

3. Drinking and irrigation water standards

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3.1 Introductions

Water quality standards are a crucial element in setting the design criteria for a water supply project. The standards apply to both the treatment plant and the distribution system. Water quality requirements should not be confused with water quality standards. Water quality requirements represent a known or assumed need and are based on the prior experience of the water user.

Water quality requirements vary according to the proposed use of the water. Water unsuitable for one use may be quite satisfactory for another and water may be deemed acceptable for a particular use if water of better quality is not available. For example, Livestock require a low level of bacteria to avoid illness, while certain types of irrigation can tolerate substantially higher levels because of the sterilizing effect of exposure to sunlight.

Water quality standards are set by a governmental agency and represent a statutory requirement.

3.1.2 Drinking water quality standards

Drinking water should be safe as much as possible and all the possible efforts should be made to achieve it. Moreover, the domestic purposes such as drinking, food preparation and personal hygiene needs to have safe drinking water. Drinking water standards and guidelines could possibly vary in regional basis or from country to country and it is not expected to have similar basis of standards due to variety of reasons. But, it is necessary to take in to consideration the existing or planned legislation relating to water, health and the capacity of regulatory body in the process of development and implementation of standards. The ideal drinking water quality standards should be based on health and risk assessment information (i.e., how much of the contaminant may be present with no adverse health effects). However, costs and availability of

technology are usually considered for legally enforced standards (cost benefit analysis and available technology). Therefore there are no universally accepted standards in the world.

Water quality refers to the water's suitability for a number of uses or processes in a sustainable way. For improved public health, it is important to have a good quality of drinking water. Different types of pollutants which deteriorate the quality of drinking water threaten human health. In order to ease the process of water quality evaluation, WHO international guidelines as well as Ethiopian national guidelines are available. Thus, these guidelines are helpful to assess different water quality parameters and to compare with the guidelines limit preventing water acceptability issues and health impacts.

The world health organization has established minimum criteria for drinking water that all nations are urged to meet. Countries with more advanced technology generally have standards that exceed this quality. Public water supplies are obliged to provide a supply of wholesome water which is suitable and safe for drinking purposes.

Potable water is water which is satisfactory for drinking, culinary and domestic purposes. Water quality standards may be set regional, national, or international bodies. Guidelines for drinking water quality have established by the World Health Organization (WHO) as shown in table below. Public water suppliers are obliged to provide a supply of wholesome water, which is suitable and safe for drinking purposes.

- ✓ A standard is a set of norms established by authorized legal body (regional, national, or international bodies), which would be implemented under legal framework.
- ✓ Guideline is somewhat flexible & designed to be more supportive to specific quality control activities.
- ✓ WHO Drinking Water Quality Guideline can be used as a general framework of UN member countries. Member countries are free to use their own standards or adopt this guideline

Ethiopian Drinking Water Quality Guideline (EDWQG)

- ✓ The EDWQG has been formulated in order to make the implementation of the water quality control activities practical and feasible in the country.

- ✓ EDWQGL developed based on the actual drinking water quality data of the country and within the context of local/national environmental, socio-economic, cultural conditions and the existing drinking water quality problems of the country.
- ✓ The national guideline should be directly proportional to the given WHO Guide line.

Table3.1: WHO Guideline for drinking water quality

Parameter	Unit	Guideline value
Microbial quality		
Fecal coli forms	Number/ 100 ml	Zero*
Coli form organisms	Number /100 ml	Zero*
Inorganic constituents		
Arsenic	Mg/1	0.05
Cadmium	Mg/1	0.005
Chromium	Mg/1	0.05
Cyanide	Mg/1	0.1
Fluoride	Mg/1	1.5
Lead	Mg/1	0.05
Mercury	Mg/1	0.001
Nitrate	Mg/1	10
Selenium	Mg/1(N)	0.01
Aesthetic Quality		
Aluminum	Mg/1	0,2
Chloride	Mg/1	250
Color	Mg/1	15
Copper	Mg/1	1.0
Hardness	True color unit(TCU)	500
Iron	Mg/1	0.3
Manganese	Mg/1(as CaCO_3)	0.3
PH	Mg/1	6.5 to 8.5
Sodium	Mg/1	200
Total dissolved solids	Mg/1	1000
Sulfate	Mg/1	400
Taste and odor		inoffensive to most consumers
Turbidity	NTU	
Zinc	Mg/1	5
		5.0

* treated water entering the distribution system

Source – Ethiopian building code standard, plumbing services of building (EBCS -9)

3.1.3 Water Quality Requirements

Water quality requirements vary according to the proposed use of the water. Water unsuitable for one use may be quite satisfactory for another and water may be deemed acceptable for a particular use if water of better quality is not available. Water quality requirements should not be confused with water quality standards. Water quality requirements represent a known or assumed need and are based on the prior experience of the water user. Water quality standards are set by a governmental agency and represent a statutory requirement. For example a farmer may know from prior experience that highly saline water will damage the crops, but there are no official water-quality standards that say such water cannot be used for irrigation purposes.

3.1.4 Potable Water Standards

Municipal water required for domestic uses, particularly the water required for drinking, must be colorless, odorless, and tasteless. It should be free from turbidity, and excessive or toxic chemical compounds. Harmless micro-organisms and radio activity must be absent. The quality of water for municipal supplies is, therefore, generally controlled throughout the world, and even World Health Organization (W.H.O) has laid down its international standards, specifying the minimum water quality requirements. When these water standards are not fulfilled, the water may not be 100 percent fit for drinking, and may be termed as “contaminated.” Drinking water standards around the world are in a continuous state of evolution as more information becomes available and is evaluated. No single standard for drinking water quality suffices for all countries but there is a considerable degree of agreement on contaminants and their allowable concentrations.

The world health organization has established minimum criteria for drinking water that all nations are urged to meet. Countries with more advanced technology generally have standards that exceed this quality. Important Consideration in Setting National Drinking Water Quality Standards .The setting of drinking water quality standards requires careful consideration of a number of very important factors that must be observed. These include

- ✓ Health Consideration

- ✓ Availability of water of better quality
- ✓ Aesthetic Consideration.

The primary aim of setting national drinking-water standards is the protection of public health and thus the elimination, or reduction to a minimum, of constituents of water that are known to be hazardous to the health of the community. However, standards achieve nothing unless they can be implemented and enforced, and this requires relatively expensive facilities and expertise as well as the appropriate legislative framework. The main reason for not promoting the adoption of international standards for drinking-water quality is the necessity of using a risk-benefit approach (qualitative or quantitative) to the establishment of national standards and regulations. This approach should lead to standards and regulations that can be readily implemented and enforced. The establishment of drinking-water quality standards must follow a very careful process in which the health risk is considered alongside other factors, such as technical and economic feasibility. When establishing national standards, consideration must be given to the practical measures that will need to be taken with respect to finding new sources of water supply, instituting certain types of treatment, and providing for adequate surveillance and enforcement. National standards will, of necessity be influenced by national priorities and economic factors such as lack of resources for water treatment or unavailability of alternative water supply sources. Such economic factors, conflicting national priorities, and varying local geographical, dietary and industrial conditions may lead to national standards that differ appreciably from the WHO Guideline Values (GV).

3.2 water quality and health

Water, although an absolute necessity for life can be a carrier of many diseases. Paradoxically, the ready availability of water makes possible the personal hygiene measures that are essential to prevent the transmission of enteric diseases. Infectious water-related diseases can be categorized as waterborne, water-hygiene, water-contact and water-habitat vector diseases. Some water related diseases, however, may fall into more than one category.

Waterborne infectious diseases are those in which the pathogen, or causative organism, is present in water and ingested when the water is consumed. Most of the pathogens involved are derived from human faeces, and the diseases transmitted by consumption of faecally contaminated water are called “faecal-oral” diseases. All of the faecal-oral diseases can also be transmitted through

media other than water, for example faecally contaminated food, fingers or utensils. The principal faecal-oral diseases are cholera, typhoid, shigellosis, amoebic dysentery, hepatitis A and various types of diarrhea.

One disease that is exclusively waterborne is dracunculiasis, or guinea worm disease, which is caused by *Dracunculus medinensis*. An individual can become infected with *Dracunculus* only by consuming water contaminated with the microscopic crustaceans (Cyclops) that contain the larvae of the pathogen. Dracunculiasis is not a faecal-oral disease.

The incidence, prevalence and severity of water hygiene diseases can be reduced by the observance of high levels of personal, domestic and community hygiene. Almost all diseases (excluding dracunculiasis) are, therefore, also water hygiene diseases.

Other water hygiene diseases include tinea, scabies, pediculosis and skin and eye infections. Tinea, a skin disease, trachoma, an eye disease, and insect infestations such as scabies and pediculosis (lice) occur less frequently when personal hygiene and cleanliness are of a high standard. Water must be available in adequate quantities to permit hand washing, bathing, laundering, house cleaning, and the cleaning of cooking and eating utensils. The quantity required for these purposes is substantially greater than that needed for drinking.

Water contact diseases are transmitted when an individual's skin is in contact with pathogen infested water. The most important example is schistosomiasis (bilharzias), in which the eggs of the pathogen (*Schistosoma* spp.) are present in the faeces and/or urine of an infected individual. The eggs hatch when they reach the water and the larvae invade a suitable snail host where they multiply and develop. Finally escaping from the snail as free swimming cercariae and infect humans by penetrating immersed or wetted skin.

Water-habitat vector diseases are transmitted by insect vectors that spend all or part of their lives in or near water. The pathogenic organisms that cause these diseases spend a portion of their life cycles in a specific vector. The best known examples are malaria and filariasis (mosquito vector) and onchocerciasis (aquatic fly vector). One method of controlling these diseases is to control the vector which, in some cases, involves some physical or chemical treatment of the water habitat.

Health effects from chemicals in water occur when an individual consumes water containing a harmful amount of a toxic substance. Infant methaemoglobinaemia, caused by the consumption of water with a high nitrate concentration by infants (usually those which are bottle fed), is an example. The occurrence of methaemoglobinaemia is usually related to nitrate (often in ground waters) which has been derived from extensive use of nitrate fertilizers. Fluorosis, damage to the teeth and bones, results from long-term consumption of water containing excess fluorides (usually from natural sources).

Water-borne diseases in humans can be caused by the presence of pathogenic bacteria and other organisms such as protozoa and viruses in drinking water supplies, in water used for bathing or immersion sports, or via other routes. It has long been recognized that the ingestion of water contaminated with mammalian excrement can result in the spread of diseases such as cholera and typhoid and that adequate treatment and other measures are required to prevent outbreaks of such diseases. The WHO Guidelines state that 'The potential consequences of microbial contamination are such that its control must always be of paramount importance and must never be compromised'. The following sections look at some of the classical intestinal diseases which are commonly, although not always invariably, water-borne. In all cases the associated organisms are present in large numbers in the excreta of an infected host and are relatively resistant to environmental decay. Many are likely to cause illness even when ingested in small numbers.

Bacterial diseases

Cholera is caused by the bacterium *Vibrio cholerae* and its variant *Eltor vibrio*. Infection is usually contracted by ingestion of water contaminated by infected human faecal material, but contaminated food and person to person contact may also be sources. It is not likely to spread in communities with controlled water supplies and effective sewerage.

Typhoid fever is caused by the bacterium *Salmonella typhi*. Infection is usually contracted by ingestion of material contaminated by human faeces or urine, including water and food (e.g. milk, shellfish) *Salm typhi* occasionally continues to proliferate in the gall bladder of a few patients who have recovered from the primary infection, and these carriers continue to excrete the organisms in their faeces or, occasionally, in their urine for long periods, even for life.

Paratyphoid fevers are also caused by *Salmonella*. Infection may exceptionally be via contaminated water.

Bacillary dysentery is caused by bacteria of the genus *Shigella*- *Sh. dysenteriae*, *Sh. Flexneri*, *Sh. boydii* and *Sh. sonnei* are some of the several subspecies. Infection can occasionally be contracted via water contaminated by human faeces, but more commonly is due to ingestion of food contaminated by flies or by unhygienic food handlers who are carriers.

Campylobacteriosis is caused by bacteria associated with the excrement from wild fowl. There are 14 species of the bacteria, some of which are intestinal illness. *Campylobacters* are frequently found in sewage and have been detected in surface waters, where they can survive for several weeks at cold temperatures.

Other bacteria

The *Pseudomonas* group is commonly found throughout the environment. They may be present in human and animal excrement and can also multiply in water containing suitable nutrients. Their subsequent growth, if present in drinking water, may also result in an overall deterioration in the microbiological quality and lead to consumer complaints of taste and odour. *Ps. aeruginosa* is an opportunist pathogen, that is, it can cause infection in people whose natural defense mechanisms may be impaired, for example the very old, the very young or the immuno suppressed. Other pseudomonads may produce undesirable slimes within the distribution system. The *Aeromonas* group is also naturally present in the aquatic environment. Their presence in drinking water does not necessarily indicate faecal pollution but highlights possible inadequacies in the treatment process or ingress within the distribution system. The number of such organisms likely to be found in a distribution system will depend on the residence time of the water, its organic content and the residual chlorine level.

Protozoa diseases

Amoebic dysentery is caused by the microscopic parasite *Entamoeba histolytica*. The parasite is distributed throughout the world and exists in two stages, only one of which, the cyst, is infective. The parasite infects mainly primates and, following infection, resides in the large intestine in humans where it produces further cysts, which are passed in the faeces. Infection

takes place by ingestion of these cysts. They can survive for several days in water at temperatures and are resistant to chlorine. Outbreaks can occur if water supplies are contaminated with domestic sewage containing viable cysts. More commonly the disease is transmitted by person-to-person contact or via food contaminated by carriers. Most infections tend to cause only minor symptoms, although liver abscess can be a serious *sequela*. **Cryptosporidiosis** is an acute self-limiting diarrhea disease caused by the parasite *Cryptosporidium parvum*, which infects domestic and farm animals as well as humans. The normal routes of exposure are via direct contact with infected animals or humans or via contaminated water or food. Not all infected individuals necessarily develop the symptoms of the disease but the illness is likely to be serious or even life-threatening for patients who are immunologically compromised.

Viral diseases

Viruses differ from bacteria in that they are very much smaller and can multiply only within suitable host cells, in which they produce changes which give rise to a range of diseases. More than one hundred different types of virus have been identified in faeces and the main sources of human enteric viruses in the aquatic environment are sewage discharges. The main areas of risk then become the use of sewage polluted waters for recreational purposes or the recycling of wastewater for domestic use without adequate treatment and disinfection. Human polioviruses which cause Poliomyelitis can be found in untreated sewage and even in the effluent from sewage disposal units. Like other viruses, they do not multiply in the absence of living cells and although there have been a few reports of water-borne infection there has been little confirmation. The viruses associated with Hepatitis A and E have been detected in sewage and polluted rivers. Several large outbreaks of drinking water transmitted Hepatitis have been reported, usually where water treatment has broken down; where the distribution system has been disturbed; or where badly constructed wells have been contaminated from adjacent cesspits or as a result of heavy rainfall.

3.2.1 Microbiological standards for drinking water

Pathogenic bacteria and other organisms are usually difficult to detect in an effectively treated water supply because, if present, their numbers are likely to be very small. Their presence even in sewage effluent or polluted river water may be only infrequent or at irregular intervals,

depending on the level and source of contamination. Analyzing directly for pathogenic bacteria is not therefore a practical safeguard for a water supply and, indeed, routine monitoring for process control purposes would be both impracticable and unnecessary. Instead, evidence of any pollution by the excreta of man or animals should always be sought and, if the evidence is positive, it should be assumed the water may also contain pathogenic bacteria and must therefore be regarded as unsuitable for supply purposes.

Table 3.2: WHO and Ethiopian biological water quality guidelines

Parameters	WHO guidelines	Ethiopian Guidelines
Total coliform Faecal coliform	Must not be detectable in any 100 ml sample	Must not be detectable in any 100 ml sample

Source:(WHO, 2017); (ESA, 2013)

3.3 water quality and agriculture

Water quality and agriculture interactions are many and complex. The development of large irrigation schemes has been an important contributor to global food security, particularly in arid areas, but it has also been associated with land and water salinity problems. Both, expansion and intensification of agriculture have led to an increasing use of fertilizers and pesticides that, when not well managed, has degraded the water quality of rivers, lakes and marine water bodies. Intensification of livestock farming systems is a case in point: concentrating inputs increases the potential transmission of pollution from both animal waste and fodder production and, if not managed or regulated well, eutrophication of freshwater bodies can easily result. At the same time, such is the level of water scarcity and pollution that millions of farmers worldwide are driven to irrigate with marginal quality water such as wastewater from urban areas or saline agricultural drainage water. Minimizing both the production and food safety risks and, at the same time, maximizing benefits when using such water is an enormous challenge. Additionally, concerns about the use of naturally occurring arsenic-laden groundwater in agriculture are growing and, therefore, this emerging issue will need special attention.

Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. Salts are present in irrigation water in relatively small but significant amounts. They originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals. These salts are carried with the water to wherever it is used. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop.

The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use.

The problems that result vary both in kind and degree, and are modified by soil, climate and crop, as well as by the skill and knowledge of the water user. As a result, there is no set limit on water quality; rather, its suitability for use is determined by the conditions of use which affect the accumulation of the water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems.

The nature and extent of irrigated agriculture has changed with respect to water quantity and quality. Understanding irrigation water quality is critical to making management decision for long-term productivity since it can have a significant effect on crop yield, physical condition of the soil, soil salinity, fertility needs, irrigation system performance (and longevity), and water application methods. In some cases, the quality of irrigation water can influence crop productivity more than soil fertility, plant cultivar, or weed control. Maintaining water quality in an irrigation system is vital to the system's effectiveness and can mean the difference between a below average yield and a bumper crop.

The quality of the available water must be tested to check its fitness prior to use. Irrigation water, whether diverted from streams or pumped from tube wells, contain appreciable quantities of harmful substances in solution those may reduce crop yield and deteriorate soil fertility. The main characteristics to assess the quality of irrigation water are Total Dissolved Solids (TDS),

Sodium Absorptions Ratio (SAR), Electrical Conductivity (EC) and Residual Sodium Carbonate (RSC). The quality of irrigation water available to farmers and other irrigators has a considerable impact on what plants can be successfully grown, the productivity of these plants, and water infiltration and other soil physical conditions. The first step in understanding how an irrigation water source can affect a soil-plant system is to have it analyzed by a reputable lab. The suitability of an irrigation water depend upon several factors such as, water quality, soil type, plant characteristics, irrigation method, drainage, climate and the local conditions.

Irrigation practice is a major factor that brings advances to crop production at a global level. However, irrigation activities cause salinization and alkalization, which result in extensive soil and water degradation everywhere where irrigation is practiced. There are well-known cases where changes in the chemistry of irrigation water have caused unacceptable effects in soils and plants. This means that the practices which caused these unwanted effects were not sustainable. Obviously, irrigated agriculture needs to be sustained and. sustaining irrigation systems is a broad general statement. Various attributes could be considered as objects for sustainability, such as irrigation facilities, production potential, operational performance, but first of all irrigation water quality. The reform of irrigation water quality policies is thus the first and most important step towards creating conditions that encourage the sustainable use of water. The use of the existing classifications and the introduction of an additional procedure for water suitability assessment are avenues towards sustainable irrigation.

The salinity of soil is also important factor for the determination of water quality. Soil salinity is developed when soil becomes more salty as a result of water movement in the soil especially due to irrigation. Water quality is critical for the survival of humans, animals, industry and agriculture. Furthermore, the proper management is requisite to meet water quality standards and for ecosystem health.

The agriculture success is highly dependable on the quality of water applied in an agriculture area. Due to the application of poor or hazardous quality water the agriculture land/soil is affected and damages the crop yield in several ways. The accumulation of salts in root zone, limited the availability of water and plant can take up lesser water which resulted in high plant stress and decreased crop yields. The presence of metals in irrigation water also has adverse effects on crop production. Also, high concentration of salts can change the plant nutrients

balance in the soil meanwhile some salts are toxic to certain plants. It is also notable that most of the normal plants tolerate wide range of salt but pasture plants are not highly salt-tolerant and would finally die out under saline conditions.

The physical and chemical properties of soil are also affected by salinity that leads in soil loss in term of surface soil compaction and erosion. Salinity also dehydrates the soil bacteria and fungi and reduces soil health. These microorganisms are useful for the formation of organic matter and nutrient recycling. Irrigation water quality is described by different parameters such as Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Residual Sodium Carbonate (RSC). Salt-affected soils develop from a wide range of factors including: soil type, field slope and drainage, irrigation system type and management, fertilizer and manuring practices, and other soil and water management practices. In Colorado, perhaps the most critical factor in predicting, managing, and reducing salt-affected soils is the quality of irrigation water being used. Besides affecting crop yield and soil physical conditions, irrigation water quality can affect fertility needs, irrigation system performance and longevity, and how the water can be applied. Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long term productivity.

Salinity, sodicity and ion toxicity are major problems in irrigation waters. In arid areas, where rainfall does not adequately leach salts from the soil, an accumulation of salts will occur in the crop's root-zone. Thus, periodic testing of soils and waters is required to monitor any change in salt content. Sodicity, the presence of excess sodium, will result in a deterioration of the soil structure, thereby reducing water penetration into and through the soil. Toxicity refers to the critical concentration of some salts such as chloride, boron, sodium and some trace elements, above which plant growth is adversely affected by those salts.

Water quality for irrigation depends upon salts type and their dissolved quantity. As the total salt concentration increases in various soils caused the crop developing problems resulting in crop yield reduction. The suitability of water to use for particular purpose is decided on the bases of its long term effect and severity. The soil problems such as salinity, sodicity, alkalinity, toxicity and water infiltration rate are discussed in the following section.

Salinity

Salts in soil or water reduce water availability to the crop to such an extent that yield is affected. When salts start accumulating in upper soil profile (root zone) in excess amount, salinity problems appear. In saline area, crop is unable to extract the required amount of water from soil resulting in crop water stress for a significant period. These salts are soluble in water and mostly transported by water. To get higher crop production, high weightage must be focused on proper availability of water for consumptive use. In areas of high salts the practice of leaching of accumulated salts from the root zone is necessary to reduce the level of salts. Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. Salts are present in irrigation water in relatively small but significant amounts. These salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop. It is expressed as electrical conductivity.

Salinity is the most important criterion for evaluating the quality of irrigation water because of the potential crop yield reductions that can result from the use of saline water which inhibits water uptake by plants. Agricultural practice tends to induce accumulation of salt in land and water. Salts accumulated in soils can be mobilized by irrigation practice through the modification of water circulation across land. In addition pumping of groundwater can induce saline intrusion in coastal aquifers or the migration of low quality water from underlying aquifers.

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (EC). The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire “pure” water, usable plant water in the soil solution decreases dramatically as EC increases.

The amount of water transpired through a crop is directly related to yield; therefore, irrigation water with high EC reduces yield potential. Actual yield reductions from irrigating with high EC water vary substantially. Factors influencing yield reductions include soil type, drainage, salt type, irrigation system and management.

The density of the water, can be harmful due to increase in TDS concentrations, determined the flow of water into and out of an organism's cells. Moreover, the high concentrations of TDS may also reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature. Flat insipid taste because of extremely low TDS level was also unacceptable.

Leaching and drainage are required to maintain the salt balance in the soil profile and to sustain crop yields in arid areas, but this drainage needs to be carefully managed to prevent salinization of water bodies. Some drainage water management options include minimizing drainage by conserving water, reuse of drainage water, safe disposal or treatment of drainage water.

Sodicity

Sodicity is a term given to the amount of sodium held in a soil. Sodium is a cation that is held loosely on clay particles in soil. It is one of many types of cations that are bound to clay particles. If the proportion of sodium is high in water for irrigation purpose, it can destroy soil structure a simple method for evaluating the changes of high sodium is the Sodium Adsorption Ratio (SAR). The most common measure to assess sodicity in water and soil is called the Sodium Adsorption Ratio (SAR). The SAR defines sodicity in terms of the relative concentration of sodium (Na) compared to the sum of calcium (Ca) and magnesium (Mg) ions in a sample.

The soils containing the large amount of sodium ions are known as sodic soils. In sodic soils the positively charged sodium ions attached with negatively charged clay particles. The soil swells and the clay particles disperse when excess in sodium ions is attached to clay particles. When water is added to the soil has sodium ions, resulted the soil structure to slump and collapse rather than sticking together. Similarly, in sodic soil the surface of the soil becomes hard and impervious layer vulnerable to water-logging also reduce aeration which is necessary for biological activity in soil. All these parameters are the reasons of reduction in crop growth and ultimately the crop production.

Reductions in water infiltration can occur when irrigation water contains high sodium relative to the calcium and magnesium contents. This condition, termed “sodicity,” results from excessive soil accumulation of sodium. Sodic water is not the same as saline water. Sodicity causes swelling and dispersion of soil clays, surface crusting and pore plugging. This degraded soil

structure condition in turn obstructs infiltration and may increase runoff. Sodicty causes a decrease in the downward movement of water into and through the soil, and actively growing plants roots may not get adequate water, despite pooling of water on the soil surface after irrigation.

The potential soil infiltration and permeability problems created from applications of irrigation water with high “sodicty” cannot be adequately assessed on the basis of the SAR alone. This is because the swelling potential of low salinity (EC) water is greater than high EC waters at the same sodium content (Table 4). Therefore, a more accurate evaluation of the infiltration/permeability hazard requires using the electrical conductivity (EC) together with the SAR. Many factors including soil texture, organic matter, cropping system, irrigation system and management affect how sodium in irrigation water affects soils. Soils most likely to show reduced infiltration and crusting from water with elevated SAR (greater than 6) are those containing more than 30% expansive (smectite) clay. Soils containing more than 30% clay include most soils in the clay loam, silty clay loam textural classes and finer and some sandy clay loams. In Colorado, smectite clays are common in areas with agricultural production.

A high sodium ion in irrigation water affects the hydraulic conductivity (permeability) of soil and creates water infiltration problems. This is because when sodium present in the soil in exchangeable form replaces calcium and magnesium, adsorbed on the soil clays and causes dispersion of soil particles (i.e. if calcium and magnesium are the predominant cations adsorbed on the soil exchange complex, the soil tends to be easily cultivated and has a permeable and granular structure). Due high value of SAR, the soil becomes hard and compact when dry and resultantly, reduces the infiltration rates of water and air into the soil affecting its structure. This problem is also related with several factors such as the salinity rate and type of soil. For example, sandy soils may not get damage as easily as other heavier soils when it is irrigated with high SAR water.

pH and Alkalinity

The ability of water to neutralize the added acids is known as alkalinity, the most important factor determining root media pH. Over the time, the pH is adversely affected by the water having high alkalinity. Alkalinity can be assessed with the measure level of calcium bicarbonate

or calcium carbonate. Undesirably, acid is injected into the water to neutralize the level of high level of bicarbonate or application of ammonium comprising fertilizers. The crops grown in cool areas have low tolerance against ammonium, so especial attention is required for those crops.

The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH range for irrigation water is from 6.5 to 8.4. Abnormally low pH's are not common. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. As described in the sodium hazard section, this alkaline water could intensify the impact of high SAR water on sodic soil conditions. Excessive bicarbonate concentrates can also be problematic for drip or micro-spray irrigation systems when calcite or scale builds up causes reduced flow rates through orifices or emitters. In these situations, correction by injecting sulfuric or other acidic materials into the system may be required. The pH of water and soil could not harm the plant growth directly. pH highly affects the efficiency of coagulation and flocculation process.

Chloride

Chloride is a common ion in Colorado irrigation waters. Although chloride is essential to plants in very low amounts, it can cause toxicity to sensitive crops at high concentrations. Like sodium, high chloride concentrations cause more problems when applied with sprinkler irrigation. Leaf burn under sprinkler from both sodium and chloride can be reduced by night time irrigation or application on cool, cloudy days. Drop nozzles and drag hoses are also recommended when applying any saline irrigation water through a sprinkler system to avoid direct contact with leaf surfaces.

Boron

Boron is another element that is essential in low amounts, but toxic at higher concentrations. In fact, toxicity can occur on sensitive crops at concentrations less than 1.0 ppm. Because B toxicity can occur at such low concentrations, an irrigation water analysis is advised for groundwater before applying additional B to irrigated crops.

Nitrogen

The nitrate ion often occurs at higher concentrations than ammonium in irrigation water. Waters high in N can cause quality problems in crops such as barley and sugar beets and excessive

vegetative growth in some vegetables. However, these problems can usually be overcome by good fertilizer and irrigation management. Regardless of the crop, nitrate should be credited toward the fertilizer rate especially when the concentration exceeds 10 ppm $\text{NO}_3\text{-N}$ (45 ppm NO_3^-).

Toxicity

As water takes nutrients when mixed with water and on the same time when crops take water containing ionic constituents, the toxicity problems are raised. The high concentration of toxic elements can reduce crop growth and result in low crop production. The primary ionic constituents are boron, sodium and chloride. It is not necessary that the high concentration cause the damage even small quantities respond the same. The water infiltration and salinity problems can also be due to toxicity. Without transpiration, the plant is unable to live as this is the basic need of plant. In this transpiration process, the dissolved ions in water move and accumulate to the leaves. These ions block the stomata in the leaves and reduce the transpiration process which adversely affects the plant growth. It is also to note that the direct application of adsorbed toxic ions from overhead sprinkler can create toxicity problems. Toxicity from both sodium and chloride or from any one is dangerous to sensitive crops such as citrus.

Toxicity problems occur if certain constituents (ions) in the soil or water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields. The degree of damage depends on the uptake and the crop sensitivity. The permanent, perennial-type crops (tree crops) are the more sensitive. Damage often occurs at relatively low ion concentrations for sensitive crops. It is usually first evidenced by marginal leaf burn and interveinal chlorosis. If the accumulation is great enough, reduced yields result. The more tolerant annual crops are not sensitive at low concentrations but almost all crops will be damaged or killed if concentrations are sufficiently high.

The ions of primary concern are chloride, sodium and boron. Although toxicity problems may occur even when these ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem. Damage results when the potentially toxic ions are absorbed in significant amounts with the water taken up by the roots. The absorbed ions are transported to the leaves where they accumulate during transpiration. The ions accumulate to

the greatest extent in the areas where the water loss is greatest, usually the leaf tips and leaf edges. Accumulation to toxic concentrations takes time and visual damage is often slow to be noticed. The degree of damage depends upon the duration of exposure, concentration by the toxic ion, crop sensitivity, and the volume of water transpired by the crop. In a hot climate or hot part of the year, accumulation is more rapid than if the same crop were grown in a cooler climate or cooler season when it might show little or no damage.

Toxicity can also occur from direct absorption of the toxic ions through leaves wet by overhead sprinklers. Sodium and chloride are the primary ions absorbed through leaves, and toxicity to one or both can be a problem with certain sensitive crops such as citrus. As concentrations increase in the applied water, damage develops more rapidly and becomes progressively more severe.

Water Infiltration Rate

Infiltration rate or intake rate of water is very necessary process to provide water to root zone from the soil surface and reduce salinity through leaching. The problems related to infiltration arise when infiltration rate is reduced to some extent which is not desirable. Due to less infiltration rate, very less water is available to plants roots or remains on the surface of the soil. Because of this problem, the necessity such as water and nutrients are unavailable to plants. Beyond this scenario, the water infiltration rate in soil also varies widely and is affected by soil structure, soil compaction, available organic matter, water quality and chemical constituents of soil. Infiltration/Permeability Problems although plant growth is primarily limited by the salinity (EC) level of the irrigation water, the application of water with a sodium imbalance can further reduce yield under certain soil texture conditions.

Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next.

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the

quality of the irrigation water, soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate.

The two most common water quality factors which influence the normal infiltration rate are the salinity of the water (total quantity of salts in the water) and its sodium content relative to the calcium and magnesium content. High salinity water will increase infiltration. Low salinity water or water with high sodium to calcium ratio will decrease infiltration. Both factors may operate at the same time. Secondary problems may also develop if irrigations must be prolonged for an extended period of time to achieve adequate infiltration. These include crusting of seedbeds, excessive weeds, nutritional disorders and drowning of the crop, rotting of seeds and poor crop stands in low-lying wet spots. One serious side effect of an infiltration problem is the potential to develop disease and vector (mosquito) problems.

An infiltration problem related to water quality in most cases occurs in the surface few centimeters of soil and is linked to the structural stability of this surface soil and its low calcium content relative to that of sodium. When a soil is irrigated with high sodium water, a high sodium surface soil develops which weakens soil structure. The surface soil aggregates then disperse to much smaller particles which clog soil pores. The problem may also be caused by an extremely low calcium content of the surface soil. In some cases, water low in salt can cause a similar problem but this is related to the corrosive nature of the low salt water and not to the sodium content of the water or soil. In the case of the low salt water, the water dissolves and leaches most of the soluble minerals, including calcium, from the surface soil.

Miscellaneous Effects

Other problems associated with irrigation water include reductions in crop yield and quality due to excessive nutrients; hindered marketability due to unsightly deposition of excessive nutrients on fruit or foliage; and increased maintenance and repair costs due to clogging or excessive corrosion of equipment. Irrigation waters high in nitrogen when applied with recommended dose of N fertilizer can cause quality problems in crops, such as malting barley and sugar beets, and excessive vegetative growth in some vegetables. However, good fertilizer and irrigation water management can usually solve these problems. Irrigation water nitrate-nitrogen should be

credited toward the fertilizer rate especially when the concentration exceeds 10 ppm nitrate-nitrogen (or 45 ppm nitrate).

Several other problems related to irrigation water quality occur with sufficient frequency for them to be specifically noted. These include high nitrogen concentrations in the water which supplies nitrogen to the crop and may cause excessive vegetative growth, lodging, and delayed crop maturity; unsightly deposits on fruit or leaves due to overhead sprinkler irrigation with high bicarbonate water, water containing gypsum, or water high in iron; and various abnormalities often associated with an unusual pH of the water. A special problem faced by some farmers practicing irrigation is deterioration of equipment due to water-induced corrosion or encrustation. This problem is most serious for wells and pumps, but in some areas, poor quality water may also damage irrigation equipment and canals. In areas where there is a potential risk from diseases such as malaria, schistosomiasis and lymphatic filariasis, disease vector problems must be considered along with other water quality-related problems. Vector problems (mosquitoes) often originate as a secondary trouble related to a low water infiltration rate, to the use of wastewater for irrigation, or to poor drainage. Suspended organic as well as inorganic sediments cause problems in irrigation systems through clogging of gates, sprinkler heads and drippers. They can cause damage to pumps if screens are not used to exclude them. More commonly, sediments tend to fill canals and ditches and cause costly dredging and maintenance problems. Sediment also tends to reduce further the water infiltration rate of an already slowly permeable soil.

Irrigation Water Quality Standards

Guidelines for evaluation of water quality for irrigation are given in Table 3.3. They emphasize the long-term influence of water quality on crop production, soil conditions and farm management, and are presented in the same format as in the 1976 edition but are updated to include recent research results.

The guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater. They are based on certain assumptions which are given immediately

following the table. These assumptions must be clearly understood but should not become rigid prerequisites. A modified set of alternative guidelines can be prepared if actual conditions of use differ greatly from those assumed.

Ordinarily, no soil or cropping problems are experienced or recognized when using water with values less than those shown for 'no restriction on use'. With restrictions in the slight to moderate range, gradually increasing care in selection of crop and management alternatives is required if full yield potential is to be achieved. On the other hand, if water is used which equals or exceeds the values shown for severe restrictions, the water user should experience soil and cropping problems or reduced yields, but even with cropping management designed especially to cope with poor quality water, a high level of management skill is essential for acceptable production. If water quality values are found which approach or exceed those given for the severe restriction category, it is recommended that before initiating the use of the water in a large project, a series of pilot farming studies be conducted to determine the economics of the farming and cropping techniques that need to be implemented.

Standards of water quality for irrigation used as with many such interpretative tools in agriculture, it is developed to help users such as water agencies, project planners, agriculturalists, scientists and trained field people to understand better the effect of water quality on soil conditions and crop production. With this understanding, the user should be able to adjust management to utilize poor quality water better. The guidelines are a first step in pointing out the quality limitations of a water supply, but this alone is not enough; methods to overcome or adapt to them are also needed. Therefore, in subsequent sections, management alternatives are presented and several examples are given to illustrate how the guidelines can be used.

There are mainly two irrigation water sources in semi-arid and arid regions such as canal water and tube well water pumped from aquifer. Water from these sources contains considerable amount of unnecessary or unwanted substances dissolved in water that may deteriorate soil fertility and crop growth and crop yield. These unwanted substances have come from natural or manmade (domestic and industrial effluents) sources and its severity depend upon the type of substance and its quantity which resulted in deteriorated water quality.

There are various water quality standards by different organizations. The US Regional Salinity Laboratory and Food and Agriculture Organization (FAO) have given the quality of irrigation water.

Table 3.3 Irrigation water quality standards (US regional salinity laboratory and FAO)

Table 3.3 GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION¹					
Potential Irrigation Problem		Units	Degree of Restriction on Use		
			None	Slight to Moderate	Severe
Salinity (affects crop water availability) ²					
	EC	dS/m	< 0.7	0.7 – 3.0	> 3.0
	(or)				
	TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC and SAR together) ³					
SAR	= 0 – 3	and EC =	> 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 (affects sensitive crops)					
	Sodium (Na)⁴				
	surface irrigation	SAR	< 3	3 – 9	> 9
	sprinkler irrigation	me/l	< 3	> 3	
	Chloride (Cl)⁴				
	surface irrigation	me/l	< 4	4 – 10	> 10
	sprinkler irrigation	me/l	< 3	> 3	
	Boron (B)⁵	mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements (see Table 21)				
Miscellaneous Effects (affects susceptible crops)					
	Nitrogen (NO₃ - N)⁶	mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO₃)				
	(overhead sprinkling only)	me/l	< 1.5	1.5 – 8.5	> 8.5
	pH		Normal Range 6.5 – 8.4		

Management of Water Quality Problems

Leaching is useful to reduce the soil salinity and its problems. The salinity level in the soil can be determined with water having no salts in it, especially the sodium. The soil of good structure and proper drainage is demanded for efficient leaching. For a soil having salinity, it is needed to determine the amount of salts free water to reclaim it. Some time, in soil, having high salinity level needs various application of fresh water to leach the salts below root zone with proper drainage. In the areas of shallow groundwater level, the leaching is impracticable; in such situation, the artificial drainage is recommended. The artificial drainage has some advantages to remove salinity from soil even with low quality water. Irrigation water management includes:

- ✓ Scheme wide considerations
- ✓ Field considerations.
- ✓ Agronomic practices
- ✓ Salinity management issues
- ✓ Leaching requirements.
- ✓ Within scheme reuse of drain water.
- ✓ Water table management