CHAPTER III

HYDROGEOCHEMISTRY
1. INTRODUCTION

The quality of groundwater is very important for evaluating its usability in various fields, such as agriculture, domestic, public water supply and industrial purposes. The groundwater quality parameters depend on geological, pedological and environmental conditions encountered during the flow from the point of recharge to the point of discharge. The study of groundwater quality reveals important clues to the geological history of rocks and indicates the zone of groundwater recharge, discharge, movement and storage (Walton 1970). Hence, hydrochemical studies are useful from the point of present utility and future development to establish quality criteria, measures of chemical, physical and bacterial constituents are estimated with the help of specified methods.

2. METHODOLOGY

In the present study the groundwater quality of study area is carried out systematically by dividing the area into 50 grids. One sample is collected from each grid during April 1999 (pre-monsoon) and November 1999 (post monsoon) period. The electrical conductivity and pH were measured at the sampling spot. The chemical characters were determined in the laboratory using standard procedures given by
Trivedy and Goel (1984) and APHA (1980). Table 3.1 shows the methods employed in chemical analysis. Water samples were analyzed for major cations (Ca Mg, Na and K), anions (CO₃, HCO₃, Cl and SO₄) and Total Hardness (TH). The Corrosivity Ratio (CR) and Total Dissolved Solid (TDS) were calculated using formula given by Ryzner (1944) and Todd (1980) respectively. Table 3.2 gives the partial chemical analyses of groundwater samples collected during April 1999 (pre monsoon) and Table 3.3 gives the partial chemical analysis of groundwater samples collected during Nov 1999 (post monsoon). The concentration of K is 1 mg/l or less than 1 mg/l and carbonate is not detected in groundwater samples. Therefore, in the Table 3.2 and 3.3 Na and K values are given in one column and HCO₃ and CO₃ values are also given in one column only. Table 3.4 and 3.5 give ppm values of all determined values for pre and post monsoon seasons respectively.

3. CHARACTERS OF GROUNDWATER

Generally, groundwater samples are colourless and clear, with little or no suspended matter and with relatively constant temperature. Because of these characteristics, groundwater can be put to direct use without treatment. The presence of H₂S, methane and some other gases gives odour to the water. Colour and taste of water may result from the presence of natural metallic ions (iron compounds, dyes etc). The turbidity in groundwater is caused due to the presence of insoluble matter, organisms and organic matter. Groundwater temperature controls the solvent action, chemical quality, viscosity and its general usefulness for drinking and industrial purposes.

The groundwater samples of the study area are free from colour, odour and turbidity.

SPECIFIC ELECTRICAL CONDUCTANCE

The term specific electrical conductance (EC) denotes the characteristics of a media to the passage of electricity. It is expressed in micro siemens/cm or micro mhos/cm. EC changes significantly with temperature. Therefore, it is usually defined at 25° C. Conductance is a function of the type and concentrations of dissolved ions. EC
permits a rapid evaluation of the chemical quality of the water sample i.e., total dissolved electrolyte context.

In the samples under study the value of electrical conductivity varies from 140 micro mhos/cm to 3400 micro mhos/cm, with an average value of 722 micro mhos/cm in pre monsoon groundwater samples. Similarly, post monsoon groundwater samples show variation from 158 micro mhos/cm to 1997 micro mhos/cm with an average value of 706.18 micro mhos/cm. Fig. 3.1 (a) and (b) shows the variation diagrams of pre and post monsoon values for all the 50-groundwater samples under study respectively. The Fig. 3.1(a) exhibits in pre monsoon season 18 groundwater samples are above average while others are below average indicates a low value of electrical conductivity and in post monsoon season (Fig. 3.1.b) 8 samples are above the average value of electrical conductivity indicating a low value of electrical conductivity.

**HYDROGEN ION CONCENTRATION (pH)**

The pH is useful for knowing acidity or alkalinity of waters. In natural water pH value is dependent on carbon dioxide, carbonate, bicarbonate equilibrium. When the equilibrium is markedly affected by temperature and pressure, change in pH is obvious. Presence of phosphates, silicates, borates, fluorides and some other salts in dissociated form may also affect the pH.

In samples under study the value of pH varies from 4.9 to 8.1 with an average value of 7.1 in pre monsoon season. Similarly, post monsoon groundwater samples show variations from 5.5 to 8.9 with an average value of 7.64.

**CALCIUM**

Calcium is one of the most common ions in the groundwater because of its abundance in most rock types and its easy solubility. Groundwater in contact with sedimentary rocks of marine origin derives most of calcium from the solution of calcite, aragonite, dolomite, anhydrite, and gypsum (Davis and Dewiest 1966). In igneous and metamorphic rocks, weathering releases calcium from minerals like apatite, wollastonite, fluorite and various members of the feldspars, amphibole and pyroxene group. The
range of calcium content in groundwater largely depends on the solubility of carbonates, sulphates and rarely chlorides of calcium.

In samples under study the concentration of calcium varies from 4.0 mg/l to 115 mg/l, with an average value of 19.7 mg/l in pre monsoon groundwater samples. Similarly, post monsoon groundwater samples show variation from 3.0 mg/l to 90 mg/l with an average value of 17.26 mg/l. Fig. 3.2 (a) and (b) shows the variation diagrams of pre and post monsoon season concentrations for all the 50 groundwater samples under study respectively. The Fig. 3.2(a) exhibits in pre monsoon season 19 groundwater samples are above average while others are below average indicates a low concentration of calcium and in post monsoon season (Fig. 3.2.b.) 20 samples are above the average concentration of calcium, while others are below average indicating a low concentration.

MAGNESIUM

The common sources of magnesium in groundwater are olivine, biotite, hornblende and augite in igneous rock; serpentine, talc, diopside and tremolite in metamorphic rocks and dolomite in sedimentary rock. Most of the limestone also contains some amount of magnesium carbonate. In normal atmospheric conditions the solubility of magnesium carbonate in water, in presence of carbon dioxide, is nearly ten times that of calcium carbonate (Karanth, 1987). Minerals with exchange capability absorb magnesium slightly more firmly than calcium, so that low magnesium contents can occasionally be attributed to certain exchange reactions (Davis and Dewiest, 1966). The solubility of magnesium is controlled by the presence of carbon dioxide.

In samples under study the concentration of magnesium varies from 1.0 mg/l to 42.0 mg/l, with an average value of 8.29 mg/l in pre monsoon groundwater samples. Similarly post monsoon groundwater samples show variation from 1.0 mg/l to 41.0 mg/l with an average value of 7.7 mg/l. Fig. 3.3 (a) and (b) shows the variation diagrams of pre and post monsoon concentrations for all the 50-groundwater samples under study respectively. The Fig. 3.3(a) exhibits in pre monsoon season 19 groundwater samples are above average while others are below average indicates a low concentration of magnesium and in post monsoon season (Fig.3.3 b) 20 samples are above the
magnesium and in post monsoon season (Fig.3.3 b) 20 samples are above the average concentration indicating low concentration of magnesium, indicating a low concentration.

**SODIUM AND POTASSIUM**

Sodium content in groundwater is derived from the soluble products during the weathering of plagioclase feldspars (Davis and Dewiest, 1966). Certain clay minerals and zeolites can increase the sodium content in groundwater by base exchange reaction. Sodium is also leaches from sodium bearing silicates such as nepheline, sodalite, jadeite, arfredsomite, glauchophane and numbers of zeolite group such as natrolite. Sodium is generally present in fresh water as sodium ions. In concentrated solutions, it occurs as complex ions and ion pairs such as Na₂CO₃, NaHCO₃ and Na₂SO₄ (Hem, 1950). Most of the sodium occurs in combination with Cl. Sodium salts are readily soluble in water, but do not take active part in chemical reactions as do the salts of alkaline earths.

Although potassium is nearly as abundant as sodium in igneous rocks and metamorphic rocks, its concentration in groundwater is one tenth or even one hundredth that of sodium (Davis and Dewiest, 1966). Two factors are responsible for the scarcity of potassium in groundwater, one being the resistance of potassium minerals to decomposition by weathering (Golditch, 1938) and the other being the fixation of potassium in clay minerals formed due to weathering (Karanth, 1987). Potassium ions in groundwater are released by weathering of some members of silicate mineral group like orthoclase, microcline, muscovite, biotite, leucite and nepheline. Higher potassium concentration in groundwater can be found in irrigated areas where potash fertilizers are used for agriculture (Herth 1965).

In samples under study the concentration of Sodium + Potassium varies from 23 mg/l to 397 mg/l, with an average value of 69.42 mg/l in pre monsoon groundwater samples. Similarly post monsoon groundwater samples show variation from 6 mg/l to 335 mg/l with an average value of 60.46 mg/l. Fig. 3.4 (a) and (b) shows the variation diagrams of pre and post monsoon concentrations for all the 50 groundwater samples under study respectively. The Fig. 3.4(a) exhibits in pre monsoon season 8 groundwater...
concentration of sodium and potassium and in post monsoon season (Fig.3.4 b) 13 samples are above the average concentration of sodium and potassium, indicating their low concentration.

**CHLORIDE**

Chloride is found in almost all types of natural waters. Bulk of the chloride contribution in groundwater is either from atmospheric sources or seawater contamination. Chloride bearing rock minerals such as sodalite and chlorapatite are minor sources of chloride in groundwater. Abnormal concentration of chloride may result due to pollution by sewage waters, salting for certain types of trees like coconuts and leaching of saline residues in the soil. Most chloride in groundwater is present in the form of sodium chloride but the chloride content may exceed the sodium content due to base exchange phenomenon. Chloride salts being highly soluble and free from chemical reactions with minerals of the rocks, remain stable once they enter into solution. Minor amounts of chloride also enter into groundwater through liquid and solid waste material, chloride containing fertilizers and highway salt.

In samples under study the concentration of chloride varies from 17.0 mg/l to 710.0 mg/l, with an average value of 69.7 mg/l in pre monsoon groundwater samples. Similarly post monsoon groundwater samples show variation from 16.0 mg/l to 605.0 mg/l with an average value of 61.62 mg/l. Fig. 3.5 (a) and (b) shows the variation diagrams of pre and post monsoon concentrations for all the 50 groundwater samples under study respectively. The Fig. 3.5(a) exhibits in pre monsoon season 8 groundwater samples are above average while others are below average indicates a low concentration of chloride and in post monsoon season (Fig.3.5 b) 8 samples are above the average concentration of chloride, indicating a low concentration.

**SULPHATE**

The sources of sulphate in natural waters are sulphur minerals, sulphides of heavy metals, which are of common occurrence in the igneous and metamorphic rocks and gypsum and anhydrite found in some sedimentary rocks. A wide range in sulphate content in groundwater is because of reduction, precipitation, solution and concentration
as the water traverses through soil and source rocks. Apart from the natural sources, sulphates can be introduced in groundwater through the application of sulphatic soil conditioners. Local abnormal concentrations of sulphate may be due to the traversing of groundwater through zones of oxidation of sulphide ore bodies, pyrite bearing shale, lignite, coal and gypsiferrous beds.

In samples under study the concentration of sulphate varies from 12 mg/l to 86 mg/l, with an average value of 24.44 mg/l in pre monsoon groundwater samples. Similarly post monsoon groundwater samples show variation from 8 mg/l to 66 mg/l with an average value of 21.76 mg/l. Fig. 3.6 (a) and (b) shows the variation diagrams of pre and post monsoon concentrations for all the 50 groundwater samples under study respectively. The Fig. 3.6(a) exhibits in pre monsoon season 21 groundwater samples are above average while others are below average indicates a low concentration of sulphate and in post monsoon season (Fig. 3.6 b) 20 samples are above the average concentration of sulphate, indicating a low concentration of sulphate.

**BICARBONATE AND CARBONATE**

The primary sources of bicarbonate and carbonate ions in groundwater are the dissolved carbon dioxide in rainwater, which is entering the soil, dissolves more carbon dioxide. Decay of organic matter in the soil releases carbon dioxide for dissolution. Increase in temperature or decrease in the pressure cause reduction in the solubility of carbon dioxide in water (Karanth 1989). Water charged with carbon dioxide dissolves the carbonate minerals, as it passes through soil and rock to give bicarbonates. Carbonate dissolution from rocks and precipitation from water is a two way process dependent on the partial pressure of carbon dioxide. The pH of water indicates the form in which the carbon dioxide is present. The presence of carbonic acid is indicated when the pH is less than 4.5, bicarbonate if the pH is between 4.5 and 8.2 and carbonate if the pH is over 8.2.

In samples under study the concentration of carbonate and bicarbonate varies from 6 mg/l to 450 mg/l, with an average value of 138.8 mg/l in pre monsoon groundwater samples. Similarly post monsoon groundwater samples show variation from 50 mg/l to 360 mg/l with an average value of 125.92 mg/l. Fig. 3.7 (a) and (b) shows
the variation diagrams of pre and post monsoon concentrations for all the 50 groundwater samples under study respectively. The Fig. 3.7(a) exhibits in pre monsoon season, 19 groundwater samples are above average while others are below average indicates a low concentration of carbonate and bicarbonate and in post monsoon season (Fig. 3.7 b) 18 samples are above the average concentration of bicarbonate and carbonate, indicating their low content. The carbonate content is not found in any samples.

TOTAL DISSOLVED SOLIDS (TDS)

The total dissolved solids include all dissociated and undissociated substances excepting suspended sediments, colloids or dissolved gases. In the present study TDS is determined by multiplying electrical conductance (EC) value by the factor 0.64 (Hem, 1950). The bulk of TDS includes bicarbonates, sulphates and chlorides of calcium, magnesium, sodium and silica. Chlorides and nitrates of potassium and boron form a minor part of the dissolved solids in groundwater.

In samples under study the concentration of Total dissolved solids varies from 88 mg/l to 2142 mg/l, with an average value of 459.36 mg/l in pre monsoon groundwater samples. Similarly post monsoon groundwater samples show variation from 52.0 mg/l to 1258.0 mg/l with an average value of 443.29 mg/l. Fig. 3.8 (a) and (b) shows the variation diagrams of pre and post monsoon concentrations for all the 50 groundwater samples under study respectively. The Fig. 3.8(a) exhibits in pre monsoon season, 18 groundwater samples are above average while others are below average indicates a low concentration of Total dissolved solids and in post monsoon season (Fig.3.8 b) 17 samples are above the average concentration and others are below the average concentration of total dissolved solids, indicating low concentration of TDS.

TOTAL HARDNESS

Hardness is an important criterion for deforming usability of groundwater for domestic, drinking and many industrial purposes. Hardness of water is due to the presence of cations such as Ca, Mg and Sr. The anions responsible for permanent hardness are mainly by sulphate and chlorides of the metals, temporary if it is caused by
bicarbonate and carbonate salts of cations and it can be removed by simple boiling. Hardness prevents the lather formation with soap and increases the boiling point of water.

In samples under study the concentration of total hardness varies from 22.3 mg/l to 316 mg/l with an average value of 83 mg/l in pre monsoon groundwater samples. Similarly it varies from 15 mg/l to 393 mg/l with an average value of 75 mg/l. Fig. 3.9 (a) and (b) shows the variation diagrams of pre and post monsoon concentration for all 50 groundwater samples under the study respectively. The Fig. 3.9(a) exhibits 25 numbers of groundwater samples are above average in pre monsoon period and 17 groundwater samples are above average in post monsoon season (Fig. 3.9 b). In pre monsoon samples equal number samples are below average and more number of samples are below average in post monsoon samples.

The table 3.2 and 3.3 also gives the standard deviation (SD) and coefficient of variation (CV) values along with average and other details of the dissolved constituents in the groundwater samples under study.

The average values of all the constituents are higher in pre monsoon samples than post monsoon samples. The similar CV values of all the constituents for both pre and post monsoon samples show same type of behaviour i.e. similar type of scattering of constituent concentrations. The SD values of Ca and Mg constituents are low whereas constituents Na, Cl and HCO₃ show high values of SD in pre monsoon samples. This is supported by the high SD value of EC for pre monsoon samples.

The distinctive behaviour of Na and Cl in pre monsoon samples indicates possible intrusion of sea water into the aquifer during dry seasons.

4. CLASSIFICATION OF GROUNDWATER

According to Mathess and Harvey (1982) the geochemical character of groundwater mainly depends on;
❖ Subsurface: The subsurface geochemical process like dissolution, absorption and ion exchange, oxidation and reduction.
❖ Chemical character of recharging water: atmospheric precipitation, inland surface water and sea water.
❖ Man made pollution: disposal of solid and liquid waste, effect of fertilizer, pesticides and road salt.

All the above mentioned parameters control the water quality, the amount of different chemical constituents in groundwater samples also depends on physical and chemical properties of surrounding rocks, the degree of weathering of rocks, time period of contact with water, the volume of water in movement and its velocity and human influence. The three fundamental factors controlling the chemistry of groundwater are mineralogy, transmissibility and regional topography of the pedological system.

In the present study, the groundwater samples are classified based on following heads:

❖ Hydrochemical types (Piper, 1944)
❖ Hydrochemical facies (Back, 1966)
❖ Schoeller's (1959) classification
❖ Soulême's (1948) classification
❖ Alekin's (1962) classification
❖ Durov's (1956) classification
❖ Factors controlling the chemistry (Gibbs, 1970)
❖ Corrossivity Ratio (Ryzner, 1944)

HYDROCHEMICAL TYPES

To know the hydrochemical types of groundwater under study Piper's (1944) classification is used (Fig. 3.10 a and b). This classification is useful in bring out chemical relationship among the groundwater samples in more definite terms than other plotting methods (Walton, 1970).
The number samples belonging to different chemical types in Piper's classification is presented below,

<table>
<thead>
<tr>
<th>Field</th>
<th>Sub areas of diamond Shape field</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>5</td>
<td>Carbonate hardness exceeds 50 percent</td>
<td>07</td>
</tr>
<tr>
<td>6</td>
<td>Non carbonate hardness exceeds 50 percent</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Non carbonate alkali exceeds 50 percent</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Carbonate alkali exceeds 50 percent</td>
<td>02</td>
</tr>
<tr>
<td>9</td>
<td>No one cat ion- an ion pair exceeds 50 percent</td>
<td>30</td>
</tr>
</tbody>
</table>

HYDROCHEMICAL FACIES

The hydrochemical facies reflect the effect of chemical process during groundwater flow. To study the hydrochemical facies of groundwater under study, Back's (1966) classification is used (Fig. 3.11 a and b). The number of samples belonging to different chemical facies in Back's classification is presented below,

<table>
<thead>
<tr>
<th>Chemical facies</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Ca+ Mg</td>
<td>--</td>
</tr>
<tr>
<td>Ca+ Mg – Na +K</td>
<td>11</td>
</tr>
<tr>
<td>Na+K – Ca+ Mg</td>
<td>35</td>
</tr>
<tr>
<td>Na+ K</td>
<td>--</td>
</tr>
<tr>
<td>Ca+SO₄</td>
<td>--</td>
</tr>
<tr>
<td>Cl+SO₄-HCO₃</td>
<td>18</td>
</tr>
<tr>
<td>HCO₃- Cl+SO₄</td>
<td>34</td>
</tr>
<tr>
<td>HCO₃</td>
<td>--</td>
</tr>
</tbody>
</table>
**SCHOLLER’S CLASSIFICATION (1956)**

Scholler has adopted classification of water based on index of base exchange and percentage of cat and an ions. In addition to this he has classified water based on quantity of chloride, sulphate, bicarbonate and carbonate. Accordingly groundwater samples under study are classified as given below.

> Differentiation according to Cl concentration

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Super chloride water, &gt;700meq</td>
<td>00</td>
</tr>
<tr>
<td>Marine chloride water, 700 –420 meq</td>
<td>00</td>
</tr>
<tr>
<td>Strong chloride water, 420-140 meq</td>
<td>00</td>
</tr>
<tr>
<td>Medium chloride water, 140-40 meq</td>
<td>00</td>
</tr>
<tr>
<td>Oligo chloride water, 40-15 meq</td>
<td>01</td>
</tr>
<tr>
<td>Normal chloride water, &lt;15meq</td>
<td>49</td>
</tr>
</tbody>
</table>

> Differentiations according to SO₄ concentration

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Super sulphate water &gt;58meq</td>
<td>00</td>
</tr>
<tr>
<td>Sulphate water, 58-24 meq</td>
<td>00</td>
</tr>
<tr>
<td>Oligo sulphate water, 24-6 meq</td>
<td>00</td>
</tr>
<tr>
<td>Normal sulphate water, &lt;6meq</td>
<td>50</td>
</tr>
</tbody>
</table>
Differentiation according to $\text{HCO}_3^+$ $\text{CO}_3^-$ concentration.

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Super carbonated water, $&gt;7$ meq</td>
<td>01</td>
</tr>
<tr>
<td>Normal carbonate water, 2-7 meq</td>
<td>24</td>
</tr>
<tr>
<td>Under carbonate water, $&lt;2$ meq</td>
<td>25</td>
</tr>
</tbody>
</table>

Indices of Chloride alkali unbalanced or base exchange $I_{BA}$

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>$\text{Cl}^-&gt;\text{Na}^+$ (+ ve index of base exchange)</td>
<td>17</td>
</tr>
<tr>
<td>$\text{Cl}^-=\text{Na}^+$ (equilibrium)</td>
<td>00</td>
</tr>
<tr>
<td>$\text{Cl}&lt;\text{Na}^-$ (- ve index of base exchange)</td>
<td>33</td>
</tr>
</tbody>
</table>

Differentiation on the basis of percentage anions and cat ions

❖ The following six groups can be established on anions

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>$\text{Cl}^-&gt;\text{SO}_4^-&gt;\text{CO}_3^-$</td>
<td>00</td>
</tr>
<tr>
<td>$\text{Cl}^-&gt;\text{CO}_3^-&gt;\text{SO}_4^-$</td>
<td>06</td>
</tr>
<tr>
<td>$\text{SO}_4^-&gt;\text{Cl}^-&gt;\text{CO}_3^-$</td>
<td>00</td>
</tr>
<tr>
<td>$\text{SO}_4^-&gt;\text{CO}_3-&gt;\text{Cl}$</td>
<td>00</td>
</tr>
<tr>
<td>$\text{CO}_3^-&gt;\text{Cl}^-&gt;\text{SO}_4^-$</td>
<td>39</td>
</tr>
<tr>
<td>$\text{CO}_3^-&gt;\text{SO}_4-&gt;\text{Cl}$</td>
<td>05</td>
</tr>
</tbody>
</table>
The following six groups can be established on cations:

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Na &gt; Mg &gt; Ca</td>
<td>08</td>
</tr>
<tr>
<td>Na &gt; Ca &gt; Mg</td>
<td>36</td>
</tr>
<tr>
<td>Mg &gt; Na &gt; Ca</td>
<td>02</td>
</tr>
<tr>
<td>Mg &gt; Ca &gt; Na</td>
<td>00</td>
</tr>
<tr>
<td>Ca &gt; Na &gt; Mg</td>
<td>04</td>
</tr>
<tr>
<td>Ca &gt; Mg &gt; Na</td>
<td>00</td>
</tr>
</tbody>
</table>

**SOULINE’S CLASSIFICATION (1948)**

Souline (1948) has classified waters into four classes. Accordingly groundwater samples under study are classified and given below:

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Na – SO₄ - Water</td>
<td>38</td>
</tr>
<tr>
<td>Na – HCO₃ - Water</td>
<td>12</td>
</tr>
<tr>
<td>Mg – Cl - Water</td>
<td>37</td>
</tr>
<tr>
<td>Ca – Cl - Water</td>
<td>13</td>
</tr>
</tbody>
</table>

**ALEKIN’S CLASSIFICATION (1962)**

Alekin (1962) has classified waters into three classes based on ionic ratios (in meq/l):

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Type I (HCO₃&gt;(Ca²⁺ + Mg²⁺))</td>
<td>41</td>
</tr>
<tr>
<td>Type II (HCO₃&lt;(Ca²⁺ + Mg²⁺)&lt;(HCO₃+SO₄²⁻))</td>
<td>06</td>
</tr>
<tr>
<td>Type III (HCO₃+SO₄²⁻)&lt; (Ca²⁺ + Mg²⁺) or Cl⁻ &gt;Na⁺</td>
<td>33</td>
</tr>
</tbody>
</table>
**DUROV’S CLASSIFICATION (1956)**

The Durov’s diagram consists of two triangles and a square in which one triangle represents cation ions and other represents anion ions. The cumulative effects of both the ions are projected in the square. The square is divided into four fields viz. A, B, C and D. The characters of each field are thus

- A is pure water
- B is no contamination
- C is moderate quality
- D is high contamination of Na and Cl

The samples under study are plotted in the Durov’s diagram (Fig.3.12 a and b), the number of groundwater samples found in different fields of Durov’s diagram is given below.

<table>
<thead>
<tr>
<th>Fields</th>
<th>Number of samples</th>
<th>Pre monsoon</th>
<th>Post monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>02</td>
<td>06</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>45</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>03</td>
<td>03</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>00</td>
<td>00</td>
<td></td>
</tr>
</tbody>
</table>

**FACTORS CONTROLLING THE CHEMISTRY(Gibbs, 1970)**

The important factors that control the chemical composition of the water of the earth have been discussed by Gorham (1961), Meckinze et.al (1965 and 1966), Sillen (1967), Gibbs (1970), Ramesan et.al (1973) etc. These days, Gibbs’ Diagram (1970) being used to know the factors controlling groundwater chemistry. The factors controlling the chemistry of groundwater of different parts of Karnataka are studied by Vishwanathaiah et.al (1978), Puranik et.al. (1981), Balsubramanian and Sastri (1987), Vastrad (1987), Patil and Puranik (1990) and Gourshetty and Puranik (1998). The plots, for the samples understudy plotted in the Gibbs diagram occupy central field (Fig. 3.13 a...
The plots that are concentrated in the central part indicate that chemistry of the groundwater samples is controlled by host lithological unit and reactions between infiltrating surface water and the litho units. A few pre monsoon groundwater samples are closer to sea water dominance field indicating the contamination of aquifer by sea water intrusion during dry seasons.

**CORROSIVITY RATIO (Ryzner, 1944)**

Corrosion is complex electrochemical and biochemical reactions between the metals and its environment. Most commonly occurring phenomenon is the oxidation. Low pH, high temperature, high TDS and certain metal ions in the water increase the corrosion rate (Raman, 1983). The rate at which corrosion is proceeds depends upon the variety of chemical equilibrium reactions as well as certain physical factors like temperature, pressure and velocity of flow of water. (Ayers and West cost, 1985). Most of the corrosion problem is associated with low salinity water and encrustation problems are associated with high salinity water (Rengarajan and Balasubramanian, 1988). Corrosive water leads to health, aesthetic and economic problems.

Groundwater is extracted to supplement the surface water facilities and is being transported through the metallic pipes. To know the suitability these pipes for transportation of groundwater, the corrosivity ratio value (CR) for the water (Ryzner 1944) is determined. Based on the corrosivity ratio value, Balasubramnian and Sastry (1987), classified groundwater into groups viz., 'safe' when CR values are less 1.0 and 'corrosive' when CR values are more than 1.0.

In the present study the CR values are determined and given below along with the number of samples more than or/and less than 1 are also given below.

<table>
<thead>
<tr>
<th>CR Value</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>38</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>12</td>
</tr>
</tbody>
</table>
The above Table shows only 12 samples from pre monsoon and 15 samples from post monsoon seasons are corrosive in nature. More number of samples are non-corrosive in character.

5. SEASONAL VARIATION OF GROUNDWATER CHARACTERS

The possible seasonal variation in chemical constituents of the groundwater samples collected during April 1999 (pre monsoon) and November 1999 (post monsoon) are studied in the present section. In order to bring out the relations, histograms are drawn for various constituents and are presented in Fig. 3.14 to 3.22

CALCIUM

The Fig. 3.14 exhibits following characters. Samples from grid numbers 2, 5, 9, 10, 11, 13, 14, 15, 17, 18, 19, 20, 21, 22, 24, 25, 27, 28, 29, 30, 32, 33, 34, 36, 37, 38, 39, 40, 41, 43, 44, 45, 48, 49 and 50 show increase in concentration of calcium in pre monsoon.

Samples from grid numbers 1, 6, 7, 8, 23, 26, 35 and 46 show increase in concentration of calcium in post monsoon and samples from grid numbers 3, 4, 12, 16, 31, 42 and 47 show same concentration in both pre and post monsoon.

MAGNESIUM

The Fig. 3.15 exhibits following characters. Samples from grid numbers 3, 5, 7, 8, 14, 16, 17, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47 and 49 show increase in concentration of magnesium in pre monsoon.

Samples from grid numbers 12, 13, 15, 18, 19, 20, 21, 23, 33, 34, 35, and 48 show increase in concentration of magnesium in post monsoon and samples from grid numbers 1, 2, 4, 6, 9, 10, 11, and 50 show same concentration in both pre and post monsoon.
**SODIUM AND POTASSIUM**

The Fig. 3.16 exhibits following characters. Samples from grid numbers 1, 3, 4, 5, 6, 7, 9, 12, 13, 14, 15, 16, 17, 18, 22, 23, 24, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, and 50 show increase in concentration of sodium and potassium in pre monsoon.

Samples from grid numbers 2, 10, 11, 19, 20, 21, 31, and 49 show increase in concentration of sodium and potassium in post monsoon and only sample from grid number 8 shows same concentration in both pre and post monsoon.

**CHLORIDE**

The Fig. 3.17 exhibits following characters. Samples from grid numbers 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 13, 14, 16, 17, 18, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49 and 50 show increase in concentration of chloride in pre monsoon.

Samples from grid numbers 8, 12, 19, 20 and 21 show increase in concentration of chloride in post monsoon groundwater sample and only a sample from grid number 15 shows same concentration in both pre and post monsoon.

**SULPHATE**

The Fig. 3.18 exhibits following characters. Samples from grid numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 20, 22, 24, 25, 26, 27, 28, 31, 32, 33, 36, 37, 38, 39, 40, 41, 42, 44, 48, 49 and 50 show increase in concentration of sulphate in pre monsoon.

Samples from grid numbers 19 and 20 show increase in concentration of sulphate in post monsoon and samples from grid numbers 13, 23, 29, 30, 34, 35, 42, 43, 45, 46 and 47 show same concentration in both pre and post monsoon.
**BICARBONATE AND CARBONATE**

The Fig. 3.19 exhibits following characters. Samples from grid numbers 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 14, 15, 16, 18, 19, 20, 22, 24, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49 and 50 show increase in concentration of bicarbonate and carbonate in pre monsoon.

Samples from grid numbers 13, 21, and 23 show increase in concentration of bicarbonate and carbonate in post monsoon and samples from grid numbers 4, 10, 17, 23 and 31 shows same concentration in both pre and post monsoon.

**TOTAL DISSOLVED SOLIDS**

The Fig. 3.20 exhibits following characters. Samples from grid numbers 1, 2, 3, 4, 5, 7, 8, 11, 13, 14, 19, 20, 21, 24, 30, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44, 45 and 46 show increase in concentration of total dissolved solids in pre monsoon.

Samples from grid numbers 6, 9, 10, 12, 15, 16, 17, 18, 22, 23, 25, 26, 27, 28, 31, 32, 39, 47, 48, 49 and 50 show increase in concentration of total dissolved solids in post monsoon.

**ELECTRICAL CONDUCTIVITY**

The Fig. 3.21 exhibits following characters. Samples from grid numbers 3, 5, 7, 8, 14, 16, 17, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47 and 49 show increase in concentration of electrical conductivity in pre monsoon.

Samples from grid numbers 6, 9, 12, 15, 16, 17, 18, 19, 22, 23, 25, 26, 27, 28, 31, 32, 47, 48, 49 and 50 show increase in concentration of Electrical conductivity in post monsoon.
TOTAL HARDNESS

The Fig. 3.22 exhibits the following characters. Samples from grid numbers, 2, 3, 4, 5, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 21, 24, 26, 27, 28, 29, 30, 33, 34, 36, 39, 40, 42, 43, 44, 49, and 50 show increase in hardness of pre monsoon.

Samples from grids 1, 6, 9, 12, 19, 20, 22, 23, 25, 32, 35, 37, 38, 41, 45, 46, 47, and 48 show increase in hardness in post monsoon and sample from grid number 4 shows same hardness in both pre and post monsoon.

6. QUALITY CRITERIA FOR DOMESTIC USES

Water is an important commodity for life. Water used should meet the required standards of physical, chemical and biological purity. Physically the water should be free from odours, turbidity, taste and colour. Chemically the water should be preferably soft, low in dissolved solids and free from poisonous constituents like arsenic, fluoride etc. The water should be free from microorganisms.

In order to evaluate the suitability of groundwater samples from the study area, the standards proposed by WHO (1971), ISI (1983) and ICMR (1975) are used. Various bar diagrams are drawn to compare the quantity of constituents of groundwater samples with all the proposed standards (Fig. 3.23 to 3.36). The bar diagrams exhibit content of each sample shown by vertical bars and horizontal lines indicate standard values depicting maximum permissible and maximum allowable values for various constituents. Such bar diagrams are prepared for both pre and post monsoon seasonal samples.

The bar diagrams (Fig. 3.23 to 3.36) reveal the character of the constituents with respect to standard values. These figures were interpreted and the numbers of samples above maximum permissible limit and above maximum allowable limit are tabulated. (Table 3.6) Below. The Table 3.6 and bar diagrams reveal that all the constituents do not cross the
standard limits except one sample that is collected from No. 37 grid. This may be because of the location of the grid, which is close to estuary.

The pH values of pre monsoon samples are below maximum allowable limit while 2 samples with respect to WHO, 5 samples with respect to ISI and ICMR are above maximum allowable limit. The TH, Ca, Mg and SO₄ values are below maximum allowable limit in both pre and post monsoon samples. The Cl values are below maximum allowable limit except one sample in both pre and post monsoon samples. The Na values are below maximum allowable limit except two samples in pre monsoon and one sample in post monsoon. The TDS values are below maximum allowable limit except one sample in pre monsoon. The actual numbers of samples below maximum permissible limit and between maximum permissible and maximum allowable limits are given in Table 3.6.

7. QUALITY CRITERIA FOR AGRICULTURAL USES

Agriculture is practiced in plain area and on soil covered places of the study area. Groundwater is utilized for the agricultural purpose, apart from rainwater and surface water. There is a masonry barrage (Kadavina Katte) constructed to Venkatapur River about 2.5 km east of Bhukkal city. The canal water from this barrage is used for agricultural purposes (Photo 1.6 and 1.7)

Karanth (1987) opines that the following factors affect the suitability of water for agriculture.

❖ The total concentration of soluble salts
❖ The relative proportion of sodium to calcium and magnesium
❖ The concentrations of boron
❖ The relative proportion of bicarbonate to calcium and magnesium
❖ The nature and composition of the soil and subsoil.
❖ The depth of the water table
❖ Topography, climate and type of crop.
In the following pages the suitability of groundwater for agricultural uses considering various ratios proposed by number of researchers are described. The various ratios used are % Na, SAR, NCH, KI, Adjusted SAR, PI and PS. All these ratios are given in Table 3.7 (Pre monsoon) and 3.8 (Post monsoon).

**SODIUM PERCENTAGE (%Na)**

Todd (1980) classified the groundwater for irrigation purposes into five classes. Accordingly the groundwater samples under study are classified;

<table>
<thead>
<tr>
<th>Class</th>
<th>Sodium percentage</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Excellent</td>
<td>&lt; 20</td>
<td>--</td>
</tr>
<tr>
<td>Good</td>
<td>20 to 40</td>
<td>01</td>
</tr>
<tr>
<td>Permissible</td>
<td>40 to 60</td>
<td>13</td>
</tr>
<tr>
<td>Doubtful</td>
<td>60 to 80</td>
<td>23</td>
</tr>
<tr>
<td>Unsuitable</td>
<td>&gt; 80</td>
<td>13</td>
</tr>
</tbody>
</table>

Eaton (1950) considered sodium percentage for classifying the irrigation water. Accordingly the groundwater samples under study are classified;

<table>
<thead>
<tr>
<th>Class</th>
<th>Sodium percentage</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Safe</td>
<td>&lt; 60</td>
<td>14</td>
</tr>
<tr>
<td>Unsafe</td>
<td>&gt; 60</td>
<td>36</td>
</tr>
</tbody>
</table>

**SODIUM ABSORPTION RATIO (SAR)**

Richard (1954) classified the irrigation water into four classes. Accordingly the groundwater samples under study are classified;
### ELECTRICAL CONDUCTIVITY (EC)

Sarma (1982) classified the irrigation water on the basis of EC. Accordingly the groundwater samples under study are classified:

<table>
<thead>
<tr>
<th>Class</th>
<th>EC (micro mhos/cm)</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
<td>Post monsoon</td>
</tr>
<tr>
<td>Excellent</td>
<td>0 to 333</td>
<td>11</td>
</tr>
<tr>
<td>Good</td>
<td>333 to 500</td>
<td>6</td>
</tr>
<tr>
<td>Permissible</td>
<td>500 to 1000</td>
<td>24</td>
</tr>
<tr>
<td>Brackish</td>
<td>1000 to 1500</td>
<td>6</td>
</tr>
<tr>
<td>Saline</td>
<td>1500 to 10000</td>
<td>3</td>
</tr>
</tbody>
</table>

### TOTAL DISSOLVED SOLIDS (TDS)

Davis & De-wiest (1966) and Carroll (1962) have classified irrigation water based on TDS contents. Accordingly the groundwater samples under study are classified:
<table>
<thead>
<tr>
<th>Class</th>
<th>TDS (mg/l)</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Fresh water</td>
<td>0 to 1000</td>
<td>02</td>
</tr>
<tr>
<td>Good</td>
<td>1000 to 10000</td>
<td>48</td>
</tr>
<tr>
<td>Saline water</td>
<td>10000 to 100000</td>
<td>--</td>
</tr>
<tr>
<td>Brine</td>
<td>&gt;100000</td>
<td>--</td>
</tr>
</tbody>
</table>

**RESIDUAL SODIUM CARBONATE (RSC)**

Richard (1954) classified irrigation water based on RSC ratio. Accordingly the groundwater samples under study are classified:

<table>
<thead>
<tr>
<th>Class</th>
<th>RSC</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Good</td>
<td>&lt;1.25</td>
<td>35</td>
</tr>
<tr>
<td>Medium</td>
<td>1.25 to 2.5</td>
<td>10</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt;2.5</td>
<td>05</td>
</tr>
</tbody>
</table>

**KELLY’S INDEX (KI)**

Kelly (1940) has classified irrigation water based on Na : Ca + Mg ratio. Accordingly the groundwater samples under study are classified:

<table>
<thead>
<tr>
<th>Class</th>
<th>KI</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>No alkali hazards</td>
<td>&lt;1</td>
<td>08</td>
</tr>
<tr>
<td>Alkali hazards</td>
<td>&gt;1</td>
<td>42</td>
</tr>
</tbody>
</table>
**USSL DIAGRAM**

Richard (1954) has proposed a diagram (USSL) based on SAR and EC values of groundwater (Fig. 3.37 a and b). Accordingly the groundwater samples under study are classified:

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>C1S1-Low salinity &amp; low sodium hazards</td>
<td>06</td>
</tr>
<tr>
<td>C2S1-Medium salinity &amp; low sodium hazards</td>
<td>18</td>
</tr>
<tr>
<td>C3S1-High salinity &amp; low sodium hazards</td>
<td>16</td>
</tr>
<tr>
<td>C2S2-Medium salinity &amp; medium sodium hazards</td>
<td>02</td>
</tr>
<tr>
<td>C3S2-High salinity &amp; medium sodium hazards</td>
<td>--</td>
</tr>
<tr>
<td>C3S3-High salinity &amp; high sodium hazards</td>
<td>01</td>
</tr>
<tr>
<td>C4S2-Very high salinity &amp; Medium sodium hazards</td>
<td>01</td>
</tr>
</tbody>
</table>

**WILCOX’S DIAGRAM**

Wilcox (1948) has proposed a diagram based on EC and Sodium percent values of groundwater (Fig. 3.38 a and b). Accordingly the groundwater samples under study are classified:

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Excellent to good</td>
<td>21</td>
</tr>
<tr>
<td>Good to permissible</td>
<td>06</td>
</tr>
<tr>
<td>Permissible to doubtful</td>
<td>18</td>
</tr>
<tr>
<td>Doubtful to Unsuitable</td>
<td>05</td>
</tr>
<tr>
<td>Unsuitable</td>
<td>--</td>
</tr>
</tbody>
</table>
AYER’S CLASSIFICATION

Ayer (1977) classified three degrees of severity in evaluation of groundwater quality for agriculture namely 'No problem', 'Increasing problem' and 'Severe problem'. He explained about Salinity level, Chloride concentration, Bicarbonate concentration, Sulphate concentration and Adjusted SAR. Bar diagrams (Fig. 3.39-3.42) are drawn to interpret the Ayer's classification. Based on these figures following tables are prepared.

Salinity level (based on EC content)

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
<th>Pre monsoon</th>
<th>Post monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing problem</td>
<td>17</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>No problem</td>
<td>33</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

Chloride concentration (Fig. 3.39 a and b)

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
<th>Pre monsoon</th>
<th>Post monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe problem</td>
<td>01</td>
<td>01</td>
<td></td>
</tr>
<tr>
<td>Increasing problem</td>
<td>02</td>
<td>03</td>
<td></td>
</tr>
<tr>
<td>No problem</td>
<td>47</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

Bicarbonate concentration (Fig. 3.40 a and b)

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
<th>Pre monsoon</th>
<th>Post monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe problem</td>
<td>00</td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>Increasing problem</td>
<td>30</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>No problem</td>
<td>20</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
Sulphate concentration (Fig. 3.41 a and b)

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Excellent</td>
<td>50</td>
</tr>
<tr>
<td>Good</td>
<td>00</td>
</tr>
<tr>
<td>Permissible</td>
<td>00</td>
</tr>
</tbody>
</table>

Adjusted SAR (Fig. 3.42 a and b)

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>No problem for toxicity</td>
<td>17</td>
</tr>
<tr>
<td>No problem for permeability</td>
<td>22</td>
</tr>
<tr>
<td>Upper limit for toxicity and permeability</td>
<td>04</td>
</tr>
<tr>
<td>Over upper limit for toxicity and permeability</td>
<td>07</td>
</tr>
</tbody>
</table>

NON-CARBONATE HARDNESS (NCH)

Raghunath (1987) proposed NCH based on relative proportions of bicarbonates of calcium and magnesium. The classification based on this is given below;

<table>
<thead>
<tr>
<th>Class</th>
<th>NCH</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Safe</td>
<td>&lt;0</td>
<td>40</td>
</tr>
<tr>
<td>Unsafe</td>
<td>&gt;0</td>
<td>10</td>
</tr>
</tbody>
</table>

PERMEABILITY INDEX (PI)

Doneen (1962) proposed permeability index based on the relation of bicarbonate and Ca-Mg-Na. The classification based on this is given below;
### Class PI

<table>
<thead>
<tr>
<th>Class</th>
<th>PI</th>
<th>No of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Class I (safe)</td>
<td>&lt;25%</td>
<td>00</td>
</tr>
<tr>
<td>Class II (allowable)</td>
<td>25 -75%</td>
<td>02</td>
</tr>
<tr>
<td>Class III (unsafe.)</td>
<td>&gt;75%</td>
<td>48</td>
</tr>
</tbody>
</table>

### POTENTIAL SOIL SALINITY (P S)

Doneen (1962) proposed potential soil salinity based on chloride and sulphate content. The classification based on this is given below;

<table>
<thead>
<tr>
<th>Class</th>
<th>PS</th>
<th>No of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre monsoon</td>
</tr>
<tr>
<td>Excellent to Good</td>
<td>&lt;3</td>
<td>--</td>
</tr>
<tr>
<td>Good to Injurious</td>
<td>3-5</td>
<td>--</td>
</tr>
<tr>
<td>Injurious–Unsatisfactory</td>
<td>&gt;5</td>
<td>50</td>
</tr>
</tbody>
</table>

### 8. INCRUSTATION AND CORROSION CHARACTER

The bicarbonates of calcium and magnesium decompose to form insoluble carbonates and release of carbon dioxide. Thus released and decomposed insoluble carbonates precipitate to form incrustation. Similar incrustation due to sulphates and silicates of calcium and magnesium are also observed. The incrustations formed due to decomposition of bicarbonates of calcium and magnesium is "soft" and can be removed by acids and other chemicals. The incrustations formed due to calcium and magnesium is "hard" and cannot be removed by acids and other chemicals easily.

Raghunath (1987) has suggested six groups depending on water chemistry to distinguish types of incrustation and corrosion characters. They are as follows;
Water samples with > 400 mg/l of bicarbonates may cause "soft type incrustations"

Water samples with >100 mg/l of sulphates or 40 mg/l of silicon may cause "hard type incrustation"

Water samples with pH values < 7 are "corrosive"

Water samples with EC values > 1500 μmhos/cm may cause "corrosion on iron and steel"

Water samples with Cl > 500 mg/l may indicate "corrosive property of water"

Water samples with > 2 mg/l of iron or 1.0 mg/l of manganese may cause precipitation hydroxides and oxides of iron and manganese (incrustations)

In the present study the chemical analyses of both pre and post monsoon samples are compared with respect to above suggestions. This comparison brings out following points.

The groundwater samples of both the seasons are free from "soft and hard type incrustation" (Based on bicarbonate and sulphate contents)

Two groundwater samples of post monsoon season show pH < 7 and 14 samples of pre monsoon season show pH < 7. These groundwater samples are of corrosive in nature

Five groundwater samples of post monsoon season show EC Values > 1500 μmhos/cm and three samples of pre monsoon season show EC values > 1500 μmhos/cm. These groundwater samples may cause corrosion of iron and steel.

Only one groundwater samples shows Cl value > 500 mg/l indicating that the sample has corrosive property.

Iron and manganese contents are not determined.
9. ELECTRICAL CONDUCTIVITY VARIATION ALONG 
AND ACROSS THE STUDY AREA


Groundwater samples are collected during above said months. Grid no.1, 3,5,11,13,15,21,23,25,21,33,25,41,42,44,48, and 50 are considered for collecting groundwater samples. These locations are shown in Fig. 3.43.

All the samples collected from above said months are subjected for the determination of electrical conductivity. The data is given in Table 3.9 (along the coast) and 3.10 (across the coast). This data is interpreted by plotting variation diagram as shown in Fig. 3.44 to 3.45.

The Table 3.9 (a) shows the variation close to the coast. The EC value of grid 11 is high when compare to other grids. The EC values show increase from March 2001 to March 2002.

The Table 3.9 (b) shows the EC variation from November 2001 to March 2002, about 3 kms away from coast. The EC values increase from November 2001 to March 2002 except in grids 33 and 42.

The Table 3.9 (c) shows the EC variation from November 2001 to March 2002, about 5 kms away from coast. The EC values increase from November 2001 to March 2002 except in grids 48.

The Table 3.9 shows high EC values close to the coast and the value is low in the samples away from the coast. This behavior is true in the months of November 2001, January 2002 and March 2002. However there are some exceptions. This behaviour of samples is shown in Fig. 3.44 (a to c).
The Table 3.10 is prepared for the EC values across the coast. Six rows are considered with three samples in first five rows and two samples in sixth row. A look at the Table 3.10 clearly reveals that the EC values are higher close to the coast and lower in the locations away from the coast. This is true in all the six rows considered. This behaviour of samples is shown in figures 3.45 (a to f).

10. COMPARATIVE STUDY OF CHEMICAL CHARACTERS WITH RESPECT TO OTHER AREAS

The chemical characters of groundwater samples understudy are compared with the groundwater samples of other areas with laterites as litho units. Following are the areas considered:

❖ Udapi area, (coastal track) Lokesh and Naryan Shenoy, (1997)
❖ Sirsi area (inland area) Hegde (1994)
❖ Belgaum city area (inland area) Puranik.(1995)
❖ Bidar area (inland area) Gourshetty (1995)
❖ Goa area (coastal track) Glen (1993)
❖ Bhatkal-Shirali (coastal track) Study area

The Table 3.11 gives the minimum, maximum and average values of chemical constituents of groundwater from above said areas. In order to appreciate the similarity or the difference between the groundwater samples of present study and those of other areas, range diagrams are prepared (Fig. 3.46 to 3.53). These diagrams also show the average contents of the individual constituents and these have been indicated by dark lines.

The Fig. 3.46 drawn for Calcium reveals that the range of Ca for the Belgaum area samples is widest and has highest values of average content. The coastal samples
show nearly same average values, except Goa samples, while those inland samples show higher values.

The Fig. 3.47 drawn for Magnesium reveals that the range of Mg for the Belgaum area samples is widest and has highest values of average content. The coastal samples show nearly same average values except Goa and Visakhapatnam while those inland samples show higher values except Sirsi area.

The Fig. 3.48 drawn for Sodium and Potassium reveals that the range of Na+K for the Goa area samples is widest. Similarly study area samples also show wide range. The average content is higher for coastal track samples than inland samples. The Visakhapatnam area samples show highest average value.

The Fig. 3.49 drawn for Chloride reveals that the range of Cl for the Bidar area samples is widest. The average content is lower for coastal track samples than inland samples. The Visakhapatnam area shows highest average value.

The Fig. 3.50 drawn for Sulphate reveals that the range of S04 for the Bidar area samples is widest. The average content is generally low in all samples and is high in Bidar samples.

The Fig. 3.51 drawn for Bicarbonate and Carbonate reveals that the range of HCO3+CO3 for the Belgaum area samples is widest. The average content is lower for coastal track except Visakhapatnam area than inland samples. The Belgaum area shows highest average value.

The Fig. 3.52 drawn for Total dissolved solids (TDS) reveals that range of TDS for the Goa area samples show widest range followed by samples under study area and Belgaum area samples. Due to wide range of T D S contents the average value is not comparable with any of the locality.

The Fig. 3.53 drawn for Total hardness (TH) reveals that the range of TH for the Belgaum area samples is widest. The average content is lower for the coastal track
samples than inland samples except Visakhapatnam area. The Belgaum area samples show highest average value.

The above explanation clearly shows that Na + K and Cl contents are higher for coastal samples while Ca + Mg and HCO₃ + CO₃ are higher in inland samples.

11. GROUNDWATER POLLUTION STUDIES

Water pollution is defined as “the introduction by man into the environment of substance or energy liable to cause hazards to human health, harm to living resources and ecological systems, damages to structure or amenity or interference with legitimate uses or the environment”. Pollutants are therefore chemical or physical in nature and can thus be measured more or less accurately in water. The measured quantities can thus be compared with standards allowable concentrations.

The groundwater contamination looms around industrialized, suburban, urban and rural areas. Common industrial solvents such as trichloroethylene, tetrachloroethane, benzene and carbon tetra chloride have been reported in wide spread areas (Fusillo, et.al.1985). Urban, suburban and rural areas groundwater shows high levels of nitrate due to fertilizers as well as septic tank discharges (Flipse.et.al.1984). The specialized synthetic organic agricultural chemicals (Rathschild.et.al.1982) and to groundwater pollution, landfills in urban and rural areas are known sources or contaminations (Noss and Johnson, 1984). Contaminated groundwater in most cases will not travel more than a few thousand meters from the sources and in many cases not more than a few 100 meters. If there is a single source, the contamination is localized. If there is multiple sources or if the contamination is a result or wide spread land use practices, than the contamination cover large area.

In the study area there are no industries. The agricultural lands are sporadically distributed. Thus the contamination of groundwater by industrial effluent is ruled out. The contaminant by use of fertilizer and pesticides in agricultural practice is also minimum.
There are few locations in the study area where a density of the population is more and use of septic tank is common practice. There is possibility of groundwater contamination by the effluents from septic tank, cess pools, land fills and ill maintained sewage channels.

The septic tank, cess pools and sewage channels (unlined) are most likely to contribute to groundwater contamination in areas, where

❖ There is high density of homes with septic tanks.
❖ Soil layer over permeable bed rock is thin.
❖ The soil is extremely permeable
❖ The water table is within couple of meters of the land surface.

The most common means of disposing of municipal refuses, ashes, garbage, leaves, and demolition debris in land fill is usual practice. The precipitation that infiltrates the waste can mix liquids already present in the waste and leach compounds from solid waste. The resulting liquid is known as leachate. The leachate can move downward from the landfill into the water table and cause groundwater contamination.

The pollutants created by a septic tanks and land fills are normally biological pollutants. Following are the reasons why biological parameters are important in groundwater.

❖ Man by using fresh water and eating organic products is directly linked to aquatic community. The effects of man waste product the aquatic community that is water.
❖ Animal and plant community also pollute water intermittently.
❖ The pollutants will kill the most vulnerable members of aquatic community. The most sensitive species act as indicates of pollution.
❖ Biological community may respond to unsuspected or new pollutants in the environment.
❖ Some chemical are accumulated in the bodies of certain organism, concentrations within them reflecting environmental pollution levels over time.
Heavy metals and organochlorine pesticides have caused particular problems in aquatic habitats and are potential threats to human health.

The biological parameters or organic pollutants resulted when large quantities of biological matter are discharged and broken down by micro organisms. This organic pollutant dissolved in groundwater and contaminates the groundwater. Such organic pollutant is measured in groundwater by estimating chemical oxygen demand (COD), dissolved oxygen (D.O), biochemical oxygen demand (BOD) and organic carbon or organic matter content.

The chemical oxygen demand (COD) is measure of organic matter content of the sample that is susceptible to oxidation by strong chemical oxidant. The biological oxygen demand (BOD) is the quantity of oxygen required for the oxidation of the organic matter by bacterial action in the presence of oxygen. The dissolved oxygen (DO) is oxygen content in the water or sewage.

In the study area thickly populated areas discharge large quantity of waste water. The soil layer is permeable. The laterites are with numerous natural openings to transmit water i.e. is the laterites are highly permeable. These features of the study area facilitate for infiltration of liquid waste.

Twelve locations are selected where there is possibility of organic pollution. Here domestic waste is found discharged in the vicinity of the residential complexes. These complexes use groundwater from the dug wells close by. The twelve locations are shown in Fig. 3.54. The Photos 3.1 and 3.2 shows the sewage waste in the study area. At these locations water samples are collected and estimated for the BOD contents. The BOD values are given below
The BOD values are more than 1 mg/l in 11 localities indicating that the groundwater is highly polluted by organic matter. It is necessary to warn the local people who are using such polluted water. They are advised to use the water from other sources.

<table>
<thead>
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<th>Grid number</th>
<th>BOD in mg/l</th>
<th>Grid number</th>
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<td>06</td>
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<td>6.8</td>
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