Indian Journal of Science and Technology Vol. 4 No. 1 (Jan 2011) ISSN: 0974- 6846

Sustainable tank irrigation: An irrigation water quality perspective

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Abstract

Thiruvallur district, a newly formed district bifurcated from erstwhile Chengalpattu district is located in the north east part of Tamil Nadu, India with agriculture as main occupation. The total cultivated area of the district is 184198 hectares. Nearly 47% of the total work force is engaged in agriculture supported by tank irrigation. In this study, 10 major irrigation tanks in the district was selected and analyzed for its water quality during the period Oct to Dec 2010 (northeast monsoon). The objective of this paper is to develop a better understanding of the effect of water quality upon soil and crops and to assist in selecting suitable alternatives to cope with the potential water quality related problems that might reduce production under prevailing conditions of use. The parameters studied include salinity hazard, sodium hazard, pH, alkalinity and other specific ions like chloride (Cl), sulphate (SO_4^{2-}) and nitrate-nitrogen (NO_3-N). Out of the 10 irrigation tanks investigated, problems related to salinity and sodium hazard was identified in irrigation waters of two tanks. The potential severity of problems that can be expected to develop during long term uses is studied for all the tanks and special management practices required to maintain acceptable crop yields is suggested.

Keywords: Tank irrigation, water quality, salinity, water management.

Introduction

The quality of groundwater used for irrigation is greatly influenced by the quantity of dissolved salts. In case of irrigation, the salts are applied with water and remain behind in the soil as water evaporates or is used by the crop. Most of the water in an irrigation tank is brought in during rainy season. However, only a small portion of the tank water is obtained from direct precipitation. The bulk of it comes from the catchment area. As water flows into the tank it brings dissolved materials by contact with soil, rock and other inorganic and organic substances. Irrigation water may benefit crops by supplying certain plant nutrients. On the other hand, a saline water or high sodium water may be harmful. Irrigated agriculture is dependent on an adequate water supply of usable quality. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. This situation is now changing in many areas. Knowledge of irrigation water quality has become critical in order to understanding management for long-term productivity. The objective of this paper is to develop a better understanding of the effect of water quality upon soil and crops and to assist in selecting suitable alternatives to cope with the potential water quality related problems that might reduce production under prevailing conditions of use. In this study 10 major irrigation tanks in the district was selected and its water quality analyzed. The potential severity of problems that can be expected to develop during long term uses is studied for all the tanks and special management practices required to maintain acceptable crop yields is suggested.

Study area

Thiruvallur district, a newly formed district bifurcated from the erstwhile Chengalpattu district (on 1st January 1997), is located in the north east part of Tamil Nadu. The district is surrounded by Kanchipuram district in the south, Vellore district in the west, Bay of Bengal in the east and Andhra Pradesh state in the north. The average rainfall of the district is 1104.4 mm of which the north east monsoon contributes to the tune of 690 mm. The main occupation of the district is agriculture and allied activities. Nearly 47% of the total workforce is engaged in agriculture sector. The major crops grown in the district are rice, cumbu, ragi, green gram, sugarcane and groundnut. Apart from this certain horticulture crops like mango, guava and vegetables have also been cultivated successfully. There are no perennial rivers in the district only seasonal rivers like Kosathalayar, Aravar, Nandi, Kallar, Coovam and Buckhingham canal. Since these seasonal rivers are not sufficient, irrigation through tanks, tube wells, open wells are very common. The various sources of irrigation, the area irrigated are shown in Table1.

Table 1. Various sources of irrigation in the district & its aerial extent.

Source of irrigation	Area in hectares
Tanks	42012
Tube well	33188
Well	63983
Canals	4240
Other sources	1846
Net area irrigated	110266
Gross area irrigated	145269

Source: National informatics centre, Thiruvallur, TN.

Tank irrigation is one of the important and oldest sources of irrigation in this district. These tank irrigation systems have a special significance to the marginal and small farmers. Marginal and small farmers make up for a very large number essentially among those depending on tank irrigation as these systems are less capital intensive and have wider geographical distribution than large projects (Palanisami & Easter, 2000). There are numerous irrigation

Indian Journal of Science and Technology Vol. 4 No. 1 (Jan 2011) ISSN: 0974- 6846

Table 2. Details of ten major irrigation tanks in Thiruvallur district.

Tank	Taluk	Ayacut (hec.)	Full tank level (m)	Capacity (Million m^3)	Water spread area (Million m^2)
Arasur tank	Ponneri	271.55	8.98	0.699	1.062
Methur large tank	Ponneri	794.01	7.31	1.419	1.522
Kollur large tank	Ponneri	269.93	4.27	0.793	1.361
Gummidipoondi large tank	Gummidipoondi	501.22	14.00	0.640	0.790
Poovalampedu large tank	Gummidipoondi	101.75	15.25	0.350	1.150
Peruvayal large tank	Gummidipoondi	199.07	30.48	0.480	0.420
Chinnampedu large tank	Gummidipoondi	625.25	18.09	8.495	4.700
Mathuravasal large tank	Uttokottai	214.08	20.88	1.310	1.255
Panapakkam tank	Uttokottai	207.20	24.23	0.661	0.634
Vengal tank	Uttokottai	149.56	30.17	0.960	3.252

tanks in this district of which ten major irrigation tanks were chosen for this study and their water quality was analyzed. The details of the 10 major irrigation tanks chosen are given in Table 2.

Irrigation water quality criteria

Soil scientists use the following categories to describe irrigation water effects on crop production and soil quality: Salinity hazard - total soluble salt content; Sodium hazard - relative proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions; pH; Alkalinity - carbonate and bicarbonate; Specific ions: chloride (Cl), sulphate (SO_4^{2-}), boron (B), and nitrate-nitrogen (NO_3-N).

Other potential irrigation water contaminants that may affect suitability for agricultural use include heavy metals and microbial contaminants. Guidelines for evaluation of water quality for irrigation are given in Table 3.

Analytical procedures for the laboratory determinations are given in several publications (Richards, 1954; Rhoades & Clark, 1978; Dewis & Freitas,1970; APHA,1980).

Salinity hazard

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (EC_w). The primary effect of high EC_w 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_w, 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_w increases.

The amount of water transpired through a crop is directly related to yield; therefore, irrigation water with high EC_w reduces yield potential. Beyond effects on the immediate crop is the long term impact of salt loading through the irrigation water. Water with an EC_w of only 1.15 dS/m contains approximately 2,000 pounds of salt for every acre foot of water. Other terms that laboratories and literature sources use to report salinity hazard are: salts, salinity, electrical conductivity (EC_w), or total dissolved solids (TDS). These terms are all comparable and all quantify the amount of dissolved "salts" (or ions, charged particles) in a water sample. However, TDS is a direct measurement of dissolved ions and EC is an indirect measurement of ions by an electrode.

Sodium hazard

While EC_w is an assessment of all soluble salts in a sample, sodium hazard is defined separately because of sodium's specific detrimental effects on soil physical properties. The sodium hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na^+) to calcium (Ca^{++}) and magnesium (Mg^{++}) ions in a sample. Calcium will flocculate (hold together) while sodium disperses (pushes

Table 3. Guidelines for interpretations of water quality for irrigation[1].

Potential irrigation problem	Units	Degree of restriction on use: None	Slight to moderate	Severe
Salinity *(affects crop water availability)*[2]				
EC_w	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_w & SAR together)*[3]				
SAR = 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 *(affects sensitive crops)*				
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	me/l	< 3	> 3	
Boron (B)	mg/l	< 0.7	0.7 - 3.0	> 3.0
Miscellaneous effects *(affects susceptible crops)*				
Nitrogen (NO_3-N)	mg/l	< 5	5 - 30	> 30
Bicarbonate (HCO_3)				
(overhead sprinkling only)	me/l	< 1.5	1.5 - 8.5	> 8.5
pH		Normal Range 6.5 - 8.4		

[1]Adapted from University of California Committee of Consultants 1974.[2]ECw means electrical conductivity, a measure of the water salinity, reported in deci siemens per metre at 25°C (dS/m) or in units millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l). [3]SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. Adapted from Rhoades, 1977 & Oster & Schroer 1979.

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Table 4. Irrigation water quality for the ten major tanks.

Water parameter	Unit	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10
Electrical conductivity EC_w	dS/m	0.280	0.230	0.160	0.910	0.230	0.260	0.640	0.850	0.190	0.090
pH	-	6.5	6.9	6.7	6.4	6.9	6.8	7.1	7.4	7.1	6.9
Ca^{++}	me/l	1.1	0.6	0.5	3.4	1.1	0.6	1.7	2.3	1.2	0.5
Mg^{++}	me/l	0.411	0.494	0.411	1.81	0.411	0.494	1.316	1.892	0.082	0.082
Na^+	me/l	1.74	1.696	1.261	3.784	1.131	1.957	4.000	5.306	1.522	0.869
K^+	me/l	0.102	0.076	0.102	0.102	0.051	0.204	0.460	0.051	0.127	0.051
HCO_3	me/l	1.999	1.507	1.294	1.999	1.507	2.097	4.195	5.598	1.016	0.816
CO_3	me/l	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
SO_4	me/l	0.104	0.021	0.104	1.749	0.249	0.041	0	0.812	0.728	0.125
Cl	me/l	0.902	0.987	0.592	4.710	0.705	0.789	2.707	2.989	0.592	0.310
NO_3-N	mg/l	18	24	18	43	14	17	32	2	37	16
TDS	mg/l	187	166	132	536	152	182	416	508	189	91
$CaCO_3$	mg/l	75	55	45	460	75	55	150	210	65	30
Total alkalinity as $CaCO_3$	mg/l	100	75	65	100	75	105	210	275	50	40
SAR	me/l	2.0	2.28	1.87	2.34	1.30	2.61	3.65	3.68	1.90	1.62

Tank 1-Arasur tank, Tank 2-Methur large tank, Tank 3-Kollur large tank, Tank 4-Gummidipoondi large tank, Tank 5-Poovalampedu large tank, Tank 6-Peruvoyal large tank, Tank 7-Chinnampedu large tank, Tank 8-Mathuravasal large tank, Tank 9-Panapakkam tank, Tank 10-Vengal tank.

apart) soil particles. This dispersed soil will readily crust and have water infiltration and permeability problems. However, many factors including soil texture, organic matter, crop type, climate, irrigation system and management impact how sodium in irrigation water affects soils. Additionally, at the same SAR, water with low EC_w (salinity) has a greater dispersion potential than water with high EC_w. Sodium in irrigation water can also cause toxicity problems for some crops, especially when sprinkler applied.

pH & alkalinity

The acidity or basicity of irrigation water is expressed as pH (< 7 acidic; > 7 basic). The normal pH range for irrigation water is from 6.5-8.4. High pH's above 8.5 are often caused by high bicarbonate (HCO^{3-}) and carbonate (CO_3^{2-}) concentrations known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. This alkaline water could intensify sodic soil conditions.

Chloride

The most common toxicity is from chloride in the irrigation water. Chloride is not adsorbed or held back by soils, therefore it moves readily with the soil-water, is taken up by the crop, moves in the transpiration stream and accumulates in the leaves. If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. Normally plant injury occurs first at the leaf tips (which is common for chloride toxicity), and progresses from the tip back along the edges as severity increases. Excessive necrosis (dead tissue) is often accompanied by early leaf drop or defoliation. With sensitive crops these symptoms occur when leaves accumulate from 0.3 to 1.0% chloride on a dry weight basis, but sensitivity varies among these crops. Many tree crops, for example begin to show injury above 0.3% chloride (dry weight).

Boron

Boron unlike sodium is an essential element for plant growth (Chloride is also essential but in such small quantities that it is frequently classed non-essential). Boron is needed in relatively small amounts however and if present in amounts appreciably greater than needed, it becomes toxic. For some crops, if 0.2 mg/l boron in water is essential, 1 to 2 mg/l may be toxic. Surface water rarely contains enough boron to be toxic but well water or springs occasionally contain toxic amounts, especially near geothermal areas and earthquake faults. Boron problems originating from the water are probably more frequent than those originating in the soil. Boron toxicity can affect nearly all crops but, like salinity, there is a wide range of tolerance among crops.

Sulphate

The sulphate ion is a major contributor to salinity in many of the irrigation waters. However, toxicity is rarely a problem, except at very high concentrations where high sulphate may interfere with uptake of other nutrients. As with boron, sulphate in irrigation water has fertility benefits and irrigation water which has enough sulphate helps for maximum production for most crops. Exceptions are sandy fields with less than one percent organic matter and less than 10 ppm SO_4-S in irrigation water.

Nitrogen

Nitrogen is a plant nutrient and stimulates crop growth. Natural soil nitrogen or added fertilizers are the usual sources, but nitrogen in the irrigation water has much the same effect as soil-applied fertilizer nitrogen and an excess will cause problems, just as too much fertilizer would. If excessive quantities are present or applied,

Fig. 1. Electrical conductivity in irrigation water of ten tanks.

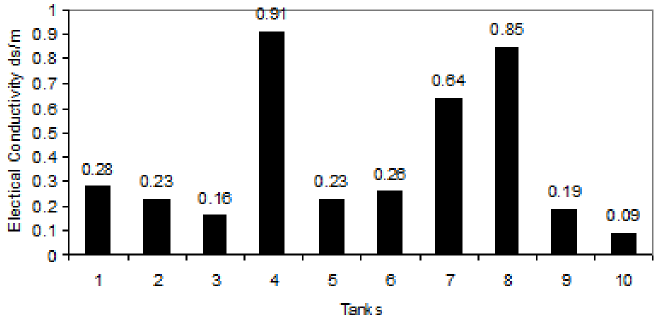


Fig. 2. TDS in irrigation water of ten tanks.

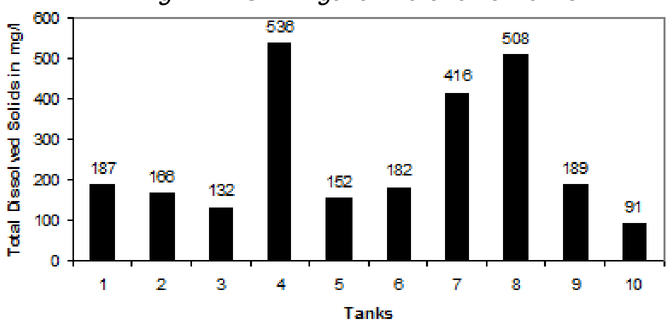
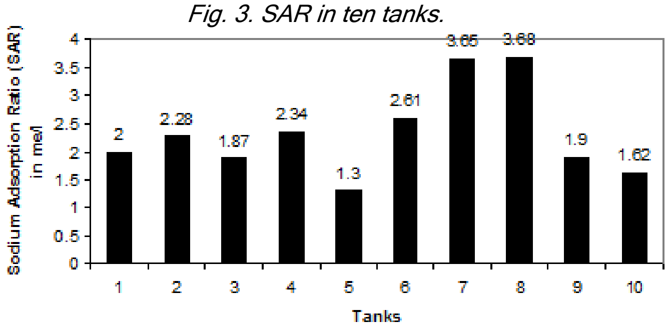


Fig. 3. SAR in ten tanks.



production of several commonly grown crops may be upset because of over-stimulation of growth, delayed maturity or poor quality. The most readily available forms of nitrogen are nitrate and ammonium but nitrate (NO_3-N) occurs most frequently in irrigation water. Ammonium-nitrogen is seldom present in excess of 1 mg/l unless ammonia fertilizer or wastewater is being added to the water supply. The concentration in most surface and groundwater is usually less than 5 mg/l NO_3-N but some unusual groundwater may contain quantities in excess of 50 mg/l. Drainage water from below the root zone frequently has higher levels of nitrogen due to deep leaching of fertilizers. Since nitrogen is present in so many water supplies, it is recommended that the nitrogen content of all irrigation water be monitored and the nitrogen present included as an integral part of the planned fertilization programme. Sensitive crops may be affected by nitrogen concentrations above 5 mg/l. Most other crops are relatively unaffected until nitrogen exceeds 30 mg/l.

Results and discussion

The prediction that a water quality-related problem will occur requires evaluation of the potential of the water to create soil conditions that may restrict its use or that may require the use of special management techniques to maintain acceptable yields. Water quality evaluation results for all the 10 tanks during the period from Oct to Dec 2010 (northeast monsoon) are shown in Table 4.

Salinity problem

Salts are added to the soil each time of irrigation. These salts will reduce crop yield if they accumulate in the rooting depth to damaging concentrations. The crop removes much of the applied water from the soil to meet its evapotranspiration demand (ET) but leaves most of the salt behind to concentrate in the shrinking volume of soil-water. At each irrigation, more salt is added with the applied water. Build-up of soil salinity can reduce the soil-water available to the crop. Water salinity hazard is measured by electrical conductivity EC_w. The EC_w values for the 10 tanks are shown in Fig. 1. Although severe salinity problem ($EC_w > 3$) was not identified in any of the tanks slight to moderate (EC_w 0.7- 3) problem was identified in 2 tanks namely the Gummidipoondi large tank (Tank 4) and Mathuravasal large tank (Tank 8). 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. The total dissolved solids (TDS) is shown in Fig. 2. The TDS value for the above 2 tanks also lie in range of 450 to 2000 mg/l. This confirms the existence of salinity problem. TDS value of 538 mg/l in the Gummidipoondi large tank (Tank 4) and TDS value of 508 mg/l in the Mathuravasal large tank (Tank 8) puts the degree of restriction on use to the category of slight to moderate. Although there is no immediate necessity to look for alternate crops as tolerance of crops grown in these districts are well within the limits, better management would help to maintain productivity in the long run. Several management options are available for salinity control and in practice a combination may be used to solve the problem. Leaching salts out of the root zone before they build up to levels that might affect yields is a basic step in production even for water of the best quality and must be practiced when necessary to avoid salt accumulation that could ultimately affect production.

The necessary leaching requirement (LR) is to be estimated for a particular crop and should be used (Rhoades, 1974; Rhoades & Merrill, 1976). In areas where a build-up of soil salinity cannot be controlled at an acceptable concentration for the crop being grown, an alternative crop can be selected that is both more tolerant of the expected soil salinity and can produce economical yields (Maas & Hoffman, 1977; Maas, 1984). Adequate drainage is equally important and long-term salinity control is not otherwise possible.

Infiltration problem

An infiltration problem occurs if the irrigation water does not enter the soil rapidly enough during a normal irrigation cycle to replenish the soil with water needed by the crop before the next irrigation. This is evaluated using EC_w and sodium adsorption ratio (SAR) together. The SAR values for the 10 tanks are shown in Fig. 3. In Kollur large tank (Tank 3), SAR value = 1.87 which lies between 0 to 3 and EC_w = 0.16 which is less than 0.2 and hence the degree of restriction on use comes under the category severe. In Chinnampedu large tank (Tank 7) and Mathuravasal large tank (Tank 8) SAR lies between 3 to 6 and EC_w lies between 0.3 and 1.2 imposing slight to moderate restrictions on use. The management steps available to help maintain yields can be either chemical or physical. Chemical practices involve changing the soil or water chemistry that influences soil infiltration rates. This is normally accomplished by adding a chemical amendment, such as gypsum, to either the soil or the water or, in a few cases, by blending two or more sources of water to reduce the potential hazard. Physical methods include cultural practices that can be expected to improve or maintain infiltration rates during periods of irrigation or rainfall.

Specific ion toxicity

Specific ion toxicity like sodium and chloride may affect sensitive crops. Chloride ion concentration was found to be less than 4 me/l in all the tanks except in Gummidipoondi large tank (Tank 4) with a value equal to 4.710 me/l imposing slight to moderate restriction in use on sensitive crops. Sodium ion concentration was slightly above normal in Chinnampedu large tank (Tank 7) and Mathuravasal large tank (Tank 8) as SAR lies between 3 to 6.

Miscellaneous effects

The usual range of nitrate-nitrogen in irrigation water is 0 to 10 mg/l. It was observed that in 9 out of 10 tanks it was greater than 10. Waters high in nitrogen 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. pH and sulphate was found to be in the normal range in all the tanks.

Conclusion

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. 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.

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