CHAPTER-II

MATERIALS AND METHODS

2.1 INTRODUCTION

An environmental quality survey, with special reference to water quality can be successfully conducted only if the sample is properly collected, preserved, prepared and analyzed. Water quality analysis is a fast growing area in analytical chemistry and effort due to their increased importance, particularly with regard to outbreaks of illness from toxic chemical species and pathogenic organisms in water, which is used for drinking and domestic purposes. Analytical procedure needed to obtain quantitative information are often a mixture of chemical, bio-chemical, biological, bacteriological, bio assay and instrumental methods and also many of the determinations fall under the micro analysis because of the small amounts of contaminants present in the sample.

It would be impossible to cover all parameters under different analytical procedures because many of the determination are highly specific for certain industrial wastes. Even though different methods are available for the same determinant only those which can be employed for routine analysis of water and wastewater samples are discussed in detail. To enable comparison of results by different analysis it is important to carry out determinations by standard methods. The samples were analyzed by using standard recommended analytical procedure, immediately considering all the regulatory guidelines, to enable to record more dependable analytical results.
2.2 SAMPLING AND PRESERVATIONS

Groundwater samples were collected directly from bore wells and discharged effluents were collected directly from nearby industrial sites in the study areas during the period of 2011-2013 with seasonal studies viz., pre-monsoon, monsoon and post-monsoon with all precautions and preserved as per the recommended standard procedures. The required quantity of water samples were collected in pre-cleaned polythene containers and labeled then preserved in a refrigerator until complete analysis.

2.3 PHYSICO-CHEMICAL ANALYSIS

Analytical grade (AR) chemicals were used throughout the study without further purification. To prepare all the reagents and calibration standards, double distilled water was used to prepare standard solutions. Graduated pipettes, burettes, standard conical flasks and standard measuring flasks were calibrated at the room temperature before use. Physico-chemical parameters like total dissolved salts, pH, and electrical conductivity were determined in the field itself. The other water quality parameters were determined within 72 h from the time of collection of sample.

2.3.1 pH

The pH of water samples were measured by using of Digital pHmeter-E1-model (111E) after proper calibration. Accuracy = ± 0.1 pH units; unit = pH unit.
2.3.2 ELECTRICAL CONDUCTIVITY

Electrical conductivity (EC) values were measured by using Elico digital conductivity meter (Model No.L1 CM 180). Cell is washed with double distilled water and then dipped into the beaker containing water samples. The observations are recorded and measured in µS/cm. Electrical conductivity is calculated using equation 2.1.

\[
\text{Electrical Conductivity} = \text{Specific conductance} \times \text{Cell constant} \quad 2.1
\]

2.3.3 TOTAL DISSOLVED SOLIDS

Exactly 20 mL of filtered water sample was taken separately, in a previously weighed \(W_1\), clean, dry china dish (100 mL capacity). Water samples were heated slowly to evaporate on a water bath until dryness. The residues are dried in an air-oven at 105-110°C for an hour, cooled and then weighed \(w_2\). Total dissolved solids (TDS) present in water samples was calculated using the formula:

\[
\text{Total Dissolved Solids (ppm)} = \frac{[(W_1-W_2) \times 1000]}{20} \quad 2.2
\]

Where,

\[
W_1=\text{Weight of the empty china dish (g)}
\]
\[
W_2=\text{Weight of the china dish with solid residue (g)}.
\]

2.3.4 TURBIDITY

Turbidity value was measured by using digital Nephelometer-Deep vision 341E model. The sample was taken in turbidity meter and read directly from
instrument scale. The observations were recorded and measured in NTU unit. Turbidity of diluted samples can be calculated by using the formula.

\[ Turdity\ Units = \left( \frac{A \times (B + C)}{C} \right) \]

Where, A= Turbidity units found in diluted sample,  
B= Volume in ml of dilution water used, and 
C= Volume of sample in ml taken for dilution.

### 2.3.5 ALKALINITY

20ml of the sample is taken in a clean conical flask, two drops phenolphthalein indicator(P) is added, the solution becomes pink colour and it is titrated against hydrochloric acid (0.02N) solution until the end point (pink to colourless). The indicator methyl orange (M) is added to the same solution and it is titrated against hydrochloric acid until the end point (appearance of reddish orange). From the observed value the amount carbonate, bicarbonate and hydroxide ions are calculated.

**Conditions**

\[ P = \frac{1}{2}M \text{ only carbonate} \]

\[ P \geq \frac{1}{2}M \text{ Hydroxide and carbonate} \]
\[ P \leq \frac{1}{2} M \text{Carbonate and bicarbonate} \]

\[ P = 0 \text{ Only bicarbonate} \]

\[ M = 0 \text{ Only Hydroxide} \]

\[ Alkalinity = \left( \frac{V_1 \times 0.02}{20} \right) \times 50 \times 1000 \text{ ppm} \]

.........................2.4

Where, \( V_1 \) is the volume of hydrochloric acid.

2.3.6 TOTAL HARDNESS

The estimation is based on complexometric titration\(^8\). Total hardness of water is estimated by titrating it against EDTA using EBT indicator. The following chemical reactions are involved:

\[ \text{EBT} + M^{n+} \rightarrow [\text{EBT-M}] \text{ (complex)} \]
\[ \text{EBT-M} + \text{EDTA} \rightarrow [\text{EDTA-M}] + \text{EBT} \]
\[ \text{(Unstable complex)} \quad \text{(Stable complex)} \]
\[ \text{(Wine red)} \quad \text{(Steel blue)} \]

Exactly 20mL of water sample was taken separately, in a clean, dry 250mL conical flask. If the sample is below pH 8-10, the pH should be adjusted to 8-10 by using 1N NaOH solution. Then, 1mL of buffer solution (pH 10 buffer; ammonia and ammonium chloride) was added and followed by the addition of two drops of Eriochrome black-T as indicator. Further, the solution was titrated against 0.02 N EDTA solutions. The end point was the color change from wine red to steel blue\(^9\).
From the titre value, the total hardness (TH) was calculated as ppm of CaCO$_3$ using the following equation.

\[
\text{Total Hardness, as CaCO}_3 \text{ mg/L} = \left( \frac{V_1 \times 0.02}{20} \right) \times 50 \times 1000 \text{ ppm}
\]

\[
......2.5
\]

Where, \( V_1 \) = Volume of EDTA (mL)

### 2.3.7 CHLORIDE

Generally water contains chloride ions (Cl$^-$) in the form of NaCl, KCl, CaCl$_2$, and MgCl$_2$. The concentration of chloride ions more than 250ppm is not desirable for drinking purpose. The total chloride ions can be determined by Argentometric method$^10$ (Mohr’s method). In this method Cl$^-$ solution is directly titrated against AgNO$_3$ using potassium chromate ($K_2CrO_4$) as indicator.

\[
\text{AgNO}_3 + \text{Cl}^- \rightarrow \text{AgCl} \downarrow + \text{NO}_3^-
\]

(In water) (White ppt.)

At the end point when all the Cl$^-$ ions are removed. The yellow Colour of chromate changes to reddish brown due to the following reaction.

\[
2\text{AgNO}_3 + \text{K}_2\text{CrO}_4 \rightarrow \text{Ag}_2\text{CrO}_4 + 2\text{KNO}_3
\]

(Yellow) (Reddish brown)

Exactly, 20mL of water sample was taken separately, in a clean, dry 250mL conical flask. About 3 drops of 10% potassium chromate solution was added as an indicator and the mixture was titrated against 0.014N silver nitrate solution until the end point was reached (permanent reddish tinge/color). From the Titre values, the
amount of dissolved chloride ions was calculated by using the following formula, and given in ppm. Standard error is ± 0.01 ppm.

\[
Chloride = \left( \frac{V_1 \times 0.014}{20} \right) \times 35.45 \times 1000 \text{ ppm}
\]

.........................2.6

Where, \( V_1 \) = Titre value (mL); Normality of silver nitrate (0.014N) solution.

### 2.3.8 SULPHATE

Exactly, 20 mL of water samples was taken separately in a clean, dry 100 mL beaker and 1mL of (1:1) HCl solution was added\(^{11}\). After boiling for about one minute, 5mL of 5% (w/v) \( \text{BaCl}_2 \) solution was added slowly with constant stirring. The precipitate was allowed to settle down for 12 hours. Further, the precipitate was filtered through the previously weighed sintered glass crucibles (G-4), washed with hot water; And the sintered glass crucible was dried in air-oven at 105°C, cooled in a desiccator and weighed until the concordant value of weight was obtained. From the weight difference, the Sulphate content was calculated by the following equation, in ppm:

\[
Sulphate = \left( \frac{W_1}{V_1} \right) \times 411.5 \text{ ppm}
\]

.........................2.7

Where, \( w_1 \) = Weight of the precipitate in mg/L; \( V_1 \) = Volume of samples; the standard error is ± 0.1 ppm and unit is given in ppm.

### 2.3.9 SULPHIDE

The total Sulphide ion can be determined by using Methylene Blue method\(^{12}\). Exactly, 10mL of sample was taken in two matched test tube (A&B), if tube A
0.5ml of Amine-Sulphuric acid reagent and 0.15ml of Ferric chloride solution was added mix and inverting slowly, To tube B add 0.5ml of 1:1 Sulphuric acid and 0.15ml of Ferric chloride solution was added. The Blue colour appears on test tube A due to the presence of sulphide. After some time Diammonium hydrogen phosphate followed by zinc acetate was added to each tube. Finally a drop of Methylene blue solution was added to tube B until colour matches that developed in the first tube. (0.05 ml of Methylene blue solution equivalent to 1mg of sulphide per liter)

\[ mg \text{ of sulphide/litre} = \text{no. of drops of methylene blue solution} \]

\[ \ldots \ldots .2.8 \]

2.3.10 Calcium

Exactly, 20mL of water sample was taken separately, in a clean, dry 250mL conical flask and 1mL of 20% NaOH solution was added to bring the pH of the solution to 12 to 13. Then, 0.5 g of on Pattern-Reeder’s [2-hydroxy-1-(2-hydroxy-4-sulphonophthyazonaphthoic acid] indicator was added. The solution was titrated against standard EDTA (0.02N) until the end point (wine red to blue color). From the Titre value, calcium concentration was calculated, in ppm by using the following equation:

\[ Total \text{ Calcium in ppm} = \left( \frac{A \times B \times 400.8}{V_1} \right) \]

\[ \ldots \ldots .2.9 \]

Where, \( A \) = Volume of EDTA consumed by the samples (mL)

\( V \) = Volume of sample of water taken (mL); and
\[ B = \left( \frac{\text{mL of standard calcium solution taken for titration}}{\text{mL of EDTA titrant}} \right) \]  

\[ \ldots \ldots \ldots \ldots 2.91 \]

### 2.3.11 MAGNESIUM

Magnesium contents present in water sample was determined by the complexometric method\textsuperscript{15} using EDTA as a complexing agent. Exactly, 20mL of water sample was taken in a clean, dry conical flask and 30mL of calcium precipitating buffer solution (6 g of ammonium oxalate in 100mL of water mixed with 144 g of ammonium chloride and 13mL of liquor ammonia solution and make up to 100mL) was added. The resultant solution was allowed to stand for half an hour and filtered through Whatman No 45 filter paper. 1 mL of pH 10 buffer solution (ammonia and ammonium chloride) was added to the filtrate solution followed by the addition of two drops of Eriochrome Black-T as indicator. This solution was further titrated against standard 0.02 N EDTA Solution until the end point is color change from wine red to purple blue. From the titre values, the magnesium content was calculated in ppm. Standard error = ± 1 ppm and unit = ppm).

\[ Total \ Magnesium \ in \ ppm = \left( \frac{A \times B \times 1 \times 1000}{V_1} \right) \]  

\[ \ldots \ldots \ldots \ldots 2.10 \]

Where,

- \( A = \) Volume of EDTA consumed by the sample (mL),
- \( B = \) mg of CaCO\textsubscript{3} equivalent to 1.0 mL of 0.02N EDTA Titrant,
- \( V_1 = \) Volume of water sample taken (mL).
2.3.12 SODIUM

Exactly 20 mL of each water sample was taken in a silica crucible and evaporated to dryness using steam bath and the heating is continued in a muffle furnace at 550-600°C for one h. The ash contents were dissolved separately in a minimum quantity of conc. HNO₃ and 10-15 mL of DD water and filtered through Whatman No 41 filter paper and made up to 100 mL, so that the final HNO₃ content was about 1% (w/v). This solution is used for estimation of Na⁺ ion.

Standard solutions containing 0.1 to 40 ppm of Na⁺ ions were prepared by diluting the standard solution of NaCl (100 ppm) and used for calibration of flame photometer. The flame photometer (Deep Vision, Model No. 381) scale reading for 40 ppm was adjusted to be 100 and the scale reading for the blank (pure DD water) was set to be zero. Calibration curve was drawn by plotting flame photometer reading (MR) vs concentration of standard Na⁺ ion. The acid digested and suitably diluted water samples were introduced with the burner unit of the instrument and the meter readings (MR) were noted. From the calibration (standard) curve, the amount of Na⁺ ions present in the diluted water samples were determined by interpolation method. Finally, the Na⁺ ions present in the water samples were calculated. Standard error is ± 0.1 ppm and unit is given as ppm.

2.3.13 POTASSIUM

A series of standard solution containing 0.1 to 0.4 mgL⁻¹ of K⁺ ions were prepared from a stock solution of KCl (100 ppm). Flame photometer (Deep Vision, Model No. 381) was calibrated using standard solution. Calibration curve was drawn
by plotting photometer scale reading (MR) vs concentration of K\(^+\) ion. The water samples (HNO\(_3\) acid digested and suitably diluted) were introduced in to the burner unit of the flame photometer. The flame photometer scale readings were noted. From the calibration curve, the amount of K\(^+\) ions present in the water sample was determined by employing the interpolation method. Standard error is ± 0.1 ppm; unit is ppm.

2.3.13.1 STANDARD SOLUTION

Take 2.5422g sodium chloride, in little deionized distilled water and make up to 1000 ml in a volumetric flask (1ml = 1mg of sodium). Similarly for potassium 1.907g of potassium chloride is taken and it is make upto 1000ml and the same procedure as followed. A series of standard solution has been prepared for 1ppm, 100ppm, 500ppm, 1000ppm). Flame Photometry is switched on and kept warm up more for half an hour and checked for the reproducibility and accuracy constantly. Sodium produces a characteristic yellow emission at 589nm, the instrument is set at \(\lambda = 589\)nm and the readings are noted. A series of standard sodium chloride solution are prepared and are pumped into the flame one by one and the readings are noted. Then for the samples the readings are noted and graph is drawn between the concentration and the intensity of the emitted light. A straight line is obtained.

2.3.14 CHEMICAL OXYGEN DEMAND

Exactly 25 mL of each water sample was taken in a clean, dry 250mL beaker. About 0.5g of mercuric sulphate (weight of mercuric sulphate to be added, depends upon the chloride concentration in water) was added and followed by the addition of
5mL of H$_2$SO$_4$ – Ag$_2$SO$_4$ solution, 12.5mL of potassium dichromate (0.041N) and 40mL of H$_2$SO$_4$ – Ag$_2$SO$_4$ solution. Then, the solutions were cooled and boiled for two hours in a water bath. Finally, the solution was transferred into a 250mL clean conical flask. Two drops of Ferroin indicator was added and the contents were titrated against standard Ferrous Ammonium Sulphate (FAS 0.02N) solution until the end point. The color changes from Bluish green to Reddish brown. From the Titre value, COD of the water sample was calculated, in ppm. Standard error = ± 1 unit and unit is expressed in ppm.

\[
Chemical\ Oxygen\ Demand = \left( \frac{V_2 \times N \times 8 \times 1000}{V_1} \right) \]

Where,

\[
V_2 = \text{Volume of FAS consumed by sample (mL)}
\]

\[
N = \text{Normality of FAS (0.02N)}
\]

\[
V_1 = \text{Volume of water sample taken (mL)}
\]

2.3.15 NITRATE

Nitrate contents present in water sample was determined by the Chromotoropic acid method\textsuperscript{17}. Exactly 2 ml of water sample was taken in 10ml volumetric flasks. 1 drop of sulphite-urea reagent, 2ml of antimony reagent and 1 ml of Chromotropic acid reagent was added to it. This mixture was placed in cold water (10 to 20°C) for 3 minutes. Conc. H$_2$SO$_4$ was added to bring the volume near 10ML. this solution stand for 45 minutes at room temperature. Further read the absorbance value at 410nm by using spectrophotometer. The unit expressed in terms of ppm.
Nitrate in ppm = \left( \frac{\text{mg of nitrate in } 10\text{mL final volume}}{\text{Volume of sample taken for test}} \right) 

2.4 HEAVY METAL ANALYSIS

The heavy metals like Pb, Cu, Fe Cd, Zn and Hg, analyzed by using Atomic Absorption Spectrophotometer\textsuperscript{18-19} (AAS) [Model 2380 using Perkin Elmer hollow cathode Lamp (HCl) as light source] and spectrophotometer-deep vision (305E model).

2.5 MODELING STUDIES

SPSS 13.0 Software\textsuperscript{20} was used to identify the ions distribution in water samples. The study area map and spatial variation was done using GIS\textsuperscript{21} (Geographical Information System). Piper Trilinear Diagram was drawn to identify the major cation and anion which are responsible for the quality of water using Aquachem 2012.

2.5.1 ASSESSMENT OF ROCK INTERACTION

Hard rock interaction can be identified using the Gibb’s ratio\textsuperscript{22} I & II equation 2.13 & 2.14. The equal weightage has been given highest rank has been given to hard rock formation for the ratio less than 0.5 and lowest rank for sedimentary rock formation for the ratio greater than 0.5.

Gibbs Ratio I (for anion) = \frac{\text{Cl}^-}{(\text{Cl}^- + \text{HCO}_3^-)} 

Gibbs Ratio II (for cation) = \frac{(\text{Na}^+ + \text{K}^+)}{(\text{Na}^+ + \text{K}^+ + \text{Ca}^+)} 

………………..2.13

………………..2.14
2.5.2 CHLORO ALKALINE INDICIES

Overlap studies have been carried out to evaluate the ion exchange process using chloro alkaline indices\textsuperscript{23-24} I and II to identify nature of the process using equation 2.15 & 2.16. The equal weightage had been given and highest rank is given for negative values indicating ion exchange process and lowest rank has been given for positive values indicating reverse ion exchange process.

\[
\text{Chloro alkaline indices I} = \frac{(\text{Cl}^- - (\text{Na} + \text{K}))}{\text{Cl}} \quad \text{equation 2.15}
\]

\[
\text{Chloro alkaline indicies II} = \frac{(\text{Cl}^- - (\text{Na} + \text{K}))}{(\text{SO}_4^2+ + \text{HCO}_3^- + \text{CO}_3^2+ + \text{NO}_3^-)} \quad \text{equation 2.16}
\]

2.5.3 GROUNDWATER QUALITY ASSESSMENT FOR IRRIGATION

Overlap studies have been carried out to identify the suitability for the irrigation purposes\textsuperscript{25} The weightage of 40 has been given to sodium adsorption ratio is calculated using equation 2.17 and weightage of 30 has been given for sodium percentage is calculated using equation 2.18. highest rank is given <10 and lowest rank has been given to >10 in the case of sodium adsorption ratio. The highest rank has been given to good quality of water and lowest rank has been given to unsuitable water in the case of sodium percentage.

\[
\text{Sodium adsorption ratio} = \frac{\text{Na}^+}{\sqrt{\left(\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}\right)}} \quad \text{equation 2.17}
\]

\[
\text{Percentage of sodium} = \frac{(\text{Na}^+ + \text{K}^+)}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)} \times 100 \quad \text{equation 2.18}
\]

2.5.4 CORROSIVITY RATIO

The corrosivity ratio\textsuperscript{26} is >1, then the water is characterized as corrosive, else it is non corrosive by using the formula 2.19. The suitability for drinking/ agricultural/ industrial purposes is described by the corrosivity ratio.
CR = \frac{((Cl(mg/l)/35.5)+(2\times SO_4(mg/l)96)}{(2\times ((CO_3 + HCO_3) (mg/l) /100))} 

2.5.5 CONTAMINATION INDICES

The contamination index method uses the degree of contamination ($C_d$) that calculates the quality of water and is computed as follows using the equation from below and “it summarizes\textsuperscript{27} the combined effects of a number of quality parameters regarded as unsafe to household water”. Classification of CF and $C_d$ terminologies has been shown in the (Table 2.1& 2.2).

\[
CF = \frac{C_{m sample}}{C_{m background}}
\]

\textit{Table-2.1} Contamination factors and degree of contamination categories

<table>
<thead>
<tr>
<th>S.No</th>
<th>CF CLASES</th>
<th>CF and $C_d$ terminologies</th>
<th>$C_d$ classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CF &lt; 1</td>
<td>Low CF indicating low contamination / low $C_d$</td>
<td>$C_d &lt; 8$</td>
</tr>
<tr>
<td>2</td>
<td>1 ≤ CF &lt; 3</td>
<td>Moderate CF / $C_d$</td>
<td>$8 \leq C_d &lt; 16$</td>
</tr>
<tr>
<td>3</td>
<td>3 ≤ CF &lt; 6</td>
<td>Considerable CF / $C_d$</td>
<td>$16 \leq C_d &lt; 32$</td>
</tr>
<tr>
<td>4</td>
<td>CF ≥ 6</td>
<td>Very high CF / $C_d$</td>
<td>$C_d \geq 32$</td>
</tr>
</tbody>
</table>

Where, $C_m$ Sample and Median $C_m$ Background are as described before. It is worth noting that (4) is a modified and generalized form of the degree of contamination ($C_d$) formula\textsuperscript{28}.

\[
C_d = \sum_{i=1}^{N} CF_i
\]
\[ mC_d = \frac{1}{N} \sum_{i=1}^{N} CF_i \]  

………………..2.20.2

**Table-2.2** Modified degree of contamination classification and description

<table>
<thead>
<tr>
<th>S.No</th>
<th>mC_d Classes</th>
<th>Modified Degree of Contamination level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>mC_d &lt; 1.5</td>
<td>Nil to very low degree of contamination</td>
</tr>
<tr>
<td>2</td>
<td>1.5 ≤ mC_d &lt; 2</td>
<td>Low degree of contamination</td>
</tr>
<tr>
<td>3</td>
<td>2 ≤ mC_d &lt; 4</td>
<td>Moderate degree of contamination</td>
</tr>
<tr>
<td>4</td>
<td>4 ≤ mC_d &lt; 8</td>
<td>High degree of contamination</td>
</tr>
<tr>
<td>5</td>
<td>8 ≤ mC_d &lt; 16</td>
<td>Very high degree of contamination</td>
</tr>
<tr>
<td>6</td>
<td>16 ≤ mC_d &lt; 32</td>
<td>Extremely high degree of contamination</td>
</tr>
<tr>
<td>7</td>
<td>mC_d ≥ 32</td>
<td>Ultra high degree of contamination</td>
</tr>
</tbody>
</table>

2.5.6 GEO-ACCUMULATION INDEX

The geo-accumulation index (I geo) has been widely used to assess the degree of metal contamination or pollution in terrestrial, aquatic and marine environments.\(^{28}\) The \(I_{\text{geo}}\) of a metal in aquatic can be calculated with the formula

\[ I_{\text{geo}} = \log_2 \frac{C_{\text{metal}}}{1.5C_{\text{metal (background)}}} \]  

………………..2.21

Where,

\[ C_{\text{metal}} = \text{concentration of the heavy metal in the enriched sample}, \]

\[ C_{\text{metal(control)}} = \text{concentration of the metal in the unpolluted control}. \]

The factor 1.5 is introduced to minimize the effect of the possible variation in the background classification of CF and \(I_{\text{geo}}\). A terminology has been shown in the Table 2.3.
### Table-2.3 Geoaccumulation Index classification and description

<table>
<thead>
<tr>
<th>S.No</th>
<th>$I_{\text{geo}}$</th>
<th>Modified Degree of Contamination level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 0</td>
<td>No pollution</td>
</tr>
<tr>
<td>2</td>
<td>0 – 1</td>
<td>Not or minimal pollution (class 1)</td>
</tr>
<tr>
<td>3</td>
<td>1 – 2</td>
<td>Moderately polluted (class 2)</td>
</tr>
<tr>
<td>4</td>
<td>2 – 3</td>
<td>Moderately polluted to polluted (class 3)</td>
</tr>
<tr>
<td>5</td>
<td>3 – 4</td>
<td>Polluted to strongly polluted (class 4)</td>
</tr>
<tr>
<td>6</td>
<td>4 – 5</td>
<td>Strongly polluted (class 5)</td>
</tr>
<tr>
<td>7</td>
<td>5 – 6</td>
<td>Strongly polluted to very strongly polluted (class 6)</td>
</tr>
<tr>
<td>8</td>
<td>&gt; 6</td>
<td>Very strongly polluted (class 7)</td>
</tr>
</tbody>
</table>

### 2.5.7 POLLUTION LOAD INDEX

The pollution load index (PLI) was also evaluated\(^{29}\) to assess the mutual contamination effects of the measured nine metals in this study. This index is expressed as the following equation:

\[
\text{PLI} = (\text{CF}_{\text{Cu}} \times \text{CF}_{\text{Zn}} \times \text{CF}_{\text{Fe}} \times \text{CF}_{\text{Cd}} \times \text{CF}_{\text{Pb}} \times \text{CF}_{\text{Hg}})^{1/N}
\] \[\text{2.22}\]

Where, \(N\) is the number of metals studied and CF is the contamination factor obtained by calculating between each metal’s concentration and its background value. The PLI is able to give an estimate of the metal contamination status and the necessary action that should be taken. A PLI < 1. Denote perfection; PLI = 1 present that only baseline levels of pollutants are present and PLI > 1 would indicate deterioration of site quality.
2.6 WATER QUALITY INDEX (WQI)

Water quality indexing method is a powerful computation technique for the quality assessment of water bodies on the basis of the suitability either potable or other useful purposes. This type of indexing system is called water quality index (WQI). It has been developed and formulated as:

\[ WQI = \text{Antilog} \left( W_n \log Q_n \right) \] ..........................2.24

Where, \( W_n \) (weight of pollutant in the sample) = \( k/S_n \);

\( K \) (constant) = \( 1/(1/S_1 + 1/S_2 + 1/S_3 + \ldots + 1/S_n) \);

\( Q_n \) (water quality rating) = \( 100 \left( V_n - V_i \right) / \left( S_n - V_i \right) \);

\( V_n \) = observed values;

\( V_i \) (ideal values) = 7.0 for pH, 14.6 for DO and 0 for all other parameters.

If WQI is less than 21, then the water sample is excellent and suitable for drinking purposes, if it is between 22 – 42 then the quality of water is good, if it is between 43-63, then quality of water is poor, it is not suitable, if the WQI is greater than 64, then the quality of water is worst and it is not suitable for any purposes.

2.7 HEAVY METAL POLLUTION INDEX (HPI)

Heavy metal pollution index (HPI) is also a powerful technique for the assessment of water quality on the basis of heavy metal concentration. Heavy metal Pollution Index (HPI) has been developed and formulated as:
HPI = \( \frac{\sum W_i Q_i}{\sum W_i} \) ..................................2.25

\( Q_i = \frac{[M_i - I_i]}{[S_i - I_i]} \times 1 \) ..................................2.26

Where, \( Q_i \) is the sub-index of the \( i^{th} \) parameter,

\( W_i \) is the unit weightage of the \( i^{th} \) parameter,

\( N \) is the number of parameters,

\( M_i \) is the monitored value of heavy metal of \( i^{th} \) parameter,

\( I_i \) is the ideal value of \( i^{th} \) parameter,

\( S_i \) is the standard value of the \( i^{th} \) parameter.

2.7.1 METAL INDEX

Another index used is the general metal index (MI) for drinking water\(^{34}\) which takes into account possible additive effect of heavy metals on the human health that help to quickly evaluate the overall quality of drinking waters.

\[
MI = \sum \left( \frac{C_i}{(MAC)_i} \right) 
\]

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Where, MAC is maximum allowable concentration and \( C_i \) is mean concentration of each metal. The higher the concentration of a metal compared to its respective MAC value the worse the quality of water. MI value > 1 is a threshold of warning. Water quality and its suitability for drinking purpose can be examined by determining its metal pollution index.

2.8 CORRELATION ANALYSIS

The ionic relationship can be analyzed by correlation coefficient. Correlation coefficient helps to predict how the ion explains the characteristics of
other ions\textsuperscript{35}. When the correlation coefficient\textsuperscript{36} value is +1 or -1, then the ions are correlated strongly. If the correlation coefficient happens to be 0 then the ions are not correlated and the ions are said to be correlated well if the ratio is greater than 0.7 and moderately correlated if the ratio is 0.7 to 0.5.

2.9 PRINCIPLE COMPONENT ANALYSIS AND FACTOR ANALYSIS

The method of principal component is a special case of the more general method of factor analysis\textsuperscript{37}. The aim of PCA is construction of new variables called principle components out of a set of existing original variables. The PCA is performed to reduce the large data set of variables in too few factors called the principal components which can be interpreted to reveal underlying data structure. The computer packages statistical packages for social sciences (SPSS17.0) and XLSTAT 2013 have been used to carry out the analysis. The factor loadings include both positive and negative loadings. Loading close to ±1 indicate a strong correlation between a variable and the factor. Loading higher than ±0.75 are considered strong correlation, loading between ±0.5 and ±0.74 are considered moderately correlated and loading approaching 0 indicate weak correlation. The data have been standardized using standard statistical procedures. The suitability of the data set for PCA tested by Kaiser-Meyer-Olkin (KMO) and Bartletts tests. KMO is a measure of sampling adequacy. A value of KMO\textsuperscript{38} that is >0.5 indicates PCA can be performed.
2.10 REFERENCES


18. BIS, (1991), Bureau of Indian standards Specifications for drinking water, IS, 10500, New Delhi, India.


