Determination Of Fluoride Concentration In Underground Water From Different Urban Areas Of Faisalabad City

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Abstract: Fluoride (F^{-1}) is an essential trace element. Occurrence of fluoride in ground water has drawn worldwide attention due to its considerable impact on human physiology. Its optimum concentration is critical because its deficiency leads to dental caries while excess causes dental fluorosis leading to skeletal fluorosis and both have been observed in certain parts of the Pakistan. In the present study the naturally occurring fluoride concentration has been determined and quantified from 161 underground water samples collected from the Faisalabad and its vicinity by using a Fluoride Ion Selective Electrode (ISE) method. The other water quality parameters were also measured. Fluoride content of 97.5% samples was below the WHO recommended value (1.5 ppm) for the general health of the people with 0.47 ± 0.13 p.m. mean values. The exceptionally high level of fluoride concentration (3.44 ppm) was recorded in the groundwater sampled in the zone of fertilizer industry, Faisalabad. The geological basis for the high concentration of fluoride in that zone was established; which was due to the dumping of phosphate rocks, which is a raw material for the production of phosphate fertilizers. Overall water quality was found unsatisfactory for drinking purposes because of higher salinity (mean 2898 ± 553 µS/cm) ranged between 265 to 6660 µS/cm . No correlation was found between fluoride concentration with EC and depth of groundwater. However, a significant positive correlation was found between fluoride concentration and pH of ground water.
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Introduction:

Water is a precious and finite commodity on the globe and is an essential natural resource for sustaining life and the environment. Safe drinking water is a basic need for all human beings on the earth, while millions of people worldwide are deprived of this. Groundwater is the most appropriate and widely used source of drinking water which is increasingly threatened by pollution from industrial and agricultural activities (Prasad & Narayana, 2004). Fluoride (F^{-1}) is an essential naturally occurring element in trace amounts. Occurrence of fluoride in groundwater has drawn worldwide attention due to its considerable impact on human physiology (Jain *et al.,* 2006). Fluoride's optimum concentration is critical because its deficiency leads to dental caries, cardiovascular diseases and osteoporosis (Binbin *et al*., 2005). High doses of fluoride are acutely toxic to human due to pathological changes in the body causing dental fluorosis (Rao, 2003; Narbutaite *et al*., 2007). Respiratory failure, fall in blood pressure, skeletal fluorosis, paralysis, thyroid, neurological complications, renal disorder, digestive and nervous disorders, etc. are also reported due to high doses of fluoride exposure through water (PCRWR, 2002; Connett, 2006). Chronic fluoride intoxication (fluorosis) occurs not only in humans but also in domestic animals, such as cattle, buffaloes, sheep & goats (Fazlul Hoque *et al.,* 2003).

Fluoride is a common geogenic contaminant found in air, soil, fresh water, sea water, plants, rocks, minerals and lots of foods. It ranks 13th among the elements in the order of abundance in the Earth's crust. The earth's crust contains about 900 ppm fluoride (WHO, 2007). It is found in all waters; however, its concentration varies in various parts of the world. Naturally occurring fluorides in surface water such as rivers, streams, and lakes usually range from 0.01 to 0.3 ppm. The levels of fluorides in underground water (0.02-1.5 ppm) are usually higher than those found in rivers, streams, and lakes. Surface and groundwater levels near industrial sites using fluorides may be higher than normal if fluorides are released (Leone, 1977). In groundwater, the natural concentration of fluoride vary significantly from region to region and depends on the geological, chemical and physical characteristics of the aquifer, availability and solubility of the parent fluoride minerals with which the water interacts, the porosity and acidity of the soil and rocks through which the

water passes, climate, the action of other chemical elements such as the concentration of calcium, magnesium and bicarbonate ions, water pH, temperature of interaction between rocks and water, depth to water table, topography, composition of the rocks, hydrogeology, dominant soil types and ground water flow systems. Fluoride is unevenly distributed in groundwater, both vertically and horizontally (Nouri *et. al.,* 2006).

The majority of the population in Pakistan is exposed to the hazards of drinking unsafe and polluted water. Water quality in Pakistan is generally poor and is chemically unfit for human consumption and is believed to have worsened dramatically because of pollution from industrial, municipal and agricultural sources.Geological settings have also affected the groundwater quality from place to place. The salt range between Kasur and Mianwali has been found to have groundwater with high fluoride content, ranging from 5 to 29 mg/L in water obtained from shallow wells and hand pumps (Aziz, 2001). Fluoride contamination in groundwater was also found in the districts of Risalpur, Chakwal, Jhelum, Mianwali, Khushab, Faisalabad, Bahawalpur, Loralai, Ziarat, Mastung, Mirpur Khas, Karachi, Raiwind, Sargodha, Kharan, Makran Coast, Mastung Valley, Umar Kot and Tharparkar (Khan, 1999). Marshall-Day & Tandan (1940) reported that high fluoride contents of drinking water could be due to the weathering of rocks enriched in fluoride. Those rocks run as a narrow belt across Punjab through Kasur, Sangla Hill, Sargodha, Shahpur and to the eastern part of Mianwali. Dental fluorosis is quite evident in Kasur, Pattoki and Raiwind. In Manga Mandi, near Lahore, limb deformities in more than 100 patients have been attributed to high fluoride groundwater (Aziz, 2002*).* In some northern areas of Pakistan high amount of fluoride is found in the runoff water that is consumed by the people living over there and has led to the discoloration of the teeth. Dental fluorosis has been observed in certain parts of the Pakistan due to high fluoride content in groundwater (Fawell *et al.,* 2006).

Fluorides may be released by anthropogenic sources like the production of phosphate fertilizers, by aluminum smelting, chemical manufacturing, in the production of steel, computer manufacturing, cement, glass, brick, tile works, ceramics, plastic factories, laundries, semiconductor industries, oil refineries, petroleum industries, floor polishes, fuels, refrigerants, rat poison, pesticides, timber preservation, uranium, in atomic bomb production, in the manufacture of bomb-grade uranium and plutonium for nuclear weapons, smoke, dust, and gases from coal burning industries and many other items. Fluoride wastes are unfortunately released to the air, water and soil, thus constantly increasing human exposure to this bio-accumulative substance (Fazlul Hoque *et al.,* 2003). The major sources of internal exposure of individuals to fluorides are the diet (food, water, beverages) and fluoride-containing dental products (toothpaste, fluoride supplements). Internal exposure to fluorides also can occur from inhalation (cigarette smoke, industrial emissions), dermal absorption (from chemicals or pharmaceuticals), ingestion or parenteral administration of fluoride-containing drugs, and ingestion of fluoride-containing soil (National Research Council, 2006). Information about water constituents is of great importance in water quality management, but only limited data are available for the distribution of fluoride in groundwater of Faisalabad City area.Keeping in view the importance of water and associated hazardous effects connected with either deficiency or enrichment of fluoride ions, the present study was designed to assess the suitability of ground water for drinking purpose owing to the scarcity of municipal water supply of Faisalabad city.

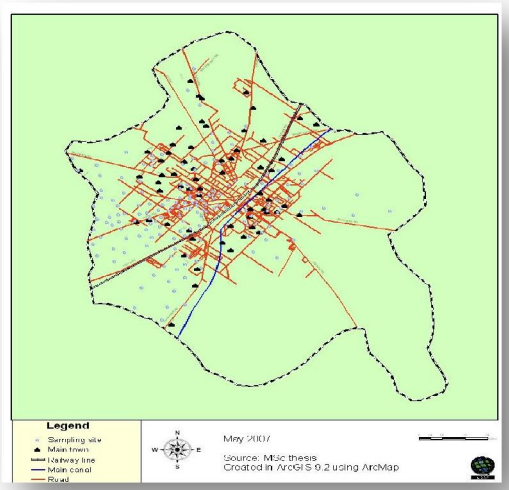
Material and Methods:

2.1 Study area:

Faisalabad is located in Punjab, Pakistan and is the third largest city in Pakistan with an estimated 2006 population of 2.6 million. It is an important industrial centre located in the Punjab province, west of Lahore. The city-district of Faisalabad is bound on the north by the districts of Gujranwala and Sheikhupura, on the east by Sahiwal district, on the south by Toba Tek Singh district and on the west by Jhang district. It lies between latitudes 30°35′ and 30°47'N and longitudes 74°73′ and 74°40″E in the province of Punjab, Pakistan. It comprises a geographical area of about 5856 km^2 exhibiting more or less a flat topography. The average elevation of land surface is 300 m AMSL. It is one of the many cities of Pakistan where industrial growth remains disorganized and is posing serious environmental problems of air and water pollution. Industry is not in a position to undertake pollution control measures due to limited financial resources, technical capacity and lack of space for combined treatment facilities in built-up areas. It lies between latitudes 30°35′ and 30°47'N and longitudes 74°73′ and 74°40″E in the province of Punjab, Pakistan. It comprises a geographical area of about 5856 km^2 exhibiting more or less a flat topography. The average elevation of land surface is 300 m AMSL. It is one of the many cities of Pakistan where industrial growth remains disorganized and is posing serious environmental problems of air and water pollution. Industry is not in a position to undertake pollution control measures due to limited financial resources, technical capacity and lack of space for combined treatment facilities in built-up areas.

2.2 Sample Collection:

A total of 161 groundwater samples was collected from different fifty two localities in Faisalabad city,three samples from each locality as mentioned on the map of the city according to the grid size.



Map1:Major localities of Faisalabad city and the groundwater sampling sites.

2.3 Groundwater Sample Collection:

Grab representative 161 groundwater samples were collected from Faisalabad city, while collecting water samples, special emphasis was given to the localities where ground water was the only source of drinking water. A random grid size site selection criterion was adopted. Groundwater depth was also noted at each sampling point.Water samples were collected in cleaned, polyethylene (PET) bottles by following the methodology described by Das *et al.* (2003). The samples were transported to the Water Laboratory of Soil Fertility Section, AARI, Faisalabad.

2.4 Analytical Methods:

Fluoride concentration was measured by ISE method (Fawell *et al.,* 2006) which makes it possible to measure the total amount of free and complex-bound fluoride dissolved in water. pH was determined by using pH Meter (pH meter–EDT/RE375Tx) and Electrical Conductivity (EC) was determined by using Electrical Conductivity Meter(EC meter–EDT/RE388Tx) (Greenberg *et al*., 1992).

2.5 Statistical analysis:

Different procedures of statistical analyses (SAS, 1995) were performed using Minitab (version 13.2) and MStat C package to analyze the data using one-way analysis of variance (ANOVA) test, Duncan's Multiple Range Test, Pearson Correlation and Simple & Multiple Regression Analysis.

Results and Discussion:

The plot of chemical analysis data in the form of concentration profiles revealed the lowest content of fluoride by the sample in the area of Canal Road (0.07 ppm) and the highest content (3.44 ppm) was shown by the sample from National Fertilizer Council, Jaranwala Road. Box-and-whisker plot (Figure, 2) provides graphical representation of sampling results for groundwater fluoride concentration measured in all the samples collected and differentiates central values, outliers, spread and symmetry among group of data. A pie distribution of samples of different F concentrations, EC variation, pH ranges and variation in groundwater depth in the study area is shown in Figures 5-8. The electrical conductivity revealed a wide range of values from 265 µS/cm to 6660 µS/cm with a minimum value (265 µS/cm) observed in the sample collected from Gulistan Colony and maximum value (6660 µS/cm) was noted in the sample from Waris Pura. The high EC value indicates the organic pollution level of groundwater.Marginal frequency distribution of fluoride contents and EC against its concentration range of groundwater samples are presented by marginal histogram plot (Figure, 1). The distributional characteristics of EC values are exhibited by boxplot (Figure, 2) which differentiates median values and extreme values observed for groundwater conductivity. We found that 73% samples transgressed the permissible limit of 1500 µS/cm as recommended by WHO for conductivity of ground water. While 23% samples were within the limit as is illustrated by the pie chart (Figure, 6) revealing different concentration ranges observed and their respective percentages.

The pH of groundwater samples ranged from 7.2 to 8.4. The pH was compared to WHO standards and were found within the permissible limit (6.5-8.5) set by WHO. A range of 6.5 - 8.5 was determined as that which would achieve the maximum environmental and aesthetic benefits. Figure 3 and 4 gives the graphical overview of the frequency distribution of the data collected in pH of groundwater and identifies the distribution of median values and outliers, respectively.

Groundwater levels in Faisalabad city from different localities studied ranged from 60-110 ft. Graphical overview of the groundwater level frequency distribution at 161 sampling sites is presented in Figure 3 in the form of marginal histogram plot. Box-and-whisker plot (Figure 4) differentiates the central values, outliers, spread and symmetry of groundwater level as observed in the study area. A pie distribution of groundwater samples of different depth ranges in

the study area is shown in Figure 8, showing that 36 out of 161 samples (22%) were <70 ft, 45 samples (28%), 77 samples (48%) were in the range of 70-80 ft and 80-90 ft, respectively. There it can be seen that groundwater depth in the study area exceeded upto 90 ft in only 2% samples.

Groundwater monitoring results were mapped using GIS, which proved useful for the identification and demarcation of risk areas in terms of human exposure to fluoride. The study areas did not show any significant variation of fluoride concentration in the water samples. Exceptionally high fluoride concentration is evident at NFC, Jaranwala Road from the Map 2. Map 3 shows the salinity variation in groundwater of Faisalabad city. The pH values in the study area were mostly found within the range of 7.2 – 8.4 indicating the alkaline nature of the groundwater and is well within the limits prescribed for various uses of water. Map 4 displays the current status of groundwater alkalinity variation in Faisalabad City. Map 5 shows the spatial variation in the current groundwater depth. The analysis variance showed that there was non- significant differences for fluoride concentration of groundwater among different localities of Faisalabad city (Table 5). The comparison of the means showed that fluoride contents in water samples from fifty two localities ranged from 0.12 ppm to 1.56 ppm with a mean of 0.47±0.13 mg/L. The fifty two localities exhibit different F concentrations with groundwater samples from the Canal Road area are having the lowest average F concentration and Jaranwala Road area having the highest average F concentrations (Figure 9). A highly significant difference in depth of groundwater sampled from different localities of Faisalabad city was evaluated by ANOVA test at 95% CI (Table 4). The comparison of the means showed that mean groundwater depth from the studied localities ranged from 60-110 feet with a mean depth of 80±0.50 ft (Table 5 and Figure 12). It is evident from the table that the maximum groundwater depth was recorded in the sample collected from the Abdullah Pur area and the minimum was noted in Pathanwala area. Examination of mean values by Duncan's multiple range test revealed that the differences remained significant for groundwater depth among all the groundwater samples analyzed (Table 5).

ANOVA indicated that there was a highly significant difference ($p<0.01$) for specific conductance of ground water at 95% CI among all the localities studied (Table 2). The comparison of the means showed that mean EC values of groundwater from the studied localities ranged from 613-5663 µS/cm with an average value of 2898 ±53 µS/cm (Table 5). The graphical representation of the mean salinity level for each locality is illustrated in Figure 10. The minimum groundwater EC value was observed in the area of Gulistan Colony and maximum was recorded at Satiana Road. Duncan's multiple range test revealed that the differences remained significant for groundwater salinity level among all the groundwater samples (Table 5). A highly significant difference ($p<0.01$) for pH of groundwater sampled from different localities of Faisalabad city was evaluated by ANOVA test at 95% CI (Table 3). The comparison of the means showed that mean groundwater pH from the studied localities ranged from 7.2 to 8.1 with an average value of 7.6 ± 0.06 (Table 5). Figure 11 shows the mean pH value for different localities. It is evident from the table 5 that the maximum groundwater pH was recorded in the sample collected at NIBGE and minimum was noted in Marzi Pura area. The comparison of the means by Duncan's multiple range test revealed that the differences remained significant for groundwater pH among all the groundwater samples analyzed from different localities (Table 5). The interrelationship or association among Fluoride concentration, Electrical Conductivity, pH and depth of groundwater was evaluated by Pearson correlation analysis as is presented in Table 6 and is also illustrated by the scatter plot (Figure 4 (a)).

The quality of groundwater is the resultant of all the processes and reactions that act on the water from the moment it condensed in the atmosphere at the time it is discharged by a well and varies from place to place with the depth of water table, composed of the aquifer and climatic conditions. A natural chemical composition of groundwater results from two main processes: the concentration by evaporation of the atmospheric salts coming from marine aerosols, dust and dissolved salts in rainwater; and the water interacts with ground minerals a substance. Natural water always contains dissolved and suspended substances of organic and mineral origin (Umar and Absar, 2003). Fluoride in water can be detrimental or beneficial. It all depends on the concentration. Fluorides are important because they have a definite relation to dental health. We recorded 1.5 mg/l of fluoride in drinking water reduces tooth decay. On the other hand, levels of fluoride greater than 1.5 mg/l may develop a condition known as endemic dental fluorosis.

The present study revealed that the levels of fluoride were below the recommended guideline value by WHO (0.5–1.5 mg/L) in most of the sampling areas. However, the fluoridation is recommended where the concentration is less than 0.5 mg/L. No other significant factor can be ascertained except for the natural occurrence of fluoride. In common with previous studies, the majority of groundwater samples

had fluoride concentration between 0.5-1.5 ppm, for all the sites, concentration remained below the WHO standards for F in drinking water. Our findings were in line with the results of Ayyaz *et al.,* (2002) and PCRWR (2004). We found no significant change in groundwater fluoride concentration in the region even after a period of nineteen years was observed.

An overall review of the concentration of salts in the groundwater samples of the area under study appears to indicate its sensitivity in relation to the industrial effluents flowing or percolating through the subsoil and can be taken as an indicator to describe the degree of pollution of groundwater in relation to the effluents of domestic waste and the industry. High conductivity of water analyzed revealed a high salinity degree. It is revealed from the results that all the water samples have pH value ranging between 7.2-8.4 indicating an alkaline condition. It provides a mean of clarifying and for collecting other characteristics or behavior such as corrosive activity (Ghandour *et al*., 1985). As eye irritation and exacerbation of skin disorders have been associated with a pH value greater than 11 (Anonymous, 1993). Since we must maintain our body pH at 7.4, highly basic or acidic water is not suitable for drinking. The pH of drinking water should be between 6.5-8.5 to minimize corrosion in pipes and fittings. All samples complied with the WHO guideline range of values and none was found above the WHO standards for drinking water.EC values in all the samples were found much higher than permissible limit, exceeding 6660 µS/cm which predicts the presence of excess of minerals and dissolved matter in water. Water with EC higher than 1500 µS/cm is harmful for human health (Tyagi and Mehra, 1990). EC of water is an important criterion for the assessment of the suitability of drinking water and was found too high that is alarming. It is evident from the results that high concentration of total dissolved solids in ground water is threatening and indicating the presence of undesirable amount of salts and minerals. Steam distillation, ion exchange (H^+ and OH^- saturated resin only) and reverse osmosis are common treatment methods for reducing TDS and conductivity levels.

The range of EC and pH of groundwater remained very similar to those found in previous studies by (PCRWR, 2004). Depth of water for the samples taken varied from 60 to 110 feet. A highly significant and positive correlation was observed for: fluoride vs. pH (p=0. 007), while significant negative correlation for: EC vs. pH (p=0.011). No significant correlations were observed for: fluoride vs. groundwater depth (p=0.674), EC vs. depth (p=0.933), fluoride vs. EC (p=0.083) and pH vs. depth (p=0.903), showing no significant trend (p >0.05). We observed significant positive correlation of fluoride with a pH of ground water was observed revealing that fluoride concentration increases with an increase in pH value and vice versa. The positive correlation of pH with F suggests that pH is important in determining F in groundwater, this result is in agreement with earlier observations of (Gupta *et al.,* 2006; PCRWR, 2002; Mirlean and Roisenberg, 2007). They also pointed out that fluoride concentration of groundwater increased with increase in pH and vice versa.

The studies conducted by Nouri *et al.,* (2006) and PCRWR (2004) revealed a significant negative correlation between groundwater fluoride content and pH which were against the present study.

PCRWR, (2003) study on groundwater in Faisalabad city under National Water Quality Monitoring Program revealed non-significant relationship between fluoride concentration and pH of ground water. In the present study no significant correlation was observed between fluoride concentration and EC of ground water. Similar findings were also reported by Meenakshi *et al.* (2004). The correlation analysis of data did not show any significant association of fluoride level with depth of groundwater in the present study. These findings are substantiated by the results of Gupta *et al.* (2005). The present study also contradicted the findings of Misra *et al.* 2006 and Farooqi *et al.* (2007). They pointed out a negative correlation between fluoride concentration and depth of groundwater. In their study high fluoride concentrations was found in shallow aquifers than those of deep aquifers. In the present study, a significant and negative correlation was found between EC and pH of groundwater revealing that the EC value of groundwater decreases with an increase in pH value and vice versa in the analyzed water samples. This result is in agreement with the findings of PCRWR (2004) while it was contradicted by the studies conducted by Gupta *et al.* (1994). Studies performed by them identified a significant and positive correlation revealing increased EC value with an increase pH of ground water.

The important finding of this study was occurrence of high fluoride concentration in groundwater sample collected in the area of fertilizer industry, Jaranwala Road. Where dumping of phosphate rocks in the past was done in the manufacture of phosphate fertilizers. There were two fertilizer plants in 1988 in Faisalabad District, one of these, in Faisalabad City, was closed down in 1997. The only running plant is located in Jaranwala, some 30 kilometers away from the City. We are of the view that the present high concentration of groundwater fluoride content at NFC Jaranwala, was the result of previous installed fertilizer plant, which was shifted at Jaranwala, about ten years before. The effects of rock

dumping on groundwater in that region are still found, even after the cessation of production of phosphate fertilizers. As no study was conducted in the past in that region of Faisalabad city to check its fluoride status, it could be much higher than the present finding some years before. Wastewater from phosphate fertilizer plants may contain up to 2% of fluoride (Rozycka & Grobelny, 1998).Samples taken from different locations showed only small differences in fluoride concentration. The only exception was the high 3.44 mg/L fluoride concentration detected in water taken from the National Fertilizer Council, Jaranwala Road Faisalabad, indicating an anthropogenic source of contamination.

CONCLUSION:

Current status of groundwater quality in Faisalabad was explored in terms of fluoride level, amount of salinity and acidity. The data indicated that the groundwater of Faisalabad city is highly deteriorated as it is polluted with high amount of salts. The study reported deficient levels of fluoride concentration of ground water. It is concluded from the present investigation on groundwater quality in Faisalabad city that groundwater in major parts of the area is saline, alkaline and fluoride deficient. To maintain quality of groundwater, the continuous monitoring of physicochemical parameters should be done and can be used for cooking and drinking after prior treatment.

Acknowledgements

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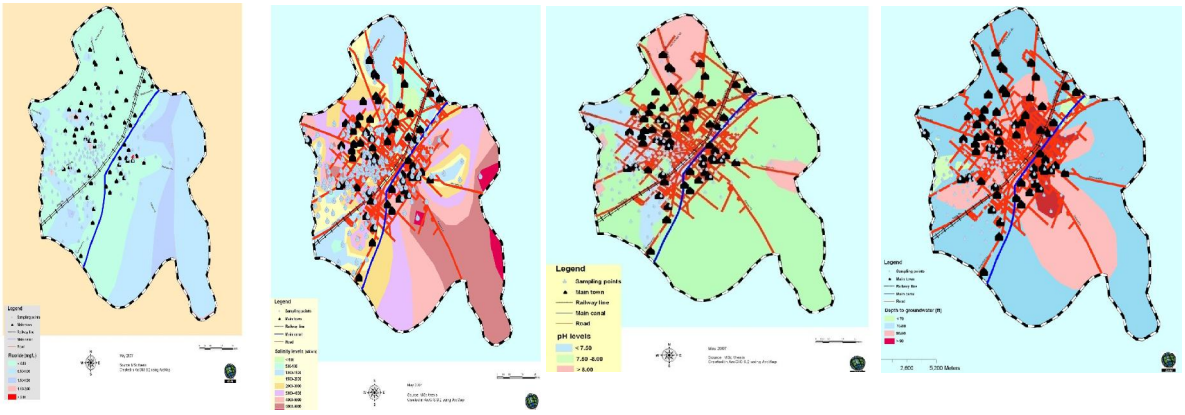
MAP2 MAP3 MAP4 MAP5



Map 2: Spatial distribution of fluoride concentration in groundwater of Faisalabad city, Map 3: Status of salinity level in groundwater of Faisalabad city, Map 4: Status of groundwater quality in Faisalabad city in terms of pH, Map 5: Variation in groundwater depth of Faisalabad city

Table 1: Analysis of variance for fluoride concentration in Groundwater from different localities

S.O.V.	D.F.	S.S.	M.S.	F. Value
Location	51	8.597	0.169	1.31^{NS}
Error	109	14.009	0.129	
Total	160	22.606		

Table 2: Analysis of variance for electrical conductivity of Groundwater from different localities

S.O.V.	D.F.	S.S	M.S.	F. Value
Location	51	315922332	6194556	4.36**
Error	109	154739687	1419630	
Total	160	470662018		

Table 3: Analysis of variance for pH of in Groundwater from different localities

S.O.V.	D.F.	S.S	M.S.	F. Value
Location	51	7.0460	0.1382	6.42**
Error	109	2.3453	0.0215	
Total	160	9.3913		

Table 4: Analysis of variance for Groundwater from different localities

S.O.V.	D.F.	S.S.	M.S.	F. Value
Location	51	12161.80	238.47	126.59**
Error	109	205.33	1.88	
Total	160	12367.13		

**= Highly Significant (P<0.01); NS=Non-Significant (P>0.05)

Table 5: Comparison of Means (± S E) & Range of concentration for Fluoride level (ppm), Electrical Conductivity (µS/cm), pH and Depth (ft) of Groundwater at different sampling locations in the study area

Sr.#	Sampling Location	No.[a]	Depth of Ground water (ft)	Fluoride Concentr-ations (ppm)	Fluoride Contents (ppm)	Electrical Conductivity (µS/cm)		Hydrogen Ion Concentration	
			Mean ± SE	Mean ± SE	Range of Fluoride	Mean ± SE	Range of EC	Mean ± SE	Range of pH
1	Pathanwala	3	60±0.33 H	0.48±0.07	0.34-0.59	1715±84.30 H – M	1550-1825	7.9±0.06 A – G	7.8-8.0
2	Rashid Abad	3	70±0.58 F	0.65±0.27	0.15-1.08	1332±280.60 J – M	801-1754	8.0±0.06 ABC	8.0-8.2
3	Saif Abad	3	70±0.47 F	0.78±0.37	0.29-1.53	3620±773.67 A - J	2080-4520	7.7±0.06 E – K	7.6-7.8
4	Shadab Colony	3	70±0.47 F	0.29±0.08	0.17-0.46	4997±567.55 A – D	3870-5680	7.5±0.12 J – P	7.3-7.7
5	Ali Housing Colony	3	70±0.33 F	0.35±0.08	0.18-0.44	4900±1107.96 A – D	2690-6140	7.5±0.06 J – P	7.4-7.6
6	Gulifshan Colony	3	70±0.33 F	0.31±0.04	0.22-0.39	4311±1343.53 A – G	1634-5850	7.4±0.03 K – P	7.4-7.5
7	Sheikh Colony	3	70±0.47 F	0.24±0.08	0.15-0.42	3483±648.38 A – K	2580-4740	7.4±0.12 L – P	7.2-7.6
8	Liaquat Abad	3	80±0.47 D	0.50±0.08	0.34-0.59	5000±975.75 A – D	3080-6260	7.4±0.10 L – P	7.2-7.5
9	Liaquat Town	3	85±0.33 C	0.35±0.04	0.26-0.41	2750±271.94 D – M	2210-3080	7.4±0.03 K – P	7.4-7.5
10	Afghan Abad	3	75±0.66 E	0.40±0.08	0.32-0.56	4093±1007.50 A – H	2620-6020	7.7±0.06 E – K	7.6-7.8
11	Guru Nanak Pura	3	85±0.66 C	0.32±0.06	0.22-0.43	2805±1340.64 C – M	1302-5480	7.6±0.26 F – L	7.4-8.2
12	Gulberg	3	85±0.47 C	0.28±0.08	0.13-0.37	1531±551.38 J – M	736-2590	7.4±0.10 L – P	7.3-7.6
13	Jinnah Colony	3	85±0.33 C	0.70±0.54	0.10-1.79	2684±768.47 D – M	1632-4180	7.5±0.20 J – P	7.3-7.9
14	GC University	3	85±0.33 C	0.38±0.08	0.22-0.50	2037±207.27 F – M	1640-2340	7.5±0.03 I – O	7.5-7.6
15	UAF	3	80±0.33 D	0.52±0.10	0.36-0.73	1621±98.15 I – M	1507-1816	7.6±0.03 F – L	7.6-7.7
16	Raza Abad	3	80±0.47 D	0.28±0.04	0.21-0.34	4230±877.02 A – G	2510-5390	7.4±0.06 M – P	7.3-7.5
17	G.M. Abad	6	75±0.66 E	0.76±0.24	0.37-1.95	3098±433.64 B – L	2010-4800	7.6±0.10 H – N	7.3-8.0
18	Marzi Pura	3	75±0.47 E	0.66±0.14	0.38-0.82	4280±121.24 A – G	4130-4520	7.2±0.03 P	7.2-7.3
19	NIBGE	3	75±0.47 E	0.31±0.06	0.18-0.41	2058±260.96 F – M	1792-2580	8.1±0.15 AB	7.9-8.4
20	NIAB	3	80±0.58 D	0.52±0.15	0.32-0.82	1683±113.74 I – M	1456-1797	7.8±0.06 C – I	7.7-7.9
21	AARI	3	85±0.58 C	0.50±0.16	0.34-0.82	1594±347.00 I – M	971-2170	7.6±0.08 H – N	7.4-7.7
22	Ayub Colony	3	85±0.47 C	0.46±0.20	0.22-0.87	3063±1018.48 B – L	2000-5100	7.7±0.06 E – K	7.6-7.8
23	Pertap Nagar	3	85±0.58 C	0.45±0.06	0.38-0.59	3977±515.01 A – I	3220-4960	7.6±0.03 H – N	7.5-7.6
24	Nazim Abad	3	85±0.47 C	0.26±0.01	0.25-0.29	3350±735.56 A – L	2260-4750	7.5±0.06 J – P	7.4-7.6
25	Khalid Abad	3	85±0.47 C	0.33±0.16	0.12-0.65	4440±536.95 A – F	3760-5500	7.6±0.06 H – N	7.5-7.7
26	Herchern Pura	3	85±0.47 C	0.32±0.10	0.13-0.46	2261±1352.77 E – M	745-4960	7.6±0.00 H – M	7.6

27	Sanat Pura	3	85±0.58 C	0.63±0.06	0.56-0.74	2028±535.79 G – M	974-2720	7.6±0.03 H – N	7.5-7.6
28	Diglos Pura	3	85±0.58 C	0.36±0.10	0.16-0.50	1111±214.78 K L M	721-1462	7.2±0.03 OP	7.2-7.3
29	Clock Tower	5	85±0.58 C	0.36±0.06	0.17-0.59	1403±53.22 J – M	1211-1534	7.4±0.08 M – P	7.2-7.6
30	Jhang Road	3	85±0.66 C	0.26±0.06	0.19-0.39	1059±398.38 KLM	534-1840	7.5±0.08 I – O	7.4-7.7
31	Jinnah Garden	3	85±0.33 C	0.39±0.12	0.17-0.57	1172±38.10 KLM	1103-1234	7.8±0.08 D – J	7.6-7.9
32	DHQ	3	85±0.47 C	0.40±0.08	0.31-0.56	1511±98.15 J – M	1370-1700	7.8±0.03 B – H	7.8-7.9
33	Allied Hosp. & Pinum	3	80±0.47 D	0.28±0.10	0.17-0.50	2314±1104.50 E – M	1119-4520	8.0±0.03 A – E	7.9-8.0
34	Sargodha Road	3	70±0.66 F	0.39±0.09	0.28-0.57	1389±28.29 J – M	1334-1428	8.1±0.03 A	8.1-8.2
35	Gulistan Colony	3	90±0.47 B	0.36±0.05	0.28-0.46	613±202.08 M	265-965	7.9±0.03 A – F	7.9-8.0
36	Abdullah Pur	3	110±0.58 A	0.40±0.08	0.27-0.56	1536±189.95 J – M	1162-1783	7.9±0.06 A – G	7.8-8.0
37	Canal Road	3	65±0.33 G	0.12±0.04	0.07-0.20	1723±196.88 H – M	1346-2010	7.6±0.06 G – M	7.5-7.7
38	Madina Town	3	90±0.47 B	0.64±0.07	0.56-0.80	4580±888.56 A – E	2980-6050	7.6±0.08 G – M	7.5-7.8
39	Officers Colony	3	90±0.47 B	1.04±0.12	0.80-1.21	5170±504.04 ABC	4560-6170	7.6±0.03 G – M	7.6-7.7
40	Satiana Road	3	90±0.66 B	0.44±0.06	0.38-0.56	5663±553.11 A	4560-6280	7.7+0.06 E – K	7.6-7.8
41	Batala Colony	3	90±0.58 B	0.37±0.10	0.18-0.53	3322±520.78 A – L	2370-4165	7.5±0.03 I – O	7.5-7.6
42	Peoples Colony	3	90±0.58 B	0.50±0.04	0.43-0.58	4620±226.90 A – E	4190-4960	7.7±0.00 E – K	7.7
43	D Ground	3	90±0.66 B	0.54±0.10	0.40-0.75	2871±546.76 B – M	1804-3610	7.6±0.06 H – M	7.5-7.7
44	Waris Pura	3	90±0.66 B	0.34±0.04	0.28-0.43	5223±765.01 AB	4050-6660	7.6±0.06 H – M	7.5-7.7
45	Jaranwala Road	3	75±0.47 E	1.56±0.94	0.57-3.44	3318±1631.64 A – L	1556-6578	8.0±0.03 A – D	8-8.1
46	Dhuddiwala	3	75±0.58 E	0.76±0.34	0.38-1.43	1117±22.51 KLM	1073-1148	7.7±0.08 E – K	7.6-7.9
47	Samundari Road	3	75±0.47 E	0.22±0.06	0.13-0.34	1924±290.42 G – M	1479-2470	7.6±0.08 G – M	7.5-7.8
48	Amin Abad	3	75±0.58 E	0.42±0.04	0.35-0.51	5560±284.64 A	5190-6120	7.4±0.03 K – P	7.4-7.5
49	Mehmood Abad	3	70±0.47 F	0.62±0.05	0.55-0.72	1014±139.14 LM	851-1291	7.6±0.08 H – N	7.4-7.7
50	Nisar Colony	3	70±0.47 F	0.66±0.02	0.62-0.72	4167±1106.24 A – G	2720-6340	7.4±0.06 L – P	7.3-7.5
51	Jawala Nagar	3	70±0.47 F	0.65±0.38	0.26-1.41	3104±1381.64 B – L	1303-5820	7.4±0.03 K – P	7.4-7.5
52	Nawabanwala	3	70±0.58 F	0.36±0.08	0.21-0.47	2273±523.67 E – M	1309-3110	7.3±0.06 NOP	7.2-7.4
	Grand Total	161	80±0.50	0.47±0.13	0.07-3.44	2898.04±553.55	265-6660	7.6±0.06	7.2-8.4

a=Number of groundwater samples taken from different locations; SE=Standard Error

Within a row or column different letters differ significantly ($p<0.01$) and the values bearing the same letters have non-significant differences.

Table 6: Relationship among Fluoride, EC, pH & Depth of Groundwater for each sampling site

Pearson correlation among Fluoride (ppm) , EC (µS/cm),pH & Groundwater Depth(ft)				
	Fluoride	**EC**	**pH**	**GW Depth**
Fluoride	1.00			
EC	0.137^{NS}	1.00		
Ph	0.211**	-0.199*	1.00	
GW Depth	-0.033^{NS}	-0.007^{NS}	0.010^{NS}	1.00

*=Significant ($P<0.05$); **=Highly Significant ($P<0.01$); NS=Non-Significant ($P>0.05$)

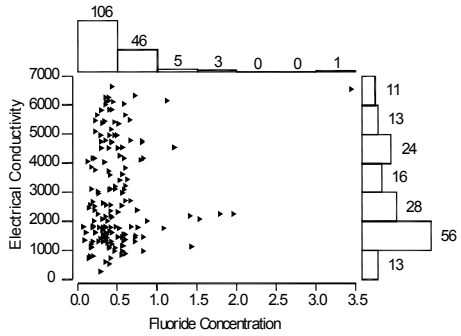


Figure 1: Distribution of fluoride content and amount of salinity distribution determined at sampling locations

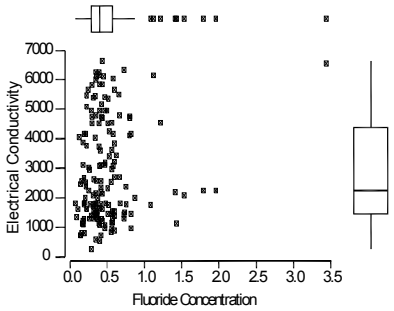


Figure 2: Marginal distribution of groundwater fluoride concentration and salinity level at each location

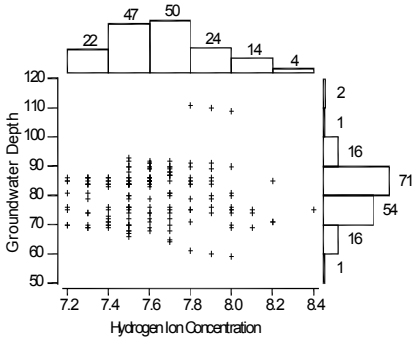


Figure 3: Distribution of pH and depth of groundwater measured at different sampling points in the study area

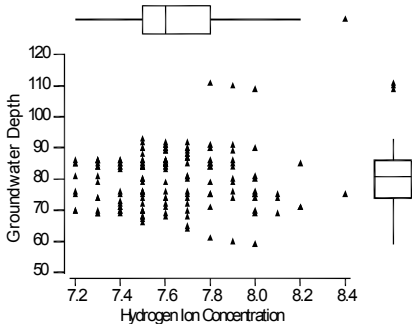


Figure 4: Marginal distribution of pH and depth of groundwater measured from different sampling localities of Faisalabad city

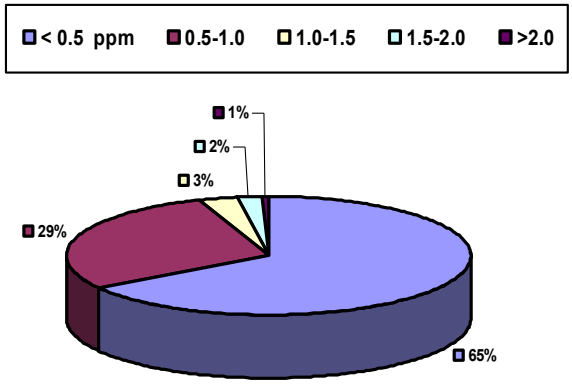


Figure 5: Percentage of groundwater samples in Faisalabad City with different Fluoride concentration ranges (ppm).

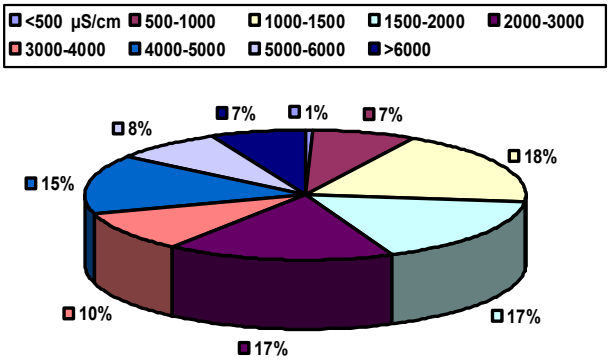


Figure 6: Percentage of groundwater samples in Faisalabad City with different Salinity Level ranges(µS/cm).

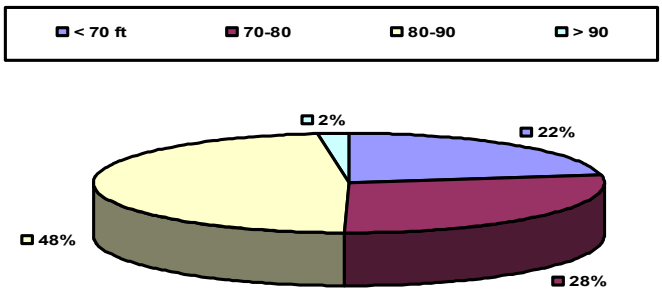


Figure 8: Percentage of groundwater samples in Faisalabad City with different groundwater depth ranges (ft).

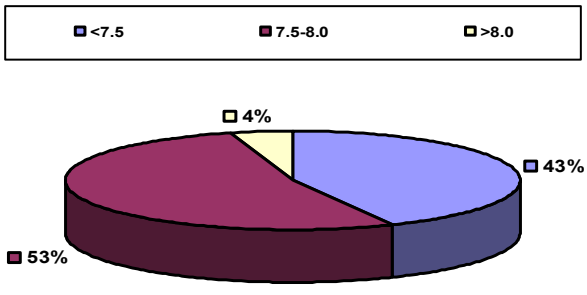


Figure 7: Percentage of groundwater samples in Faisalabad City with different pH value ranges.

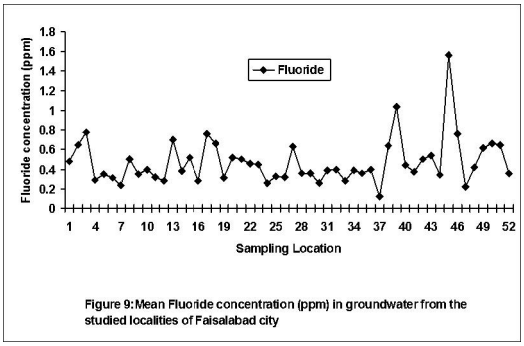


Figure 9: Mean Fluoride concentration (ppm) in groundwater from the studied localities of Faisalabad city

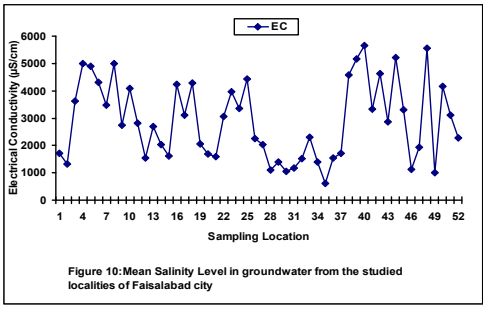


Figure 10: Mean Salinity Level in groundwater from the studied localities of Faisalabad city

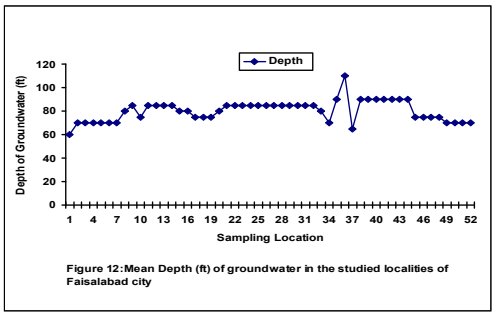


Figure 12: Mean Depth (ft) of groundwater in the studied localities of Faisalabad city

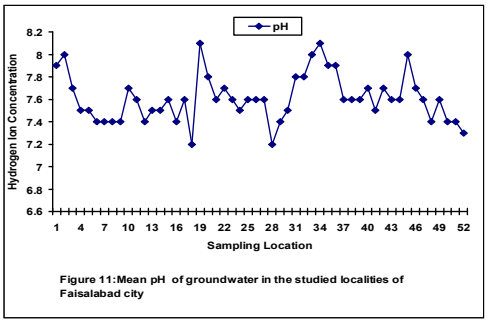


Figure 11: Mean pH of groundwater in the studied localities of Faisalabad city

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