# ASSESSMENT OF GROUNDWATER QUALITY INDEX AND PROPOSING A MODEL USING FUZZY LOGIC OF SELECTED AREAS OF LUCKNOW CITY

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**ABSTRACT**

In the last few decades, the over population and industrial revolution have changed the global groundwater scenario. The majority of groundwater quality problems present today are caused by contamination and over exploitation, or by combination of both. Rapid urbanization and industrialization in India has resulted in steep increase of generation of wastes. Due to lack of infrastructure and resources the waste is not properly collected, treated and disposed; leading to accumulation and infiltration causing groundwater contamination. The problem is more severe in and around large cities including various clusters of industries. In many of these areas, groundwater is the only source of drinking water, thus a large population is exposed to risk of consuming contaminated water.

The present study deals with the calculation of groundwater quality index using weighted arithmetic water quality index method (WAWQI) of selected areas of Lucknow city and proposing a model with the help of fuzzy logic toolbox of MATLAB. For this, groundwater samples are collected from different areas of Lucknow city like Aliganj, Gomti Nagar and Amausi and tested for various physico-chemical parameters like pH, total dissolved solid (TDS), total alkalinity (TA), total hardness (TH), chloride (Cl), sulphate ($SO_4$), iron (Fe), nitrate ($NO_3$) and fluoride (F). The WQI is calculated and matched with WQI status along with the statistical analysis of physico-chemical parameters. Secondly, a fuzzy logic model is prepared through which we can determine the water quality of any area considering the above mentioned parameters and classify it into excellent, good, poor, very poor and unfit for drinking (UFD) categories.

**KEYWORDS:** Groundwater, groundwater quality index, fuzzy logic, Lucknow, MATLAB.

## I. INTRODUCTION

Groundwater is the water contained beneath the surface in rocks and soil, and is the water that accumulates underground in aquifers. Groundwater constitutes 97 per cent of global freshwater and is an important source of drinking-water in many regions of the world (W.H.O, 2006). It has been revealed from the past investigations that several man-made activities are responsible for deteriorating the quality of groundwater (Umar R. et al.,2006; Singh UK et al.,2008; Raju NJ et al.,2011; Oinam JD et al.,2012; Rajmohan N et al.,2016; Raju NJ et al.,2007; Jain CK et al.,2010). In India, groundwater is one of the most important water resource and accounts for 63 per cent of all irrigation and over 80 per cent of the rural and urban domestic water supplies. In fact, the United Nations Educational, Scientific and cultural organization (UNESCO) world water development report states that India is the largest extractor of groundwater in the world (WWDR, 2017). Fifty-four percent of India's groundwater wells have declined over the past seven years, and 21 major cities are expected to run out of groundwater by 2020. Therefore, India faces a dual challenge, first to regulate the growing demand of groundwater and to replenish its resources at the same time.

Groundwater quality index gives a clear understanding of various water quality issues by compiling data available in the form of physico-chemical parameters and generating a score that describes water quality (Reza R. et al. 2010). Also, a fuzzy logic groundwater model helps in determining the water quality of the area selected.

## II. STUDY AREA

The city Lucknow which is the capital of Uttar Pradesh spreads over an area of 2528sq. km on both side of river Gomti. It is a part of Central Ganga Plain in the state of Uttar Pradesh and lies between North latitudes 26°30' and 27°10' and East longitudes 80°30'and 81°13'. The single source of water and lack of sustainability plan have put Lucknow under groundwater stress (G.W.D. UP report, 2015). For the present study, the areas selected are Aliganj, Gomti Nagar and Amausi which are considered as the residential, commercial and industrial area of the city.

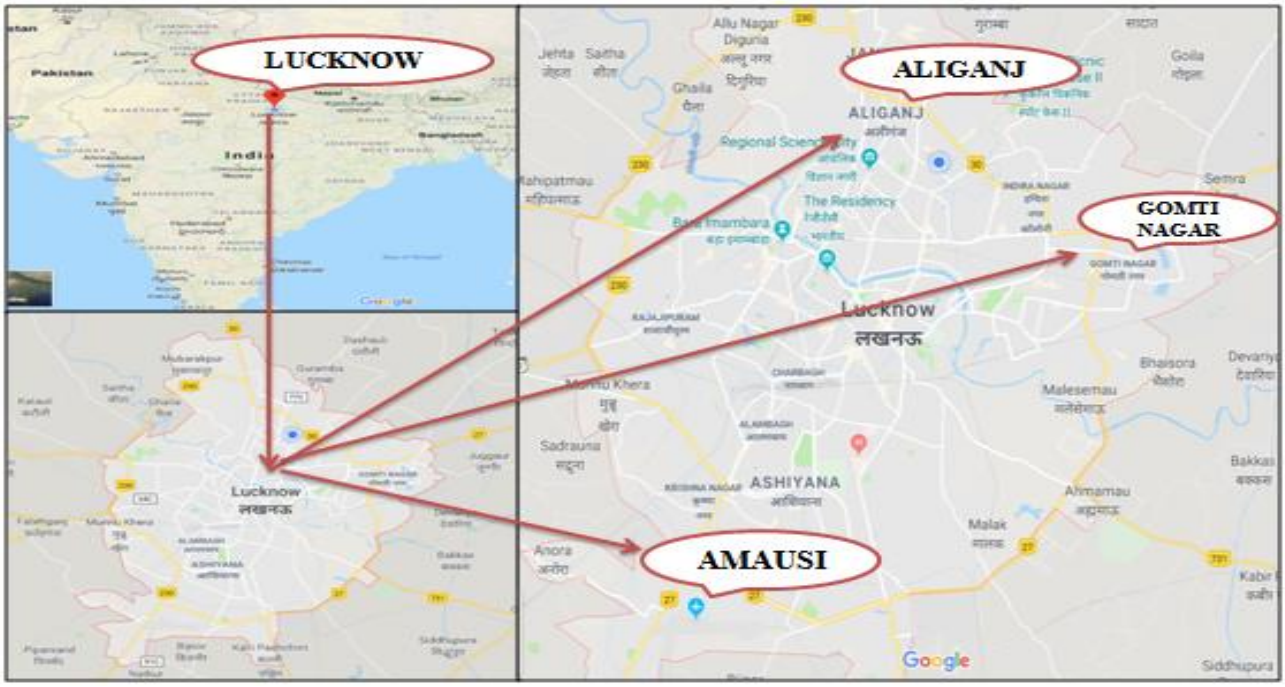


**Figure 1: Locations of groundwater sample collection in Lucknow city.**

## III. MATERIAL AND METHODS:

The city Lucknow which has been divided into 4 tehsils, 8 community development blocks and having a general elevation between 103 and 130 metres above the mean sea level showing south easterly slope (Groundwater Lucknow UP report, 2008). For the present study, groundwater samples are collected from different locations like Aliganj, Gomti Nagar and Amausi as mentioned earlier. A particular area like Aliganj which is now a semi-commercial area is divided into 3 sub areas like sector B, purania and sector N. In all 9 samples are collected from these sub-areas comprising of three samples from different locations of one sub-area. Similar is the case with Gomti nagar and Amausi area. The groundwater samples were collected from private, government hand pumps and bore wells. In all 27 samples are collected from different regions for physico- chemical testing. For sample collection a standardized polyethylene bottle with 1 litre capacity is used. It was ensured that all the sampling bottles were thoroughly washed with dil. $HNO_3$, and rinsed with distilled water before taking the sample. The samples were then sent to laboratory for testing.

**Table 1: Water quality parameters with their abbreviations, units and analytical methods used as per IS 3025**

| S.No. | Parameter | Abbreviation | Unit | Analytical method |
|---|---|---|---|---|
| 1 | pH | pH | - | pH meter |
| 2 | Total Dissolved Solid | TDS | $mgl^{-1}$ | Gravimetric method |
| 3 | Alkalinity | TA | $mgl^{-1}$ | Titration |
| 4 | Total Hardness | TH | $mgl^{-1}$ | EDTA method |
| 5 | Chloride | Cl | $mgl^{-1}$ | Titration |
| 6 | Sulphate | $SO_4$ | $mgl^{-1}$ | Turbidity method |
| 7 | Iron | Fe | $mgl^{-1}$ | Phenanthroline method |
| 8 | Nitrate | $NO_3$ | $mgl^{-1}$ | Phenoldisulfonic acid (PDA) method |
| 9 | Fluoride | F | $mgl^{-1}$ | Zirconium alizarin method |

**Table 2: Test results of physico-chemical parameter.**

| S.No. | Location | Depth(m) | pH | TDS | TA | TH | Cl | $SO_4$ | Fe | $NO_3$ | F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sector $B_1$ | 60.90 | 7.91 | 329 | 282 | 194 | 56.8 | 38 | 0.12 | 12 | 0.3 |
| 2 | Sector $B_2$ | 54.87 | 7.90 | 456 | 194 | 182 | 62.3 | 29 | 0.32 | 2 | 0.9 |
| 3 | Sector $B_3$ | 53.00 | 8.10 | 334 | 182 | 189 | 21.6 | 24 | 0.22 | 3 | 0.5 |
| 4 | $Purania_1$ | 61.24 | 8.07 | 452 | 193 | 192 | 57.2 | 28 | 0.28 | 3 | 0.7 |
| 5 | $Purania_2$ | 53.28 | 7.59 | 503 | 202 | 182 | 28.1 | 24 | 0.16 | 19 | 0.8 |
| 6 | $Purania_3$ | 52.91 | 7.67 | 362 | 129 | 145 | 142 | 10 | 0.11 | 3 | 0.6 |
| 7 | Sector $N_1$ | 58.42 | 7.92 | 282 | 152 | 92 | 57.2 | 14 | 0.35 | 10 | 0.7 |
| 8 | Sector $N_2$ | 57.12 | 7.15 | 291 | 148 | 102 | 71.9 | 10 | 0.19 | 10 | 0.3 |
| 9 | Sector $N_3$ | 58.31 | 7.12 | 344 | 52 | 188 | 99.1 | 65 | 0.21 | 12 | 0.4 |
| 10 | Viraj $Khand_1$ | 58.12 | 7.80 | 428 | 250 | 189 | 26.9 | 43 | 0.13 | 13 | 0.7 |
| 11 | Viraj $Khand_2$ | 59.30 | 7.91 | 256 | 201 | 216 | 24.1 | 24 | 0.25 | 23 | 1.1 |
| 12 | Viraj $Khand_3$ | 61.14 | 7.87 | 289 | 199 | 217 | 28.2 | 28 | 0.17 | 2 | 0.7 |
| 13 | Vineet $Khand_1$ | 62.92 | 7.90 | 542 | 216 | 162 | 64.2 | 67 | 0.19 | 2 | 0.7 |
| 14 | Vineet $Khand_2$ | 54.86 | 7.98 | 482 | 179 | 156 | 142.1 | 48 | 0.11 | 4 | 0.3 |
| 15 | Vineet $Khand_3$ | 59.00 | 7.96 | 306 | 120 | 148 | 35.2 | 38 | 0.20 | 12 | 0.6 |
| 16 | Vipul $Khand_1$ | 65.10 | 7.92 | 291 | 156 | 132 | 14.2 | 10 | 0.32 | 3 | 0.9 |
| 17 | Vipul $Khand_2$ | 62.32 | 8.23 | 265 | 128 | 125 | 21.1 | 19 | 0.21 | 3 | 0.8 |
| 18 | Vipul $Khand_3$ | 60.14 | 8.00 | 512 | 209 | 160 | 35.2 | 14 | 0.26 | 19 | 0.5 |
| 19 | $Chillawan_1$ | 65.29 | 7.80 | 452 | 372 | 220 | 70.3 | 108 | 0.32 | 32 | 1.1 |
| 20 | $Chillawan_2$ | 63.21 | 8.01 | 512 | 289 | 215 | 85.1 | 97 | 0.29 | 46 | 0.2 |
| 21 | $Chillawan_3$ | 62.10 | 7.90 | 562 | 275 | 232 | 57.8 | 82 | 0.28 | 28 | 0.3 |
| 22 | Gindan $Khera_1$ | 65.24 | 8.10 | 482 | 216 | 282 | 193.2 | 48 | 0.16 | 25 | 0.6 |
| 23 | Gindan $Khera_2$ | 63.49 | 8.22 | 479 | 233 | 191 | 121.1 | 67 | 0.28 | 56 | 0.8 |
| 24 | Gindan $Khera_3$ | 59.22 | 8.34 | 506 | 245 | 182 | 142.6 | 49 | 0.28 | 50 | 1.2 |
| 25 | Sarojini $Nagar_1$ | 60.10 | 7.85 | 528 | 209 | 172 | 129.3 | 38 | 0.31 | 21 | 1.2 |
| 26 | Sarojini $Nagar_2$ | 55.45 | 8.00 | 512 | 210 | 163 | 181.2 | 65 | 0.35 | 62 | 1.1 |
| 27 | Sarojini $Nagar_3$ | 59.21 | 7.96 | 506 | 207 | 145 | 171.2 | 56 | 0.29 | 65 | 0.9 |

## IV. WATER QUALITY INDEX:

Water quality index was first formulated by Horton (1965) and later on used by several workers for the quality assessment of different water resources (Alam M. et al. 2010). It is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It is used for the assessment and management of surface and groundwater sources (Yisa J. et al. 2010). Water quality index (WQI) is defined as the rating reflecting the composite influence of different water quality parameters that were taken into consideration for the calculation of water Quality index (WQI). WQI indices are broadly classified into two types; they are physico-chemical and biological indices. The physico-chemical indices are based on the values of various physico-chemical parameters in a water sample, while biological indices are derived from the biological information. The objective of an index is to turn multifaceted water quality data into simple information that is comprehensible and useable by the public.

The water quality index for the present study is calculated by weighted arithmetic water quality index method (WAWQI). The expression (1) used for this is as follows:

$$\mathbf{WQI} = \frac{\sum q_n W_n}{\sum W_n} \qquad (1)$$

Where,

$q_n$ = Quality rating of $n^{th}$ water quality parameter.

$W_n$ = Unit weight of $n^{th}$ water quality parameter.

In the above expression, the quality rating ($q_n$) is calculated by using the following equation (2):

$$q_n = \left[\frac{V_n - V_{id}}{S_n - V_{id}}\right] \times 100 \quad (2)$$

Where,

$V_n$ = Estimated value of $n^{th}$ water quality parameter at a given sample location.
$V_{id}$ = Ideal value for $n^{th}$ parameter in pure water.
($V_{id}$ for pH = 7 and 0 for all other parameters)
$S_n$ = Standard permissible value of $n^{th}$ water quality parameter.

For equation (1), the unit weight ($W_n$) is calculated by the following expression (3):

$$W_n = \frac{K}{S_n} \quad (3)$$

Where,

$S_n$ = Standard permissible value of the $n^{th}$ water quality parameter.
K = Constant of proportionality and it is calculated by using the expression.
$K = [1 / (1 / \sum S_{n=1,2.....n})]$

The table below shows the standard values of the physico-chemicals taken into account for this study, their recommending agencies, unit weights and ideal values.

**Table 3: Standard values and their recommending agencies along with unit weights and ideal values**

| S. NO. | Parameters | Standard Values ($S_n$) | Recommending Agency for $S_n$ | Unit Weight ($W_n$) | Ideal Value |
|---|---|---|---|---|---|
| 1 | pH | 8.5 | IS | 0.026117 | 7 |
| 2 | Total dissolved solid (TDS) | 500 | IS | 0.000444 | 0 |
| 3 | Total alkalinity | 120 | ICMR | 0.00185 | 0 |
| 4 | Total hardness | 300 | ICMR | 0.00074 | 0 |
| 5 | Chloride | 250 | IS | 0.000888 | 0 |
| 6 | Sulphate | 200 | IS | 0.00111 | 0 |
| 7 | Iron | 0.3 | IS | 0.74 | 0 |
| 8 | Nitrate | 45 | IS | 0.004933 | 0 |
| 9 | Fluoride | 1 | IS | 0.222 | 0 |
| | | | | $\sum W_n = 0.998082$ | |

After calculating the water quality index (WQI), the WQI is matched with the WQI status shown in table 4 below. The WQI status have been classified into excellent, good, poor, very poor and unfit for drinking (UFD) category along with their possible usages:

**Table 4: WQI status along with their possible usages.**

| S.NO. | WQI | Status | Possible Usages |
|---|---|---|---|
| 1 | 0-25 | Excellent | Drinking, Irrigation and Industrial |
| 2 | 26-50 | Good | Domestic, Irrigation and Industrial |
| 3 | 51-75 | Poor | Irrigation |
| 4 | 76-100 | Very Poor | Restricted use for Irrigation |
| 5 | Above 100 | Unfit for Drinking | Proper treatment required before use |

## V. FUZZY LOGIC TOOL BOX

The fuzzy system was programmed using the software MATLAB (Fuzzy Logic Toolbox).The classical notion of membership functions (Zadeh., 1965) was used to evaluate the input and output parameters as fuzzy variables. The membership functions are in the form of triangular shape and trapezoidal functions. The triangular shape is a function of a vector, x, and depends on three scalar parameters a, b, and c and the trapezoidal function is a function of vector y, which depends on four scalar parameters a, b, c, and d. This toolbox relies heavily on graphical user interface (GUI) tools to provide help to build the automated mode.

## VI. FUZZY SETS

In fuzzy logic, fuzzy sets are the sets whose elements have degrees of membership. A fuzzy set is broadly defined as a set without clearly defined boundaries. It contains elements with only partial degree of membership. The following are fuzzy sets implemented on this project to design the computational tool:

- pH
- TDS
- TA
- TH
- Cl
- $SO_4$
- Fe
- $NO_3$
- F
- Water quality

## VII. IF-THEN RULE EDITOR

The fuzzy logic system has a rule editor window that allows user to add set of rules that defines the behaviour of the system. It allows user to input user defined rules which govern the overall fuzzy logic system. The fuzziness of the task intended has to be put by the user by selecting the parameters of the membership function and using ‘or’ and ‘and’ connections. The rule editor allows user to input infinite number of rules that helps the user to assess the future conditions of the water quality. For the present study, approximate two hundred rules were added for checking the fuzziness of the system.

## VIII. RESULT AND DISCUSSION

The water quality index (WQI) of the selected area calculated by weighted arithmetic water quality index method is shown in the following tables. The bar graph of water quality index (WQI) on Y-axis and selected locations on Y-axis were also drawn as shown in figure no. 2.

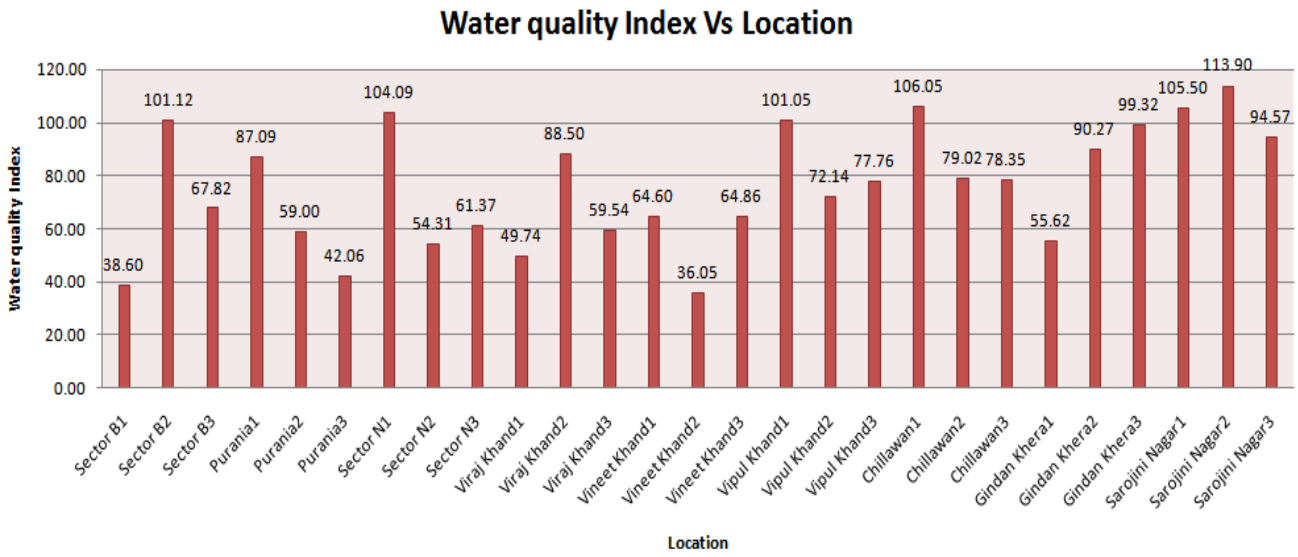


**Figure 2: WQI Vs Location graph**

The locations having good, poor, very poor, and unfit for drinking (UFD) WQI status are as follows:

**Table 5: Locations having Good WQI status**

| S.No. | Area | Location | Coordinates | | WQI | WQI status (26-50) |
|---|---|---|---|---|---|---|
| | | | N | E | | |
| 1 | Aliganj | Sector $B_1$ | 26°54'28.3" | 80°56'49.4" | 38.60 | Good |
| 2 | Aliganj | Purania$_3$ | 26°53'48.3" | 80°56'24.28" | 42.06 | Good |
| 3 | Gomti Nagar | Viraj Khand$_1$ | 26°51'5.2" | 81°1'37.7" | 49.74 | Good |
| 4 | Gomti Nagar | Vineet Khand$_2$ | 26°50'52.1" | 81°0'44.7" | 36.05 | Good |

**Table 6: Locations having Poor WQI status**

| S.No. | Area | Location | Coordinates | | WQI | WQI status (51-75) |
|---|---|---|---|---|---|---|
| | | | N | E | | |
| 1 | Aliganj | Sector $B_3$ | 26°54'22.3" | 80°56'52.7" | 67.82 | Poor |
| 2 | Aliganj | Purania$_2$ | 26°54'43.8" | 80°56'25.2" | 59.00 | Poor |
| 3 | Aliganj | Sector $N_2$ | 26°54'10.5" | 80°57'9.5" | 54.31 | Poor |
| 4 | Aliganj | Sector $N_3$ | 26°54'5.4" | 80°57'12.2" | 61.37 | Poor |
| 5 | Gomti Nagar | Viraj Khand$_3$ | 26°51'11.8" | 80°1'55.4" | 59.54 | Poor |
| 6 | Gomti Nagar | Vineet Khand$_1$ | 26°50'58.7" | 81°0'49.0" | 64.60 | Poor |
| 7 | Gomti Nagar | Vineet Khand$_3$ | 26°51'1.02" | 81°0'47.5" | 64.86 | Poor |
| 8 | Gomti Nagar | Vipul Khand$_2$ | 26°50'28.2" | 80°59'5.4" | 72.14 | Poor |
| 9 | Amausi | Gindan Khera$_1$ | 26°45'50.6" | 80°52'4.6" | 55.62 | Poor |

**Table 7: Locations having Very Poor WQI status**

| S.No. | Area | Location | Coordinates | | WQI | WQI status (76-100) |
|---|---|---|---|---|---|---|
| | | | N | E | | |
| 1 | Aliganj | Purania$_1$ | 26°53'47.8" | 80°56'25.6" | 87.09 | Very Poor |
| 2 | Gomti Nagar | Viraj Khand$_2$ | 26°51'5.9" | 80°1'47.2" | 88.50 | Very Poor |
| 3 | Gomti Nagar | Vipul Khand$_3$ | 26°50'35.7" | 80°59'11.2" | 77.76 | Very Poor |
| 4 | Amausi | Chillawan$_2$ | 26°46'10.0" | 80°53'3.6" | 79.02 | Very Poor |
| 5 | Amausi | Chillawan$_3$ | 26°46'16.4" | 80°53'0.0" | 78.35 | Very Poor |
| 6 | Amausi | Gindan Khera$_2$ | 26°45'58.0" | 80°52'11.2" | 90.27 | Very Poor |
| 7 | Amausi | Gindan Khera$_3$ | 26°46'3.8" | 80°52'13.8" | 99.32 | Very Poor |
| 8 | Amausi | Sarojini Nagar$_3$ | 26°44'40.1" | 80°51'48.3" | 94.57 | Very Poor |

**Table 8: Locations having UFD WQI status**

| S.No. | Area | Location | Coordinates | | WQI | WQI status ( >100 ) |
|---|---|---|---|---|---|---|
| | | | N | E | | |
| 1 | Aliganj | Sector B$_2$ | 26°54'24.4" | 80°56'49.6" | 101.12 | UFD |
| 2 | Aliganj | Sector N$_1$ | 26°54'8.2" | 80°57'10.3" | 101.09 | UFD |
| 3 | GomtiNagar | Vipul Khand$_1$ | 26°50'34.6" | 80°59'8.6" | 101.05 | UFD |
| 4 | Amausi | Chillawan$_1$ | 26°46'8.5" | 80°52'50.4" | 106.05 | UFD |
| 5 | Amausi | Sarojini Nagar$_1$ | 26°44'45.5" | 80°51'45.6" | 105.50 | UFD |
| 6 | Amausi | Sarojini Nagar$_2$ | 26°44'45.1" | 80°51'46.8" | 113.90 | UFD |

## STATISTICAL ANALYSIS OF PHYSICO-CHEMICAL PARAMETERS:

The following figures show the trendline of various physico-chemical parameters at a particular location. The physico-chemical parameters selected for this study shows great variation in terms of their location. From the trendline we can depict the maximum, minimum, mean and standard deviation of the parameters taken into account.

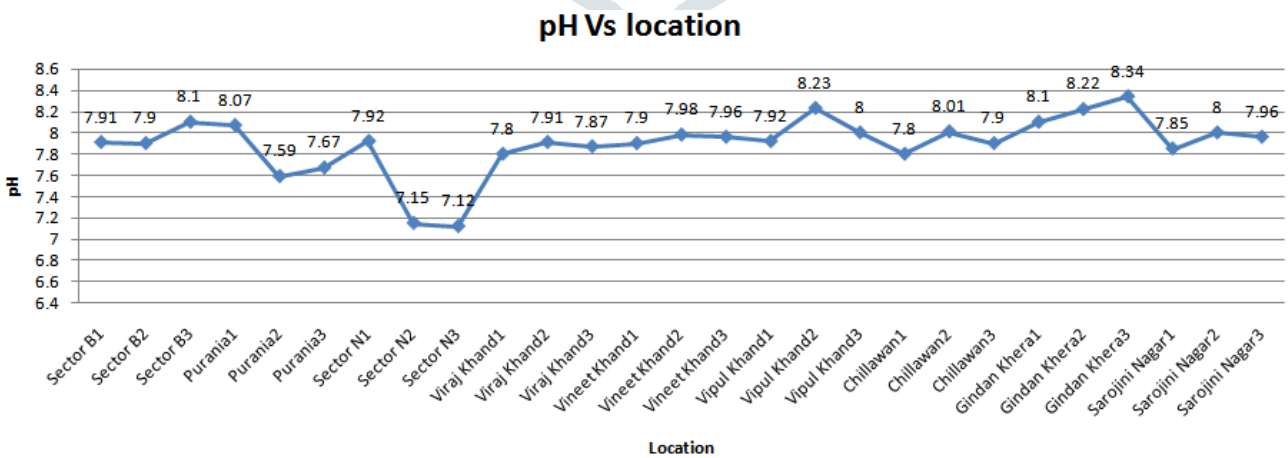


**Figure 3: Variation of pH**

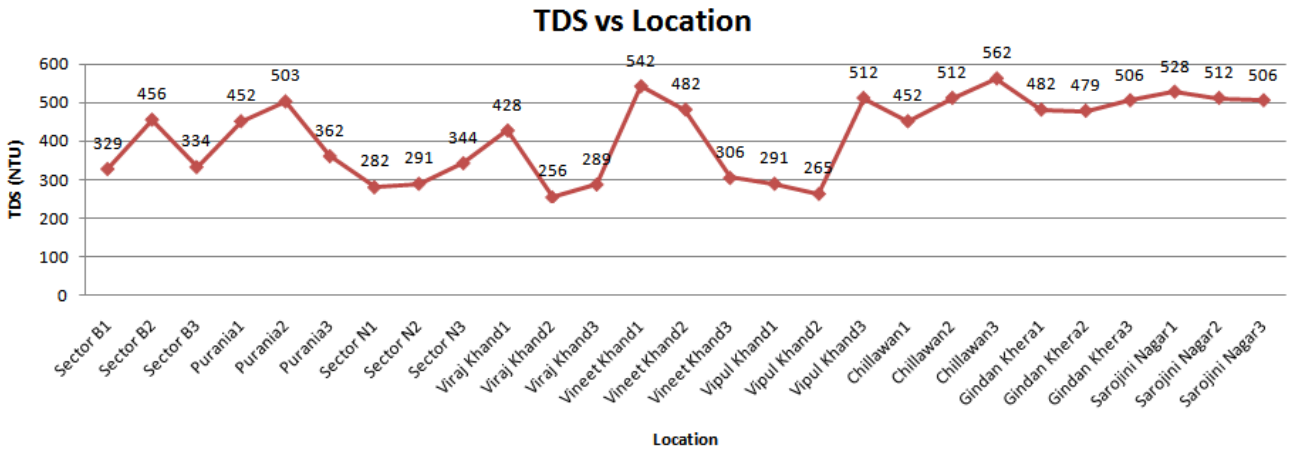


**Figure 4: Variation of TDS**

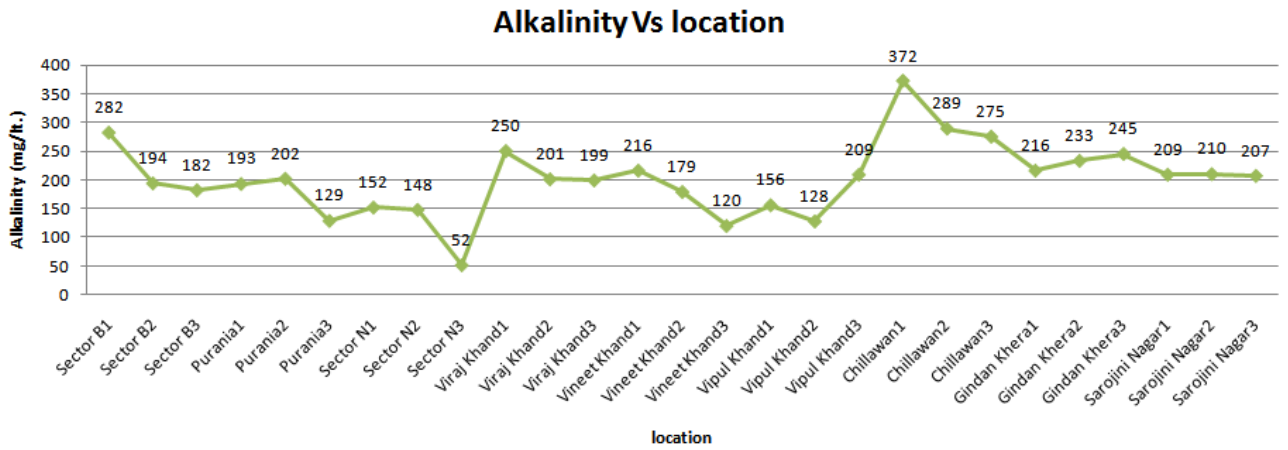


**Figure 5: Variation of alkalinity**

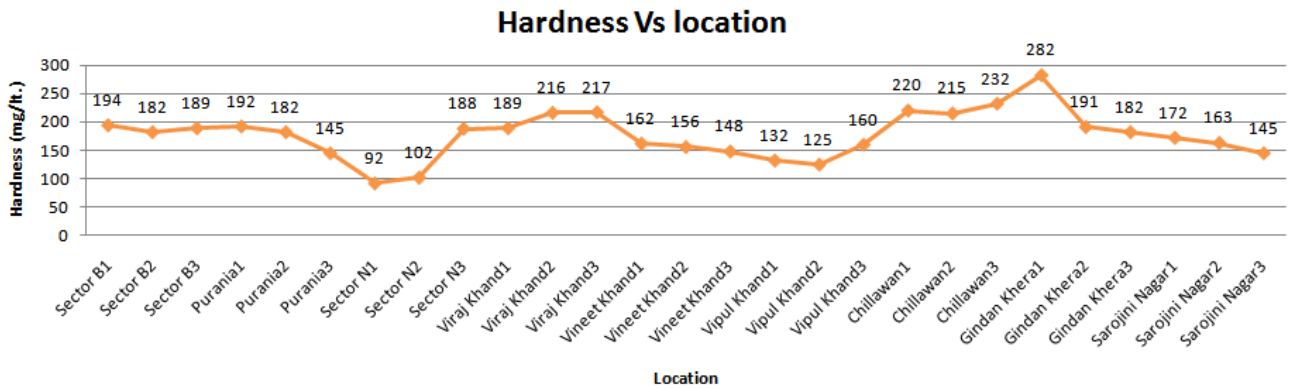


**Figure 6: Variation of Hardness**

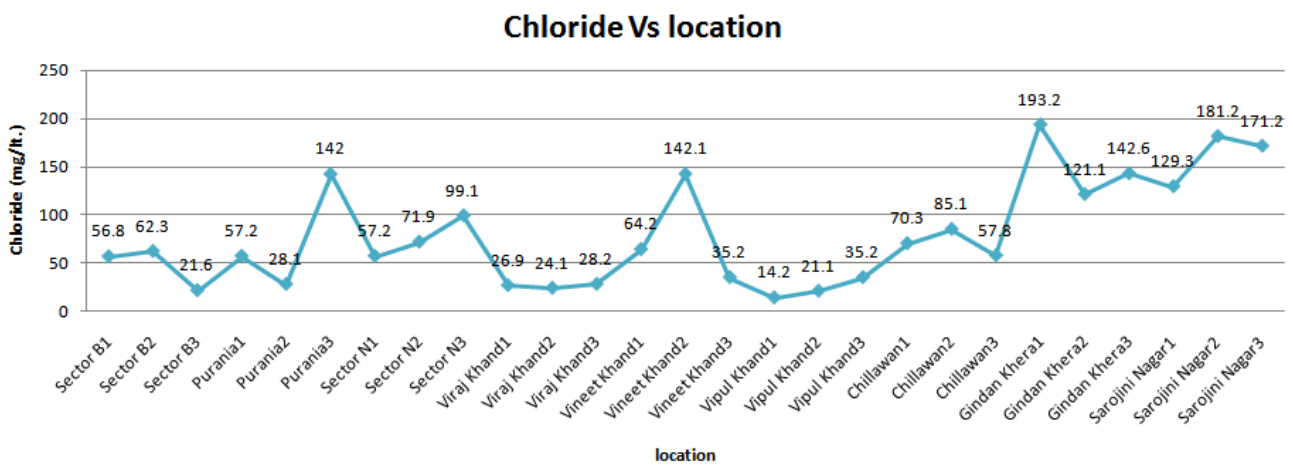

**Figure 7: Variation of Chloride**

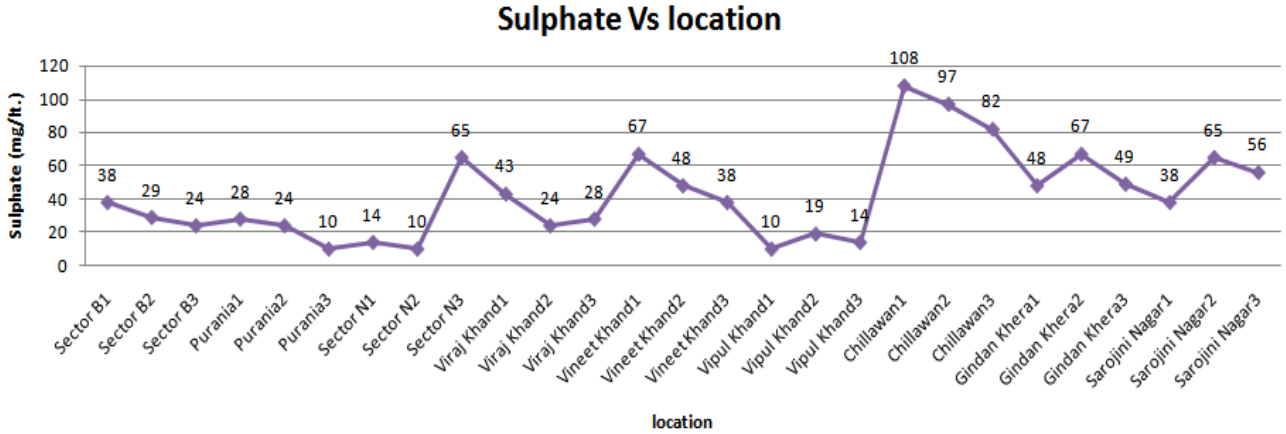


**Figure 8: Variation of Sulphate**

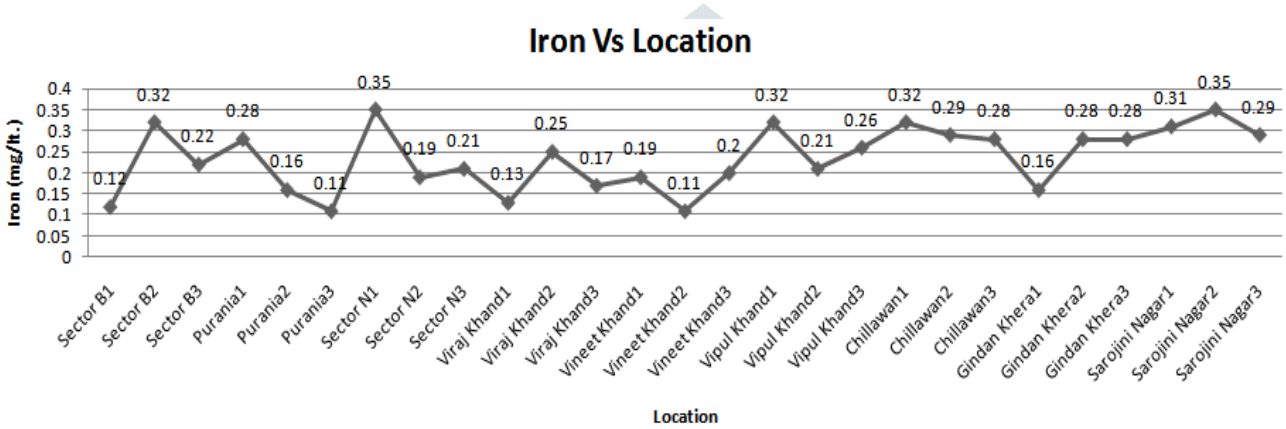


**Figure 9: Variation of Iron**

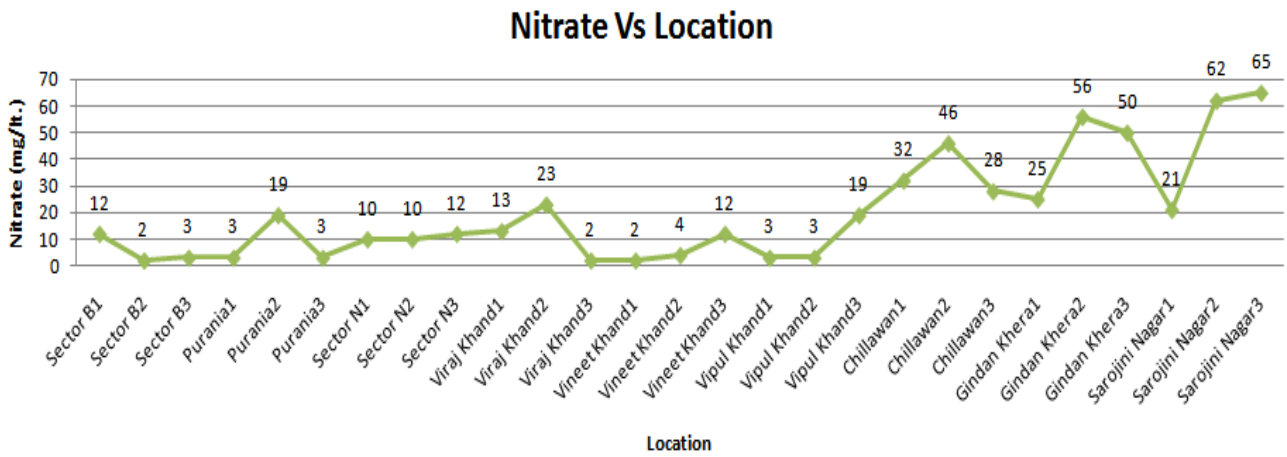


**Figure 10: Variation of Nitrate**

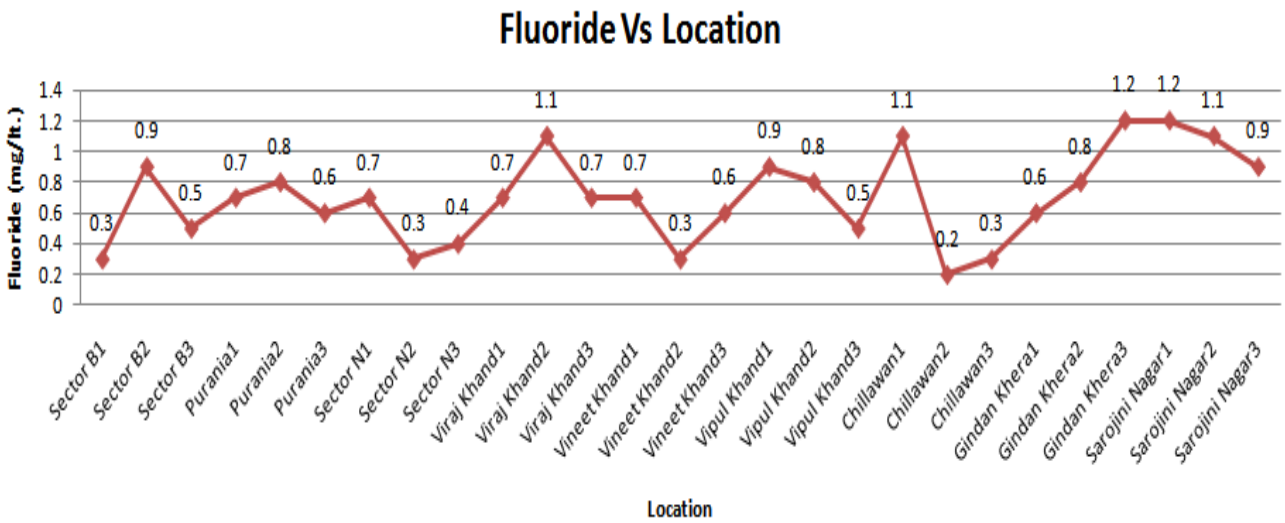


**Figure 11: Variation of Fluoride**

**Table 9: Individual parameters exceeding the permissible limit (IS10500:2012) at a particular location**

| S.No. | Location | PH | TDS | Alkalinity | Hardness | Chloride | Sulphate | Iron | Nitrate | F |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sector $B_1$ | ✓ | ✓ | × | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2 | Sector $B_2$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | ✓ |
| 3 | Sector $B_3$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4 | $Purania_1$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5 | $Purania_2$ | ✓ | × | × | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 6 | $Purania_3$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 7 | Sector $N_1$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | ✓ |
| 8 | Sector $N_2$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 9 | Sector $N_3$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 10 | Viraj $Khand_1$ | ✓ | ✓ | × | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 11 | Viraj $Khand_2$ | ✓ | ✓ | × | × | ✓ | ✓ | ✓ | ✓ | × |
| 12 | Viraj $Khand_3$ | ✓ | ✓ | ✓ | × | ✓ | ✓ | ✓ | ✓ | ✓ |
| 13 | Vineet $Khand_1$ | ✓ | × | × | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 14 | Vineet $Khand_2$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 15 | Vineet $Khand_3$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 16 | Vipul $Khand_1$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | ✓ |
| 17 | Vipul $Khand_2$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 18 | Vipul $Khand_3$ | ✓ | × | × | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 19 | $Chillawan_1$ | ✓ | ✓ | × | × | ✓ | ✓ | × | ✓ | × |
| 20 | $Chillawan_2$ | ✓ | × | × | × | ✓ | ✓ | ✓ | × | ✓ |
| 21 | $Chillawan_3$ | ✓ | × | × | × | ✓ | ✓ | ✓ | ✓ | ✓ |
| 22 | Gindan $Khera_1$ | ✓ | ✓ | × | × | ✓ | ✓ | ✓ | ✓ | ✓ |
| 23 | Gindan $Khera_2$ | ✓ | ✓ | × | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 24 | Gindan $Khera_3$ | ✓ | × | × | ✓ | ✓ | ✓ | × | ✓ | × |
| 25 | Sarojini $Nagar_1$ | ✓ | × | × | ✓ | ✓ | ✓ | × | × | × |
| 26 | Sarojini $Nagar_2$ | ✓ | × | × | ✓ | ✓ | ✓ | ✓ | × | × |
| 27 | Sarojini $Nagar_3$ | ✓ | × | × | ✓ | ✓ | ✓ | ✓ | × | ✓ |
| **IS 10500:2012** | **permissible values** | 6.5-8.5 | 500 | 200 | 200 | 250 | 200 | 0.3 | 45 | 1 |

✓Marks indicate the parameter within permissible limit.

× Marks indicate the parameters above permissible limit.

**Table 10: Minimum, maximum and mean values along with standard deviation**

| Parameters | Min. value | Max. value | Mean value | Std. deviation |
|---|---|---|---|---|
| **pH** | 7.12 | 8.34 | 7.90 | 0.27 |
| **Total dissolved solid(TDS)** | 256 | 562 | 417.15 | 101.22 |
| **Alkalinity (TA)** | 52 | 372 | 201.78 | 62.80 |
| **Hardness (TH)** | 92 | 282 | 176.78 | 40.81 |
| **Chloride (Cl)** | 14.2 | 193.2 | 79.23 | 54.36 |
| **Sulphate ($SO_4$)** | 10 | 108 | 42.33 | 26.57 |
| **Iron (Fe)** | 0.11 | 0.35 | 0.24 | 0.08 |
| **Nitrate ($NO_3$)** | 2 | 65 | 20.00 | 19.63 |
| **Fluoride (F)** | 0.2 | 1.2 | 0.70 | 0.29 |

From figure 3 and table 9 we can depict that the value of pH for all the locations are within range specified by IS 10500:2012. The minimum, maximum and mean values of pH are 7.12, 8.34 and 7.90 respectively with the standard deviation of .027.

The total dissolve solid (TDS) value for the sample ranges from 256 to 562 NTU. The samples having TDS value above the IS permissible value are Purania$_2$, Vineet Khand$_1$, Chillawan$_2$, Chillawan$_3$, Gindhan khera$_3$, Sarojini nagar$_1$, Sarojini nagar$_2$, Sarojini nagar$_3$. The mean value and standard deviation of TDS are 417.15 and 101.22 respectively.

The alkalinity value of the locations selected ranges from 52 to 372 mg/l. The samples having higher alkalinity are Sector B$_1$, Purania$_2$, Viraj Khand$_1$, Viraj Khand$_2$, Vineet Khand$_1$, Vipul Khand$_3$, Chillawan$_1$, Chillawan$_2$, Chillawan$_3$, Gindan Khera$_1$, Gindan Khera$_2$, Gindan Khera$_3$, Sarojini Nagar$_1$, Sarojini Nagar$_2$, Sarojini Nagar$_3$. The mean value and standard deviation of alkalinity are 417.15 and 101.22 respectively.

The range of hardness for the samples collected are 92 to 282 mg/l. The samples having higher hardness value are Viraj Khand$_2$, Viraj Khand$_3$, Chillawan$_1$, Chillawan$_2$, Chillawan$_3$, Gindan Khera$_1$. The mean value and standard deviation of hardness are 176.78 and 40.81 respectively.

All the samples have chloride and sulphate value within the permissible limit. The range of chloride values are 14.2 and 193.2 mg/l with the mean and standard deviation as 79.23 and 54.36 respectively. The range of sulphate varies from 10 to 108 mg/l. with the mean and standard deviation as 42.33 and 26.57 respectively.

As for iron(Fe) all the values are within the acceptable range except that of Sector B$_2$, Sector N$_1$, Vipul Khand$_1$, Chillawan$_1$, Gindan Khera$_3$, Sarojini Nagar$_1$. The mean and standard deviation values of iron are 0.24 and 0.08 respectively.

The nitrate ($NO_3$) values ranges from 2 to 65 mg/l. The areas having nitrate value above the permissible value are Chillawan$_2$, Sarojini Nagar$_1$, Sarojini Nagar$_2$, Sarojini Nagar$_3$. The mean value and standard deviation are 20.00 and 19.63 respectively.

Lastly, the value of fluoride ranges (F) from 0.2 to 1.2 mg/l. The areas having higher fluoride content are Viraj Khand$_2$, Chillawan$_1$, Gindan Khera$_3$, Sarojini Nagar$_1$, Sarojini Nagar$_2$. The mean and standard deviation are 0.70 and 0.29 respectively.

The rule viewer graph of the fuzzy logic system for determining the water quality of the selected area is as follows:

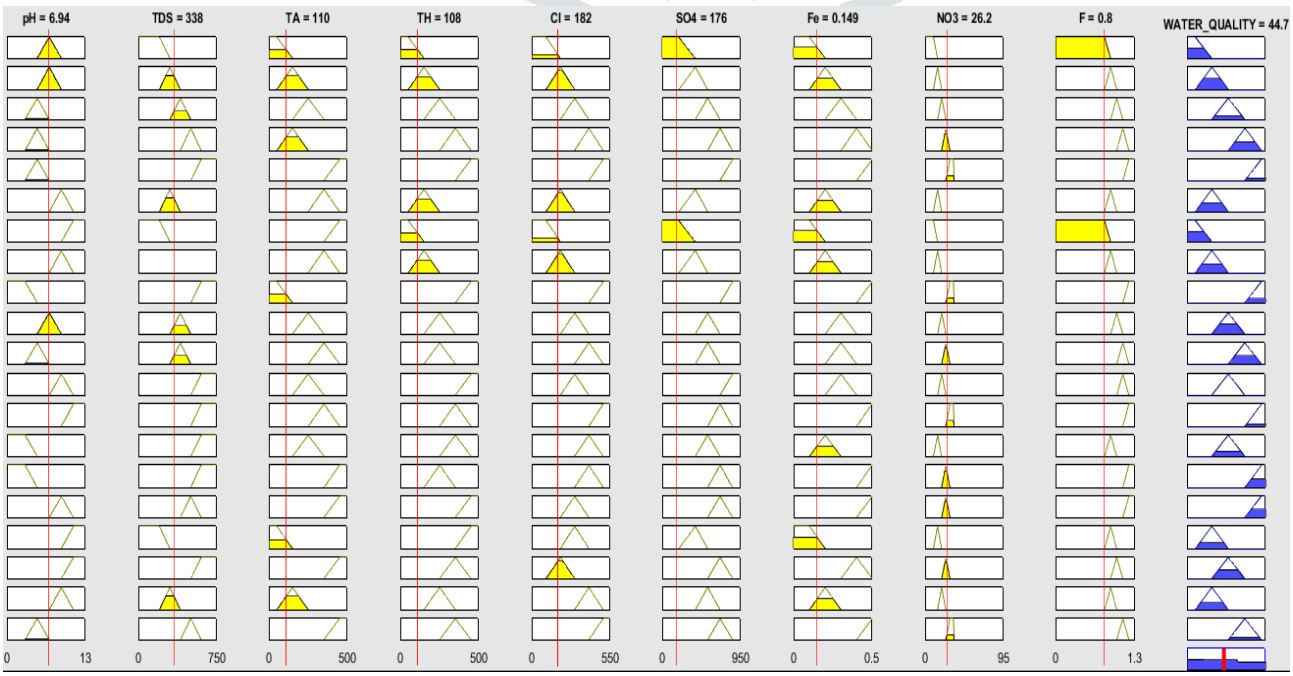


**Figure 12: Fuzzy logic system rule viewer for water quality**

## IX. CONCLUSION

The water quality assessment of the Aliganj, Gomti Nagar and Amausi areas of Lucknow city reveals the true picture of groundwater quality in these areas. Out of the 27 groundwater samples collected, none of the samples lie in an excellent category while most of samples belong to poor and very poor categories of water quality status. 6 samples are also the ones whose WQI lie above 100 i.e. unfit for drinking (UFD) category, therefore groundwater from these locations requires treatment of one or the other form for their domestic and agricultural use. Overall the groundwater quality of selected areas of Lucknow city was not satisfactory and it requires immediate steps to eradicate its contamination and sustainable use.

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