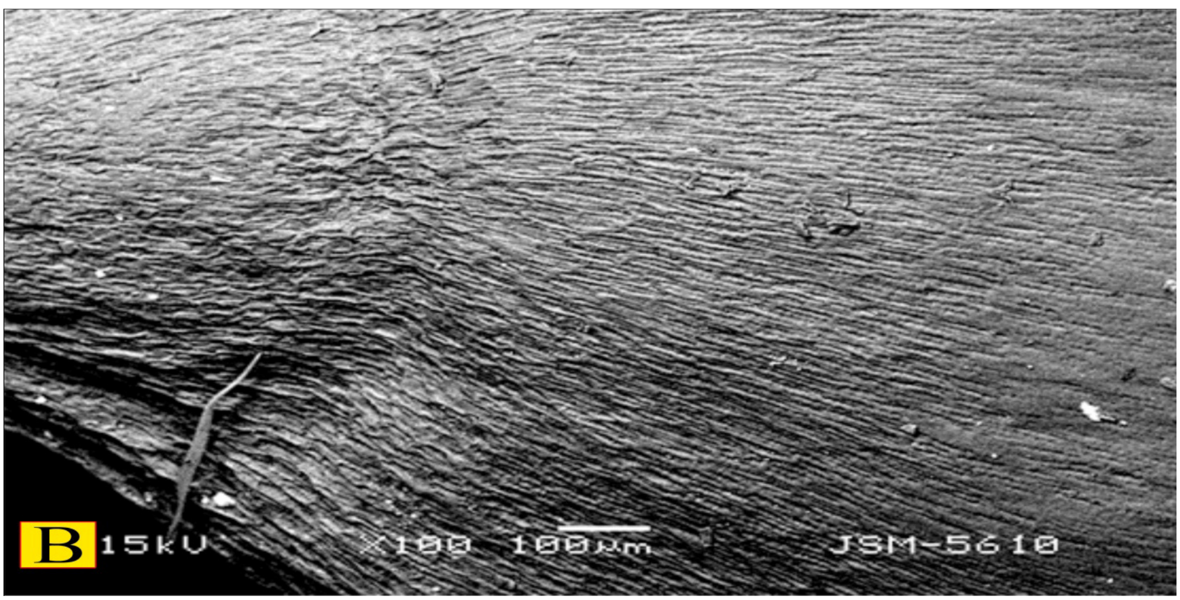


PLATE 14

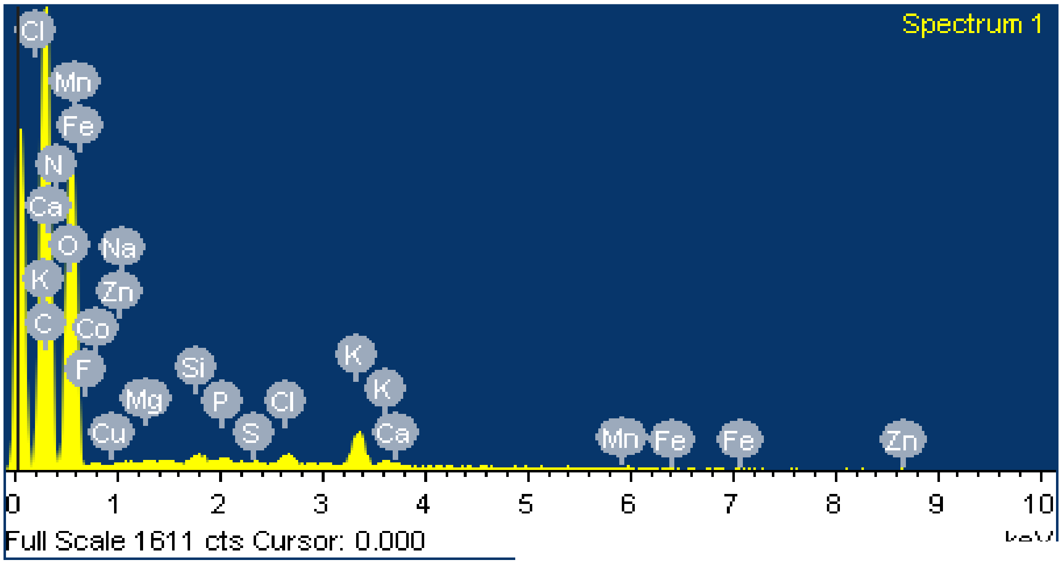
3.5.2 EDX Analysis

The energy dispersive x-ray microanalysis (EDX) is a fully developed, well-known technique for semi-quantitative determination of the elemental composition of sample surfaces (Goldstein *et al*., 2003; Eggert, 2005). Despite its lower sensitivity (0.1–2%) in comparison to classical analytical procedures, EDX has the advantage of giving precise information on the spatial element distribution on the surface when used jointly with a scanning electron microscope (SEM). Moreover, its non-destructive nature and the short processing time are important reasons for the application of SEM–EDX in research areas such as engineering, material sciences, geology, paleontology, archaeology, arts and biology (Hunsche and Noga, 2008).

EDX analysis was performed in the study, to determine the elemental composition present in the grains of control and Fluoride treated plants of *Triticum aestivum* L. and *Pennisetum glaucum* R.Br..

The quantitative analysis using EDX of grain of. *Triticum aestivum* L.of control plant (Fig. 64) showed that carbon and oxygen are the major constituents i.e. 26.75% and 71.27 % respectively. The spectrum also showed the presence of sodium 0.04%, magnesium 0.06%, silicon 0.14%, phosphorus 0.11%, sulphur 0.01%, chlorine 0.29 %, potassium 1.18%, calcium 0.10% and iron 0.06% Fluoride ion was found to be absent in control plant. All the metal clearly shows peak while Fluoride ion peak did not occur in control plant.

The results on EDX analysis on grains of Fluoride treated *Triticum aestivum* L. plant (Fig. 65) showed that carbon and oxygen are the major constituents i.e. 26.33% and 71.27% respectively. The spectrum also showed the presence of nitrogen 0.15%, sodium 0.26%, magnesium 0.01%, silicon 0.05%, phosphorus 0.06%, sulphur 0.06%, chlorine 0.47%, potassium 1.10%, calcium 0.07%, cobalt 0.05% and copper 0.05%. Fluoride ion with concentration of only 0.16 % was found. This was again confirmed by occurrence of a very small peak of Fluoride ion and it also had proved that though in small quantity; the grains might have adsorbed Fluoride ion.



Element	Weight%	Atomic%
C K	26.75	33.40
Na K	0.04	0.03
Mg K	0.06	0.04
Si K	0.14	0.08
P K	0.11	0.05
S K	0.01	0.00
Cl K	0.29	0.12
K K	1.18	0.45
Fe K	0.06	0.02
O	71.27	66.60
Totals	100.00	

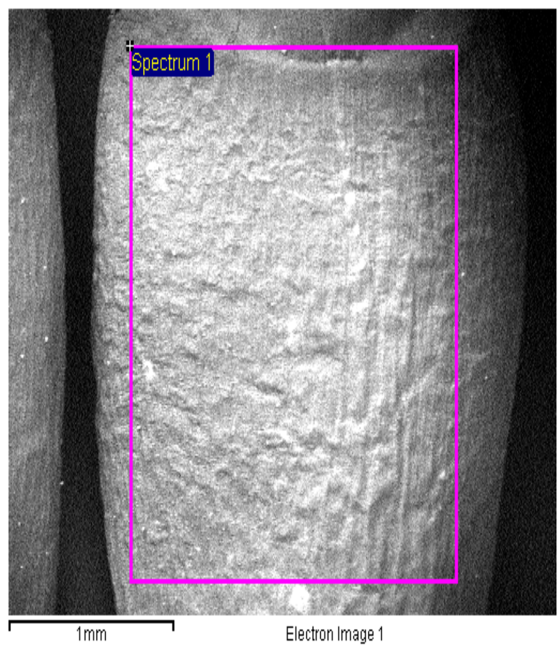
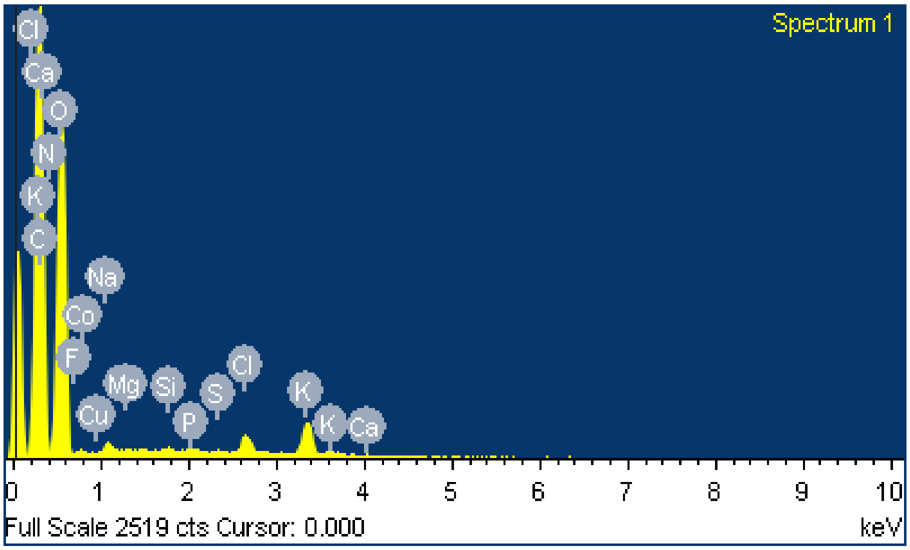


Figure 64: **EDX of Control *Triticum aestivum* L.**



Element	Weight%	Atomic%
C K	26.33	32.61
N K	0.15	0.16
F K	0.16	0.13
Na K	0.26	0.17
Si K	0.05	0.03
P K	0.06	0.03
S K	0.06	0.03
Cl K	0.47	0.20
K K	1.10	0.42
Ca K	0.07	0.03
Co K	0.05	0.01
Cu L	0.05	0.01
O	71.17	66.18
Totals	100.00	

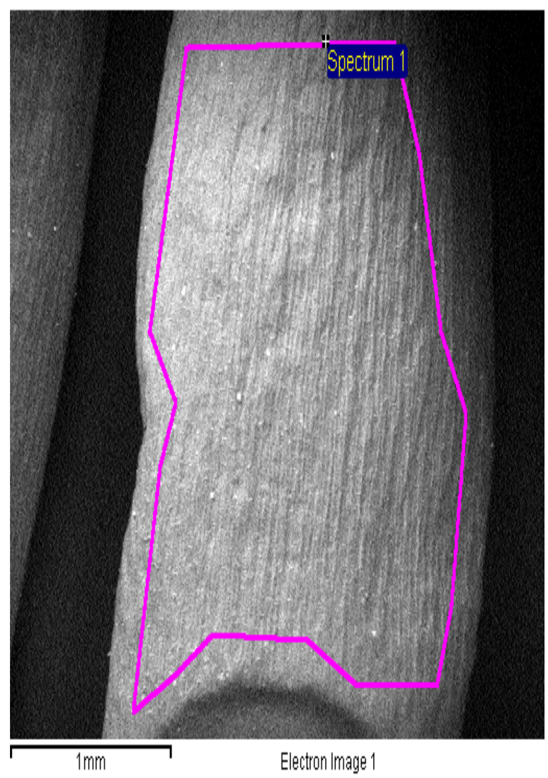
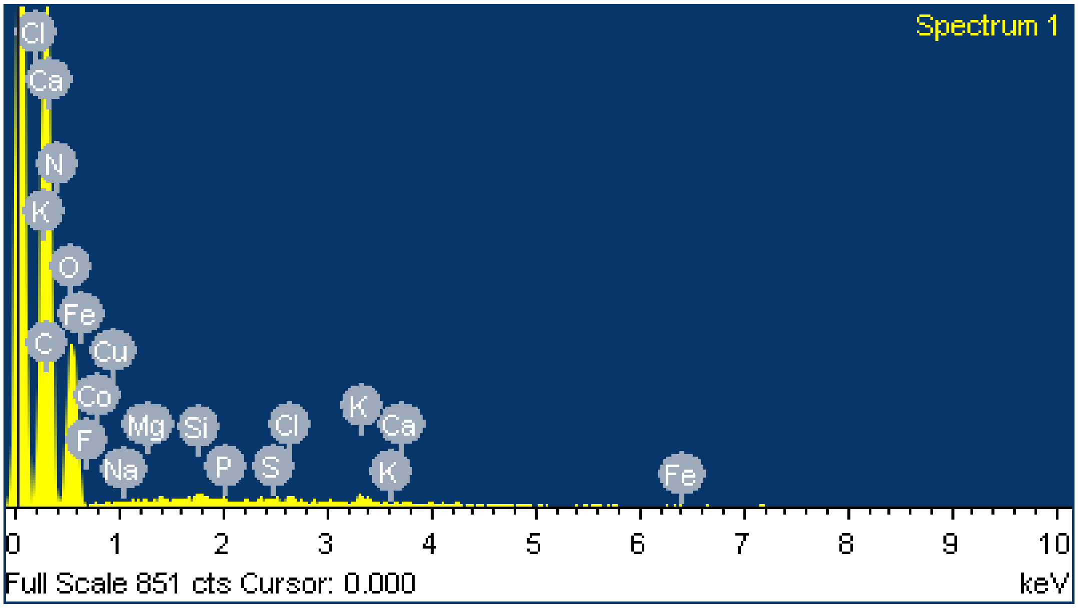


Figure 65: EDX of Treated *Triticum aestivum* L.



Element	Weight%	Atomic%
C K	27.94	34.71
Na K	0.04	0.02
Si K	0.11	0.06
P K	0.03	0.01
Cl K	0.14	0.06
K K	0.23	0.09
Ca K	0.06	0.02
Cu K	0.12	0.03
O	71.35	66.55
Totals	100.00	

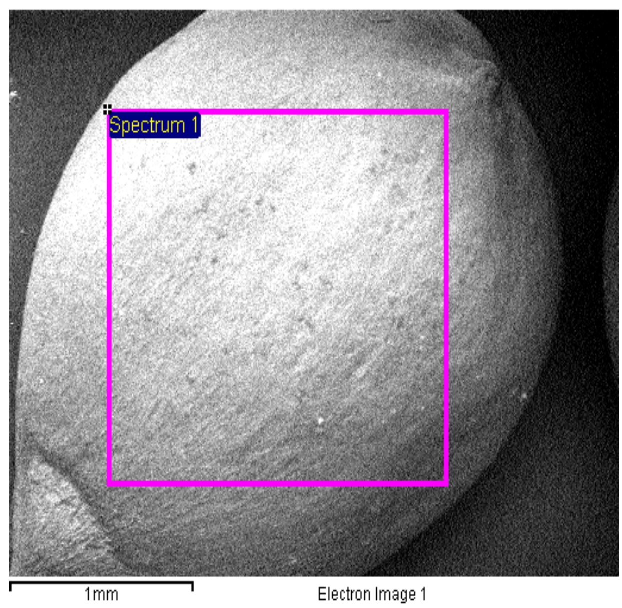
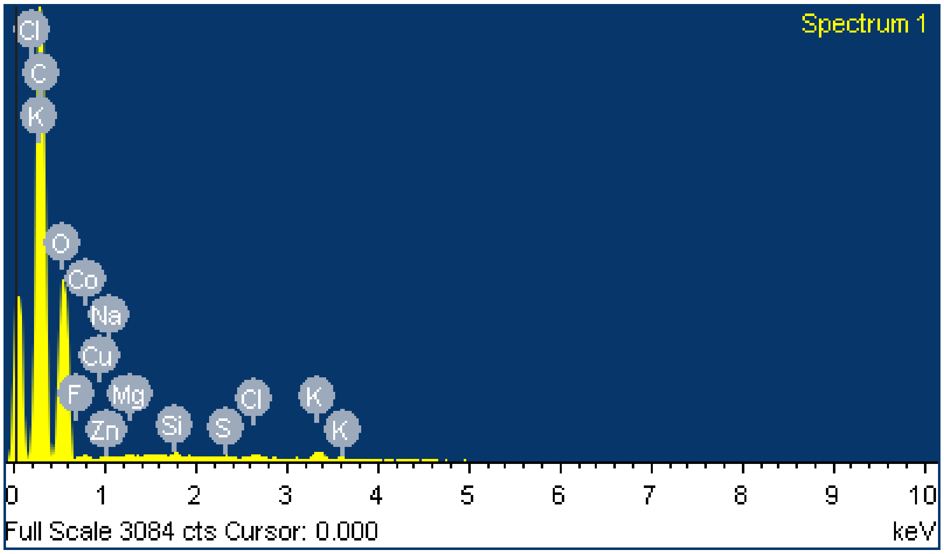


Figure 66: EDX of Control *Pennisetum glaucum* R.Br.



Element	Weight%	Atomic%
C K	27.00	33.15
F K	0.03	0.02
Na K	0.05	0.03
Mg K	0.05	0.03
Si K	0.05	0.03
S K	0.05	0.02
Cl K	0.11	0.05
K K	0.28	0.11
Cu K	0.15	0.04
Zn L	0.05	0.01
O	72.19	66.54
Totals	100.00	

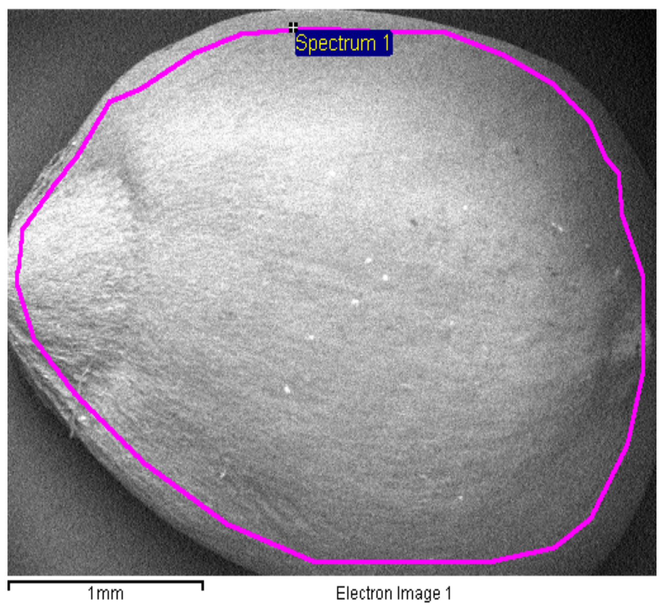


Figure 67: EDX of Treated *Pennisetum glaucum* R.Br.

The quantitative analysis using EDX of grain of *Pennisetum glaucum* R.Br. of control plant (Fig. 66) showed that carbon and oxygen are the major constituents i.e. 27.94% and 71.35 % respectively. The spectrum also showed the presence of sodium 0.04%, silicon 0.11%, phosphorous 0.03%, chlorine 0.14%, potassium 0.23%, calcium 0.06% and copper 0.12 %. Fluoride ion was not found in control plant. All the metal clearly showed peak while Fluoride ion peak was absent in control plant.

The EDX of grain of Fluoride treated *Pennisetum glaucum* R.Br. (Fig.67)showed that carbon and oxygen are the major constituents i.e. 27.00% and 72.19% respectively. The spectrum also showed the presence of sodium 0.05%, magnesium 0.05%, silicon 0.05%, sulphur 0.05%, chlorine 0.11%, potassium 0.28%, copper 0.15% and zinc 0.05%. Fluoride ion with concentration of 0.03% was found which indicated absorbance of Fluoride ion in treated plant. It was further confirmed by presence of a very small peak of Fluoride ion.