groundwater data analysis shows that the ill effects of using the aquifers beyond safe yield limits are emerging with passage of time. Groundwater depletion is now a fact and its consequences are emerging in the form of quality deterioration and increased costs of groundwater development and pumping. Groundwater depletion is also important in coastal areas, where lowering of the watertable induces salt-water intrusion into water supplies either directly from sea side or from river side due to back seawater flow during no/low River Indus flows.

2.1 Increasing Groundwater Development

Current situation and practices regarding groundwater development is manifested in the exponential growth of tubewells within last three decades. Particularly, the increased cropping intensity in agriculture sector is responsible for major depletion of groundwater mostly in fresh groundwater areas. To highlight this increased use of groundwater by the agriculture sector, groundwater pumping in LBDC command has been compared. The reported number of tubewells in Lower Bari Doab Canal (LBDC) command in 1994-95 was about 20,000 with annual groundwater abstraction of 2710 MCM (NESPAK-NDC-AHT, 1995). The tubewell numbers in LBDC then exploded to about 48,000 in 2005 (NESPAK, 2005). Total groundwater pumping for agriculture purposes over the LBDC command has been estimated afresh as 3394 MCM based on 2005 data. Thus within a period of 10 years 684 MCM increase in groundwater usage per annum has been found in LBDC command. This indicates 2.3 % annual increase in groundwater pumping which is comparable with that of population growth rate of 2.1%. That means population growth resulting in increased water demand in the form of increasing cropping intensities is mainly responsible for unprecedented groundwater depletion along with other factors e.g. recent drought conditions. The resulting decline in groundwater level has been computed for the period 1987 to 2008 as shown in Table 1, based on the data of 79 observation wells falling in Sahiwal and Khanewal Divisions of LBDC command. The data also covers the drought period with the highest depletion rate of 1.74 ft per year. On an average for Sahiwal and Khanewal Divisions of LBDC command the rate of groundwater depletion is 1.2 ft/year for the period 1987 to 2008. The volume of groundwater depleted in these two irrigation divisions for the above period, using 15% specific yield is 4.68 MAF (GCA 1.48 million acres).

Table 1: Change in Depth To Watertable (DTW) per year over different periods in Irrigation Divisions of LBDC.

LBDC Division	1987 to 1996		1998 to 2002 (drought)		2005 to 2008	
	# of observation Wells	decline (ft)	# of observation Wells	decline (ft)	# of observation Wells	Decline (ft)
Sahiwal	7	0.52	6	1.74	43	0.59
Khanewal	3	0.62	6	1.74	36	1.16

2.2 Lateral Pollution

Given that the aquifer system prior to broad scale irrigation was in equilibrium with outflow control by the rivers as the hydraulic boundaries. The brackish waters were generally captured in the middle of the alluvial doabs between the rivers. Other geological features also influenced the location. As the aquifer system was filled as a result of irrigation all the aquifers rose to be close to the surface. This caused the broad scale waterlogging and salinity of the 60's and 70's. Now we are faced with aquifers that are falling as a result of the one million tubewells installed in the fresh water zones to supplement irrigation. As water is only being pumped from the freshwater zones, this may had already set up the conditions for lateral movement. The danger from this saline intrusion has been reported frequently but still needs to be proved with actual field data evaluated specifically.

2.3 Impacts on Poorer Farmers

As the groundwater drops, the cost of pumping increases. If it falls much further then the need arises to change technologies from centrifugal pumps to the more expensive turbine pumps. The cost imposes a significant burden on the small farmer who do not normally have sufficient cash flow to accommodate such changes. Cost of groundwater pumping with increase in depth to watertable has been estimated from data of drilling depth and pumping equipment commonly used across the LBDC command (Halcrow 2006). It is apparent that cost per cubic meter of groundwater pumped increases about 3.5 times as the depth to watertable drops from 6 to 21 m from head to tail in LBDC command as shown in figure 5.

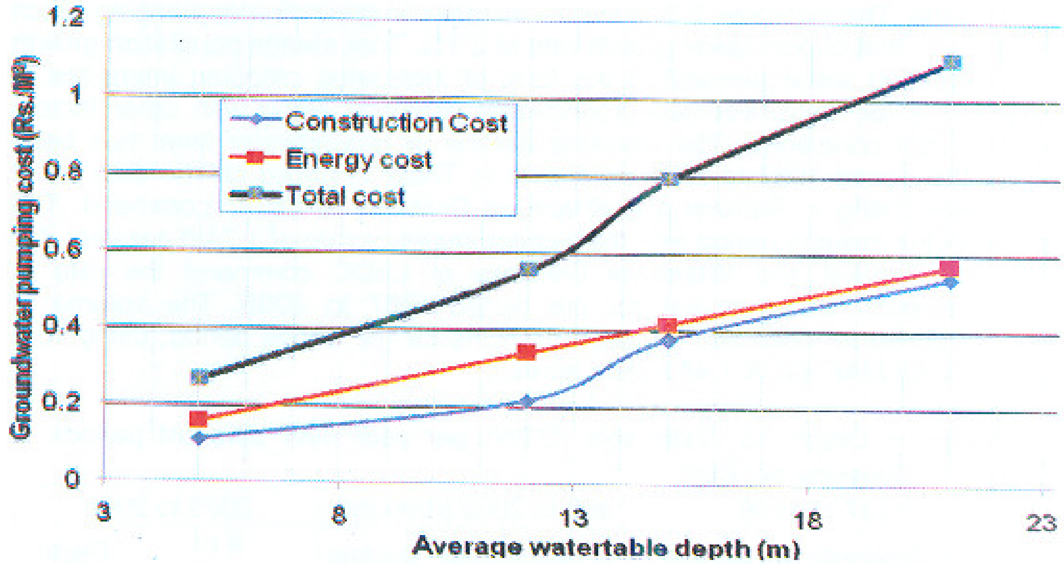

Figure 5: Increase in cost of groundwater pumping with decline in watertable.

2. WATER STORAGE

In conjunctive use, the two most important issues that planners have to face concern the storage of surplus water and the optimal allocation of water withdrawals. With regard to the first problem, a question that needs to be answered is where to store water and which reservoirs to develop: surface or subsurface?

3.1 Subsurface Storage, Merits & Demerits

The advantages of subsurface over surface reservoirs are:

- surface reservoirs are lost forever once they are silted up, while underground storage capacities remain practically unaffected by development;
- yields from groundwater storage, less affected by evaporation and leakage, are more dependable than yields from surface reservoirs;
- subsurface storage is achievable without loss of water-spread areas thus no need for relocation of the local population;
- groundwater can be put to use where and when it is required, with less risk of seepage or evaporation losses during storage and transmission;
- there is less ecological hazard compared to surface storage projects;
- the cost of storing groundwater is less than that of surface storage and;
- there is no risk of surface flooding in the form of dam breaks in case exceptionally high floods develop in the system.

In spite of many advantages over surface storage, there are some constraints also, such as:

- groundwater storage withdrawal is a highly energy intensive process, while surface water is often available by gravity flow;
- surface reservoirs are more suitable for multiple uses e.g. energy production and recreation;
- mineralization is generally lower in surface water storage.

4. GROUNDWATER MANAGEMENT

For sustainable development of water resources in IBIS, it is imperative to make a quantitative estimation of the available water resources. First task would be to make a realistic assessment of the surface water and groundwater resources and then plan their use in such a way that full crop water requirements are met and there is neither waterlogging nor excessive lowering of groundwater table. It is necessary to maintain the groundwater reservoir in a state of dynamic equilibrium over a period of time encompassing wet and drought years. So that water level fluctuations are kept within a particular range, thus making it possible for utilizing groundwater storage developed during wet years to be used during drought years. It is proposed that classification of areas under different depths to watertable (DTW) may be based as suggested in table 2. This will help to delineate areas where artificial recharge is needed urgently. Last column of the table, proposes how to tackle the groundwater depletion on DTW basis.

Table 2: Proposed classification of areas under different depths to watertable

Sr. #	DTW (ft)		Proposed classification	Revising Water allocations
1	0	5	Waterlogged	Allowance to be decreased
2	5	10	Likely to be waterlogged	No change
3	10	30	Normal	No change
4	30	45	Likely to be depleted	Extra water allowance during monsoon
5	45	60	Depleted	Permanent extra water allowance
6	More than 60		Highly depleted	Creation of permanent lakes in addition to extra water allowance

Recharge to groundwater by creating artificial lakes in areas with depth to watertable more than 60 feet needs to be permanent feature of irrigation system. These proposed lakes called command level surface/groundwater storage of flood supplies, can be filled during flood season on the basis of flood share of each canal command. It is likely that these areas are away from possible sources of recharge to groundwater such as main canals and barrages, mostly these area lie at tail ends of the canal commands falling within the centers of doabs. This will require proper water balance/groundwater modeling studies regarding surface water allocations and its impact in raising the watertable in surrounding areas. Areas will have to be selected based upon;

- Depth to watertable and remoteness from recharge sources such as rivers and canals.
- Areas with high infiltration rates and adjoining deep watertable.
- Proper water allowance during floods depending upon intensity of flood flows in respective areas. Also some extra/minimum allocation during each monsoon season.

4.1 Recharge Potential

It is well established that our aquifers are depleting and on average (1976-2008) there is 31.5 MAF surplus water going below the Kotri Barrage without any intended regulation for seawater intrusion and other needs such as environmental flows in dry river reaches mostly in Punjab. So there is need to quantify both the requirement for groundwater recharge i.e. the recharge potential of our aquifers and the surface water which can be allocated for the purpose without disrupting the existing uses. As 70 % of the 21.6 Mac of irrigated area in Punjab having fresh groundwater, is already supplementing canal water supplies by depletion of groundwater storage and current recharge from the irrigation system. It is assumed that out of this

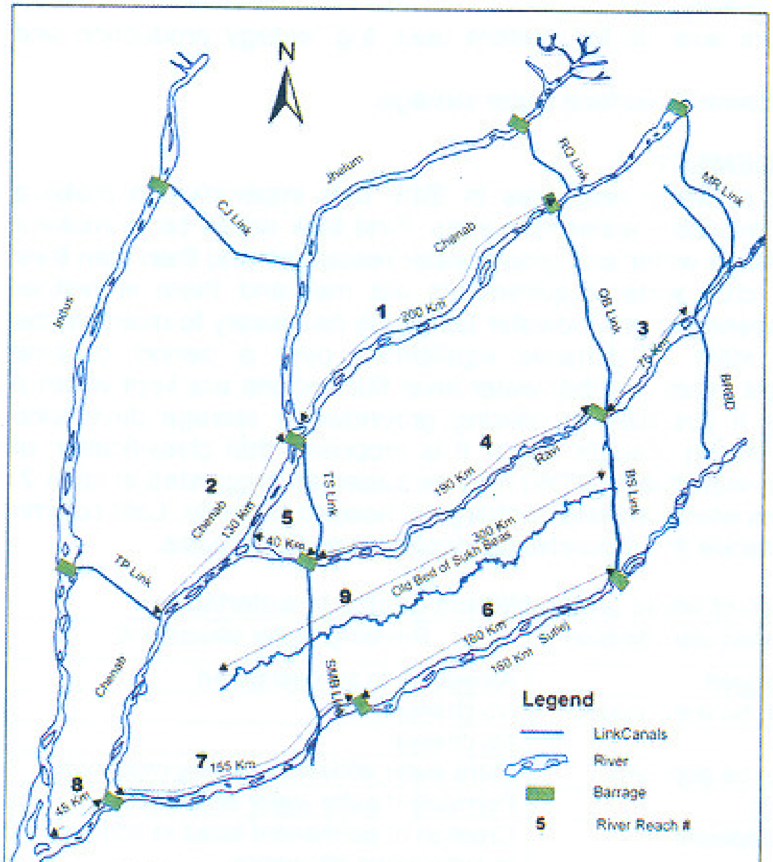

Figure 6: River reaches proposed for groundwater recharge.

fresh zone, 50 % area i.e. 7.5 Mac can be used to fill the upper 30 ft of the aquifer. With 15% storage coefficient, the possibility of water storage in the above area comes out to be 33.75 MAF. This groundwater storage if properly managed in integration with surface water resources can serve on cyclic basis for as long a period as are the droughts which are cyclic in nature. Purpose built infrastructure building/remodeling of existing canals where needed, for water conveyance to depleted areas will be required on priority basis.

4.2 River Management

All the rivers in Punjab are connected through inter river link canals for conveying water to the canals under the command of eastern rivers. At present, river water management is being implemented with the objectives of meeting demands of agriculture ignoring even the environmental flow requirements of rivers. In this regard Kamal (2008) has recommended environmental flows allocation of the Indus, Jhelum, Chenab, Ravi and Sutlej as 2.25 and 6 MAF for Rabi and Kharif seasons respectively. In Indus river system, it is only during floods that certain reaches receive water (figure 6, marked with length and reach #). Total length of rivers lying with out water during non flood season is about 995 km, all of them lying in Punjab. Assuming 500 m river width under water spreading during minimum flows and seepage rate of about 4 cfs/msf, the total wetted perimeter contributing towards seepage to the underground is 5516 million square feet. Thus total seepage rate from these river reaches comes out to be 22,065 cusecs. Using reservoir storage in such a way that this discharge is allowed to flow for four months will add about 5.35 MAF to aquifers along the rivers. The old bed of Sukh-Beas lying in the center of Bari doab i.e. the area with maximum groundwater depletion can offer maximum aquifer storage potential. The flood water can be diverted to Sukh-Beas via the B.S. link where the escape structure already exists. Adding 0.3 MAF required to check below Kotri seawater intrusion as recommended by MWH-ACE-NESPAK (2005), total releases required for the purpose for a period of four months are 6.55 MAF as given in Table 3.

Table 3: Proposed discharges and volumes calculated for 4 months, within different reaches of river system assuming 500 m as river perimeter contributing to seepage @ 4 cfs/msf.

Reach #	River Reach		Wetted perimeter (msf)	Discharge (cfs)	Volume (MAF)
	start-end	Length (Km)			
1	Qadirabad to Trimu	200	1076.36	4305.46	1.04
2	Trimu to TP Link	130	699.64	2798.55	0.68
3	Ravi up to Balloki	75	403.64	1614.55	0.39
4	Balloki to Sidhnai	190	1022.55	4090.19	0.99
5	Sidhnai down to Chenab river	40	215.27	861.09	0.21
6	Sulemanki to Islam	160	861.09	3444.37	0.83
7	Islam to Punjnad	155	834.18	3336.73	0.81
8	Punjnad to Indus	45	242.18	968.73	0.23
9	Old Sukh Beas	300	161.45[1]	645.82	0.16
10	Below Kotri	-	-	5000[2]	1.20
Total		1295	5516.37	27065.48	6.55

5. RIVER FLOWS

Scarcity of water for irrigated agriculture and high temporal and spatial variability of flows in the Indus river system demands very careful analysis of the river flows for decision making purpose. The pattern of flows at Kotri Barrage is affected by the canal withdrawals at upstream barrages and storage by the reservoirs in addition to inflows at the rim stations. Over 80 % of inflows to the Indus river system occurs, on average, during two flood months of July and August (MWH ACE NESPAK 2005). The 1991 Water Accord primarily determined the river water apportionment among the four provinces of Pakistan. It also comprised the share of provinces in the surplus discharges flowing in the rivers as floods. The IRSA apportions the Indus River System flows through two large and one small reservoir, 19 barrages and 45 major canal systems. In the absence of any additional storages in the system, it is proposed to manage the excess flows by diverting through dry river reaches for groundwater recharge and environmental flows for Punjab and releases to check seawater intrusion and environmental flows below Kotri Barrage for Sind. For the purpose it is suggested to divert the proposed flows for four months (before and during flood season) in the dry river reaches in lieu of expected excess flows in the system.

Annual river flows going below Kotri Barrage (figure 7) has been analyzed for the post Tarbela (76-77 to 2008-09) period. Still on an average there is spillage of about 31.47 MAF annually to the sea. The long term downstream average flows below the Kotri Barrage has been calculated as given in table 4. The yearly escapages below Kotri Barrage were ranked and % chance of exceedance for these values was calculated. The resulting values are plotted in the form of graph as shown in figure 8. For the proposed releases of 6.55 MAF from the existing storages before the monsoon season as environmental/groundwater recharge flows, the chance that during succeeding monsoon season their will be excess available in the system are 87.13%. This shows that the proposed releases can be managed with 12.86% probability of water shortage due to these releases in advance. However chances of this shortage can be further reduced by improved prediction of river flows for Kabul and Indus rivers and acting accordingly.

Table 4: Longterm average flows, downstream Kotri Barrage (MAF).

Period	Pre-Kotri	Post-Kotri	Post-Tarbela
	1937 to 1954	1955 to 1975	1976 to 2008
Kharif	71.656	56.455	29.6
Rabi	8.862	5.862	1.87
Annual	80.52	62.32	31.47

1. For Sukh Beas, wetted perimeter has been assumed 50 m, which can be developed by weirs at appropriate intervals along the length of the river course.

2. For Below Kotri 5000 cfs is based on recommendations made in the Kotri Study-I (2005) as the required minimum flow.

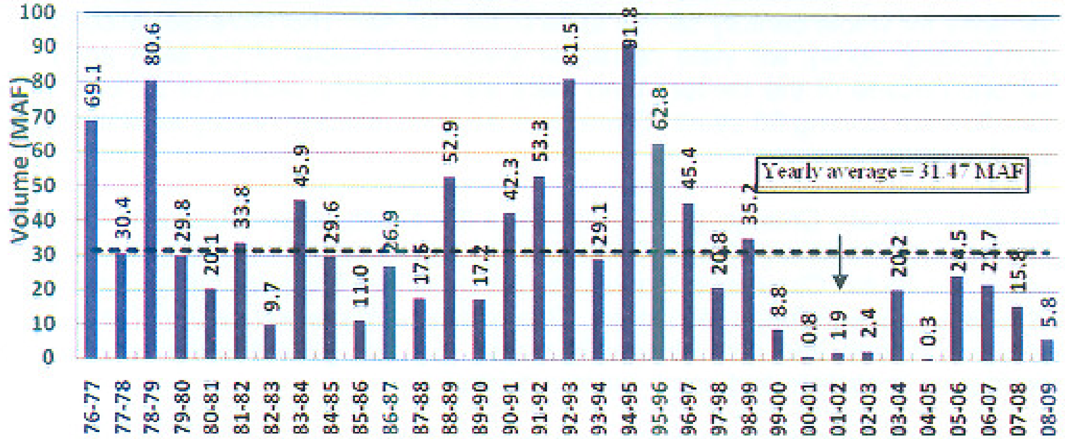

Figure 7: Escapages below Kotri Barrage for post Tarbela period (1976-77 to 2008-09).

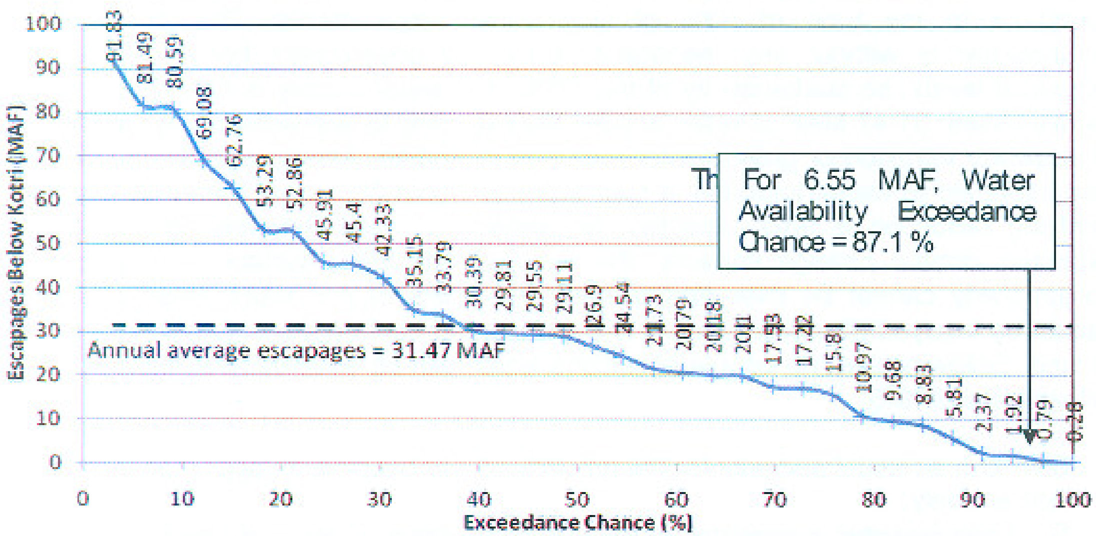

Figure 8: Historical escapages below Kotri with corresponding exceedance chances.

5.1 Climate Change Impact on Future Water Availability

Although the science of Climate Change is still in infancy, there are reports that, it is going to effect the melting of Western Himalaya glaciers. It is reported, that in early few decades of twenty first century, there will be excessive glacier melt of Karakoram Glaciers and flows of River Indus at Besham Qila will be increased by about 50 percent, and thereafter there will be terrifying reduction in flows and they will be reduced to about 40 percent of Year 2000 value by the end of the century (Rees and Collins, 2004). Climatology section of Global Change Impact Study Centre has worked out by ensemble the results of six Global Circulat ion Models for this area. The reasonable temperature increase for whole century seems to be 0.035 °C/year. This increase, according to Rees and Collins, 2004), will yield additional flows of the order of 5.2 MAF annually for the second decade of the century then there will be steady decline of 22 MAF in Besham Qila flows in coming 80 years. There must be some storage readily available to store this surplus water.

Similarly Climate Change is going to affect the South Asian Monsoon. It is reported in International Panel on Climate Change Third Assessment Report that the results of nine out of ten Global Circulation Models results show that there will be increase of the order of 8-24% in South Asian Monsoons. This additional water will be variable and intense in space and time and can be readily stored in fresh ground water aquifer of Punjab, preferable in eastern and south eastern doabs.

6. RECHARGE MANAGEMENT OPTIONS

Presently there is no plan and even lack of thinking prevails towards groundwater management and recharge of precious aquifers lying under the IBIS, which at present contribute to the tune of 50% of crop water requirements. This contribution of groundwater is without any management by any government body, at national or provincial levels, so sustainability of this 50% crop water supply is very much doubtful. As discussed, 31.47 MAF of water is currently escaping to sea without any management of seawater intrusion or groundwater recharge in Punjab. Anticipated climate change is also expected to cause increase in river flows by about 50 % and thereafter probably a terrifying reduction is also expected. So keeping in view the existing scenario and expected climate change impacts, the need of managing surface and groundwater conjunctively cannot be over emphasized. The fruits of this much needed approach cannot be enjoyed till a considerable experience and confidence is gained with passage of time. Following are the course of options which can be adopted step wise to harness full potential of IBIS;

- Business as usual and wait for the groundwater to become an opportunity for the rich farmers only;
- Start groundwater augmentation by diverting surplus water in old bed of Sukh Beas as a pilot project during flood season. This requires little further planning and investment because the proposed site is already connected to river Ravi via BS Link.
- Start planning for reserving and using part of Mangla storage which can be released for recharge through river reaches connected through the link canals or otherwise.
- Similarly start the same feasibility process for planning to use part of Tarbela storage and Kabul river flows as groundwater recharge releases before the monsoon season.
- Develop a comprehensive feasibility for groundwater recharge and regular releases below Kotri barrage to check seawater intrusion by utilizing the prevailing escapages below Kotri within the provisions of 1991 water accord.

7. CONCLUSIONS

Diversion of surplus surface water to groundwater storage appears to offer the most favorable prospects for controlling below Kotri escapages of our precious resource in the absence of any surface storages to be added in future. The alluvial aquifer that underlies the Punjab is ideal for the purpose in nearly all respects. It is favorably situated with respect to both availability of water for recharge and to areas of use of water, and there are no extensive geologic barriers to recharge or to circulation within the aquifer. The storage capacity of groundwater reservoir is equal to many times the annual flow of the Indus River system. The question is how to manage this big reservoir. Moreover the groundwater reservoir has infinite life because the groundwater storage is free of sediments. Thus it is concluded that the use of groundwater storage would permit more flexible and complete control of water resources of the Indus Basin. The groundwater reservoir can be replenished according to the availability of surface water for recharge and the reservoir can be tapped according to the demand for water with out regard to seasonal or annual variations in river flows.

The major problem involved in the management of the aquifers as a reservoir is that of promoting artificial recharge at a sufficient rate to accommodate surplus surface supplies during the period of high river flows. Although the problem is formidable but this needs further insight and search to be implemented step by step until all the surplus river supplies are allocated. All of these matters must be carefully studied before the most desirable plan for resource development and utilization can be taken up. Specific conclusions are:

- Tapping the recharge potential of our aquifers can provide a reliable buffer to cyclical or annual shortages of surface supplies; recharge during wet years and extraction during dry years can limit the impact of cyclical droughts.
- A huge groundwater recharge potential exists in the aquifers due to their depletion beyond optimum limits.
- New and emerging uses of groundwater e.g. small water supply schemes along fresh water resources such as rivers and canals will have substantial impact in future on already under stress groundwater areas particularly with respect to quality deterioration of the resource with passage of time.

8. RECOMMENDATIONS

Groundwater is a basic resource for humans and natural ecosystems and is one of the nation's most important natural resources. Keeping in view the rate of groundwater depletion and availability of surplus river flows in the system during wet season, following are the recommendations.

- There has been wastage of excess water to Sea during wet years to the tune of 31.47 MAF annually. After subtracting 10 MAF below Kotri requirements for checking seawater intrusion, still there is potential of 21.47 MAF on an annual average to be effectively controlled through multi-purpose storages. Part of this can also be utilized as groundwater recharge/environmental flows even without any big investment at this very initial stage.
- Proper sites can be developed in groundwater depletion areas of each canal command for command level surface/groundwater storage during wet years for groundwater recharge.

- Environmental flows can be managed for dry river reaches lying in Punjab by ensuring certain flows for few months during non monsoon season. As a next step, structures can be built at appropriate sites for flooding of flood plains along the rivers.

- Diverting flood waters through nalas and abandoned river beds such as the old bed of Beas River in Bari Doab can be very easily managed by allocating certain amount of river water for the purpose.

- For scientific based water resources management in IBIS, modeling of river system needs to be undertaken. This can answer many of the issues regarding water resources management.

- Criteria of depth to watertable classification in irrigated areas needs to be revised to include areas under stress with respect to groundwater availability as proposed in table 2.

- A feasibility study is recommended to highlight the prospects of groundwater recharge for enhancing the IBIS productivity. At large scale this would lead to creating scientific capability and investment for building infrastructure for groundwater recharge.

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ROLE OF BRACKISH WATER IN THE RECLAMATION OF SALT AFFECTED SOILS

By

Munawar Ali and Muhammad Rafiq*

ABSTRACT

The specific objective of this study was to observe the role of brackish water for reclaiming salt affected land. Experiment was carried out on a saline-sodic, non-gypsiferous soil. The treatments tried were: T1) Irrigations with pure tubewell water; T2) T1+Sub-soiling upto 45 cm; T3) T1+Gypsum @ 100% GR of soil; and T4) T1+Pressmud @ 25 tons ha^{-1}.

Wheat-rice crop rotation was practiced. Recommended doses of NPK (134 – 56 - 31 kg ha^{-1}) was applied. The infiltration rate of the soil increased in all the treatments at the end of the experiment. Maximum increase of 100% was recorded with the application of gypsum @ 100% GR of the soil. The pH of the soil in all the treatments at most of the soil depths increased by 1 to 3 percent at the end of the experiment except at a few soil depths where, it remained static. However, at the end of the experiment the pH ranged between 9.1 to 9.7. The soil EC_e decreased in all the treatments at all the soil depths whereas, in treatment 1 and 4, EC_e increased by 35 percent and 5 percent only at 60-90 cm soil depth, respectively. The SAR decreased in all the treatments at all the soil depths. In the upper 0-15 cm soil depth the SAR in all the treatments had higher values than the safe limit (13 mmol $L^{-1})^{1/2}$. The maximum wheat grain yield was obtained with the application of gypsum @ 100% GR of soil and was followed by T4 (pressmud application @ 25 tons ha^{-1}) in both the years. Due to very high salinity/sodicity as well as the continuous application of hazardous water, wheat 2003-04 and rice 2003, 2004 and 2005 could not survive. Application of gypsum @ 100% GR of soil with brackish water irrigations proved the best treatment to get the maximum possible yield i.e. 1983 percent more than the irrigations with pure tubewell water application.

1. INTRODUCTION

1.1 Background

Pakistan is predominantly an agricultural country. Agricultural sector being the lynchpin of the country's economy, continues to be the single largest sector and a dominant driving force for the growth and development of the national economy. This sector provides 80 percent of the Pakistan's export earnings and employs about 48.4 percent of the total labour force. Agriculture also accounts for 24 percent to the gross domestic products (GOP, Economic Survey 2003).

Crop production has to be increased in order to meet the food, fibre and shelter requirements of the increasing population. The shortage of fresh water and dry spell in most of the cultivated areas are compelling the farmers to use poor quality groundwater

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for crop production. Soil salinity/sodicity is another jeopardy for our agriculture. Recent survey conducted by SMO, WAPDA (2004) showed that more than 30 percent of the irrigated area of the country is affected by the menace of salinity/sodicity. This climity adversely affects the production of most of the agricultural crops of our country. In order to obtain the maximum possible crop yields and reclamation of these soils, physical, chemical and biological amendments are being practiced depending upon the nature and extent of the problem. Similarly, brackish water of varying intensity of salinity and sodicity can be amended accordingly. It is the dire need of the country to ensure the safe use of brackish drainage water for crop production and soil reclamation. For this purpose, a field study was planned to find out the solution of these problems by using the amendments such as gypsum, pressmud, and sub-soiling in the Mona Project area, Tehsil Bhalwal, District Sargodha.

1.2 Objectives of the study

The main objectives of this study were:

- To test the effectiveness of different amendments alongwith brackish water to reclaim the salt affected soils.
- To evaluate the use of gypsum, pressmud and sub-soiling for crop production.

2. METHODOLOGY AND DATA COLLECTION

2.1 Establishment of the Experiment

2.1.1 Experimental Site

The study was carried out in an area of 0.15 ha under the command of a farmer's tubewell. The selected field was abandoned/barren before the start of the experiment. The soil was saline-sodic, non-gypsiferous in nature. The site was located on Sargodha - Sher Muhammad Wala Road, about 1 km towards West of Sargodha Road. The selection of the study site was based on the availability of desired quality of tubewell water, saline-sodic field, cooperative farmer and easy accessibility.

2.1.2 Duration of Field Trial

The study was started with the sowing of wheat crop 2003-04 and continued for six crop seasons therefore, the study completed with the harvest of rice crop 2006. The main study indicators including soil infiltration rate, pH, soil salinity/sodicity, irrigation water quality and yields of rice and wheat crops were monitored during the study period.

2.1.3 Treatments Evaluated

Rice-wheat crop rotation alongwith the application of organic and inorganic amendments were used to avoid the ill effects of brackish water on saline-sodic soil. The treatments tested were as under:

T1 = Irrigations with brackish tubewell water;

T2 = T1 + Sub-soiling upto 45 cm;

T3 = T1 + Gypsum @ 100% GR of soil; and

T4 = T1 + Pressmud @ 25 tons ha^{-1}

Each treatment was quadruplicated.

2.1.4 Layout of the Experimental Field

The field was barren, abandoned and had sporadic and sparse stand of salt bushes. After clearance of saline vegetation the field was intensively ploughed and planked. The entire field was divided into 16 equal plots of 15 m x 4.5 m (148th of a hectare). Strong bunds were constructed within the plots to avoid the overflow of irrigation water and interference of the treatments and also to facilitate the irrigation process. Layout plan of the experimental field is shown in Figure 2.1.

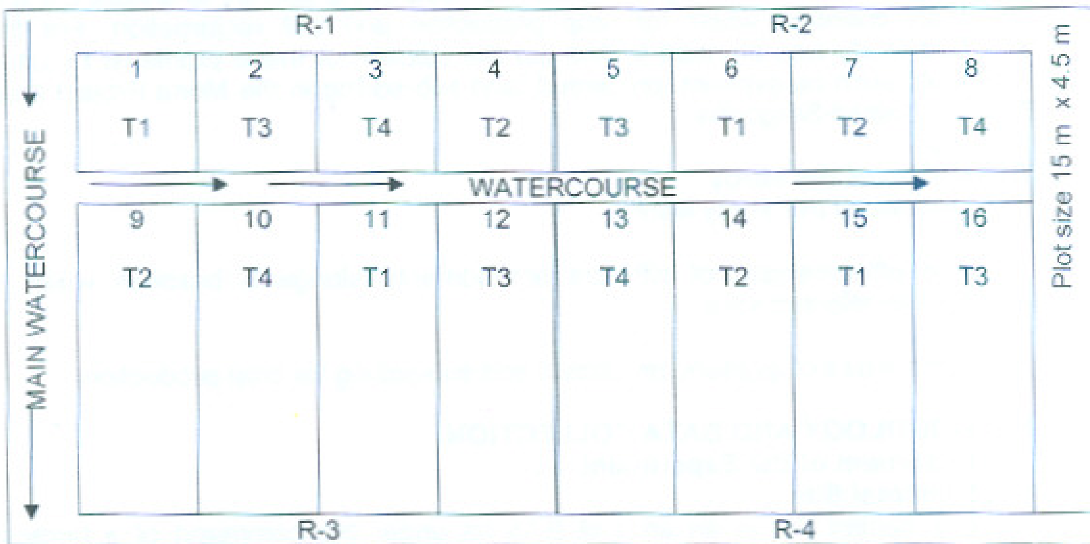

Figure 2.1 Layout Plan of the Experimental Field

2.2 Data Collection

2.2.1 Soil Texture

The soil samples were collected from 0-15, 15-30, 30-60 and 60-90 cm soil depths before the start of the experiment to determine the soil texture and chemical analysis. These samples were analysed in the Soil and Water Testing Laboratory, Mona Project, according to standard procedures of Bouyoucos, 1951. The physical properties of the experimental field are given in Table 2.1.

Table 2.1 Physical Properties of the Experimental Field

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class
0-15	26	42	32	Clay loam
15-30	18	48	34	Silty clay loam
30-60	08	50	42	Silty clay
60-90	04	52	44	Silty clay

2.2.2 Soil Infiltration Rate

The infiltration rate of each plot was measured in the beginning and just after the harvesting of each wheat crop by "Standard Ring Method" (Aronovici, 1955). The infiltration ring was hammered in the soil upto 15 cm depth and about 8 cm water was ponded in the ring. The readings were taken after three hours and mean of these readings was used to evaluate the infiltration rate of the soil under different treatments.

2.2.3 Quality of Irrigation Water

The tubewell water was used for irrigation according to the water requirements of both the crops. The quality of the tubewell water is given in Table 2.2.

Table 2.2 **Quality of Irrigation Water**

pH	TDS (ppm)	SAR $(mmolL^{-1})^{1/2}$	RSC (meL^{-1})
8.3	1779	23.2	4.8

2.2.4 Soil Salinity and Sodicity

The first soil sampling was done before the start of the experiment and later on after the harvest of each crop from 0-15, 15-30, 30-60 and 60-90 cm soil depths. Each sample was composited from three locations of each plot. These samples were analysed in the laboratory for pH, Electrical Conductivity of Saturated Extract (EC_e) and Sodium Adsorption Ratio (SAR) determinations. The chemical properties of the experimental field are given in Table 2.3.

Table 2.3 **Chemical Properties of the Experimental Field**

Depth (cm)	EC_e $(dS\ m^{-1})$	SAR $(mmol\ L^{-1})^{1/2}$
0-15	6.8 - 13.1	38.9 - 54.6
15-30	6.1 - 8.3	23.4 - 39.0
30-60	3.2 - 4.9	12.4 - 26.7
60-90	2.2 - 4.0	9.0 - 25.6

2.2.5 Sowing of Crops/Cultural Operations

Following the rice-wheat crop rotation, Super Basmati variety of rice and wheat variety of Inqlab-91 were sown at their respective time of sowing. Cultural practices carried out and inputs applied including ploughings, plankings, seed, irrigation, fertilizer, insecticide, weedicides and hoeing etc. are narrated in Table 2.4. Full dose of phosphorus and potash and half nitrogen was applied at the time of sowing whereas, the rest half nitrogen was applied with the 2nd irrigation to wheat crop and 45 days after transplanting of rice seedlings.

Table 2.4 **Cultural Operations Carried Out at the Experimental Field**

Operation	No./Quantity	
	Rice	Wheat
Ploughing	6	6
Planking	2	3
Date of sowing nursery	Last week of May	-
Seed rate	25 kg ha^{-1}	175 kg ha^{-1}
Date of transplanting/sowing	First week of July	2nd fortnight of November
Nitrogen	134 kg ha^{-1}	134 kg ha^{-1}
Phosphorus	56 kg ha^{-1}	56 kg ha^{-1}
Potash	31 kg ha^{-1}	31 kg ha^{-1}
Irrigations (No)	13	4
Rainfall (mm)	275	150

2.2.6 Yield Estimation

The crop yields were estimated on the whole plot basis and computed as yield kg ha^{-1}.

3. RESULTS AND DISCUSSION

This section deals with the observations and discussion about the field trial.

3.1 Changes in Soil Infiltration Rate

Initial infiltration rate of the soil was recorded before the start of the experiment when the field was lying barren before Rabi crop (wheat 2003-04). Subsequent infiltration rates were taken after the harvest of every Rabi crop i.e. in the month of May. The data given in Table 3.1 reveal that there was substantial increase in the soil permeability showing the improvement in the soil properties with the passage of time. The effect of different treatments on the soil infiltration rate is shown in Figure 3.1.

Table 3.1 Historic Soil Infiltration Rate

(mm hr^{-1})

Treatment	Year				% increase over T1
	2003 (initial)	2004	2005	2006	
T1 Irrigation with pure tubewell water	3	4	4	4	-
T2 T1 + Sub-soiling upto 45 cm	3	5	5	6	50
T3 T1 + Gypsum @ 100% GR of soil	4	7	8	8	100
T4 T1 + Pressmud @ 25 tons ha^{-1}	4	6	7	7	75
Average	3.5	5.5	6.0	6.3	57.5

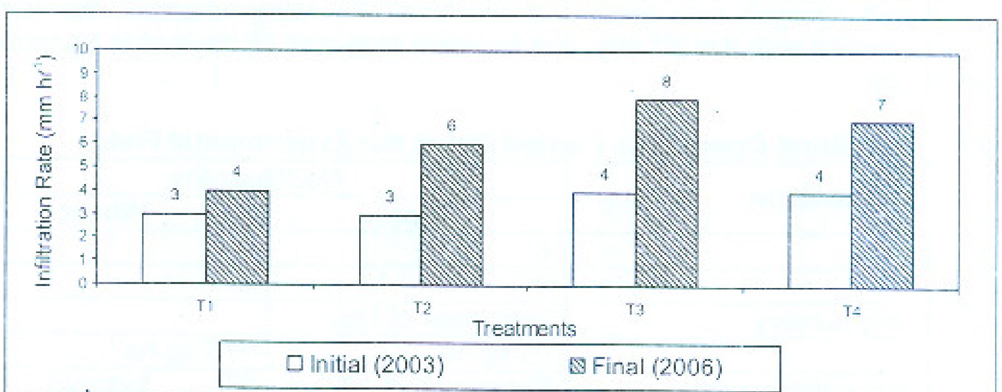

Figure 3.1 Effect of Different Treatments on Infiltration Rate of the Soil

The maximum increase in the infiltration rate of the soil was recorded in treatment 3 where gypsum was applied @ 100% GR of soil. The infiltration rate in this treatment was 100% more than the control. However, the infiltration rate of the treatment 2 and 4 was 50 and 75 percent more respectively than treatment 1. Treatment 2 did not show any improvement in the soil properties in the year 2005 as compared to 2004 which might be due to the greater cohesion of the clay particles. The average increase in the infiltration rate of the soil in the season 2006 depicted the improvement in the soil properties. However, the average increase in the infiltration rate was recorded as 57.5% over the treatment 1 and 80% increase than the average infiltration rate of the initial year. The application of marginal quality irrigation water alongwith gypsum @ 100% GR of soil proved the best treatment for the improvement in the soil properties. Haider et al. (1978) reported that infiltration rate of soil was significantly increased with the application of gypsum @ 100% GR of soil.

3.2 Changes in pH of the Soil

The effect of different treatments on the pH of the soil is shown in Table 3.2. The initial pH i.e. before the start of the experiment (Pre Wheat 2003-04) and final pH (Post Rice 2006) have been compared to observe the effect of treatments on the pH of the soil. The initial pH of all the treatments ranged between 9.4 to 9.5, 9.2 to 9.5, 9.2 to 9.3 and 9.0 to 9.1 at the soil depths of 0-15, 15-30, 30-60 and 60-90 cm respectively. After the harvest of rice crop 2006, the final pH ranged between 9.5 to 9.7, 9.3 to 9.5, 9.3 to 9.4 and 9.1 to 9.2 at the soil depths of 0-15, 15-30, 30-60 and 60-90 cm respectively. The data predicted that the pH increased in all the treatments at 0-15 cm soil depth except treatment 2 where it remained the same but at the depth of 15-30 cm the increase was more in sub-soiling treatment as compared to the other treatments. On overall basis, the change in pH at the time of final analysis ranged between nil to 3 percent. The initial and final pH of the experimental field remained more or less the same which is not suitable for the successful growth of the agricultural crops.

Table 3.2 Effect of Different Treatments on pH of the Soil

Treatment	Soil depth (cm)	pH		Percent increase over the initial
		Pre-wheat 2003-04 (Initial)	Post-rice 2006 (Final)	
T1 Irrigation with pure tubewell water	0-15	9.4	9.7	+ 3
	15-30	9.3	9.3	-
	30-60	9.3	9.3	-
	60-90	9.1	9.2	+ 1
T2 T1 + Sub-soiling upto 45 cm	0-15	9.5	9.5	-
	15-30	9.2	9.5	+ 3
	30-60	9.3	9.4	+ 1
	60-90	9.0	9.2	+ 2
T3 T1 + Gypsum @ 100% GR of soil	0-15	9.5	9.6	+ 1
	15-30	9.5	9.5	-
	30-60	9.3	9.3	-
	60-90	9.1	9.2	+ 1
T4 T1 + Pressmud @ 25 tons ha^{-1}	0-15	9.5	9.7	+ 2
	15-30	9.4	9.5	+ 1
	30-60	9.2	9.3	+ 1
	60-90	9.1	9.1	-

3.3 Changes in Electrical Conductivity (EC_e) of the Soil

The electrical conductivity (EC_e) of the soil profile is based on the movement of soluble salts with water in the soil matrix. If the movement of water is restricted by soil crusting, hardening of soil layers, inadequate drainage etc. the soil salinity is developed and as such EC_e is increased and vice versa. On the other hand if the soil environment facilitates proper leaching, the EC_e could be managed even with marginal quality irrigation water. The tubewell water used for irrigation had the EC_e 2.8 dS m^{-1} and TDS 1779 ppm.

To determine the detailed soil salinity and sodicity status of the study field, composite soil samples were collected from 0-15, 15-30, 30-60 and 60-90 cm soil depths and analysis was performed in the Soil and Water Testing Laboratory of MREP. The data provided in Table 3.3 indicate that EC_e of the experimental field was much higher at the time of initial or pre-wheat 2003-04 season because the field was lying barren before the start of the experiment. The EC_e in the initial season varied from 10.7 to 13.0, 6.1 to 8.3, 3.4 to 4.9 and 2.2 to 3.1 dS m^{-1} in all the treatments at the soil depths of 0-15, 15-30, 30-60 and 60-90 cm respectively.

The maximum decrease (73 percent) in EC_e was recorded at 0-15 cm soil depth in the treatment where sub-soiling was done followed by the treatment where only pure tubewell water was applied (Table 3.3 & Figure 3.2). At 15-30 cm soil depth, the decrease was again the highest (72 percent) in the treatments where pure tubewell water alone and with pressmud @ 25 tons ha^{-1} were applied (Fig. 3.3). At 30-60 cm soil depth, the maximum decrease (51 percent) was also observed in pressmud application treatment (Figure 3.4). At the lowest depth (60-90 cm) the decrease in EC_e was the maximum (45 percent) in the treatment 3 where gypsum @ 100% GR of soil was applied (Figure 3.5). At this depth the increase in EC_e in untreated tubewell water alone (35 percent) and pressmud application (5 percent) was observed.

Table 3.3 Changes in EC_e of the Experimental Field after the Study

Soil depth (cm)	Treatment	EC_e (dS m^{-1})		Percent change over the initial
		Initial	Final	
0-15	T1	13.0	3.9	- 70
	T2	12.2	3.3	- 73
	T3	10.7	4.7	- 56
	T4	10.8	5.2	- 52
15-30	T1	7.5	2.1	- 72
	T2	7.6	2.3	- 70
	T3	6.1	2.1	- 66
	T4	8.3	2.3	- 72
30-60	T1	4.9	4.1	-16
	T2	3.5	2.2	- 37
	T3	3.4	2.2	- 35
	T4	4.3	2.1	- 51
60-90	T1	3.1	4.2	+ 35
	T2	3.0	2.3	- 23
	T3	2.9	1.6	- 45
	T4	2.2	2.3	+ 5

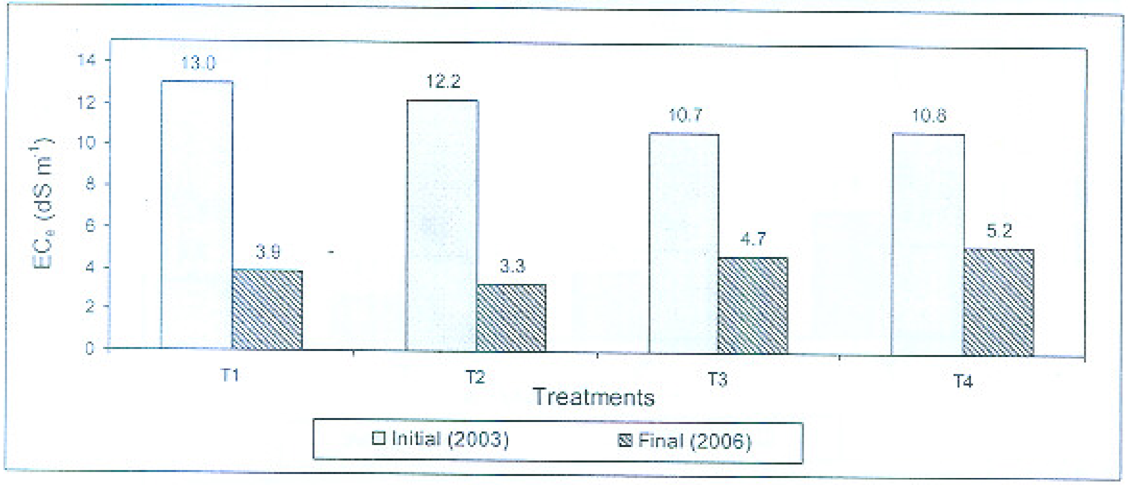

Figure 3.2 **Effect of Different Treatments on EC_e at 0-15 cm Soil Depth**

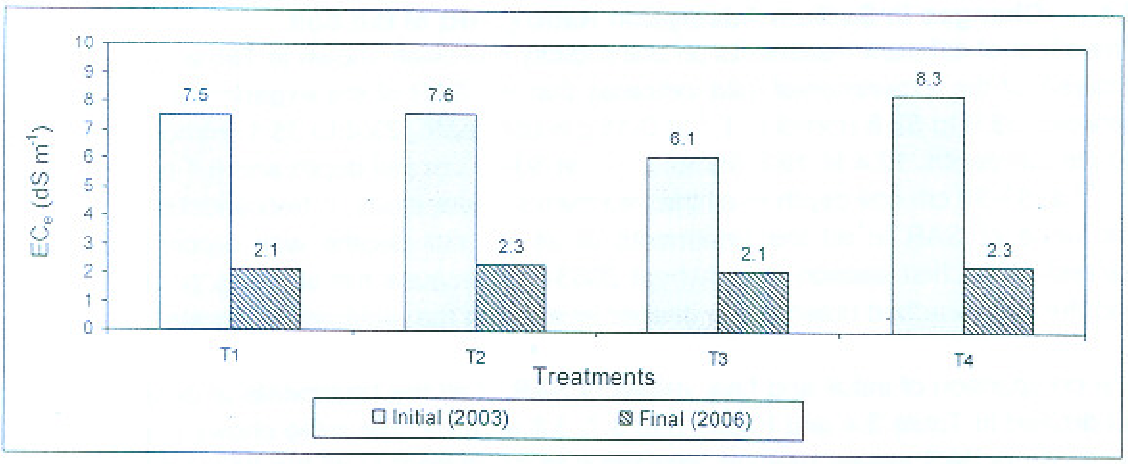

Figure 3.3 **Effect of Different Treatments on EC_e at 15-30 cm Soil Depth**

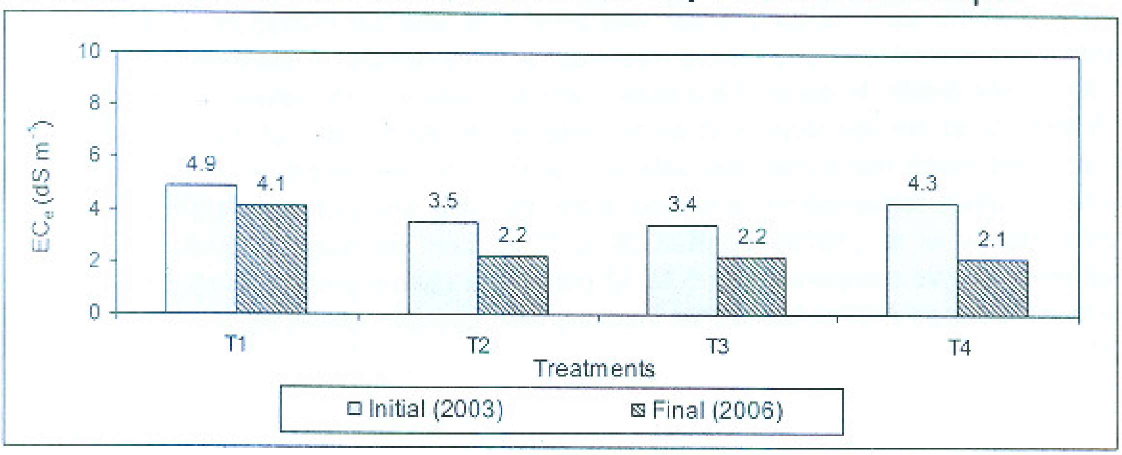

Figure 3.4 **Effect of Different Treatments on EC_e at 30-60 cm Soil Depth**

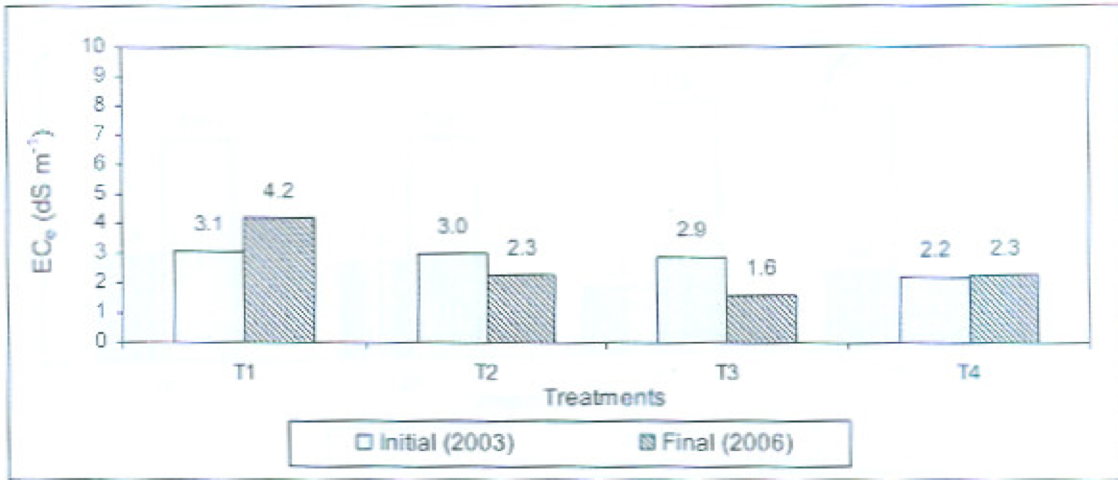

Figure 3.5 **Effect of Different Treatments on EC_e at 60-90 cm Soil Depth**

3.4 Changes in Sodium Adsorption Ratio (SAR) of the Soil

The effect of different treatments on soil sodicity has been shown in Table 3.4. The initial analysis of the experimental field indicates that the SAR of the experimental soil ranged between 38.9 to 53.8 (mmol $L^{-1})^{1/2}$ at 0-15 cm soil depth, 23.4 to 35.1 (mmol $L^{-1})^{1/2}$ at 15-30 cm soil depth, 12.4 to 19.8 (mmol $L^{-1})^{1/2}$ at 30-60 cm soil depth and 9.1 to 11.7 (mmol $L^{-1})^{1/2}$ at 60-90 cm soil depth in all the treatments under study. A tremendous decrease in the value of SAR in all the treatments at all the soil depths was recorded after the harvest of the first season crop (wheat 2003-04) because the soil was primarily barran and the salts leached down to the deeper layers with the application of water.

The comparison of initial and final values of SAR of all the treatments at different depths is narrated in Table 3.4 and Figure 3.6, 3.7, 3.8 and 3.9. The table shows that there was decrease in SAR values ranging between 6 to 64 percent in all the treatments at all the soil depths. The minimum decrease of 6 percent was noted at 60-90 cm soil depth in the treatment where pure tubewell water was used lone and the maximum decrease of 64 percent was recorded in sub soiling treatment at 0-15 cm and in pressmud treatment at 15-30 cm soil depth. In general the maximum decrease in SAR values was observed at 0-15 and 15-30 cm soil depths of all the treatments. At the end of the study the SAR values were much more than the safe limit at 0-15 cm soil depth in all the treatments whereas, values remained more or less within the safe limit (13 mmol $L^{-})^{1/2}$ at the lower depths. Haider et al. (1976) reported 29 to 72 percent decrease in SAR in pressmud treatment plots as compared with 5 to 32 percent in control plots at 0-15 cm soil depth whereas, Waheed (1971) found that leaching with gypsum efficiently brought down the ESP.

Table 3.4 **Changes in SAR of the Experimental Field after the Study**

Soil depth (cm)	Treatment	SAR (mmol L^{-1})$^{1/2}$		Percent decrease over the initial
		Initial	Final	
0-15	T1	42.1	22.0	48
	T2	53.8	19.3	64
	T3	38.9	27.0	31
	T4	43.2	27.5	36
15-30	T1	26.2	11.5	56
	T2	25.2	15.3	39
	T3	23.4	11.5	51
	T4	35.1	12.8	64
30-60	T1	19.8	10.4	47
	T2	13.6	12.3	10
	T3	12.4	11.5	7
	T4	15.1	10.3	32
60-90	T1	11.7	11.0	6
	T2	10.5	9.1	13
	T3	11.7	9.0	23
	T4	9.1	8.4	8

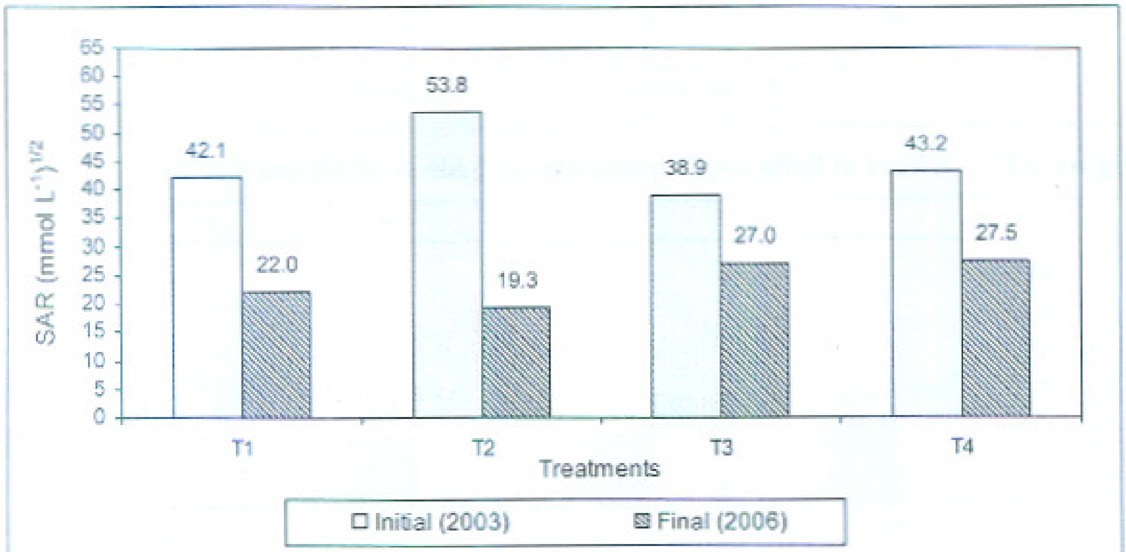

Figure 3.6 **Effect of Different Treatments on SAR at 0-15 cm Soil Depth**

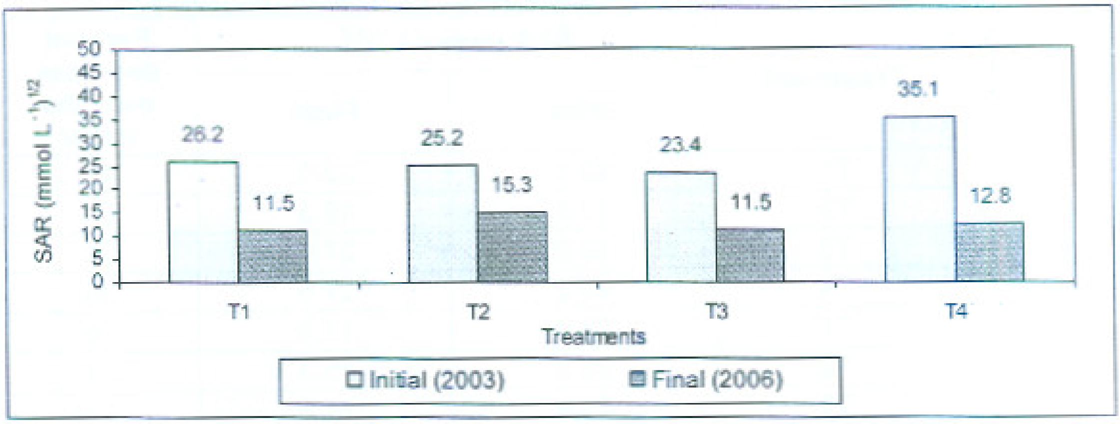

Figure 3.7 Effect of Different Treatments on SAR at 15-30 cm Soil Depth

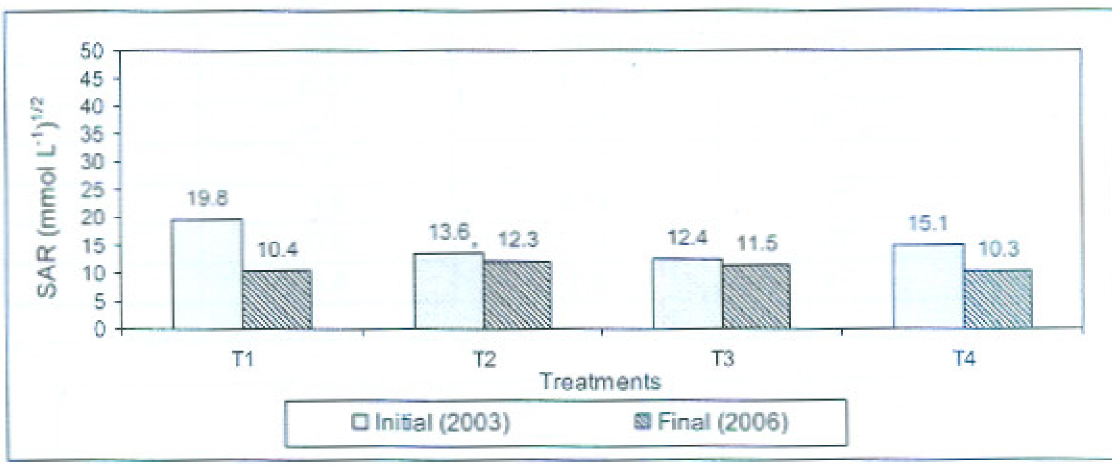

Figure 3.8 Effect of Different Treatments on SAR at 30-60 cm Soil Depth

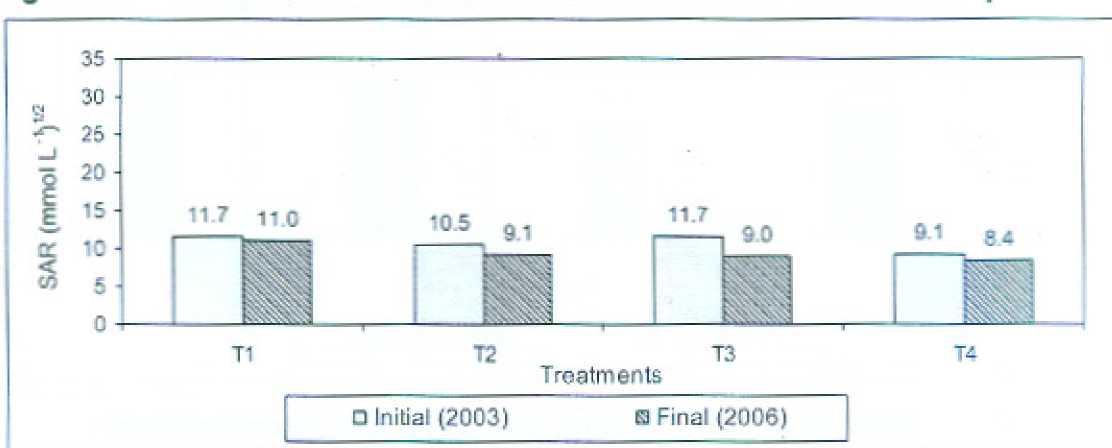

Figure 3.9 Effect of Different Treatments on SAR at 60-90 cm Soil Depth

3.5 Crop Yield

Due to high salinity and sodicity of the soil and continuous application of marginal quality water, wheat 2003-04 and rice 2004, 2005 and 2006 could not survive. The salts rapidly moved upward due to evaporation during the dry period (hot spell of weather) therefore, the plants scorched in all the treatments. During Rabi 2004-05, the wheat crop stand was patchy in all the treatments. The yield of wheat crop for the year 2004-05 and 2005-06 is given in Table 3.5.

The data reveal that the yield got by treatment-1 in both the seasons was the least (144 kg ha^{-1} and 48 kg ha^{-1} respectively).

Table 3.5 Effect of Different Treatments on the Wheat Grain Yield

(kg ha^{-1})

Treatment	Wheat grain (2004-05)	Wheat grain (2005-06)	% increase over control
T1 Irrigation with pure tubewell water	144	48	-
T2 T1 + Sub-soiling upto 45 cm	172	250	421
T3 T1 + Gypsum @ 100% GR of soil	502	1000	1983
T4 T1 + Pressmud @ 25 tons ha^{-1}	287	321	569

The reason for lowest yield in treatment 1 was that only the marginal quality tubewell water was used for irrigation purpose and no amendment was used. The application of gypsum @ 100% GR of soil gave the highest yield in both the seasons i.e. 502 kg ha^{-1} and 1000 kg ha^{-1} respectively. This treatment yielded 1983 percent more than the control and was almost double in the year 2005-06 as compared to the previous year (2004-05). It was followed by treatment 4 where pressmud @ 25 tons ha^{-1} was applied in both the seasons and was about 43% and 68% less than the yield of treatment 3 in the respective years (Figure 3.10). The general stand of the wheat crop by the treatment 3 and 4 for the year 2005-06 is clear from plate 1 and 2 respectively.

The wheat grain yields got by all the treatments in Rabi 2005-06 were almost in the same order as in Rabi 2004-05. The application of gypsum @ 100% GR of soil showed the improvement in the grain yield of saline-sodic soils. The grain yield obtained by gypsum application treatment was about 212 percent more as compared to pressmud application treatment in the last season of the study period.

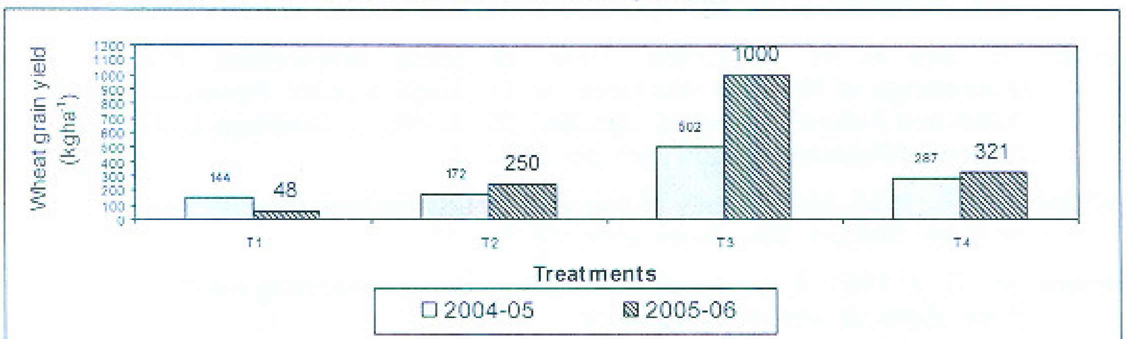

Figure 3.10 Effect of Different Treatments on the Wheat Grain Yield.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have been drawn on the basis of the field data of six crop seasons i.e. Rabi 2003-04 to Kharif 2006. The conclusions and recommendations are mainly based on soil characteristics such as salinity, sodicity, pH, soil permeability and crop yield. These are narrated as follows:

4.1 Conclusions

- None of the treatments showed any positive impact on the pH of the soil at any soil depth.
- Infiltration rate of the soil increased with the application of all the treatments but EC_e and SAR of the soil decreased in all the treatments at all the soil depths.
- Maximum increase in infiltration rate of the soil (100% more than the control) was with the treatment 3 where gypsum @ 100% GR of soil was applied.
- The decrease in SAR and EC_e was rapid initially in almost all the treatments at all the soil depths.
- Maximum wheat grain yield was obtained with the application of gypsum @ 100% GR of soil in both the seasons.
- Rice crop showed more susceptibility towards EC_e and SAR of the soil than wheat crop.

4.2 Recommendations

- Gypsum should be broadcast on the surface of the soil @ 100% GR of soil for rapid reclamation and the field should frequently be irrigated.
- Pressmud, the cheaper source of organic matter than gypsum can successfully be used for the reclamation of saline-sodic soils.

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