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Impact of Tile Drainage on Soil and Water Quality in Mardan SCARP Area

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Abstract: Fieldwork was conducted to study the impact of tile drainage on soil and water quality in Mardan Salinity Control and Reclamation Project (SCARP) from July to October 2000. Eleven sites were selected to investigate electrical conductivity (EC), pH and Sodium Adsorption Ratio (SAR) of soil samples and forty two sites to investigate EC, pH, SAR and residual sodium carbonate (RSC) of drainage water. The data were analyzed and compared with soil and water quality data of Mardan SCARP collected by Water and Power Development Authority (WAPDA) during 1979, 1986, 1995 and 1996 in the same area. The average EC of upper soil layer (0-30cm) during the year 1979 and 2000 were 4.72 and 1.09 dS m^{-1} respectively, which shows a decline of 77%. The salinity in the lower layer (30-60cm) of soil has decreased by 50%. This significant decrease in soil EC shows the leaching of soluble salts due to installation of tile drains. Average EC of drainage water showed an increase of 55% in Contract-I area and two-fold in Contract-II area, which also proves the leaching of soluble salts from the soil. No significant change was observed in the pH of soil and drainage water. Average SAR in the upper layer of soil has decreased by 58% due to addition of gypsum. Soils of some sites were still found to be sodic, therefore, appropriate remedial measures should be undertaken in such areas. SAR of drainage water shows that carbonates and bicarbonates have leached down in drainage water. About 35% of drainage water of Mardan SCARP area is of marginal quality because of high RSC (2.5-5.0 meq L^{-1}) and the rest is good for crop production. It is concluded from the results of this study that tile drainage has been effective in reducing salinity and sodicity problems. The drainage water of those areas, which were classified as marginal, should be treated or mixed with canal water before being used for irrigation.

Key words: Soil and water quality evaluation, drainage, waterlogging, salinity

Introduction

Waterlogging and salinity in the irrigated areas of Pakistan are major threats for sustainability of agriculture (Hunt, 1991). Measures to control these problems were intensified in 1960 when WAPDA launched SCARP programme. Initially, reclamation was sought through installation of tubewells; later on, tile drainage was introduced especially for the areas having poor aquifer characteristics and saline groundwater (Ahmad and Sipraw, 1999). The ultimate objective of these projects was to increase agricultural production by controlling waterlogging and salinity (Bhutta and Wolters, 1997).

The tile drainage is becoming much popular in the North West Frontier Province of Pakistan. Major SCARP projects undertaken in NWFP are: Mardan SCARP and CCADP (Chashma Command Area Development Project) and Swabi SCARP. Mardan SCARP was a multilateral aided project jointly funded by the International Development Agency (IDA), Canadian International Development Agency (CIDA) and Government of Pakistan. The project was implemented jointly by Water and Power Development Authority (WAPDA) of the Government of Pakistan and by the Government of NWFP. Two major components of Mardan SCARP were; installation of tile drains in roughly 50,000 ha area of Lower Swat Canal (LSC) and increase of water allowance from 0.35 to 0.77 L/s ha^{-1}. (Harza/Nespak, 1981). The tile drainage system in Mardan SCARP was installed during 1982-92 with the objective of lowering the watertable from about 2 to 4.5ft or more below the ground surface (Harza/Nespak, 1984).

Mardan SCARP encompasses 50,000 ha of the 54453 ha culturable command area (CCA) of the Lower Swat irrigation canal, which emanates from the Swat River via the Munda Head works. Within the project area, about 38000 ha of land had a high watertable during September/October, 1980 (Harza/Nespak, 1981). About 30,000 ha of land having high water table were provided with horizontal subsurface drains. The remaining area, consisting of small patches scattered within the waterlogged area, was not provided with subsurface drainage due to the presence of soils having very low hydraulic conductivity or the presence of shallow impermeable layers. The project area is situated within the administrative districts of Peshawar and Mardan. Mardan is the largest town in the project and the other prominent towns within the project boundaries are Charsadda, Utmanzai, Nisatta and Takhtbai.

The significance performance of the completed pipe drainage projects is increasing their popularity day by day and demands are coming to the Government of Pakistan from the people of other areas affected by waterlogging and salinity to start similar projects in their areas also (Niazi *et al.*, 1997). Improvement of new pipe drainage projects in Pakistan including NWFP is ongoing, using the experience and results of the studies carried out in the completed projects (Sarwar and Khan, 2001).

The proposed work aims to study the impact of tile drainage installation on soil and water quality of Mardan SCARP area. The SCARP Monitoring Organization (SMO) of WAPDA has collected data on soil and water quality of Mardan SCARP area in 1975, 1986, 1995 and 1996. Data collected in the study was compared with SMO-WAPDA data in order to investigate changes in soil and water quality with respect to time. The study of comparison is of utmost importance because it will provide information about the effectiveness of tile drainage in controlling salinity and shallow ground water pollution. Because of extensive increase in land utilization for irrigation and losses from water utilization for irrigation, it would be possible to make recommendations on the reuse of drainage water for crop production and on the design of environment-friendly drainage systems in Pakistan. Main objectives of the study were to investigate the changes in salinity, alkalinity, SAR and RSC of soil and drainage water and suitability of drainage water for crop production.

Materials and Methods

Mardan SCARP was completed in two Contracts i.e., Contract-I and Contract-II. Contract-I was started in 1982 and completed in 1987. It consists of 36 drainage plans (101-136). Just after the completion of Contract-I, the Contract-II was launched, which operated for 5 years, i.e., from 1987-1992. Contract-II consists of 88 drainage plans (200-250 and 300-338). In case of soil analyses, 11 sites (plans) from both Contract-I and Contract-II were selected for this study. The soil samples were collected from two depths i.e., 0-30cm and 30-60cm. For water analyses, 20 plans from Contract-I and 22 plans from Contract-II were selected for study. All water samples were collected from flowing collectors of the respective plans.

Soil and water sampling: Soil samples were taken with the help of soil auger. The collected samples were taken in plastic bags and were air-dried. The samples were crushed and passed through 2 mm sieve and were stored for analysis. Soil samples were analyzed for EC, pH, and SAR. Water samples were collected from selected flowing collectors in glass bottles and were properly labeled. The water samples were analyzed for EC, pH, SAR, and RSC. All samples were analyzed in the Soil and Water Quality Laboratory of SMO– WAPDA, Peshawar.

Soil and water analyses

Preparation of soil extract: A 200g of soil was taken in a can. Distilled water was added and the suspension was shaken with the help of spatula for about 10-15 minutes. The suspension was then kept in a can for 24 hours. Next day more water was added in order to make a complete paste. Indication was the free falling of paste from spatula. The saturation paste was then placed in extraction trolley and allowed to extract through filter paper. The soil extract was then collected in a 60 mL glass bottle.

Determination of electrical conductivity: Electrical conductivity of soil samples was determined by using the Beckman EC meter. The temperature was adjusted according to the room temperature. Electrode of EC meter was dipped in each sample one by one. Readings were taken when blinking of red and blue lights started at the same time. After each reading, the probe of EC meter was washed with distilled water and dried by using the filter paper.

Determination of pH: The pH was determined by using the Beckman pH meter. The pH meter was first standardized with buffer solution of known pH i.e. 7.0 and 9.2. Readings were taken directly by immersing the probe of pH meter into saturated paste. After each reading the probe of pH meter was washed with distilled water and wiped with filter paper.

Determination of sodium adsorption ratio: Sodium adsorption ratio (SAR) of soil extract was calculated by using the following relationships (Richards, 1975).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad (1)$$

Sodium ions (Na^+) were determined with the help of Flame Photometer by directly introducing the samples. A series of standards were prepared and from standard chart the amount of Na^+ was determined. Ca^{+2} and Mg^{+2} ions were determined by titration method using the following formula.

$$\text{Ion (meq L}^{-1}) = \frac{\text{Burette reading (ml) x Normality (meq L}^{-1})}{\text{Volume of sample (ml)}} \times 100 \quad (2)$$

Determination of residual sodium carbonate (RSC): The concept of residual sodium carbonate (RSC) is to predict the tendency for calcium carbonate to precipitate from higher Bicarbonate water. The RSC is defined as:

$$RSC = (HCO^-_3 + CO^-_3) - (Ca^{++} + Mg^{++}) \quad (3)$$

Where all the ionic concentrations are expressed in meq L^{-1}. Carbonates and Bicarbonates were also determined by titration method using equation (2).

Results and Discussion

A total of 22 soil samples were collected from 11 selected locations, at 0-30 cm and 30-60cm depths. The soil data of 11 locations was compared with SMO-WAPDA data collected during the year 1979 and 1996. A total of 42 water samples were analyzed, 20 water samples from Contract-I area and 22 from Contract-II area. The data for the Contract-I area, for the same collectors was collected by SMO-WAPDA in 1986 and the results of all the analyzed water samples of Contract-I were compared with this data. The data collection for Contract-II area was done by SMO-WAPDA in 1995 but not for the same collectors, therefore, results of water analysis of Contract-II area were compared with the averages of 1995 data.

Electrical conductivity of soil extract: Table 1 presents the electrical conductivity of soil at selected locations in Mardan SCARP during the year 1979, 1996 and 2000. The average EC in upper soil layer (0-30cm) during 1979 and 1996 was 4.72 and 2.28 dS m^{-1}, respectively and in the year 2000 was 1.09 dS m^{-1}. Generally, the salinity has decreased by 77%. This decrease in salinity could be due to the fact that the water table has been lowered and salts in the ground water do not come to surface. There were some areas, which were severely affected by salinity, have now bee reclaimed. In areas, 104/11 and 106/4, the value of EC was 13 dS m^{-1} in 1979, which has now reduced to 1.25 and 0.55 dS m^{-1}, respectively. This shows a remarkable decline in soil salinity in the severely affected areas. The tile drainage has been effective in reducing soil salinity in the upper layer of soil.

In the lower soil layer (30-60cm), the average EC in the year 1979 and 1996 was 3.03 and 1.93 dS m^{-1} and in the year 2000 it was 1.51 dS m^{-1}, which shows the general decline in EC (50%) in the lower layer of soil. Only one location (104/11) had a higher value of EC (16 dS m^{-1}) in 1979. In the year 2000, the EC of this area has decreased to 1.00 dS m^{-1}. In areas 100/4, 102/15, 100/5 and 104/6, the EC has slightly increased which may be due to leaching of salts from the upper soil layer.

From the above discussion it is clear that salinity in Mardan SCARP area has been decreasing with the passage of time. It can concluded that tile drainage in Mardan SCARP has been effective in reducing salinity both in upper and lower layer of soil. Similar results were reported by Khan *et al.* (1997) who concluded that the salinity problem has reduced by more than 50% after implementation of Mardan SCARP.

Electrical conductivity of drainage water: The average EC of drainage outflow in Contract-I area in 1986 was 0.75 dS m^{-1} and in 2000, it was 1.16 dS m^{-1}, which shows an increase of 55% (Table 2). This increase could be due to the fact that soluble salts have leached down into drainage water by the installation of tile drains in the area. All of the drainage water samples showed the similar trend of increase in salinity. The average EC in Contract-II area during 1995 was 0.42 dS m^{-1} and in 2000 it was 1.28 dS m^{-1} which shows about two-fold increase. This increase could be due to the similar reasons discussed above. Generally, electrical conductivity of drainage water in Contract-I and Contract-II areas of Mardan SCARP has increased after the installation of tile drains. It can be concluded that tile drainage has been effective in leaching the salts from the soil, which was also confirmed by reduction in soil EC.

pH of saturated paste: Average pH in the upper soil layer during 1979 was 9.1 and in 2000 it was 8.7, which shows the decrease of 4% (Table 3). This decrease in soil pH may be due to addition of gypsum into the soil. According to Ayers and Westcot (1989), gypsum is effective in reducing a high soil pH (pH $>$ 8.5) caused by high exchangeable sodium. No significant change was observed in the pH of lower soil layer. Only at site 100/4, the pH was higher (10), which shows that this area is alkaline. This high range of pH may cause nutritional imbalance for crops grown in the area. It can be concluded from the results that pH of soil has decreased slightly in the upper and lower soil layers due to the addition of gypsum. The overall pH of soil in Mardan SCARP area ranged from 7.7-10.0. This range of pH does not have any hazardous effect on crop production. It is also concluded that the pH of Mardan area is moderately alkaline in nature. Similar results were reported by Asim (1997), who found that the pH of soil and drainage water in Swabi SCARP is slightly alkaline in nature.

pH of drainage water: Average pH in Contract-I area of Mardan SCARP in 1986 was 7.9 and whereas in 2000, it was 8.0, which shows only a slight increase (Table 4). This increased may be due to the leaching of salts in drainage water. In some areas such as 124/1 and 127/2, the pH of drainage water has decreased from 8.0 and 8.2 to 7.7 and 8.0, respectively. It is still in the alkaline range and showed a very little decrease of 3%. No significant change in pH of drainage water in Contract-II area was found after implementation of Mardan SCARP. The overall results have shown slight increase in the pH of drainage water, which may be due to the leaching of salts from the rootzone. The pH of drainage water varied from 7.0-8.4, which comes under slightly alkaline range. Asim (1999) also reported the similar results in Swabi SCARP area.

Sodium adsorption ratio of soil extract: The general trend shows that SAR of soil has decreased with time (Table 5). In 1979, the average SAR of upper soil layer was 27.88 and in 2000 it was 11.52, which shows a decrease of 58%. This decrease could be due to addition of gypsum. According to Ayers and Westcot (1989), gypsum is very effective in reducing soil sodicity. Some areas were also identified where sodicity problem still exists. In 104/9, 100/9 and in 104/11, SAR of soil was 27.80, 18.80 and 17.78, respectively. These high values could be due to the fact that either soil was not properly drained or very little quantity of gypsum was applied to soil. Further research needs to be conducted to investigate the real cause of sodicity problem at these locations.

Table 1: Comparison of EC of soil at selected locations in Mardan SCARP

Drainage plan No.	Upper soil layer (0-30 cm) 1979	1996	2000	Lower soil layer (30-60 cm) 1979	1996	2000
100/4	4.30	1.50	0.55	0.29	1.40	1.70
100/5	0.70	0.50	0.32	0.69	0.85	1.70
100/9	0.50	0.75	1.35	0.45	1.60	0.66
102/7	3.30	2.20	2.60	5.00	2.50	1.90
102/15	7.50	1.40	0.50	1.40	0.95	1.70
102/16	3.00	1.50	1.10	1.60	1.80	1.25
104/9	1.50	1.20	2.65	0.60	1.20	0.66
104/10	4.50	2.65	0.53	1.70	4.70	0.80
104/11	13.00	3.40	1.25	16.50	1.15	1.00
106/4	13.00	9.00	0.55	4.60	4.50	4.80
399/8	0.67	0.50	0.60	0.55	0.60	0.42
Average	4.72	2.24	1.09	3.03	1.93	1.51

Table 2: Comparison of electrical conductivity of drainage at selected locations in Mardan SCARP

Drainage plan No.	Contract-I area EC (dS m^{-1}) 1986	2000	Contract-II area Drainage plan No.	EC (dS m^{-1}) 2000
102/2	0.60	0.83	203/1	1.20
102/6	0.67	1.32	204/1	1.30
103/2	0.75	0.98	205/1	1.04
104/4	0.76	1.30	208/2	1.15
105/5	0.67	1.20	211/2	1.70
108/4	0.80	0.80	214/1	1.10
110/1	0.68	1.12	215/3	1.80
110/2	0.79	1.20	217/2	1.20
110/3	0.77	1.30	224/2	1.30
111/1	0.64	1.20	233/1	1.20
115/7	0.80	1.14	234/2	1.20
117/1	0.70	1.10	235/3	1.15
121/2	0.80	1.20	246/1	2.20
124/1	0.70	1.12	304/1	1.00
124/4	0.85	1.00	304/3	1.20
125/3	0.90	1.50	305/2	1.00
125/7	0.80	1.14	307/2	1.30
126/2	0.85	1.15	308/2	1.40
127/2	0.85	1.10	324/6	1.30
129/2	0.70	1.68	325/3	0.95
			326/2	1.10
			334/2	1.40
Average	0.75	1.16		1.28

Table 3: Comparison of pH of soil at selected locations in Mardan SCARP

Drainage plant No.	Upper soil layer (0-30cm) 1979	1996	2000	Lower soil layer (30-60cm) 1979	1996	2000
100/4	9.5	8.4	8.7	9.2	8.3	10.0
100/5	8.4	7.3	9.0	8.5	7.8	9.8
100/9	8.4	7.9	9.2	8.4	8.8	9.0
102/7	9.8	9.3	8.2	9.6	9.4	9.6
102/15	9.8	8.2	8.2	9.8	7.8	8.6
102/16	9.5	8.7	8.9	9.7	9.0	9.0
104/9	8.1	7.2	9.1	8.0	7.2	9.0
104/10	9.6	9.0	8.5	8.9	9.6	8.9
104/11	9.6	9.0	8.5	9.7	8.6	8.4
106/4	8.7	9.7	9.2	9.1	9.3	8.6
399/8	9.1	7.0	7.9	8.2	7.0	7.7
Average	9.1	8.3	8.7	9.0	8.4	8.9

Table 4: Comparison of pH of drainage water at selected locations in Mardan SCARP

Drainage plan No.	Contract-I area pH 1986	2000	Contract-II area Drainage plan No.	pH 2000
102/2	8.2	8.0	203/1	7.9
102/6	7.8	8.1	204/1	8.0
103/2	8.0	8.4	205/1	7.9
104/4	8.0	7.7	208/2	8.1
105/5	7.7	7.9	211/2	7.5
108/4	8.0	8.7	214/1	8.0
110/1	7.8	8.0	215/3	7.4
110/2	7.8	8.1	217/2	7.3
110/3	7.6	8.1	224/2	7.3
111/1	8.0	7.2	233/1	7.3
115/7	7.7	8.0	234/2	7.6
117/1	8.0	8.0	235/3	7.9
121/2	7.6	8.0	246/1	8.0
124/1	8.0	7.7	304/1	8.0
124/4	7.7	8.0	304/3	7.0
125/3	7.6	8.1	305/2	8.0
125/7	7.6	8.2	307/2	7.5
126/2	8.0	8.0	308/2	8.1
127/2	8.2	8.0	324/6	8.0
129/2	8.1	8.4	325/3	7.5
			326/2	8.0
			334/2	8.1
Average	7.9	8.0		7.7

Table 5: Comparison of SAR of soil at selected locations in Mardan SCARP

Drainage plan No.	Upper soil layer (0-30cm) 1979	1996	2000	Lower soil layer (30-60cm) 1979	1996	2000
100/4	48.83	10.80	08.00	01.06	10.90	29.41
100/5	12.70	09.40	00.69	12.70	10.84	23.09
100/9	00.40	05.70	18.70	01.23	14.10	11.20
102/7	32.90	21.61	15.51	38.54	19.55	25.80
102/15	20.27	10.09	06.24	09.40	05.53	25.80
102/16	10.43	13.30	09.00	16.68	16.35	10.70
104/9	04.86	04.65	27.80	07.22	04.65	11.20
104/10	41.16	21.61	08.80	08.49	39.37	06.29
104/11	108.23	28.10	17.78	50.23	08.45	08.00
106/4	24.00	77.95	10.80	29.90	38.30	42.19
399/8	02.88	01.42	04.30	01.67	01.63	02.30
Average	27.88	18.60	11.60	16.10	15.42	17.82

Results of the lower soil layer show that at some locations SAR has increased and in some cases it has decreased. In areas 100/4, 102/15, 102/7, 104/9, 106/4 and 399/8, the SAR of soil has increased. This increase in SAR may either be due to inadequate drainage, which was unable to remove exchangeable sodium from the soil, or inadequate gypsum application. Detailed studies needs to be conducted in these areas to investigate the severity of sodicity problem and appropriate interventions should be

Table 6: Comparison of SAR of drainage water at selected locations in Mardan SCARP

Drainage plan No.	Contract-I area SAR 1986	2000	Contract-II area Drainage plan No.	SAR 2000
102/2	0.00	3.26	203/1	4.68
102/6	0.16	5.90	204/1	4.88
103/2	0.18	2.80	205/1	3.35
104/4	0.23	6.81	208/2	4.52
105/5	0.20	4.68	211/2	9.35
108/4	0.25	1.65	214/1	5.15
110/1	0.25	4.29	215/3	3.79
110/2	0.47	4.60	217/2	4.70
110/3	0.39	6.69	224/2	4.00
111/1	0.16	4.27	233/1	10.14
115/7	0.33	5.80	234/2	4.60
117/1	0.00	3.74	235/3	4.52
121/2	0.00	6.08	246/1	12.02
124/1	0.26	4.75	304/1	5.07
124/4	0.18	4.41	304/3	4.58
125/3	0.18	7.58	305/2	5.62
125/7	0.82	5.01	307/2	8.61
126/2	0.82	4.16	308/2	4.47
127/2	1.89	3.98	324/6	6.10
129/2	0.74	9.64	325/3	4.32
			326/2	2.82
			334/2	6.58
Average	0.38	5.01		5.63

Table 7: Comparison of RSC of drainage water at selected locations in Mardan SCARP

Drainage plan No.	Contract-I area RSC (meq L^{-1}) 1986	2000	Contract-II area Drainage plan No.	RSC (meq L^{-1}) 2000
102/2	0.00	1.10	203/1	2.60
102/6	0.00	3.00	204/1	2.20
103/2	0.00	0.90	205/1	1.60
104/4	0.00	2.80	208/2	2.40
105/5	0.00	1.70	211/2	4.80
108/4	0.00	0.40	214/1	1.70
110/1	0.00	2.30	215/3	4.80
110/2	0.40	2.30	217/2	2.40
110/3	0.30	3.40	224/2	2.30
111/1	0.00	2.20	233/1	1.80
115/7	0.00	3.30	234/2	1.50
117/1	0.00	1.80	235/3	2.00
121/2	0.00	2.40	246/1	4.80
124/1	0.00	3.46	304/1	2.40
124/4	0.00	2.40	304/3	3.80
125/3	0.00	4.30	305/2	2.20
125/7	0.25	2.64	307/2	2.70
126/2	0.50	2.10	308/2	4.50
127/2	1.50	2.20	324/6	4.00
129/2	0.00	4.70	325/3	1.10
			326/2	1.70
			334/2	2.70
Average	0.15	2.47		2.73

undertaken to control it. It may be concluded from the above discussion that generally SAR has decreased in upper soil layer and increased in the lower soil layer, after implementation of Mardan SCARP.

Sodium adsorption ratio of drainage water: In the Contract-I area, the average SAR in 1986 was 0.37 and in 2000 it was 5.01, which shows an increase of more than twelve folds (Table 6).

The increase could be due to fact that exchangeable sodium has leached down into the drainage water. The average value of SAR in Contract-II area in 1995 was 1.27 and in 2000 it was 5.63, which shows an increase three times. From the results, it is obvious that the SAR of drainage water has increased, after installation of tile drainage in Mardan SCARP area. So, it is concluded that Mardan SCARP has been effective in reducing soil sodicity problem. This was also confirmed by reduction of SAR in the soil samples.

Residual sodium carbonate of drainage water: It depicts a clear trend that RSC of drainage water has increased after the installation of tile drains in Mardan SCARP (Table 7). In 1986, the average value of RSC in Contract-I area was 0.15 and in 2000 it was 2.47 meq L^{-1}, which shows an increase of more than 15 times. In 1986, RSC of drainage water at most of the locations was zero which showed that the concentration of anions (Bicarbonates and Carbonates) were equal to the concentration of calcium and magnesium. Higher values of RSC in the year 2000 showed that exchangeable sodium has leached down from the soil as sodium carbonate (Na_2CO_3) into the drainage water due to addition of gypsum. In area 125/3 and 129/2 the value of RSC in 2000 was 4.30 and 4.70 meq L^{-1}, respectively. It is recommended that the drainage water of these areas should either be treated or mixed with good quality canal water before being used for irrigation, because direct use may results build up of sodicity in the soil. Average RSC in Contract-II area in 1995 was 0.74 meq L^{-1} and in 2000 it was 2.73 meq L^{-1}, which shows an increase of 2.7 times. This increase in RSC could be due to the similar reasons as discussed above. RSC of all drainage water samples were found with in the safe limits, except for sites 215/3, 246/1, 308/2 and 324/6 which had higher values of RSC (4.80, 4.80, 4.50 and 4.00 meq L^{-1}, respectively). Generally, RSC of drainage water has increased after implementation of Mardan SCARP, so it can be concluded that tile drainage has been effective in leaching anions (carbonates and bicarbonates) from the soil.

Suitability of drainage water for crop production: A total of 20 water samples were analyzed from Contract-I area. Results shows (Table 8) that 65% water samples were classified as usable and 35% were marginal quality. In areas 102/6, 104/4, 110/3, 115/7, 124/1, 125/3 and 129/2, water samples were classified as marginal, because of high RSC value. It is recommended that drainage water of these area must be treated or mixed with canal water before being used for irrigation because direct use of such water may increase the carbonates and bicarbonates concentrations in soil. Drainage water of usable quality can be safely used for irrigation.

Overall 22 water samples were analyzed from Contract II area. According to the results 64% of water samples were usable and 36% were marginal. There were eight locations (211/2, 215/3, 246/1, 304/3, 307/2, 308/2, 324/6 and 334/2), which had high RSC values, so the water in these areas should be treated before being used for irrigation due to the above mentioned same reasons.

From the results it is clear that the overall quality of drainage water in Mardan SCARP area is good for crop production. In case of shortage of canal water, the drainage water of the most of the areas can be directly used for irrigation and drainage water of few areas need little treatment.

The electrical conductivity of soil has decreased by 73% and electrical conductivity of drainage water has increased by 30%. From the decrease of EC in soil and increase in drainage water, it is concluded that salinity problem in Mardan SCARP has significantly reduced. No significant changes were observed in the pH of soil and drainage water and were found to be in the range of 7.00 to 10.00. It is concluded that area of Mardan SCARP is moderately alkaline in nature. SAR of soil has decreased by 58% and increased by 3 to 12 times in drainage water. From this significant decrease of SAR in soil and increase in drainage water, it is concluded that tile drainage in Mardan SCARP has been effective in reducing sodicity problem. RSC of drainage water has increased by 2.7 to 15 times, which shows that tile drainage in Mardan SCARP has been effective in leaching carbonates and

Table 8: Overall drainage water quality status in Contract-I and II areas of Mardan SCARP

Contract-I area					Contract-II area				
Drainage plan No.	EC (dS m^{-1})	SAR	RSC (meq L^{-1})	Water quality status	Drainage plan No.	EC(dS m^{-1})	SAR	RSC (meq L^{-1})	Water quality status
102/2	0.83	3.26	1.10	Usable	203/1	1.20	4.68	2.60	Marginal
102/6	1.32	5.90	3.00	Marginal	204/1	1.30	4.88	2.20	Usable
103/2	0.98	2.80	0.90	Usable	205/1	1.04	3.35	1.60	Usable
104/4	1.30	6.81	2.80	Marginal	208/2	1.15	4.52	2.40	Usable
105/5	1.20	4.68	1.70	Usable	211/2	1.70	9.35	4.80	Marginal
108/4	0.80	1.65	0.40	Usable	214/1	1.10	5.15	1.70	Usable
110/1	1.12	4.29	2.30	Usable	215/3	1.80	3.79	4.80	Marginal
110/2	1.20	4.60	2.30	Usable	217/2	1.20	4.70	2.40	Usable
110/3	1.30	6.69	3.40	Marginal	224/2	1.30	4.00	2.30	Usable
111/1	1.20	4.27	2.20	Usable	233/1	1.20	10.14	1.80	Usable
115/7	1.14	5.80	3.30	Marginal	234/2	1.20	4.60	1.50	Usable
117/1	1.10	3.74	1.80	Usable	235/3	1.15	4.52	2.00	Usable
121/2	1.20	6.08	2.40	Usable	246/1	2.20	12.02	4.80	Marginal
124/1	1.12	4.75	3.46	Marginal	304/1	1.00	5.07	2.40	Usable
124/4	1.00	4.41	2.40	Usable	304/3	1.20	4.58	3.80	Marginal
125/3	1.50	7.58	4.30	Marginal	305/3	1.00	5.62	2.20	Usable
125/7	1.14	5.01	2.64	Marginal	307/2	1.30	8.61	2.70	Marginal
126/2	1.15	4.16	2.10	Usable	308/2	1.40	4.47	4.50	Marginal
127/2	1.10	3.98	2.20	Usable	324/6	1.30	6.10	4.00	Marginal
129/2	1.68	9.64	4.70	Marginal	325/3	0.95	4.32	1.10	Usable
					326/2	1.10	2.82	1.70	Usable
					334/2	1.40	6.58	2.70	Marginal

Usable: EC (dS m^{-1}): 0-1.5 SAR: 0-10 RSC (meq L^{-1}): 0-2.5
Marginal: EC (dS m^{-1}): 1.5-2.7 SAR: 10-18 RSC (meq L^{-1}): 2.5-5.0

bicarbonates from soil. About 35% of drainage water was found to be of marginal quality and 65% was usable, which can be safely used for crop production. The marginal quality drainage water should either be treated or mixed with good quality water before being used for crop production.

Long-term studies should be undertaken to know the sustainability of tile drainage projects. Continuous functioning of tile drainage system in irrigated areas should be ensured to minimize salt buildup and ground water pollution. In water scarce areas, the good quality drainage water of can be safely used for crop production, however the marginal quality drainage water should first be treated or mixed with good quality water. Soil of some parts in Mardan SCARP were still reported as sodic, therefore, further research should be conducted to investigate the real cause of sodicity problem and appropriate intervention should be undertaken to control it.

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