Mathematical Model to Estimate Drain Water Quality in Saturated Soils and its Comparison with Field Experiments in South of Khuzestan

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Abstract: In order to attain sustainable agriculture, optimum use of water resources and reduction of the adverse effect of irrigation and drainage networks development, it is compulsory to prepare their drain water management plans before construction. To compile such a plan a proper estimate of drain water quality and quantity should be available in both reclamation and operation periods. For the validation of this model, Drainage water salinity data from public 6 pipe drainage units near Khuzistan, Iran were studied. The control volume was between the drainage level and the soil surface, the soil condition was assumed saturated. In this research the mathematical model for forecasting how much of salinity in drain water quality is related to irrigation water and soil salinity. In this research in unsaturated zone water flow is assumed to be in Steady-state. Ultimately the model indicated that the proportions of deep and shallow groundwater entering the drain laterals were very large in this area.
[Majid Sharifipour, AbdAli Naseri, Siroos Jafari, Shadman Veysi. **Mathematical Model to Estimate Drain Water Quality in Saturated Soils and its Comparison with Field Experiments in South of Khuzestan.** Rep Opinion 2013;5(1):1-6]. (ISSN:1553-9873). http://www.sciencepub.net/report. 1

Key words: Groundwater, Impervious Layer, Leaching, Reclamation, Salinity

1. Introduction

At present around 20-30 million hectares of the world's 260 million irrigated lands are affected by salinity (FAO, 2002). Therefore drainage development is inevitable especially in areas with saline ground water for the optimum plant growth and controlling the land salinity. On the other hand, although a clear picture has not been presented in this regard, but numerous cases of problem of drain water removal from vast irrigated land have been reported, in areas such as South Asia, South East Asia, Central Asia, North Africa, Middle East, Australia and the United States of America (Iranian national committee on Irrigation and drainage, 2001).

Jury (1975) has declared based on research in San Joaquin valley that it might take years before the rate of salt discharge from the root area reaches a certain level. The initial leaching for land reclamation is the most critical stage of drain water salinity; because this stage is usually performed in salt affected soils and the goal is to remove a considerable amount of salt, which has been accumulated in the land profile over thousands of years, in a short period of leaching (reclamation) time. Therefore the highest rate of salt discharge into a recipient source (such as rivers) is during this initial leaching stage.

A study by (christen et al. 2001) on underground drainage systems in irrigated areas in Australia demonstrated that in many cases the amount of outlet salt is 5 to 10 times the amount of irrigation water salts. When reclamation of root zone was completed it established that these systems extract the salt of the soil and groundwater. These salts mainly aren't from the root zone and their extraction has no benefit to the plants.

Christen and Skehan (2001) compared the distant deep drains with close shallow drains. Deep drains extracted 5867 kg/ha salt with an 11 dS/m drain water over two seasons and has a 50% efficiency in reduction of salt levels. While shallow drains which are only active after each rainfall or irrigation and their drain water electric conductivity is around 2 dS/m.

In another study by Muirhead et al (1996) it was determined that shallow close drains are more practical than deep, distant ones in clay soils. The advantage of this method is that the root area is cleared quicker and the salt content in shallow drains is 10% of those deep drains. In addition to that, shallow drains have more control over the salinity levels in root area.

Grisimer (1990) studied the effect of drain depth and distance over drain water salinity based on numerical simulation. In this research the effects of 2.5, 3 and 4 m depths and 20, 40, 60 and 80 m distances on drain water salinity was studied And concluded that an increase in drain depth in relation to an increase in drain distance had more effect on drain water salinity.

Kelleners et al (2000) partitioned the soil profile into two areas of one higher and the other than the drains level in order to study the effects of groundwater and irrigation water mixture on the quality of drain water. They simulated the water and salt of higher drains with dispersion and mass flow equation and by steady flow functions for levels lower than the drains. In a long study, they demonstrated that it would take 10 to 15 years to bring the quality of drain water in the test areas to an equilibrium state

Khuzestan plain is one of the most important agricultural areas in Iran and the biggest rivers of the country flow through this region. There are More than half million hectares of irrigation and drainage networks in this area either under study or under construction. The majority of which are faced with salinity problem. Thus the proper management of the produced drain water in Khuzestan, as a source of reusable water seems to be necessary.

During the operation period of irrigation and drainage networks in salt affected soil, the drain water salinity decreases gradually until equilibrium in salt reaches a balance.

If the quantity and quality of drain water were determined, in different stages, the drain water can be managed according to capacity of the recipient sources. The goal of this research is to enhance a model to forecast portion of irrigation water and soil salinity drain water during initial leaching uptake in south Khuzestan plain, Iran.

2. Materials and Methods

2.1 Development of Mathematical Model

Salt balance estimation was used for evaluation of root zone and drain water salinity in different scales (Milnes and Perrochet (2006), Schoups et al. (2005), Sharma (1999)). The stored water in root zone can be explained with the fallowing equation:

$$SM = L\theta \qquad (1)$$

Where *SM* is the content of water storage in a soil depth, *L* is the depth of soil and θ is the volume water content of soil.

If the root zone is considered as a control volume by assuming the one dimensional model, then the water inlet to this control volume would be irrigation water and precipitation and the outlet would be evaporation and deep percolation. To make up a correlation between salt and water balances, some simplifications will be assumed:

Soil is saturated by water and then, Soil water content is considered in a full mixing state, i.e. the concentration of soil water content is equivalent at the same time.

Sorption isotherm is linear:

$$S_S = K'C_S$$

Where S_s is the absorbed salt in soil mass unit, K' is the distribution coefficient and C_s is the soil water concentration.The total salt content calculated from the sum total of dissolved salts and absorbed salts in the root zone:

$$TS = \theta LC_S + L\rho K'S_S$$

Where *TS* is the total salt of soil and ρ is the dry bulk density. Equation (3) can be rearranged as:

$$TS = \theta L(1+\frac{\rho K'}{\theta})Cs$$

With $R = 1+\frac{\rho K'}{\theta}$, then

Equation (4) can be written as:

$$TS = \theta \; L \, R \, C_S$$

Where *R* is the retardation factor.

The partnership of precipitation and evaporation in salt balance are negligible so fluctuation of amount of salt in soil can be written as:

$$\frac{d(TS)}{dt} = IC_i - PC_s$$

Where *t* is the time, *I* is the rate of irrigation, C_i is the concentration of irrigation water and *P* is the rate of drainage.

As a result of considering saturation condition for soil, the control volume is full of water and the income and outcome must be equal. So *P* and *I* are same, then using (5), equation (6) can be written as:

$$\frac{d(\theta L C_S R)}{dt} = I(C_i - C_S)$$

The θ, *L* and *R* are constant, so:

$$\frac{dC_S}{C_i - C_S} = \frac{Idt}{\theta LR} \qquad (8)$$

Considering boundary conditions as:

$$t = 0 \; , \quad C_s = C_{s_0}$$

$$t = t \; , \quad C_s = C_{s_t}$$

$$\int_{C_s=C_{s_0}}^{C_s=C_{s_t}} \frac{dC_s}{C_i - C_s} = \int_{t=0}^{t=t} \frac{I}{\theta LR} dt$$

Where C_{St} is the soil water concentration after a duration of *t*. Solving

$$C_{s_t} = C_i + (C_{s_0} - C_i)e^{-\frac{It}{\theta LR}}$$

Due to preoperational flow, part of leaching water escapes from the macro porous media and its salinity does not change. Another part flow through the micro porous media and its salinity becomes the same as the salinity of soil water (Smedema et al, 2005). As result taking into consideration the definition of leaching efficiency, the concentration of water passing through the soil will be as follows:

$$C_p = f.C_{s_t} + (1-f)C_i$$

Where C_p is the drain water concentration, f is the leaching efficiency and C_{St} calculated from equation (10).

2.2 Experiments

This experiment was established in a field near the Karun River, south of Khuzestan province, SW Iran. This farm has 10 hectares areas.

Leaching water was supplied from Karun River. PVC pipes with synthetic envelop were used for the drainage. The lateral drains are 35 meters distance and they are installed at an average depth of 1.3 meters. The collector drains were open.

The average annual rainfall in this area is about 158.56 mm. the mean temperature in July is 37°C and in January 12.5°C, which are respectively the warmest and the coolest months of the year. The mean of maximum temperature in July is 45.4°C and in 18.1°C January.

The soils were sampled from 0-30, 30-60 and 60-90 cm depths and the electrical conductivity (EC) of their saturation extract were measured.

The leaching water was supplied at 143 cm (the volume of water divided by the area of the land). After the end of watering operation and allowing enough time for the land to dry, sampling of the soil was done again. This time soil from same depths ware taken and their saturation extract EC were measured.

The discharge of the lateral drains was measured daily by volumetric method and samples were determined for electrical conductivity by a WTW EC meter. This measurement was carried out for leaching water.

3. Results and Discussion

Table (1) soil saturation extracts EC before reclamation

Points														
1			2			3			4			5		
Sampling depths														
60-90	30-60	0-30	60-90	30-60	0-30	60-90	30-60	0-30	60-90	30-60	0-30	60-90	30-60	0-30
EC (dS/m)														
67.1	71.7	96.0	61.3	80.0	85.7	58.2	73.2	113.0	63.9	82.4	93.0	46.7	68.7	87.0

The soil texture was very heavy and the depth of impervious layer was about 270-280 cm from the soil surface. The soil surface has different signs of salinity in all parts, such as a soil swelling, lack of vegetation cover, salt crystal formation, etc. The results of hydrometric study of soil texture showed that the soil averagely has 68 percent clay, 21 percent silt and 11 percent sand.Groundwater level was at 120-130cm from the soil surface. The electric conductivities of groundwater in the both drilled pits were 124 and 129 dS/m. Initial salinity of soil saturated extracts before leaching are shown in table (1) and the average discharge of lateral drains in the reclamation period and their related salinity are shown in figures (1) and (2) respectively.

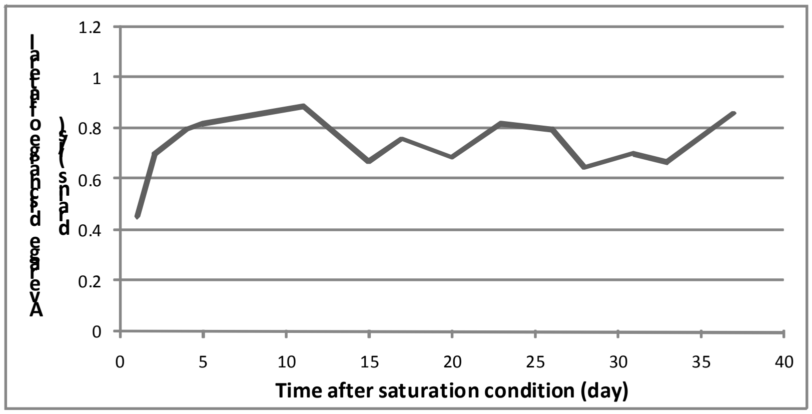

Figure (1) Average discharge of lateral drains

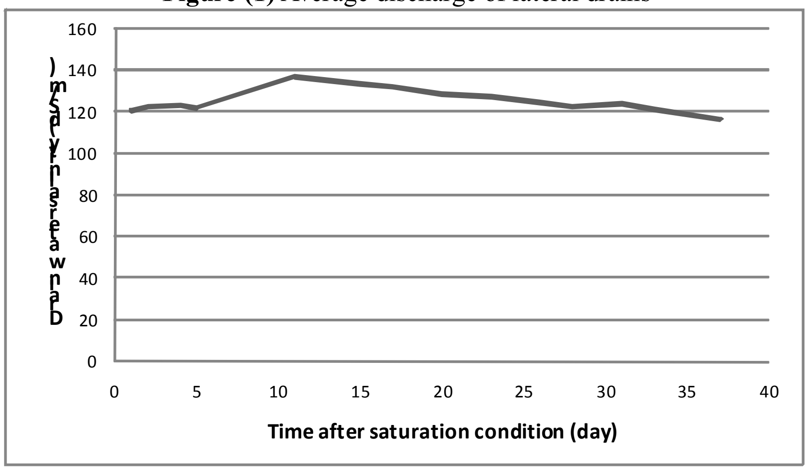

Figure (2) drain water salinity in the reclamation period

As it can be observed in Fig (2) the drain water salinity does not alter considerably during the reclamation period. Also despite the general decreasing trend shown by the diagram, during the leaching period there were some fluctuations. It seems that these fluctuations in line with individual ponds filling inside each part in direction of longitudinal slope of the farm. During the water filling of different sections, first the part at the higher level was filled and then the lower ponds. it is needless to say that when the soil is not completely saturated, the water passing through the smaller pores and dissolving a higher proportion of the salts and as the soil is approaching saturation point due to the amount of water passing through bigger holes and gaps, as the result of preferential flow, the level of salts in drain water will be reduced.

The results of electric conductivity of saturation extract of soil after reclamation have been shown in table (2).

Table (2) soil samples saturation extract EC after reclamation

Points								
1			2			3		
Sampling depths								
60-90	30-60	0-30	60-90	30-60	0-30	60-90	30-60	0-30
EC (dS/m)								
26.50	18.64	6.59	5.84	5.53	3.82	7.36	5.11	4.02

The remarkable point is the general change in the soil saturation extract EC before and after leaching. Before leaching the direction of water and salt movement is upwards due to great evaporation potential from shallow and saline groundwater table which increase the salinity of soil profile over a long period. During leaching due to water piston pressure, the salts are driven downwards, hence higher accumulation of salt at lower layers. Figure (3) demonstrates the fluctuation of average of soil saturation extract salinity at different depths before and after leaching.

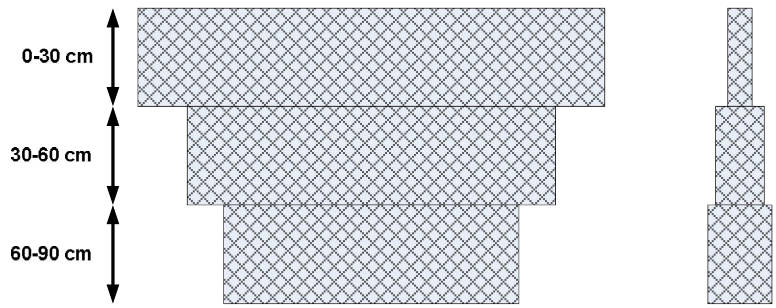

Figure (3) soil saturation extracts salinity at different depth before and after leaching

The model was solved considering experiments conditions and was compared to field results. The outcome is shown in figure (4) which is drain water salinity estimated by model compared with the ones observed in field experiments.

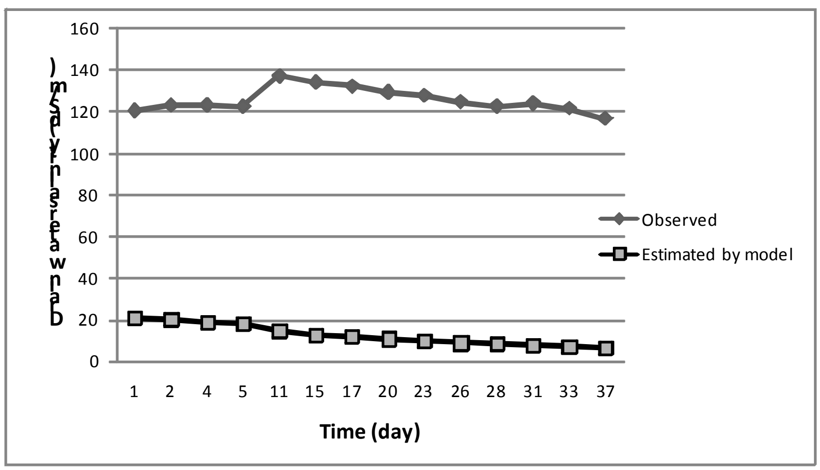

Figure (4) drain water salinity: observed and estimated by model

As it can be observed, there is no accordance between observed drain water salinity and model estimation. On the other hand, the measured drain water salinity is very close to shallow groundwater salinity. The temporal mean of drain water salinities in different lateral drains are 118.8, 120.0, 119.6 and 116 dS/m which are slightly lower than groundwater salinity, which have been measured at two pits and 124 and 129 dS/m prior to leaching operation.

The movement of water and salt in this mathematical model is assumed in one dimensional vertical flow and the control volume is between soil surface and drainage level, whereas the leached water is mixed in with groundwater and as a result concentration of salts in the outlet drain water is significantly affected by ground water salinity.

Jury et al (2003) demonstrated that depth of impervious layer has a great influence on the time taken for the outlet drain water salinity to reach equilibrium and the deeper impervious layer the longer it would take to reach this state. As it is shown in figure (5) if the drains are installed on top of the impervious layer, it would take the drain water a reasonably shorter period to reach the equilibrium state.

4. Conclusions

The mathematical model to estimate share of irrigation water and soil salinity in pipe drain in saturated soils (in leaching and reclamation period) which was developed by combining water and salt balance and the control volume was from soil surface to drainage level, the result has shown that drain water salinity is highly affected by ground water salinity, it is proposed that control volume be expanded to impervious layer and water movement assumed two dimensional.

The drain water salinity is a little lower than ground water salinity because of irrigation water. The main reason that increases groundwater contribution in drain water salinity is the drain depth. Deep drains increase groundwater contribution so increase the environmental dangers and pumping costs, especially in no irrigation seasons.

Acknowledgement:

The authors are very grateful to Sazab Pardazan Consulting Engineering Company for financial support also Faculty of water engineering and sciences of Shahid Chamran university of Ahwaz, Sugarcane research center and Farday e Sabz e Jonob Company for helping the field experiments.

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12/12/2012