“Water is the driver of Nature”.

1.1 INTRODUCTION
For the existence of all living beings (human, animals and plants), water is very crucial. Almost all human activities—domestic, agricultural and industrial, demand use of water although water is nature’s most wonderful and abundant compound but only less than 1% of the world’s water resources are available for ready use. Hence it is required to use it carefully and economically. This chapter deals with the hardness of water and various methods of purification of water for municipal water supply.

1.2 SOURCE OF WATER
The main sources of water are:

(i) **Surface water**: It includes flowing water (streams and rivers) and still water (lakes, ponds and reservoirs).

(ii) **Underground water**: It includes water from wells and springs.

(iii) **Rain water**

(iv) **Sea water**.

1.3 IMPURITIES OF WATER
The impurities present in water may be categorised into following categories:

(A) **Dissolved Impurities**
   (a) **Dissolved gases**: \( \text{O}_2, \text{CO}_2, \text{H}_2\text{S} \) etc.
   (b) **Inorganic salts**:
       (i) **Cations**: \( \text{Ca}^{++}, \text{Mg}^{++}, \text{Na}^+, \text{K}^+, \text{Fe}^{++}, \text{Al}^{+++} \) etc.
       (ii) **Anions**: \( \text{CO}_3^{-}, \text{Cl}^-, \text{SO}_4^{2-}, \text{NO}_3^- \) etc.
   (c) **Organic salts**.
(B) Suspended Impurities

(a) Inorganic: Clay and sand.

(b) Organic: Oil globules, vegetables, and animal material.

(C) Colloidal Impurities

Finally divided clay and silica $\text{Al(OH)}_3$, $\text{Fe(OH)}_3$, organic waste products, colouring matter, amino acids etc.

(D) Microscopic Matters

Bacteria, algae, fungi etc.

1.4 SOURCES OF IMPURITIES IN WATER

Following are the sources of impurities in water:

(i) Gases ($\text{O}_2$, $\text{CO}_2$ etc.) are picked up from the atmosphere by rainwater.

(ii) Decomposition of plants and animals remains introduce organic impurities in water.

(iii) Water dissolves impurities when it comes in contact with ground, soil or rocks.

(iv) Impurities are also introduced in water when it comes in contact with sewage or industrial waste.

Impurities in various sources of water

River water contains dissolved minerals like chlorides, sulphates, bicarbonates of sodium, magnesium, calcium and iron. It also contains suspended impurities of sand, rocks and organic matter. The composition of river water is not constant. The amount of dissolved impurities in it depends on its contacts of the soil. Greater the duration of contact, more soluble is the minerals of soil in it.

Lake water has high quantity of organic matter present in it but lesser amount of dissolved minerals. Its chemical composition is also constant.

Rain water is obtaining as a result of evaporation from the surface water. Probably it is the purest form of natural water. But during its downward journey through the atmosphere it dissolves organic and inorganic suspended particles and considerable amount of industrial gases like ($\text{CO}_2$, $\text{NO}_2$, $\text{SO}_2$ etc.). Rain water is expensive to collect and is irregular in supply.

Underground water is free from organic impurities and is clearer in appearance due to the filtering action of the soil. But it contains large amount of dissolved salts.

Sea water is very impure due to two reasons:

1. Continuous evaporation increases the dissolved impurities content, which is further increased by the impurities thrown by rivers as they join sea.

2. It is too saline for most industrial uses except cooling.
1.5 HARDNESS OF WATER

“Hardness in water is that characteristics, which prevents the lathering of soap”. In other way we may define it as “soap consuming capacity of water”.

1.5.1 Cause of Hardness

Hardness is due to presence of certain salts of Ca\(^{2+}\), Mg\(^{2+}\) and other heavy metal ions like Al\(^{3+}\), Fe\(^{3+}\) and Mn\(^{2+}\) in water.

**Mechanism of cause of hardness:** It can be explained by the reaction of soap in soft and hard water.

**Reaction of soap in soft water**

When soft water is treated with soap, lather is produced according to the following reaction:

\[
C_{17}H_{35}COONa + H_2O \rightarrow C_{17}H_{35}COOH + NaOH
\]

<table>
<thead>
<tr>
<th>Soap (Sodium stearate)</th>
<th>Stearic acid</th>
</tr>
</thead>
</table>

\[
C_{17}H_{35}COONa + C_{17}H_{35}COOH \rightarrow \text{Lather}
\]

<table>
<thead>
<tr>
<th>Soap (Sodium stearate)</th>
<th>Stearic acid</th>
</tr>
</thead>
</table>

**Reaction of soap in hard water**

A sample of hard water, when treated with soap (sodium or potassium salt of higher fatty acid like oleic, palmitic and stearic acid), does not produce lather, but on the other hand forms insoluble white scum or precipitate which do not possess any detergent action. This is due to the formation of insoluble soap of calcium and magnesium. Typical reaction of soap (sodium stearate) with calcium chloride and magnesium sulphate are shown below.

\[
2 C_{17}H_{35}COONa + CaCl_2 \rightarrow (C_{17}H_{35}COO)_2Ca \downarrow + 2 NaCl
\]

<table>
<thead>
<tr>
<th>Soap (Sodium stearate)</th>
<th>(From hard water)</th>
<th>Calcium stearate</th>
</tr>
</thead>
</table>

*(Insoluble scum)*

\[
2 C_{17}H_{35}COONa + MgSO_4 \rightarrow (C_{17}H_{35}COO)_2Mg \downarrow + Na_2SO_4
\]

<table>
<thead>
<tr>
<th>Soap (Sodium stearate)</th>
<th>(From hard water)</th>
<th>Magnesium stearate</th>
</tr>
</thead>
</table>

*(Insoluble scum)*

Actually hardness is due to presence of Cl\(^-\), SO\(^4\(^{-2}\), HCO\(^-\) and CO\(^3\(^{-2}\) of Ca\(^{2+}\), Mg\(^{2+}\) and other heavy metal ions like Fe\(^{3+}\), Al\(^{3+}\) and Mn\(^{2+}\). The presence of CO\(^3\(^{-2}\) also breaks up Na or K soaps into free fatty acids and does not allow lather to be formed.
1.5.2 Types of Hardness

It is of following types:

1. **Temporary Hardness**
   
   (a) Temporary hardness is caused by the presence of dissolved bicarbonates of calcium, magnesium and other heavy metals and the carbonates of iron and other metals also. Thus, the main salts responsible for temporary hardness are Ca(HCO₃)₂ and Mg(HCO₃)₂.
   
   (b) Temporary hardness can be largely removed by more boiling of water, when bicarbonates are decomposed, yielding in soluble carbonates or hydroxides, which are deposited as a crust at the bottom of vessel.
   
   
   \[
   \text{Ca(HCO}_3\text{)}_2 \rightarrow \text{CaCO}_3 \downarrow + \text{H}_2\text{O} + \text{CO}_2 \uparrow
   \]
   
   \[
   \text{Mg(HCO}_3\text{)}_2 \rightarrow \text{Mg(OH)}_2 \downarrow + 2\text{CO}_2 \uparrow
   \]
   
   (c) Temporary hardness is also known as carbonate hardness or alkaline hardness.
   
   (d) Alkaline hardness is due to the presence of bicarbonates, carbonates and hydroxides of the hardness producing metal ions. This is determined by titration with HCl using methyl orange as indicator.

2. **Permanent Hardness**

   (a) It is due to the presence of dissolved chlorides and sulphates of calcium, magnesium, iron and other heavy metals. Hence, the salts responsible for permanent hardness are CaCl₂, MgCl₂, CaSO₄, MgSO₄, FeSO₄, Al₂(SO₄)₃ etc.
   
   (b) Unlike temporary hardness, permanent hardness is not destroyed on boiling.
   
   (c) It is also known as non-carbonate or non-alkaline hardness.
   
   (d) The difference between total hardness and alkaline hardness gives the non-alkaline hardness.

1.5.3 Disadvantages of Hard Water or Effect of Hardness

Hardness causing impurities present in the hard water exert following effects:

   (a) **Effect on efficiency of soap:** It is decreased due to the formation of scum.

   \[
   2 \text{C}_{17}\text{H}_{35}\text{COONa} + \text{CaCl}_2 \rightarrow (\text{C}_{17}\text{H}_{35}\text{COO})_2\text{Ca} \downarrow + 2\text{NaCl}
   \]

   Soap (Sodium stearate) (From hard water) Calcium stearate (Insoluble scum)

   (b) **Effect on economy:** It is decreased due to decrease in the efficiency of soap in hard water as the consumption of soap is increased.

   (c) **Effect on health:** It adversely affects digestive system and increased possibilities of forming calcium oxalate crystals in the urinary track on drinking.

   (d) **Effect on domestic uses:**

   (i) **Washing:** Hard water, when used for washing purposes, it does not lather freely with soap, on the other hand, it produces sticky precipitate (i.e. scum) of calcium and magnesium soaps. The formation of such insoluble sticky
precipitates continues till all calcium and magnesium salts present in water are precipitated. After that, the soap (i.e., sodium stearate) gives lather with water.

\[
\text{C}_{17}\text{H}_{35}\text{COONa} + \text{H}_2\text{O} \rightarrow \text{C}_{17}\text{H}_{35}\text{COOH} + \text{NaOH}
\]

Soap (Sodium stearate) \hspace{1cm} \text{Stearic acid}

\[
\text{C}_{17}\text{H}_{35}\text{COONa} + \text{C}_{17}\text{H}_{35}\text{COOH} \rightarrow \text{Lather}
\]

Soap (Sodium stearate) \hspace{1cm} \text{Stearic acid}

This causes wastage of lot of soap being used. The sticky precipitate adheres on the fabric giving spots and streaks. Iron salts may cause staining of cloth.

(ii) **Bathing:** Sticky scum produced by hard water with soap depresses the cleansing quality of soap and a lot of it is wasted.

(iii) **Cooking:** Due to presence of dissolved hardness producing salts, the boiling point of water is elevated. Consequently, more fuel and time are required for cooking. Certain foods such as pulses, beans and peas do not cook soft in hard water. Also tea or coffee, prepared in hard water, has an unpleasant taste and muddy looking extract. Moreover, the dissolved salts are deposited as carbonates on the inner walls of the water heating utensils.

(e) **Effect on steam generation in boilers:** For steam generation, boilers are almost invariable employed. If the hard water fed directly to the boilers, there arise many troubles such as: (i) Scale and sludge formation, (ii) corrosion (iii) priming and foaming, and carry over, (iv) caustic embrittlement.

(f) **Effect on laboratories:** Hardness causing ions interference in various reactions therefore it is not a suitable solvent.

(g) **Effect on industries:** Due to presence of dissolved salts, it exerts adverse effects on various industries like

(i) **Textile industries:**
- Wastage of soap.
- Scum adhere to the fabric and exact shades of colour cannot be produced on such fabrics during dyeing.
- Salts may cause coloured spots on fabrics, thereby spoiling their beauty.

(ii) **Sugar industries:**
- Difficulties in crystallization of sugar.
- Produced sugar may be deliquescent.

(iii) **Dyeing industry:**
- Dissolved salts may react with costly dyes, which gives result of impure shade.
- Spot on fabric being dyed.

(iv) **Paper industry:**
- Dissolved salt may react with the chemicals used to give shining to paper.
- Iron salts may affect colour of paper being produced.
(v) Laundry industry:
- Wastage of soap.
- Iron salts may effect coloration of cloths.

(vi) Concrete industry:
- Effect adversely the hydration of cement and final strength of the hardened concrete.

(vii) Pharmaceutical industries:
- It may produce certain undesirable products in the pharmaceutical products like drugs, injections, ointments etc.

1.5.4 Types of Water on the Basis of Hardness

On the basis of hardness water can be classified into two classes.

1. Hard water: “Water which does not produce lather with soap but produces an insoluble white precipitate i.e., scum is called hard water”.

\[ 2 \text{C}_{17}\text{H}_{35}\text{COONa} + \text{MgSO}_4 \rightarrow (\text{C}_{17}\text{H}_{35}\text{COO})_2\text{Mg} \downarrow + \text{Na}_2\text{SO}_4 \]

Soap (Sodium stearate) \hspace{1cm} (From hard water) \hspace{1cm} Magnesium stearate \hspace{1cm} (Insoluble scum)

2. Soft water: “Water which produces lather with soap is known as soft water”.

\[ \text{C}_{17}\text{H}_{35}\text{COONa} + \text{H}_2\text{O} \rightarrow \text{C}_{17}\text{H}_{35}\text{COOH} + \text{NaOH} \]

Soap (Sodium stearate) \rightarrow Stearic acid

\[ \text{C}_{17}\text{H}_{35}\text{COONa} + \text{C}_{17}\text{H}_{35}\text{COOH} \rightarrow \text{Lather} \]

Soap (Sodium stearate) \hspace{1cm} Stearic acid

1.5.5 Differences between Hard Water and Soft Water

The differences between hard and soft water are summarized in Table 1.1.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Criteria</th>
<th>Hard Water</th>
<th>Soft Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Definition</td>
<td>“Water which does not produce lather with soap solution readily but forms a white scum is called hard water.”</td>
<td>“Water which lathers easily on shaking with soap solution is called soft water”.</td>
</tr>
<tr>
<td>2.</td>
<td>Dissolved salt</td>
<td>Salts of Ca and Mg and other heavy metals are present.</td>
<td>Does not contain such salts.</td>
</tr>
<tr>
<td>3.</td>
<td>Wastage of soap</td>
<td>Soap is wasted to get desired results.</td>
<td>Does not waste.</td>
</tr>
<tr>
<td>4.</td>
<td>Cleansing quality of soap</td>
<td>It is depressed due to hardness and a lot of soap is wasted during washing and bathing.</td>
<td>It is good in soft water as it gives lather readily.</td>
</tr>
</tbody>
</table>

(Cont.)
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
<td>Taste of water</td>
<td>It is usually better than soft water. The label on the bottle of mineral water shows that it contains Mg(^{++}) and Ca(^{++}) ions.</td>
</tr>
<tr>
<td>6.</td>
<td>Strong teeth and bones</td>
<td>It helps in producing strong teeth and bones due to presence of Ca(^{++}) ions.</td>
</tr>
<tr>
<td>7.</td>
<td>Prevention of lead dissolution</td>
<td>Lead piping used for distribution of water in old house are coated with insoluble CaCO(_3) present in hard water. This prevents any of the poisonous lead dissolving in the drinking water.</td>
</tr>
<tr>
<td>8.</td>
<td>Elevation of boiling point of water</td>
<td>Due to presence of dissolved salts, the boiling point of water is elevated consequently more fuel and time are required for cooking. Moreover the dissolved salt are deposited as carbonates on the inner walls of the water heating utensils.</td>
</tr>
<tr>
<td>9.</td>
<td>Effect on health</td>
<td>It causes bad effect on our digestive system more over the possibility of the forming calcium oxalate crystals in urinary track is increased.</td>
</tr>
</tbody>
</table>
| 10. | Effect on steam generation in boiler | Direct use of hard water in boiler creates following troubles:
- Scale and sludge formation
- Corrosion
- Caustic embrittlement
- Priming, foaming and carry over. | No such effect is observed. |
| 11. | Effect on industries | **Textile industries**
- Wastage of soap
- Scum adhere to the fabric and exact shades of colour cannot be produced on such fabrics during dyeing.
- Salts may cause coloured spots on fabrics, thereby spoiling their beauty.
**Sugar industries**
- Difficulties in crystallisation of sugar.
- Produced sugar may be deliquescent.
**Dyeing industry**
- Dissolved salts may react with costly dyes. Which will give result of impure shade.
- Spot on fabric being dyed.
**Paper industry**
- Dissolved salt may react with the chemicals used to give shining to paper.
- Iron salts may affect colour of paper being produced.
**Laundry industry**
- Wastage of soap.
- Iron salts may effect colouration of cloths. | No such effect is observed as there are no salts present in soft water. |

(Cont.)
1.5.6 Degree of Hardness

Although hardness of water is never present in the form of the calcium carbonate, because it is insoluble in water, hardness of water is conveniently expressed in terms of equivalent amount of CaCO$_3$.

The reason for choosing CaCO$_3$ as the standard for reporting hardness water is the ease in calculation as its molecular weight is exactly 100. Moreover, it is the most insoluble salt that can be precipitate in water treatment.

Equivalents of CaCO$_3$ = \[\text{Amount of hardness producing substance} \times \left( \frac{100}{\text{Chemical equivalent of hardness producing substance} \times 2} \right)\]

\[= \text{Amount of hardness producing substance} \times \left( \frac{100}{\text{Multiplication factor}} \right) \text{ in mg/lit. or ppm.}\]

Multiplication factor

Weight of MgSO$_4$, Mg(HCO$_3$)$_2$, MgCl$_2$ and CaCl$_2$ actually present, may be converted in terms of weight of CaCO$_3$ by multiplying $100/120, 100/146, 100/95$ and $100/111$ respectively. Factors used for such conversion are called multiplication factor. It can be shown as follows:

\[\text{Mg(HCO$_3$)$_2$} = \text{CaCO$_3$}\]

\[146 = 100\]

Where, we are comparing hardness due to Mg(HCO$_3$)$_2$ in terms of CaCO$_3$ equivalents.

X quantity of Mg(HCO$_3$)$_2 = X \times 100/146$ amount of CaCO$_3$ thus the factor 100/146 is multiplication factor (M.F.) for Mg(HCO$_3$)$_2$.

Multiplication factor = $100/\left( \text{Chemical equivalent of hardness producing substance} \times 2 \right)$

M.F. for various compounds are shown in Table 1.2.
Table 1.2: Multiplication factors for various compounds

<table>
<thead>
<tr>
<th>Compounds/Salt/Ions</th>
<th>Molar mass</th>
<th>Chemical equivalent</th>
<th>Multiplication factor (for conversion into CaCO&lt;sub&gt;3&lt;/sub&gt; equivalent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca(HCO&lt;sub&gt;3&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>162</td>
<td>81</td>
<td>100/162</td>
</tr>
<tr>
<td>Mg(HCO&lt;sub&gt;3&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>146</td>
<td>73</td>
<td>100/146</td>
</tr>
<tr>
<td>CaCO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>100</td>
<td>50</td>
<td>100/100</td>
</tr>
<tr>
<td>MgCO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>84</td>
<td>42</td>
<td>100/84</td>
</tr>
<tr>
<td>CaSO&lt;sub&gt;4&lt;/sub&gt;</td>
<td>136</td>
<td>68</td>
<td>100/136</td>
</tr>
<tr>
<td>CaCl&lt;sub&gt;2&lt;/sub&gt;</td>
<td>111</td>
<td>55.5</td>
<td>100/111</td>
</tr>
<tr>
<td>MgSO&lt;sub&gt;4&lt;/sub&gt;</td>
<td>120</td>
<td>60</td>
<td>100/120</td>
</tr>
<tr>
<td>MgCl&lt;sub&gt;2&lt;/sub&gt;</td>
<td>95</td>
<td>47.5</td>
<td>100/95</td>
</tr>
<tr>
<td>Mg(NO&lt;sub&gt;3&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>148</td>
<td>74</td>
<td>100/148</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>44</td>
<td>22</td>
<td>100/44</td>
</tr>
<tr>
<td>Ca&lt;sup&gt;2+&lt;/sup&gt;</td>
<td>40</td>
<td>20</td>
<td>100/40</td>
</tr>
<tr>
<td>Mg&lt;sup&gt;2+&lt;/sup&gt;</td>
<td>24</td>
<td>12</td>
<td>100/24</td>
</tr>
<tr>
<td>CO&lt;sub&gt;3&lt;/sub&gt;&lt;sup&gt;2-&lt;/sup&gt;</td>
<td>60</td>
<td>30</td>
<td>100/60</td>
</tr>
<tr>
<td>H&lt;sup&gt;+&lt;/sup&gt;</td>
<td>1</td>
<td>1</td>
<td>100/02</td>
</tr>
<tr>
<td>HCO&lt;sub&gt;3&lt;/sub&gt;&lt;sup&gt;-&lt;/sup&gt;</td>
<td>61</td>
<td>61</td>
<td>100/2×61 = 100/122</td>
</tr>
<tr>
<td>OH&lt;sup&gt;-&lt;/sup&gt;</td>
<td>17</td>
<td>17</td>
<td>100/2×17 = 100/34</td>
</tr>
<tr>
<td>NaAlO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>82</td>
<td>82</td>
<td>100/64</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;(SO&lt;sub&gt;4&lt;/sub&gt;)&lt;sub&gt;3&lt;/sub&gt;</td>
<td>342</td>
<td>57</td>
<td>3×100/342 = 100/114 or 100/57</td>
</tr>
<tr>
<td>FeSO&lt;sub&gt;4&lt;/sub&gt;·7H&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>278</td>
<td>139</td>
<td>100/278</td>
</tr>
<tr>
<td>Ca(NO&lt;sub&gt;3&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>164</td>
<td>82</td>
<td>100/164</td>
</tr>
<tr>
<td>HCl</td>
<td>36.5</td>
<td>1</td>
<td>100/2×36.5 = 100/73</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;SO&lt;sub&gt;4&lt;/sub&gt;</td>
<td>98</td>
<td>49</td>
<td>100/98</td>
</tr>
</tbody>
</table>
1.5.7 Units of Hardness

The analyzed result of hard water are expressed in one of the following units:

<table>
<thead>
<tr>
<th>Unit</th>
<th>ppm</th>
<th>Mg/lit</th>
<th>°Fr</th>
<th>°Cl</th>
<th>Meq/lit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part per million</td>
<td>ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milligram/litre</td>
<td>Mg/lit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degree French</td>
<td>°Fr</td>
<td>10</td>
<td>1</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Degree clark</td>
<td>°Cl</td>
<td>14.3</td>
<td>14.3</td>
<td>1.433</td>
<td>1</td>
</tr>
<tr>
<td>Milliequivalent/litre</td>
<td>Meq/lit.</td>
<td>50</td>
<td>50</td>
<td>5</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Relation between various units of hardness

**Unit**  
**Definition**

1. **1 ppm** = Parts of CaCO$_3$ eq. hardness in 10$^6$ parts of water. “It is the number of parts by weight of CaCO$_3$ equivalent hardness present per million parts of water”.

2. **1 mg/lit.** = Mg of CaCO$_3$ eq. hardness in 1 lit. of water. “It is the number of mg of CaCO$_3$ equivalent hardness present per lit of water “1 mg/lit = 1 ppm”.

3. **°Fr** = Parts of CaCO$_3$ eq. hardness in 10$^5$ parts of water. “It is the parts of CaCO$_3$ equivalent hardness present per 10$^5$ parts of water.”

4. **°Cl** = Parts of CaCO$_3$ eq. hardness in 70,000 parts of water. “It is the number of Grains (1/7000 lb) of CaCO$_3$ equivalent hardness present per gallon (10 lb) of water or parts of CaCO$_3$ equivalent hardness present per 70,000 parts of water”.

5. **1 meq/lit.** = Meqs of CaCO$_3$ eq. hardness in 10$^6$ parts of water. “It is the number of milliequivalents of CaCO$_3$ equivalent hardness present per lit of water” 1 meq/lit. = 50 ppm.

Numerical Examples

Example 1: A sample of water contains 33.3 mg of CaCl$_2$ per liter. Calculate the hardness of water sample in terms of CaCO$_3$ equivalent.

**Solution:** 1 liter of water contains 33.3 mg of CaCl$_2$  
= 33.3 mg of CaCl$_2$  
= 33.3 × 100/111 mg of CaCO$_3$ eq.  
= 30 mg of CaCO$_3$ eq.

Hence, hardness of water sample = 30 mg/l CaCO$_3$ eq.

(*1 lb (libra) = 7,000 grains and 1 gallon = 70,000 grains or 10 lbs)