STATE OF ART REPORT

Scientific Contribution
No.:INCOH/SAR - 19/99

IRRIGATION WATER QUALITY

INDIAN NATIONAL COMMITTEE ON HYDROLOGY
(Committee Constituted by Ministry of Water Resources, Govt. of India)

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INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247 667, INDIA

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PREAMBLE

It has been estimated that the total world population will be about 8.3 billion by the year 2025, with the most rapid growth in the developing countries. By that time the countries with in the humid tropics and the other warm humid regions will represent almost one-third of the total world population. This proportion will continue to rise in the twenty-first century. The developing and under developed countries thus quite clearly are the regions facing potentially serious water problems. Hence, it is urgent to question as to whether the fields of hydrology and water resources management have the appropriate methods in place to meet the rising demands that will be made on the water resources. Hence, it becomes very important and expeditious to review and update the state-of-art in different facets of hydrology and component processes. This calls for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

It is estimated that about 80% of the total water use is for agriculture. With in agriculture use the major component is utilised for irrigation of food and horticulture crops, livestock production, irrigation for agro/social forestry and to smaller extent for agriculture. The quantity and quality of water used in agriculture are two interrelated properties controlling the production capabilities of the land and the quality of environment and the water resources. Water is considered suitable for agricultural use when it has no osmotic or toxic effects on crop production, when it contains no solutes affecting the chemical and hydraulic properties of the soil and when it does not cause the deterioration of surface and ground water.

Also, the two most important consumptive uses of water for agriculture are irrigation and livestock. With respect to irrigation, the most important quality factor is dissolved salts which have an impact on the accumulation of salts in soils and salinity of underlying ground water aquifers. Therefore the sodium absorption ratio has been introduced as an important and critical factor. The salinity quality of water used for irrigation is another crucial factor which needs to be considered with due care. Similarly, irrigation with raw sewage or with party treated waste water should not be allowed for cops which are to be consumed without cooking . This makes the study of irrigation water quality an important area and merits periodic review and preparation of State of Art in this facet of hydrology.

This Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The Committee is also effectively participating in the activities of UNESCO and is the National Committee for International Hydrology Programme (IHP) of UNESCO. In pursuance of its objectives of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the Committee invites experts in the country to prepare these reports on important areas of hydrology.

The Indian National Committee on Hydrology with the assistance of its erstwhile Panel on Erosion, Water Quality and Sedimentation has identified this important topic for preparation of this state-of-art report and the report has been prepared by Dr. N.V. Pundarikanthan, Dr. S. Ravichandran and Dr. N.K. Ambujam of Centre for Water Resources, Anna University, Chennai. The guidance, assistance and review etc. provided by the Panel are worth mentioning.

It is hoped that this state-of-art report would serve as a useful reference material to practising engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilisation of the water resources of the country.

(S.M.SETH)
Executive Member, INCOH
& Director, NIH
Roorkee

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1. INTRODUCTION

1.1. Water in Agriculture.

Water is a necessary component in society's agricultural, industrial and domestic sectors. In the face of rapidly growing population of our country it is not surprising that major portion of the water is used for agriculture. In approximate terms more than 80% of the water is used in agriculture today with the industry accounting another 10%, leaving the rest for all other sectors including the domestic water supply. Within agricultural water use, the major component is utilised for irrigation of food and horticulture crops, livestock production, irrigation for agro/social forestry and to a smaller extent for agriculture.

Crop and animal production are water dependent. The quality and quantity of water used in agriculture are two interrelated properties controlling the production capability of the land and the quality of the environment and the water resources. Water is considered suitable for agricultural use when it has no osmotic or specific toxic effects on crop production, when it contains no solutes affecting the chemical and hydraulic properties of the soil and when it does not cause the deterioration of surface and ground water.

The management of agricultural production may be designed as a function of the quality of water to be used since the water quality is the main parameter to be considered in an economically efficient and ecologically sustainable agricultural system. A large amount of inter disciplinary and multi disciplinary research on the suitability of irrigation water has been carried out over the years on many of these aspects.

Water quality is generally defined by its relation to specific use. The chemical and the biological composition of any water resource is a result of the interaction it has with its natural environment. Water is an aggressive solvent that interacts with geologic media and the quality of the water resource is primarily controlled by the geochemical process of the water system. The major chemical composition of the water is always in a dynamic equilibrium dependent on the relations occuring at suspended or sediment/water interface that include acid - base relations, redox relations, solution - precipitation relations and adsorption.

1.2. Natural Water Quality.

The rapid pace of development, increase in population and the environmental management are not just going to rise in demand for water but also for quality in future. There are severe concerns for water quality which have arisen now.

The hydrological cycle is the movement of water through a series of temporary storage and flux from one to another; starting and ending in the Ocean. This cycle mainly driven by solar and wind energy brings water through evaporation from the ocean to the land surface which through precipitation forms fresh water sources on land that finally reaches sea through runoff / drainage. The quality of water at every stage of storage and transfer in this hydrological cycle is subjected to various atmospheric and surface phenomena on land such that water displays differences in its natural quality depending on its specific location in the cycle. (see fig. 1).

The major part of the evaporation/evapotranspiration takes place from the oceans/ water bodies, the resultant moisture in the form of cloud, a part of which moves on land for precipitation, probably, water in this part of the cycle appears to be in its purest form of as water vapour devoid of any dissolved ions present. But the moment precipitation occurs, water starts picking up the dissolved load. The atmospheric gases like the carbondioxide, sulphur and nitrogen oxide gases present in the atmosphere dissolve in the water droplets and produce the corresponding dilute mineral acids. Further, the processes like rain out and wash out takes place in the atmosphere before the droplet falls on the surface of the earth, increasing its ionic load. Therefore, the rain water probably the purest form in which it occurs in the hydrological cycle has a measurable ionic load and acidic pH by the time it reaches the surface of the earth.

The rain water, before it makes the runoff in the streams, seeps through the canopy of the vegetation, stems of the trees and plants, picks up the metabolites and excreta and some times exchanges ions on plant surface. Thus the ionic composition of the fresh water increases as well as can gets changed The erosion, surface wash off and litter leaching are the major processes that increase the dissolved load before the runoff process takes place on the floor of the drainage basin.

The sediment load, water temperature, dissolution of atmospheric gases predominate the chemical process that determines the dissolved load of the fresh water in the streams, lakes, ponds and pools. The evaporation of water as well as uptake by the aquatic plants can also affect the concentration of ions and the water quality.

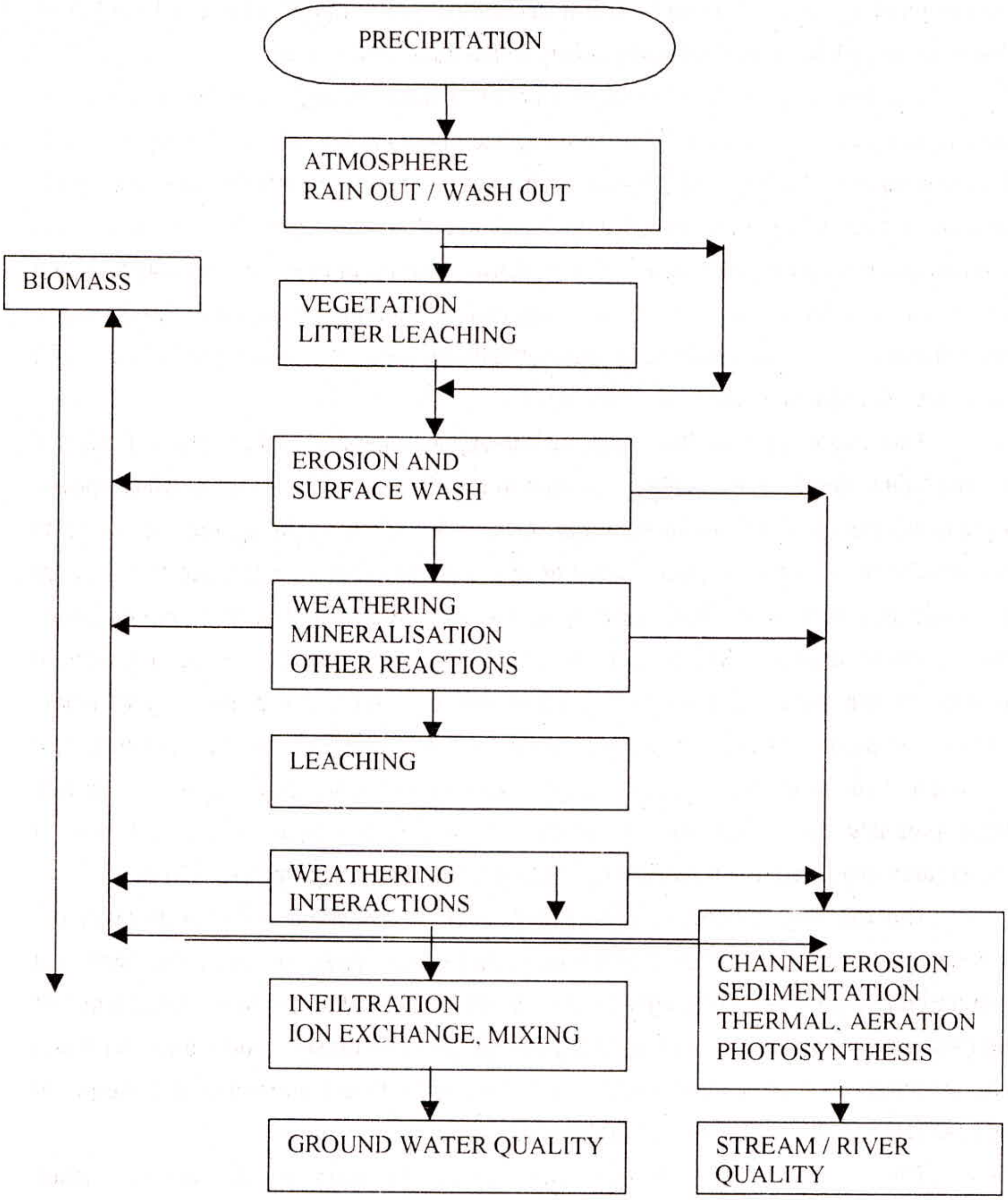


Figure 1. Hydrological Cycle and Water Quality

Irrigaiton Water Quality

The water that infiltrates into the soil has more opportunities to pick up solids especially from the soil minerals. The soil air present in the root zone contain higher tension of carbondioxide which readily dissolves in the infiltrating water and decreases the pH. This alters the solubilities of many minerals and expedite their dissolution. The ion exchange processes also dominate in the vadose zone between the infiltrating water and the soil matrix depending upon the chemical affinities of the ions present. Thus, significant changes in the quality of the water can occur here, in addition to the nutrient uptake by rooted plants.

The water that is infiltrating, when it meets the ground water table processes such as mixing of two water masses and precipitation / dissolution reactions can occur, further adding / removing dissolved load from the water. Generally, the ground water contains more solids than fresh water which is also highly variable in composition.

The surface as well as the ground water ultimately discharge into the ocean and adds dissolved load to the sea water whereas the evaporation from the sea moves only the water molecules through clouds. Thus the sea water has the highest amount of solids than any other type of water resources on the land.

Major ionic composition of water.

The total concentration of dissolved ionic components in water is a general indication of its suitability for any particular use. The total dissolved solids may be determined from the weight of dry residue remaining after a sample of water has evaporated. It may also be calculated by adding the concentrations of the ions present in the water sample.

1.3 Environmental threats to water resources.

The description of critical watershed structure and functions has combined with rapidly raising demands featured by population growth, irrigation expansion and industrial development to compound pressure on our water bodies. The concern today is the shrinking ground water resources, the falling water tables, increased flooding and draughts and water budgets that are badly out of balance. There are tangible indications that the imperatives of efficiency and ecological integrity in water use have been ignored, leading to severe water quality problems.

As population increases and with the cities growing faster competition for water between cities and irrigation is expected to grow and only water of lower quality will be available for irrigation. It is likely, therefore, as water supply gets affected, the focus of water use will be shifted from agriculture section to the economically more profitable industrial sector.

The competition for water quality is going to just raise as the quantity, because, as new water resources dwindle, so will be the water available to dilute the waste water / effluent discharges. In a global sense, it was reported that nearly 50,000 km^2 of river sections were severely affected by non point sources of pollution and another 1,50,000 km^2 are moderately affected. Similarly, the quality impairment in the case of lakes has reached about 6.7 lakh hectares. As a consequence, with a reduction of good quality fresh water resources, only lower quality water is available for irrigation. The fertiliser leaching, agrochemicals, pesticides, nutrients and changes in land use such as urbanisation are the major environmental problems for the poor quality of water. It is not only a surmise, that water quality consideration is going to preclude water use for many purposes in future including irrigation, but also a reality.

In order to protect the water resources themselves, now, more attention is being given to instream values and non consumptive uses. Now demands for instream uses such as fish and wild life habitat, ecological needs of natural communities, recreation and aesthetic values are being heard. Even now water diversions are being done with no regard to stream needs that may invariably have consequences of degradation of water quality and environmental problems in the downstream sector of the river basin.

In addition to loss of water, the climate changes from the increasing build up of 'green house' gases especially the Carbondioxide in the atmosphere may result in a rise in mean air temperature from 1 to 3^0 C. These changes could affect the hydrological cycle and water balance; increased variability in precipitation over large areas, either an increase or decrease of more than 10%. These changes in evaporation and evapotranspiration, may aggravate water quality problems in semi arid regions.

1.4. Water Quality Problems

The assessment of water suitability for irrigation for crop production involves mainly of its salinity, acidity - alkalinity, specific ions and toxic organic effects.

1.4.1. Salinity

The most important water quality parameter for salinity is the Total Dissolved Solids(TDS) or as measured by the Electrical Conductivity(EC) of the irrigation water. The effect of salinity on plant growth is mainly due to TDS. The salinity varitations can induce osmotic effect that is often stressful to most crops, since it decreases the external water potential by making water less readily available. The crop salt tolerance is the ability of the plant to survive and produce economic yields under adverse conditions caused by the salinity of irrigation water. The irrigation water can be classified into five classes in the salinity scale (<1.3 mS/cm to >10.0mS/cm) which also takes into consideration the soil medium.

1.4.2. Acidity - Alkalinity

The acidity - alkalinity of water as measured by pH of the irrigation water has less importance, because water is applied through the soil surface, since, it could be buffered by the soil system. However, it could affect the crops by foliar contact. In acidic soils, however, there could be a real problem in irrigation water with <pH 4.5, since, the solubilities of cations will be enhanced to the extent of becoming toxic to the plants. In contrast, the irrigation water in the alkaline side (>8.3) may increase the carbonate/ bicarbonate status of the soils and may make plant nutrients unavailable and therefore is not suitable for irrigation.

1.4.3 Crop Nutrients

Crop nutrition may be affected by an imbalance of common nutrient chemicals in water and soil solutions and can create unfavourable environment for plant growth. Essential ions such as Calcium, Magnesium and Potassium may differ growth if their total or relative concentration is out of balance. Saline conditions may affect the uptake of nutrients such as Nitrates. Excessive concentrations of Sodium, Chloride and bicarbonates can reduce growth and cause specific injury. Boron in irrigation water can have a negative effect on plant growth. The other components such as trace elements, organic micro pollutants may be present in irrigation water mostly due to social activities are generally toxic to plant growth and therefore, impair the suitability of water for irrigation.

1.4.4 Context and Organisation

This report has been organised into four sections such that the Irrigation Engineer understands the natural water quality of the water resources and then evaluate it for irrigation.

The Chapter 1. Describes the general status of the environment today and the natural processes responsible for the presence of dissolved and suspended solids in water. This chapter also outlines the major areas of problems of irrigation water quality.

The Chapter 2. Describes the background hydrochemical processes responsible for the water quality. The major hydrochemical reactions occuring water / air / atmospheric interface has been explained that manifest in the quality of the water surface.

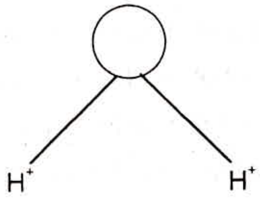
The Chapter 3. Explains the importance of water quality estimation, through a hydrochemical data sheet. This shows the steps required to be done from field investigation, collection of samples and upto analysis so that the necessary water quality data is generated for evaluation. A brief mention of water parameters as well as laboratory measurements are indicated here.

The Chapter 4. Describes the water quality standards for irrigation purposes, the charts and indices to be calculated and the guidelines, especially in the context of soil conditions and crop selection. This chapter also describes the management practices required to handle the situation where water quality is poor for irrigation purposes that include, soil management, cropping pattern, irrigation practices, drainage and crop selection. The potential for the use of waste water as a source of irrigation and the prospects of saline water irrigation are also discussed in this chapter as future options available for us.

2. HYDROCHEMISTRY OF WATER

2.1. Water: the universal solvent.

The water molecule consists of two hydrogen atoms joined by a single covalent bond to an oxygen atom. The electronic arrangement of the water molecule is unique in that the outer shell of the oxygen atom has four electron pairs and considering the size difference between the oxygen and hydrogen atoms the distribution of electrons in the O - H bonds is uneven leading to the water molecule having partial charges.



Please see the figure above, which imparts a high electric dipole moment to the individual water molecule. This makes water a highly polar substance.

The unlike electric charges of water molecules attract each other leading to the formation of temporary hydrogen bonds. On a larger scale, the spatial distribution of the partial charges impose geometrical constraints on how the linkages can occur such that a degree of order prevails that depends on the water temperature. This ordering is very obvious from 4^0 to 0^0 C cooling of water to become ice and expansion on freezing. This makes water heavy at 4^0 C and ice becomes lighter than water, and also responsible for the high melting as well as boiling points, due to the latent heat of energy. The latent heat of energy of water molecule also affects larger phenomena such as overturn of water bodies, sea-land breeze etc.

Water dissolves a large number of compounds through two processes: chemical reaction and hydration. The former process is permanent, non reversible with the resultant product of the reaction being soluble in water. The latter process, unique to water is its ability to leave any ionic solute into their positive and negative ions. The positively charged ion is covered by the negative ends of water molecule., while the negatively charged ion is covered by the positively charged ends of the water molecule. Thus, the solute disappears into water and the degree of dissolution of compounds depends on the electrostatic field strength and ionic radius. Since water has a dipole moment of 80, high compared to any other liquid on earth and its ability of hydration of ions has earned it the name 'universal solvent'. This is how water could dissolve a large number of minerals and compounds, transport materials, support and sustain life on earth.

2.2. Hydrochemistry and water quality

The chemical reactions in water are generally governed by the 'Le Chatliers principle' which states that a chemical system in equillibrium when subjected to a stress that disturbs the equillibrium, will adjust its position of equillibrium in the direction that tends to relieve the stress. As we have seen earlier that water never exists in pure form, except in polar ice caps, the concentration of ions present in the water at any point of its stay on earth is in a dynamic equillibrium with its immediate environment. This can be explained by a very familiar example of dissolution of carbondioxide in water, an important component of carbonate chemistry of water.

$$CO_2 \text{ (gas)} + H_2O \text{ (liquid)} \rightleftarrows H_2CO_3 + \text{Heat} \uparrow$$

If the carbondioxide concentration is increased by raising its partial pressure, the reaction proceeds to the right to establish a new equillibrium, dissolving more carbondioxide. If the temperature of the solution is raised, the equillibrium moves to the left by absorbing heat.

Therefore the nature and quality of dissolved ions present in the water during the hydrological cycle depends on the chemical nature and physical conditions of the water resources.

2.2.1. Acid - base reactions

Acid - base reactions are normally defined in terms of proton transfer where acids are proton donors and bases are proton acceptors. Water itself behaves both as a weak acid and weak base because of the interaction between water molecules.

$$H_2O + H_2O \rightleftarrows H_3O^+ + OH^-$$

This equillibrium shows that pure water must contain equal numbers of hydronium and hydroxyl ions (10^{-7} mol l^{-1}). Water when it occurs in pure form is neither acid nor alkaline and is therefore neutral. In the same way, a solution is described neutral if it contains equal numbers of hydronium and hydroxyl ions. The solution becomes acidic if the hydronium ions are in excess and alkaline if the hydroxyl ions are in excess, the pH scale measures the concentration of the hydronium ions in a scale of 0-14 with 7 being neutral.

The acid - base reactions are very common in the water, mostly associated with the dissolution of carbondioxide, carbonic acid and to a lesser extent the boric, orthophosphoric and humic acids. The pH of the water and the carbonic acid chemistry largely dominate the rate and the quantity of the dissolution of most minerals and thereby affect their concentrations and the quality of water.

2.2.2. Redox reactions

The electron loss results in oxidation and the electron gain results in the reduction and in many surface and ground water systems transfer of electrons take place between water and dissolved, gaseous and solid constituents of the immediate environment. Since the electrons do not exist in nature, the oxidation - reduction reactions always takes place together. In surface water systems, generally the oxides of iron and manganese are extensively involved in these reactions. The most important agents for oxidation in ground water systems are dissolved oxygen, oxy-ions such as nitrate and sulphate. The reducing substances are organic compounds such as carbohydrates, iron silicates and sulphates. These reactions in water are mostly catalysed by bacteria and they get their metabolic energy by promoting redox reactions.

2.2.3. Solution - precipitation reactions

Since water has powerful solvent properties, the solution - precipitation reactions are important in controlling composition of water. The dissolution of any mineral in water takes place when water is in contact with excess of the mineral: the concentration increases to a maximum for a given physical condition when the solution is said to be in saturated condition. The solubility of the mineral is given by the concentration at saturation that depends on NTP and some times on other chemical factors. For example the following equation describes the dissolution of calcite, a common mineral in sedimentary aquifers;

$$CaCo_3\,(S) \rightleftarrows Ca^{++} + Co_3^{--}$$

Here, the solubility can be controlled by altering the concentration of carbonate ion, which in turn is controlled by the H^+ ion concentration and the partial pressure of carbondioxide in the system. Therefore, the equillibrium is conditional and the solubility is also conditional. The surface and ground waters move through different types of geological environments with differences in contact time and NTP, the solubilities of the minerals differ to a larger extent affecting the concentration of the major ions.

Under natural conditions sometimes, some solutes can occur in concentration greater than its solubility, then it is termed as super saturation. Certain minerals such as calcites, dolomites and silicates are found to precipitate occur in super saturation and are reluctant to precipitate. When the physical conditions change, such as ground water movement in aquifer, the excess concentration may be precipitated in to the aquifer. The presence of other related chemical species can also affect the precipitation of a super saturated mineral. For example, the sea water is super saturated with respect to calcite and dolomite, however, the presence of magnesium ions prevents it.

Therefore, the solution - precipitation reactions are more complex under natural conditions and could affect the concentration of many dissolved species in water.

2.2.4 Adsorption reaction

Some dissolved constituents in water are concentrated at the interface between the solid and solution and they are said to be adsorbed. This is a surface phenomena and is relevant for water chemistry because several minerals present in the aquifers as well as the sediment load carried by the surface runoff are fine grained in nature and thus have large surface area. It may be staggering to note that clay minerals can have as much as10^3 m^2g^{-1} whereas clean sand has a specific area as low as 10^3 m^2g^{-1} . Therefore surface effects of adsorption of ions on the charged clay minerals are significant. The surface charges on these clay minerals are pH dependent, being positive in acid solutions and negative in alkaline conditions. Therefore, the ion exchange is dependent on the pH of the water masses. In many cases, the adsorbed ions are relatively mobile, because counter ions are readily exchangeable, subjected to the constraint of charge balance being maintained. Under suitable conditions ion exchange phenomena can have pronounced effect on water chemistry by altering their composition.

3. WATER QUALITY ESTIMATION

3.1. Hydrochemical Data sheet

The hydrochemical parameters required to be studied for the evaluation of water quality has to be done at the field site as well as laboratory. Besides, certain parameters or indices also needs to be computed based on the primary field and laboratory data. A hydrochemical data sheet will be useful to record the details of sampling and analysis results which will be used for evaluation. The parameter list is chosen for a general evaluation for irrigation and if there are specific water quality problems expressed then it must be recorded for further specific observation and analysis. A sample data sheet is shown below and its various sections are explained below.

The measurement of certain chemical parameters are carried out at the sampling site for the purposes of convenience and rapid assessment and to provide control for the laboratory measurements. Further, these parameters are likely to change between the time of sampling and their measurement at laboratory. The changes that most frequently occur can affect the pH and carbonate chemistry leading to mineral precipitation, which can also include co-precipitation of trace constituents, especially metals. Therefore, field measurements for some parameters also highly advisable and samples may be pretreated before they are sent to laboratory for analysis. Today, with the advancement of technology, integrated field kits with improved accuracy and precision for measurements are available now. The field parameters that are generally measured at site are the pH, Turbidity, Dissolved Oxygen, Electrical Conductivity and water temperature.

3.2. Temperature

Temperature measurements in degree celsius at the sampling sites can be measured with a sensitive mercury thermometer or the thermistor- temperature probe in the field kits water temperatures are generally required in the case of calculations of mineral saturation indices or thermodynamic calculations, unless the water resources are affected by the thermal discharges from industrial units. When taking measurements, the thermometer reading should be given time to stablise.

Hydrochemical Data Sheet

SAMPLE ID

LOCATION GRID / SPECIFIC

SAMPLED BY DATE / TIME OF LOCATION

SAMPLE INFORMATION

SAMPLE NO : FILTERED : ACIDIFIED :

UNFILTERED :

SAMPLING DETAILS :______________________________

TYPE OF SAMPLE :________________SITE DESCRIPTION:____________

FIELD SITE CHEMISTRY

pH : ________ Temperature : __________ °C

EC : _________ (mS cm^{-1})

Turbidity : _________ ppm Dissolved Oxygen : _________ ppm

GENERAL LABORATORY PARAMETERS

Laboratory pH : _________ Laboratory EC :__________mS cm^{-1})

Total Suspended Solids : _________ Total Dissolved Solids :_________

Total Hardness : _________ Total Alkalinity : _________

MAJOR IONS

	mg/l	Meq/l		mg/l	meq/l
Sodium			Carbonate		
Potassium			Bicarbonate		
Calcium			Chloride		
Magnesium			Sulphate		

Irrigaiton Water Quality

NUTRIENTS

Nitrate	
Phosphate	
Silicate	

TRACE CONSTITUENTS / MINOR IONS

Boron	
Copper	
Zinc	
Molybdenum	
Aluminium	

CALCULATED PARAMETERS

Hardness	
SAR	
ESR	
RSC	
Adj SAR	
USSL Class	
Magnesium hazard	
Chloride hazard	
Permeability	

OTHER CONSTITUENTS (Specify) :

LABORATORY DETAILS

Laboratory Code : ____________ Analysed by : ________________________

Date of Completion : ____________ Signature : ________________________

3.3. pH

The pH of a solution is the negative logarithm of the hydrogen ion activity in moles per litre. When water is removed from the water body, the physical controls governing the hydrogen ion activity will get changed, and so the water sample pH can change. Therefore, pH is measured at the field site as well as Laboratory. pH can be determined by using a glass electrode that selectively permits moment of Hydrogen ions and develop a potential measuring device. Nowadays, highly durable glass electrodes are available for a variety of applications including water testing. Good quality pH meters are now battery operated, read from 0 - 14 pH units with digital displays, reach quick equilibrium and stable readings with two decimal accuracy. The pH meter can easily be calibrated even at field sites with colour coded buffer solutions available of the sheet.

3.4. Electrical Conductivity

The ions in water occur mainly in a dissociated form, the charged ions are able to move under the influence of an electrical potential. The ability of the solution to conduct current is a function of the concentration and charge of the ions and the rate at which the ions move can be under the influence of the potential. The Electrical Conductivity of water is therefore directly proportional to the amount of total dissolved ions present in the water, which in other words can describe the salinity of water sample. Electrical Conductivity has the units of reciprocal ohms per metre or Siemens per metre. However, conductivities are rather low in natural water bodies, usually micro Siemens per centimeter. The ionic conductivity is affected by the temperature of the water EC will increase with increase in temperature, therefore,EC values are generally reported as that of a water sample at 25° C.

There are study and reliable field instruments available to measure electrical conductivity with throw in type cells, digital displays and battery operation. These instruments can immediately suggest the general quality of the water being sampled as in the case of the pH of the water.

3.5. Dissolved Oxygen

The Dissolved Oxygen in surface and ground waters have many sinks and sources of which the atmospheric reaeration is important. The dissolved oxygen concentration can therefore change rapidly and are measured in a cell sealed from the atmosphere or by throw in type electrodes. The electrodes used for the measurement of oxygen is a central anode surrounded by a perforated silver cathode covered by a membrane permeable to oxygen. The oxygen in the water differs through the membrane, gets reduced at the cathode to give a current proportional to the partial pressure of oxygen. Since oxygen is consumed as it is measured, it is advisable to use through in type electrodes into the water or in streams where the velocity is more than 10 cm S^{-1} .

3.6. Total Solids

The total suspended solids and dissolved solids are estimated through classical physical methods in laboratory. A known quantity of the water sample is made to pass through a standard filter paper that is preweighed, either by gravity flow or by applying vaccum. The filter paper with the filtrate is then dried in a dessicator and weighed to the nearest milligram in an electronic balance. Sometimes, the turbidity of the water can be measured conveniently at field sites because, field turbidity meters employing Infrared light back scattering cells are now available. These can provide instant reliable field estimation for suspended solids.

The total dissolved solids are estimated by evaporating a known quantity of filtered water sample in a china dish and weighing the residue to the nearest milligram. Now there are electrical conductivity meters that directly display the TDS based on the measurements of conductivity, temperature and a suitable coefficient.

3.7. Laboratory measurements

The laboratory analysis provide the necessary chemical data required for the chemical characterisation of the water quality. These include the major anions and cations, the nutrients and minor ions or trace constituents. Simple sample collection procedures for water samples and their transportation under cold conditions are generally sufficient for these laboratory analyses. Only when detailed hydrochemistry analyses are required or in situations where the water resource has been subjected pollution or water quality degradation by social activities, special sampling procedures and precautions are to be resorted to.

There are standard hydrochemical methods available and practised in Analytical laboratories.The amount of time and expense devoted shall be proportional to the level of interpretation or inference desired. Generally, the desire for water quality estimation is driven by the requirements:

1. Sample	:Collection, storage and pretreatment conditions; available volume, distinction between dissolved and particulate matter.
2. Analytical method	:Specificity, sensitivity, accuracy, time and cost of analysis.

The hydrochemical data sheet shown above includes all parameters that are required for the interpretation of the suitability of the irrigation water for crops. Good laboratory practices (GLP) include today a good analyst use of suitable internal working standards, inter laboratory calibrations exercise, different analytical methods, triplicate analysis for the same sample etc.,

The sampling and analytical procedures for the minor ions / trace constituents may be special such as field preservation, preconcentration, sample pretreatment, organic extraction etc.,

A wide based literature is available concerning the application of the various modern instrumental methods to the analysis of trace metals in water. However, the nutrients can be very satisfactorily estimated by the presently available standard methods.

The primary water quality data generated by the laboratory can be improved for evaluation of irrigation suitability by calculating some parameters. These parameters are derived on the basis of laboratory / field data. These parameters are listed under the section 'calculated parameters' in the hydrochemical data sheet. The completion of the hydrochemical data sheet with the analysis of any other constituent / observations will be complete and produce information on water quality of the resource under investigation.

A check on the water quality data, to ensure its validity will be desirable, since the Irrigation Engineer may be getting his samples analysed by one or more than one laboratory. One such procedure available as a post analysis check is computing the ion balance error of the water sample analysis.

Water samples are electrically neutral and therefore the total charges on the cations and anions reported in the analysis should be equal. The total positive and negative charges are obtained by summing up the equivalents of cations and anions respectively. The ion balance error is generally expressed by the difference as a percentage of the sum;

$$\text{Ion balance error} = \frac{\Sigma\ \text{cations} - \Sigma\ \text{anions}}{\Sigma\ \text{cations} + \Sigma\ \text{anions}} * 100$$

The ion balance error of a good analysis should be less than 5% and definitely less than 10%. It may be taken that an error above this range shall indicate analytical error or an unanalysed ion.

4. WATER QUALITY FOR IRRIGATION

4.1. Irrigation Water Quality Standards

Applicability of water for irrigation use depends upon the physical chemical & microbiological quality of water. The water quality criteria for irrigation takes into consideration effects of constituents or parameters of crops and other vegetation, soil, ground water etc. As the use of treated wastewater and industrial effluents are more common, special attention has to be paid to the constituents of these waters. Reuse of treated wastewater addresses public health protection as an important criteria along with quality criteria for fresh water industrial effluents may contain certain other constituents and parameters, here again the effect of the constituents in reclaimed water used for crop irrigation may warrant special attention.

Existing standards and guidelines.

Water Quality Criteria

Crop irrigation is the major use of fresh water world over. Landscape irrigation of parks, golf course, green belt areas etc are also irrigated. Table 4.1.1. shows the information required on effluent supply and quality.

Chemical constituents

The effects of many chemical constituents present in the water are well known and recommended limits have been established for inorganic constituents and other parameters.

The guideline for interpreting water quality can be used to identify potential problems in the use of the particular quality of water for crop irrigation. Potential irrigation problems are classified based on salinity, permeability, specific ion toxicity and miscellaneous effects, Guidelines which can be used to interpret irrigation water quality based on these classifications are presented in Table 4.1.2. The sodium adsorption ratio (SAR) numbers in the table should be adjusted for reclaimed water to include a more accurate estimate of calcium in the soil water following an irrigation(Westcot and Ayers 1984). Recommended limits for some trace elements in irrigation water is given in Table 4.1.3. In most cases, these elements accumulate in plants and soils and long-term build up in soils could result in human and animal health hazards or cause phytotoxicity.

Table 4.1.1. INFORMATION REQUIRED ON EFFLUENT SUPPLY AND QUALITY

Imation	Decision on irrigation management
Effluent supply	
The total amount of effluent that would be Made available during the crop growing Season.	Total area that could be irrigated
Effluent available throughout the year.	Storage facility during non crop growing period either at the farm or near waste water treatment plant, and possible use for aquaculture.
The rate of delivery of effluent either as m^3 per day or litres per second.	Area that could be irrigated at any given time, lay out of fields and facilities and system of irrigation.
Type of delivery: continuous or intermittent,or on demand.	Lay out of fields and facilities,irrigation system,and irrigation scheduling.
Mode of supply: supply at farm gate or effluent available in a storage reservoir to be pumped by the farmer.	The need to install pumps and pipes to transport effluent and irrigation system.
Effluent quality	
Total salt concentration and/or electrical conductivity of the effluent	Selection of crops, irrigation method, leaching and other management practicies.
Concentration of cations, such as Ca^{++} Mg^{++} and Na^{+}.	To assess sodium hazard and undertake appropriate measures.
Concentration of toxic ions, such as heavy metals, Boron andCl-.	To assess toxicities that are likely to be caused by these elements and take appropriate measures.
Concentration of trace elements (particularly those which are suspected of being phyto-toxic).	To assess trace toxicities and take appropriate measures.
Concentration of nutrients, particularly nitrate-N.	To adjust fertilizer levels, avoid over-fertilization and select crop.
Level of suspended sediments.	To select appropriate irrigation system and measures to prevent clogging problems.
Levels of intestinal nematodes and faecal coliforms.	To select appropriate crops and irrigation systems.

Table 4.1.2. GUIDELINES FOR INTERPRETATION OF WATE QUALITY FOR IRRIGATION

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity				
EC_w	dS/m	< 0.7	0.7 –3.0	> 3.0
Or				
TDS	mg/l	< 450	450 – 2000	>2000
Infiltration				
SAR[2]=0-3 and EC_w		> 0.7	0.7 – 0.2	< 0.2
3-6		> 1.2	1.2 – 0.3	< 0.3
6-12		> 1.9	1.9 – 0.5	< 0.5
12-20		> 2.9	2.9 – 1.3	< 1.3
20-40		> 5.0	5.0 – 2.9	< 2.9
Specific ion toxicity				
Sodium(Na)				
Surface irrigation	SAR	< 3	3 – 9	> 9
Sprinkler irrigation	me/l	< 3	> 3	
Chloride(Cl)				
Surface irrigation	me/l	< 4	4 – 10	> 10
Sprinkler irrigation	m_3/l	< 3	> 3	
Boron	mg/l	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous effects				
Nitrogen(NO_3-N)[3]	mg/l	< 5	5 – 30	> 30
Bicarbonate(HCO_3)	mg/l	< 1.5	1.5 – 8.5	> 8.5
PH			Normal range 6.5 - 8.4	

1. EC_w means electrical conductivity in deciSiemens per meter at 25 degree Celsius
2. SAR means sodium adsorption ratio
3. NO_3-N mean nitrate nitrogen reported in terms of elemental nitrogen

Salinity

This is of particular concern in the use of brackish water, treated domestic wastewater, industrial effluents and reclaimed water from irrigation return flow, since wastewater generally has higher salt content than freshwater. Where TDS are high , the problem is aggravated by poor leaching of the soil and high evapotranspiration rates. Food crops are generally more sensible to TDS than pasture or grasses.

Total Salt Concentration

Total salt concentration is one of the most important water quality parameter. This is because the salinity of soil is related to and often determined by, the salinity of the irrigation water. Accordingly, plant growth, crop yield and quality of products are affected by the total dissolved salts in irrigation water.

Electrical Conductivity

EC is widely used to indicate total ionized constituents of water. It is directly related to the sum of the cations or anions as determined chemically and is closely correlated in general, with the total salt concentration.

Table 4.1.3. THRESHOLD LEVELS OF TRACE ELEMENTS FOR CROP PRODUCTION

	Element	Recom. Maximum Concent-ration (mg/l)	Remarks
Al	(aluminium)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity
As	(arsenic)	0.10	Toxicity to plants varies widely, ranging from 12mg/l for Sudan grass to less than 0.05mg/l for rice.
Be	(beryllium)	0.10	Toxicity to plants varies widely, ranging from 5mg/l for kale to 0.5mg/l for bush beans.
Cd	(cadmium)	0.01	Toxic to beans , beets and turnips at concentrations as low as 0.1mg/l in nutrient solutions . Conservative limits recommended due to in potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co	(cobalt)	0.05	Toxic to tomato plants at 0.1mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr	(chromium)	0.10	Not generally recognised as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu	(copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.

F	(fluoride)	1.0	Inactivated by neutral and alkaline soils.
Fe	(iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of avilability of essential phosphorus and molybdenum Overhead sprinkling may result in unsightly deposits on plants, equipment andbuildings.
Li	(lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (< 0.075 mg/l). Acts similarly to boron.
Mn	(manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo	(molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to plants at livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	(nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd	(lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se	(selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. As essential element to animals but in very low concentrations.
Sn Ti W	(tin) (titanium) (tungsten)	-	Effectively excluded by plants; specific tolerance unknown.
C	(vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn	(zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

Irrigaiton Water Quality

Microbial constituents

The effluent quality guidelines given in Table 4.1.3. are intended for the use of treated waste water for irrigation purposed. The table is adopted from WHO scientific group recommendations for use of treated wastewater for Agriculture and Aquaculture.

Table 4.1.4 RECOMMENDED MICROBIAL QUALITY GUIDELINES FOR WASTEWATER USE IN AGRICULTURE

Cate-gory	Reuse condition	Exposed group	Intestinal nematodes (arithmetic mean no. of eggs per litre)	Faecal coliforms (geometrical mean no. per 100 ml)	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, consumers, public	≤1	≤1000	A series of stabilisation ponds designed to achieve the microbiological quality indicated , or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology but not less than primary sedimentation.

4.2 Irrigation with marginal quality and Saline water.

Marginal quality water will be from surface run off, shallow horizontal sub surface flow, water found in perched water table or the ground water reservoir, or irrigation return flow. The term marginal quality water will include Brackish water, Saline water, Sewage, Sullage and industrial and trade effluents.

Even if excellent quality of water from any of the above sources when used for water supply or irrigation, the resulting return flow is of marginal quality. That portion of the water supply which has been diverted for irrigation but lost by evapotranspiration is essentially salt free. Therefore, the return flow contains most of the salt originally in the water supply, hence the concentration of salt in the return flow increases.

In some cases, water moves through the soil profile, it picks up additional salts by dissolution. In addition some salts may be precipitated in the soil and there will be an exchange between some salt ions in the water and in the soil. The salts picked up by the water in addition to the salts that were in the water applied to land is termed salt "pick up". The total salt load is the sum of the original mass of salt in the applied water as the result of the concentration effect plus the pick up.

The following changes in the quality might be expected in water. 1. Dissolved solids concentration increases, 2. Additional variable and fluctuating amount of pesticides 3. Addition of variable amount of fertilizers 4. Increase in other sediments and other colloidal material 5. Crop residue and other debris 6. Increase in bacterial content.

Potential solutions

Three possibilities have been identified for reuse of marginal quality waters,

1 Mixing of good quality water which leads to dilution of marginal quality water

2. Cyclic or rotational use of good quality water with marginal quality water

3 Direct use of marginal quality water in soils and crops in such a way that no detrimental effect is felt

A guideline for the use of marginal quality water for irrigation for different crops has been given in table 4.2.1.

Table 4.2.1. Guidelines for using Saline waters (RSC <2.5 meq/l) for different crops.

Soil Texture (% Clay)	Crop tolerance	Upper limit of Eciw (dS/m) in annual rainfall zones		
		<350	350-550	550-750 mm
Fine (>30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Mid.fine (20-30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Mid.coarse (10-20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (<10)	S	-	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

S – Sensitive, ST – Semi-tolerant, T – Tolerant.

The guideline is based on the annual rainfall of the area, taking into consideration the soil texture with percentage of clay. The E.C of water in (dS/m) will indicate the crops that could be irrigated with the water.

The crops which are tolerant to brackish water are given in Table.4.2.2.

Table 4.2.2. Crop Tolerance to Salinity of Irrigation Water (ECiw) and to Drainage Salinity (ECdw)

	ECiw[a]	ECdw[b] (mmho/cm)
Tolerant Crops: Bermuda grass wheat grass, barley, sugar beets, cotton	6.5 – 8.5	40 – 45
Moderately tolerant crops: alfalfa, soybeans, rice, tomato	2 – 3.5	32 – 35
Sensitive crops: clovers, beans, onions, carrots	1 – 1.3	14 – 16

[a] Limits for full yields when ECe in upper root zone does not exceed ECiw.

[b] Yield of 85 to 100% of maximum are obtained when these ECdw values are used to calculate LR

Precaution in use of marginal quality water

When using marginal quality water for irrigation the following points should be considered:

Selection of crops

Most agricultural crops differ in their tolerance to salt concentration in the root zone. Crops which are semi-tolerant to tolerant, as well as those with low water requirement should be grown under marginal quality water.

Pre-sowing irrigation

Critical stages of crop growth should be irrigated with good quality water. Period of germination and seedling emergence are critical stages. A failure at these stages will lead to poor crop stand and resultant yield decrease. Hence pre-sowing and germination stage should be irrigated with fresh water.

Adequate subsurface drainage

Marginal quality water will add salt in the root zone. In the absence of leaching, these salts may accumulate in the root zone and consequently affect the plant growth. Under subsurface drainage system the critical limits of saline irrigation water for different degrees of yield reduction in crops will be higher. Hence provision for subsurface drainage is necessary.

4.3 Waste water irrigation (with special reference to sewage)

The agronomic and economic benefit of wastewater use in irrigation.

In the developing countries with rapid urbanization, cities are teeming with increased population. The provision of protected water supply in the urban areas generate a large volume of wastewater. These wastewaters when treated could be used for irrigation successfully. To illustrate the above a typical Indian metropolis like Chennai city has a population of 3.4 million people. The average water supply is 70 l/d per person, this produces approximately 238,000 m^3/d(86.87Mm^3/year) of wastewater. If treated effluent is carefully used for irrigation with an application rate of 5000 m3/ha per year, an area of some 17,400 ha could be irrigated with typical concentration of nutrients in treated wastewater effluent from concentrated sewage treatment is as follows.

Nitrogen (N) - 50mg/l
Phosphorus(P) - 10mg/l
Potassium(K) - 30mg/l

Assuming an application rate of 5000m^3/ha.yr the fertilizer contribution of effluent would 250kg/ha.yr of Nitrogen , 50kg/ha.yr of Potassium. Thus, all the Nitrogen and much o f Phosphorus and Potassium normally required for agricultural crop production would be supplied by the effluent. In addition, other valuable micronutrients and organic matter contained in the effluent will provide additional benefits.

Characteristics of wastewater

Municipal wastewater is mainly comprised of water (99.9%) together with small to relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Table 4.3.1 shows the major constituents of strong, medium and weak domestic wastewaters.

Table 4.3.1. MAJOR CONSTITUENTS OF TYPICAL DOMESTIC WASTE WATER

Constituent	Concentration, mg/l		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chloride[1]	100	50	30
Alkalinity	200	100	50
Grease	150	100	50
BOD_5[2]	300	200	100

1 The amounts of TDS and chloride should be increased by the concentrations of these constituents in the carriage water.

2 BOD^5 is the biochemical oxygen demand at 20^0C over 5 days and is a measure of the biodegradable organic matter in the wastewater.

Table 4.3.2. POSSIBLE LEVELS OF PATHOGENS IN WASTEWATER

Type of pathogen		Possible concentration per litre in municipal wastewater
Viruses:	Enteroviruses2	5000
Bacteria:	Pathogenic E. coli3	
	Salmonella spp.	
	Shigella spp.	
	Vibbrio cholerae	
	Entamoeba histolytica	
	Ascaris Lumbricoides	
	Hookworms	

4.4 WASTE WATER IRRIGATION MANAGEMENT PRACTICES

The components of an on-farm strategy in using treated wastewater will consist of a combination of :

- Crop selection

- Selection of irrigation method, and
- Adoption of appropriate management practices

To Overcome Toxicity Hazards

A toxicity problem is different from a salinity problem in that it occurs within the plant itself and is not caused by water shortage.Toxicity normally results when certain ions are taken up by plants with the soil water and accumulate in the leaves during water transpiration to such an extent that the plant is damaged.The degree of damage depends upon time , concentration of toxic material , crop sensitivity and crop water use and , if damage is severe enough , crop yield is reduced.Common toxic ions in irrigation water are chloride,sodium,and boron,all of which will be contained in sewage.Damage can be caused by each individually or in combination.Not all crops are equally sensitive to these toxic ions.Some guidance on the sensitivity of crops to sodium,chloride and boron are given in tables. 4.4.1, 4.4.2 and 4.4.3 respectively. However,toxicity symptoms can appear in almost any crop if concentration of toxic materials are sufficiently high.Toxicity often accompanies are complicates a salinity or infiltration problem, although it may appear even when salinity is not a problem.

To prevent Health Hazards

From the point of view of human consumption and potential health hazards, crops and cultivated plants may be classified into the following groups:

(i) Food Crops
- those eaten uncooked
- those eaten after cooking

(ii) Forage and feed Crops
- direct access by animals
- those fed to animals after harvesting

(iii) Landscaping plants
- unprotected areas with public access
- semi-protected areas

(iv) Afforestation plants
- commercial (fruit, timber, fuel and charcoal)
- environmental protection
- (including sand stabilization).

Categorization of crops according to the exposed group and the degree to which health protection measures are required as shown below.

Category A
- Protection required for consumers, agricultural workers, and the general public.
- Includes crops likely to be eaten uncooked, spray
- irrigated fruits and grass (sports fields, public parks and lawns.

Category B
- Protection required for agricultural workers only.
- Includes cereal crops, industrial crops (such as cotton and sisal),food crops for canning, fodder crops pasture and trees,
- In certain circumstances some Vegetable crops might
- Be considered as belonging to Category B if they are not eaten raw (potatoes, for instance) or if they grow well above ground (for example, chillies), in such cases it is necessary to ensure that the crop is not contaminated of Sprinkler Irrigation or by falling on to the ground, and that contamination of kitchens by such crops, before cooking, does not give rise to a health risk.

Table 4.4.1. : RELATIVE BORON TOLERANCE OF AGRICULTURAL CROPS[1]

VERY SENSITIVE (<0.5 mg/l)

Lemon	Ctrus limon
Blackberry	Rubus spp.

SENSITIVE (0.5-0.75 mg/l)

Avocado	Persea americana
Grapefruit	Citrus X paradist
Orange	Citrus sinensis
Apricot	Prumus armeniaca
Peach	Prunus persica
Cherry	Prunus avium
Plum	Prunus domestica
Persimmon	Diospyros kaki
Fig , Kadota	Ficus carica
Grape	Vitis vinifera
Walnut	Juglans regia
Pecan	Carya illinoiensis
Cowpea	Vigna unguiculata
Onion	Allium cepa

SENSITIVE (0.75-1.0 mg/l)

Garlic	Allium sativum
Sweet potato	Ipomoea bataatus
Wheat	Triticum eastivu
Barley	Hordeum vulgare
Sunflower	Helianthus annuus
Bean, mung	Vigna radiata
Seasame	Sesamum indicum
Lupine	Lupinus hartwegii
Strawberry	Faragaria spp.
Artichoke, jerusalem	Helianthus tuberosus
Bean, Kidney	Phaseolus vulgaris
Bean, lima	Phaseolus lunatus
Groundnut/Peanut	Arachis hypogaea

MODERATELY SENSITIVE (1.0-2.0 mg/l)

Pepper, red	Capsicum annuum
Pea	Pisum sativa
Carrot	Daucus carota
Radish	Raphanus sativus
Potato	Solanum tuberosum
Cucumber	Cucumis sativus

MODERATELY TOLEREN(2.0-4.0 mg/l)

Lettuce	Lactuca sativa
Cabbage	B. oleracea capitata
Celery	Apium graveolens
Turnip	Brassica rapa
Bluegrass , Kentucky	Poa pratensis
Oats	Avena sativa
Maize	Zea mays
Artichoke	Cynara scolymus
Tobacco	Nicotiana tabacum
Mustard	Brassica juncea
Clover, sweet	Melilotus indica
Squash	Cucurbita pepo
Muskmelon	Cucumis melo

TOLERANT (4.0-6.0 mg/l)

Sorghum	Sorghum bicolor
Tomato	L.lycopersicum
Alfalfa	Medicogo sativa
Vetch, purple	Vicia benghalensis
Parsluy	Petroselinum crispum
Beet, red	Beta vulgaris
Sugarbeet	Beta vulgaris

VERY TOLERANT (6.0-15.0 mg/l)

Cotton	Gossypium hirsutum
Asparagus	Asparagus officinalis

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[1] Maximum concentration tolerated in soil water with it yield or vegetative growth reductions. Boron tolerances vary depending upon climate , soil condition and crop variety. Maximum Concentrations in the irrigation water are approximately equal to these values or slightly less.

Table 4.4.2 : RELATIVE TOLERANCE OF SELECTED CROPS TO EXCHANGEABLE SODIUM

Sensitive	Semi-tolerant	Tolerant
Avocado (Persa americanna)	Carrot (Daucus carota)	Alfalfa (Medicago sativa)
Deciduous Fruits	Clover, Ladino (Trifolium repens)	Barley (Hordeum vulgare)
Nuts	Dallisgrass (Paspalum dilatatum)	Beet, garden (Beta vulgaris)
Bean, green (Phaselous vulgaris)	Fescue, tall (Festuca arundinacea)	Beet, sugar (Beta vulgaris)
Cotton (at germination) (Gossypium hirsutum)	Lettuce (Lactuca sativa)	Bermuda grass (Cynodon dactylon)
Maize (Zea mays)	Bajara (Pennisetum typhoides	Cotton (Gossypium hirsutum)
Peas (Pisum sativum)	Sugarcane (Saccharum officinarum)	Paragrass (Brachiaria mutica)
Grape fruit (Citrus paradist)	Berseem (Trifolium alexandrinum)	Rhodes grass (Chloris gayana)
Orange (Citrus Sinensis)	Benji (Mililotus parviflora)	Wheat grass, Crested (Agropyron cristarum)
Peach (Prunus persica)	Raya (Brassica juncea)	Wheat grass, fairway (Agropyron cristatum)
Tangerine (Citrus reticulata)	Oat (Avena sativa)	Wheat grass, tall (Agropyron elongatum)
Mung (Phaseolus aurus)	Onion (Allium cepa)	Karnal grass (Diplachla fusca)
Mash (Phaseolus mungo)	Radish (Raphanus sativus)	
Lentil (Lens culinaris)	Rice (Oryza sativus)	
Groundnut(Peanut) (Arachis hypogaea)	Rye (Secale cereale)	
Gram (Cicer arietinum)	Ryegrass, Italian (Lolium multiflorum)	
Cowpeas (Vigna sinensis)	Sorghum (Sorghum vulgare)	
	Spinach (Spinacia oleracea)	
	Tomato (Lycopersicon esculentum)	
	Vetch (Vicia sativa)	
	Wheat (Triticum vulgare)	

Table 4.4.3: CHLORIDE TOLERANCE OF SOME FRUIT CROP CULTIVARS AND ROOTSTOCKS

Crop	**Rootstock or Cultivar**	**Maximum permissible cl^- without leaf injury**[1]	
		Root zone (Clc) (me/l)	**Irrigation water (Cl_w)[23] (me/l)**
	Rootstocks		
Avocado (Persea americana)	West Indian	7.5	5.0
	Guatemalan	6.0	4.0
	Mexican	5.0	3.3
Citrus (Citrus spp.)	Sunki Mandarin	25.0	16.6
	Grape fruit		
	Cleopatra Mandarin		
	Rangpur lime		
	Sampson tangelo	15.0	10.0
	Rough Lemon		
	Sour Orange		
	Ponkan Mandarin		
	Citrumelo 4475	10.0	6.7
	Trifoliate Orange		
	Cuban shaddock		
	Calamondin		
	Sweet Orange		
	Savage Citrange		
	Rusk Citrange		
	Troyer Citrange		
Grape (Vitis spp.)	Salt Creek, 1613-3	40.0	27.0
	Dog Ridge	30.0	20.0
Stone Fruits (Prunus spp.)	Marianna	25.0	17.0
	Lovell, Shalil	10.0	6.7
	Yunnan	7.5	5.0
	Cultivars		
Berries (Rubus spp.)	Boysenberry	10.0	6.7
	Olallie Clackberry	10.0	6.7
	Indian Summer Raspberry	5.0	3.3

Grape (Vitis spp.)	Thompson Seedless		
	Perlette	20.0	13.3
	Cardinal	20.0	13.3
	Black Rose	10.0	6.7
		10.0	6.7
Stawberry	Lassen		
(Fragaria spp.)	Shasta	7.5	5.0
		5.0	3.3

4.5. Saline Water – Alkaline Water - Management Practices

Irrigation has successfully been carried out with water which does not meet the required quality standards. Investigations have revealed that in some parts of Rajasthan and Gujarat ground water having EC values as high as 6000 to 8000 micro Siemens/cm is being used for crop cultivation. Whereas according to U.S. Salinity Laboratory (1954), irrigation water with EC in the range of 750- 2250 micro Siemens/cm is classified as high salinity water. These high salinity waters are to be used on soils only with adequate drainage.

Successful growing of crops using such saline water could be attributed to the following reasons:

1. A certain variety of Wheat such as ' Karachi' can withstand very high salt concentration in irrigation water.
2. Soils in parts of Haryana and Western Rajasthan are Sandy to Sandy loam in texture, hence salt build up and deterioration of soil structure is less.
3. During monsoons, due to heavy rainfall there is leaching down of salts from the profile.

Some management practices had been tried after conducting trials in microplots at Haryana Agricultural University, Hissar. (Jagan Nath et. al 1983). The results of the study show that, saline water having 8000 micro Siemens/cm. EC can safely be used for irrigation of wheat provided presowing irrigation is given with canal water. Addition of farmyard manure to wheat had beneficial effect. When FYM was applied and leaching was done as a management practice, the salt build up was not appreciable even with saline water irrigation. Crop rotation was found to help increasing yield of crops. The management practices for crop production while using saline water for irrigation could be summarised as follows.

1. Conservation of rainfall by bunding etc to increase infiltration through soil profile which helps leaching of salts.
2. Conjunctive use of surface and ground water
3. Use of salt tolerant crops
4. Crop Rotation
5. Sub surface Drainage
6. Addition of Organic matter through FYM

Some of the strategies employed in management alkali water for crop production is similar to that of saline water. In case of alkali water, it lends itself for chemical amelioration at economic cost.

1. Amelioration through chemical amendment. Gypsum can be added to water to increase its SAR as Calcium is added.
2. Cyclic application - saline water and alkali water are used in avoiding saline water during sensitive crop stages.
3. Blending with fresh water - High sodic water as indicated by high SAR could be diluted with fresh water.
4. Addition of organic matter.
5. Growing tolerant crops.

4.6. Conjunctive Use of Poor and Good Quality Water.

Blending of poor and good quality water is another possibility for reducing the salinity/sodicity hazards of irrigation waters. The proportion of the good and poor quality waters can be varied till the final EC and RSC levels are lower than the permissible limits.

Use of poor and good quality waters alternately has also been found to maintain high crop yields by controlling the build up of salts and ESP in the soil. It is preferable that poor quality waters only supplement the good quality waters. Better quality water should be used in the early crop growth stage and the poorer quality water later when the crop can tolerate higher salinity levels. However, alternate irrigation with good quality and poor quality waters high in EC and SAR may cause infiltration problem because leaching of soluble salts can result in the build up of high ESP. Under such situations application of chemical amendments also have to be made.

Bajwa and Josan (1994) reported that sodic irrigation increased pH and ESP of the surface layers of a sandy loam soil, decreased its infiltrability and reduced wheat and rice yield. But when such sodic water was used in cyclic modes with canal water, yields of both the crops were maintained at par with good quality canal water. Cyclic use waters resulted in lower build up of ESP. These observations suggest that use of sodic and canal waters cyclically or blending them together can be safely recommended. However, the build up of salts and ESP in the soil over time must be periodically monitored.

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