Soil Salinity / Sodicity and Ground Water Quality Changes in Relation to Rainfall and Reclamation Activities

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ABSTRACT

The agronomic, chemical and engineering approaches for reclamation of saline sodic soil were investigated at the research farm of Soil Salinity Research Institute, Pindi Bhattian, Pakistan. A catchment area of nine acres was selected, sampled and analyzed for salinity parameters. A sub-surface evaporative basin (SEB) of 0.3 acre size having depth of six feet was dug in the center of the catchment area. Piezometers network on all the directions and in the SEB were installed to record the water levels weekly. The groundwater quality was monitored quarterly. The soil analysis of catchment area was conducted pre and post-monsoon. Rain and pan evaporation data were also recorded.

It was observed that during the dry spell the surface accumulation of salts increased many times. The intensive rains of monsoon season reverted the cycle and salts started leaching into lower depths. However, the quantity of total precipitation in the two years was not ample to sequester the salts into SEB because the groundwater level was consistently going downwards. Hence, in spite of deep ploughing and cultivation of the catchment area, the land reclamation was nominal. But when chemical amendments were applied, mixed into the soil, irrigation water provided and subsequent rice crop was grown in selected two acres adjacent to the SEB, the salts moved into the SEB. The groundwater of SEB Piezometers installed in the directions of cropping area (East and South) was having significantly higher EC. pH, SAR, CO_3^{-2} HCO_3^{-2} and Na^{+1} as compared to Northern and Western sides without crops. Each irrigation attempt caused a substantial movement of salt into the SEB. The SEB bed was having EC, pH and SAR of 6.33 dSm^{-1}, 9.98 and 150.6 respectively. There have been no conspicuous changes in groundwater quality in two years except through soil reclamation and crop growing activities, which resulted in appreciable increase of EC, SAR and RSC of it.

INTRODUCTION

There are different approaches for reclamation of salt-affected soils. The prominent ones are chemical, biological, hydro-technical, physical and engineering approaches. The synergistic approach is the combination of any two or more approaches. (Hussain et al. 1990). In the conventional approach, the salts are not removed from the hydro-cycle. Recently, it has been emphasized by the scientists that such ways and measures should be devised in which the salts are

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removed from the cycle. Subsurface evaporation basin (SEB) is the technique which has been proposed to find answer to the current question. Under this technique, a bigger sized basin is excavated at a low-lying point in the topographical configuration of the affected area. The salts dissolved in the rainy water or irrigation water move ultimately to this basin. Resultantly, the salts are removed from the hydro-cycle and accumulate in the basin. The catchment area is kept clean and cultivated so as to harvest the maximum benefits of the rainfall, especially in the monsoon season. The ripping (deep ploughing) has been reported to ease the leaching of salts into the profile (Hussain et al. 2000).

In arid and semi-arid regions of the world, salinity / sodicity is a permanent problem inherited due to climatic conditions (high temperature and low rainfall). The net movement of water is upwards. The salts dissolved in the water accumulate slowly and gradually in the surface of the soil as the water evaporates. Hence, the soil salinity / sodicity pattern, changes with variations in the frequency and intensity of rainfall as well as temperature regime. Mostly, salts accumulate on the surface in the winter and dry season and wash down into the lower profile with rainfall. The alternating dry shell and intensive monsoon rainfalls in some of the years are very common. Soil salinity increases through capillary rise from the saline water table and from concentration of irrigation water in the filed. Desalinization may occur through vertical percolation of salts and surface drainage. Changes in salinity with time are usually rapid depending upon management practices or abandoning the land (Cauppens et al. 1997). The reclamation activities in which water is applied in excess to the salt affected soils also favor leaching of salts downwards.

To find a scientific answer to the above-mentioned questions, present investigations were conducted. The variations in soil salinity / sodicity with respect to time span and climatic conditions (rainfall and evaporation) as well as reclamation activities were monitored. The resultant changes in the quality of water were also assessed. The probability of salt mobility towards the SEB was evaluated as well. Hence, the current burning issues were included in this research study.

MATERIALS AND METHODS

A soil reclamation experiment employing synergistic approach combining agronomic, biological, chemical and engineering measures was conducted at the research farm of Soil Salinity Research Institute, (SSRI) Pindi Bhattian, Pakistan (Figure 1).

These investigations were conducted by collaborative efforts of SSRI, International Water Management Institute (IWMI), Lahore, Pakistan Council for Research in Water Resources (PCRWR) and CSRIO, Australia under the project, "Conjunctive Water Management for Sustainable Agriculture in South Asia". A catchment area of nine acres, highly saline sodic, barren and bald for last three decades was selected. A topographic and lithological survey was undertaken to locate a low-lying area within the catchment area. A six feet deep basin of 0.33 acre was excavated at the located point in May 2000.

A network of 18 observation wells (Piezometers) was installed in all the four directions to monitor the changes in groundwater level and quality in relation to climatic conditions and agricultural practices. A schematic lay out has been indicated in Figure 2. The groundwater level was recorded weekly and its quality was assessed quarterly. Rainfall data was noticed at the event of occurrence while pan evaporation was observed daily.

Figure 1: Location of Study Site.

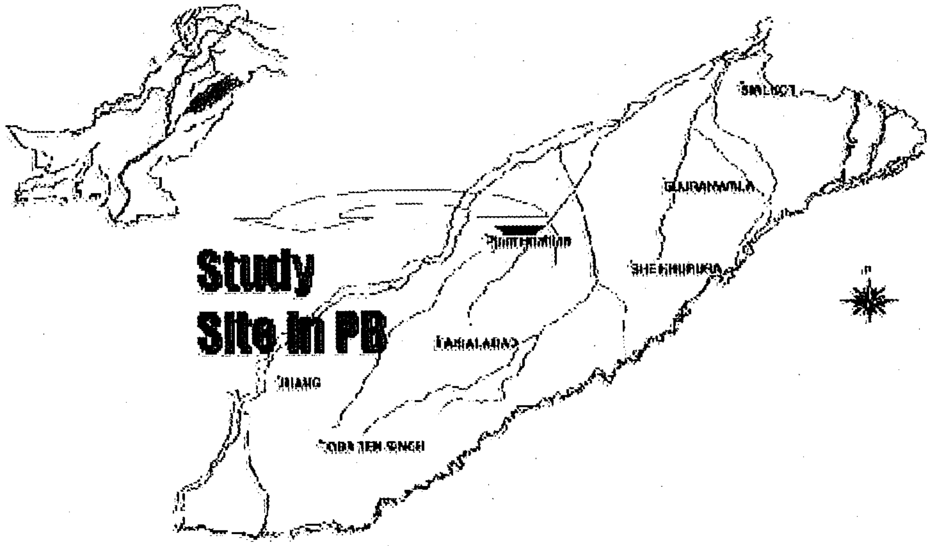
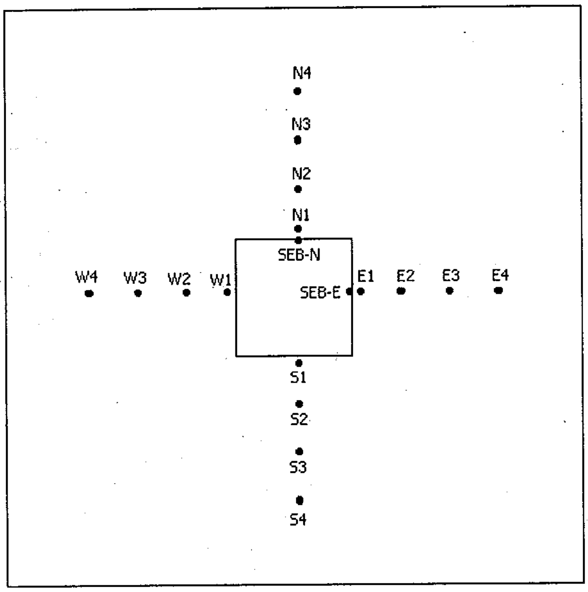


Figure 2: Schematic Lay Out of Piezometers in the Surrounding Area of SEB.



The detailed soil analysis of catchment area was conducted pre and post-monsoon. Composite soil samples were obtained up to the depth of 165 cm for analysis. The deep ploughing and disking operations in the catchment area were also completed pre and post-monsoon. Agricultural practices being carried out in the catchment and vicinity areas were recorded.

In the second year, 2 acres area adjoining to SEB on Eastern and Southern sides were selected for the growing of crops after reclaiming soil. Soil samples were obtained and gypsum requirement was determined (Richard, 1954). After ploughing these fields, gypsum @ 100 % of the requirement was applied and mixed into the 15-cm surface soil. Subsequent leaching for 10 days was provided to sequester the salts into SEB. Rice crop was grown subsequently. Soil samples were obtained at the time of crop harvesting. Water samples of piezometers installed in the SEB were collected 3 times during irrigation of the crops for quality assessment. The climatic data was related to the variations in the soil characteristics and groundwater quality.

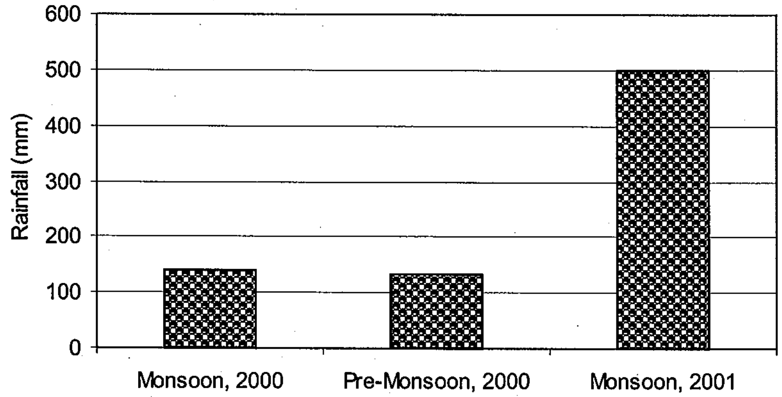
RESULTS AND DISCUSSIONS

Results of the data (2000-2001) on rainfall, evaporation, soil salinity / sodicity status and quality of ground water are discussed as under:

Rainfall

It was observed that monsoon season 2000 did not cause significant rainfall because a total of 140 mm (Figure 3) were received with four events above 20 mm and only one event above 10 mm. The period from September to December, 2000 and January to May 2001 was extremely dry except for only one event of 8 mm rainfall in May, 2001.

Figure 3: Seasonal Fluctuation of Rainfall.

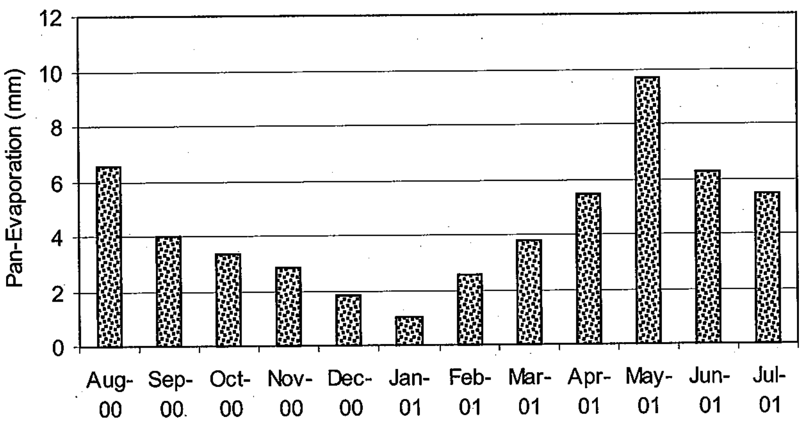


The dry spell continued up to first week of June 2001. The monsoon season started earlier in the year 2001 when rainfall of 20 mm was received in the second week of June, 2001. This season proved fruitful and a total 499 mm rainfall was conceived during the period of June to September. This period was followed by a consistent dry spell up to December 2001 and not a single mm of rainfall was received.

Pan Evaporation

The pan evaporation data indicated very wide variable pattern during various months of the year (Figure 4). As low as 1 mm/day pan evaporation was recorded in the month of January, while maximum magnitude of this parameter was noticed in the month of May with an average value of 9.7 mm/day. The months of December, January and February had very low pan evaporation, where as April, May, June, July and August were having maximum values. The other months of the year were conducive to cause intermediate level of this parameter. It may be concluded that under high temperature and dry conditions, the pan evaporation was maximum and the low temperature and the fog prevailing in the months of December and January caused a significant decrease in it.

Figure 4: Monthly variation of Pan Evaporation.

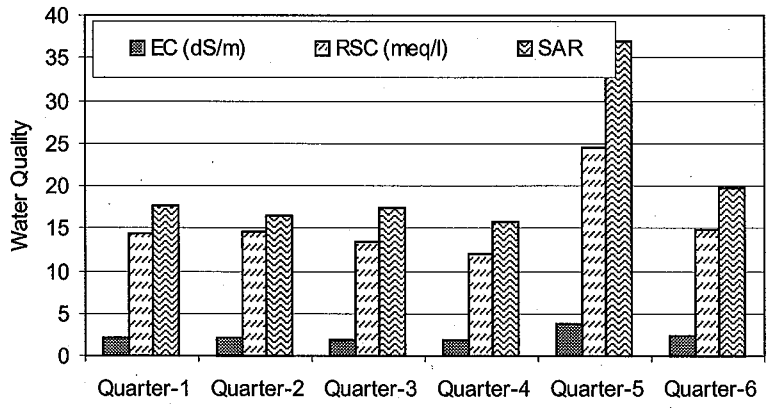


Natural changes in groundwater Quality

The groundwater was assessed 6 times during the study period after a span of 3 months. It was observed that the parameters of EC, SAR and RSC were comparatively higher in piezometers of Northern side than the Southern, and on Eastern side than the Western. The magnitude of EC was the highest in the Western side. No wide spatial differences were found in case of RSC whereas Northern land configuration was having maximum SAR. The piezometer N3 was mostly assessed with the highest values of EC, SAR and RSC throughout the study period and indicated the exceptional behaviour. The piezometers installed in the SEB (SEB-E & SEB-N) were mostly found with higher values of the studied parameters indicating a slight salt movement of salts from the catchment area towards the SEB.

The quality of groundwater remained fairly consistent during the first four quarters with only spatial variations discussed as above. When this period was correlated with the rainfall pattern of this time span, it could clearly inferred that non-significant changes in quality of groundwater could be attributed to the consistent dry spell with no intensive rainfall in monsoon season 2000 (Figure. 4). The enhanced intensity and quantity of rainfall in monsoon 2001 indicated its impact on ground water quality, which was resultantly diluted. The magnitude of parameters in quarter five supported this inference (Figure 5). The recorded values of SEB-E piezometer increased highly indicating a clear salt movement into the SEB with intensive rains. Similar behavior was also observed for other piezometers close to SEB. The subsequent dry spell from October to December caused a reversion of the dilution effect into concentration impact and observed values of EC, SAR, and RSC again went low.

Figure 5 Temporal Variation of different Water Quality Parameters in SEB-E Piezometer.



Natural soil salinity / Sodicity changes

Horizontal and vertical variations of salinity and sodicity parameters (EC, SAR and pH) were observed in the catchment area at the time of initiating this study. The surface with 0-15 cm depth of the soil was saline sodic with magnitude of EC, SAR and pH more than critical values of 4 dSm^{-1}, 15 and 8.5 respectively. The degree of salinity / sodicity decreased downwards into lower profile but the subsoil up to 165 cm depth was not found to be normal. Rather, it was assessed as saline sodic or sodic. The spatial variations within the catchment area were very clear in respect of EC, pH and SAR e.g. for top 0-15 cm layer SAR varies from minimum 43.65 (acre 12/4) to maximum 77.25 (acre 11/88).

The consistent dry spell of April 2000 to April 2001 with nominal monsoon rains caused concentration of salt in the surface and subsurface soil and degree of salinity / sodicity was enhanced many times. The impact was very much pronounced in the surface 0-15 cm depth as shown in Figure 6 and 7.

Figure 6: Impact of Rainfall on EC in Top 15 cm. of Soil for Acre NO. 11/16.

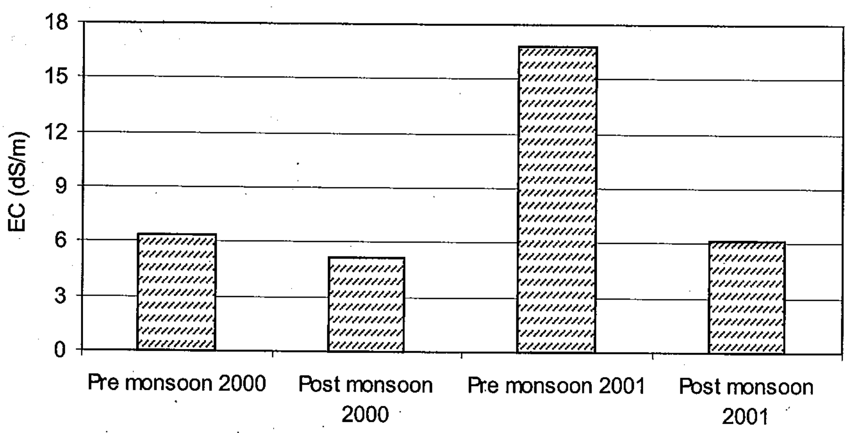
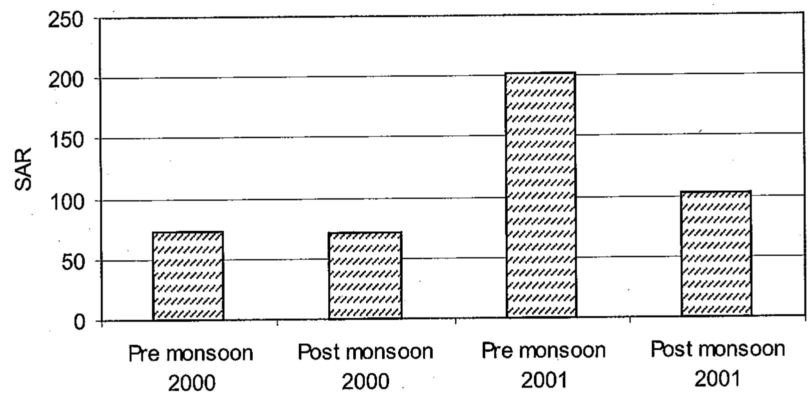


Figure 7: Impact of Rainfall on SAR in Top 15 cm. of Soil for Acre NO. 11/16.



It indicates that EC of acre No. 11/16 increased from 6.42 to 16.8 dSm^{-1}, which was calculated as 161 % or 2.6 times increase. The SAR of this very acre was enhanced from 72.45 to 202.29, which was about 2.79 times more than the original one. This trend was found in whole of the catchment area with variable impact of severity in different parts. However, the intensive rains of monsoon reverted the situation and the concentration process was converted in to dilution and leaching. The EC and SAR of the same acre (11/16) was deceased respectively from 16.8 dSm^{-1} and 202.29 (pre-monsoon, 2001) to 6.12 dSm^{-1} and 102.36 (post-monsoon, 2001). The effect on soil pH was observed as slightly deviating. The extreme soluble salt concentration in dry season decreased the soil pH, which was further decreased in monsoon 2001 as a result of appreciable reduction in SAR.

Changes of Soil and Groundwater Salinity / Sodicity in Relation to Reclamation Activities

Significant changes are brought in the soil characteristics when reclamation activities are started. Natural variations do not remain valid and soil health start improving rapidly. To compare the natural and man-initiated changes, reclamation activities (gypsum application, mixing, leaching and subsequent growing of rice crop) were started in acre number 11/25, 12/4 and 12/5 of the catchment area. The soil surface EC (0-15 cm) decreased to permissible limits, of less than 4 dSm^{-1}, in all these acres after growing only first rice crop subsequent to application of amendments and leaching (Table 1). There was very pronounced decrease in pH and SAR but values were still higher than the critical limits of 8.5 and 15. Gypsum requirement was also reduced. Hence, it can be concluded that reclamation activities proved positive and clearly conducive towards improving soil health compared with simple cultural operation and leaving the salt affected soil prone to natural climatic conditions.

Table 1: Effect of Reclamation Activities on Soil Properties (0-15 cm Depth).

Acre #	EC (dSm^{-1})		pH		SAR		Gypsum requirement (t/acre)	
-	Before rice	After rice	Before rice	After rice	Before rice	After rice	Before rice	After rice
4	17.19	3.24	9.82	9.01	92.2	28.8	4.64	1.72
5	8.6	3.87	9.93	8.07	193.5	30.3	8.94	3.44
25	15.64	3.45	9.81	8.90	183.2	39.6	6.71	2.58

The reclamation activities also affected the groundwater quality. It was observed that EC, SAR and RSC of piezometer S_2 and S_3 (installed in area No. 4) were very high at the end of fifth quarter in which reclamation was started. Similar trend was also found in E_2 and E_3 (installed in acre 25) but somewhat later (quarter six). The higher magnitude of values in SEB-E compared with SEB-N not only supported this point but also indicated the flow of salts towards the SEB as a result of reclamation process. To ascertain this fact a new piezometer SEB-S was installed during the reclamation activates, which were going on in the adjacent Southern acre to SEB. The two times analysis of the groundwater collected from this piezometer clearly proved this viewpoint. All the determinations (EC, SAR, RSC, CO_3, HCO_3, Ca + Mg and Na) here were higher than the SEB-N where no reclamation operations were being carried out (Table 2). A critical consideration of the water constituents showed that carbonates and bicarbonates of Na were moving towards the SEB of along with the irrigation or rainy water.

Table 2 Effect of Reclamation Activities on Groundwater Quality.

Sampling Dates	Piezo-meters	EC (dS m^{-1})	CO_3 (meL^{-1})	HCO_3 (meL^{-1})	Ca+ Mg (meL^{-1})	Na (meL^{-1})	SAR	RSC (meL^{-1})
May 28, 2001	SEB-E	1.8	5.0	9.0	2.1	16.1	15.7	11.9
May 28, 2001	SEB-N	1.5	3.0	9.5	1.6	13.2	14.8	10.9
Aug. 28, 2001	SEB-E	3.8	4.0	22.0	1.9	36.5	37.1	24.1
Aug. 28, 2001	SEB-N	1.1	1.0	10.5	1.5	9.7	11.2	10.0
Oct. 3, 2001	SEB-E	3.1	4.0	19.0	1.3	29.5	36.6	21.7
Oct. 3, 2001	SEB-N	1.2	1.0	11.5	1.4	10.1	12.1	11.1
Oct. 15, 2001	SEB-E	3.0	2.0	20.5	2.0	27.7	27.7	19.5
Oct. 15, 2001	SEB-S	2.0	2.0	10.5	2.4	17.4	16.1	10.2
Oct. 15, 2001	SBE-N	1.2	1.0	9.5	1.5	10.4	11.9	9.9
Nov. 28, 2001	SEB-E	2.3	-	17.0	2.2	20.5	19.8	14.8
Nov. 28, 2001	SEB-S	1.5	-	12.0	1.2	13.9	17.7	10.7
Nov. 28, 2001	SEB-N	1.3	-	12.0	2.1	10.7	10.6	9.9

CONCLUSIONS

- Monsoon season of 2000 did not bring significant rainfall (140 mm) but monsoon, 2001 was very much fruitful with total rainfall of 499 mm. There was consistent dry spell in post monsoon of 2000 and 2001.
- Pan evaporation varied in between 1-9.7 mm. The period (November to February) was having minimum while the period (April to August) indicated maximum values of this parameter.
- Groundwater quality did not change during dry spell. Salts diluted after intensive rainfall and concentrated as result of reclamation activities.
- Soil salinity/sodicity parameters increased during dry spell and decreased due to intensive rainfall. Reclamation activities (application of amendments, leaching and rice growth) rapidly decreased soil EC, pH and SAR.
- No significant movement of salts was observed under natural conditions except under very intensive rainfall. However, the reclamation process caused sequestering appreciable amount of salts in SEB.

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