CHAPTER-VI
HYDROCHEMISTRY

Water is extensively used as a natural resource for drinking, industrial and agricultural purposes. Much greater importance has been given to groundwater quality over the past decade due to increasing reliance on groundwater, and the realization, that once contaminated, it is difficult, expensive and sometimes impossible to restore this natural resource to its original state.

The chemical, physical and biological parameters determine the usefulness of water for various purposes. Moreover hydrochemical study gives an important indication of the geologic history of the enclosing strata, the velocity and direction of water movement.

Thus it is now, generally, recognised that the quality of groundwater is just as important as its quantity (Todd, 1980). The water quality is important not only because of its linkage to the availability of water for various uses and its impact on public health but also, because of water quality has intensive value. The quality of life is often judged on the availability of pristine water.

Water is called "the universal solvent" because of its extraordinary ability to dissolve the substances. In fact, it dissolves more substance in greater quantities than any other liquid (Fletcher, 1987). Water becomes impure due to the percolation down through various lithologies, it undergoes soil water interaction until a quasi-chemical equilibrium is reached between the groundwater and the minerals in the soil. This ability of water to dissolve minerals determine the chemical nature of groundwater (Fletcher, 1987). The occurrence and widespread migration of chemical contaminants in the underground environment may ultimately become the most serious threat.
to groundwater quality. As groundwater moves along its flow paths in the saturated zones it increases the total dissolved solid due to the presence of carbon dioxide by which the most important acid \( \text{H}_2\text{CO}_3 \) is produced in the soil zone (Freeze and Cherry, 1979).

Domenico (1972), also noted that groundwater chemistry changes with depth. He found that shallow aquifers are characterized by low dissolved solids and high bicarbonates, the intermediate aquifer is characterized by sulphate dominance while in the deeper aquifer chloride ion (\( \text{Cl}^- \)) predominates with high concentration of total dissolved solids. Briefly the chemical quality of groundwater is an index of its complex flow history. Groundwater quality problems can only be resolved using a more holistic approach to agricultural management and management of industrial effluents. Moreover, safe drinking water is a basic necessity of all human beings as the 80% disease are reported to be simply water borne (United Nation, 1992).

The major constituents in groundwater occur mainly in ionic form and are commonly referred as \( \text{Na}^+, \text{K}^+, \text{Ca}^+, \text{Mg}^{2+}, \text{Cl}^-, \text{HCO}_3^-, \text{CO}_3^{2-}, \text{and SO}_4^{2-} \) which comprises more than 90% of the total dissolved solids in the water (Freeze and Cherry, 1979). A typical analysis of water samples has been carried out to evaluate the groundwater quality as well as the interrelationship between surface water and groundwater quality. In order to study the groundwater quality in Aligarh city and adjoining areas, 96 water samples were collected during June 1999 from different groundwater structures, such as dug wells shallow and deep tubewells. Besides surface water samples were also collected from Upper Ganga Canal, Kali river and some ponds. In all, 72 water samples were analysed for major ions and 28 water samples for trace element studies.
Method of sampling:

The validity of chemical analysis reflects the care with which the water samples were obtained in the field (Fletcher, 1987). Water samples were collected in well cleaned polyethylene bottles of one litre for major ions and duly acidified one litre polyethylene bottle with 10 ml 0.6N HNO₃ for trace element studies, water samples were capped and sealed with wax instantly in the field.

Analytical Procedure:

The physico-chemical characters of water samples were determined (Appendices VIII-A,B,C & IX-A,B,C) as per the standard methods (APHA, 1992; Jackson, 1985; and Goel, 1984) in the laboratory of the Department of Geology, A.M.U., Aligarh. The following table shows some physical properties, major ions and trace elements and their analytical methods.

<table>
<thead>
<tr>
<th>CONSTITUENTS</th>
<th>METHODOLOGY</th>
<th>LABORATORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical properties</td>
<td>Electric kit &amp; pH meter</td>
<td>Geology Department</td>
</tr>
<tr>
<td>pH and E.C.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major Ions</td>
<td>Volumetric (Titration)</td>
<td></td>
</tr>
<tr>
<td>CO₃⁻², HCO₃⁻, Ca⁺²,</td>
<td>Flame Photometer</td>
<td></td>
</tr>
<tr>
<td>Mg⁺², Cl⁻, Na⁺, K⁺</td>
<td>Gravimetric</td>
<td></td>
</tr>
<tr>
<td>SO₄²⁻, TDS</td>
<td>Spectrophotometer</td>
<td></td>
</tr>
<tr>
<td>F⁻, NO₃⁻</td>
<td>Voltameter 2000</td>
<td></td>
</tr>
<tr>
<td>Trace Elements</td>
<td>Atomic absorption spectrophotometer</td>
<td></td>
</tr>
<tr>
<td>Pb, Cu, Zn, Cd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co, Ni, Cr, Mn</td>
<td></td>
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</tr>
</tbody>
</table>
During the analysis of cations and anions reaction errors may be caused by some analytical errors of individual parameters and the fact that all possible ions are commonly measured (Emanuel Mazor, 1997).

**PHYSICAL PROPERTIES**

**Hydrogen Ion Concentration (pH):**

The pH is one of the most important operational water quality parameters as it influences many chemical and biological processes within a water body. It is a measure of the acid balance of a solution and is defined as the negative of the logarithm to the base 10 of the hydrogen ion concentration. The pH values ranges from 0-14 (i.e. very acidic to very alkaline), with pH < 7 indicates an acidic solution. However a pH > 7 indicates an alkaline solution and with pH 7 shows a neutral condition where H⁺ and OH⁻ ions have the same concentrations. The pH of the natural water is most often controlled by the balance between the carbon dioxide, carbonate and bicarbonate ions (Fletcher, 1987). In as much as the solubility of carbon dioxide changes with pressure and temperature, so temperature plays an important role in determining the pH. Very high pH values (>8.5) are commonly associated with sodium-carbonate-bicarbonate waters. Moderately high pH values with waters high in bicarbonates and low values (<4.0) are associates with water containing free acids derived from oxidizing sulphide minerals.

The desirable limit of pH for drinking water, as given by the W.H.O. (1984) is 7.0 to 8.5 while the maximum permissible level is given as 6.5 to 9.2. The pH values of the water sample in the study area vary from 7.73-8.94 which indicates that the groundwater is slightly to moderately alkaline. The highest value (8.94) was recorded at Lal Diggi, whereas the lowest value
Fig. 31. Electrical conductivity map of the area.
(7.25) was observed at Morthal. Thus the pH values in the area of investigation falls within the permissible limit.

**Electrical Conductivity (μhmhos/cm at 25°C)**

The electrical conductivity is defined as reciprocal of the electrical resistance of one cubic centimeter material at 25°C. It is a function of temperature, type of ion present and concentration of various ions. The specific conductance readings are usually adjusted to 25°C, so that variations in conductance are a function only of the concentration and type of dissolved constituents present.

The electrical conductivity with 400 μhmhos/cm at 25°C is considered suitable for human consumption (WHO, 1984). While more than 1500 μhmhos/cm at 25°C may cause corrosion of iron structures.

The electrical conductivity values in the area vary between 200 μhmhos/cm at 25°C to 2000 μhmhos/cm at 25°C where the highest value was recorded at Hardaspur, Nanda Wajidpur and Hajipur and the lowest was observed at Hardua. The electrical conductivity map (Fig. 31) of the study area shows that major part of the area falls in 250-750 μhmhos/cm range.

**MAJOR IONS:**

Groundwater contains dissolved ions acquired initially as precipitation falls through the atmosphere and later as the water moves through the soil and sediments underlying the land surface. Dissolved ions vary in type and concentration due primarily to the composition and the solubility of the various deposits that the water encounters and the length of time that the water remains in contact with these deposits. Temperature, Pressure and pH also affect dissolution rates and concentration of dissolved ions.
Carbonate:

The primary source of carbonate ion in groundwater is the dissolved carbon dioxide in rain which, as it enters the soil, dissolves more carbon dioxide. An increase in temperature or decrease in pressure causes reduction in the solubility of carbon dioxide in water.

The carbonate concentration in shallow as well as in deeper aquifer waters were found to be varying from 13.0 ppm - 52.0 ppm. In the surface water sample it ranges from 13.0 ppm to 39.0 ppm. The higher values were recorded at Panjipur, Naugawan Arjuna, Khera Khushkpur, Mahuwa Khera and Harsana Ki Sarai.

Bicarbonate:

Most carbonate and bicarbonate ions in groundwater are derived from the carbon dioxide in the atmosphere, carbon dioxide in the soil, and solution of carbonate rocks. The presence of bicarbonate influences the hardness and alkalinity of water.

Bicarbonate in the groundwater is an indicative of the partial pressure of carbon dioxide in the soil, consequently, it shows wide fluctuation. The water containing 600 ppm of bicarbonate is considered fairly safe and good for domestic and irrigation purposes (WHO, 1984). The concentration of bicarbonate in water samples shows a wide variation which ranges between 39.0 - 468.0 ppm. Maximum concentration was recorded at Harsana Ki Sarai and at Tar Banglow on the western upland of the study area whereas the lowest concentration is observed at Daula Nirpal in the central depression of the study area which indicates that the overall concentration is well within the limits.
Fig. 32. Isochloride map of the area.
Chloride:

Chloride in drinking water originates from natural sources, sewage and industrial effluents, urban run-off containing de-icing salt and saline intrusion. The main source of human exposure to chloride is the addition of salt to food, and the intake from this source is usually greatly in excess of that from drinking water.

The highest desirable and maximum permissible limit of chloride for drinking water is 250 ppm and 1000 ppm respectively (ISI, 1983). But the W.H.O. (1984) suggested the maximum permissible limit as 600 ppm. However, water containing less than 150 ppm chloride is satisfactory for most purposes while higher chloride water may affect the kidney tissues of the infants.

All chloride salts are highly soluble, so chloride is rarely removed from water by precipitation except under the influence of freezing or evaporation. Chloride is also relatively free from effects of exchange adsorption and biological activity. Thus if water contains chloride, it is difficult to remove it through natural processes.

The concentration of chloride in the water samples taken from shallow and deep tubewells ranges between 11.36 to 340.8 ppm and 14.2 to 124.96 ppm where as in the surface water it varies from 8.52 to 89.0 ppm. Except at few places, chloride content is well within permissible limit. (Fig. 32) shows the chloride distribution pattern in the study area as mentioned above.

Sulphate:

Sulphate is naturally present in the water as $\text{SO}_4^{2-}$. It is the stable, oxidized form of sulphur and is readily soluble in the water (with the
exception of lead, barium and strontium sulphate which precipitates).

The sulphate content of atmospheric precipitation is only about 2 ppm but a wide range in sulphate content in groundwater is made possible through oxidation, precipitation, solution and concentration as the water traverses through different lithologies.

Sulphate is one of the least toxic anions; however, catharsis, dehydration and gastrointestinal irritation have been observed at high concentrations. Indian Standard Institution has suggested the highest desirable and maximum permissible limit of sulphate as 150 ppm and 400 ppm. But if the limit of sulphate exceeds 250 ppm it may cause gastrointestinal irritation (Raghunath, 1982). The excess of sulphate (>250 ppm) may also cause bitter taste and may have laxative effect at higher level (W.H.O., 1984). The sulphate concentration in the water sample of study area taken from shallow and deep aquifers ranges between 42.79 ppm to 316.0 ppm and 82.3 ppm to 329.0 ppm respectively where as the samples of surface water show a variation from 86.41 ppm to 170.0 ppm. The maximum concentration was observed at upper-kot which is located on upland. The concentration of sulphate in water samples shows that by and large sulphate is well within the permissible limits.

**Sodium:**

All natural water contains measurable amount of sodium and it is one of the most abundant element on the earth. The most significant and important source of sodium in groundwater, with concentration of over 50 ppm of sodium, are the precipitates of sodium salts impregnating the soil in shallow water tracts particularly in arid and semiarid regions, sea water influx in coastal areas and connate water. Certain clay minerals can increase
the sodium content in groundwater by base exchange reaction.

Most sodium salts are readily soluble in water, but take no active part in chemical reactions as do the salts of alkaline earths. For this reason sodium salts tend to remain in solution unless extracted during evaporation. Sodium content in groundwater ranges from about 1 ppm in humid and snow fed regions to over 100,000 ppm in brines.

Sodium is considered to be harmful to persons suffering from hypertension, cardiac, renal and other vascular ailments, therefore, the concentration of sodium should be with in the limit recommended by (W.H.O., 1984) as, 200 ppm for drinking water.

The concentration of sodium in the water samples taken from shallow and deep aquifers ranges between 40 to 210 ppm and 22.85 to 160.0 ppm respectively. Its concentration in surface water ranges between 60 to 143.0 ppm. Some samples from shallow aquifer shows a higher concentration. However, the concentration of sodium is well within permissible limit.

Potassium:

All natural water contain measurable amount of potassium. Two factors are responsible for the scarcity of potassium in groundwater one being the resistance of potassium minerals to decomposition by weathering (Golditch, 1938) and other the fixation of potassium in clay minerals formed due to weathering. The concentration of potassium ranges from 1 ppm or less to about 10 to 15 ppm in potable waters and from 100 ppm to over several thousand ppm in some brines. Potassium salts, being more soluble than sodium salts, are the last to crystallize during evaporation.

The concentration of potassium in the water samples taken from
shallow and deep aquifers ranges between 10 to 184 ppm and 11.40 to 58.37 ppm respectively where as the concentration of potassium in surface water varies from 4.0 to 16.88 ppm. Minimum concentration was recorded at Hardua close to the Upper Ganga Canal.

Calcium:

Calcium is one of the most abundant substance of natural water (Trivedy and Goal, 1984). It is readily dissolved from rocks rich in calcium minerals, particularly as carbonates and sulphates. Calcium, when in the form of sulphate in groundwater, can reach a rather high concentration in view of its comparatively higher solubility. The solubility of calcium carbonate varies widely with the partial pressure of carbon dioxide in the air in contact with the water. The salts of calcium together with the magnesium are responsible for the hardness of water. Calcium forms an essential element for the growth of the human body, which is required between 0.7 to 2.0 grams/day.

The maximum permissible limit and highest desirable limit as given by I.S.I. (1983) an W.H.O. (1984) is 200 and 75 ppm. The absence or dearth of calcium from drinking water causes rickets in children if there is deficiency of vitamin D in their diet, on the contrary the excess of calcium in water increases its hardness and also causes gout and rheumatism. The calcium concentration in the shallow and deep tubewells varies from 4.81 ppm to 79.0 ppm and 4.81 to 28.86 ppm respectively where as the concentration of calcium in surface water varies from 6.41 to 38.0 ppm.

Magnesium:

The geochemistry of magnesium is quite similar to that of calcium. The solubility of magnesium carbonate is also controlled by the presence
of carbon dioxide. Magnesium arises principally from the weathering of rocks containing ferromagnesium minerals and from some carbonate rocks.

Magnesium is one of the constituent responsible for hardness of water. However higher magnesium concentration may be cathartic and diuretic (Lehr et al., 1980). Also the values of magnesium combined with sulphate acts as laxative to human beings. The maximum permissible and highest desirable limit given by the W.H.O. (1984) and Indian Standard Institution (1983) is 100 mg/l and 30 mg/l respectively.

The magnesium concentration of shallow and deep tubewells of study area varies from 16.0 to 123.77 ppm and 23.39 to 84.79 ppm respectively, whereas in the surface water it varies from 21.0 to 43.86 ppm. The minimum concentration was reported at Kothi Ka Nagla close to the Upper Ganga Canal and the maximum concentration was reported at Delhi Gate on the western upland of the study area. At few places it was reported that the concentration of magnesium is higher but at most places it is well within the permissible limit.

Fluoride:

Fluoride is generally present in low concentration in groundwater (Fletcher, 1986). The concentration of fluoride in groundwater is limited due to the low solubility of most fluoride. The solubility of fluoride in pure water, at 25°C, is only 8.7 ppm fluoride (Aumeras, 1927). Magnesium fluoride is more soluble than calcium fluoride, sodium fluoride is very soluble.

W.H.O. (1984) has recommended the limit of fluoride in drinking water upto 1.5 ppm. If it exceeds, it may cause motelling of teeth enamel and further concentration above 5 ppm may cause crippling problem (WHO,
The concentration of fluoride in the water samples taken from shallow and deep aquifers ranges between 0.48 to 1.18 ppm and 0.75 to 1.03 ppm whereas the concentration in surface water ranges from 0.48 to 0.92 ppm. The minimum concentration was recorded at Brahti whereas the maximum was observed at Naugawan Arjuna.

**Hardness:**

Hardness denotes the concentration of calcium and magnesium in water, and is usually expressed as the equivalent of CaCO$_3$. Basically, hardness is considered as the soap consuming property of water (Fletcher 1987). This is controlled by the magnesium and calcium ions present in water and is computed from the sum of the two ions expressed in Mg CaCO$_3$L$^{-1}$ (McCutcheon et al., 1993). The hardness in water is derived from the solution of carbon dioxide released by bacterial action in the soil by percolating rain water (Sawyer and McCarly, 1967).

Hardness can be classified on the basis expressed in MgCaCO$_3$L$^{-1}$ as follows: (after McCutcheon et al., 1993).

<table>
<thead>
<tr>
<th>Class of Hardness</th>
<th>Concentration in MgCaCO$_3$/L</th>
<th>Percentage in the study area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>00-50</td>
<td>00</td>
</tr>
<tr>
<td>Moderately hard</td>
<td>51-120</td>
<td>6.7%</td>
</tr>
<tr>
<td>Hard</td>
<td>121-180</td>
<td>27%</td>
</tr>
<tr>
<td>Very hard</td>
<td>&gt;180</td>
<td>66.3%</td>
</tr>
</tbody>
</table>
Fig. 33. Total hardness map of the area.
The permissible limit for hardness as recommended by WHO (1993) is 500 ppm, whereas the maximum permissible limit and desirable limit of hardness given by ISI (1983) is 600 ppm and 300 ppm respectively.

A perusal of the above table shows that the groundwater in the study area is moderately hard, hard and very hard in nature.

The total hardness as CaCO₃ in the water samples of shallow and deep aquifers ranges between 112.0 to 544.0 ppm and 144.0 to 372.0 ppm respectively, whereas the hardness in surface water ranges in between 112.0 ppm to 312.0 ppm (Fig.33) shows the total distribution of hardness in the study area.

**Nitrate:**

Nitrate is the end product of oxidation of nitrogen in the environment and its higher level of concentration in groundwater is often an indication of pollution from either sewage or fertilizer waste. It is an essential plant nutrient but is also a potential threat to human health when in excess concentration in groundwater.

Hill (1982) stated the decomposition of soil organic matter, leaching of soluble synthetic or chemical fertilizers, human and animal excreta are the potential sources of nitrate in groundwater.

Pandey and Mukherji (1944) have stated that more alarming toxicity of nitrate is the cause of carcinogenic diseases like intorsamines of stomach cancer. Nitrate cyanosis (blue baby diseases - methemoglobinemia) among infants is caused by nitrate pollution in areas where bottle feeding is practiced.
Sehgal and others (1989) state that the nitrate is converted to nitrite and then ammonia by bacterial reduction in the human system. Excess nitrate is absorbed by haemoglobin and is converted to methemoglobin and oxygen carrying capacity of the red blood corpuscles, is reduced.

Variable and maximum permissible limit of nitrate in drinking waters are observed in the literature; Bulgaria (30 ppm); Canada, India, Poland, USPHA, WHO (45 ppm) and Europe (50-100 ppm).

The nitrate concentration in the water samples from shallow and deep aquifers ranges between 0.78 to 11.5 ppm and 1.25 to 11.5 ppm respectively whereas the concentration in surface water varies from 0.94 to 2.4 ppm. A perusal of Appendix (VIII-A&B) show that the concentration of nitrate in the shallow aquifer as well as in deeper aquifer are well within permissible limit.

**Total Dissolved Solid:**

Dissolve solids is the term generally associated with fresh water systems and contains a number of different dissolved inorganic constituents. The major cations are calcium, magnesium, sodium and potassium; and the major anions are chloride, sulfate, carbonate and bicarbonate. Although not in ionic form, silica can also be a major constituent. These major constituents constitute the bulk of the mineral matter contributing to total dissolved solids.

The simplest classification of water is based on the total concentration of dissolved solids. The classification is suggested by Gorrel which is shown in the following table:
TABLE 13

<table>
<thead>
<tr>
<th>Quality of water</th>
<th>Concentration of TDS in ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater</td>
<td>0-1000</td>
</tr>
<tr>
<td>Brakish water</td>
<td>1000-10,000</td>
</tr>
<tr>
<td>Salty water</td>
<td>10,000-100,000</td>
</tr>
<tr>
<td>Brine</td>
<td>&gt;100000</td>
</tr>
</tbody>
</table>

The water, with TDS less than 600 mg/l is considered good for drinking purposes and water with TDS more than 1200 ppm is considered unpalatable (W.H.O. 1984).

In the area of investigation water samples taken from shallow and deep aquifers show a wide variation of total dissolved solid which ranges from 256 to 1280 ppm and 256 to 960 ppm respectively where as in the surface water it ranges from 128.0 to 377.6 ppm.

Generally, the concentration of total dissolved solid is less than 1000 ppm. However at some places the concentration of total dissolved solids was observed 1280.0 ppm.

TRACE ELEMENTS:

The trace elements are the elements which are present in water in less quantity (less than 1 ppm). Many of the trace elements are also known as heavy metals (Freeze and Cherry 1979). These metals present in trace concentration play a major role in the human and animal metabolism and healthy growth of plants: The same metals, however, at increased concentration may have severed toxicological effects on human beings (Champman, 1992). The most important and natural sources of trace elements is rock water interaction from which the released metal find their
way in the water bodies. However industrial effluents, and domestic sewage, and agricultural activities are also responsible for the higher concentration of heavy metals in the groundwater. Therefore, trace elements such as iron, zinc, copper, lead, manganese, cadmium, cobalt, nickel and chromium were determined to check their concentration in the water samples of the study area. The results of the chemical analysis are given in (Appendices XI).

As a result, the concentration of trace elements is found to be more in shallow aquifers water samples than in the deeper aquifer water samples. Trace elements analysed in the groundwater samples of the study area are as follows:

**Iron:**

Iron is naturally present in the water as ferric hydroxide, in concentration less than 0.5 ppm. Water derived from swamps and peat bogs with low pH have higher concentration (Karanth, 1997). It is an essential element in the human nutrition as well as for animals and plants.

World Health Organization and U.S. Environmental Protection Agency recommended the acceptability value of iron as 0.3 ppm. But iron becomes toxic when it crosses the permissible limit. Children from 1 to 2 years of age are particularly vulnerable to the iron toxicity from the ingestion of iron supplements (Fairbanks et al., 1971). However, higher concentration of iron will cause toxic effect on the public health. Also, presence of iron can give rise to an astringent taste, discoloration, deposits of rust and could promote the growth of iron bacteria.

The iron concentration in the water sample of study area taken from shallow and deep aquifers ranges between 0.005 to 0.52 ppm and 0.13 to
0.30 ppm respectively. A perusal of the Appendix (XI) shows that the concentration of iron is high in few water samples of shallow aquifer where as the concentration of iron in deeper aquifers is well within the permissible limit.

**Lead:**

The concentration of lead in drinking water is 0.1 ppm as recommended by WHO (1984). Pb is found in low concentration in the natural water because lead containing minerals are less soluble in water. Concentration of lead in natural water increases mainly through anthropogenic activities (Goel, 1997). Excess of lead does not permit utilization of oxygen and glucose for life sustaining energy production which can be detected in the blood at 0.3 ppm concentration.

It is one of the hazardous and potentially harmful pollutant. It's efficiency causes hypertension, neurological disfunction and renal impairment (WHO, 1993). The most common symptoms of lead poisoning are anaemia, severe intestinal cramps, paralysis of nerves, loss of appetite and fatigue (Train, 1979). Lead toxicity also causes irreversible damage to the brain in the children. Such lead intoxication most commonly results from ingestion of lead containing paints found in homes. Lead causes mental retardation in children.

The lead concentration in the water samples of the study area in shallow and deep tubewells ranges between 0.02 to 0.098 ppm and 0.03 to 0.098 ppm respectively. The analytical results show that the concentration of lead in shallow aquifers as well as in the deeper aquifers are well with in the permissible limit.
Zinc:

Zinc is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. The diet is normally the principal source of zinc. Although levels of zinc in surface and groundwater normally do not exceed 0.01 and 0.05 ppm respectively (WHO, 1993).

The daily requirement of zinc for adult is 15-20 mg/day. Drinking water containing zinc at levels above 30 mg/litre may not be acceptable to consumers as it imparts an undesirable astringent taste to water. Water containing zinc at concentration in excess of 5 mg/litre may appear opalescent and develop a greasy film on boiling (WHO, 1993). However, its deficiency causes growth retardation in children, dermatitis, loss of taste, sensitivity and delay in the healing of wounds (Carla, 1986).

The zinc concentration in the water samples of the study area in shallow and deep tubewells ranges between non-detectable to 0.58 ppm and 0.092 to 0.198 ppm. The highest concentration of zinc was recorded at Nai Basti of Aligarh city.

Copper:

Copper levels in drinking water are usually low only a few micrograms per litre, but copper plumbing may result in greatly increased concentrations. Concentration can reach several mgs/litre following a period of stagnation in pipes.

Copper is an essential element and the intake from food is normally 1-3 mg/day. Acute gastric irritation may be observed in some individuals as concentration in drinking water increases above 3 mg/litre. In adults with hepatolenticular degeneration, the copper regulatory mechanism is
defective, and long term ingestion can give rise to liver cirrhosis. At levels above 5 mg/litre imparts a colour and an undesirable bitter taste to water (WHO, 1993).

In the shallow aquifer of the study area copper concentration ranges from not detectable to 0.52 ppm while in deeper aquifers concentration ranges between 0.006 ppm to 0.202. This shows that the deeper aquifer waters are more safe in comparison with shallower aquifers for drinking purposes.

**Cadmium:**

Cadmium is highly toxic element to man and animals (Friberg *et al.*, 1974). Cadmium is released to the environment in waste water, and diffuse pollution is caused by contamination from fertilizers and local air pollution. In the drinking water contamination may also be caused by impurities in the zinc of galvanized pipes and solders and some metal fittings, although levels in drinking water are usually less than 1 µg/litre. Smoking is the significant additional source of cadmium exposure.

Cadmium accumulates mainly in the liver and kidney thus causing pathological changes of the hepatocytes of the liver as well as the kidney (Itokawa *et al.*, 1975; Colucci *et al.*, 1975). Cadmium of high concentration causes kidney problems, anaemia, bonemarrow disorders and lenticular tumours, it also causes renal disfunction, hypertension, genetic defects, chronic diseases of old age and cancer. The recommended permissible limit of cadmium in drinking water is 0.01 ppm (ISI, 9183; WHO, 1984). However a guideline value for cadmium of 0.003 mg/litre is established by WHO (1993). The cadmium concentration in the groundwater of the study area ranges between non-detectable to 0.016 ppm in shallow aquifers while in
the deeper aquifer it ranges from non-detectable to 0.011 ppm. The analytical result shows that the value of cadmium in shallow aquifer as well as in deeper aquifer are well within the permissible limit except at few places.

**Manganese:**

Manganese is one of the most abundant metals in the earth's crust and usually occur together with iron. It is an essential trace element with an estimated daily nutritional requirement of 30-50 μg/kg of body weight. It's absorption rate can vary considerably according to actual intake, chemical form and presence of other metals, such as iron and copper in the diet. However, large does of ingested manganese can cause liver damage (Trivedy and Goal, 1984). Although manganese concentrations below 0.1 ppm are usually acceptable this may vary with local circumstances, WHO (1984) recommended the limit of manganese in drinking water as 0.05 ppm.

The concentration of manganese in the shallow aquifer ranges between 0.012 to 0.084 ppm while in the deeper aquifers it ranges between 0.012 to 0.053 ppm. Except few places the manganese are well within the permissible limit.

**Chromium:**

High dose of hexavalent chromium causes digestive track cancer in men (Guideline for Canadian drinking water quality). Disorders of skin and respiratory tract are common symptoms of chromium poisoning. Respiratory intake can lead to cancer of respiratory tract (Goel, 1997). High concentration of chromium in groundwater may causes ulceration of nasal septum and dermatitis (Singh and Bhyayana, 1986).

The chromium concentration in the groundwater of the study area ranges between non-detectable to 0.096 ppm in shallow aquifer water while in
| S.No | Concentration in the study area | Minimum | Maximum | Hexavalent chromium | Zinc | Lead | Cadmium | Manganese | Iron | Copper | Nitrate | Fluoride | Chloride | Magnesium | Calcium | Total Hardness | pH | \( \text{i.e.} \ \text{WHO (1983)} \) |
|------|--------------------------------|---------|---------|---------------------|------|------|---------|-----------|------|--------|---------|----------|-----------|-----------|---------|-------------|-----|----------------|----|----------------|-----|
| 1    | 1.8                            | 72.92   | 72.5    | 6.2-5.9  ppm        | -    | -    | 15      | -         | 0.5  | -      | 0.2      | 0.9       | 0.05      | 0.05      | 6.2-5.9  ppm | 6.2-5.9  ppm | 7.0-8.5    | 6.2-5.9  ppm | 8.94  | 7.25 |
| 2    | 10                             | 544     | 300     | 100                 | -    | -    | -       | -         | 0.05 | 0.05  | 0.05    | 0.05      | 0.05      | 0.05      | -       | -           | -   | -   |
| 3    | 16                             | 123.77  | 150     | 200                 | 100  | 0     | 0.2     | -         | -    | 1.5   | 1.5     | 1.5       | 1.5       | 1.5       | 200     | 100         | -   | -   |
| 4    | 8.6                            | 340.8   | 600     | 200                 | 1000 | 1    | 0.05    | 0.05      | 0.05 | 0.2   | 0.2     | 0.2       | 0.2       | 0.2       | 200     | 100         | -   | -   |
| 5    | 0.48                           | 11.5    | 100.0   | 0.05                | 3.0  | -    | -       | -         | -    | 0.5   | 0.5     | 0.5       | 0.5       | 0.5       | -       | -           | -   | -   |
| 6    | 0.6                            | 1.18    | 1.5     | 0.05                | -    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |
| 7    | 5.8                            | 3.40.8  | 600     | 200                 | 0    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |
| 8    | 16.0                           | 123.77  | 150     | 200                 | 1000 | 1    | 0.2     | 0.2       | 0.2  | 0.5   | 0.5     | 0.5       | 0.5       | 0.5       | 200     | 100         | -   | -   |
| 9    | 0.0                            | 0.0      | 0.0     | 0.0                 | -    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |
| 10   | 0.2                            | 5.8     | 6.0     | 0.2                 | -    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |
| 11   | 0.2                            | 0.0      | 0.0     | 0.0                 | -    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |
| 12   | 0.2                            | 0.0      | 0.0     | 0.0                 | -    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |
| 13   | 0.2                            | 0.0      | 0.0     | 0.0                 | -    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |
| 14   | 0.2                            | 0.0      | 0.0     | 0.0                 | -    | -    | -       | -         | -    | -     | -       | -         | -         | -         | -       | -           | -   | -   |

**Table 1.6** Range of concentration of various major and trace elements in water samples and their comparison with WHO (1983) and IS:1 (1983) Drinking Water Standards.
deeper aquifer water it ranges between 0.019 ppm to 0.063 ppm respectively. The recommended limit of chromium is 0.05 mg/l (ISI, 1983). This shows that in the deeper aquifer the concentration is within the limit except at few places.

**Nickel:**

The concentration of nickel in drinking water is normally less than 0.02 ppm. Nickel released from the taps and fittings may contribute upto 1 mg/lit. In special cases of release from natural or industrial nickel deposits in the ground, the nickel concentration in drinking water may be even higher. The average daily dietary intake is normally 0.1-0.3 mg of nickel but may be as high as 0.9 mg with a intake of special food items.

The relevant database for deriving a no observed adverse effect level is limited. In the study area the nickel concentration in shallow aquifer ranges between 0.007 ppm to 0.068 ppm where as in the deeper aquifers it ranges from 0.009 to 0.036 ppm in the village.

**GRAPHIC REPRESENTATION OF CATIONS AND ANIONS:**

Graphical representation of chemical analysis data is the convenient way to represent the cations and anions. For a quick perusal, which may involve comparing the similarities and dissimilarities between major ions. Graphs can also aid in detecting the mixing of water of different compositions and in identifying chemical processes occurring as groundwater moves. A variety of graphic techniques have been developed for showing the major chemical constituents, some of the more useful graphs include bar graph, circular graph, radial graph and stiff diagram which are easily constructable and provides a quick visual comparison of individual chemical analysis. However, they are not convenient for graphic presentation.
of large number of analysis. One of the most useful graphs for representing and comparing water quality analysis is trilinear diagram by Piper (1944), which is given below.

**Trilinear Diagram:**

Among the various trilinear method of plotting (Palmer, 1911; Hill, 1940; Piper, 1953), Piper's diagram has been extensively used to understand problems about the geochemical evolution of groundwater. Here cations, expressed as percentage of total cations in milliequivalents per litre, plot as a simple point on the left triangle; while anions, similarly expressed as percentage of total anions, appear as a point in the right triangle. These two points are then projected into the central diamond shaped area parallel to the upper edges of the central area. This single point is thus uniquely related to the total ionic distribution. Thus, water samples with different concentration can have identical representation in this diagram and the major trends in the data can be discerned visually.

**Groundwater Facies:**

To categorize the water composition in a convenient manner, the concept of hydrochemical facies was developed by Back (1961, 1966), Back and Hanshaw (1965), Morganan Winner (1962) and Seaber (1962). Hydrochemical facies are distinct zones that have cation and anion concentration described within defined composition categories (Freeze and Cherry, 1979). According to Back (1961) the term hydrochemical facies is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition. Again Back (1986) suggested that the facies are a function of lithology, solution kinetics and flow pattern of the groundwater through the aquifer.
Fig. 34a. Plot of chemical composition of dugwells water on trilinear diagram.
Fig. 34b. Plot of chemical composition of tubewells and surface water on trilinear diagram.
The plot of chemical analysis (Fig. 34a&b) shows that the majority of the groundwater samples belongs to bicarbonate type and few samples fall in no dominant type and sulphate type in the anion facies while on the cation facies the water samples belong to sodium or potassium type and few samples belong to No dominant type and Magnesium type.

Finally, the trilinear diagrams show that groundwater in the study area belongs to an Alkali Bicarbonate type.

WATER QUALITY CRITERIA IN RELATION TO ITS USES:

The usefulness of water for various specific uses, like domestic, irrigation and industry are determined by the water quality. The term water quality includes the physical, chemical, biological and radionuclids characteristics which are the dominant factor in determining the suitability of groundwater for various purposes. Mandatory limits have been set for certain poisonous constituents, but no rigid limits can be set for water required for other uses.

The water which is not suitable for drinking may be good for irrigation, or water unsuitable for irrigation may be quite suitable for industrial purposes (Goel, 1997). Thus, it is not possible to have a single criteria that can have universal application. Therefore, certain chemical quality standards have been established for evaluating the suitability of water for domestic, agricultural and industrial uses.

In the present study only physical and chemical characteristics of groundwater are considered to establish its suitability for various uses.

Domestic and Municipal Uses:

Water to be used in the home for drinking should be free from colour, turbidity, odour and microorganisms. Chemically, the water should
preferably be soft, low in dissolved solids, and free from poisonous constituents. WHO (1984), ISI (1983) and ICMR have laid down drinking water standards, which assure in general, the protection of human health.

According to the concentration of various major and trace elements encountered in the water samples of the study area were compared with the drinking water standard of the WHO (1984) and ISI (1993) which are given in the table 14.

A perusal of the table shows that, the concentration of anions, cations and trace elements are well within the permissible limits as recommended by WHO (1984), and ISI (1993). At few places water quality of dugwells and shallow tubewells were not found suitable because of its susceptibility to various polluting sources. The deep tubewell water was found safe for drinking purposes. Some elements which are harmful and insidious pollutants because of their adverse effects on human health on certain level of exposure and absorption.

**Irrigation use:**

The suitability of groundwater for irrigation is contingent on the effects of the mineral constituents of the water on both the plant and soil. There are various chemical constituents which affect the suitability of water for irrigation. Some of these are:

(a) The total concentration of soluble salts (which is broadly related to the specific conductance of water) as it effects the crop yields through osmotic effects.

(b) The relative proportion of sodium to calcium and magnesium.

(c) The concentration of boron, and
(d) The relative proportion of bicarbonate to calcium and magnesium.

Besides, the above suitability criteria there are some other factors such nature and composition of the soil and subsoil, depth of water table, topography, climate, the type of crop etc.

The quality criteria for irrigation purpose were developed by various workers Asgar et al. (1936), Kelley et al. (1994), Wilcox (1955), Ramamorthy (1964); FWPCA (1968); EPA (1973); Ayers and Branson (1975) and Ayers and Westcot (1976).

The most effective hazards are the salinity and the sodium hazard, because the germination of seed is reduced when excessive accumulation of salts exists in agricultural soil as it causes flocculation resulting into the formation of a relative impermeable crust which lowers the permeability and hence the fertility of soil (Mem, 1959).

To study the suitability of groundwater in the study area for irrigation purposes, the electrical conductivity, relative proportion of sodium to other cations residual sodium carbonate and concentration of certain specific elements were analysed. Subsequently, the chemical analysis data were processed, plotted and interpreted on the basis of the established guidelines proposed by various workers of the discipline.

**Salinity and sodium hazards:**

The total dissolved solids content, measured in terms of specific electrical conductance, gives the salinity hazard of irrigation waters. Besides the salinity hazard, excessive sodium content in water renders it unsuitable for soils containing exchangeable Ca$^{2+}$ and Mg$^{2+}$ ions.

Based on the sodium Adsorption Ratio (SAR) and electrical conductivity (E.C.) graphic classification was given by US Salinity
Laboratory Staff (USSL, 1954) to help interpreting the suitability of water quality for agricultural uses.

Sodium adsorption ratio and conductance values are taken into consideration because they behave as an index of salinity hazards which has an adverse effect on the suitability of irrigation water. The SAR is defined as follows

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}}$$

where ion concentration are given as equivalent per million (eqm).

The quality classification for irrigation water is given below in the table (After Richard et al., 1954).

<table>
<thead>
<tr>
<th>Water Quality</th>
<th>Electrical Conductivity in $\mu$mhos/cm at 25°C</th>
<th>Alkali SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&lt;250</td>
<td>Upto 10</td>
</tr>
<tr>
<td>Good</td>
<td>250-750</td>
<td>10-18</td>
</tr>
<tr>
<td>Fair</td>
<td>750-2250</td>
<td>18-26</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt;2250</td>
<td>&gt;26</td>
</tr>
</tbody>
</table>

A perusal of the (Fig. 35) shows that nearly 38% water samples in the area falls under C$_2$-S$_1$ and 47% water samples fall under C$_3$-S$_1$ while 15% falls under C$_3$-S$_2$ series.

The Residual Sodium Carbonate (RSC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purposes. It is calculated by the formula given by Eaton.
Fig. 35. Plot of SAR vs. E.C. of dugwells, tubewells and surface water.
(1950) which is as follows:

\[ \text{R.S.C.} \ (\text{CO}_3^{2-} + \text{HCO}_3^{-}) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \]

where the concentration of cations and anions is expressed in epm.

To determine the hazardous effect of carbonate and bicarbonate on the quality of water for irrigation purpose, Eaton (1950) gave the following classification.

<table>
<thead>
<tr>
<th>Water</th>
<th>R.S.C. (in epm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&lt;&lt;1.25</td>
</tr>
<tr>
<td>Good</td>
<td>&lt;1.25</td>
</tr>
<tr>
<td>Fair</td>
<td>1.25-2.5</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt;2.5</td>
</tr>
</tbody>
</table>

The values of RSC have been calculated (Appendix IX-A,B&C) and compared with the classification given in the table above which reveals that most of the values are within the limits of suitability except few values which are above the limit. So, it can be said that the groundwater of the study area is suitable for irrigation purposes.

Wilcox (1955), has proposed another classification for irrigation which is based on electrical conductivity and soluble sodium percent and boron concentration (Fig. 36).

The sodium percent is calculated from the following relationship:

\[
\text{Percent sodium} = \frac{(\text{Na}^+ + \text{K}^+)}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \times 100
\]
Fig. 36. Plot of sodium percent (Na%) Vs. E.C. of dug wells, tubewells and surface water.
where ion concentrations are given as equivalents per million (epm).

The following table indicates the quality classification for the irrigation water (after Wilcox, 1955).

**TABLE 17**

<table>
<thead>
<tr>
<th>Water Quality</th>
<th>Na%</th>
<th>EC μmhos/cm at 25°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&lt;20</td>
<td>&lt;250</td>
</tr>
<tr>
<td>Good</td>
<td>20-40</td>
<td>250-750</td>
</tr>
<tr>
<td>Permissible</td>
<td>40-60</td>
<td>750-2000</td>
</tr>
<tr>
<td>Doubtful</td>
<td>60-80</td>
<td>2000-3000</td>
</tr>
<tr>
<td>Unsuitable</td>
<td>&gt;80</td>
<td>&gt;300</td>
</tr>
</tbody>
</table>

A perusal of the Wilcox diagram suggests that the quality of groundwater as well as surface water falls into four categories i.e. Excellent to good, Good to permissible, Permissible to doubtful and a few sample fall into Doubt to unsuitable. By and large the quality of water is good for agricultural purposes.

The role of trace elements for the proper growth of plant cannot be looked out as they have been found to be profoundly beneficial to crops for growth of plants at different stages of their development. Many agencies put forward the tolerance limit for irrigation water and suggested proper interpretation of analytical data, thus micronutrients like Cu, Zn, Fe, Pb, Mn and Cd were compared with the standard limit (FWPCF, 1968; Ayers and Branson, 1975).
TABLE 18

Trace element tolerance limit of irrigation water as proposed by FWPCF, 1968 and Ayers and Branson (1975)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continuous</td>
<td>Short term in fine textured soils</td>
</tr>
<tr>
<td>Zinc</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Iron</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Copper</td>
<td>0.20</td>
<td>5.0</td>
</tr>
<tr>
<td>Lead</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Manganese</td>
<td>2.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.005</td>
<td>0.05</td>
</tr>
</tbody>
</table>

In the study area the concentration of trace elements determined in the water samples found well within the permissible limit. Hence it can be said that the groundwater of the study area is good for irrigation purposes.

**Industrial Uses:**

Industrial water quality requirements are highly dissimilar. There are so many uses of water in different industries. For example in Food & Beverage industries water quality should satisfy the general requirement of drinking water. Pure water is also required for manufacture of pharmaceutical and antibiotic requirements. Water which is used for cooling should be free from corrosive nature and the concentration should be less than 80 ppm (Anon, 1940). Accordingly, the water quality of the study area fulfils the criteria for all industrial uses and even for the pharmaceutical and paper uses too, after the preliminary treatment of hardness.
SURFACE WATER QUALITY:

To ascertain the quality of surface water and its relation with groundwater, water samples for major and trace elements studies were collected from the river Kali, Upper Ganga Canal and some ponds for chemical analyses.

A persual of Appendix (VIII-C & IX-C) having a hydrochemical data of samples from surface water sources shows that the E.C., S.A.R. and Na% of surface water are well within permissible limit for irrigational purposes. Thus after reviewing the data it may be said that the surface water in the area is widely alkaline with a low degree of mineralization. All the chemical constituents are generally within the maximum desirable limit. The surface water sample fall in the $C_2S_1$, $C_3S_1$ and $C_3S_2$ classes of the U.S. Salinity Diagram. Thus the water from surfaces sources is fresh, potable and fit for domestic as well as irrigational purposes.