Water Quality Constituents and Assessment

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INTRODUCTION

Water quality is fundamental for good river health, and for maintaining health of groundwater system; water quality sustains ecological processes that supports native fish populations, vegetation, wetlands, birdlife and many of our own uses such as irrigation, watering stock, drinking, and recreation, and also meets our cultural and spiritual needs. Thus water for different purposes has its own requirements for the composition and purity and each body of water has to be analyzed on a regular basis to confirm to suitability. The types of analysis could vary from simple field testing for a single analysis to laboratory based multi component instrumental analysis.

The analytical process involves sampling and sample storages. The following sections outline about importance of water quality, water quality constituents and their measurement techniques and analysis procedures.

WHAT IS WATER QUALITY?

Water is essential to human life and to the health of our environment. As a valuable natural resource, it comprises marine, estuarine, freshwater (river and lakes) and groundwater environments, across coastal and inland areas. Water has two dimensions that are closely linked to quantity and quality. Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics.

A healthy environment is the one in which the water quality supports a rich and varied community of organisms and protects public health.

Water quality in a body of water influences the way in which communities use the water for activities such as drinking, swimming or commercial purposes. More specifically, the water may be used by the community for:

- supplying drinking water
- recreation (swimming, boating)
- irrigating crops and watering stock
- industrial processes
- navigation and shipping
- production of edible fish, shellfish and crustaceans
- protection of aquatic ecosystems
- wildlife habitats
- scientific study and education

WHY IS WATER QUALITY IMPORTANT?

Water resources have a major value to our environmental, social and economic system, and if water quality becomes degraded this resource will lose its value. Water quality is important not only to protect public health but also our ecosystem habitats, farming, fishing and mining, and it contributes to recreation and tourism. If water quality is not maintained, it is not just the environment that will suffer but also the commercial and recreational value of our water resources will also diminish.

WHAT AFFECTS THE QUALITY OF OUR WATER?

Water quality is closely linked to the surrounding environment and land use. Water is never pure and is affected by community uses such as agriculture, urban and industrial use, and recreation. The modification of natural stream flows by dams and weirs can also affect water quality.

Groundwater is a major source of water in India. Groundwater is an integral part of our water supply. At times of low river flow groundwater enters the rivers, maintaining river flow. Like other bodies of water, groundwater close to urban or industrial development is vulnerable to contamination. Further, groundwater quality is vulnerable to the aquifer material in which it is stored. It's quality is also influenced by the contaminants of geogenic sources, the salinity and seawater ingress along the coastal aquifers. Leakage from septic tanks and seepage from landfills wastes also cause groundwater contamination.

Generally the water quality of rivers is best in the headwaters, where rainfall is often abundant. Water quality often declines as rivers flow through regions where land use and water use are intense and pollution from intensive agriculture, large towns, industry and recreation areas increases. There are of course exceptions to the rule and water quality may improve downstream, behind dams and weirs, at points where tributaries or better quality groundwater enter the mainstream, and in wetlands.

HOW IS WATER QUALITY MEASURED?

The presence of contaminants and the characteristics of water are used to indicate the quality of water. These water quality indicators can be categorized as:

- **Biological:** bacteria, algae
- **Physical:** temperature, turbidity and clarity, color, salinity, suspended solids, dissolved solids
- **Chemical:** pH, dissolved oxygen, biological oxygen demand, nutrients (including nitrogen and phosphorus), organic and inorganic compounds (including toxicants)
- **Aesthetic:** odors, taints, color, floating matter
- **Radioactive:** alpha, beta and gamma radiation emitters.

Measurements of these indicators can be used to determine, and monitor changes in, water quality, and determine whether the quality of the water is suitable for the health of the natural environment and the uses for which the water is required.

The design of water quality monitoring programs is a complex and specialized field. The range of indicators that can be measured is wide and other indicators may be adopted in the future. The cost of a monitoring program to assess them all would be prohibitive, so resources are usually directed towards assessing contaminants that are important for the local environment or for a specific use of the water. This water quality information can then be used to develop management programs and action plans to ensure that water quality is protected.

UNDERSTANDING WATER QUALITY TERMINOLOGIES

One of the major problems within the quality management field is a lack of common understanding of water quality-related terminology relative to regulatory requirements and appropriate evaluation of water quality. This lack of understanding, especially as it relates to developing technically valid, cost-effective water pollution control program, leads to over-regulation of wastewater discharge and storm water runoff-associated constituents for which there are water quality criteria/standards. It also leads to under-regulation of real significant water quality use managements caused by the unregulated constituents for which there are no water quality criteria/standards.

It is important to use such terms as "pollutants", "pollution", "water quality", "water chemistry", etc. in accord with legal and technical usage to eliminate the inappropriate characterization of a water quality evaluation situation. The meanings of these terms are as follows:

Pollution : Pollution is defined as the Clean Water Act as an important of the beneficial use(s) of a waterbody.

Water Quality: Water quality should be assessed based on the characteristics of the water relative to the beneficial uses of the water. Water quality is not, as frequently used, a list of chemical constituent concentrations. It is necessary to evaluate on a site-specific basis whether the constituent is present in toxic/available forms at a critical concentration for a sufficient duration to be significantly adverse to aquatic life that is important to the beneficial uses of the waterbody.

Water Quality Assessment : An water quality assessment is an evaluation of the beneficial use impairment that is occurring or could potentially occur due to the presence of a particular chemical(s) or constituent. It is not an assessment of frequency of exceedance of a water quality standard.

Water Quality Standard Compliance: Water quality standard compliance is based on an assessment of the frequency of exceedance of a water quality standard in ambient waters receiving the discharge/runoff. Such compliance does not ensure that the beneficial uses of the water body are being protected or that significant over-regulation is not occurring.'

WATER QUALITY STANDARDS IN INDIA

For any water body to function adequately in satisfying the desired use, it must have corresponding degree of purity. Drinking water should be of highest purity. As the magnitude of demand for water is fast approaching the available supply, the concept of management of the quality of water is becoming as important as its quantity.

Each water use has specific quality need. Therefore, to set the standard for the desire quality of a water body, it is essential to identify the uses of water in that water body. In India, the Central Pollution Control Board (CPCB) has developed a concept of *designated best use*. According to this, out of the several uses of water of a particular body, the use which demands highest quality is termed its *designated best use*. Five *designated best uses* have been identified. This classification helps the water quality managers and planners to set water quality targets and design suitable restoration programs for various water bodies.

In India, CPCB has identified water quality requirements in terms of a few chemical characteristics, known as primary water quality criteria. Further, Bureau of Indian Standards has also recommended water quality parameter for different uses in the standard IS 2296:1992.

Table 1: Designated Best Uses of Water

Designated Best Use	Class	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	1.Total Coliforms Organism MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6mg/l or more 4. Biochemical Oxygen Demand 5 days 20 °C, 2mg/l or less
Outdoor bathing (Organised)	B	1.Total Coliforms Organism MPN/100ml shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 5mg/l or more 4. Biochemical Oxygen Demand 5 days 20 °C, 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 and 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand 5 days 20 °C, 3mg/l or less
Propagation of Wild life and Fisheries	D	1. pH between 6.5 and 8.5 2. Dissolved Oxygen 4mg/l or more 3. Free Ammonia (as N) 4. Biochemical Oxygen Demand 5 days 20 °C, 2mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	1. pH between 6.0 and 8.5 2. Electrical Conductivity at 25 °C micro mhos/cm, maximum 2250 3. Sodium absorption Ratio Max. 26 4. Boron Max. 2mg/l
	Below-E	Not meeting any of the A, B, C, D & E criteria

Source: CPCB

Table 2. A color coding frequently used to depict the quality of water on maps

Blue water	This water can be directly used for drinking, industrial use, etc.
Green water	Water contained in soil and plants is termed as green water
White water	Atmospheric moisture is white water
Brown or grey water	Various grades of wastewater are shown by brown or grey colour

Sodium adsorption ratio (SAR) is a measure of the suitability of water for use in agricultural irrigation, as determined by the concentrations of solids dissolved in the water. It is also a measure of the sodicity of soil, as determined from analysis of water extracted from the soil.

The formula for calculating sodium adsorption ratio is:

$$SAR = [Na^{+}] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2} \tag{1}$$

where sodium, calcium, and magnesium are in milliequivalents/liter.

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100 \tag{2}$$

where all ionic concentrations are expressed in milliequivalent per liter. Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazard for a given SAR. Although SAR is only one factor in determining the suitability of water for irrigation, in general, the higher the sodium adsorption ratio, the less suitable the water is for irrigation. Irrigation using water with high sodium adsorption ratio may require soil amendments to prevent long-term damage to the soil.

Table 3. Water Quality Standards in India (Source IS 2296:1992)

Characteristics	Designated best use				
	A	B	C	D	E
Dissolved Oxygen (DO)mg/l, min	6	5	4	4	-
Biochemical Oxygen demand (BOD)mg/l, max	2	3	3	-	-
Total coliform organisms MPN/100ml, max	50	500	5,000	-	-
pH value	6.5-8.5	6.5-8.5	6.0-9.0	6.5-8.5	6.0-8.5
Colour, Hazen units, max.	10	300	300	-	-
Odour	Un-objectionable			-	-
Taste	Tasteless	-	-	-	-
Total dissolved solids, mg/l, max.	500	-	1,500	-	2,100
Total hardness (as $CaCO_3$), mg/l, max.	200	-	-	-	-
Calcium hardness (as $CaCO_3$), mg/l, max.	200	-	-	-	-
Magnesium hardness (as $CaCO_3$), mg/l, max.	200	-	-	-	-
Copper (as Cu), mg/l, max.	1.5	-	1.5	-	-
Iron (as Fe), mg/l, max.	0.3	-	0.5	-	-
Manganese (as Mn), mg/l, max.	0.5	-	-	-	-
Cholorides (as Cu), mg/l, max.	250	-	600	-	600
Sulphates (as SO_4), mg/l, max.	400	-	400	-	1,000
Nitrates (as NO_3), mg/l, max.	20	-	50	-	-
Fluorides (as F), mg/l, max.	1.5	1.5	1.5	-	-
Phenolic compounds (as C_2H_5OH), mg/l, max.	0.002	0.005	0.005	-	-
Mercury (as Hg), mg/l, max.	0.001	-	-	-	-
Cadmium (as Cd), mg/l, max.	0.01	-	0.01	-	-
Salenium (as Se), mg/l, max.	0.01	-	0.05	-	-
Arsenic (as As), mg/l, max.	0.05	0.2	0.2	-	-
Cyanide (as Pb), mg/l, max.	0.05	0.05	0.05	-	-
Lead (as Pb), mg/l, max.	0.1	-	0.1	-	-
Zinc (as Zn), mg/l, max.	15	-	15	-	-
Chromium (as Cr^{6+}), mg/l, max.	0.05	-	0.05	-	-
Anionic detergents (as MBAS), mg/l, max.	0.2	1	1	-	-
Barium (as Ba), mg/l, max.	1	-	-	-	-
Free Ammonia (as N), mg/l, max	-	-	-	1.2	-
Electrical conductivity, micromhos/cm, max	-	-	-	-	2,250
Sodium absorption ratio, max	-	-	-	-	26
Boron, mg/l, max	-	-	-	-	2

Guidelines are available to evaluate quality of water for irrigation. For irrigation, water can be classified in five classes depending upon its chemical properties.

Table 4. Guidelines for Evaluation of Irrigation Water Quality

Water class	Sodium (Na) %	Electrical conductivity (μS/cm)	SAR	RSC meq/l
Excellent	< 20	< 250	< 10	< 1.25
Good	20 - 40	250 – 750	10 – 18	1.25 – 2.0
Medium	40 - 60	750 – 2,250	18 – 26	2.0 – 2.5
Bad	60 – 80	2,250 – 4,000	> 26	2.5 – 3.0
Very bad	> 80	> 4,000	> 26	> 3.0

Table 5. Drinking Water Specifications (IS 10,500:1991)

Characteristics	Desirable limit	Permissible limit
Essential Characteristics		
Colour, Hazen Units, Max	5	25
Odour	Unobjectionable	-
Taste	Agreeable	-
Turbidity, NTU, Max	5	10
PH value	6.5 to 8.5	-
Total Hardness (as $CaCo_3$), mg/l, Max	300	600
Iron (as Fe), mg/l, Max	0.3	1.0
Chlorides (as Cl), mg/l, Max	250	1,000
Residual free chlorine, mg/l, Max	0.2	-
Desirable Characteristics		
Dissolved solids, mg/l, Max	500	2,000
Calcium as (Ca), mg/l, Max	75	200
Magnesium (as Mg), mg/l, Max	30	75
Copper (as Cu), mg/l, Max	0.05	1.5
Manganese (as Mn), mg/l, Max	0.1	0.3
Sulphate (as So_4), mg/l, Max	200	400
Nitrate (as No_3), mg/l, Max	45	100
Flouride (as F0, mg/l, Max	1.0	1.5
Phenolic compounds (as C_6H_5OH), mg/l, Max	0.001	0.002
Mercury (as Hg), mg/l, Max	0.001	-
Cadmium (as Cd), mg/l, Max	0.01	-
Selenium (as Se), mg/l, Max	0.01	-
Arsenic (as As), mg/l, Max	0.05	-
Cyanide (as CN), mg/l, Max	0.05	
Lead (as Pb), mg/l, Max	0.05	-
Anionic detergents (as MBAS), mg/l, Max	0.02	1.0
Chromium (as Cr^{6+}), mg/l, Max	0.05	-
PAH, mg/l, Max	-	-
Mineral oil, mg/l, Max	0.01	0.03
Pesticides, mg/l, MAX	Absent	0.001
Alkalinity, mg/l, Max	200	600
Aluminum (as Al), mg/l, Max	0.03	0.2
Boron, mg/l, Max	1	5

If irrigation water with a high SAR is applied to a soil for years, the sodium in the water can displace the calcium and magnesiam in the soil. This will cause a decrease in the ability of the soil to form stable aggregates and a loss of soil structure and tilth. This will also lead to a decrease in infiltration and permeability of the soil to water leading to problems with crop production.

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++}) \qquad (3)$$

where all ionic concentrations are expressed in epm. Groundwater containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation.

WHAT IS THE DIFFERENCE BETWEEN SALT WATER AND FRESHWATER?

Salt water is water that contains a certain amount of salts. This means that its conductivity is higher and its taste much saltier when one drinks it. Salt water is not suited to be used as drinking water, because salt drains water from human bodies. When humans drink salt water they risk dehydration. If we want to drink seawater, it needs to be desalinated first. Salt water can be found everywhere on the surface of the earth, in the oceans, in rivers and in saltwater ponds. There are two kinds of freshwater reservoirs: standing bodies of freshwater, such as lakes, ponds and inland wetlands and floating bodies of freshwater, such as streams and rivers. These bodies of water cover only a small part of the earth's surface, and their locations are unrelated to climate. Only about 1% of the earth's surface is covered with freshwater. Fresh water zones are usually closely connected to land; therefore they are often threatened by a constant input of organic matter, inorganic nutrients and pollutants.

Compositional Differences Between Freshwater and Seawater

Seawater contains more dissolved ions than all types of freshwater. However, the ratios of various solutes differ dramatically. For instance; although seawater contains about 2.8 times the bicarbonate than river water based on molarity, the percentage of bicarbonate in seawater as a ratio of *all* dissolved ions is far lower than in river water. Bicarbonate ions also constitute 48% of river water solutes, but only 0.41% of all seawater ions. Differences like these are due to the varying residence times of seawater solutes; sodium and chlorine have very long residence times, while calcium (vital for carbonate formation) tends to precipitate much more quickly.

The density of surface seawater ranges from about 1,020 to 1,029 $kg \cdot m^{-3}$, depending on the temperature and salinity. Deep in the ocean, under high pressure, seawater can reach a density of 1,050 $kg \cdot m^{-3}$ or higher. Seawater pH is limited to the range 7.5 to 8.4. The speed of sound in seawater is about 1,500 metres/second, and varies with water temperature, salinity, and pressure.

GROUNDWATER CONTAMINANTS AND ASSESSMENT

The wide range of contamination sources is one of the many factors contributing to the complexity of groundwater assessment. It is important to know the geochemistry of the chemical-soil-groundwater interactions in order to assess the fate and impact of pollutant discharged on to the ground. The serious implications of this problem necessitate an integrated approach in explicit terms to undertake groundwater quality assessment and abatement programmes.

The mechanism of groundwater pollution is quite different than that of surface water and is more complicated. Surface water pollution is rapid and becomes evident in comparatively short times from perceptible changes in colour, taste, odour and at times by dead aquatic life. The process of groundwater pollution is comparatively much slow and the time lag between pollution discharge at land and when pollutants reach groundwater may be several years or decades.

Contaminated groundwater generally shows increased levels of various constituents. Depending on the redox potential, nitrate contents more than 100 mg/L are not exceptional in contaminated groundwater. Leachate of domestic waste tips may contain concentrations in the order of g/L of Na, K, NH_4, Cl and CO_2/HCO_3. Levels of metals in contaminated soil and groundwater can also reach very high values near dumps of specific waste materials and under conditions of low pH and low redox potential. High levels of nitrate (more than 45 mg/L) may cause methemoglobinemia or blue baby disease, and fluoride content more than 1.5 mg/L can cause dental, skeletal and non-skeletal manifestations. High levels of sodium can be hazardous to the agricultural activities.

Intensive use of natural resources and the large production of wastes in modern society often pose a threat to groundwater quality. Groundwater also has specific natural quality problems, which are mainly related to local geology of the region. One of such serious problems facing the country today is the prevalence of the disease known as fluorosis involving lakhs of people which arises primarily due to excess of fluoride in drinking waters. Excessive ingestion of fluoride for a prolonged period (six month to several years) causes fluoride toxicity in the form of dental, skeletal and gut fluorosis. Fluoride toxicity also affects the soft tissues and the enzyme system but its effect on teeth, bones and gut are of practical importance. About 96% of the fluoride in the body is found in bones and teeth. Fluoride is essential for the normal mineralization of bones and formation of dental enamel. The principle sources of fluoride to the physiology of man are water and food. Fluorine in small dosages has remarkable influence on the dental system. The control of the fluoride contamination in the groundwater is very difficult as the contamination of fluoride in groundwater is controlled by a number of hydro-geological and physico-chemical parameters. However, various artificial recharge techniques including Aquifer Storage Recovery (ASR) technique may be applied to improve the quality of water by dilution. Keeping in view the severity of the problem, there is a need to create awareness among population on presence of fluoride in groundwater, its action on body tissues and on the disease itself including available technologies for removal of fluoride from water.

Arsenic concentrations in groundwater have been found in excessive of permissible limit of 0.05 mg/L in seven states in India; they are West Bengal, Bihar, Uttar Pradesh, Jarkhand, Assam, Manipur and in Chattisgarh. Population in the vulnerable areas is suffering from 'Arsenic Dermatosis' by drinking arsenic rich groundwater. Its presence in natural water depends on the local geology, hydrology and geochemical characteristics of the aquifer material. The geochemistry of arsenic is a complex phenomenon and is affected by various processes, viz., oxidation-reduction, dissolution-precipitation, adsorption-desorption, mineralogy, aquifer characteristics, etc. An understanding of all these processes is very much essential to understand the occurrence and mobilization of arsenic in the multi layer aquifer system.

In addition to the conventional inorganic contaminants, organic contaminants (pesticides, insecticides, hydrocarbons, etc.) may also be present in the groundwater system. The extensive use of chemical fertilizers and pesticides in agriculture and vector control programmes has already indicated sign of organic contamination in groundwater. In India, chemical pesticides such as organochlorines contribute bulk of the pesticides followed by organo-phosphorous and carbamates. Chemical pesticides are usually not target specific and therefore, may cause harm to non-target species also and many of them are quite persistent for long periods in the environment. Many organochlorine pesticides are either carcinogens or suspected carcinogens.

Furthermore, owing to their inherent chemical stability, organochlorines tend to accumulate into living tissues where it poses a serious health hazard. Therefore, sources of organic pollutants and their extent of contamination in groundwater need to be monitored to minimize health hazards associated with such contaminants.

GROUNDWATER CONTAMINANTS

In groundwater assessment, the quality of groundwater is of equal importance as quantity of water. To deal with the problems of groundwater contamination, an understanding of groundwater contaminants is very essential. The physical, chemical, biological and radiological characteristics of groundwater determine its usefulness for domestic, industrial and agricultural water supplies. The groundwater quality data give important clues to the geologic history of rocks and indications of groundwater recharge, discharge, movement and storage.

Groundwater contaminants can be broadly divided into four categories, viz., Physical, Chemical, Biological and Radiological. Health related inorganic constituents are given in Table 6.

Table 6. Health Related Inorganic Constituents

Arsenic	Lead
Asbestos	Mercury
Barium	Nickel
Cadmium	Nitrate
Chromium	Selenium
Cyanide	Silver
Fluoride	Sodium
Hardness	Zinc
Iron	

Physical Parameters

Colour: Colour in groundwater mainly results from degradation process in the natural environment. It may occur due to the presence of humic acids, fluvic acids, metallic ions such as iron and manganese, suspended matter, industrial wastes, etc. Colour is expressed in terms of Hazan standard unit which is defined as the colour produced by 1 mg/L of platinum in the form of chloroplatinic acid in the presence of 2 mg/L of cobaltous chloride hexahydrate.

Foam: It is a suspension or dispersion of gases or air bubbles in a liquid medium. Foams are caused by the presence of foaming substances such as synthetic detergent, soaps, protein, etc. Sometimes, it traps pathogenic organisms.

Odor and Tastes: The odors and tastes are present mainly due to dissolved impurities often organic in nature. The odor may be of natural origin, caused by living and decaying aquatic organisms and accumulation of gases like ammonia and hydrogen sulphide, etc. Many algae also impart taste and odors to water. Sometimes reagents added to water supply systems may also produce odor and tastes. The objectionable tastes and odours are sometimes rejected on the ground of aesthetic value. Some organic substance imparting taste and odors may also be toxic. The tastes and odors in the water are also not suitable in food, pharmaceuticals and beverage industries.

Temperature: Variations in solar energy received at the earth's surface create periodicities, both diurnal and annual in temperature below ground surface. In marked contrast to the large seasonal variation of surface water temperature groundwater temperature tend to remain relatively constant.

Below the zone of surface influence groundwater temperatures increases approximately 2.9°C for each 100 m of depth in accordance with the geothermal gradient of the earth's crust. Temperature must be measured immediately after collecting the sample. It is basically important for its effect on the chemistry and biological reactions in the organisms in water. A rise in temperature of the water leads to the speeding up of the solubility of gases and amplifies the taste and odours. Water in the temperature range of 7 to 11°C has pleasant taste and is refreshing. At higher temperatures with less dissolved gases the water becomes tasteless. Temperature is also important in the determination of various parameters such as pH, conductivity, saturation level of gases and alkalinity. Data on temperature is also required by the industries in heat transmission calculation, cooling towers and process use.

Turbidity: Turbidity in water is caused by the substances like clay, silt, organic matter, phytoptankton and other microscopic organisms. It is actually the expression of optical property. Turbidity makes the water unfit for the domestic purposes and some industries, however it is negligible in groundwater. Sometimes turbidity is measured to evaluate the performance of water treatment plants.

Chemical Parameters

pH: pH is the measure of the intensity of acidity or alkalinity and measures the concentration of hydrogen ion in water. Very high pH values above 8.5 are usually associated with sodium carbonate bicarbonate waters, moderately high pH values are commonly associated with waters high in bicarbonates, very low pH values may be associated with small amounts of mineral acids from sulphide sources or with organic acids. pH has no direct adverse affect on health, however a low value below 4 will produce sour taste and higher value above 8.5 an alkaline taste.

Electrical Conductivity (EC) and Total dissolved solids (TDS): Conductivity is the measure of capacity of a substance or solution to conduct electric current. Electrical conductivity is expressed as mhos per centimeter. It is such a large unit that most natural water has a value much less than one unit. For convenience these values can be reported as milli mhos or micro mhos at 25°C. Total dissolved solids denote mainly the various kinds of minerals present in the water. In natural waters, dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron and manganese, etc. Concentration of dissolved solids is an important parameter in drinking water and other water quality standards. They give a particular taste to the water at higher concentration and also reduce its palatability.

Dissolved Oxygen (DO): Dissolved oxygen is one of the most important parameters in water quality assessment and reflects the physical and biological processes prevailing in the water. Its presence is essential to maintain the higher forms of biological life in the water. Low oxygen in water can kill fish and other organisms present in water. Low oxygen concentrations are generally associated with heavy contamination by organic matte.

Biological Oxygen Demand (BOD): Biological Oxygen Demand is the amount of oxygen utilized by microorganisms in stabilizing the organic matter. BOD approximates the amount of oxidizable organic matter present in the solution. The BOD values are very useful in process design and loading calculations as well as the measure of treatment plant efficiency and operation.

Chemical Oxygen Demand (COD): Chemical Oxygen Demand is the oxygen required by the organic substances in water to oxidize them by a strong chemical oxidant. The COD test is very important parameter in management and design of the treatment plant because of it rapidity in determination.

Alkalinity: The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural waters is due to the salts of carbonates, bicarbonates, borate, silicates and phosphates along with the hydroxyl ions in the free state. However, the major portion of the alkalinity in natural water is caused by hydroxide, carbonate and bicarbonates. Alkalinity values provide guidance in applying proper doses of chemicals in water and waste water treatment processes, particularly in coagu1ation softening and operational control of anaerobic digestion. The ratio of alkalinity to that of alkaline earth metals is a good parameter determining the suitability of irrigation waters.

Acidity: Acidity of water is its capacity to neutralize a strong base and is mostly due to the presence of strong mineral acids, weak acids (carbonic acetic acids) and the salts of strong acids and weak bases (ferrous sulphate, aluminum sulphate, etc.). These salts on hydrolysis produce strong acid and metal hydroxides, which are sparingly soluble thus producing the acidity. However, in natural waters, most of the acidity is present due to the dissolution of carbon dioxide which forms carbonic acid. Determination of acidity is significant as it causes corrosion and influences the chemical and biochemical reactions.

Ammonia: Ammonia of mineral origin is rare in natural waters. The most important source of ammonia is the ammonification of organic matter. Occurrence of ammonia in the waters can be accepted as the chemical evidence of organic pollution.

Phosphates: The major sources of phosphorous are domestic sewage, detergents, agricultural effluents with fertilizers and industrial waste waters. The prime concern of phosphorous lies in the ability to increase the nuisance algae and eutrophication.

Sulphate: Sulphate is naturally occurring anion in all kinds of natural waters. It is an important constituent of hardness with calcium and magnesium. Sulphate produces an objectionable taste at 300-400 mg/L. Above 500 mg/L a bitter taste is produced in the water. At concentrations around 1000 mg/1, it is laxative.

Chlorides: Chlorides occur naturally in all types of waters. The most important source of chlorides in the waters is the discharge of domestic sewage.

Biological Parameters

Biological indicators are generally neglected compared to the chemical methods. Since water contamination in many instances a biological phenomenon, it would appear logical that it ought to be measured biologically. Biological indicators show the degree of ecological imbalance that has been caused and the chemical methods measure the concentration of pollutants responsible. Both types of assessment are therefore necessary.

Biological indicators are useful to assess the water quality required for amenity, fishing, recreation and irrigation. These indicators are also useful in assessing the organic pollution, toxic pollution, solids pollution, eutrophication and heated discharges.

Water Born Bacterial Pathogens: Contamination of groundwater by pathogenic organisms most frequently causes problems in situations where private wells and poorly constructed septic tanks are in proximity. Because of the filtering capability of soil, most of the pathogenic organisms present in sewage, including bacteria, viruses, protozoa, and parasitic worms, are effectively removed. Due to their small size, viruses can penetrate into the groundwater most extensively, and their removal from the water phase is dependent on adsorption.

Faecal pollution of drinking water may introduce a variety of intestinal pathogens-bacterial, viral and parasitic - their presence being related to microbial diseases and carriers, present at that movement in the community. The known intestinal bacterial pathogens are Salmonella, Shigella, enterotoxigenic, Escherichia Coli, Vibrio cholerae, Yersinia enterocolitica and Campylobacter fetus. These orgganisms may cause diseases that vary in severity from mild gasteroentites to severe and sometimes fatal dysentery, cholera or typhoid. Other organisms such as pseudomonas Flavobacterium, Acinetobacter, Klebsiella and Serratia may produce a variety of infections involving the skin and mucous membranes of the eye, ear, nose and throat.

Organisms used as bacterial indicators of faecal pollution include the coliform group of organisms as a whole, E.Coli and Coliform organisms that have been described as 'Faecal Coliforms', faecal streptococci and sulphite reducing clostridia, especially clostridium ferfringens.

Nuisance Organisms: These constitute a morphologically and physiologically diverse group of organisms, which includes planktonic and sessile algae, fungi, crustacean, and protozoa as well as actinomycetes and iron and sulphur bacteria. These organisms can cause objectioable tastes, colour, odour and turbidity and may interfere with treatment processes by blocking stainers and filters. In addition, certain planktonic orgaliisms, although not themselves harmful, may harbour pathogens and protect them against disinfection by chlorine.

Nuisance organisms may also cause problems with groundwater sources by encrusting well-screens, thus causing loss of yield and impairing the asthetic quality of the supply. Indeed, their presence may indicate organic pollution of the aquifer.

Virological Quality of Drinking Water: Viruses enter the water environment primarily by way of sewage discharges. It is generally believed that the primary root of exposure to enteric viruses is by direct contact with infected persons or by contact with faecally contaminated objects explosive out breaks of viral hepatites and gastroenterites resulting from sewage contamination of water supplies have been well documented epidemiologically. Enteric viruses are capable of producing a wide variety of syndromes including rashes, fever, gastroentrities, myocardities, meaningities, respiratory disease and hepatitis.

Free Living Organisms: Plankton and macroinvertebrates are generally considered significant in water supplies. Phytoplankton consists of free-living bacteria, fungi and algae. Zooplankton consists of free- living protozoa, rotifers, cladocera, copepods, worms and the larvae of some aquatic insects and fish. The macroinvertebrates include the benthic animals, such as aquatic insect larvae, crustacea arid gastropods. These organisms are important in water supplies because they interfere with water treatment processes, produce substances toxic to humans, harbour htiman pathogens, and contribute organic matter. On the other hand the macroinvertebrates may affect the efficiency of water distribution systems and the acceptance of water by consumers.

Health Related Inorganic Constituents

Arsenic: Arsenic minerals are widely distributed. Common minerals include two sulphides, realgar and orpiment and the oxidized form arsenolite. Many arsenic compounds are water soluble and thus contamination of water can occur. Most of the arsenic found in water derives from industrial discharges. Arsenic is present in most food stuffs. Acute poisoning by arsenic involves the central nervous system leading to coma and for doses of 70 - 180 mg/L to death. The gastro intestinal tract, nervous system, the respirated tract and skin can be severely affected.

Asbestos: Asbestos is introduced into natural waters by the dissolution of asbestos containing minerals and ores and from industrial effluents. The use of asbestos cement pipes in distribution systems is a. potential source of asbestos contamination of drinking water. Asbestos is derived from two large groups of rock forming minerals - the serpentines and the amphiboles. The epidemiological studies have shown a marginally significant association between asbestos levels in drinking water and cancers of the digestive tract.

Barium: Most waters contain some barium. The source is normally natural mineral matter. Barium is present in traces in many food stuffs. Brazil nuts are an especially rich source. Barium is acutely toxic when soluble salts are ingested in excess, if taken as the chloride, the fatal dose of barium for an adult is about 550 - 600 mg/L.

Cadmium: Cadmium is found as greenockite. But the commercially important source is found in most zinc ores. Drinking water normally contains very low concentrations of cadmium. Most food stuffs contain traces of cadmium. Higher levels of cadmium in tap water are associated with plate plumbing fittings, silver base solders and galvanized iron piping material. Acute effects have been seen where food has been contaminated by cadmium from plated vessels. Health effects have been demonstrated in industrial workers having exposed to cadmium oxide fuels and dust. The renal cortex is generally accepted to be the critical organ for cadmium accumulation in man. A guideline value of 0.05 mg of cadmium per litre is recommended.

Chromium: Most rocks and soil contain small amounts of chromium. Because of the low solubility of chromium generally the levels found in water are usually low. However, there are examples of contamination of water in some cases where effluents containing chromium compounds are discharged to rivers. The only ore of chromium of any commercial importance is chromite. Other less plentiful sources are crocoite and chrome ochre. Chromium is absorbed through both the gastrointestinal and respiratory tracts. The amount absorbed differs in each system and depends on the form of chromium. Chromium appears to be necessary for glucose and lipid metabolism and for utilization of amino acids in several systems. It also appears to be important in the prevention of mild diabetes and atherosclerosis in humans. The harmful effects of water borne chromium in man are associated with hexavalent chromium. Hexavalent chromium at 10 mg/Kg of body weight result in liver necrosis, nephritis and death in man, lower doses will cause irritation of the gastrointestinal mucosa. A guideline value of 50 μg/L is recommended for drinking water.

Cyanide: Cyanide is present wherever life and industry occur. Cyanides form part of life processes in particular as metabolic intermediates. Hydrocyanic acid dissociates to gives the cyanide ion in water. A single dose or 50-60 mg for a human being is usually fatal. On the basis of animal experiments it has been calculated that an acceptable daily intake for man is 8.4 mg of cyanide. A guideline value of 0.1 mg/l is recommended.

Fluoride: Fluorine has been fairly conclusively demonstrated to be an essential element for some animal species. The three most important fluorine bearing minerals are fluorite, cryolite and fluorapatite. In little quantities it can reduce dental caries. Once fluoride is incorporated into teeth, it reduces the solubility of the enamel under acidic conditions and there by provides protection against dental caries. Long term consumption of water containing 1 mg of fluoride per litre may lead to mottling. Skeletal fluorosis has been observed in persons when water contains more than 3 - 6 mg of Fluoride per litre. In high doses F is actually toxic to man. Pathological changes include haemorrhagic, gastroentrities, acute toxic nephritis and various degrees of injury to the liver and heart muscle.

Hardness: Hardness of water is the property attributable to the presence of alkaline earths. The major alkaline earth elements present in most natural waters are Ca and Mg. Other elements such as Sr, Ba (also alkaline earths), Fe, Mn and Al are normally not present in waters in sufficient amount to affect a test for hardness. The degree of hardness in water is commonly based on the following classification:

Hardness, mg/L as CaCO3	Water Class
0-75	Soft
75-150	Moderately hard
150-300	Hard
Over 300	Very hard

Water hardness is primarily the result of interaction between water and the geological formations containing it, or over which the water flows. There is some suggestive evidence that drinking extremely hard water might lead to an increased incidence of urolithiasis.

Iron: Iron is abundant in the crust by weight and is a major constituent in pyroxenes, amphiboles, micas (silicates), pyrite and chalco-pyrite (sulphides) and magnetite and haematite (oxides). Iron is an essential element in human nutrition. Iron ingestion in large quantities results in a condition of haemochromatosis (normal regulatory mechanisms do not operate effectively). Iron bearing water often tastes unpalatable and stains laundry and plumbing fixtures.

Lead: The most important lead ore is galena. Other ore minerals are anglesite, cerussite, pyromorphite and mimetestite. Lead in high doses has been recognized for centuries as a cumulative general metabolic poison. Some of the symptoms of acute poisoning are tiredness, lassitude, slight abdominal discomfort, irritability, anaemia and in the case of children. behavioural changes.

Mercury: Natural degassing of the earth's crust is major source of mercury. In most surface waters mercuric hydroxide and chloride are the predominant mercury species. The major effects of mercury poisoning take the form of neurological and renal disturbances. In addition to producing general toxic effects, mercury causes gonadotoxic and mutagenic effects and. disturbs the cholesterol metabolism.

Nickel: Many nickel salts are water soluble, therefore contamination of water can arise. Garnierite, nickeliferous limonite and pentlandite are the important source minerals. Nickel is relatively non-toxic element. The levels of nickel usually found in food and water are not considered a serious health hazard. However, high doses (1600 mg/kg in the diet) were shown in early animal studies to cause mineral toxic effects.

Nitrate and Nitrite: Nitrates are widely present in substantial quantities in soil, in most waters and in plants including vegetables. It has been well documented that in some countries, water supplies containing high levels of nitrate have been responsible for cases of infantile methaemoglobinaemia and death. This problem does not arise in adults. There are conflicting conclusions regarding the nitrate threshold level for an effect.

Selenium: Selenium has been identified as an essential nutrient in several animal species. It is comparatively a rare element. Selenium is essential for human health. Recent studies on Keshan disease suggest that this myocardial disease of children could be induced below-level salenium intake. Exposure to high salenium results Nausea, dermatitis and pathological changes in the nails.

Silver: Silver is widely distributed in sulphide ores of which argentite is the most important. Levels of silver in natural waters are very low. There is no evidence that silver is essential to the human organism.

Sodium: Sodium is present mainly in rock salt. This ion is ubiquitous in water owing to the high solubility. In general, sodium salts are not acutely toxic substances because of the efficiency with which mature kidneys excreate sodium. Excessive intake of sodium chloride causes vomiting and the elimination of the much of the salts. Acute effects may include convolutions, muscular twitching and rigidity and cerebral and pulmonary Oedema. Acute effects and death have been reported in the case of children.

Sulphate: Majority of the sulphates are soluble in water (exceptions, sulphates of lead, barium, and strontium). Sulphate is poorly absorbed from the human intestine. Sulphate doses of 1.0 - 2.0 g have a cathartic effect on humans, resulting in the purgation of the alimentary canal. Infants ingesting sulphate equivalent to 21 mg/Kg of body weight per day may also suffer from this effect. High sulphate concentrations in water may contribute to the corrosion of metals in the distribution system, particularly in waters having low alkalinity.

Zinc: The major source of zinc is sphalerite, smithsonite,. hemimorphite and franklinite. Zinc is an essential element for both animals and man and is necessary for the functioning of various enzyme systems. Symptoms of zinc toxicity in humans include vomiting, dehydration, electrolyte imbalance, abdominal pain, nausea, lethargy, dizziness, and lack of muscillar co-ordination. Acute renal failure caused by zinc chloride has been reported.

Health Related Organic Constituents

More than 2000 chemical contaminants of all kinds have been found in water, about 750 of which have been identified in drinking water, of these, mere than 600 are organic substances, including many that are pharmacologically active, several that are recognized carcinogen or carcinogenic promoters, and a number that have been shown to be mutagenic. Compounds of potential health significance are shown in Table 7.

GROUNDWATER QUALITY ASSESSMENT FOR DRINKING WATER

The quality of groundwater is of great importance in determining the suitability of particular groundwater for a certain use (public water supply, irrigation, industrial applications, power generation etc.). The quality of groundwater is the resultant of all the processes and reactions that act on the water from the moment it is condensed in the atmosphere to the time it is discharged by a well or spring. Therefore, the quality of groundwater varies from place to place, with the depth of water table, and from season to season and is primarily governed by the extent and composition of dissolved solids present in it.

Among the diffuse sources of groundwater pollution, the use of fertilizers in agriculture deserves special attention. Not only are salt and nitrate levels increasing in agricultural areas, but pesticide and pesticide metabolites can also be found in groundwater. Metals like Cd, Se, Mo, and U (present as contaminants in fertilizers), may ultimately create groundwater quality problems. To assess the importance of groundwater pollution, one must first have to establish whether the type and concentration of contaminants is different from natural levels. Ranges of the content of various elements in uncontaminated soil are given in Table 8.

Natural levels of these elements in groundwater are roughly lower by a factor of 1000. Levels of organic substances in uncontaminated groundwaters are generally below 0.1 μg/L. If higher levels of these constituents are present, the seriousness of the contamination must be evaluated on the basis of the prescribed standards.

Table 7. Groups of Organic Compounds of Potential Health Significance

1.	**Source contaminants**
	humic substances
	chlorinated alkanes and alkenes
	nitrosamines
	polynuclear aromatic hydrocarbons (PAH)
	nitriolotriacetlc acid (NTA)
	phenols
	synthetic detergents
	pesticides
	polychlorinated byphenols (PCB)
	phthalate esters
	petroleum oils, including gasoline
	chlorobenzenes
	chlorinated phenols
	benzene and alkyl aromatics
	carbon tetrachloride
2.	**Introduced during treatment**
	carbon tetrachloride
	acryl amide
	trihalomethanes
3.	**Introduced during distribution**
	vinyl chloride monomer
	polynuclear aromatic hydrocarbons (PAH)

The quality of groundwater depends on a large number of individual hydrological, physical, chemical and biological factors. Generally higher proportions of dissolved constituents are found in groundwater than in surface water because of greater interaction of groundwater with various materials in geologic strata.

The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The contamination of groundwater by heavy metals has assumed great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The determination of the concentration levels of heavy metals in these waters, as well as the elucidation of the chemical forms in which they appear is a prime target in environmental research today.

CLASSIFICATION OF GROUNDWATER

Different accepted and widely used graphical methods such as Stiff diagram, Piper trilinear diagram and U.S. Salinity Laboratory classification can be used to study the quality of groundwater. Stiff classification (Stiff, 1951) is used to classify the type of water based on dominant cations and anions. Piper classification (1953) is used to express similarity and dissimilarity in the chemistry of different water samples based on the dominant cations and anions. U.S Salinity Laboratory Classification is used to study the suitability of groundwater for irrigation purposes. The description of each classification is given below.

Table 8. Contents of Some Elements in Uncontaminated Soils

Element	Common Range in Soils, mg/kg
Ag	0.01 – 5.0
As	1 – 50
B	2 – 100
Ba	100 – 3000
Be	0.1 – 40
Br	1 – 10
Cd	0.01 – 0.7
Co	1 – 40
Cr	1 – 1000
Cu	2 – 100
Hg	0.01 – 0.3
Mo	0.2 – 5
Ni	5 – 500
Pb	2 – 200
Se	0.1 – 2
Sn	2 – 200
Ti	1000 – 10000
V	20 – 500
Zn	10 - 300

Stiff Classification

The Stiff classification (Stiff, 1951) is used to define the type of water based on the presence of dominant cations and dominant anions. The Stiff graphical method plots four major cations (Ca, Mg, Na+K, Fe) on the left side and four major anions (HCO_3 + CO_3, SO_4, Cl, NO_3) on the right side. Concentrations on the diagram are expressed in milliequivalents per liter. Since iron and nitrate are normally present in insignificant concentrations, most natural waters can be represented as solutions of three major cations (calcium, magnesium, sodium with or without potassium) and three major anions (bicarbonate plus carbonate, sulphate, chloride with or without nitrate)

Piper Trilinear Diagram

Piper (1953) developed a form of trilinear diagram which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in groundwater, modifications in the character of water as it passes through an area, and related geochemical problems. For the Piper trilinear diagram, groundwater is treated substantially as though it contained three cation constituents (Mg, Na+K and Ca) and three anion constituents (Cl, SO_4 and CO_3+HCO_3). The diagram presents graphically a group of analysis on the same plot.

The diagram combines three distinct fields of plotting two triangular fields at the lower left and lowers right respectively and an intervening diamond-shaped field (Fig. 1). All three fields have scales reading in 100 parts. In the triangular field at the lower left, the percentage reacting values of the three cation groups (Ca, Mg, Na+K) are plotted as a single point according to conventional trilinear coordinates. The three anion groups (CO_3+HCO_3, SO_4, Cl) are plotted likewise in the triangular field at the lower right. Thus, two points on the diagram, one in each of the two triangular fields, indicate the relative concentrations of the several dissolved constituents of a groundwater.

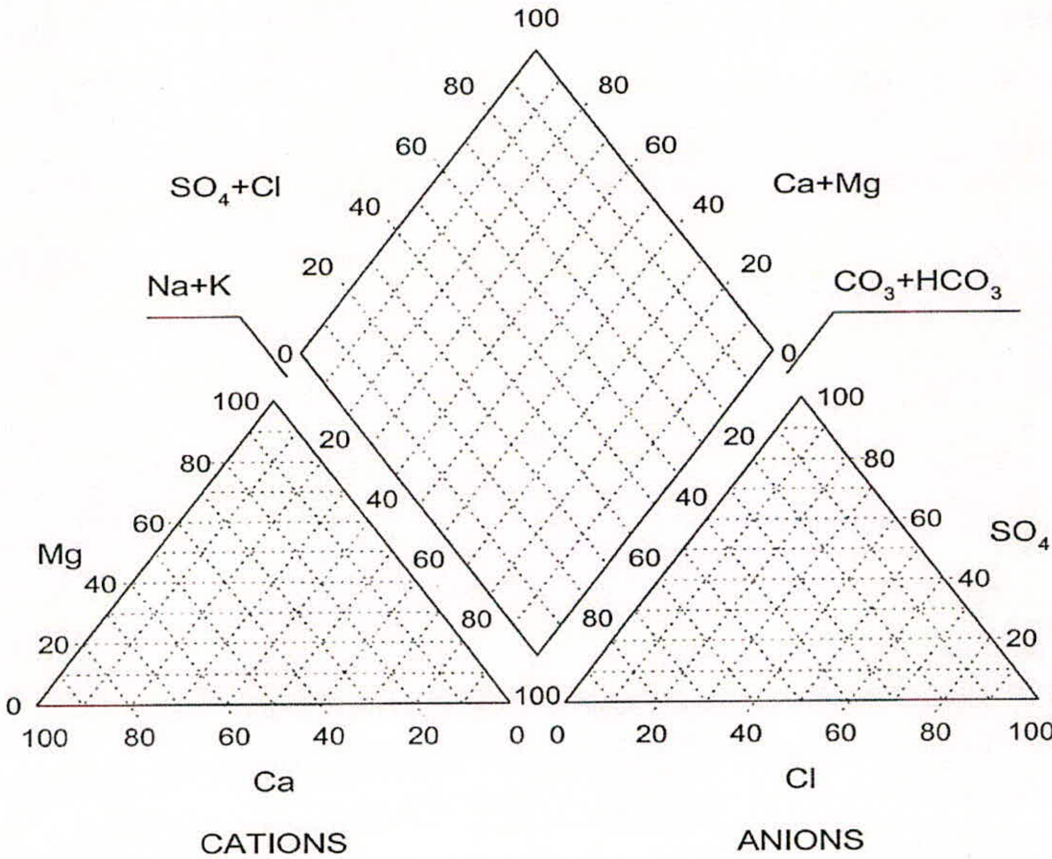

Fig. 1 Piper Diagram

The central diamond-shaped field is used to show the overall chemical character of the groundwater by a third single-point plotting, which is at the intersection of rays projected from the plotting of cations and anions. The position of this plotting indicates the relative composition of a groundwater in terms of the cation-anion pairs that correspond to the four vertices of the field. The three trilinear plotting shows the essential chemical character of a groundwater according to the relative concentrations of its constituents.

U.S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by sodium absorption ratio (SAR). A diagram for use in studying the suitability of groundwater for irrigation purposes is based on the sodium adsorption ratio (SAR) and conductivity of water expressed in μS/cm (Fig. 2). The significance and interpretation of the quality class ratings on the diagram are given in Table 8.

In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, and drainage, quantity of water used, climate and salt tolerance of crop.

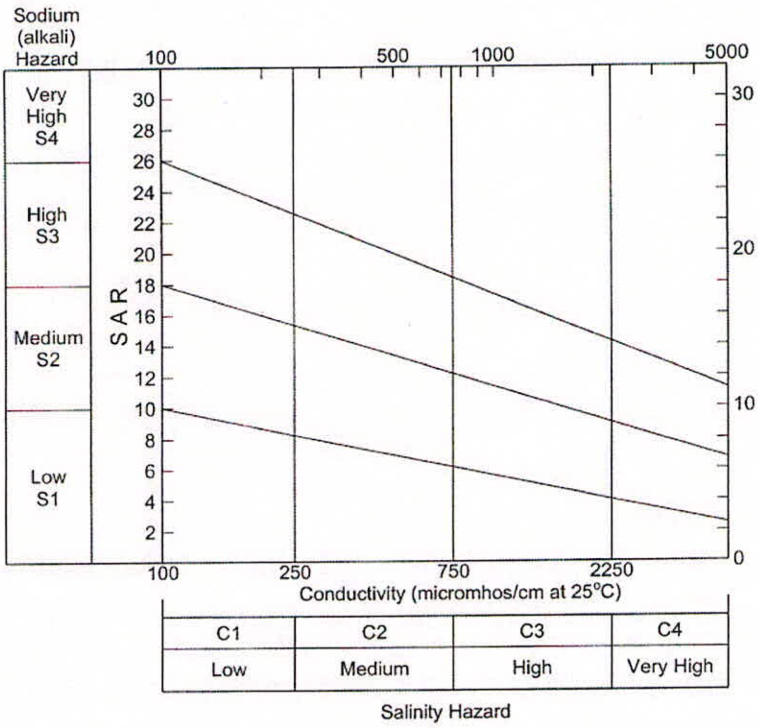

Fig. 2. U.S. Salinity Laboratory Classification

Table 9. Significance of Quality Class Ratings on U.S. Salinity Laboratory Diagram

Classification of Irrigation Waters	
Low Salinity (C1)	Low salinity water (C1) can be used for irrigation with most crops on most soils.
Medium Salinity (C2)	Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
High Salinity (C3)	High salinity water (C3) can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected.
Very High Salinity (C4)	Very high salinity water (C4) is not suitable for irrigation water under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate and irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected.
Classification of Irrigation Waters	
Low SAR (S1)	Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.
Medium SAR (S2)	Medium sodium water will present an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions. This water may be used on coarse-textural or organic soils with good permeability.
High SAR (S3)	High sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions.
Very High SAR (S4)	Very high sodium water is generally unsatisfactory for irrigation purposes.

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