Suitability of Groundwater for the Irrigation Purpose

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GENERAL

The term "water quality" is generally used to describe the non-aqueous components of a volume of water which includes suspended sediment, biota and dissolved species. Suspended sediment and biota filtered out of recharging water during infiltration through a porous medium. If an aquifer is strongly fractured or karstified, then suspended sediment and biota may persist during subsurface transport.

Hydro-chemical analysis of Groundwater is mainly carried for (i) to assess the suitability for the intended purpose, (ii) to evaluate the corrosion and/or the incrustation potential of the groundwater with regard to the materials used as well as components, and (iii) to evaluate the likely origin of the groundwater.

COMMON COMPONENTS OF GROUNDWATER ANALYSIS INCLUDE:

(i) Temperature
(ii) Conductivity
(iii) pH
(iv) Eh (redox)
(v) Total Dissolved Solids
(vi) Alkalinity
(vii) Hardness

Water quality plays an important role in irrigated agriculture. Many problems arise during inefficient management of water for agriculture use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Under good soil and water management practices, good quality water has the ability to cause maximum yield. The quality of irrigation water is assessed by the following characteristic:

1. Salinity
2. Relative Proportion of Sodium to other Cations (SAR)
3. Residual Sodium Carbonate (RSC)
4. Boron

SALINITY

Salinity is expressed in terms of total dissolved solids (TDS) and thereby electrical conductivity (EC). If the salt concentration in water increases, the soil salinity also increases, it is difficult for plants to extract water. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solid content of the residual water in the root zone also has to be maintained within limits by proper leaching.

The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are given in Table 1. The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels.

Table 1. Safe limits of electrical conductivity for irrigation water

Sl. No.	Nature of soil	Crop growth	Upper permissible safe limit of EC, μS/cm
1.	Deep black soil and alluvial soils having clay content more than 30% soils that are fairly to moderately well drained	Semi-tolerant	1500
		Tolerant	2000
2.	Having textured soils having clay contents of 20-30% soils that are well drained internally and have good surface drainage system	Semi-tolerant	2000
		Tolerant	4000
3.	Medium textured soils having clay 10-20% internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4.	Light textured soils having clay less than 10% soil that have excellent internally and surface drainage system	Semi-tolerant	6000
		Tolerant	8000

***Source:** CGWB and CPCB (2000).*

RELATIVE PROPORTION OF SODIUM TO OTHER CATIONS

The clay minerals in the soil absorb divalent cations, like calcium and magnesium ions from irrigation water. Whenever the exchange sites in clay are filled by divalent cations, the soil texture is conductive for plant growth. Sodium reacts with soil to reduce its permeability. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

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

The sodium percentage is calculated as:

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

Where all ionic concentrations are expressed in milliequivalent per litre.

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 hazards for a given SAR (Richards, 1954).

RESIDUAL SODIUM CARBONATE (RSC)

Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate, changing the residual water to high sodium water with sodium bicarbonate in solution. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$\text{RSC} = (\text{HCO}_3^{-} + \text{CO}_3^{--}) - (\text{Ca}^{++} + \text{Mg}^{++})$$

Where all ionic concentrations are expressed in epm. 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.

The recommended classification with respect to electrical conductivity, sodium content, Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are given in Table 2 (CGWB and CPCB, 2000).

Table 2. Guidelines for evaluation of irrigation water quality

Water class	Na (%)	EC (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	750-2250	18-26	2.0-2.5
Bad	60-80	2250-4000	> 26	2.5-3.0
Very bad	> 80	> 4000	> 26	> 3.0

***Source:** CGWB and CPCB (2000).*

BORON

Boron is essential for plant nutrition and is sometimes added to fertilizers in small amounts to make up for the boron deficiency particularly in humid regions. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. Boron is present in many soaps and thus may become a crucial factor in the use of sewage irrigation water. Traces of boron > 0.5 ppm are injurious to citrus, nuts and deciduous fruits; cereals and cotton are moderately tolerant to boron; while alfalfa, beet, asparagus and dates are quite tolerant (1 to 2 ppm).

CLASSIFICATION OF GROUND WATER

For the classification of ground water, different graphical methods such as Piper trilinear diagram, Chadha's diagram, Stiff classification (1951), Durov's diagram, U.S. Salinity Laboratory classification and Gupta's classification can be used. Piper trilinear (Piper, 1944), Chadha's diagrams (1999) and Durov's diagram (1948) are used to express similarity and dissimilarity in the chemistry of groundwater based on major cations and anions. U.S. Salinity Laboratory classification (Wilcox, 1955), Gupta's classification (1979) and permeability index method can be used to study the suitability of ground water for irrigation purposes. Other diagrams include bar graphs, vector diagrams, pie diagrams, Schoeller semi-logarithmic diagram, Eh-pH diagrams, etc. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage characteristics, quantity of water used, climate and salt tolerance of crop.

BAR GRAPHS

Bar graphs are widely used in the United States for portraying chemical quality. Each analysis appears as a vertical bar having a height proportional to the total concentration of anions and cations, expressed in milli-equivalents per liter. The left half of a bar represents cations, and the right half anions. These segments are divided horizontally to show the concentrations of major ions or groups of closely related ions and identified by distinctive shading patterns.

VECTOR DIAGRAMS

The lengths of the six vectors represent ionic concentrations in milli-equivalents per liter.

PIE DIAGRAMS

Pie diagrams are constructed so that the radius indicates the TDS content of the water.

PIPER TRILINEAR CLASSIFICATION

The concept of hydrochemical facies can be used to denote the diagnostic chemical characteristics of water in hydrological system. The facies reflect the effect of chemical processes occurring between the mineral within the lithologic frame work and in the ground water. Hydrochemical facies has been carried out by plotting percentage reacting values of major ions in trilinear diagrams by Hill Piper. Piper (1944) has developed a form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of water as it passes through an area and related geochemical problems. The diagram is useful in presenting graphically a group of analysis on the same plot.

The Piper trilinear diagram consists of two lower triangular fields at the left and right respectively and a central diamond-shaped field. All three fields have scales reading in 100 parts. The percentage reacting values of the three cations (Ca, Mg, Na+K) and three anions (HCO_3, SO_4, Cl) are plotted as a single point according to conventional trilinear coordinates at lower left and right triangles respectively. These are projected upwards parallel to the sides of the triangles to give a point in the central diamond-shaped field, which indicate the overall chemical character of the ground water. The position of this point indicates the relative composition of a ground water in terms of cation-anion pairs that correspond to the four vertices of the field. The three areas of plotting show the essential chemical character of ground water according to the relative concentrations of its constituents.

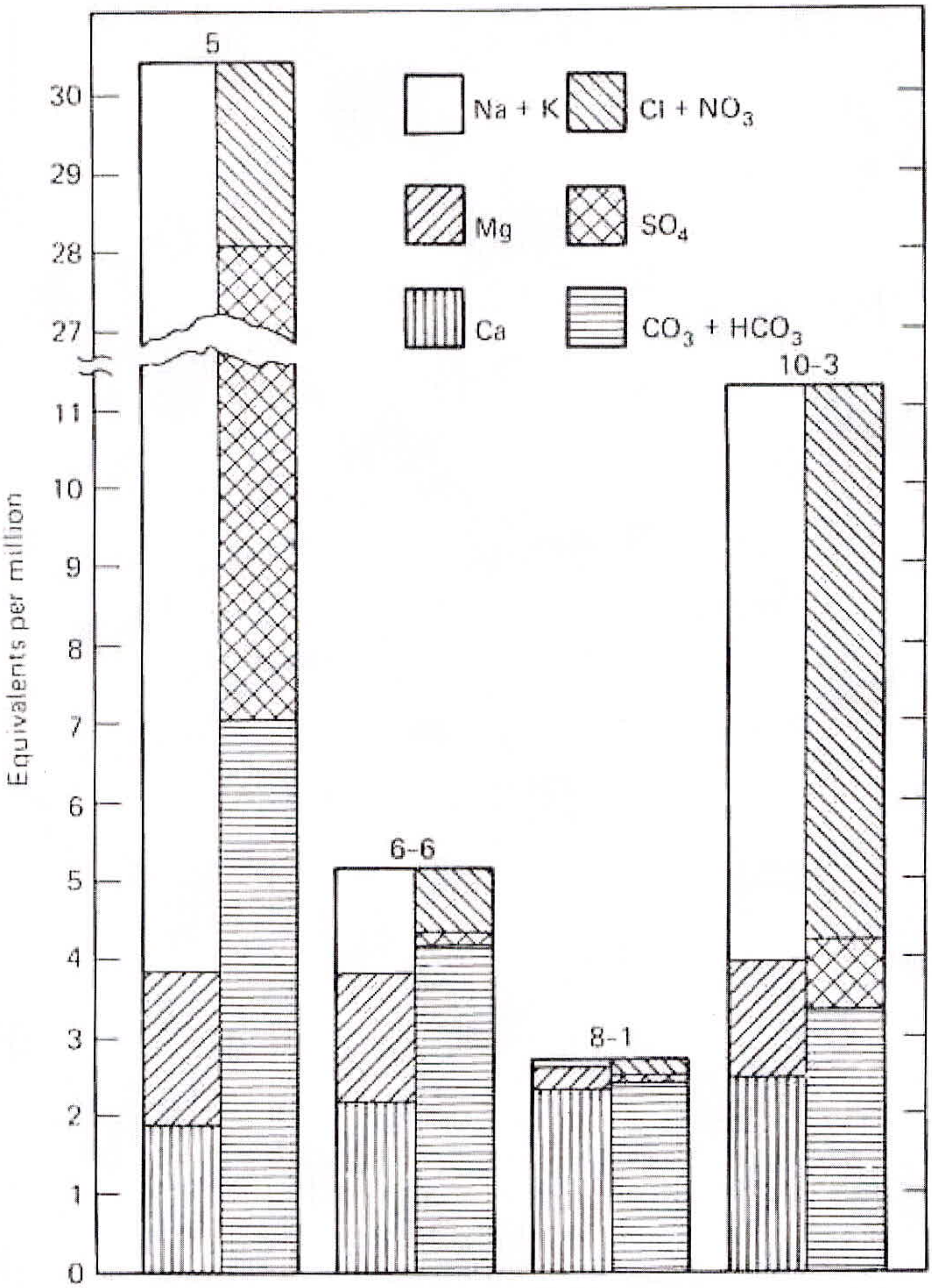

Fig. 1 Vertical bar graphs for representing analysis of groundwater quality

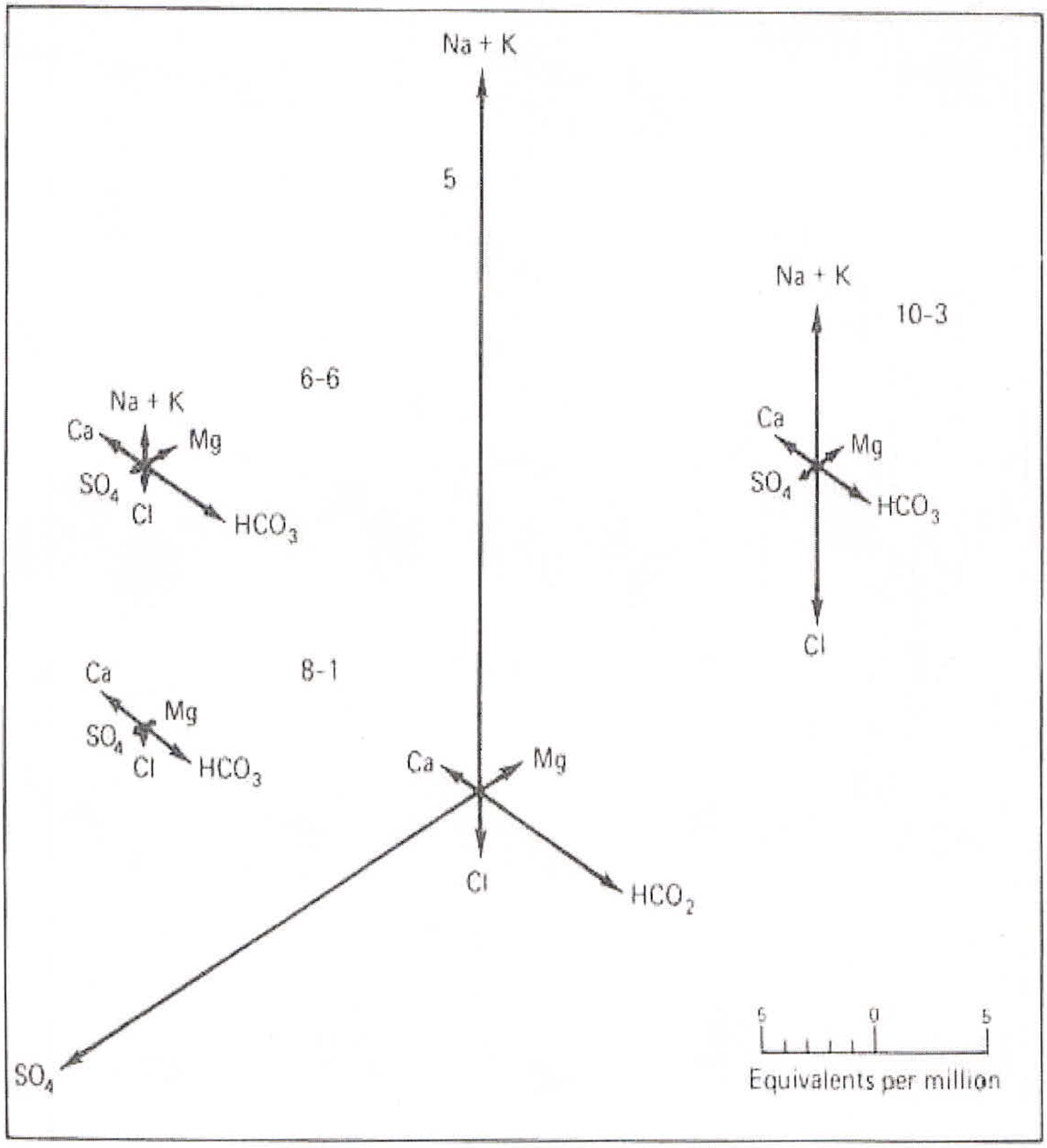

Fig. 2 Vector diagrams for representing analysis of ground water quality

CHADHA'S DIAGRAM

Modified version of the piper trilinear diagram is developed by Chadha (1999). In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in two base triangles and the type of water is determined on the basis of position of the data in the respective cationic and anionic triangular fields. The plottings from triangular fields are projected further into the central diamond field, which represents the overall character of the water. Piper diagram allow comparisons to be made among numerous analyses, but this type of diagram has a drawback, as all trilinear diagram do, in that it does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydrochemical process terms, so the diagram lacks certain logic. This method is not very convenient when plotting a large volume of data. Nevertheless, this shortcoming does not lessen the usefulness of the Piper diagram in the representation of some geochemical processes.

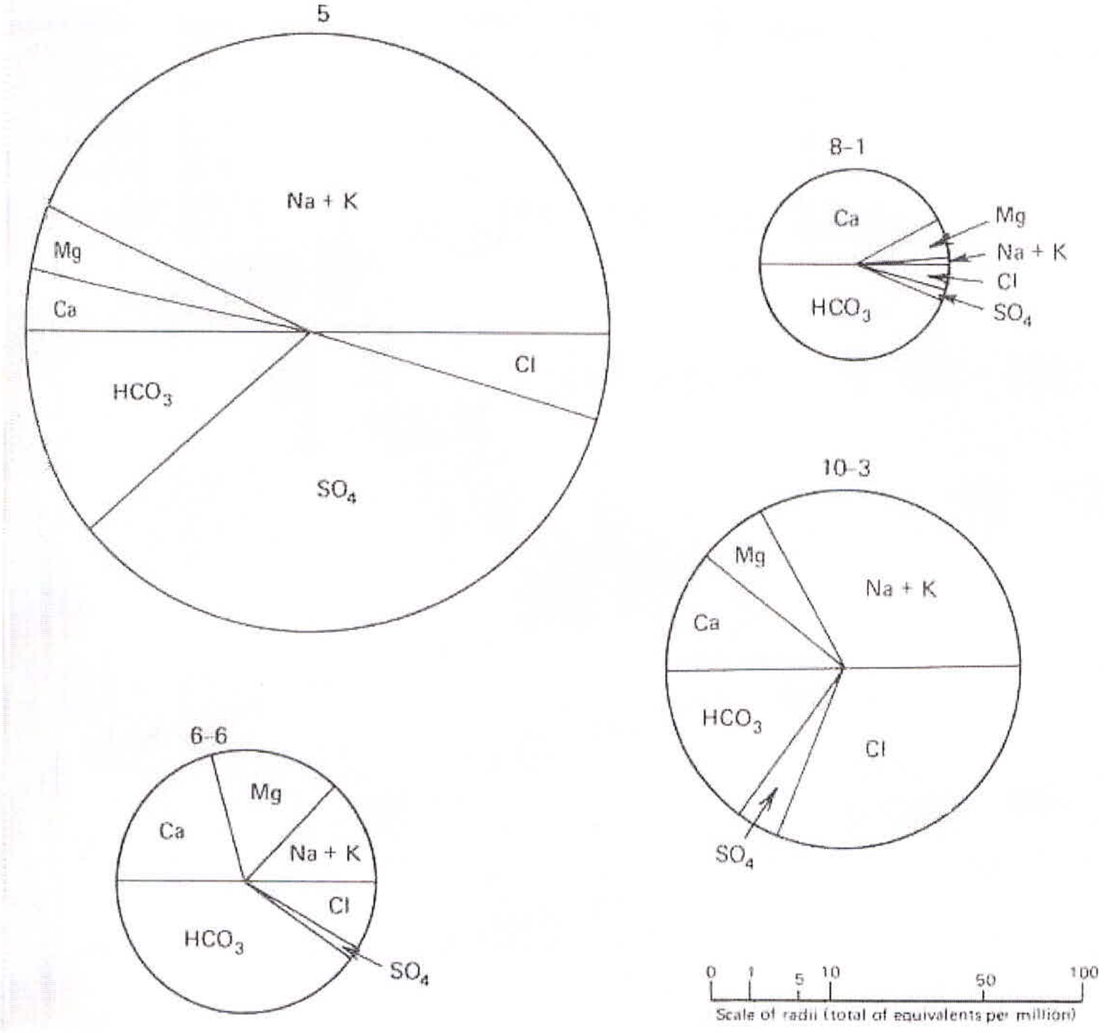

Fig. 3 Circular diagrams for representing analyses of groundwater quality

In contrast, in Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

The square or rectangular field describes the overall character of the water. The diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end product water) and other related hydrochemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows:

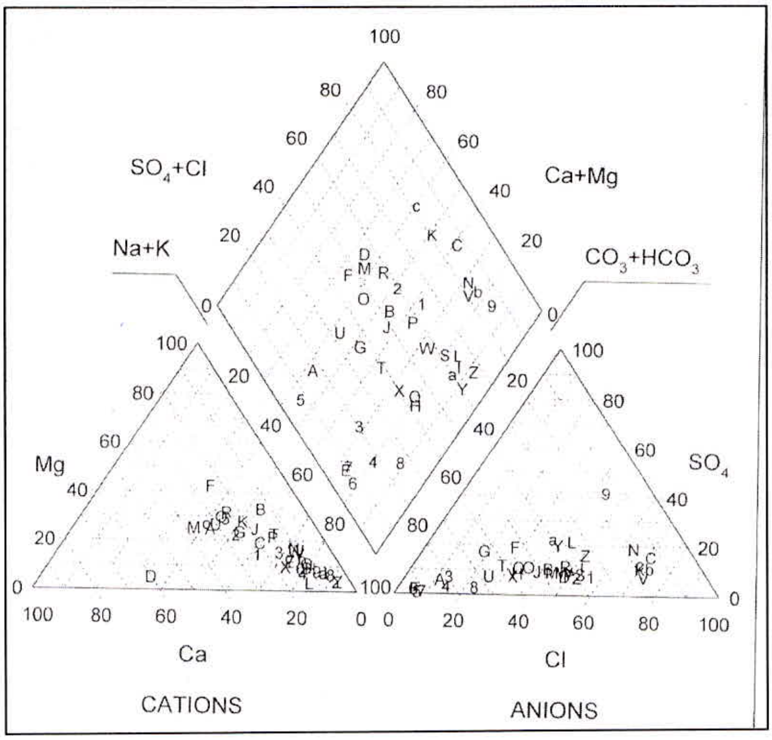

Fig. 4 Piper trilinear diagram showing water type categories

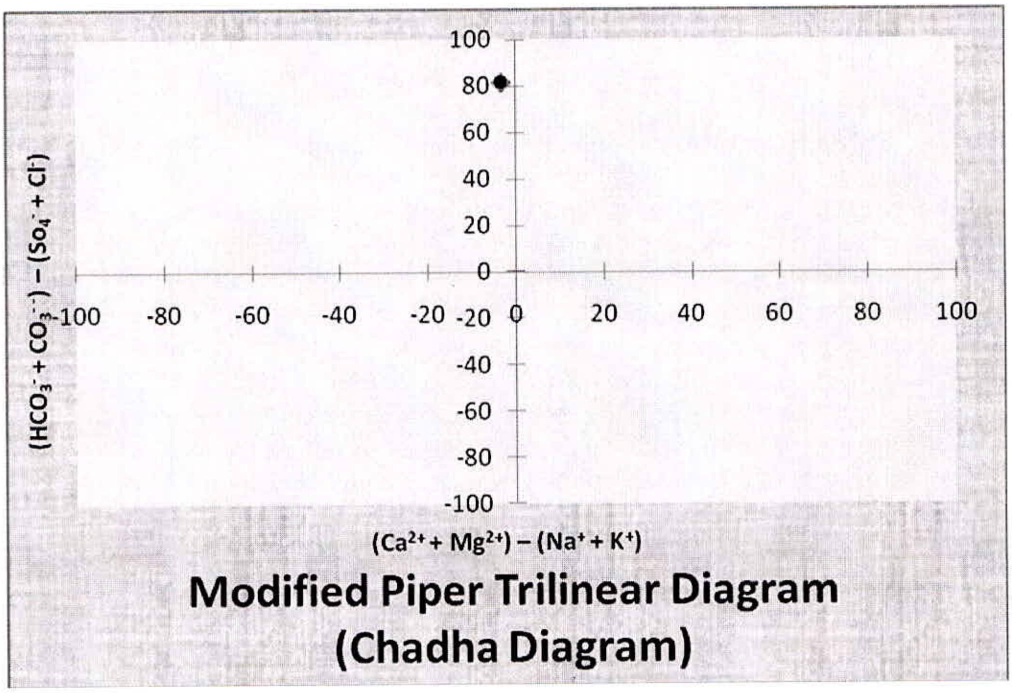

Fig. 5 Modified Piper trilinear diagram showing water type

1. Alkaline earth exceeds alkali metals.
2. Alkali metals exceed alkaline earth.
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness. The position of data points in the diagram represent Ca^{2+} -Mg^{2+}-HCO_3^- type, Ca^{2+} -Mg^{2+}- dominant HCO_3^- type, or HCO_3^- - dominant Ca^{2+} -Mg^{2+}- type waters.
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The position of data points in the diagram represents Ca^{2+} -Mg^{2+}-Cl^- type, Ca^{2+} -Mg^{2+}- dominant Cl^- - type or Cl^- - dominant Ca^{2+} -Mg^{2+}- type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The position of data points in the diagram represent Na^+-Cl^-- type, Na_2SO_4- type, Na^+-dominant Cl^--type, or Cl^--dominant Na^+-type waters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the diagram represent Na^+- HCO_3^- -type, Na^+-dominant HCO_3^- -type, or HCO_3^- -dominant Na^+-type waters.

The Chadha's diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

STIFF DIAGRAM

Stiff diagrams are polygons representing the major ion distributions of water samples as shown in Fig. 6.

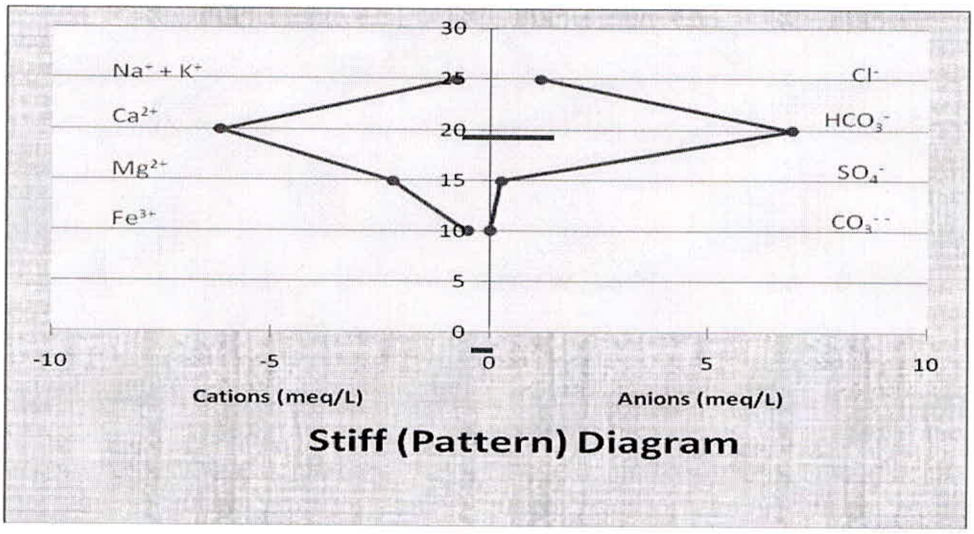

Fig. 6: Stiff diagram showing water type

DUROV DIAGRAM

Durov diagram closely resemble Piper Diagrams, but allow additional plotting of pH and TDS.

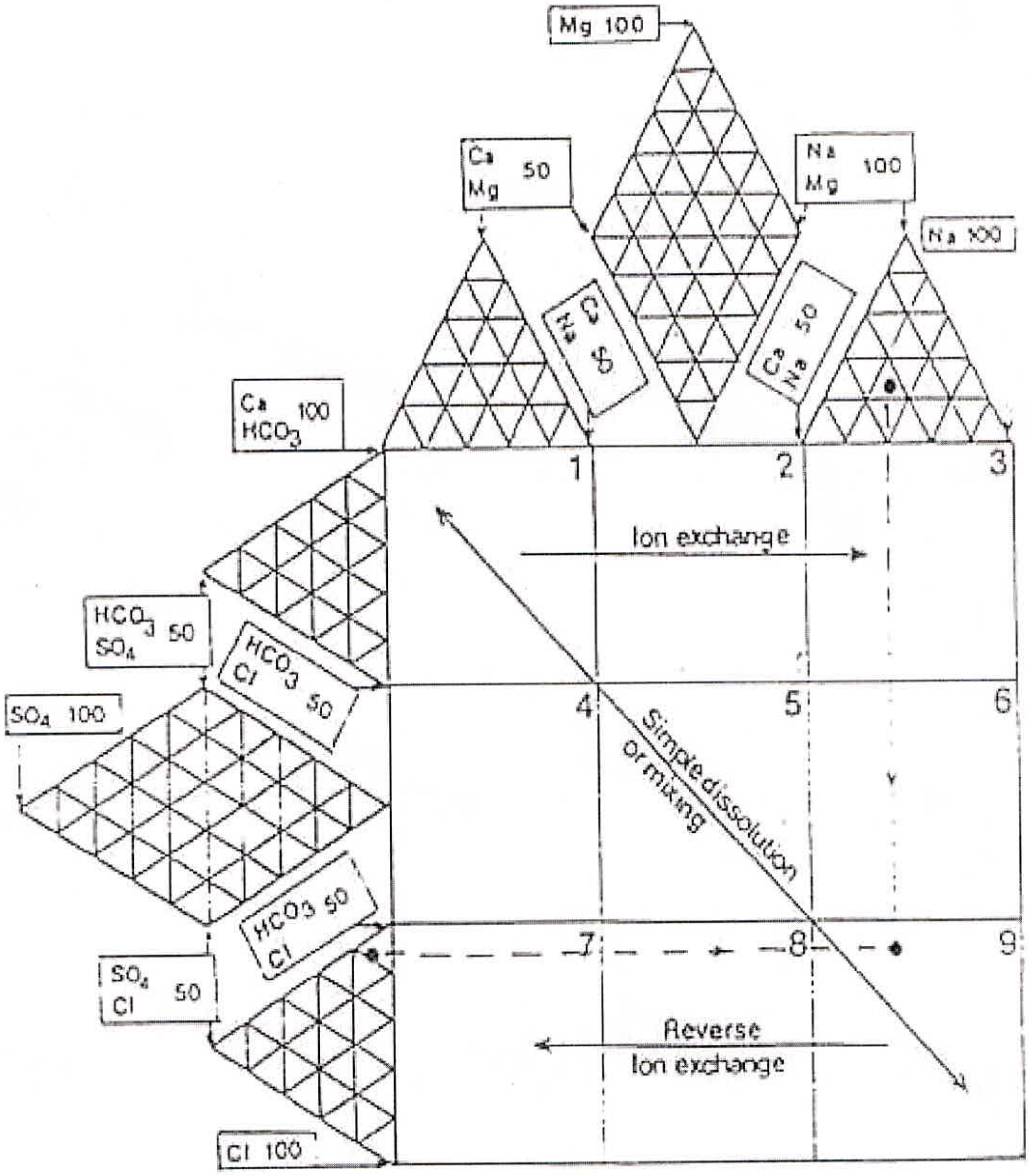

Fig. 7 Expanded Durov Plot

U. S. SALINITY LABORATORY CLASSIFICATION

Sodium concentration plays an important role 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 Adsorption Ratio (SAR). The U.S. Regional Salinity Laboratory has developed a diagram for use in studying the suitability of ground water for irrigation purposes with reference to sodium adsorption ratio (SAR) as an index for sodium hazard S and electrical conductivity (EC) of water expressed in μS/cm as an index of salinity hazard C. The quality classification of irrigation water is given in Table 3.

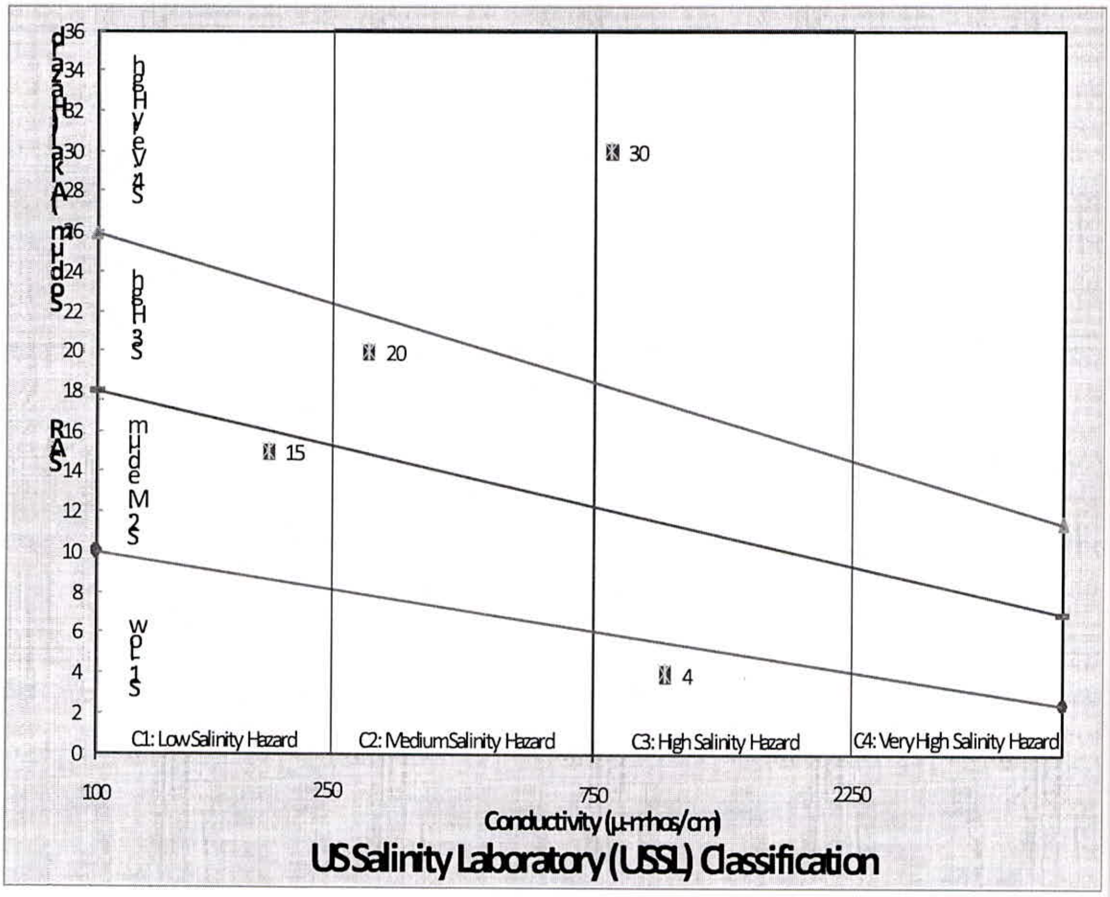

Fig. 8 U. S. Salinity Laboratory Classification

Table 3. U.S. salinity laboratory classification

Salinity Based	
Salinity Level	Suitability for Irrigation
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.
SAR Based	
SAR Level	Suitability for Irrigation

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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