analysis of data due to perhaps not fully realizing the limiting conditions of the method. An attempt has been made in the present section to discuss the theory behind Papadopoulos-Cooper method and to highlight the limiting conditions for applicability of the method. The application of the Papadopoulos-Cooper method has demonstrated by conducted pumping tests of the large diameter wells existing in the study area.

Papadopoulos-Cooper (op.cit.), presented for the first time a method for analysis of pumping test data from dugwells of large diameter, taking into consideration that the water is derived from the storage within the well. It is an extension of the non-equilibrium formula of Theis (op.cit.). In case of large diameter well, the water stored in it contributes partly to the discharge when pumping commences, thereby reducing the magnitude of drawdown in the pumped well. The distortion thus introduced on drawdown persists for variable periods of time, depending on the hydraulic characteristics of the aquifer and the radius of pumped well. Once the effects of well storage are dissipated, the Theis non-equilibrium formula becomes essentially valid. Papadopoulos-Cooper (1969) attempted a rigid mathematical analysis of the problem and defined the behaviour of drawdown curve over the duration when effect of well storage persists.
Fig. 6.19 shows the type curves for the drawdown in large diameter wells indicating initially almost straight portion of type curve corresponding to the period when water is essentially derived from the storage. As the storage effect reduces the curve merges with the Theis curve. The general flow equation given by Papadopulas-Cooper describing the drawdown 's' in the vicinity of large diameter well is represented by the following equation -

\[
s = \frac{Q}{4\pi T} F(\theta, \alpha, \phi) \quad \text{- eq. (1)}
\]

Where, \( Q \) = rate of constant discharge, \( T \) = coefficient of transmissibility, \( s \) = drawdown in metre, \( F(\theta, q, \phi) \) = function for which the numerical values were calculated on the basis of following equations:

\[
\theta = \frac{4t}{r^2S} \quad \text{- eq. (2)}
\]

\[
\alpha = \frac{r^2WS}{rC^2} \quad \text{- eq. (3)}
\]

\[
\phi = \frac{r}{rW} \quad \text{- eq. (4)}
\]

Where, \( r \) = radius of well, \( rW \) = radius of pumped well, \( rC \) = radius of unscreened part of well.

The drawdown \( sW \) inside the well of large diameter (when \( r = rW \)) is given by

\[
sW = \frac{Q}{4\pi T} F(\theta, W, \alpha, 1) = \frac{Q}{4\pi T} W(u) \quad \text{eq. (5)}
\]
FIG. 6.19 DATA PLOT MATCH WITH PAPADOPULOS-COOPER TYPE CURVE ($\%_o = 1$)
Papadopulos (1967) presented tables for the function \( F (U, \phi) \) where \( U = 1/\theta \) from which type curves were prepared. The data plot of drawdown versus the reciprocal of time has been matched with the type curve to obtain a match point giving values of \( W_1(1/U) \), \( s_w \) and \( t \) which can be substituted in equation 5 and 2 to obtain values of 'T' & 'S' (Table No. 12).

The method is basically valid for confined aquifers. However, field experience has shown that the stratification within shallow aquifers that are only partially penetrated by a production well, can often lead to apparent confined conditions with total penetration of a group of stratifications.

Thus, the Papadopulos method is generally applicable for confined aquifer tapped in dugwells. Boulton-streltsova (1976) has provided higher degrees of freedom, applicable to a partially penetrating well in an unconfined aquifer and taking account of the compressibility of the aquifer to the method mentioned above. However, the method is very complex involving families of type curves. Papadopulos equation is in fact a limiting case of the Boulton-streltsova equation and generally yields reasonably good results.
Papadopulos-Cooper method can be indiscriminately applied to every dug well. The well should be representative of the aquifer to be tested and its design should be such that it fulfills most of the limiting conditions of the method.

The pumping of the test well should be done for a sufficiently long duration so that a sizable part of the data plot falls on the curved part of the type curve. The data which falls completely on the relatively straight part of the type curve can not be analysed by this method.

Pumping the well for longer duration, the data collected in the field often corresponds to the period when most of the water is derived from aquifer. Any attempt to match this data with straight part of type curve could lead to erroneous results.

Since the form of the type curve differs only very slightly when \( U \) differs by an order of magnitude, the value of 'S' determined from the method has questionable reliability.

Papadopulos-Cooper presented tables for the function \( F(U, \alpha, \beta) \) where \( U = 1/\theta \) such that the data can be plotted with drawdown versus the reciprocal of time. To facilitate the data plotting, the tables were recasted for function
\( F(\theta, \phi, \psi) \) which enables the data to be plotted directly as drawdown versus time. The values of the function \( F(\theta, \phi, \psi) \) and a number of type curves with different \( \psi \) values can be referred in the Manual on analysis of pumping test data of large diameter wells prepared by a technical committee of Central Groundwater Board. The type curve for \( r/r_w = 1 \) i.e., pumping well has been utilised to demonstrate the applicability of the Papadopoulos-Cooper method.

The pumping tests have been conducted in ten dugwells existing in the area under study. Each well was pumped at a constant rate till the equilibrium conditions were obtained in the dug well. The drawdown and recuperation data of the pumped well (Appendix No. 8) have been measured and recorded.

Out of the aquifer characteristics, such as porosity, permeability, specific yield, specific retention, 'T' and 'S', the most important ones 'T' (coefficient of transmissibility) and 'S' (coefficient of storage), have been determined by using the Papadopoulos and Cooper method. In India some of the workers such as Narasimhan (1968), Saral and Manikonda (1974) and Romani (1987), etc., have used the Papadopoulos and Cooper method.

The values of drawdowns have been plotted against the reciprocal of time \( (1/t) \) on double logarithmic graph
paper which is on the same scale as that used for the type curve. This is known as experimental curve. It has been placed over the type curve and keeping the axes of both the curves, i.e. experimental and type curves parallel, the position of the best fit (match), between the experimental curve and one of the type curves has been determined. Then an arbitrary match point has been selected on the overlapping position of both the curves and the corresponding values of $F(\theta, \alpha, \varphi)$, 'r' and $1/t$ have been determined for the match point by using these values in the following equations, the 'T' & 'S' have been determined and tabulated in Table No. 12 through the following equation -

$$T = \frac{Q}{4 \pi s \omega}, \text{ and}$$

$$S = \frac{Q r^2}{4 \pi t}$$

The initial position of the type curves are in the form of almost straight lines. These positions represent the period of the pumping when most of the water is pumped from the storage and the contribution from the inflow is less. Therefore, these positions do not represent the aquifer characteristics. As a consequence, the data that completely fall on the straight line portions of the type curve can not be used for this method. From the pumping test data of dug-wells, the experimental curves for each dugwell has been plotted and shown in Fig. 6.20 & 6.21. The recuperation data of pumping test have not been analyzed because the 'T' is calculated by the drawdown data.
FIG. 6.20 TIME DRAWDOWN CURVES FOR PUMPED WELLS TAIL PEACHES

OF MATATILA COMMAND

(M.R.)

1. VIJAYPUR
2. DARYAO PUR
3. AJNAR

△ MATCH POINT

1. KHITOW
2. SINPURA

DRAWDOWN IN METRES

TIME (T/4) IN DAYS
Fig. 6.21: Time drawdown curves for pumped wells tail peaches of Matatila Command (M.P.)
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Dug-well Location village</th>
<th>Aquifer</th>
<th>Coefficient of Transmissibility (T) in m²/day</th>
<th>Coefficient of Storage (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Khitow</td>
<td>Sandy Horiz.</td>
<td>131</td>
<td>9 x 10⁻⁵</td>
</tr>
<tr>
<td>2.</td>
<td>Sinpura -do-</td>
<td>105</td>
<td>1 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Vijaypura -do-</td>
<td>160</td>
<td>5 x 10⁻⁵</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Ajnar -do-</td>
<td>44</td>
<td>1 x 10⁻³</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Daryaopur -do-</td>
<td>80</td>
<td>1 x 10⁻³</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Aswar -do-</td>
<td>113</td>
<td>2 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Daboh -do-</td>
<td>185</td>
<td>1 x 10⁻³</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Lahar -do-</td>
<td>297</td>
<td>1 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Machand -do-</td>
<td>345</td>
<td>2 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Sujanpur -do-</td>
<td>247</td>
<td>5 x 10⁻⁵</td>
<td></td>
</tr>
</tbody>
</table>

A glance at the table no. 12 reveals that the aquifer tapped by the dug wells is confined.
7. QUALITY OF WATER AND ITS UTILISATION

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CHAPTER - 7

QUALITY OF WATER
AND ITS UTILISATION

Recently it is recognised that the quality of water is just as important as its quantity (Todd, 1980). The water that is evaporated as vapour from the surface of the earth is devoid of any impurities. When the rain falls, this water may be contaminated by atmospheric gases and suspended particles. The relatively slow movement of water percolating through the ground affords intimate and long contact of the water with the minerals that make up the earth's crust. These minerals are soluble in the water to a certain degree, so groundwater increases in mineral content until a combined equilibrium of the dissolved substances is attained.

The dissolved minerals in the groundwater affect its usefulness for various purposes. Fertilisers, pesticides and insecticides, which the farmers use to promote quality and quantity of crop as well as to prevent various plant diseases, also play important roles in deterioration of water quality. If one or more of the minerals are present in excess of the amount that can be tolerated for a given
use, some type of treatment may be applied to change or remove the undesirable minerals, so that the water will serve the intended purpose. Thus, the primary purpose of the water analysis here is to determine its suitability for the drinking as well as irrigation purposes. The water quality data also provides information about geologic formation, groundwater recharge, discharge, movement and storage. Therefore, in groundwater resources evaluation, the quality of groundwater bears nearly equal importance as quantity. The chemical analysis of eighty five samples, collected from the study area has been undertaken and the results of the same are presented in Appendix No. 9. The chemical analysis of water samples has been made as the object of this study is limited to the determination of its suitability for drinking and irrigation purposes only.

7.1 **GENERALISED COMPOSITION OF GROUNDWATER**

Davis and Dewiest (1966) have proposed a generalised chemical composition of groundwater and have given a list of various dissolved elements in the groundwater that determine its suitability for different purposes. They have classified the dissolved constituents in three major groups according to their range of concentration. These are given below in Table No. 13.
### TABLE No. 13

**DISSOLVED CONSTITUENTS IN GROUNDWATER ACCORDING TO RANGE OF CONCENTRATION**

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Range of Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) <strong>Major Constituents:</strong></td>
<td>1 - 1000 ppm.</td>
</tr>
<tr>
<td>Sodium, sulphate, Calcium, chloride, Magnesium, bicarbonate and Silicon.</td>
<td></td>
</tr>
<tr>
<td>(B) <strong>Secondary Constituents:</strong></td>
<td>0.01 - 10 ppm.</td>
</tr>
<tr>
<td>Iron, Strontium, Potassium, Boron, Carbonate, Nitrate and Fluoride.</td>
<td></td>
</tr>
<tr>
<td>(C) <strong>Minor Constituents:</strong></td>
<td>0.00001 - 0.01 ppm.</td>
</tr>
<tr>
<td>Antimony, Aluminium, Barium, Nickle, Bromine, Cadmium, Chromium, Lithium, Cobalt, Copper, Iodine, Molybdenum, Phosphate, Titanium, Rubidium, Selenium, Uranium, Venedium and Zinc.</td>
<td></td>
</tr>
</tbody>
</table>
7.2 COLLECTION OF WATER SAMPLES:

In order to determine the quality of the water in the area under study, author has collected twenty water samples from the surface water. Out of twenty water samples, six samples are from Sind river, six samples are from Pahuj river and eight samples have been collected from the Canals. Location of sample points has been shown in Fig. 7.1 with the help of different symbols. These locations originally have been marked on toposheet of 1:50,000 scale which were later reduced to present scale. Similarly 65 representative water samples were collected from the groundwater. Out of sixty five samples, 35 samples are from the open dugwells, ten samples from the tubewells and 20 water samples are from the dug-cum-bore wells. Sample locations of these points have been marked in the same manner as for surface water samples and are presented in same fig.(7.1).

The water samples have been collected in the clean plastic bottles having capacity of holding two liters of water, with screw caps and sealed immediately by candle wax so that no gases would escape from the samples. To avoid the contamination from users, the water samples have been collected early in the morning.
7.3 METHODS OF CHEMICAL ANALYSIS:

The physical parameters determined in the 85 samples collected from the area under study are electrical conductivity, pH & total hardness while the chemical parameters determined are total dissolved solids, alkali elements (Na, K), alkaline earth elements (Ca, Mg, ), acid radicals (HCO₃, CO₃, Cl, SO₄) and the toxic elements (Cr, Co, Ni, Zn, Wo, Sn, Mn and Pb).

The standard methods of the chemical analysis of water described by APHA (1976) have been used by the author to determine the constituents present in the surface as well as groundwater. The parameters determined in the laboratory are pH value, specific conductivity, carbonate, bicarbonate, chloride, sulphate, sodium, potassium & calcium. The pH has been determined with the help of pH meter and conductivity with the help of conductivity meter. The carbonate, bicarbonate, calcium, total hardness, chloride and sulphate contents have been determined by the titration methods (Volumetric analysis). Magnesium contents have been calculated from the total hardness and calcium hardness values using the following equation:

\[ Mg = \frac{TH - 2.5 \text{ Ca}}{4.1}, \text{ in which all values are in ppm.} \]

The sodium and potassium contents have been determined with the help of Flame Photometer. The total dissolved solids (T.D.S.) values have been calculated from the conductivity...
values using the formula given below:

\[ \text{T.D.S.} = \text{Sp. conductivity} \times 0.64 \, \text{(micro\hspace{1mm}mhos/cm)} \]

Toxic elements have been determined by evaporating 1 liter of water in an evaporating dish to concentrate the toxic elements and using Emission Spectrography.

With the help of above said analytical data, Sodium Absorption Ratio (SAR), percent sodium (\(\% \text{ Na}\)), permeability index (PI), potential salinity (PS) and residual sodium carbonate (RSC) have been calculated to describe the suitability of water for irrigation purposes. These values have been calculated by using following equations:

\[
\text{SAR} = \frac{\text{Na}^+}{\sqrt{\text{Ca}^{++} + \text{Mg}^{++}}} \times 2
\]

\[
\% \text{ Na} = \frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{++} + \text{Mg}^{++} + \text{Na}^+ + \text{K}^+} \times 100
\]

\[
\text{PI} = \frac{\text{Na}^+ + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{++} + \text{Mg}^{++} + \text{Na}^+} \times 100
\]

\[
\text{PS} = \text{Cl}^- + \frac{1}{2} \text{SO}_4^{--}
\]

\[
\text{RSC} = \left( \text{HCO}_3^- + \text{CO}_3^{--} \right) - \left( \text{Ca}^{++} + \text{Mg}^{++} \right)
\]

Where all values are in epm.
7.4 THE INFLUENCE AND IMPORTANCE OF THE VARIOUS PARAMETERS ON THE QUALITY OF WATER:

(A) Hydrogen Ion Concentration (pH):

The relative concentration of hydrogen ions in water indicates whether the water will act like a weak acid or as an alkaline solution.

The hydrogen ion concentration of water is expressed by its pH value. A pH value of 7 indicates a neutral solution. A pH value less than 7 indicates an acid solution and pH greater than 7 corresponds to an alkaline solution.

The results of the chemical analysis of the water samples reveal that the pH value varies from 7 to 8.5. According to international standard of Geneva the permissible pH limit is 7 to 8.5 and the excessive limit of pH value could go down to 6.5 or goes up to 9.2 and the same limits are prescribed by I.C.M.R. (1975) also.

(B) Total Dissolved Solids (T.D.S.):

The total concentration of dissolved minerals in water is a general indication of the overall suitability of water for different uses. The total dissolved solids may be determined from the weight of the dry residue remaining after a sample of water has been evaporated. It may also be
calculated by adding together the concentration separately determined for all the ions in the water or it may be computed from the specific conductivity value using the following formula -

$$T.D.S. = \text{Sp. conductivity} \times 0.64$$
(in ppm.) (in /umhos/cm at 25°C.)

Swenson and Baldwin (1965) have classified the degree of salinity of water on the basis of dissolved solids which is given below -

<table>
<thead>
<tr>
<th>T.D.S. (ppm.)</th>
<th>Degree of Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>Non saline</td>
</tr>
<tr>
<td>1000 - 3,000</td>
<td>Slightly saline</td>
</tr>
<tr>
<td>3000 - 10,000</td>
<td>Moderately saline</td>
</tr>
<tr>
<td>10000 - 50,000</td>
<td>Extremely saline</td>
</tr>
</tbody>
</table>

Out of 85 samples analysed 54 samples fall in the category of the non saline group and rest of them fall under the category of slightly saline group. Most of the water samples contain less than 500 ppm dissolved solids which can be used for domestic purpose. The water samples that contain more than 1000 ppm of dissolved solids which have made it disagreeable in taste and make the water unsuitable for drinking purpose. In some water samples, high content of T.D.S. makes them potentially corrosive with the results the screens of many tube wells existing in the study area have collapsed and destroyed.
(C) **SPECIFIC ELECTRICAL CONDUCTIVITY**

The electrical conductivity is the ability of a substance to conduct an electrical current. Chemically pure water has a very low electrical conductance. If more ions are present in water, the greater will be conductance of the solution. The values of specific conductance for surface and groundwaters are reported in micromhos/cm.

Fig. 7.2 depicts the relation between conductance and total dissolved solids for the water samples of the study area. It is clear that total dissolved solids in a sample from the study area can be readily estimated from its electrical conductivity. The specific conductance multiplied by a factor of about 0.64 gives the dissolved solids in this case. Thus, estimating total dissolved solids by measuring conductivity is rather convenient because it can be applied quickly and easily.

Due to high specific conductance present in some water samples, collected from the study area, corrosion of iron and steel takes place as specific conductance reflects the activity of the electronically charged ions in the water. It follows that the higher the conductivity, the greater is the opportunity for electrochemical action.
(D) **HARDNESS**: 

Hardness is a term commonly used to depict the impurities in water and loosely denotes the quantity of soap consumed before suds are formed. Such soap-consuming hardness is mostly caused by calcium and magnesium.

The total hardness of water may be divided into two types - Carbonate and noncarbonate hardness. The carbonate hardness includes a portion of the calcium and magnesium that would combine with the bicarbonate and the small amount of carbonate present. This is called temporary hardness as it can be removed by boiling the water.

The non-carbonate hardness usually known as permanent hardness is the difference between the total and carbonate hardness. It is caused by those amounts of calcium and magnesium that would normally combine with the sulphate, chloride and nitrate ions. This part of the hardness can not be removed by boiling.

Generally, water that has a hardness of less than 50 ppm is considered soft. A hardness of 50-150 ppm is not objectionable for most purposes but the amount of soap needed increases with hardness. Water having 100-150 ppm hardness will deposit considerable scale in steam boilers. According to Schroeder (196?), softness of water is one of the parameters responsible for cardiovascular disease.
(E) SODIUM

Sodium, an ubiquitous constituent of natural water, is derived geologically from the leaching of surface and underground salt deposits. As all sodium compounds are soluble, so that sodium leached from rocks and soils remains in solution causing clogging of wells. The concentration of sodium found in groundwater from a survey of 65 water samples is presented in appendix No. 9.

Evidence suggests that chronic excessive intake of sodium may be associated with adult hypertension (S.D.W.C., 1977). Therefore, American Heart Association advocates a sodium restricted diet for the long term management of hypertension.

(F) POTASSIUM:

Potassium, which is slightly less abundant than sodium, is similar in behaviour to sodium. In groundwater its concentration is generally not more than 20 ppm.

(G) CHLORIDE:

The chloride content of the groundwater of the humid region is low. Water that contains less than 150 ppm of chloride is satisfactory for most purposes. A chloride content of more than 250 ppm is generally objectionable for municipal water supply. Water containing more than 350 ppm is objectionable for irrigation or industrial uses.
(H) **SULPHATE:**

Sulphate in groundwater is derived principally from gypsum or anhydrite (calcium sulphate). If present in sufficient quantities, it will impart a bitter taste to the water and the water may act as a laxative for people not accustomed to drink it.

**7.5 REPRESENTATION AND INTERPRETATION:**

The results of the chemical analysis of the water samples are very difficult to compare and interpret in tabulated form specially when more than a few analysis are involved. To overcome this problem, graphic representations play very important role for display purposes, comparing analysis and for emphasizing similarities and differences. Studies commonly include statistical analysis of the data and preparation of maps, diagrams, graphs, etc. The analytical data can help in solving many problems including determination of the suitability of groundwater for a given use, studies of mixtures of waters from different sources, etc.

There are number of methods used for presentation & interpretation of water quality data suggested by various workers. These are Scatter diagram, Frequency diagram, Circular or Pie diagram, Collin's bar chart (Collin's 1923),
Stiff pattern diagram (Stiff 1951), Vector diagram (Maucha, 1940), Schoeller diagram, Hydrochemical facies diagram (Back, 1961), Langelier and Ludwing diagram (Langelier and Ludwing 1942). Hill diagram (Hill 1940), Piper trilinear diagram (Piper 1944), modified Hill-Piper diagram (Handa, 1965), Hem diagram (Hem, 1969) Durov diagram (Durov 1948), Back and Hanshaw diagram (Back and Hanshaw 1965), Zaporozec diagram (Zaporozec 1972) and water quality maps.

Out of these diagrams, the Stiff pattern diagram, Collins bar chart, Piper trilinear diagram, hydrochemical facies diagram and water quality maps have been used by the author to represent and interpret the results of the chemical analysis data. The interpretation of these diagrams are presented below:

(A) Surface Water:

It is already mentioned that twenty representative surface water samples have been collected from different sources viz. river, canal, etc., of the Matatila Command area. The quality characteristics of the surface water have been utilised in the preparation of Collins bar chart, Stiff pattern diagram, trilinear Piper diagram, hydrochemical facies diagram as these are widely used and also easy in presentation.
(i) **Collin's Bar Chart:**

Hem (op.cit.) has proposed vertical bar graphs (Collin's bar chart) for representing the results of the chemical analysis of water. This chart is widely used in the United States. In this chart the total concentration is represented by the height of the vertical bars. The left half of the bar represents cations and the right half anions. It becomes clear from the chart (Fig. 7.3a) that the height of the left half of the bar (indicating cation values) is almost equal to the height of the right half bar (indicating anion values). From this it can be concluded that the concentrations of anions and cations are equal. In some cases the height of the right half bar is slightly smaller than left bar as the concentration of cation NO₃⁻ is not included in the chart. The fig. 7.3a shows that sample No. SR₂ and SR₄ have higher concentrations. The sample No. SR₄ has maximum ion concentration where as the sample No. C₁₃ and C₁₄ have the minimum ion concentration. Cations and anions are under the permissible limit for drinking and irrigation purpose in all the samples.

(ii) **Stiff Pattern Diagram:**

Stiff (op.cit.) has suggested pattern diagrams for representing chemical analysis. In this system four horizontal axes and one vertical axis are used.
Four cations have been plotted on one side and four anions on the other sides of the vertical axis. All values have been reported in epm. The resulting points have been connected which form an irregular polygonal pattern. It becomes clear from the fig. 7.4a that all surface water samples depict same pattern which indicates that there is not much variation in the quality of surface water from place to place.

(iii) **Trilinear Diagram**:

The most important way of representing and comparing water quality analysis is the trilinear diagram. One of the earliest attempt to use trilinear diagram was made by Hill (op.cit.) and later by Piper (op.cit.). Piper's diagram is almost same as the Hill's diagram. Hill's original diagram of 1940 showed bicarbonate and sulphate grouped together but later Hill (1941-42) combined sulphate with chloride in the diagram. However, Piper (1944) combined carbonate and bicarbonate together but sulphate was shown separately.

The Piper's (ibid.) diagram consists of two lower triangular fields and a central diamond shaped field. All the three fields have scale readings in 100 parts. First of all, the percentage values of cations and anions have been plotted as a single point (fig. 7.5) at the left and right triangles respectively. After that, these points are projected upward parallel to the sides of the triangles to
FIG. 75 SURFACE WATER SAMPLES

Percentage values in e.p.m.

PIPER'S TRILINEAR DIAGRAM (After Piper, 1953)
give a single point representing one sample in the rhombs. It becomes clear from the fig. 7.5 that all the points fall in the subarea No. 2 (Walton, 1970, p. 454).

(iv) **Statistical Analysis:**

The statistical analysis of the chemical analysis data of the surface water samples has been undertaken. The important statistical parameters such as minimum, maximum, mean, median, standard deviation & coefficient of standard deviation have been calculated and given in table No. 14. The table points out that the mean values of all the chemical quality characteristics are within the permissible limit for drinking as well as irrigation purposes.

(B) **GROUND WATER:**

Out of the sixty five groundwater samples collected, 35 water samples are from dug wells, 20 samples from the dug-cum-bore wells and 10 samples belong to tubewells. Similar to surface water samples, the chemical quality data as given in appendix No. 9 for groundwater, has been utilised by the author in the preparation of Collin's chart, Stiff's diagram, Scatter diagram, Piper's diagram, water quality maps, etc. The interpretation of these diagrams for the groundwater samples is discussed below.
### Table No. 11

**Statistical Analysis of the Chemical Quality of Water Samples Collected from Tail Reaches of Matatila Command Area (M.P.)**

#### (A) Surface Water Samples

| PH | Specific Conductivity mhos/m | T.D.S. | Carbonate in ppm | Bi-carbonate in ppm | Calcium in ppm | Chloride in ppm | Sodium in ppm | Potassium in ppm | Magnesium in ppm | Sulfate in ppm |
|----|------------------------------|--------|------------------|---------------------|-----------------|----------------|---------------|---------------|-----------------|----------------|--------------|
| 1  | 2                            | 3      | 4                | 5                   | 6               | 7              | 8             | 9             | 10              | 11             |
| MINIMUM | 7.3                      | 363.00 | 238.00           | 13.00               | 140.00          | 20.00          | 23.00         | 28.08         | 5.31            | 27.00          | 35.00        |
| MAXIMUM | 8.5                      | 619.16 | 633.00           | 43.07               | 256.00          | 43.50          | 73.00         | 289.00        | 13.86           | 71.00          | 183.00       |
| MEAN   | 7.9                      | 442.64 | 326.85           | 28.99               | 193.50          | 33.32          | 46.35         | 84.15         | 9.33            | 36.04          | 100.52       |
| MEDIAN | 7.9                      | 423.00 | 284.00           | 29.00               | 186.00          | 35.20          | 45.54         | 71.00         | 8.87            | 32.29          | 105.47       |
| STANDARD DEVIATION | 0.278 | 74.83 | 108.90 | 9.23             | 27.76          | 6.06           | 13.00         | 70.97         | 2.47            | 8.81           | 45.46        |
| COEFFICIENT OF S.D. | 0.035 | 0.16 | 0.03 | 0.31 | 0.01 | 0.18 | 0.02 | 0.83 | 0.26 | 0.24 | 0.45 |

#### (B) Groundwater Samples

<p>| MINIMUM | 7.0 | 515.00 | 461.00 | 9.00 | 12.00 | 7.98 | 29.82 | 28.00 | 6.00 | 22.80 | 25.44 |
| MAXIMUM | 8.5 | 3228.00 | 2345.32 | 188.08 | 706.00 | 112.00 | 520.26 | 276.00 | 216.00 | 170.00 | 480.00 |
| MEAN   | 7.6 | 1533.30 | 1021.82 | 70.50 | 423.34 | 40.72 | 139.83 | 126.59 | 37.20 | 67.44 | 204.73 |
| MEDIAN | 7.5 | 1425.00 | 1013.00 | 54.00 | 446.00 | 39.00 | 130.00 | 113.00 | 26.00 | 68.00 | 184.00 |
| STANDARD DEVIATION | 0.38 | 595.38 | 361.58 | 47.16 | 178.54 | 30.72 | 106.42 | 66.19 | 14.12 | 2.80 | 100.00 |
| COEFFICIENT OF S.D. | 0.05 | 0.38 | 0.35 | 0.66 | 0.42 | 0.75 | 0.76 | 0.52 | 0.37 | 0.04 | 0.48 |</p>
<table>
<thead>
<tr>
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<th>4</th>
<th>5</th>
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<th>8</th>
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<tbody>
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<td>499.56</td>
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<td>11.50</td>
<td>27.87</td>
<td>46.00</td>
<td>4.00</td>
<td>29.00</td>
<td>48.00</td>
</tr>
<tr>
<td>MAXIMUM</td>
<td>8.5</td>
<td>1715.00</td>
<td>1214.00</td>
<td>113.00</td>
<td>898.00</td>
<td>69.65</td>
<td>105.00</td>
<td>436.00</td>
<td>97.50</td>
<td>173.00</td>
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<tr>
<td>MEAN</td>
<td>7.8</td>
<td>931.12</td>
<td>712.63</td>
<td>36.90</td>
<td>430.81</td>
<td>29.80</td>
<td>57.49</td>
<td>135.24</td>
<td>17.04</td>
<td>51.71</td>
<td>128.56</td>
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<td>771.5</td>
<td>644.00</td>
<td>29.34</td>
<td>394.67</td>
<td>23.50</td>
<td>52.72</td>
<td>106.72</td>
<td>8.77</td>
<td>48.00</td>
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</tr>
<tr>
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<td>375.63</td>
<td>169.60</td>
<td>28.05</td>
<td>186.29</td>
<td>13.92</td>
<td>23.96</td>
<td>87.63</td>
<td>22.65</td>
<td>29.04</td>
<td>61.92</td>
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<td>COEFFICIENT OF S.D.</td>
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<td>0.22</td>
<td>0.76</td>
<td>0.43</td>
<td>0.46</td>
<td>0.41</td>
<td>0.64</td>
<td>1.33</td>
<td>0.56</td>
<td>0.48</td>
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(iii) TUBE WELLS WATER SAMPLES

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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINIMUM</td>
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<td>1987.00</td>
<td>1198.00</td>
<td>55.69</td>
<td>398.00</td>
<td>8.20</td>
<td>257.83</td>
<td>29.00</td>
<td>6.43</td>
<td>38.00</td>
<td>307.20</td>
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<td>MAXIMUM</td>
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<td>2402.00</td>
<td>1420.00</td>
<td>66.00</td>
<td>460.00</td>
<td>19.68</td>
<td>283.00</td>
<td>503.00</td>
<td>17.63</td>
<td>63.65</td>
<td>450.72</td>
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<td>MEAN</td>
<td>8.0</td>
<td>2210.40</td>
<td>1325.00</td>
<td>68.04</td>
<td>426.75</td>
<td>14.34</td>
<td>271.96</td>
<td>458.75</td>
<td>10.60</td>
<td>51.91</td>
<td>392.88</td>
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<td>3309.50</td>
<td>1340.50</td>
<td>64.50</td>
<td>430.00</td>
<td>14.30</td>
<td>272.10</td>
<td>448.50</td>
<td>14.23</td>
<td>51.36</td>
<td>420.12</td>
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<tr>
<td>STANDARD DEVIATION</td>
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<td>134.53</td>
<td>80.62</td>
<td>10.29</td>
<td>19.82</td>
<td>3.35</td>
<td>7.52</td>
<td>20.77</td>
<td>3.14</td>
<td>7.49</td>
<td>39.87</td>
</tr>
<tr>
<td>COEFFICIENT OF S.D.</td>
<td>0.03</td>
<td>0.06</td>
<td>0.06</td>
<td>0.14</td>
<td>0.04</td>
<td>0.23</td>
<td>0.02</td>
<td>0.03</td>
<td>0.29</td>
<td>0.14</td>
<td>0.10</td>
</tr>
</tbody>
</table>
(i) Collin's bar chart:

Fig.7.3b illustrates the collin's bar chart which were prepared by adopting the same procedure as adopted for surface water. The left half of the bar represents cations whereas the right half of the bar represents anions. It becomes clear from the fig. that the height of the left half of the bar is almost equal to the height of the right half bar. This indicates that the concentrations of anions and cations present in the groundwater are equal. In some water samples i.e. $B_{20}$, $B_{19}$, $B_{3}$, $B_{7}$, $B_{2}$, $A_{11}$, $A_{12}$, $A_{15}$, $A_{17}$, and $A_{18}$, the height of the right half bar is less than the height of the left bar because the concentration of $NO_3^-$ is not included in the chart. The maximum ion concentration is found in sample No. $T_5$ whereas the minimum concentration of ions is present in sample No. $B_6$. Sodium and sulphate ions are in abundance in most of the samples i.e. from $T_1$ to $T_{10}$ which indicates that quality of groundwater is just on the border line as far as its irrigational use is concerned.

(ii) Stiff's pattern diagrams:

Fig.7.4b illustrates pattern diagrams for groundwater samples which were prepared by following same method as used for surface water. It becomes clear from fig. that shape of the diagrams are almost same and looks like a fish. This indicates similar quality characteristics of groundwater present in the study area.
Fig. 7.6a Piper's Trilinear Diagram (After Piper, 1953)

Tube well water samples from T1 to T10

Percentage values in ppm
FIG. 7.6B WATER SAMPLES FROM DUG WELL AND DUG-CUM BORE WELLS

Percentage values

LEGEND
- DUG WELLS WATER SAMPLE
- DUG-CUM-BORE WELL WATER SAMPLES
WATER SAMPLES FROM 1-15 DUG WELLS

Percentage values in epm

FIG. 7.6(c) PIPER'S TRILINEAR DIAGRAM (After Piper, 1953)
(iii) **Piper's trilinear diagram:**

With the help of the chemically analysed data of groundwater samples, trilinear diagram has been prepared and shown in fig. 7.6. It becomes clear from the figure 7.6-a that all the tube well water samples \((T_1 \text{ to } T_{10})\) fall in 2nd and 3rd sub areas of diamond shaped field whereas dug well and dug-cum-bore well water samples fall halfhazardly in the 1st, 2nd, 3rd and 4th sub areas of diamond shaped field (Fig. 7 6 b). Therefore, it can be concluded that tube well water (Deep aquifer) at places is unsuitable for irrigation but it can be used for irrigation along with the surface water.

(iv) **Water Quality Maps:**

In order to demarcate the concentration of different constituents in groundwater of the region, water quality maps have been prepared. The important constituents determined in 65 samples have been plotted at their respective well location and the isopleths (lines of equal values) of total dissolved solids, chloride, bicarbonate, hardness and sulphates have been drawn to get iso-T.D.S. contour map, iso-bicarbonate contour map, iso-hardness map and iso-sulphate contour map respectively.

Fig. 7.7 illustrates the iso-total dissolved solids map which was prepared on a horizontal scale of 1 cm = 2Kms
and at the contour interval of 100 ppm. The values of TDS are plotted at their respective sample points and contours are drawn to prepare iso-total dissolved solids' map. It becomes clear from the fig. 7.7 that the T.D.S. values vary from 461 to 2345.3 ppm. with an average of 1021 ppm. The study area does not show much variation in the T.D.S. values.

Fig. 7.8 illustrates the iso-total hardness map of the study area which has been prepared on a horizontal scale of 1 cm = 2 Kms. with a contour interval of 100 ppm. The hardness determined for the 65 samples of water has been plotted at their respective points and contours are drawn. This map depicts the variation in hardness of the water of the study area. It is seen that the area comprising granitic rocks is characterised by water showing hardness upto 300 ppm. However, majority of the granitic terrain is characterised by hard water (150-300). The total hardness varies from 107 to 648 ppm with an average of 325 ppm. It becomes clear from the fig. 7.8 that the variation in hardness from North to South and East to West. Most of the north-eastern part of the area has hardness below 300 ppm. indicating Moderate to very hard water.

A iso-bicarbonate map (fig. 7.9) has been prepared with the horizontal scale of 1 cm = 2 kms. with a contour interval of 100 ppm. It becomes clear from the fig. 7.9 that the variation in bicarbonate concentration can be seen from
north to south and east to west in the study area. Bicarbonate concentration ranges from 12 to 898 ppm. with an average of 423.3 ppm.

Fig. 7.10 illustrates the iso-chloride map of the area under study. This map is also prepared on a horizontal scale of 1 cm = 2 Kms. with a contour interval of 100 ppm. The values of chlorides determined in 65 water samples have been plotted at their respective sample points and contours are drawn to prepare iso-chloride map. It points out that the variation in chloride concentration is from north to south. The variation in the chloride concentration ranges from 5 to 195 ppm. with an average of 139.8 ppm.

Iso-sulphate map (fig. 7.11) is also prepared on the same scale with the contour interval of 100 ppm. It becomes clear from the map that there is a great variation in the sulphate concentration. It ranges from 25.44 to 480 ppm. with the average value of 204 ppm.

The variation in the parameter shown in fig. 7.7 to 7.11 is due to variation in the flow system, variation in the texture and chemical composition of the aquifer material in the area.

(v) **Statistical Analysis**

In order to represent and interpret the chemical quality of groundwater, statistical analysis has been carried out by the author. For all the constituents determined in the 65 groundwater samples, the values of maximum, minimum, mean, median, standard deviation and coefficient of standard deviation have been calculated and represented in table No.14.
The statistical formula given by Elhance (1970) has been used by the author for this purpose. The important weight ratios such as \( \text{Cl}^-/\text{SO}_4^{2-} \), \( \text{HCO}_3^-/\text{Cl}^- \), \( \text{HCO}_3^-/\text{SO}_4^{2-} \), \( \text{Na}/\text{Mg}^+2 \), \( \text{Na}/\text{Ca}^+2 \), \( \text{Mg}/\text{Ca}^+2 \) and \( \text{K}/\text{Na}^+ \) have also been calculated and presented in Appendix No.16.

7.6 **UTILISATION OF WATER FOR DIFFERENT PURPOSES**

Water is widely needed for domestic, agriculture and industrial uses, each of which requires water of particular specifications. There are international standards for different purposes.

(i) **Domestic Use**

Water for domestic use should be colourless and tasteless. The standard by which the suitability of water for domestic use is judged are established by ECAFE and UNESCO (1963) which are prescribed by W.H.O., ICMR (1975), and the U.S. Environmental protection Agency (1977, 1979). These drinking water standards have been presented in table No.16.

On considering the drinking water standards given in table no.16 and the results of chemical analysis of the water samples given in appendix No.9, it becomes clear that both surface water and groundwater are suitable for drinking purposes, although some constituents in few samples
have crossed the permissible limit but they are below the excessive limit. At present there is no significant effect of pollution on the quality of water except salinity in some water samples. The bacteriological and radiological analysis have not been carried out by the author due to lack of laboratory facilities. The important toxic elements are determined. They are also well within the permissible limit.

The toxic elements determination pertains to chiefly 8 elements namely, chromium, cobalt, Nickel, copper, lead, Manganese, Zinc and molybdenum. These elements have been determined in 18 water samples by evaporating one litre of water in an evaporating dish to concentrate the toxic elements and then using Emission spectrography. The results of the analysis of the water samples for toxic elements have been presented in table No. 15.

A glance at table No. 15 reveals that the toxic elements are within the prescribed limits of water for drinking purposes.

(ii) Irrigational Use:

The chemical quality of water is an essential factor to be considered in evaluating its suitability for irrigation. The exchange of ions alters the physical characteristics of the soil.
### Table No. 15

**TOXIC AND HEAVY ELEMENTS PRESENT IN GROUNDWATER SAMPLES**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Cr</th>
<th>Ni</th>
<th>Co</th>
<th>Cu</th>
<th>Pb</th>
<th>Mn</th>
<th>Zn</th>
<th>Mo</th>
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</thead>
<tbody>
<tr>
<td>A2</td>
<td>0.06</td>
<td>3.00</td>
<td>6.2</td>
<td>1.3</td>
<td>0.009</td>
<td>0.4</td>
<td>13.00</td>
<td>2.50</td>
</tr>
<tr>
<td>A3</td>
<td>0.04</td>
<td>3.5</td>
<td>5.2</td>
<td>1.0</td>
<td>0.008</td>
<td>0.3</td>
<td>5.00</td>
<td>3.25</td>
</tr>
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<td>A5</td>
<td>0.05</td>
<td>3.2</td>
<td>5.3</td>
<td>1.25</td>
<td>0.010</td>
<td>0.3</td>
<td>8.00</td>
<td>-</td>
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<tr>
<td>A6</td>
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<td>1.2</td>
<td>0.90</td>
<td>0.002</td>
<td>0.6</td>
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<td>0.50</td>
</tr>
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<td>A8</td>
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<td>4.5</td>
<td>7.5</td>
<td>0.59</td>
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<td>0.4</td>
<td>13.00</td>
<td>3.50</td>
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<tr>
<td>A10</td>
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<td>4.5</td>
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<td>0.93</td>
<td>0.015</td>
<td>0.5</td>
<td>7.5</td>
<td>-</td>
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<tr>
<td>A11</td>
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<td>2.5</td>
<td>6.5</td>
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<td>0.5</td>
<td>14.00</td>
<td>3.50</td>
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<td>4.0</td>
<td>0.9</td>
<td>0.93</td>
<td>0.003</td>
<td>1.5</td>
<td>13.35</td>
<td>-</td>
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<td>1.3</td>
<td>0.009</td>
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<td>0.010</td>
<td>0.2</td>
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<td>3.5</td>
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<td>-</td>
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<td>0.016</td>
<td>0.3</td>
<td>13.75</td>
<td>-</td>
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<tr>
<td>T3</td>
<td>0.06</td>
<td>3.50</td>
<td>6.25</td>
<td>1.52</td>
<td>0.009</td>
<td>0.5</td>
<td>14.75</td>
<td>4.5</td>
</tr>
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<td>-</td>
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<td>1.56</td>
<td>0.012</td>
<td>0.56</td>
<td>9.5</td>
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### TABLE NO. 16

**DRINKING WATER STANDARDS ESTABLISHED BY DIFFERENT ORGANISATIONS.**

**I. U.S. Environmental Protection Agency**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Constituents</th>
<th>(1977) Primary standard in mg/l</th>
<th>(1979) Secondary standard in mg/l</th>
<th>Equivalent trace constituents in μgrams/l</th>
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<tbody>
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<td>1.</td>
<td>Arsenic</td>
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<tr>
<td>2.</td>
<td>Barium</td>
<td>1.00</td>
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<td>1000</td>
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<tr>
<td>3.</td>
<td>Cadmium</td>
<td>0.01</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Chloride</td>
<td>-</td>
<td>250</td>
<td>-</td>
</tr>
<tr>
<td>5.</td>
<td>Chromium</td>
<td>0.05</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>6.</td>
<td>Copper</td>
<td>-</td>
<td>1</td>
<td>1000</td>
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<tr>
<td>7.</td>
<td>Dissolved solids</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>8.</td>
<td>Fluoride</td>
<td>2.20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9.</td>
<td>Iron</td>
<td>-</td>
<td>0.3</td>
<td>300</td>
</tr>
<tr>
<td>10.</td>
<td>Lead</td>
<td>0.05</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>11.</td>
<td>Manganese</td>
<td>-</td>
<td>0.05</td>
<td>50</td>
</tr>
<tr>
<td>12.</td>
<td>Mercury</td>
<td>0.002</td>
<td>-</td>
<td>2</td>
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<tr>
<td>13.</td>
<td>Nitrate (as N)</td>
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<td>-</td>
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<tr>
<td>14.</td>
<td>Selenium</td>
<td>0.01</td>
<td>-</td>
<td>10</td>
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<tr>
<td>15.</td>
<td>Silver</td>
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<td>-</td>
<td>50</td>
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<tr>
<td>16.</td>
<td>Sulphate</td>
<td>-</td>
<td>250</td>
<td>-</td>
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<tr>
<td>17.</td>
<td>Zinc</td>
<td>-</td>
<td>5</td>
<td>-</td>
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Contd..
## II- ECAFE AND UNESCO (WHO) (1963)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Constituents</th>
<th>Permissible limits (ppm)</th>
<th>Excessive limits (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Total dissolved solids</td>
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<td>1500</td>
</tr>
<tr>
<td>2.</td>
<td>Iron</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>3.</td>
<td>Manganese</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>4.</td>
<td>Copper</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>5.</td>
<td>Zinc</td>
<td>5.0</td>
<td>15.0</td>
</tr>
<tr>
<td>6.</td>
<td>Calcium</td>
<td>75</td>
<td>200</td>
</tr>
<tr>
<td>7.</td>
<td>Magnesium</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>8.</td>
<td>Sulphate</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>9.</td>
<td>Chloride</td>
<td>200</td>
<td>600</td>
</tr>
<tr>
<td>10.</td>
<td>Magnesium &amp; sodium sulphate</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>11.</td>
<td>Phenolic substance (as phenol)</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>12.</td>
<td>pH range</td>
<td>7.0-8.5</td>
<td>6.5-9.2</td>
</tr>
</tbody>
</table>

Maximum allowable limit (ppm)

| 1.    | Fluoride                         | 1.5                      |
| 2.    | Lead                             | 0.1                      |
| 3.    | Selenium                         | 0.05                     |
| 4.    | Arsenic                          | 0.2                      |
| 5.    | Chromium (as hexavalent)         | 0.05                     |
| 6.    | Cyanide (as CN)                  | 0.01                     |
| 7.    | Nitrate (as NO₃)                 | 50-100                   |
### III- INDIAN COUNCIL OF MEDICAL RESEARCH (1975)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Constituents</th>
<th>Permissible limits</th>
<th>Excessive limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A) PHYSICAL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Turbidity (silica scale)</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>2.</td>
<td>Colour (unit on platinum cobalt scale)</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>3.</td>
<td>Taste</td>
<td>Not disagreeable</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Odour</td>
<td>Not disagreeable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(B) CHEMICAL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>pH</td>
<td>7.5-8.5</td>
<td>6.5-9.2</td>
</tr>
<tr>
<td>2.</td>
<td>TDS</td>
<td>500 Mg/l</td>
<td>1500 Mg/l</td>
</tr>
<tr>
<td>3.</td>
<td>T.H. as CaCO₃</td>
<td>300 &quot;</td>
<td>600 &quot;</td>
</tr>
<tr>
<td>4.</td>
<td>Ca as CaCO₃</td>
<td>75 &quot;</td>
<td>200 &quot;</td>
</tr>
<tr>
<td>5.</td>
<td>Mg as Mg</td>
<td>50 &quot;</td>
<td>150 &quot;</td>
</tr>
<tr>
<td>6.</td>
<td>Fe as Fe</td>
<td>0.3 &quot;</td>
<td>1.00 &quot;</td>
</tr>
<tr>
<td>7.</td>
<td>Cu</td>
<td>1.0 &quot;</td>
<td>3.00 &quot;</td>
</tr>
<tr>
<td>8.</td>
<td>Zn</td>
<td>5.0 &quot;</td>
<td>15.00 &quot;</td>
</tr>
<tr>
<td>9.</td>
<td>Cl⁻</td>
<td>250 &quot;</td>
<td>1000 &quot;</td>
</tr>
<tr>
<td>10.</td>
<td>SO₄</td>
<td>250 &quot;</td>
<td>400 &quot;</td>
</tr>
<tr>
<td>11.</td>
<td>Phenol</td>
<td>0.001 &quot;</td>
<td>0.002 &quot;</td>
</tr>
<tr>
<td>12.</td>
<td>F</td>
<td>1.0 &quot;</td>
<td>2.0 &quot;</td>
</tr>
<tr>
<td>13.</td>
<td>NO₃</td>
<td>20 &quot;</td>
<td>50 &quot;</td>
</tr>
<tr>
<td></td>
<td>(C) TOXIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>As</td>
<td>-</td>
<td>0.2 &quot;</td>
</tr>
<tr>
<td>2.</td>
<td>Cr</td>
<td>-</td>
<td>0.01&quot;</td>
</tr>
<tr>
<td>3.</td>
<td>Cu</td>
<td>-</td>
<td>0.01&quot;</td>
</tr>
<tr>
<td>4.</td>
<td>pb</td>
<td>-</td>
<td>0.01&quot;</td>
</tr>
<tr>
<td>5.</td>
<td>Se</td>
<td>-</td>
<td>0.05&quot;</td>
</tr>
</tbody>
</table>
If the same clay takes up sodium, it becomes sticky when wet and has very low permeability. It shrinks when dry into hard clods which are difficult to break up by cultivation. High concentration of sodium salts develops alkali soils in which little or no vegetation will grow. If the irrigation water contains calcium and mangnesium ions in a quantity that equals or exceeds the sodium, a sufficient concentration of calcium or mangnesium will be retained on the clay particles of the soil to maintain good tilth and permeability. Such waters serve well for irrigation, even though the total mineral content may be quite high. The author has considered the concentration of total dissolved solids (TDS), electrical conductivity, percent sodium, sodium absorption ratio (SAR) and permeability index (Appendix No. 11) for determination of suitability of water for irrigation purpose.

(a) **Wilcox Diagram**:

In order to determine suitability of water for irrigation purposes, Wilcox (1955) has used the values of total dissolved solids in epm and percent sodium values. Total dissolved solids in epm have been plotted on the abscissa and percent sodium on the ordinate (fig. No. 7.12).

The fig. reveals that the majority of the surface water samples fall in the field of good to permissible category, therefore assigning the surface water good for
FIG. 7.12 PLOT OF PERCENT SODIUM VS TOTAL CONCENTRATION IN epm (AFTER WILCOX, 1948)
ELECTRICAL CONDUCTIVITY EC x 10^6

PERMISSIBLE TO DOUBTFUL

LEGEND:
- WATER SAMPLE FROM DUG-WELLS
- WATER SAMPLES FROM DUG-CUM-BORE WELLS
- WATER SAMPLES FROM TUBE WELLS
- SURFACE WATER SAMPLES

TOTAL CONCENTRATION IN epm
irrigation purpose whereas the tubewell water samples fall in the field of unsuitable category. Some of the dug well water samples also fall in the field of unsuitable category, whereas majority of dug well water samples fall in the field of Good to permissible category. The dug cum bore well water samples fall in the field of doubtful to unsuitable category, of course, some dug cum bore well water samples fall in the field of permissible to doubtful category.

(b) **U.S. Salinity Laboratory Diagram**

The United State Salinity Laboratory Staff (1953) has constructed a diagram for classification of irrigation water with reference to SAR as an index for sodium hazard 'S' and EC as an index of salinity hazard 'C'. In this system, they have used semilog paper in which specific conductivity has been plotted on the log scale and SAR value on the ordinary scale (see Fig. 7.13).

In the proposed diagram, $C_1$, $C_2$, $C_3$, $C_4$, etc., represent progressively increasing hazards from total salt concentration while $S_1$, $S_2$, $S_3$, $S_4$, etc., denote increasing hazards due to exchangeable sodium. In this diagram, the water has been subdivided into 20 different groups, each having specified properties which are given below separately. It should be noted that suitability of a particular water also depends upon the type of the crop. There are many
FIG. 7-13

U.S. SALINITY DIAGRAM FOR CLASSIFYING IRRIGATION WATERS.

Legend:
- ○ Surface water
- □ River water, stream water, canal water
- ● Ground water
- ▲ Dug/dug-cum-bore, well water
- △ Tube well water

Conductivity (μhos cm⁻¹) at 25°C

<table>
<thead>
<tr>
<th>Class</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Salinity Hazard
- Low
- Moderate
- Medium High
- H. V.H.
crops which are more resistant to EC & sodium hazard than others (Thorne and Paterson, 1954)

(A) **Conductivity Classification**:

\[ C_1 \] - Low salinity water - Good.

\[ C_2 \] - Moderate salinity water - Good for soils of medium permeability for most of the plants.

\[ C_3 \] - Medium to high salinity water, satisfactory for plants having moderate salt tolerance, i.e. Jowar, Karela, Lemon, Mango, Onion etc., on soils of moderate permeability with leaching.

\[ C_4 \] - High salinity water - Satisfactory for salt tolerant crops viz. Sugar cane, Sarson, on soils of good permeability with special leaching.

\[ C_5 \] - Excessive salinity water not fit for irrigation.

(B) **Sodium Classification**:

\[ S_1 \] - Low sodium water.

\[ S_2 \] - Medium sodium water. Good for coarse-grained permeable soils. Unsatisfactory for highly clayey soils with low leaching.

\[ S_3 \] - High sodium water suitable only with good drainage, high leaching and organic matter addition.

\[ S_4 \] - Very high sodium water - unsuitable.
The sodium adsorption ratio and electrical conductivity of all the water samples have been plotted in the fig. 7.13. It reveals that the majority of the surface water samples fall under C₂-S₁, field, which indicates moderate salinity & low sodium water. It is good for irrigation for soils of medium permeability for most of the plants. On the other hand the majority of the groundwater samples fall under C₃-S₁, field indicating medium to high salinity water, which is satisfactory for plant growth having moderate salt tolerance like Jowar, Karela, Lamon, Mango, Onion, etc., on soils of moderate permeability with leaching. Some of the dug well & dug cum bore well water samples fall under the C₂-S₁, field indicating moderate salinity & Low sodium water. Almost all the tube well water samples fall under the category of C₃-S₄ field indicating medium to high salinity water containing very high sodium content which is unsuitable for irrigation. Some of the tube well water samples fall under the C₄-S₃ field indicating high salinity water satisfactory for salt tolerant crops like sugar can, Sarson etc. with high sodium water suitable only with good drainage, high leaching & organic matter addition.

It is being suggested that high sodium waters can be made suitable by adding calcium to it in the form of gypsum.
The applicability of the U.S. salinity diagram to the Indian conditions is under examination by many agricultural research centers existing in the country. There are evidences that at many places, the U.S. salinity diagram gave rather conservative indications.

(C) **Doneen Classification**:

Doneen (1962) proposed a diagram based on T.D.S. and permeability index. It is an improvement over the U.S. salinity diagram, though it has not yet been tested under various agroclimatic regions of the World and not yet universally accepted. In this diagram, the abscissa denotes the permeability index (PI) and the Ordinate the total concentration (T.D.S.) in epm.

It becomes clear from the fig. 7.14 that all the surface water samples fall under class I field, which indicates that surface water is good for the irrigation purpose. Majority of the dug well and dug-cum-bore well water samples fall under the class I field indicating good water for irrigation purpose. Some of the dug well, dug cum bore well and all the tube well water samples fall under class-II field, indicating their unsuitability for irrigation purpose. According to Doneen, the boundaries of classes are not rigid and under certain circumstances water of one class may be as successfully used as water of another class.
FIG. 7.14 CLASSIFICATION OF IRRIGATION WATERS
(AFTER DONEEN 1962)

SCALE
HORIZONTAL
10 0 10 20 30 PI
VERTICAL
5 0 5 15 epm

LEGEND
• WATER SAMPLES FROM DUG WELLS
△ WATER SAMPLES FROM DUG CUM BORE WELLS
□ WATER SAMPLES FROM TUBE WELLS
○ SURFACE WATER SAMPLES

TOTAL CONCENTRATION IN ppm

25% of max. permeability
75% of max. permeability
CLASS III
CLASS II
CLASS I

PERMEABILITY INDEX
7.7 HYDROCHEMICAL FACIES:

Back (1966) divided waters into different hydrochemical facies. The concept of hydrochemical facies plays an important role in the detection of regional relations among chemical characters of groundwater, lithology and regional flow pattern (Back, Op.cit.).

Fig. 7.15 A shows a diagram, with various hydrochemical facies designated in the diamond-shape field. In the triangular field at the left, the proportion of each cation constituent is plotted as a single point. The same procedure is followed in the lower right hand triangular field with the three anion groups. The central diamond field is used to demonstrate the overall chemical character of the water by a third single point, which is at the intersection of the rays projected from the plotting of cation and anion points. The subareas of Fig. A serve as a basis for specific classification of hydrochemical facies, which may be studied in terms of anions or cations or both. A particularly useful classification is shown in the following table. The nomenclature, although suggested in Fig. 7.15 A is shown more clearly in the Fig. 7.15 B.

Back (ibid) identified calcium-Mg facies in recharge areas and a sodium facies in discharge area. According to him, Bicarbonate content is low in recharge areas and high in discharge areas. It is
Fig. 7.15(a) : NOMENCLATURE FOR HYDROCHEMICAL FACIES.

Diagram showing the nomenclature for hydrochemical facies with triangles representing different types: Calcium type, Magnesium type, Sodium type or Potassium type, Bicarbonate type, Chloride type, Sulfate type, and No dominant type.
due to the utilisation of CO$_2$ in the root zone to form bicarbonates in downward moving groundwaters and little addition of bicarbonates thereafter. Sulphate content decreases in the direction of flow and bicarbonate increases, undoubtly both occurrences being the result of sulphate reduction.

**TABLE No.17**

CLASSIFICATION OF HYDROCHEMICAL FACIES (AFTER BACK, 1966)

<table>
<thead>
<tr>
<th>Percentage of constituents (epm)</th>
<th>Ca+Mg</th>
<th>Na+K</th>
<th>HCO$_3$+CO$_3$</th>
<th>Cl+SO$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cation Facies :</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium-magnesium</td>
<td>90-100</td>
<td>0&lt;10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium-sodium</td>
<td>50-90</td>
<td>10&lt;50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium-Calcium</td>
<td>10-50</td>
<td>50&lt;90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium-potassium</td>
<td>0-10</td>
<td>90-100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anion Facies :</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicarbonate</td>
<td></td>
<td></td>
<td>90-100</td>
<td>0&lt;10</td>
</tr>
<tr>
<td>Bicarbonate-chloride-sulphate</td>
<td>50-90</td>
<td>10&lt;50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride-sulphate-bicarbonate</td>
<td>10-50</td>
<td>50&lt;90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chloride-sulphate</td>
<td>0-10</td>
<td>90-100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIG. No. 7.15 (b): WATER ANALYSIS DIAGRAM SHOWING HYDROCHEMICAL FACIES
IN PERCENT OF cpm.
In order to determine the hydrochemical facies for water samples, of the study area, the results of the chemical analysis have been plotted in the Back (Op.cit.) diagram and resulting hydrochemical facies are presented in table No. 18:

**TABLE NO. 18**

**CLASSIFICATION OF HYDROCHEMICAL FACIES FOR CHEMICALLY ANALYSED WATER SAMPLES**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Sample No.</th>
<th>Hydrochemical facies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>A1, B1, B6, B7, B10, B12, B13, B15, B18, B19, B20, SR1, SR4, SR5, SR6, PR7, PR8, PR9, PR10, PR11, PR12, C13, C14, C15, C16, C17, C18, C19, C20</td>
<td>Calcium-Magnesium Bicarbonate</td>
</tr>
<tr>
<td>3.</td>
<td>A6, A8, A9, A10, A12, A13, A16, A19, A24, A31, A34, B5, B9, B11, T1, T2, T4, T5, T6, T7, T8, T10</td>
<td>Sodium-calcium-chloride-sulphate-Bicarbonate</td>
</tr>
<tr>
<td>4.</td>
<td>Ar, A11, A32, T3, T9</td>
<td>Sodium-Potassium-chloride-sulphate</td>
</tr>
</tbody>
</table>

By comparing the trilinear diagram and hydrochemical facies determined for the water in the different lithological units, it is evident that the above two methods are inadequate to differentiate groundwaters of the various lithology. The chemical facies of the groundwater samples are determined, on the basis of Back principle which has been
shown in the fig. 7.15 A. The hydrochemical facies in the water-logged zone is sodium-potassium-chloride & sodium-potassium-bicarbonate type whereas in the nonwater-logged zone it is of calcium-magnesium and bicarbonate type.

7.8 Delineation of Flow System with the Help of Chemically, Analyzed Data:

Groundwater in motion is continually dissolving mineral matter in an attempt to reach equilibrium with its surroundings. Consequently, water chemistry may be considered an important parameter of the environment and may reflect the history of the flow path.

A method for delineating flow system with the help of the water chemistry has been described by Maxey and Miffin (1966). Apart from the Maxey and Miffin, several other examples of hydrochemical applications to flow system delineation may be mentioned. Brown (1967) discussed some work in Southern Monitoba, where a large supply of potable water is found in an area of highly saline water. Toth (1966 b) related the chemical characters of groundwater to areas of recharge and discharge in the region of South Alberta. Henningsen (1962) distinguished between groundwater in two recharge areas where the water intermingles further down gradient, a third type of water reflects the characteristics of the primary sources and is easily distinguishable.
FIG. 7.16(a) CHEMICAL PLOT FOR GROUND WATER SAMPLES
$\text{Na}^+ + \text{K}^+ \text{ VS } \text{Cl}^- + \text{SO}_4^- \text{ (AFTER MAXEY & MIFFIN 1966)}$

**Legend**
- △ EVIDENCE OTHER THAN CHEMICAL INDICATES REGIONAL FLOW SYSTEM
- ○ EVIDENCE OTHER THAN CHEMICAL INDICATES LOCAL FLOW SYSTEMS
- . EVIDENCE OTHER THAN CHEMICAL INADEQUATE TO CLASSIFY.
FIG 16c: CHEMICAL PLOT FOR GROUND WATER $\text{Na}^+ + \text{K}^+$ VS $\text{Ca}^{++} + \text{Mg}^{++}$ (AFTER MAXEY & MIFFIN 1966)

LEGEND
- △ EVIDENCE OTHER THAN CHEMICAL INDICATES REGIONAL FLOW SYSTEM
- ○ EVIDENCE OTHER THAN CHEMICAL INDICATES LOCAL FLOW SYSTEM
- . EVIDENCE OTHER THAN CHEMICAL INADEQUATE TO CLASSIFY

$log_{10} \text{Na}^+ + \text{K}^+$ (ppm)

$log_{10} \text{Ca}^{++} + \text{Mg}^{++}$ (ppm)
In order to determine the flow system author has adopted the Maxey and Mifflin (Cp. cit.) criteria and plotted the \( Na^+ + K^+ \) on ordinate (Y-axis) and \( Cl^- + SO_4^- \) in ppm on abscissa (X-axis) and further \( Na^+ + K^+ \) (ppm) on the same place whereas \( Ca^{++} + Mg^{++} \) (ppm) on the abscissa (X-axis) on the log-log graph paper (fig. 7.16).

7.16

It is evident from Fig. 7.16 that water chemistry of the area is associated with the regional flow systems, & characteristically shows an increase in sodium, potassium, sulphate and chloride with the length of flow path (fig. 16a). On the other hand calcium and magnesium ions rapidly approach equilibrium with carbonate minerals and achieve a relatively constant concentration fig. 7.16 b).

From the above discussion, it is concluded that:

(a) In general, the chemical quality of groundwater of shallow aquifer and deep aquifer is more or less similar except at few places. The tube well waters have more T.D.S. than the dug well water. This may be due to the presence of alternate thick clay layers at the greater depth.

(b) The groundwater of water-logged areas is sodium-potassium-chloride and sodium-potassium-bicarbonate type whereas in non-water-logged areas, the groundwater is calcium-magnesium-bicarbonate type.

(c) The effect of lithology is also observed in the chemical quality of groundwater. Wherever, the thick clay layer is present the groundwater is more mineralised.

The author have concluded the above facts on the basis of random groundwater sampling in the study area only.
8. PLANNING AND MONITORING OF GROUNDWATER

8.1 GROUNDWATER POTENTIAL

ANNUAL GROUNDWATER RECHARGE

8.2 ANNUAL GROUNDWATER DRAFT

8.3 GROUNDWATER BALANCE

8.4 MONITORING OF GROUNDWATER

8.5 MONITORING OF WATER LOGGING & SOIL SALINITY

8.6 AN ASSESSMENT OF THE AVAILABILITY OF GROUNDWATER IN THE FIRST (SEMICONFINED TO CONFINED) AQUIFER

8.7 GROUNDWATER EXPLOITATION

8.8 PLANNING FOR CONJUNCTIVE UTILISATION OF SURFACE AND GROUNDWATER RESOURCES

(a) CONJUNCTIVE USE WITH SALINE GROUNDWATER

(b) ECONOMICAL CONSIDERATIONS
CHAPTER 8

PLANNING AND MONITORING
OF GROUNDWATER

Water management is a burning problem of all canal command area. For a controlled development and proper management of water resource and its conservation, the primary requirement is the knowledge of the available total resource potential. It, therefore, warrants appropriate planning which needs careful study of the availability of surface as well as groundwater and manner of its utilisation. In the study area, excessive and improper use of irrigation water of canal system has created the rise in water table and as such has disturbed the groundwater equilibrium. Hence proper planning for large scale development of groundwater is needed in order to balance the hydrological equilibrium. Further, the utilisation of groundwater and surface water resources should be planned in such a way that the level of groundwater remains below the ground surface.

8.1 GROUNDWATER POTENTIAL

The area under investigation belongs to the Indo-Gangetic alluvial plain. Most of the plain lies at elevation of 120 meters above mean sea level. Rainfall is
erratic and uncertain with average annual rainfall 640 mm. Groundwater occurs in the alluvium of the Indo-Gangetic plain. These alluvial deposits range in the thickness upto 82 meters and consist of alternating sequence of silts, sands and clays with occasional beds of gravel and kankar. The more permeable beds of sand and gravel act as aquifers that transmit and store enormous quantities of groundwater. Assessment of total recharge has been made for entire sind basin using empirical assumptions suggested by Groundwater Estimation Committee (GEC), Govt.of India. These assessments, when considered with the estimated total draft from wells provide groundwater balance for its future development.

I. ANNUAL GROUNDWATER RECHARGE:

In order to determine groundwater recharge, water level fluctuation and specific yield approach have been adopted which is suggested by GEC(NABARD 1984).

30 wells have been selected for permanent observation (P.O.W.) of water levels and monitored twice in a year i.e. premonsoon and post monsoon. Data on water level fluctuation were also collected from the Groundwater Survey Department, Gwalior (M.P.) and is presented in Appendix No. 7, with a view to maintain accuracy in calculation of water level fluctuation.
For the present study, the value of specific yield is considered 12% which is suggested by GEC, for alluvial terrain. Other norms which are used in the calculation and suggested by GEC for the computation of groundwater recharge are given below.

(i) Recharge from Rainfall : 20% of Normal rainfall.
(ii) Recharge due to seepage from unlined canals : 20 ha. /day/10^6 sq.m.of wetted area of Canal.
(iii) Return seepage from irrigation fields
     a. Irrigation by surface-water sources : 35% of water delivered at the outlet for application in the field.
     b. Irrigation by groundwater sources : 30% of the water delivered at outlet.
(iv) Seepage from tanks : 40-60 cums per year over the total water seeped.

A. **CALCULATION OF GROUNDWATER RECHARGE**
   (Based on Water Table Fluctuation Approach)

Total annual recharge

= Monsoon recharge due to rainfall
  + Non monsoon recharge
  + Potential recharge

(a) **Monsoon Recharge** :

(i) Geographical Area (ha) = 200100
(ii) Average depth to water table (in meter below groundwater level) April-May = 11.04
(iii) Average depth to water (in meters below ground level) October-November = 9.34

(iv) Water table fluctuation in meter (year of observation from 1987-1989) = 1.7

(v) Indian Meteorological Department Normal annual rainfall (mm) = 695.35

(vi) Indian Meteorological Department Normal monsoon rainfall (mm) = 643.4

(vii) Indian Meteorological nonmonsoon rainfall (mm) = 51.95

(viii) Average monsoon rainfall (mm) (years of observation from 1901-86) = 639.84

(ix) Average non monsoon rainfall (mm) (Years of observation from 1901-86) = 55.82

(x) Specific yield = 12%

(xi) Gross Kharif Draft (ham) = Nil

Monsoon Recharge (ham) = Geographical area x Sp. yield x water table fluctuation + Gross Kharif Draft - monsoon canal Seepage + Monsoon recharge from surface water irrigation + Monsoon recharge from groundwater irrigation x Normal Monsoon rainfall (MM) x Average monsoon rainfall (MM)

+ Monsoon Canal Seepage

+ Monsoon recharge from surface water irrigation.
Monsoon Recharge (ham) = \[122500 \times 0.12 \times 1.7 - 171 + 221 \times \frac{64.4}{639.84} + 171 + 221\]

= 40820.4 - 232 \times 1.00 + 232

= 40820.4

= Say 40820 ham.

(b) Nonmonsoon Rainfall Recharge:

(i) Geographical area (ha) = 200100

(ii) IMD Nonmonsoon rainfall (mm) = 51.95

(iii) Infiltration factor (%) = 14.5%

Nonmonsoon rainfall recharge (ham) =

= \text{Geographical area} \times \text{Infiltration factor} \times \text{IMD Nonmonsoon rainfall} \times \frac{1}{1000}

= \frac{200100 \times 0.145 \times 51.95}{1000}

= \frac{1507303.3}{1000}

= 1507.30 ham.

(c) Recharge from Surface Sources:

(1) Recharge from Canals

Applied seepage factor = 20 ham/day/10^6 Sq.m.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name</th>
<th>Total Length (m)</th>
<th>Average Wetted Perimeter (m)</th>
<th>Average Running Days</th>
<th>Seepage (ham)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Irrigation</td>
<td>355234</td>
<td>3.23</td>
<td>94</td>
<td>2262</td>
</tr>
<tr>
<td></td>
<td>canal</td>
<td></td>
<td></td>
<td>94</td>
<td>2091</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63</td>
<td>171</td>
</tr>
</tbody>
</table>

.157.
(2) Recharge from Surface water irrigation

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Crop</th>
<th>Area irrigated (ha)</th>
<th>Average water depth (m)</th>
<th>Irrigation water applied (ham)</th>
<th>Seepage Factor %</th>
<th>Non-monsoon (ham)</th>
<th>Monsoon (ham)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Kharif</td>
<td>1261</td>
<td>0.35</td>
<td>441.35</td>
<td>40</td>
<td>-</td>
<td>221.00</td>
</tr>
<tr>
<td>2.</td>
<td>Rabi</td>
<td>32362</td>
<td>0.61</td>
<td>20290</td>
<td>35</td>
<td>7795</td>
<td>-</td>
</tr>
</tbody>
</table>

(3) Recharge from tanks:

(a) No. of tanks : Nil
(b) Water spread area(ha) = a : Nil
(c) Seepage factor(cm/year) = c : Nil
(d) Total non monsoon seepage (ham) = c

Recharge from Tanks = \( \frac{a \times b}{100} \times \frac{c}{365} \) = Nil

Total non monsoon seepage (ham)

\[ 1 + 2 + 3 \]

= 2091 + 7795 + 0

= 9886 hectare metre.

(d) **Potential Recharge** :

(1) Recharge from flood prone areas:

a. Yearly flooded area(ha) : Nil
b. Duration of floods (days) : Nil
c. Seepage factor (cm/year) : Nil

Potential recharge due to flood plain =

\[ \frac{a \times b \times c}{365 \times 100} = \text{Nil} \]
(2) Recharge from shallow water areas:

a. Geographical area (ha) : Nil
b. Premonsoon depth to water table (mbgl) : Nil
c. Permissible depth to water table (mbgl) : Nil
d. Adopted specific yield(12%) : Nil
e. Potential recharge from shallow water table areas (ham). = (5-b) x a x d : Nil

Total potential recharge (ham) = Nil

Total annual recharge = Monsoon recharge + non monsson recharge + potential recharge

= 40820 + 1507.30 + 2262 + 221 + 7795 = 52605.3 hectare meter

Say 52,605 = 0.52 million hectare meter.

Net annual recharge available for groundwater development

= 85% of the total annual recharge

= 44,711.2 Say 44,711

= .044 million ham.

(e) Check on water table Fluctuation:

1. Monsoon recharge by water table fluctuation approach.

(a) Monsoon recharge by water table fluctuation approach (ham) : 40820

(b) Component of above -

i. Due to monsoon seepage from canals (ham) : 171.00

ii. Due to monsoon surface water irrigation (ham) : 221.00

TOTAL : 392.00
Monsoon recharge due to rainfall alone (ham) 

\[ a-b = 40820 - 392 = 40,428 \text{ hectare metre} \]

2. Monsoon Rainfall recharge on Ad-hoc norms Geographical area (ha)

\[ = 200100 \text{ hectare} \]

IMD Normal Monsoon Rainfall (mm) = 643.4 mm

Recharge Factor (%) = 14%

\[ \text{Monsoon recharge (ham) on adhoc norms} = \frac{200100 \times 0.14 \times 643.4}{1000} = 18024.00 \text{ hectare mts.} = 0.018 \text{ million ha.mts.} \]

3. Check

Monsoon recharge due to rainfall by water table fluctuation approach

\[ = 40,428 - 18,024 = 22,404 \text{ he.mts.} = 0.022 \text{ m.he.mts.} \]

\[ \text{Variation} \% = \frac{22,404}{18024} \times 100 \]

\[ \text{Monsoon rainfall recharge on adhoc Norms} \]

\[ = \frac{22,404 \times 100}{18024} = 124.30, \text{ Say 124}\% \]

(Note: If the variation is more than 20% the water table fluctuation approach may be accepted and only adhoc norms may be used for recharge estimation).
8.2 **ANNUAL GROUNDWATER DRAFT**

In order to determine approximate annual groundwater draft in the study area (Sind main drainage basin), the number of different types of existing wells have been recorded, though most of the wells are not in use due to advent of surface water irrigation. In order to calculate the annual groundwater draft from different types of wells, (dug wells/dug-cum-bore wells/Tube wells) the number of pumping hours have been recorded by consulting the users and the average rates of discharge have been calculated for each well. In the case of the dugwells used for domestic purposes the villagers have been consulted.

With the help of total number of existing wells and their total pumping hours average rates of annual draft for different types of wells have been calculated by using following equation.

\[
\text{Annual Draft} = \text{No. of wells} \times \text{Average rate of discharge in Kilo liter per hours (KLPH)} \times \text{number of pumping hrs.in a year.}
\]

The results obtained are given in table.19

8.3 **GROUNDWATER BALANCE**

A study of groundwater balance is essential in order to evaluate total groundwater potential of a basin. Water balance of an area is defined by the hydrologic
### TABLE NO. 15

**AVERAGE RATES OF DISCHARGE FOR DIFFERENT TYPES OF WELLS IN TAIL REACHES OF MATALILA COMMAND AREA**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Type of wells</th>
<th>No. of wells</th>
<th>Mode of lift</th>
<th>Average rate of discharge from groundwater bodies in KLPH</th>
<th>Number of pumping hrs. in year</th>
<th>Annual Draft (hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dug wells (Domestic)</td>
<td>3356</td>
<td>Bucket</td>
<td>2.5</td>
<td>900</td>
<td>7475.49</td>
</tr>
<tr>
<td>2.</td>
<td>Dug wells (Domestic + Irrigation)</td>
<td>3250</td>
<td>Disel/Electric Pump set</td>
<td>40</td>
<td>1,300</td>
<td>16731.10</td>
</tr>
<tr>
<td>3.</td>
<td>Dug cum bore wells/shallow Tube wells</td>
<td>117</td>
<td>Electric Pump</td>
<td>45</td>
<td>1,500</td>
<td>781.85</td>
</tr>
<tr>
<td>4.</td>
<td>Deep tube wells</td>
<td>85</td>
<td>Submersible pump</td>
<td>50</td>
<td>1,840</td>
<td>774.18</td>
</tr>
<tr>
<td>5.</td>
<td>Flowing wells</td>
<td>27</td>
<td></td>
<td>13</td>
<td>7,830</td>
<td>272.08</td>
</tr>
</tbody>
</table>

**Gross Annual draft (in hectare meters)**

Say 26034.7

**Net Annual Draft**

\[
\text{Net Annual Draft} = \frac{70\% \text{ of the Gross annual draft}}{100} = \frac{26035 \times 70}{100} = 18,224.5
\]

= Say 18,225 hectare meters

= 0.018 million hectare meters
equation which states that in a specified period of time all water entering in a given area must be consumed. It can be calculated by using following equation.

\[
\text{Groundwater balance} = \text{Net annual recharge} - \text{Net annual draft} \\
= 0.044 - 0.018 \text{ million hectare meters.} \\
= 0.026 \text{ million hectare meters.}
\]

Calculations show that the net annual groundwater utilisation (draft) approximates to be 0.018 million hectare meters whereas the net annual recharge approximately determined amounts to be 0.044 million hectare meters. Therefore, the balance of groundwater available for future development in a year works out to be 0.026 million hectare meters.

8.4 **MONITORING OF GROUNDWATER:**

In order to determine the water level fluctuation, 30 permanent observation wells have been monitored twice in a year i.e. in the months of April and May (pre-monsoon) and in the months of October-November (Post-monsoon). Choudhari (1988) has given the following suggestions for improving monitoring and accurate assessment of groundwater recharge.

1. Presently the fluctuation of water levels in the phreatic aquifer is monitored. Monitoring of fluctuation of the piezometric surface of the confined aquifers should be started systematically by the Government.
2. Presently census of groundwater structures covers only dug wells and tube wells. Large numbers of dug-cum-bore wells are also there in the area which are included under dug well category. It is well known that dug-cum-bore wells tap the confined aquifers. Therefore, their unit draft is much higher which is not counted if dug-cum-bore wells are classified as dug wells.

3. Automatic water level recorders should be installed so that continuous data of water level fluctuation in some of the wells will be available.

4. To have more realistic values of unit draft per geologic formation, thorough studies should be taken up to represent different hydrogeological conditions.

5. Specific yield of different hydrogeological strata should be calculated from actual field studies and pump tests.

6. Storage co-efficient of confined aquifers should be determined by gradually taking up aquifer performance test of tube wells.

7. One who observes water tables in dug-cum-bore wells should ascertain himself whether the water level in the well represents free water table or piezometric surface of confined aquifers.
Observations of water in the wells require thorough understanding of the hydrogeological regime of the area. Therefore, the persons engaged in the monitoring work should possess a certain minimum scientific background and knowledge of the subject.

8.5 MONITORING OF WATER-LOGGING & SOIL SALINITY:

As already mentioned in chapter II that remote sensing techniques provide timely and true synoptic record of terrain, facilities of automatic contour production, terrain evaluation, informations for artificial recharge so necessary for planning and monitoring of available water and its ill effects.

Using Landsat-5 false colour composit (TM) the pre-monsoon and post-monsoon seasons of the year 1986-87 period have been studied by visual interpretation technique. Observations made from the imageries point out that the areas subjected to water logging & soil salinity are successively increasing (Refer Fig. 2.7 and Fig. 2.8 in chapter II). These observations have been compared and confirmed on the ground.

As the groundwater resources are more or less not utilized, the groundwater levels are rising year after year causing water logging and soil salinity in the area under study. The quality of groundwater is just on the border line for use as irrigation water. In order to improve the quality, the surface and groundwater have to be mixed
together prior to its use for irrigation. There is paucity of water for irrigating the farmlands in the tail end reaches. The rainfall as a source of irrigation is effective for about 65 days in a year. The only way to overcome these problems is to exploit & utilise groundwater on a planned basis.

8.6 AN ASSESSMENT OF THE AVAILABILITY OF GROUNDWATER IN THE FIRST AQUIFER

In order to assess the quantity of the groundwater available in the first aquifer of the study area, an approximate isopach map (Fig. 8.1) of the first aquifer has been prepared as the first aquifer is present throughout the area for which reliable lithological log data are available to calculate the approximate water-holding & yielding capacities of this aquifer as the water is occurring under the water table conditions.

The tubewells drilled in the study area are widely distributed, covering the entire area under investigation. The isopach map has been prepared on a scale of 1 cm = 3 kilometers with the contour interval of 3 meters. The isopach map shows that the thickness of the first aquifer varies from 1.8 meters to 33.3 meters. It has a maximum thickness around the Daboh town and the minimum thickness around the village Denwara and Tharet. It shows an elliptical shape
FIG. 8.1
ISOPACH MAP OF THE FIRST AQUIFER OF TAIL REACHES OF MATATILA COMMAND.

CONTOUR INTERVAL 3 METERS
contour patterns between the Lahar and Daboh towns. To the north of the Lahar town, the first aquifer is distributed uniformly and its thickness varies from 9 mts. to 15 meters. To the southwest of the Lahar town, the thickness of the first aquifer varies from 6 mts. to 15 mts.. The contours are widely spaced which show consistency in the thickness of the first aquifer. The first aquifer consists of fine to coarse-grained sands. By using the isopach map, the volume of the first aquifer has been calculated in order to calculate the water-holding capacity, porosity for fine to coarse-grained sands has been assumed and an average value of 33% has been used. For water-yielding capacity, 12% effective porosity has been taken into consideration. The results obtained are given in table No. 20. The table brings out the fact that the water holding capacity of the first aquifer in the Matatila Command is 0.50 million hectare meters whereas the aquifer is capable of yielding (assuming water table condition) about 0.06 million hectare meters. But it has been noticed that the groundwater occurs under confined conditions. It also gives rise to flowing wells under favourable topographic conditions.\textsuperscript{1} Out of the quantity of groundwater available for pumping from the aquifer itself, the present utilisation of water of the first aquifer by about 1500 tubewell and dug-cum borewells amounts to 0.015 million hectare meters taking into consideration 1000 hours as pumping time in a year for a
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Average thickness of aquifer in meters</th>
<th>Area in hectares</th>
<th>Volume of aquifer in hectare meters</th>
<th>Water holding capacity in hectare meters</th>
<th>Water available for pumping in hectare meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>6.06</td>
<td>5920</td>
<td>35875.2</td>
<td>11840</td>
<td>1420.8</td>
</tr>
<tr>
<td>2.</td>
<td>7.57</td>
<td>13936</td>
<td>105495.0</td>
<td>34840</td>
<td>4180.8</td>
</tr>
<tr>
<td>3.</td>
<td>9.09</td>
<td>2528</td>
<td>22979.0</td>
<td>7584</td>
<td>910.06</td>
</tr>
<tr>
<td>4.</td>
<td>10.60</td>
<td>30304</td>
<td>321222.0</td>
<td>106064</td>
<td>12727.68</td>
</tr>
<tr>
<td>5.</td>
<td>12.12</td>
<td>2432</td>
<td>29476.0</td>
<td>9728</td>
<td>1167.36</td>
</tr>
<tr>
<td>6.</td>
<td>13.63</td>
<td>30672</td>
<td>418059.0</td>
<td>138024</td>
<td>16562.88</td>
</tr>
<tr>
<td>7.</td>
<td>15.15</td>
<td>22160</td>
<td>335724.0</td>
<td>110800</td>
<td>13296.10</td>
</tr>
<tr>
<td>8.</td>
<td>16.66</td>
<td>11936</td>
<td>198854.0</td>
<td>65648</td>
<td>7877.75</td>
</tr>
<tr>
<td>9.</td>
<td>18.18</td>
<td>3104</td>
<td>56431.0</td>
<td>18624</td>
<td>2334.88</td>
</tr>
</tbody>
</table>

122992 255285.2 503152 60378.24
tubewell and taking an average rate of pumping 10,000 gph. The net available groundwater still available for exploitation is more than 0.045 million hectare meters. Based on the estimated quantity of groundwater available for pumping in the alluvial aquifer and by taking about 1200 mts. as a safe distance in between two tubewells, the number of tubewell suggested for drilling is about 290 which may be located on either side of the canal.

8.7 GROUNDWATER EXPLOITATION:

Water-logging is an important problem in the Mataiala Command area due to which about 21044 hectares of land have got adversely affected. Various kinds of drainage schemes are under implementation to reduce and check the water logging. The year after year groundwater levels are rising by about 4 centimetres in the areas adjacent to the canals, where seepage and leakages occur. During the field studies in the year 1987-88, it has been found that out of 21044 hectares of land 10000 hectares of land have groundwater levels within a depth of 2 meters below the ground surface at the end of rainy season. These are the areas of more mineralized groundwater, which are probably associated with the shallow water table areas where chemical constituents are concentrated by evaporation.
In the area under study, the dugwells, dug-cum-bore wells or shallow tube wells, deep tube wells and flowing wells already exist apart from the surface water irrigation by canals and their distributaries. It is observed during the field work that the farmlands lying at the tail-end reaches of the Matatila Command area are the worst hit for the lack of surface water irrigation, due to paucity of water in the canal at tail reaches. In this connection, the reports (Chourasia, et al., 1976, 1978) have been submitted by the author’s supervisor to Irrigation Department, Government of Madhya Pradesh. The results of these reports have been considered by the World Bank Authority and they are willing to give the loan to solve the above mentioned problems of the study area.

The above considerations have led to demarcate the area under investigation into three zones (fig. 8.2) for proper groundwater exploitation keeping in view:

(i) The groundwater occurrences and their movements.
(ii) The depth at which groundwater reservoirs occur.
(iii) The nature of formations overlying and underlying the groundwater reservoirs, etc. In the areas, where thin alluvial covers overlie the unproductive bed rocks like sandstones, dugwells have been proposed (Zone I). Before demarcating the areas for dug cum bore wells, or shallow tube wells (Zone II) and deep tube wells (Zone III) the overburden
FIG. 8.2 AREAS SUGGESTED FOR GROUND WATER EXPLOITATION, TAIL REACHES OF MATATILA COMMAND, (M.P.)

LEGEND

I. AREA SUITABLE FOR DUGWELL
II. AREA SUITABLE FOR DUG CUM BORE WELL
III. AREA SUITABLE FOR DEEP TUBE WELLS

PROPOSED TUBE Wells TO BE DRILLED ALONG THE CANAL

RIVER/ROAD

CANAL

SCALE 0 5.5 KM.

11 KM.
lying over the first semiconfined to confined aquifer in relation to the height from which the confined water pressures rise from the top of the first aquifer including the construction problems have been considered.

The hydrogeological studies made in the study area indicate that the groundwater conditions are different in different parts. The following recommendations for groundwater development are made by demarcating suitable zone for groundwater exploitation by different methods.

(I) Zone Suitable for Shallow and Deep Tube Wells:

In Seondha block a patch of 150 square kms. around Indergarh is proposed for exploitation of groundwater by means of tubewells. The area has an overburden of unconsolidated material of 20 to 30 meters. It is expected that tube wells may yield 300 to 600 L.P.M. The main village fall in this zone are Baina, Jaswantpura, Shiyampahari, Kuleth, Uchar, Chhaikurri, Bilaspur, Lanch, Indergarh, Bharrawli, Andaura, Netuapura, Ikauna, Bhadauna, Bharsula, Sunari, Jujharpur, Jignia Bharaul and Silauri. An area of 328 sq.kms. in Lahar appears to be suitable for construction of deep tubewells. These demarcations have been made on the basis of the knowledge of geological formations, the nature of the drainage patterns, the study of pre-monsoon, post-monsoon water level contour maps and water level fluctuation
map and also lithological logs of bore holes drilled in the study area. The resistivity surveys conducted at various places are also very helpful in suggesting the sites for tube well. As per the geological study and the result of the resistivity survey, the zone having a layer of sand of different gradations with gravels beyond 40 meters and continued upto a depth of 80 meters is considered suitable for deep tubewells. Taking into consideration the success of all the existing tube wells, these areas are recommended for construction of tube wells upto a depth of 80 meters.

(II) **Zone Suitable for Dug-Cum-Bore Wells**

An area of about 170 square kms. in the Seondha tahsil appears to be suitable for dug-cum-bore wells. In this zone, weathered granite is present which is overlain by the alluvium of 10 m. to 25 meters in thickness. The wells are expected to yield 7000 to 10000 l.p.h. of groundwater. In the existing dug wells, 15 to 30 meters of boring is recommended to make a dug-cum-bore well from the dug well. The important villages falling in this zone are Jonia, Pipraua, Paharirawat, Dohar, Tharet, Kudari, Jaroli, Maharoli, Changpura, Alampil, Basit, Parsonda, Gujar, Sikri, Laharia, Pachara, Raruajiwan, Padari, Murgawan, Jaura, Bagurdanfiroz, Bagurdan sidho, Uchia, Danauli, Anadpur, Baderi, Delua, Durgapur, Kutonda, Mohnajat, Nadna, Ranipura, Anaoli, Bahera, Bhobaikhud and Bhobai-buzurg.
Also an area of about 300 square kilometres in the Lahar tahsil of Bhind district appears to be suitable for the construction of dug cum bore wells. The results of the resistivity survey and lithology of bore holes give an idea of the presence of a good aquifer up to a depth of 57 meters from which the groundwater may be exploited. Thus, there is a great scope for increasing the irrigation capacity in the area by drilling more wells. Their locations have been decided on the basis of the resistivity survey.

(III) Zone Suitable for Dug Wells:

An area of about 94 square Kms. as demarcated in the fig. 8.2 may be recommended for the construction of dug wells. In this zone, weathered granite is present. The well should be 3 to 5 meters in diameter and 15 m. to 20 m. in depth. The dug wells in this zone are expected to yield 2500 l.p.h. to 4000 l.p.h. of groundwater as observed in the field.

8.8 PLANNING FOR CONJUNCTIVE UTILISATION OF SURFACE AND GROUNDWATER RESOURCES

In the study area maximum water development can only be obtained by planning conjunctive utilisation of both surface and groundwater reservoirs. Such an approach will ensure maximisation of the future net benefits within the framework of appropriate social and economic objectives. Presently, the irrigation facilities could be extended to only 45 percent of the command area
during Rabi and 25 percent for the summer crop due to paucity of surface water at the tail end reaches. However, Matatila command area has a vast potentiality of groundwater. These conditions not only produce acute shortage of surface water but also create problems of water logging and salinity both in soils and groundwater in the area under study.

In this connection, it is interesting to note the concept of "conjunctive use" of water as given by Shankaran (1977), who states that in an area where both surface and groundwater are available, irrigation should be based on the use of both the sources but with proper planning and co-ordinated development for optimum benefits. The utilisation of surface and groundwater resources together in such a manner as to obtain higher yields would be possible by using either of these two resources separately without deteriorating the capacity of the soil to retain plant growth, may be defined as their conjunctive use. The conjunctive use, thus aims at rectifying the shortcomings inherent in the use of either of these two resources and leads to optimum utilisation of water resources in the area.

Keeping the above broad concepts in view and also to make use of the existing canal system for delivery of water to the farmlands located at tail end reaches, 290 medium to high production tube wells have been proposed for groundwater exploitation (fig. 8.2). A high production tube well
can be pumped at an average rate of about 200 m$^3$/h. Similarly a medium production tube well can be pumped at an average rate of about 100$^3$/h. No emphasis has been laid on dug-cum-bore wells & in their place shallow tube wells are recommended. In suggesting the location of Augmentation (proposed) tube wells along the carrier channels the following hydrogeological and engineering considerations have been kept in mind:

(i) Adequate potential zones should be present within a depth of 80 meters.

(ii) The aquifer zones present below the base of the unconfined aquifer, as far as possible, should be exploited, so that water level will not be adversely affected.

(iii) The carrier channels should preferably be lined so that the water due to seepage losses will not be circulated. In case of unlined canal, the spacing of augmented tube wells from the canals should be kept 500 to 600 meters. The canals & the spacing between the tubewells are kept about 500 meters as it is considered that the cone of depression of the pumping tube wells does not extend beyond it.

(iv) There should be adequate storage of water in the aquifer and annual recharge should be good enough to sustain the draft from contemplated augmentation tube wells for obvious reasons.
(v) Depth to water table should not be very deep.

Generally, Augmentation tube wells are installed along the canals in such areas where the aquifer parameters i.e., T & S are promising and groundwater balance i.e., difference between recharge & discharge is ample to support exploitation of the groundwater potential. Normally, such studies like water balance are made area-wise for the State each year which is made on the basis for the scheme. It so happens that in case of augmentation tube wells, the water is transported to areas lower down in the canal system and such areas receive the benefits where normally groundwater potential is either brackish or deficient. The augmentation tubewells are installed after taking into account that the demand for the direct tubewell irrigation in the area is fully met with and only in such conditions, the augmentation tubewell water is exported for other areas. Psychologically, there arises an agitation in the minds of people to export such water but so long as their requirements are met with through the direct irrigation tubewell including shallow tubewells the resistance is uncalled for.
(a) **Conjunctive use with Saline Groundwater**:

Conjunctive use of surface and groundwater has larger scope of its application in areas where quality of groundwater is termed as brackish or saline and the area is covered with a good network of carrier channels. The conjunctive use along certain carrier channels has been observed to be one of the practical solutions to the problem to some extent. This is so because configuration of the State is such that the natural drainage is absent and outfall of the drainage water is not feasible. In saline groundwater areas, a precise knowledge of the presence of aquifer zones at different depth-ranges, variation in quality with depth, type of aquifer material and hydraulic parameters and the discharge in the carrier channels along which the tubewells are being contemplated, are some of the basic parameters required for planning the conjunctive use of saline groundwater with surface water.

Studies carried out by the author on the chemical composition of surface waters in different parts of the area show that in most of the cases the EC of surface waters lies below 800 \( \text{micromhos/cm} \). Thus conjunctive use will help utilization of saline irrigation waters. Similarly high sodium groundwaters can, in some circumstances, be put to use as surface waters in the area. They are primarily of the alkaline earth bicarbonate type and the SAR will become lower not only due to the presence of Ca &
Mg ions in the surface waters (in greater proportion as compared to Na ions) but also due to simple dilution effect.

The utilization of surface and ground-water resources conjunctively also tends to remove the drawbacks inherent in each of these two systems, if operated independently. For example, exploitation of groundwater resources often leads to overdraft and lowering of water table. Recharge of groundwater by natural seepage or artificial recharge can help to prevent occurrence of this phenomenon. On the other hand, introduction of canal irrigation has often resulted in rising of water table, waterlogged conditions and salinization of soils with loss in availability of productive soils, a situation that can be remedied by installation of tubewells to pump out groundwater. Further, since ground-water is to be utilized, the seepage from canals may be permitted in certain circumstances thereby avoiding the cost involved in lining of canals.

(b) Economic Considerations:

The Irrigation Department, Govt. of Madhya Pradesh has estimated that the cost per hectare of the created potential under major and medium schemes (surface water) is about Rs. 15,000/-.

The cost for the same unit under minor irrigation is about Rs. 3000 per hectare and thus the irrigation is more economical. The schemes for deep tubewells both for augmentation tubewells and direct
irrigation tubewells work out to be financially viable with yearly working hrs. of 4000 & 3000 respectively. Both these types of tubewells become financially viable only during last span of its life which is taken as 30 years. In case of these tubewells the projections are being achieved as electricity is available through independent feeders but in case of direct irrigation tubewells the achievement is of the order of 30% due to non availability of electricity for the required period. As such direct irrigation tubewells in actual practice are not achieving financial viability. The position may improve if independent electric feeders are provided for the direct irrigation tubewells also instead of present practice of connecting these tubewells from Rural feeders as this arrangement shall enable government to allow priority for supply of electricity of State directed irrigation tubewells. As far as benefit cost ratio is concerned, it works out to be above as 3:1 with adoption of actual achievements of working hours in both types of tubewells.

The scanty and variable surface supply in the area under study has necessiated management of irrigation and thus, resulting in direct necessity of the application of conjunctive use of surface and groundwater. All groundwater structures: Augmentation, Direct irrigation tubewells & shallow tubewells, play a vital role in augmenting water resources of the study area and demonstrate the conjunctive
use with surface water through rains, canals, streams & drains, etc. This technique provides timely relief during droughts. The conjunctive use of surface and groundwater not only entails greater availability of water resources which can augment the area under irrigation, but it can also result in changing the cropping pattern and introducing flexibility in the entire irrigation programme. Further, during floods, surface water may be stored underground using suitable recharge sites. Similarly, pollution effects by waste discharge during the lean period in rivers may be lessened by augmenting the flows through pumping of groundwater.
9.1 SOILS

9.2 SOIL EROSION AND FORMATION OF RAVINES

9.3 SOIL SALINITY AND ALKALINITY

9.4 SALINITY AND ALKALINITY HAZARDS

OF IRRIGATION WATER

9.5 WATER LOGGING

9.6 REMEDIAL MEASURES

9.7 GROUNDWATER POLLUTION

9.8 ENVIRONMENTAL HEALTH HAZARDS

9.9 CONSERVATION OF ENVIRONMENT
The life of man is closely related to the environment of the earth. This environment consists of two major elements, the biological environment and the physical environment. The biological environment refers to plants and animals and provides food for men and fulfils their certain other needs. The physical environment includes the sum of the non-living or inorganic matter, such as the land, water and soil. The physical environment on the earth provides favourable conditions for the existence and growth of different forms of life, including man.

The surface features of land masses are undergoing changes. The mountains are being eroded and worn down gradually. Rivers flow ceaselessly carrying huge quantities of eroded sediments and carving deep valleys. Sudden floods change river courses and cause large scale destruction. These changes in the natural environment, whether they are slow or sudden, are the results of natural processes at work. It will be interesting to know that the changes, whether they are slow and imperceptible or abrupt and violent, are primarily for establishing an overall balance or equilibrium, among different geomorphic processes if we consider the earth as a whole. This chapter presents the
various environmental aspects pertaining to physical environment i.e., the problems related to land, soil and water existing in the study area.

9.1 **SOILS**

The human settlement and distribution in the past and also in the present has followed the pattern of soil fertility. Soil may be defined as the weathered superficial layer of the earth crust, capable of supporting life. It is formed by the combined action of climatic factors such as water and temperature and biotic factors such as plant and microbes. It consists of inorganic material of the parent rock, organic products of the living organisms, living organism themselves especially micro-organism, water film and air filling the interparticle spaces or pores. The topography of a region is another factor affecting the formation of soils. Steep slopes usually have thin layer owing to the denudation of such slopes by running water. Valleys and lowlands develop generally thick fertile soils.

A well developed soil is formed only when the weathered particles of rocks remain undisturbed at one place for a long period of time. During such a long time, the actions of physical, chemical and organic process lead to the formation of well developed layers one below the other. Each type of soil has a well developed vertical cross section called the soil profile (fig. 9.1). Four layers or
Fig. 9.1: A Soil Profile

Four layers are clearly distinguished in the soil profile.
sections may be distinguished in the soil profile. The top layer consists of fine particles and organic matter. Below this layer is the subsoil which contains material removed from the top layer by the percolation of water from the surface. Below the subsoil is the zone of partly weathered rock and the fourth layer consists of hard rock (bed rock). Each layer is distinguished from the other by its colour and the size of particles. The quality of a given soil is assessed mainly on the basis of its fertility, texture, structure, organic content and water air relationship. The fertility or productivity of soil is its ability to support plant life. It depends on the availability of water, air and nutrients. The available supply of plant nutrients in soil can be reduced by many factors namely soil erosion, overcropping and by leaching of mineral nutrients. Such soil can not remain fertile for long time, unless the minerals are added artificially.

Texture of soil depends on the relative proportion of the size of the inorganic particles. The soils, based on particle size can be classified as clayey, loamy and sandy. Clay soils having very fine particles provide greater surface area for chemical and microbiological activity and better retention of soil water after the excess has drained away.

The soils of the study area vary from silty loam to sandy loam with variation in percentage of clay. In the
water logged area, it has been observed that the top soil is clayey with clay percentage varying from 18 to 35% and underlying soils are yellow with varying percentage of Kankar. Clay particles are less than 0.001 mm in diameter and function like negatively charged colloids in ion exchange processes.

9.2 SOIL EROSION AND FORMATION OF RAVINES:

The surface of the soil layer is subject to both soil forming processes and the denudational processes of running water and winds. In the regions with a cover of natural vegetation, there is generally an equilibrium or balance between these two processes. The rate of removal of fine particles from the soil is the same as the rate of addition of particles to the soil layer. Such an equilibrium is disturbed by natural or human activities and this leads to greater rate of denudation of soil. This phenomenon is called soil erosion and the entire soil layer may be removed in a few years.

In the study area, the problem of soil erosion mainly exists in the northern region (Photograph No.16) where the Gangetic alluvium is prone to be cut along the bank of the Sind and Pahuj river, their tributaries and fast moving nallas of the region. The erosion is due to both natural and human factors like water, wind, fires.
Photograph No. 16
Large scale soil erosion along the bank of the Sind river due to mechanical action of water

Photograph No. 17
Extensive rill erosion along the bank of the Pahuj river
dessication, shifting cultivation, uncontrolled indiscriminate grazing and destruction of forest, etc. The removal of forest and other natural vegetation by man produces greater runoff leading to soil erosion and over-grazing of land especially by goats is responsible for soil erosion from the hill slopes. The cultivation of hill slopes such as ploughing down the slope increase soil erosion. Soil erosion in the study area has been intensive due to presence of loose unconsolidated material. The absence of vegetation cover increases soil erosion as the soil particles are no longer hold together by the roots of plants. Torrential rains cause greater erosion rather than moderate to light showers and drizzles spread over many days.

Nearly three forth of the study area is covered by alluvium. Along the Sind river section, the thickness of the alluvium often exceeds 20 metres. This tract is marked by the gullies along the major rivers and their tributaries caused by water action on the loose soil. On the steeper slopes, running water flows along definite paths down the slope and this leads to gully erosion. Gullies are small and shallow to start with but they branch off rapidly and become wider and deeper. Due to this type of erosion, most of the study area is rendered unsuitable for cultivation. Banks of the deep streams and their upper reaches in the alluvial tracts are experiencing the rill erosion (Photograph No. 17)
Photograph No. 18
Alluvium of Sind river showing
development of gullies and ravines
which is the early stage of the gully formation. The effect of soil erosion is not only removal of soil but it also brings frequent and devastating floods. To some extent soil erosion is natural process but is accelerated because of the removal of natural flora, uncontrolled grazing, careless ploughing and unplanned management of drainage. Gullies or ravines have been developed in the alluvium all along the Sind and Pahuj rivers (Photograph No. 18). The region with a large number of ravines is called badland.

The intensities of presence of ravines increase towards the confluences of the Kanwari and Pahuj with the river Sind and Sind with the river Yamuna. Wherever fine texture is present on either side of the banks of these rivers and their tributaries, the headward erosion helps in the formation of new ravines. As a consequence, very deep ravines occur in the extreme tail reaches of Matatila Command (Photograph No. 19). Based on these characteristics of the ravines, the alluvial part of the Matatila Command has been divided into two parts. The upper part has a low density of ravine formation where as the lower part of the Command is dense with the ravines adjacent to both the banks of Sind and Pahuj rivers. The headward erosion of the ravines makes the ravines closed and sometime the erosion causes small part of the alluvium to occur as knolls within the ravines.
Photograph No. 19
Formation of deep ravines in the
tail reaches of Matatila Command area
Various views have been expressed by a number of workers from time to time. Out of which the important ones have been considered such as Bryan (1941), Antevs (1952) and Tuan (1966). They state that the gullies are the result of climatic changes due to alternate dry and wet periods, resulting in degradation and aggradation conditions. Bennett (1955) and Brice (1966) are of the opinion, that the ravines formed, are due to the misuse of land, on account of which gullies form. Schumm (1956) has pointed out that the formation of rills is the badland topography is due to the channelling of water on steep slopes during rapid run-off. The rills get enlarged into the gullies and then into the ravines in course of time. Sharma (1968) attributes the formation of ravines in the alluvial parts of the Matatila Command due to rejuvenation phenomenon. In support of his contention, he states that in some areas, the ravines are 40 to 50 metres deep in the Chambal alluvium, the ravines have extensive distribution beyond the confluence of the Sind and Pahuj and Sind and Yamuna rivers. According to him, the area covered by the ravines in the area is as much as 3 lakh hectares.

In addition to the above mentioned views, Chourasia (1984) has studied a number of ravine cross sections at various localities of the river Sind, Chambal and Kunwari. These studies point out that the uppermost part of the ravine consists of loose soils followed by
a thick layer of clay-kankary horizon and then, by a clay bed in depth. A cross-sectional traverse from Sabalgarh town to the river Chambal studying the groundwater levels in the existing wells has indicated that the groundwater level about 8 to 10 meters below the ground surface suddenly falls down to a depth of about 18 to 20 meters in a dugwell adjacent to the ravines.

A few auger holes driven into the clay-kankary layer by the author in the vicinity of the village Ron indicated that the clay-kankary horizon is water-bearing and the groundwater is under pressure. One hole indicated a pressure as much as 180 kilograms per square meters. The depth of the hole was only one meter below the ground surface. In the clay-kankary horizons of the ravines, leakage and seepages of the groundwater are commonly seen. In the villages, which lie at the bank of the river Sind and the ravines, mud flows have been seen through the cracks and fissures of the bottom clay bed. The dugwell and the flowing wells studied in these village farmlands indicate that the overburden loads over the confined aquifer just balance the pressures caused by the confined aquifer below the clay bed. Wherever, the overburden loads are less than the confining pressure of the aquifer underneath, the mud flows through fissures, mud volcanoes through centres are seen at the floor of the valley of the ravines due to pressure bursts. Wherever, the overloads are greater than the confining pressures of the aquifer, the
above mentioned features are not seen. From such studies, the author has come to the conclusion that there are three stages in the formation of ravines. The first stage is due to sheet washing of the loose soils capping the clay-kankary layer, leading to the minor depression. The second stage is the clay-kankary material getting pushed out by groundwater pressures within them into the depressions, caused by sheet washing. As a consequence, the caving of the clay-kankary layer with roof collapse takes place. Thus, the headward erosion of the ravine progresses. The third stage is ground bursts leading to the widening and deepening of the ravines.

Formation of ravines is destroying our fertile land year after year and it is an alarming geoenvironmental hazard to our agriculture. More attention should be given to protect our fertile land and the remedial measure of ravines should be immediately implemented by the Government to save the Nation's land.

Soil erosion may be prevented by adopting suitable measures of soil conservation. Afforestation is one of the most effective methods of soil conservation along hill slopes and other cultivated lands. The vegetation holds the soil together and makes it stable. It is suggested that where trees could not be grown, grass could be relied on as a very efficient substitute in the prevention of soil erosion. On gently sloping lands contour ploughing, strip
cropping and bunding help in soil conservation. The terracing of hill slopes also prevent soil erosion. Gully erosion can be prevented by constructing check dams to prevent the spread of gullies. Some check dams already exist on the Seondha nallah which traverses the town of Seondha, preventing problem of soil erosion to the layout area of the town. Apart from the thirteen check walls already constructed for all nallah in 1960, three more such walls have been constructed under the flood protection scheme. One protective bund at Begampur village is also being constructed. Soil conservation is most essential as loss of soil due to erosion can not be easily made up. Soil conservation helps to retain fertility of the soils also. When the natural balance has been restored, then and then only will the soil be rendered stable and man and his animals will live in harmony with their surroundings.

9.3 **SOIL SALINITY AND ALKALINITY**

Conditions of low precipitation, high evaporation and relatively small amount of soil leaching result in the accumulation of the excess quantities of soluble salts that retard or inhibit plant growth. Soils having excessive soluble salts are designated as saline soils and those having excessive quantity of exchangeable sodium (greater than 15%) are designated as alkaline or sodic soils. One of the effect of this is to decrease porosity of soil. A
portion of water that is adsorbed and brought up by plant root is taken away before it reaches stem and plant is left to die of food and moisture. Some of the fertile agricultural land within the study area has gone out of cultivation due to soil salinity. The research findings at the Central Soil Salinity Research Institute (CSSRI) Karnal, have successfully demonstrated that the productivity of such soils can be restored by adopting specific soil management and reclamation techniques. The formulation of an effective management and reclamation scheme for full use of these resources require several types of information. At present, however, there is information about the area affected by soil salinity particularly data on their geographic distribution and areal extent. The use of Landsat MSS imagery in mapping soil resources has been demonstrated by Westin and Frazee (1976), Singh, et al. (1982) and Dwivedi (1985). Sharma and Bhargwa (1988) determined the usefulness of Landsat imagery for determining the areal extent and geographic distribution of saline soils in the north-western parts of India. The author has delineated the saline soils within the study area following the similar principle.

The saline soils are imaged on the imagery in white coloured irregular patches. Barren saline soils with a 1-2 cm. thick salt crust on the surface with a high degree of reflectance appeared in similar tone. Saline soil mapped
Table No. 21
MORPHOLOGICAL AND PHYSICO-CHEMICAL CHARACTERISTICS OF SALINE SOIL PROFILES FROM TAIL REACHES OF THE MATATILA COMMAND AREA (M.P.)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Sample No.</th>
<th>Soil colour</th>
<th>Roots</th>
<th>Soil textural class</th>
<th>pH</th>
<th>ECa (dS/m)</th>
<th>OC (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1</td>
<td>10 YR 7/3</td>
<td>Very few</td>
<td>Sandy loam</td>
<td>8.4</td>
<td>19.37</td>
<td>0.30</td>
</tr>
<tr>
<td>2</td>
<td>S2</td>
<td>10 YR 7/3</td>
<td>Few</td>
<td>Loamy sand</td>
<td>8.2</td>
<td>38.20</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>S3</td>
<td>10 YR 7/3</td>
<td>Very few</td>
<td>Sandy loam</td>
<td>9.2</td>
<td>3.84</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>S4</td>
<td>10 YR 5/4</td>
<td>Few</td>
<td>Loamy sand</td>
<td>8.5</td>
<td>16.80</td>
<td>0.18</td>
</tr>
<tr>
<td>5</td>
<td>S5</td>
<td>10 YR 7/4</td>
<td>Few</td>
<td>Sandy loam</td>
<td>9.5</td>
<td>9.23</td>
<td>0.15</td>
</tr>
<tr>
<td>6</td>
<td>S6</td>
<td>10 YR 5/6</td>
<td>Absent</td>
<td>Sandy loam</td>
<td>9.0</td>
<td>13.00</td>
<td>0.13</td>
</tr>
<tr>
<td>7</td>
<td>S7</td>
<td>10 YR 5/4</td>
<td>Few</td>
<td>Sandy loam</td>
<td>9.5</td>
<td>7.20</td>
<td>0.15</td>
</tr>
<tr>
<td>8</td>
<td>S8</td>
<td>10 YR 5/4</td>
<td>Very few</td>
<td>Sandy loam</td>
<td>8.7</td>
<td>14.70</td>
<td>0.13</td>
</tr>
<tr>
<td>9</td>
<td>S9</td>
<td>10 YR 7/3</td>
<td>Few</td>
<td>Loamy sand</td>
<td>8.5</td>
<td>38.90</td>
<td>0.35</td>
</tr>
<tr>
<td>10</td>
<td>S10</td>
<td>10 YR 5/4</td>
<td>Few</td>
<td>Loamy sand</td>
<td>8.3</td>
<td>15.90</td>
<td>0.15</td>
</tr>
<tr>
<td>11</td>
<td>S11</td>
<td>10 YR 5/4</td>
<td>Very few</td>
<td>Sandy loam</td>
<td>8.4</td>
<td>15.00</td>
<td>0.14</td>
</tr>
<tr>
<td>12</td>
<td>S12</td>
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<td>12.90</td>
<td>0.13</td>
</tr>
<tr>
<td>13</td>
<td>S13</td>
<td>10 YR 7/3</td>
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<td>Sandy loam</td>
<td>8.4</td>
<td>20.00</td>
<td>0.14</td>
</tr>
<tr>
<td>14</td>
<td>S14</td>
<td>10 YR 5/4</td>
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<td>Sandy loam</td>
<td>9.4</td>
<td>7.35</td>
<td>0.14</td>
</tr>
<tr>
<td>15</td>
<td>S15</td>
<td>10 YR 7/4</td>
<td>Few</td>
<td>Sandy loam</td>
<td>9.3</td>
<td>9.90</td>
<td>0.15</td>
</tr>
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</tr>
<tr>
<td>16.</td>
<td>S16</td>
<td>10 YR 7/3</td>
<td>Very few</td>
<td>Sandy loam</td>
<td>9.5</td>
<td>3.86</td>
<td>0.13</td>
</tr>
<tr>
<td>17.</td>
<td>S17</td>
<td>10 YR 5/4</td>
<td>Very few</td>
<td>Sandy loam</td>
<td>8.5</td>
<td>15.00</td>
<td>0.14</td>
</tr>
<tr>
<td>18.</td>
<td>S18</td>
<td>10 YR 7/3</td>
<td>Few</td>
<td>Sandy loam</td>
<td>9.3</td>
<td>3.65</td>
<td>0.15</td>
</tr>
<tr>
<td>19.</td>
<td>S19</td>
<td>10 YR 5/4</td>
<td>Few</td>
<td>Lomay sand</td>
<td>8.7</td>
<td>14.70</td>
<td>0.18</td>
</tr>
<tr>
<td>20.</td>
<td>S20</td>
<td>10 YR 5/4</td>
<td>Few</td>
<td>Sandy loam</td>
<td>9.4</td>
<td>7.84</td>
<td>0.12</td>
</tr>
</tbody>
</table>
from the satellite imagery is shown in fig. 2.8 chapter II. In order to understand the nature of soils about 20 surface soil samples (0-15 cms depth) have been collected (Fig. 9) & analysed. Based on the physico-chemical and morphological characteristics (table No. 21), the soils have been classified as Ustorthents (saline phase) and Ustifluvents (saline phase) according to United States Department of Agriculture (USDA, 1975). The chemical composition of surface soil samples (0-15 cm depth) from 20 sample points indicates a moderate degree of salinity. The electrical conductivity of Soil Saturation Extract (SSE) varies from 3.5 to 80 ds/m.

The main causes leading to the development of saline and alkaline soils are arid climate, high subsoil water table, poor drainage, irrigation with water containing soluble salts and saline nature of the parent material. The phenomenon of salts coming up in solution due to a rise in groundwater table and forming a thin crust on the surface after evaporation of water is called salt efflorescence (Raghunath, 1983, p.283). The following measures can be adopted to reclaim the salt affected land existing in the study area.

1. Ploughing salt surface crust deep into soil.
2. Removing surface accumulation from the soil.
3. Neutralising by additives:

Gypsum (CaSO₄) as a source of soluble calcium can be used for reclaiming black alkali soils. When gypsum is not available, sulphur can be used. Sulphur is oxidised to sulphuric acid and reacts with CaCO₃ to form gypsum. Waste lime from beet sugar refinery is sometimes used. Other amendments are Al₂(SO₄)₃ and FeSO₄. After the chemical amendments have converted the Na-soil into Ca-soil, the soluble products of the reaction like NaHCO₃ and Na₂SO₄ are removed by leaching through flooding. The quantity of amendment required depends on the soil depth of reclamation and the amount of exchangeable sodium initially present.

4. Artificial drainage to lower the water table by open or tile drains. Drainage is necessary in the study area to control surplus water in such a way as to render the soil more suitable for cultivation and growth of crops. When natural processes like surface runoff, evaporation and transpiration and deep seepage to remove excess water do not cope up with disposal of excess water sufficiently fast enough, artificial drainage is resorted to. It consists of the following:

(a) Surface drainage and intercepting drains.
(b) Subsurface drainage.
(c) Relief wells.
(d) Vertical drains by pumping.
5. Better irrigation practices and lining of canals to prevent seepage.

6. By leaching excess salts out of soil with the help of 5-30\% more water depending on salt content of water and type of soil to leach out the salts.

Leaching requirement = \( \frac{\text{EC of irrigation water}}{\text{EC of drainage water}} \)

7. Applications of manure and organic matter improve tilth and permeability. Decomposition of organic matter liberates \( \text{CO}_2 \) which dissolves in water forming carbonic acid which increases solubility of \( \text{CaCO}_3 \) in soil.

8. Growing salt tolerant crops like rice, sweet clover and bermuda grass. They also cover the land surface and reduce evaporation.

9. Intelligent management of the soils.

Preventive measures are preferable in comparison to remedial measures as later are very costly. Preventive measures include:

1. Observe the rate of rise of water table in irrigated tracks by noting water level in open wells or in piezometer tubes to diagnose approaching danger and take timely action to prevent damage.

2. All standing pools of water in area and local depressions should be suitably drained to natural drainage.
(3) Locate sources of excessive seepage and resort to lining and/or interpercepting drains parallel to channel.

(4) Where water table is already high (say within 3 meters from the ground) cropping pattern should be modified and conservation rotation, cover crops and other soil improving cultivation practices should be enforced by extension work.

(5) Any obstruction due to communication embankments to natural drainage should be removed to allow excess water to have free flow to nallah.

(6) In areas, where water table is high, irrigation by wells should be encouraged by giving suitable incentives to cultivators.

(7) Excessive application losses should be remedied by land shaping.

(8) Restricting use of water by resorting to volumetric measurement, intermittent supply and extending command.

The alkalinity of soils in the command is more where the water of the lime-kankary horizon is under pressure. The alkaline materials are more in solution the ground surface through the overlying soil cover, on account of pressure as well as capillary and seasonal drying action.
9.4 **SALINITY AND ALKALINITY HAZARDS OF IRRIGATION WATER**

The works carried out by numerous investigators such as Jacob et al. (1961), Wahab (1961), Thorn and Thorn (1964) have shown a general positive correlation between salinity of irrigation water and accumulation of salt in soils irrigated by them. A high salt content of the soil results in increase in osmotic pressure and decrease in specific free energy of the water or increase in total moisture stress (which is the sum of osmotic effect and soil moisture tension) leading to decreased absorption of water. Water deficit, affects numerous internal processes such as turbidity, diffusion pressure deficit, photosynthesis, respiration and cell enlargement. Plants adversely affected by salinity grow more slowly or often stunted, their leaves are smaller but may be thicker than those of normal plants and often darker green in colour.

Another important factor is the increase in exchangeable sodium percentage of soil through absorption of sodium contained in irrigation water by cation exchange. The increase in exchangeable sodium percentage in the soil results in lowering of their structure stability. Soils that have low stability of structure tend to disperse and slake when they are wetted by rain or irrigation water. The downward percolation of water is affected and the soil may develop a hard crust as the soil surface dries. This crust presents a serious barrier for emerging seedlings and results in poor stand.
In addition to its contribution to deterioration of soil structure, excessive sodium may also create specific problems as a source of toxicity in certain sensitive crops. However, the deleterious effects of excessive sodium on crop growth are not as closely related to absolute sodium concentration in the soil water as to the exchangeable sodium percentage. Crops that are specifically sensitive to sodium may be affected by sodium toxicity when the ESP of the soil is even below those levels associated with soil structure deterioration. As little as 5% exchangeable sodium may cause severe sodium injury.

9.5 WATER-LOGGING

National Commission on Agriculture (1976) has defined an area to be waterlogged, when the water table rises to an extent that the soil pores in the root zones of a crop become saturated, resulting in restriction of the normal circulation of air, decline in the level of oxygen and increase in the level of carbon dioxide. The water table which is considered harmful, would depend upon the type of crop, type of soil and quality of water. The actual depth of water table, when it starts affecting the yield of a crop adversely may vary over a wide range from zero for rice to about 1.5 meters for other crops. In general, the areas with water table within 2 meters below ground level can be considered prone to water logging and those with water table within 2 to 3 meters below ground level may be
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Name of Village</th>
<th>District</th>
<th>Total Number of Wells in Which Water Level Measured</th>
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(B) AREAS WHICH ARE APPROACHING TOWARDS WATER-LOGGING CONDITIONS
viewed as critical areas wherein any additional input of water without protective measures can turn into water-logged area (Pathak, 1984). Despite the seriousness of the problem, precise data on the location and extent of the water-logged area is not collected so far.

As already mentioned in chapter II that Sharma and Bhargava (Op.cit.) has demonstrated the utility of Landsat imagery for mapping the areal extent and geographic distribution of water-logged soil with minimum cost and time. The author has delineated the water-logged soil of the study area on Landsat imagery following the same principle as adopted by Sharma and Bhargava. Water-logged soils have been delineated with their unique tone and diffused blue colour on the imagery. They were verified by selective field visits which were aimed for measurement of water table from open dugwells (Table No. 22). The total water-logged soils identified, within the study area cover an area of about 21,044 hectares. It lies in between 26°0' to 26°17'N latitude 78°, 18' E to 78°58'E longitude (Photograph No. 20).

Due to the irrigation from the waters of the Matatila reservoir in the command, two causes of water-logging conditions have been noticed. The first cause is mostly due to irrigation water which is neither being able to drain through the soils nor getting drained as run off into the streams and rivers. The second cause is on account of general rise in groundwater levels. Wherever, the first
Photograph No. 20
Growth of Bermuda grass, a botanical indicator of water-logged area
Cause of water-logging conditions is noted in the area which has low ground, inadequate surface drainage, and clay soils having poor drainage profiles.

The second cause of water-logging is due to the rise in the groundwater levels. This rise is due to the improved recharge and infiltration conditions of the water-bearing beds on account of irrigation as well as due to the presence of water pockets in the depressions on recharging grounds for want of surface water drainage facilities. A study of groundwater level profile starting from the Bhandar main canal towards the Sind river indicates that the water levels suddenly drop down to a depth of 35 meters or even more, in areas immediately adjacent to the Sind river. Such abrupt changes in the groundwater levels may be due to so-called Sind river fault and consequent downward displacement of the aquifer zone towards the Sind river.

It has been observed that the farmlands adjacent to the canals are water-logged, and those which are away from them are less water-logged. In between them water table is gradually rising towards the surface. The water-logging problem in the tail reaches of the command area is more severe and extensive than in upper reaches. In the villages, Machharya, Pantri, Nodhini and Imlaha, the houses and mango trees are collapsing. The houses are getting affected due to rise of water table.

At some places, the walls of the houses stay wet
1.5 to 1.5 meters upward, even up to the commencement of summer. Due to this there is an increase in the incidence of malaria specially in the rural areas after the introduction of irrigation in the command area. Although irrigation by itself may not have contributed substantially to the spread of mosquitoes and thereby to Malaria, water-logged areas and stagnant water in the borrow pits has facilitated the breeding of mosquitoes considerably. Further, the intensive irrigation has increased the average humidity of the atmosphere, which has made the region conducive to mosquitoes' survival due to which most of the people living within the study area usually suffer from Malaria.

The groundwater system in an area is generally in dynamic equilibrium prior to introduction of surface water irrigation. During the pre-irrigation stage, the groundwater regime is generally in a state of balance with inflow and outflow. The experience in the area has shown that the increased recharge due to additional seepage through canal network causes water table to rise, to the extent that it has encroached upon the crop root. This condition of water-logging is affecting the physical, chemical and biological properties of soils.

As the root zone of plants gets flooded with water, there is lack of aeration in the soil causing decay of roots. The water table being very near the ground, the
water from the water table rises up by capillary action and brings with it salts in solution. Water evaporates from the surface of land, leaving behind an accumulation of these salts. This concentration of salts when present in the root zone of any plant has corroding effect on the roots, as a result the growth of the plants get checked and productivity decreases. These excessive soluble salts if not removed earlier, a base exchange reaction begins, as the soils in the study area are clayey, making it impermeable and highly unproductive.

The major drainage that crosses the Matatila Command area are Pahuj, Sind and Son rivers. Due to the additional seepage through canal network, excessive field application of irrigation water and due to lack of adequate drainage, the water table in the area has started rising. A systematic study of water levels in the study area has been taken up since January 1977 by State Groundwater Survey through a network of dug wells. Based on the analysis of these data, it was estimated that by January 1986, the area with the depth to water table below ground surface from 0 to 1.5 meter is 18244 ha. whereas the area with the depth to water level below ground surface from 1.5 - 3.0 m is 9,536 hectares.

Field levelling has not been done in most of the area resulting in accumulation of water for a longer time,
further, due to lack of adequate drainage, excessive drawal of irrigation water in the head reaches and confining irrigation to day time only leaving water to flow from open outlets during night and heavy seepage of water from the canal bed and sides when canal is in embankment or a previous strata has been out, lead to serious water-logging conditions in the area.

9.6 **REMEDIAL MEASURES**:

Water-logging and related problems are assuming gigantic proportions in the study area, preventive rather than remedial measures have been given due importance and attention at the planning stage of these projects. Water logging being essentially due to surplus groundwater and inadequate drainage. The approach to tackle this should include the proper understanding of groundwater regime and physiography. Detailed hydrogeological surveys need to be undertaken in the command area for delineating aquifers and their characteristics for proper planning of subsurface development structures. With a strong data base, simulation studies may also be undertaken for predicting the behaviour of groundwater regime with the additional surface water in the command. The combination of surface and subsurface drainage together with selective canal lining, land levelling, judicious application of irrigation water by rostering the lining of
canals in the affected areas and eukeliptus tree plantation could prove to be quite effective in controlling and preventing water-logging. The remedial measures suggested for the water-logging are given below:

1. Deepening and/or widening of the aqueducts as may be necessary in order to prevent formation of water pools.

2. Reopening of all the effective natural drainage courses, such that the surface waters are conducted to their respective river systems.

3. Construction of drainage channels parallel to the main canal at locations where seepage occur through the floor and the sides of the canal.

4. Construction of drains to dispose of the surface run-off of low grounds into the natural drainage courses.

5. Supply of irrigation waters should be drastically curtailed in the case of farmlands, where groundwater levels have reached up to one meter below the ground surface.

6. On lands, where groundwater levels are more than one meter below the ground surface, irrigation supplies should be based—by taking into consideration, the soil profile, depth of profile, drainage profile and the ground slopes along with the consideration on the
water requirements of the crops at various stages of their growth. Irrigation on the concept of "Duty of Water" should not be practised.

7. The type of crops that are to be grown, should also be based on the groundwater level depths during different seasons of the year.

8. Land shaping practices should be implemented and the bunds dividing them into small fields should be spaced far apart.

9. Adequate provision should be made for run-off from the fields.

10. Intensive exploitation of groundwaters for irrigation purpose should be resorted in the command area, where, canal water is not being used for irrigation. The sites for the wells should be located on the recharging grounds of the water logged areas and in the command area. These wells will serve a dual purpose, namely, that they will not only bring new area under irrigation, but they will also reduce the groundwater level in general.

11. Wherever, proper underground reservoir capacities are available for the intake of water from the upper groundwater zones, inverted wells should be located.
12. Wherever, serious recharging conditions occur in ponded areas adjacent to the water-logged areas, clay material have to be dumped into the pool to reduce the infiltration capacities.

13. Lining of canal floors and sides wherever the yellow clay with kankar (water-bearing zone) are exposed.

It should be noted that the water-logging in the Matatila Command is in the initial stage of its development, therefore, preventive measures will be much cheaper than the curative measures. As a first step, all the natural drainage courses should be opened and broadened to drain the run-off and the supply of irrigation waters to water-logged areas should be stopped. As a second step, wherever, pools of water occur, they should be drained. The third step consists of providing drainage channels parallel to the main canal on the left bank side. The fourth step consists of the use of proper agronomical practices along with the levelling of land and provision of adequate drains to implement economical use of irrigation waters. Water-logging, salinity and alkalinity of the soils in the command area are intimately associated with one another. The water in the yellowish clay-kankary water-bearing zone appears to contribute the alkalinity of the soils. Therefore, the prevention of water-logging helps in checking the salinity and alkalinity of the soils also.
9.7 GROUNDWATER POLLUTION:

The programmes of economic development and environmental protection are mostly interlinked and complimentary to one another. It is unfortunate that there is a direct conflict between economic development on the one hand and environmental pollution control on the other hand in developing countries. The former provides greater development leading to a generally higher standard but the environmental pollution leads to deterioration of the quality of natural waters and affects the lives of many people throughout the world. Among the causes are the large volumes of waste water often subject to little or no control originating from highly populated cities, the discharge of untreated effluents by industrial complexes and the use of a wide variety of fertilizers and pesticides in agriculture. It's results include harm to humans, animals and plant life, unpleasant odours, reduced water clarity and reduction in recreational activity of surface and inland waters. However, concern for prevention and control of water pollution has been evidenced but the groundwater pollution, monitoring and control measures are still in a state of infancy and yet to gather momentum to make impact at the national level.

Pollution of water is defined as the presence of some foreign organic, inorganic, biological, radiological or physical substances in water that tend to degrade its
quality and either constitutes a health hazard or decreases the utility of water. "Pollutant can be defined as a constituent in the wrong amount at the wrong place or at the wrong time." The process of surface water pollution is rapid and becomes evident in comparatively short time from perceptible changes in colour, taste, odour and at the times by dead aquatic life. The mechanism of groundwater pollution is different from surface water and the time span between pollution discharge at land surface and reach to groundwater body, may be several years.

In order to study water pollution, 65 groundwater samples have been collected from dug wells, dug-cum-bore wells and tube wells (Ref. Chapter 7). The water samples have been collected early in the morning in order to avoid contamination from users. Nearly two liters of water samples have been collected in a plastic container with screw caps and sealed immediately by candle wax. These samples have been analysed for chemical parameters and the results are presented in appendix No. 9.

Toxic elements (Co, Mo, Ni, Pb, Cr, Cu, Zn, Mn) have been determined in 18 samples by evaporating one litre of water samples in an evaporating dish to concentrate the toxic elements and then using Emission Spectrography. The results show that these are within the permissible limits and do not create environmental pollution. The results of
the chemical analysis of the water samples collected from the area under study reveals that the water falls between good to moderately suitable for human consumption as well as for irrigation, although some water samples show salinity as mentioned earlier in the quality of water in chapter 7 (quality of water). Results show that in some water samples sulphate content has also crossed the permissible limit (200 ppm.).

9.8 ENVIRONMENTAL HEALTH HAZARDS:

The relationship between chronic diseases and geologic environment is complex and difficult to analyse; Nevertheless, considerable evidence are being gathered and studied. Preliminary results suggest that the geological environment is indeed a significant factor in the incidence of several hygienic problems such as cardiovascular disease, hypertension, stomach diseases and cancer. Medical geology, radiological pathology and diseases describe the relationship between health and geology.

Recent environmental health studies investigate a direct link between various chronic diseases and particular geologic environment. Recent works of Crawford et al (1971), Livingston (1970), Voors (1969-70) and Blackley (1969) have shown that the cardiovascular diseases are apparently, related with hardness of water.
Health hazard study has been undertaken in order to establish a correlation between quality of water and the diseases prevalent in the study area. The diseases prevalent may be due to other interacting parameters as well; and hence this study is an attempt to explore whether the quality of water is one among them. Therefore, it is difficult to come to definite conclusions from these studies, nevertheless it gives a broad generalised idea of the relation between health and the surrounding geological environment.

In order to carry out this study, data with respect to the health hazards have been collected from the local medical centers and also a cursory health survey has been made. Every care has been taken so that the inhabitants of the villages, who have been constantly using the groundwater for more than 5 years, have been interviewed for various diseases. In all, a total 25 villages were selected and in each village, 150-200 people were interviewed family wise including both male and female in various age groups (<5, 5-25, 25-45, >45). In all 2,609 people in various categories interviewed and out of them 200 people were found suffering from cathartic physiological effects on human body due to presence of high sulphate concentration (above 250 ppm) in groundwater whereas about 317 people living in the vicinity of wells containing higher concentration of sodium are suffering from hypertension.
American Heart Association advocates sodium restricted diet for long term management of hypertension. Other miscellaneous diseases prevalent in the people living within the study area are congestive cardiac failure, renal disease, cirrhosis of the liver, toxemia of pregnancy and meniere's disease etc. The results of the health survey carried out on 2609 people from 25 villages covering the age group between 5 and 45 are presented in table No.23.

<table>
<thead>
<tr>
<th>Total Surveyed People</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>2609</td>
<td>1680</td>
<td>929</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total people</th>
<th>Healthy</th>
<th>Unhealthy</th>
</tr>
</thead>
<tbody>
<tr>
<td>2609</td>
<td>2009</td>
<td>600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Unhealthy People</th>
<th>Suffering from Cathartic effect</th>
<th>Suffering from hypertension</th>
<th>Miscellaneous diseases</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>200</td>
<td>317</td>
<td>83</td>
</tr>
</tbody>
</table>

| Percentage | 22.99% | 33.3% | 52.83% | 13.83% |
FIG. 9.3

PIE DIAGRAM ILLUS TRATING PERCENTAGE WISE DISEASES PREVALENT IN THE STUDY AREA

Suffering from
tetnic effect

Miscellaneous
diseases

Suffering from
typerension

(33.37)

(13.57)

(82.57)
It is clear from Table No.23 that out of 2609 people, only 600 are unhealthy constituting only 22.99% which clearly indicates that groundwater is not much polluted, as evidenced from the 88.11% of the healthy people using the groundwater.

The diseases prevailing among the unhealthy people of the 25 villages for purpose of broad categorisation, have been grouped into three main categories they are cathartic physiological effect, hypertension and miscellaneous diseases.

Percentage wise study of the people of the three broad categories, irrespective of male and female, indicates that miscellaneous diseases are the least, followed by cathartic physiological effect while the people suffering from hypertension predominate (fig. No. 9.3).

9.9 CONSERVATION OF ENVIRONMENT:

Man has utilised different elements of the natural environment to suit his needs. He has cultivated land to provide himself with food grains and other raw material. He has harnessed river water for irrigation and power development. Such use of the diverse resources should be in conformity with the law of nature. If the natural equilibibrium is upset as for example by large scale deforestation, it leads to soil erosion, floods, silting up
of river channels and reservoirs. A proper understanding of the natural processes at work and of the relation between different elements of the physical and biological environment is necessary for human existence and progress. Pollution of water is caused by the effluents from factories and this can pollute the water supply of cities and towns. Pollution also results from the disposal of urban waste such as empty cans, boxes, refuse and sewage. Environmental pollution leads to the spread of diseases through polluted water. The use of insecticides and pesticides leads to the concentration of DDT and other harmful chemicals in plants and animal food products.

If the man has to survive on the earth, he has to live in harmony with nature knowing its secrets to exploit them. He should learn to adopt his mode of life, food habits, etc., in such a manner that he is able to make the best use of environment. Such a step will bring peace and prosperity to the mankind.

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