Silent Pollution due to Sodium in Irrigation Agriculture

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Irrigation Water Quality

The largest user of water in Sri Lanka is irrigation agriculture. The irrigation water flows through a system of tunnels, streams, reservoirs (Wewa), canals etc. before it reaches the field where a crop is grown. During this flow some soluble salts are always dissolved in, and the water becomes saline containing high dissolved salts. Man's activities in industries, deforestation etc. in and around water sources **enhance dissolution of salts.** In the fields, the water will undergo evapo-transpiration resulting in the accumulation of dissolved salts, which will affect soil properties, especially soil permeability and subsequently crop growth. It has been reported that in countries such as Afghanistan, Pakistan, Egypt etc. **millions of hectares** of irrigated lands have been abandoned due to loss of soil permeability which affects the crop growth.

The ancient concept of availability of water for economic prosperity does not hold true today. **The 'quantity'** of available water along with **the 'quality'** plays an important role. In ancient times, available sources of water undoubtedly was suitable for the purpose of its use such as drinking, agriculture etc. Therefore, the need to check the 'suitability' for use did not arise, and also was not a factor to be considered. It is also obvious that the re-use of irrigation water was done only to a limited extent, and was not given any priority. The water once used for irrigation was allowed to drain off to the sea. The availability of irrigation water of suitable quality in ancient times made this possible. In addition, the judgment on the quality of water was not possible prior to reuse. It was based on strict abidance to the myth ***'respect water'***, which undoubtedly assisted in preventing water becoming unsuitable for irrigation. **"Respect water"** was the concept introduced to me by our teachers in the village school in the early 1950's. This can be considered as the wisdom from the past relating to sustainable development - an "Unwritten Science". The term "respect" excluded spitting or urinating on water i.e. not to pollute water. This system was practiced in Sri Lanka during the past 2,500 years in the domestic and agricultural use of water. In ancient times toilets were designed on the concept "respect water", thus preventing pollution of water in the past. Is there any such respect for water today in our domestic usage? Today, the quantity but also the suitability of water for the purpose i.e. quality would be significant. For example, if water containing injurious chemicals is available in large quantities, the people who drink such water will become sick, thus affecting the economy. Even if there is a plenty of water of poor quality for irrigation, it would lead to a crop failure, and consequently affecting the economy.

A knowledge of the quality of irrigation water is important in judging its suitability for irrigation. Suitability of a source of irrigation water depends upon several factors which include, soil, plant, and climate, and it can be expressed by the following relationship.

$$SI = f\ (QSPDC)$$

Where

SI = Suitability of irrigation water,
Q = Quality of water i.e. the total salt concentration, cationic and anionic composition,

S =Physico – chemical properties of the soil profile,
P =Salt tolerance characteristics of the crop plant at different stages of growth,
D = Drainage conditions,
C = Climatic parameter.
It is difficult to suggest a single water quality criterion **(Q)** because of the interaction of several factors. The degree of adverse effects on soil properties is mainly related to the chemical composition of water. The adverse effects of a particular quality water on soil-plant system depends upon the total salt concentration, relative proportion of sodium to other cations, boron concentration and bicarbonate content. Water with low electrical conductivity contain mostly sodium and chloride ions. The relative proportions of sodium to other cations is determined by the sodium adsorption ratio (SAR).

$$\textbf{SAR} = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}}$$

where ionic concentration of each is in mmol L^{-1}.

Any increase in the SAR of irrigation water increases the SAR of the soil solution, which ultimately increases the exchangeable sodium by the soil. Therefore, Exchangeable Sodium Percentage (ESP) or the adj.SAR has a wider role to play in the judgment on the suitability of water-for irrigation.

The degree of adverse effects on soil properties and crop growth are mainly related to the composition of irrigation water. Food and Agriculture Organization of the United Nations **(FAO)** has put forward the guidelines shown in Table 2, to evaluate water quality for irrigation using the problem approach. The Exchangeable Sodium Percentage (ESP) or the adj. SAR is expressed as follows:

$$\textbf{adj SAR or ESP} = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}} \quad (1 + (8.4 - pH_C)$$

where pHc is the theoretical,

calculated pH of irrigation water in contact with lime and is in equilibrium with soil carbon dioxide.

Since there are several factors associated with the soil-water system, the calculated pH of irrigation water in contact with lime, in equilibrium with soil carbon dioxide (pHC), plays an important role in assessing the value of ESP, which is directly responsible for the possible loss of soil permeability on continuous irrigation with poor quality waters. The pHC is expressed as:

$pH_C = pK'_{sp} - pK'_{sp} + p[Ca^{2+} + Mg^{2+}] + p(Alk.)$ K_{a2} = Conditional second dissociation constant of carbonic acid. K'_{sp} = Conditional solubility product of calcium carbonate (magnesium carbonate). $p(Ca^{2+} + Mg^{2+})$ = - $\log_{10}$ the sum of the concentrations of magnesium and calcium in $cmol.dm^{-3}$.
$p(Alk)$ = - $\log_{10}$ the sum of the concentrations of carbonate and bicarbonate in $cmol.\ dm^{-3}$. In recent reports, journal articles, the adj. SAR is more and more frequently being reported as Adjusted R_{Na}. The terms are synonymous. The SAR procedure encompasses the infiltration problems due to an excess of sodium in relation to calcium and magnesium. It does not take into account changes in calcium in the soil water that take place because of changes of solubility of calcium resulting from precipitation or dissolution during or following irrigation. Sodium, and important part of salinity, remains soluble and in equilibrium with exchangeable soil sodium at all times. Whether concentrated from withdrawal of water by the crop between a long irrigation interval, diluted with applied water, or leached away in drainage, outside influences have little effect on sodium solubility or precipitation. Calcium, however, does not remain completely soluble in constant supply, but is constantly changing until an equilibrium is established. Calcium changes occur due to dissolution of soil minerals into soil-water, thus raising its calcium content, or precipitation from soil-water, usually as calcium carbonate, thus reducing the calcium. Dissolution is encouraged by dilution and by carbon dioxide dissolve in the soil water; while precipitation may take place because of the presence of sufficient calcium along with enough carbonate, bicarbonate or sulphates exceeding the solubility of calcium carbonate (limestone) or calcium sulphate (gypsum). Soon after an irrigation activity, dissolution precipitation may occur, changing the supply of calcium, and establishing an equilibrium at a new calcium concentration, different to that in the applied water. The SAR equation, since it does not account for these changes, is therefore somewhat in error. However, the SAR equation and procedure is still considered an

$$CaCO_3(s) + H_2O(l) + CO_2(aq)(HCO_3) \underset{\text{Precipitation}}{\overset{\text{Dissolution}}{\rightleftarrows}} Ca^{2+}(aq) + 2HCO_3^-(aq)$$

acceptable evaluation procedure for most of the irrigation water encountered in irrigated agriculture. Water from an irrigation water tank (wewa or vari) was used to irrigate about a 100 hectare paddy field for over 1000 years. About 50 years ago a canal with poor water quality (Adj. SAR 55.9) was diverted to this tank to increase the quantity of water.(Fig. 1) The farmers were happy with the availability of plenty of water for a few years. Subsequently, a crop failure was observed and now the farmers lost their paddy fields. This is the consequence of increasing the quantity without quality.

The previous example was the abandoning of about100 hectares of paddy fields in Sri Lanka due to the loss of soil permeability. This may be a possibility in all the other irrigation schemes if priority is given only for the quantity rather than the quality. Therefore, it is essential to take adequate

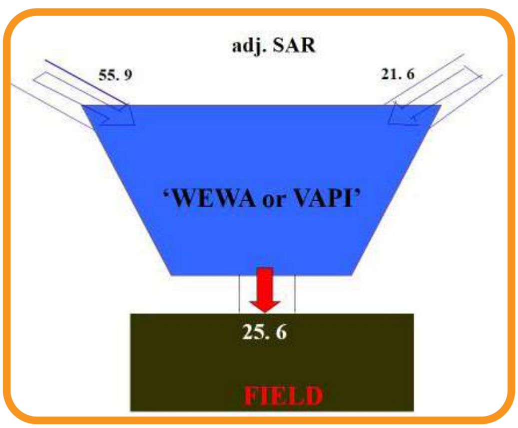

Fig.1 (Above) Schematic representation of silent sodium pollution of irrigation waters in Sri Lanka

precautionary measures, especially in the areas irrigated by Mahaweli waters, in order to prevent any such salt danger caused by the increased utilization of irrigation water resources.

Prevention is better and less expensive than the cure.

The Mahaweli irrigation project involves utilization of water of the Mahaweli Ganga to irrigate an **extensive area of the dry zone. When completed, the Mahaweli Development Project is expected to supply water** for the irrigation need of 900,000 acres for two crops a year. The master plan also envisages the generation of 2,037 million kilowatt hours of hydroelectric energy. The phase 1 of the project, (Kala Oya, Abanganga) covers 132,000 acres of existing lands and 91,000 acres of new lands. A monitoring programme was initiated in 1978 to check the quality of irrigation waters in the system H of the Mahaweli diversion scheme. The block 302 of the system H of the Mahaweli development scheme was selected for this purpose. It was reported that there is a remarkable increase of the Sodium Adsorption Ratio(SAR) and Residual Sodium Carbonate (RSC) values especially in the drainage waters in April, and in November. This coincides with the Maha and Yala harvesting seasons of the system H. Usually, a heavy rainfall leads to the decrease of these values significantly. BalaluWewa is the reservoir which supplies irrigation water to Block 302 through the Left Bank Canal (L.B.C.). Seasonal variation of the filterable residue and total residual contents of waters from BalaluWewa, Left Bank Canal, and at the beginning of D1 Channel of Block 302 shows similar trends. It was seen that there was an increase in the filterable residue as well as the total residue of the irrigation waters in April 1978 and 1979. The Maha harvest starts in March and ends in April. During this period the water supply to the field being completely cut off and consequently, as a result of rapid evaporation of existing water, the filterable residual content increases.

$$= \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}}$$

where ionic concentration of each is in mmol L^{-1}.

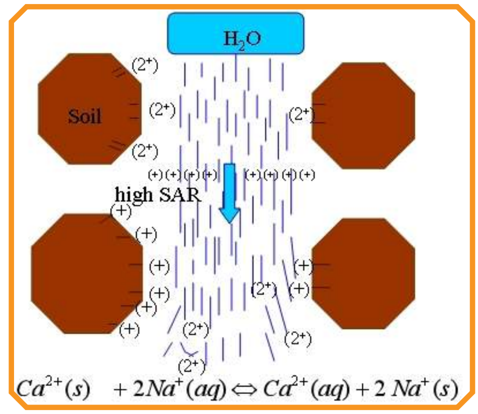

Figure 2: Illustration of the loss of soil permeability when waters of high SAR values are used for irrigation.

The history of conservation of water in Sri Lanka could be traced to the reign of King Pandukabhaya (380 – 310 B.C.), who constructed the first reservoir (Wewa) at Anuradhapura. Thereafter, several hundreds of reservoirs have been constructed mainly to conserve rainwater. Very little evidence could be gathered on the construction of reservoirs by building dams across flowing streams or rivers. In such instances a **forest cover** was maintained in and around the streams carrying water to the reservoirs and also the canals which supplied water to paddy fields. The belief was that such divine beings living in trees assisted to preserve the forest cover. In addition, powerful dictatorship and good governance prevented people from clearing a forest. One method of **achieving sustainability** in the ancient irrigation projects, is to maintain the forest cover. According to modern science clearing of forests increases the sodium ion concentration of irrigation waters, thus causing water unsuitable for irrigation, which ultimately leads to a loss of soil permeability. Ancient water management was based on this type of ancient scientific views (unwritten science).

Kalawewa is one such reservoir constructed by King Dathusena (6th Century A.D.) by building a dam across a stream (presently Dambulu Oya – Kala Oya). He may have constructed this to fulfill his wishes, and may have gone against the opinion of his advisors in making the decision. Three or four hundred years later, the continuous use of Kala Wewa waters for irrigation, resulted in the Anuradhapura kingdom getting shifted to Polonnaruwa. One could attribute this change to crop failure due to the loss of soil permeability. This administrative failure during the period 6th to the 9th century resulted in poor water management, which ultimately led to crop failures. Continuous irrigation with poor quality water and consequent crop – failure affected the agricultural economy in the Anuradhapura area, ultimately resulting in the shift of the kingdom to Polonnaruwa in the 10th century.

The recurrence of large scale crop–failures cannot be ruled out today. However, it is now impossible to shift the population in the affected areas unlike in the 10th century. A possible crop failure today will lead to disaster, and destruction of the developments achieved during the last two decades. A proper water management programme guided by the results of a continuous monitoring programme and water quality criteria, will undoubtedly prevent such disasters.

In the case of a natural resource such as water, it has been revealed that the per capita availability has declined to alarming levels affecting the future generations. To maintain sustainability without curtailing the current human needs, it is essential to develop technologies on the reuse or recycling of water, effluent treatment processes etc. The development of such technology is impossible without the necessary scientific knowledge on the water bodies. The immediate requirement is to assess the water quality and its seasonal variation by monitoring programmes, and the subsequent use of scientific principles, to monitor sustainability without a decrease in the per capita availability.

Table.1: FAO Guidelines for interpretation of water quality for irrigation.

IRRIGATION PROBLEM	DEGREE OF PROBLEM		
	No Problem	Increasing Problem	Severe Problem
Salinity (affects crop water availability) ECw (mmhos/cm)	< 0.75	0.75 – 3.0	> 3.0
Permeability (affects infiltration rate into soil)			
ECw (mmhos/cm)	> 0.5	0.5 – 0.2	< 0.2
adj. SAR (or ESP)			
Montmorillonite (2:1 crystal lattice)	< 6	6 – 9	> 9
Illite – vermiculite (2:1 crystal lattice)	< 8	8 –16	> 16
Kaolinite – sesquioxides (1:1 crystal lattice)	<16	16 - 24	> 24
Specific toxicity (affect sensitive crops)			
Sodium (adj. SAR)	< 3	3 – 9	> 9
Chloride (meq/dm-3)	< 4	4 – 10	> 10
Boron (mg/dm-3)	< 0.75	0.75 – 2.0	> 2.0

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