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Environmental and socio-economic impacts of pipe drainage in Pakistan

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Abstract Many drainage schemes and salinity control projects have been executed world wide. Pipe drainage has widely been used in Pakistan, Egypt and India to control waterlogging. The impact of pipe drainage on land and water was evaluated in this paper using data of three pipe drainage projects in Pakistan namely Khushab Salinity Control and Reclamation Project, Fourth Drainage Project in Faisalabad and Swabi Salinity Control and Reclamation Project. Data by regular monitoring of these projects were collected. The effect of pipe drainage on water table depth at these three locations has been compared. Water quality and soil salinity improvement due to the pipe drainage has also been investigated. Data, related to water table depths and discharges from drain pipes/wells, was collected. Observation wells, installed at various places by the Water and Power Development Authority, were used for collection of this data. To evaluate the impact of the projects on salinity, soil samples from all the three locations were tested. A questionnaire was prepared to get the view of the people about the projects. It was revealed that in these areas, due to subsurface pipe drainage, the percentage of the abandoned land has been considerably decreased. Over drainage was observed in a few places of the projects. The farmers at such places were asked to change their cropping patterns. Ultimately, there has been an increase in area under cultivation, crop yields and cropping intensity in the projects' area.

Keywords Pakistan · Intensity · Soil · Salinity · Waterlogging

Introduction

The economy of many countries worldwide depends upon agriculture. Waterlogging and salinity is affecting agriculture badly at several places. Dry land salinity, due to high evaporation, is a serious problem in the low-lying parts of West Asia. In Iraq, for example, more than 50% of the lower

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Rafidain Plains face a stern salinity and waterlogging problems (El-Hinnawi 1993). Similarly, salinity and waterlogging have been inevitable problems in Egypt. These problems have existed during the pre- and post-Aswan High Dam periods (Ritzema 2009; IPTRID Secretariat 2007). To overcome this twin problem, subsurface drainage projects were commissioned in 1942 in Egypt. About 55% of agricultural land is reported as saline in Iran, (FAO 1994)

Waterlogging and drainage problems occur in the central and southern parts of the Saudi Arabia. About 0.6% of the irrigated area has drainage facilities in the form of open drainage canals controlled by Governmental of Saudi Arabia. In some projects, like that of the Al-Hassa irrigation project, the agricultural drainage water is mixed with fresh groundwater and reused for irrigation. So, due to the poor quality of irrigation, water soil salinity problem is increasing (AQUASTAT 2008).

The canal irrigation system in Pakistan started in the mid-nineteenth century when Britain was ruling the region. After extensive developments, Pakistan now possesses the world's largest contiguous irrigation system commonly called as the Indus Basin Irrigation System that commands about 14.2 Mha canal irrigated area (Niazi 2008). Most of the system consists of unlined canals. Due to poor operation and maintenance of canals and lacking measures to control seepage it caused waterlogging and salinity problems. As a result, a major part of agricultural lands of Pakistan has been destroyed by the problem due to inadequate drainage facilities. About four decades ago Government of Pakistan assigned high priority to drainage for the control of waterlogging and salinity in the fertile areas where agricultural production was declining day by day (Niazi 2008; Ghumman et al. 2010). Various methods of drainage were applied. These methods included surface drains, subsurface pipe drainage and tubewells. Subsurface pipe drainage started in the country in around the 1970s. The Pakistan Council of Research in Water Resources has done extensive work regarding tile drainage in Pakistan (Kahlown and Khan 2004). Eight subsurface pipe drainage projects were installed in due course. Smedema (1990) analysed various aspects of three subsurface pipe drainage projects namely the Fourth Drainage Project (FDP), Mardan and East Khairpur Project. This analysis was related to the phases of planning, design and construction of these projects. This study revealed that there were some gaps and weaknesses in several fields. These fields include the availability of basic information, the applied methodology, and the understanding of processes. All of these needed to be addressed and investigated properly. Sarwar (2000) reported that different drainage projects installed in Pakistan had not generated enough benefits due to improper designs. However, the research work by the Ex-Chairman of the Pakistan Council of Research in Water Resources shows that the observed values of drainage coefficients of three selected drainage systems (NIA, Bughio and Nawazabad farms in Pakistan) were very close to the designed values (Kahlown et al. 2010). Recent research done in various regions world wide proves that properly designed and studied subsurface drainage is highly beneficial and efficient for controlling waterlogging and salinity. Hornbuckle et al. (2007) has proven benefits of a multi-level subsurface drainage system. Hirekhan et al. (2007) have investigated behaviour before and after installations of subsurface drainage in a semi-arid climate area and has stressed on rigorous analysis before adopting a subsurface drainage technique. Chahar and Vadodaria (2010) have investigated optimal spacing in an array of fully penetrating ditches for subsurface drainage. They have developed an explicit equation for computing the optimal spacing between the ditches. Eldeiry and Garcia (2010) have compared ordinary kriging, regression kriging and co-kriging techniques to estimate soil salinity using various images. The best combinations have been evaluated to estimate soil salinity with different crop types. Commissioning of abandoned drainage water reuse systems in Egypt has been investigated by Gammal El and Ali (2010).

The subsurface drainage installations in Pakistan are still less than 1% of the total cultivable commanded areas which needs subsurface drainage

(Azhar et al. 2004). Bhutta (2007) has discussed salient findings of drainage research and its benefits in Pakistan. Kahlown et al. (2007) have evaluated performance of small tile drainage systems in the Indus Basin, Pakistan. However, after the completion of eight subsurface pipe drainage projects in Pakistan, the Government stopped further construction since 2000. On the other hand, the huge surface drains full of weeds and withstanding hazardous brackish water are occupying a lot of precious land without any benefit and have been left un-attended since long time. The long-term impacts of the subsurface drainage system with respect to its performance and benefits in Pakistan have not been evaluated properly yet. Hence, it was important to investigate the subsurface drainage system with respect to controlling the problem of waterlogging and salinity and their impact on economy of the country. This research has investigated three subsurface drainage projects with different topographic locations out of eight projects executed in Pakistan.

Study area and subsurface pipe drainage projects

Three projects (Khushab SCARP, FDP Faisalabad and Swabi SCARP) as shown in Figs. 1, 2, 3 and 4

Fig. 1 Map of Pakistan showing location of various drainage projects (after Ritzema 2009 and Niazi 2008)

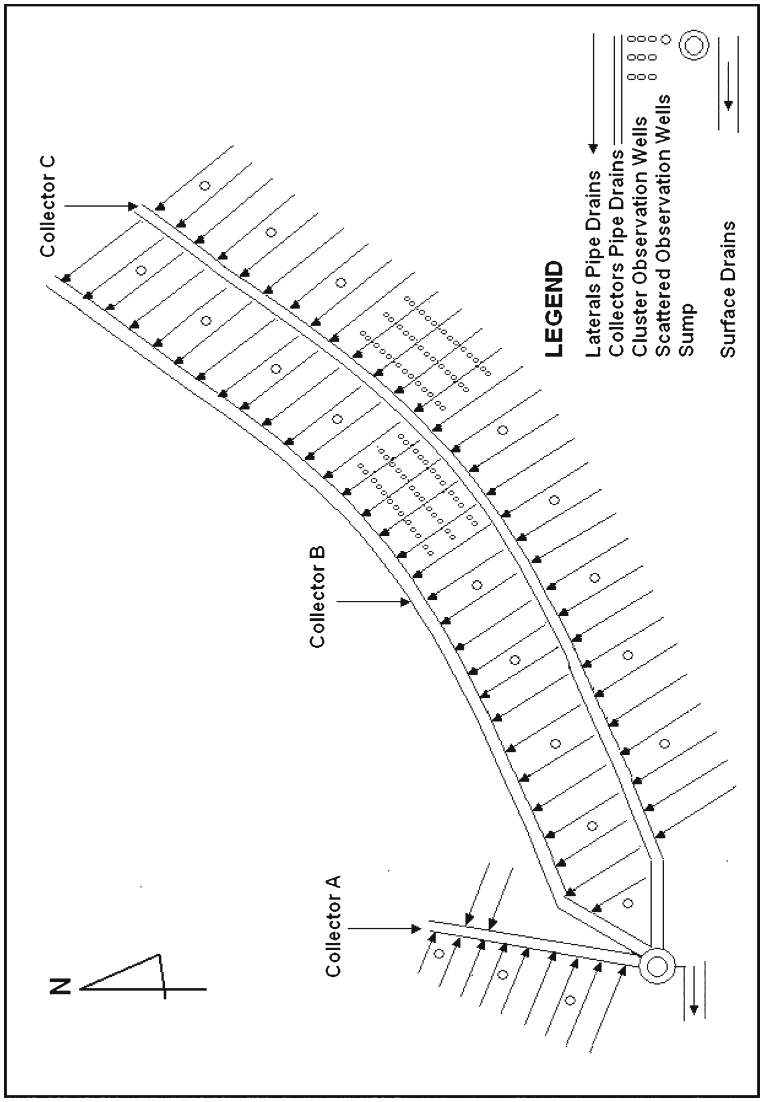

Fig. 2 Layout of pipes and observation wells for Khushab Project (after Niazi 2008)

were studied. Details of these projects are given below.

Khushab SCARP project (KSP, 1990–99)

The project area is situated in district of Khushab between latitudes 32°16′N to 32°18′N and longitudes 72°20′E to 72°24′27″E. The gross area of the project is 0.042 million hectares and the cultivable command area is 0.038 million hectares. The project started in 1990 before which the disaster area was about 95% (Niazi 2008). Subsurface pipe drainage was constructed over an area of 0.0234 million hectares. Ninety kilometres of surface drains were also remodelled for drainage improvement. The groundwater was highly saline before the start of the project which has gradually been improved due to the pipe drainage project. Water and Power Development Authority (WAPDA)

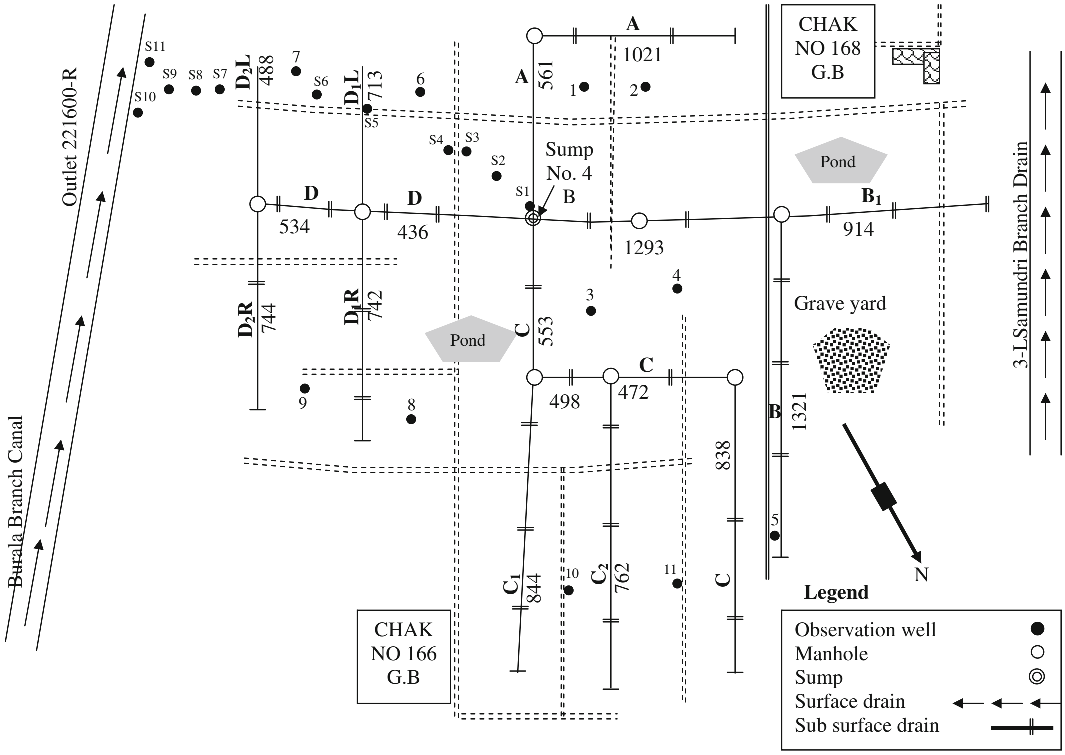

Fig. 3 Layout of observation wells for FDP (after Niazi 2008)

handed over the project to the provincial government after its completion in 1999.

Fourth drainage project, Faisalabad (1983–94)

The project area is situated in district of Faisalabad between latitudes 31°30′N to 32°15′N and Longitudes of 71°48′E to 73°20′E, in the south western Rechna Doab. The gross area of the project is 0.052 million hectares and the cultivable command area is 0.044 million hectares. The project started in 1983 before which the disaster area was about 28% (Niazi 2008). Subsurface pipe drainage with gravel envelopes and sumps were installed over an area of 0.030 million hectares. The project was executed by WAPDA. The Government of Punjab took over the project in 1994.

Swabi SCARP project (SSP, 1994–2000)

The project area is situated in districts of Mardan, Charsadda and Swabi between latitudes 34°5′27″N to 34°12′48″N and longitudes 71°43′11″E to 72°30′18″E. The gross area of the project is 0.113 million hectares and the cultivable command area is 0.078 million hectares. The project started in 1994 before which the disaster area was about 28% (Niazi 2008). The subsurface pipe drainage system was constructed over an area of about 0.0022 million hectares. In addition, surface drainage was applied over an area of 0.076 million hectares. A 457 km of Upper Swat Canal were also remodelled to avoid seepage. The North West Frontier Government took over the project from WAPDA in 2000.

Salient features of all the three projects are given in Table 1.

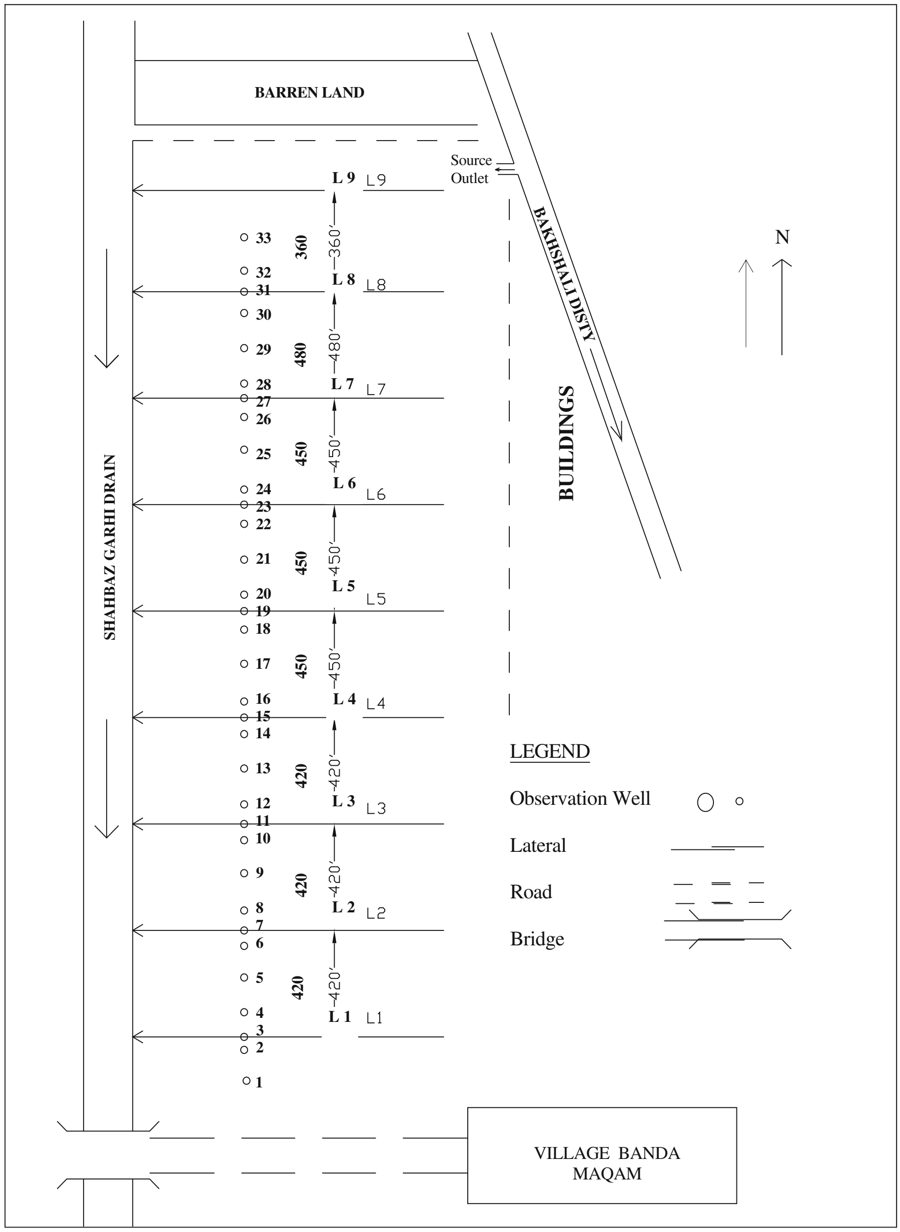

Fig. 4 Layout of laterals and observation wells for Swabi (after Niazi 2008)

Materials and methods

The methodology adopted in this paper was based on surveys, measurements and a questionnaire. The most important questions in the questionnaire were related to pre- and post-project uncultivated, waterlogged, saline and waste area, cropping pattern, crop yield, living standard, education, health, income, soil fertility, investment opportunities, and good quality water availability, etc. Data was collected for a long period to study the pre-project and the latest possible post-project condition of the selected three projects. A regular monitoring of groundwater levels, groundwater quality and soil salinity was made. Data regarding agro-socio-economic conditions of local

Table 1 Salient features of selected subsurface pipe drainage projects

Salient feature	Khushab SCARP	FDP Faisalabad	SWABI SCARP
Gross area	0.0420 Mha	0.0520 Mha	0.1130 Mha
Cultivable commanded area	0.0380 Mha	0.0440 Mha	0.0780 Mha
Subsurface pipe drainage area	0.0234 Mha	0.0300 Mha	0.0222 Mha
Elevation (average)	200 m	178 m	350 m
Annual rainfall (average)	200 mm	350 mm	550 mm
Annual evaporation (average)	1800 mm	2100 mm	1500 mm
Horizontal hydraulic conductivity	2 m/d	2.5 m/d	3 m/d
Vertical hydraulic conductivity	0.5 m/d	0.5 m/d	1 m/d
Drainage coefficient (discharge)	1.8 mm/d	2.44 mm/d	2.0 mm/d
Initial water quality of effluent	5 dS m^{-1}	3 dS m^{-1}	0.5 dS m^{-1}
Pipe spacing	150–300 m	500–600 m	150–200 m
Lateral pipe diameter in mm	90, 150	90, 150	90, 150
Main pipe diameter in mm	180, 250, 300	180, 250, 300	180, 250, 300
No. of sumps	56	79	Nil
Soil profile salinity 0–4 m deep %	19%	56%	Nil
Boundary conditions (right and left)	Canal and surface drain	Canal and surface drain	Canal and surface drain
Effective porosity	0.25	0.25	0.25

After Niazi (2008)

population, i.e., reclaimed area, cropping intensity and crop yields was collected through a questionnaire.

Two pilot sites both of 2 ha (5 ac) land in Khushab were used for data collection: one sump was situated in the light soil comprising sandy loam zone; and the other one in the heavy soil comprising clayey zone. The effluent from sump number is disposed off in Khushab Main Drain. The depth of lateral ranges from 1.68 to 1.98 m and spacing of the laterals is kept at 122 m throughout the sump area. The diameters of laterals are 100, 150 and 200 mm and that of collectors are 200, 250, 300 and 375 mm. The data was collected in collaboration with WAPDA, Pakistan.

The area under the Fourth Drainage Project Faisalabad was divided into two units namely, schedule area I and schedule area II. Schedule area I was selected for research which has 38 sumps. This area was further subdivided into IA, IB, IC and ID areas. Only one sump out of 38 was allowed for data collection. The sump was called SIB4. It comprised of a network of four collectors, ten laterals and eight manholes discharging into the sump which further was to dispose the drainage effluent into adjacent existing surface drain named as 3-L Branch Samundri Drain. The Sump system construction was completed in June 1989. For the study, 11 observation wells were installed in between the laterals and 11 observation wells were installed in between collectors for recording the water table fluctuation and the pipe system's work monitoring wells near the main pipe collector line towards the sump SIB4 at a distance of 1, 5, 10, 50, 100, 500 and 1000 m from sump to check influence of the Sump pumps working. The area under Sump Number SIB4 was 330 ha approximately and was divided into 11 big cells of equal sizes approximately 30 ha per cell to assess the groundwater inflow or outflow.

In Swabi, three pilot sites were surveyed in collaboration with WAPDA and SWABI SCARP consultants. The area was divided into three subsites named as sites #1, 2 and 3. Site #1 was further subdivided into three pilot sub-sites named as site 1-A, 1-B and 1-C. All the lateral pipes drained into the adjacent surface drain of respective site. The lateral pipes were laid down at 1.5 m depth from higher elevation (eastern side of the experimental site) towards the lower elevation (western side of the site). There was no collector for the site 1-A. All the laterals of this site were draining into the adjacent natural drain of Shahbaz Garhi. In between the lateral pipes, about 33 observation wells were symmetrically installed for monitoring the subsurface water levels at site 1-A of Swabi SCARP.

For all the three projects, 10 to 12 years' field data was collected. The data was analysed and compared with the design data to assess the percentage achievements of the proposed targets and benefits.

Results and discussion

Subsurface water levels

The pipe drainage impact on the subsurface water levels in the first 10 years of all the three projects, i.e. Khushab SCARP, FDP Faisalabad and Swabi SCARP is shown in Fig. 5. In this figure, the first year for Khushab SCARP was 1990, FDP Faisalabad was 1983 and Swabi SCARP was 1994.

For FDP, there is a sharp decrease in subsurface water levels (increase in water table depth) for the first 4 years after commissioning of the project. Then, there is a slight increase in subsurface water levels (decline in the water table depth). The interviews of the farmers in case of FDP showed that most of them were educated and watchful for the proper operations of the sump pumps. Hence, the electric equipments remained in working condition most of the time. Therefore, the improvement in the water table was better for FDP than that for other two projects. The performance of pipe drainage project of Swabi was second as there were no sumps and just the laterals and collector were laid at steep slopes for direct drainage into the adjacent surface drains. However, a gap between the government and people of the area was found. There is a need of capacity building and creating know-how about the projects, so that local people may have a sense that these are their own projects. Participatory management for drainage may be the best solution. The decline in water table depth after a few years was observed due to improper maintenance and operations from the part of the government.

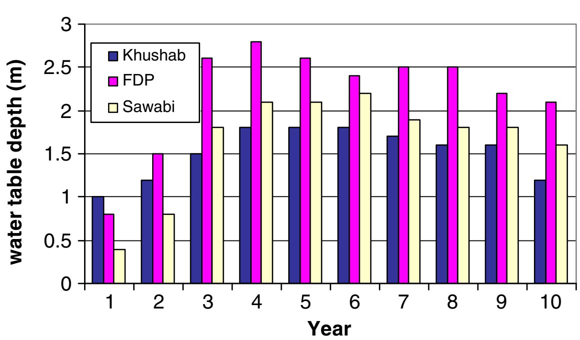

Fig. 5 Change in water table depth in project area

Groundwater discharge

The design discharge and measured discharge for the first 12 years of all the three projects is shown in Fig. 6. It is observed that Khushab and FDP were over designed. The actual discharge was low, so the problem of over drainage was not occurring. The word "over design" means that the diameter of pipes is more than the required. Obviously, if the pipes with such a high diameter would have been running full, then there was a chance that irrigation water supplied to crops would also have been drained resulting to over drainage. This situation however did not occur. Figure 6 demonstrates this aspect. In Swabi, the actual discharge was observed to be a little bite higher than the design discharge. The people in this area were found blocking collectors because they believed that water is being lost and should not be drained.

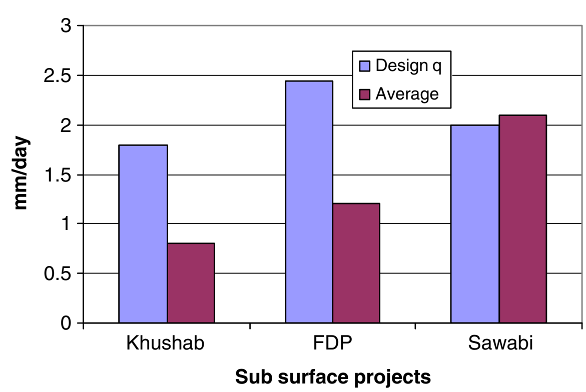

Fig. 6 Design discharge and average measured discharge of the three projects

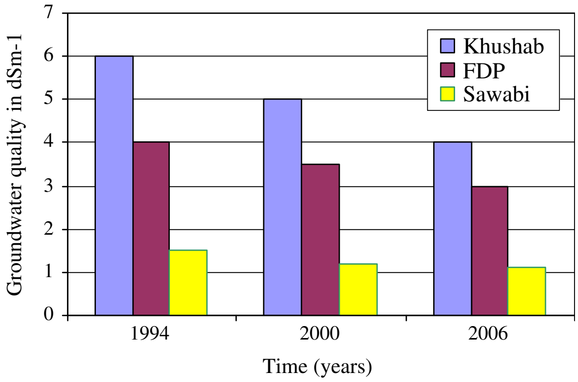

Fig. 7 Groundwater quality of Khushab, Faisalabad and Swabi areas

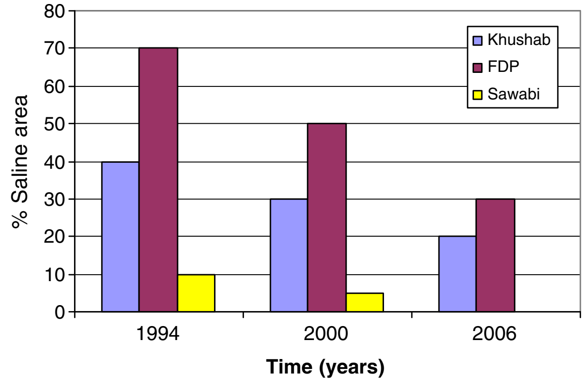

Fig. 9 Percent decrease in saline area in 12 years at three projects

Drained water quality

The changes in the groundwater quality are shown in Fig. 7. It is observed that in Khushab and Faisalabad, the quality of drained water was improved. In Khushab and Faisalabad, the water salinity measured in terms of dS/m was reduced by 33% and 25% respectively in 12 years. However, the water still was not usable for irrigation. A knoll of groundwater was developed due to 807 mm of extraordinary rain in Faisalabad during 1997. The initial quality of subsurface water in Faisalabad was better than that of Khushab SCARP. That is why Khushab water quality improved faster than that of Faisalabad as shown in Fig. 7. In Swabi, there was no problem of salinity.

Recovery of disaster area

The area under waterlogging and salinity was slowly reclaimed due to pipe drainage in 12 years in all the three projects as shown in Fig. 8. The disaster area in Khushab was initially 40% and it was reduced to 20% in 12 years. The disaster area in Faisalabad was initially 80% which reduced to 40% in 12 years. Swabi recovered 8% out of a total 10% disaster area. Swabi was having only small problem of salinity which was recovered by 80% in 12 years.

Soil salinity

The improvements in soil salinity are shown in Fig. 9. It is observed that the profile salinities have

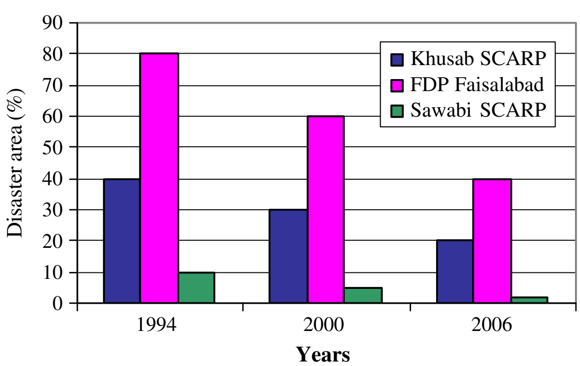

Fig. 8 Percentage recovery of disaster area in 12 years at three projects

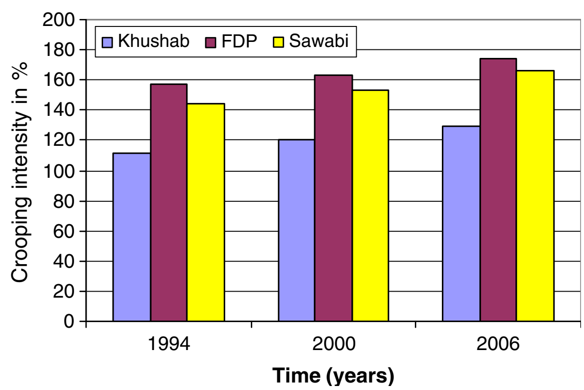

Fig. 10 Variation in cropping intensity with respect to time at three projects

been decreased significantly. The saline area in Khushab was initially 40% and it was reduced to 20% in 12 years. The saline area in Faisalabad was initially 70% which reduced to 30% in 12 years. The saline area in Swabi was 10% initially and it has been recovered completely.

Cropping intensity

The increase in cropping intensities due to the pipe drainage projects is shown in Fig. 10. It is observed that there is an increase in cropping intensities by 20% in all three projects. This increase should have been comparative more if the design and management would have been better.

Agro-socio-economic conditions of local population

The agro-socio-economic analysis was mainly based on the data collected through the questionnaire. The pre- and post-project conditions were compared on the basis of uncultivated area, waterlogged and saline area, fellow area in each season, cropping pattern, crop yield, living standard, education, health, income, soil fertility, investment opportunities and good quality water availability, etc. Figure 11 shows the socio-economic improvement of the people of the area after 12 years in all the three projects. Socio-economic conditions were improved by about 20% in 12 years. The comparison of pre-project and post-project after 12 years shows that the standard of living of the people of the area improved by 30% at FDP Faisalabad, 30% at Khushab SCARP and 20% at Swabi SCARP. The number of schools increased in the project areas. Social welfare centers were established for the villagers. The quantitative comparison as done above shows that there is positive impact of the projects in terms of land reclamation, cropping intensity improvements and crop yield improvements.

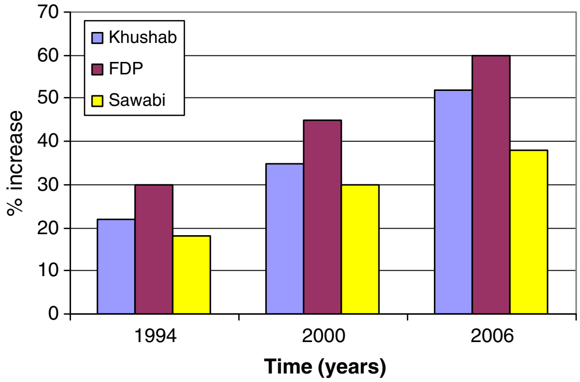

Fig. 11 Improvement in socio-economic condition in 12 years

Summary and conclusions

Subsurface drainage is successful in controlling waterlogging and salinity in Pakistan. It has effectively reduced the groundwater levels in the project areas. The disaster area (due to waterlogging and salinity) is recovered due to subsurface drainage at all the three sites. The cropping intensity has increased by about 20%.

A few over drainage complaints by the local farmers were reported. However, capacity building and participatory management is required for better drainage. Standard of living of the rural population improved with the control of waterlogging and salinity and increased cropped area within a 12-year period. Socio-economic benefits per year have been increased by 2.5% from 1994 to 2006 in case of Khushab and Faisalabad. In the case of Swabi, it is about 1.8% per year. The know-how and education of the farmers in the project area plays an important role in performance of subsurface pipe drainage schemes.

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