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Socio-Economic Assessment for Improving Groundwater Management in the Left Bank Command of the Sukkur Barrage, Sindh Pakistan

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
WB	World Bank
GOP	Government of Pakistan
UNDP	United Nations Development Programme
WFP	World Food Programme
FAO	Food and Agriculture Organization
SIDA	Sindh Irrigation and Drainage Authority
UNEP	United Nations Environment Programme
MAD	Mobile Acquired Data
PRA	Participatory Rural Appraisals
GW	Ground Water
DEA	Data Envelopment Analysis
EMS	Efficiency Measurement System
VRS	Variable Return to Scale
WUE	Water Use Efficiency
TE	Technical Efficiency
SBA	Shaheed Benazirabad (district)
SE	Scale Efficiency
EE	Economics Efficiency
AE	Allocative Efficiency
MDS	Mounds/ (40 Kg)

1 Executive Summary

1. In Pakistan, agriculture is one of the most important sectors of the economy. Agriculture accounts for approximately 20% of GDP and provides a livelihood to 200 million people. In Pakistan, irrigation is critically important for agricultural production and agriculture also accounts for approximately 90-95% of the country's water usage. However, Pakistan is ranked third among the countries that are facing water shortages water and it is estimated that the country could reach absolute water scarcity by 2025. Shortages in surface water have resulted in the agricultural sector being heavily dependent on groundwater. However available groundwater is not sufficient to meet growing demands and is under immense pressure from over-extraction.
2. Sindh Province, with 5000 years of civilization, is the second largest province of Pakistan with a population of 47 million people. Groundwater and canal (surface) water are the main sources of irrigation water in Sindh. As a province that's located in the lower end of the Indus Basin, Sindh is facing issues of grave surface and groundwater shortage, and soil and groundwater which is exacerbated by the mismanagement of groundwater.
3. Some research has been undertaken in relation to groundwater modelling in Sindh Province, but there is a lack of information about how the availability and use of surface and groundwater in differs between the head, middle and tail ends of irrigation systems. In addition, the social and economic aspects of groundwater management are not well understood. This study aimed to address both of these knowledge gaps.
4. This research was conducted as part of the Australian Centre for International Agricultural Research (ACIAR) funded project "Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan". The study aimed to aimed to (i) examine socio-economic characteristics of farming communities from two irrigation systems in Sindh (ii) explore groundwater availability across head, middle and tail areas of the systems (iii) examine the cropping patterns and irrigation methods practiced by farmers in the study areas (iv) explain problems faced by the farmers with reference to availability and management of groundwater (v) calculate farm level technical, economic and water use efficiencies of the main crops grown in the area (wheat, rice, cotton and sugarcane).
5. Six villages were selected in total, one from the head, middle and tail areas of two irrigation systems: Cheeho Minor, in the Naushahro Feroze district, and Malwa Minor, in the Shaheed Benazirabad (SBA) district. Farmers were categorised based on the size of their farms as: (i) small farmers (own 1 to 12.5 acres of land) (ii) medium farmers (own 12.5 to 35 acres of land) and (iii) large farmers (own more than 35 acres of land). Stratified random sampling was used to select respondents.
6. Results showed that in the SBA district the average number of milking animals owned by farmers at the tail end of the system area was higher (2.68) compared to farmers from the head (1.39) and the middle areas (0.23). The per day average milk production was also higher in tail areas (23.75 litres) compared to mid (16.05 litres) and head areas (18.66). Farmers at the tail area owned higher number of milking animals and were getting higher average per day milk production. However, they were earning less average monthly income from selling milk (Rs. 16680 at head and Rs. 14306 at tail in Naushahro Feroze and Rs.17119 at head and Rs. 14086 at tail in SBA). This is because tail area farmers mostly sell milk to shopkeepers in local villages to avoid transport costs. The distance between tail farms and the nearest markets prohibit efficient transportation. Head and middle farmers are closest to markets and hence receive higher prices. In contrast, in both districts, the average monthly income obtained from selling livestock) was higher at tail areas of the system as compared to head areas (average monthly income from livestock: Rs. 12816 at head, Rs.27615at middle and Rs.21814 at tail).
7. Cotton, wheat and sugarcane are the major crops of both research sites. Rice is also grown in some parts of Naushahro Ferozeas well as small scale vegetable and fruit crops.
8. In both districts, the majority of farmers depend on informal credit (mostly from traders, middlemen, relatives and friends).

9. Farmers at both sites ranked storage of water as the most significant issue and difficulty in purchasing water and difficulty in purchasing inputs for cropping was ranked second. A high shortage of irrigation water was reported in both research areas, particularly during the Kharif(summer/monsoon) season.
10. Per acre irrigation cost at tail areas are higher compared to head areas at both research sites. This can be attributed to the fact that tail farmers mostly purchase diesel and lubricants on credit which is more expensive when compared to head farmers who purchase diesel and lubricants for diesel engines for cash.
11. Data revealed that higher gross margin per cubic meter of irrigation water was earned by the wheat growers at head and middle areas as compared to tail areas. Similarly, margins were higher for cotton and rice crops in both districts.
12. Irrigation practices also play a significant role in groundwater and surface water management. Results of this study show that a significant majority of farmers use flood irrigation, which is inefficient in terms of water use, at both research sites. In both systems, head areas, flood irrigation was used to irrigate an average of 8 to 15 acres of land, furrow irrigation was used on significantly less land area (0.9 to 4.8 average acres). Similarly, at the middle of both systems, 9 to 11 average acres of land were irrigated by flood irrigation, while in same area fewer acres of land (0 to 1.89 average acres) were irrigated by furrow irrigation. This shows that flood irrigation is common practice in research areas and the literature suggests that flood irrigation is an important contributing factor in the mismanagement of available water for irrigation.
13. Time allocated for irrigation at tail areas is greater than head and middle areas. Water is allocated when water starts to flow from the watercourse, in tail areas, the distance to the watercourse is greater meaning that it takes longer for water to reach the farm. In addition, in head areas, water flow is higher than in tail areas. Therefore, despite the fact that more time is allocated to tail flows,less water is available. At the head, middle and tail reaches in the Naushahro Feroze district, the allocated timing of canal water was 9.32, 12.37 and 20.47 minutes per acre, respectively. Likewise, in the SBA district, farmers indicated that in the head, middle and tail reaches the allocated time was 7.97, 11.13 and 15.29 minutes to fill per acre, respectively.
14. Diesel engines were the main source of energy for tube-wells at both research sites. More than 88% of tube-wells in Naushahro Ferozeand 85% of tube-wells in SBA, are powered by diesel engines.
15. The availability of canal water is not equal at head and tail areas of the irrigation systems. Farmers from the tail areas of both systems are highly dependent on groundwater and farmers from the head areas of both systems use canal water for irrigation. In Naushahro Feroze 73%and in SBA 64%of respondents from head areas use canal water for irrigation. Conversely, the majority oftail reach farmers depend on tube-well water for irrigation, 83% in SBA and 59 % in Naushahro Feroze.

2 Introduction

Water is essential for life on earth but only 2.5% of water is fresh and about 99 %of all fresh water is stored in underground aquifers and glaciers and icecaps (UNEP, 2002). More than a quarter of the world's population draws water from these underground aquifers. In Pakistan agriculture is the mainland use and it contributes significantly (20.9 %) to gross domestic production (GDP) (GOP, 2015). More than 200 million people in Pakistan directly or indirectly rely on the agricultural sector for their livelihoods. However, Pakistan is ranked the third most water-stressed country in the world and could reach absolute water scarcity by 2025, due to high depletion and degradation of underground water (Nabi et al 2019). The United Nations has noted that in Pakistan major threats to water are the high level of scarcity of water, rapid deterioration of water quality, mismanagement, over extraction of ground water and climate change risk. The Asian Development Bank (ADB) and World Bank (WB) have placed Pakistan in the red zone of countries that are water stressed and that are likely to face acute shortages of water over the next five years. In 1947, the per capita availability of water in Pakistan was 5650 cubic meters while in 2013 it decreased to 990 cubic meters (GoP, 2014; Lalzad, 2007; Innovateus, 2014; Water information, 2013; Kahlown, et al., 2002).

In Pakistan shortages in surface water have resulted in the agricultural sector being heavily dependent on groundwater (Watto and Mugera, 2016; Khair et al., 2019). Approximately 75% of agriculture depends on groundwater for irrigation (Maalsonganv et al., 2016, Qureshi et al., 2008). Even though Pakistan has the fourth largest groundwater aquifer, available groundwater is not sufficient to meet growing demands and is under immense pressure from over-extraction (Khan et al., 2008; Rodell et al., 2009; Wada et al., 2010). Groundwater use in Pakistan continues increase to due to greater demand for expanding agricultural, industrial and domestic water use. This is facilitated by the availability of subsidized electricity and locally made diesel engines for tube-wells. Currently in Pakistan it is estimated that there are more than 1.4 million tube-wells that are in use (Watto and Mugera, 2014). Approximately 90% of these tube-wells are used for agriculture (Mangan et al., 2016, Qureshi et al., 2008). This has resulted in massive pumping of groundwater and an associated rapid decline of water tables.

This research was conducted as part of theLWR-036groundwater project "Improving groundwater management to enhance agriculture and farming livelihoods in Pakistan" which is one of the four projects under the Water Program funded by Australian Centre for International Agricultural Research (ACIAR). This project aimed to be a step towards more effective use of groundwater for social, economic and environmental benefits. Charles Sturt University from Australia and various institutions of Pakistan (including Sindh Agriculture University Tandojam) and other stakeholders are the part of this project.

The aim of this project was to build the capacity of researchers, farmers, farming communities and relevant government and non-government agencies to improve groundwater management in ways that enhance the livelihood of farming families in Pakistan. Building capacity means building skills, knowledge and the provision of tools and processes. Enhancing farming livelihoods includes ensuring the long-term sustainability of agriculture.

2.1 Sindh province

The Sindh province in Pakistan has a 5000-year history of human occupation, and is located between Europe and the Far East, and close to Middle East. The province has the potential to become one of the largest logistical, trade, business, and human resource hubs in the South Asia (GoP, 2018). Sindh is the second largest province of Pakistan with a population of 44 million (23 %of country's total population). Sindh is located in a hot and dry region in southern of Pakistan. Agriculture is the main economic product of Sindh. Approximately 1.60 million hectares of land is culturable land that isn't currently used for cultivation, 5.17 million hectares area is under cultivation and, due to shortage of irrigation water, there is approximately 2.51 million hectares of fallow land. Wheat, sugarcane, rice and cotton are the major field crops in Sindh and these comprise 68% of the total cropped area. Major horticultural crops of Sindh are mango, chillies and banana (FAO, 2003; GOP, 2016; SIDA, 2012).

Being in the lower end of the Indus Basin, Sindh is facing grave surface water shortages and problems with soil and groundwater salinity (70 %of the groundwater is saline). This is exacerbated by mismanagement of groundwater. It is estimated that groundwater resources for the Sindh province vary from 13 to 16 million-acres with estimates of safe use of 4.4 to 8.0 million-acres (WB, 2013; Subhash et al., 2014 and GOP, 2018). The shortage and unreliability of canal irrigation water in Sindh has increased the importance of groundwater management, wherever fresh water or even saline water of marginal quality is available (FAO, 200; FAO, 2019; PCZ, 2016).

Reductions in canal water supply has led to an increase in demand for freshwater and competition between municipal, industrial and agriculture sectors. This has intensified water crises in the province. In Sindh, the high pressure for food production and inability of the canal irrigation systems to fulfil irrigation requirements, means that the majority of farmers depend on groundwater as a sole or additional source of irrigation and tube-well irrigation has become an important characteristic of agriculture economy of Sindh (Gaur et al., 2008; Qureshi et al.,2003).

The vast plains of fertile soils can support intensive agriculture but because of insufficient availability of irrigation water, the number of acres of fallow land is rapidly increasing. Groundwater pumping and canal water are the main sources of irrigation in Sindh. The irrigation canal system was designed for copping intensities of 35%inthe Kharif (summer) season and 55% in the Rabi (winter) season. Nowadays, cropping intensities are very high (more than 70 %for each season) (FAO, 2003; Habib, 2011; FAO, 2018; GoP, 2018; WFP, 2018) and this has resulted in increased pressure on the canal systems and shortages of water. In the lower parts of Sindh, the number of tube-wells has increased significantly from2000 to 2013 (Figures 2.1 and 2.2). In Sindh, the number of diesel-powered tube-wells has increased up to 80,000 in 2012-2013 (Figure 2.1), while private and public electric-powered tube-wells are also increasing at significant level (Figure 2.2). In Sindh during 2012-2013, the number of private and public electric tube-wells increased to 60,000 (Munir et al., 2015).

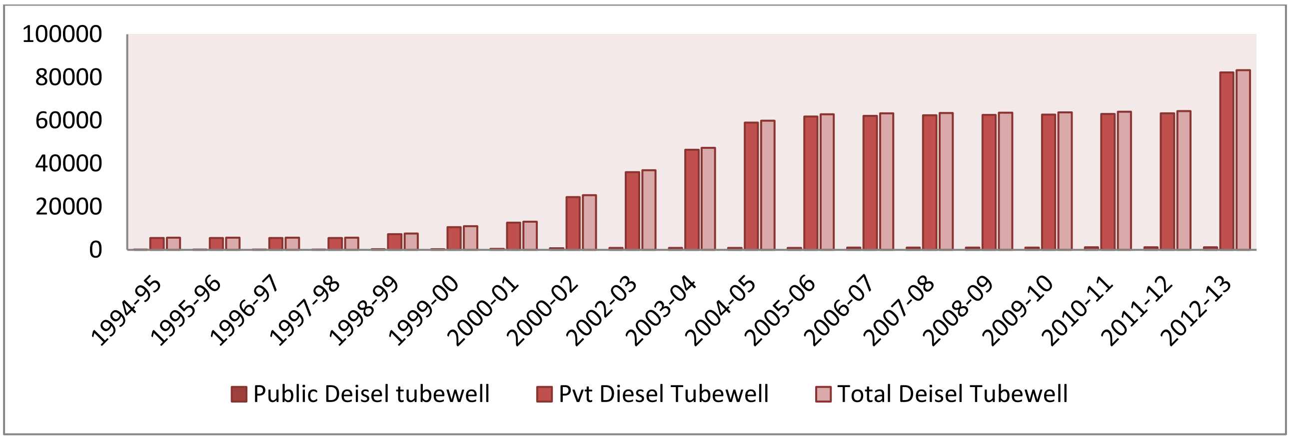

Figure 2.1: Number of diesel tube-wells installed in Sindh(Agricultural Statistics of Pakistan, 2012-13)

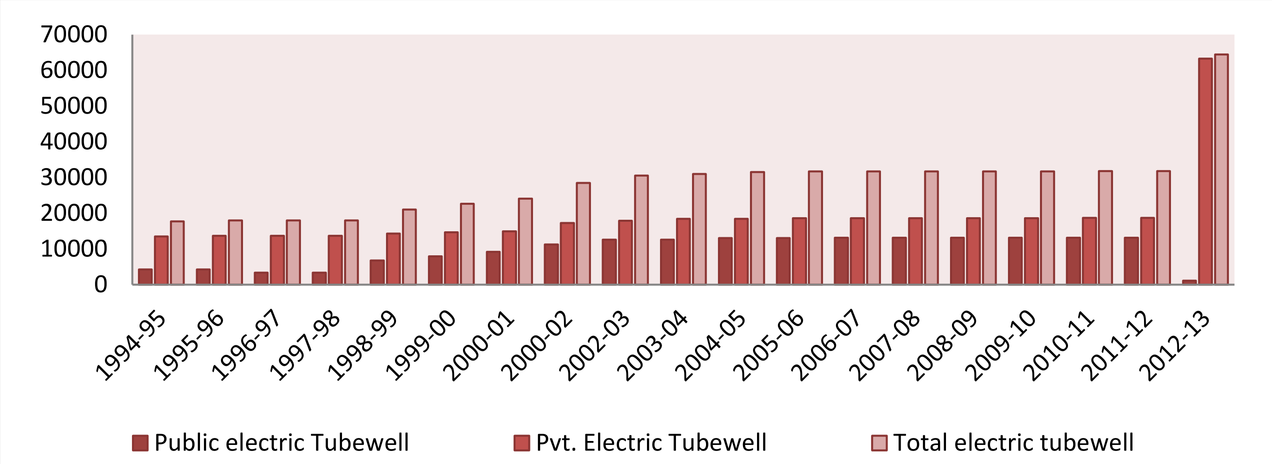

Figure2.2: Number of electric (public and private) tube-wells installed in Sindh (Agricultural Statistics of Pakistan, 2012-13)

2.2 Study areas

The Malwa Minor irrigation system in Shaheed Benazirabad (SBA) (formerly Nawabshah) and the Cheeho Minor irrigation system in Naushahro Feroze were selected as study areas for the research. Both irrigation systems are part of the Sukkur Barrage. The Sukkur Barrage was commissioned in 1932 and it is the world's largest single unified irrigation network (9,923 km) and it feeds an irrigation system of more than 3.05 million hectares. Sukkur Barrage was the first barrage constructed on the Indus River with a design discharge of 42,475 cusecs. Malwa Minor has a deep-water table (depth to water table = 6-10.8) with marginal groundwater quality (1500-3000 PPM). Chiho Minor in Naushahro Feroze was selected based on GIS information because of the high use of groundwater and surface water of usable quality.

The SBA division covers an area of 4,502 km² and has a population of 5,282,277 people. The SBA division comprises of the district of SBA, Naushahro Feroze and the Sanghar. The SBA District is in the centre of Sindh province and is surrounded by the river Indus in west the Sanghar and Khairpur districts in the east, the Hyderabad district in the south and the Naushahro Feroze district in the north. The SBA district is connected with the rest of the province and country by air, railways and roads. It has a Peoples Medical College (for girls) Hospital and an Engineering University. The main crops of this district are sugarcane; wheat, cotton and this district also has three sugar mills (PWD, 2020; GoS, 2017).

The total area of the Naushahro Feroze district is 7,050,000 acres, while its population is more than 1,612,373 people. It is an important historical area called the Sahati region referring to the literature of central Sindh. In 1989, this district was given the status of district headquarters. The Indus River flows in the west of Naushahro Feroze. This district of Sindh is mostly comprised of agricultural lands. Different types of cash and food crops are grown in Naushahro Feroze including wheat, cereals, barely, maize, cotton and rice. Fruits grown in Naushahro Feroze are mangoes, guava, berries, bananas, oranges, lemons. Shortages of water and salinity are the main water-related issues in this area. Sukkur Barrage's largest Rohri Canal is located in this district. In summer season Naushahro Feroze experiences the hottest days in Pakistan (PWD, 2020; Sindh at glance, 2017.

2.3 Rational of research and research gap

The population of Pakistan is increasing at a rate of 2.8% and is projected to increase to 250 million by 2025 (Qureshi, 2021). The percentage of the urban population will increase from its current 35 to 52% by 2025. As a result, water demand for domestic, industrial, and non-agricultural uses will increase by ,8% and is expected to reach 10% of the total available water resources by the year 2025 (Qureshi, 2021). Sindh, with a current population of 47 million people, is the second biggest province of Pakistan Growth in population will lead to urbanisation and increased demand for food production for growing populations. With an increasing population and if current irrigation practices remain unchanged, demand for irrigation water for agriculture could increase by 50% (Azad, 2003). Roughly estimated, current extraction of groundwater is 4-6 bm³/year (5 million-acre feet/year). It is also estimated that siltation of reservoirs and climate change will reduce the surface water storage capacity by 30% by 2025, which is challenging when an additional 30.0 million-acre feet will be required only for irrigation purposes, to maintain current balance of demand and supply of agriculture commodities (Azad, 2003).

Most of the available literature in Sindh is about groundwater modeling but the literature on two aspects is lacking: (i) social and economic aspects of groundwater management and (ii) study of groundwater with reference to head, middle and tail of the minor irrigation systems, as availability and use of surface and groundwater is different at head, middle and tail areas of the systems. At head areas, farmers use more water compared to tail areas. This study will contribute to filling these two research gaps with reference to groundwater management in Sindh.

In Sindh, the types of groundwater and surface water management approaches and practices that are needed to handle the projected water shortage are poorly known (Bridget et al., 2012). For irrigation water management (including surface and groundwater), the approach of "business as usual" is no longer sufficient in Sindh. Therefore, efficient use of current water resources is imperative. Lower agricultural productivity compared to other countries with similar environments suggests there is huge potential to increase productivity and efficiency. To harness that potential there is an urgent need for improved groundwater management. In Sindh, improving groundwater management as well as water logging and salinity could result in increased crop yields. Therefore, it is essential to understand the causes of mismanagement of groundwater. In water stressed areas of Sindh the socio-economic conditions of people play a significant role in management and mismanagement of groundwater. Therefore, a socio-economic survey was conducted under the ACIAR funded groundwater project to understand the socio-economic conditions of farmers living in water stressed areas, in order to suggest effective and implementable policy.

2.4 Objectives of the study

This study aimed to:

i. Examine the socio-economic characteristics of farming communities from the Malwa Minor and Cheeho Minor irrigation areas
ii. Explore groundwater availability across head, middle and tail areas of the irrigation systems
iii. Examine the cropping patterns and irrigation practices adopted by farmers from the study areas
iv. Explore the problems that are faced by the farmers with respect to availability and management of groundwater
v. Calculate farm level technical, economic and water use efficiencies of wheat, cotton and sugarcane in the study areas.

3 Methodology

3.1 Selection of research sites

Workshops and meetings with project partners and other stakeholders were held during the initial stages of the larger LWR-036 projectto select research sites. The first step in this process was conducting participatory rural appraisals (PRAs) (Khair et al., 2021). A workshop was organized to finalise the irrigation systems for PRA at Mehran University of Engineering and Technology (MUET). In that workshop five minor irrigation systems in Naushahro Feroze and four minor irrigation systems in SBA were proposed (based on certain criteria with reference to objectives of the LWR-036 project) for conducting PRAs (details are in Appendix A, Table A1).

The aim of PRAs was to collect information that could help to identify the research sites for the project. Various strategies were used to get the required information such as; (1) diagramming (transect walk), (2) interviewing (group and key informant interviews and focus group discussions) (3) mapping (including social maps, consists of household information such as population, social classes, land use patterns etc.) and (4) resource maps (that shows resources of the area like soil, water, minerals etc.). During the PRAs the research team took efforts to ensure participation of male, female, youth and small, medium and large farmers to ensure detailed knowledge was gathered from communities.

Participatory Rural Appraisals (PRAs) were conducted at nine proposed minor irrigation systems in Sindh. At each site PRAs were conducted at head, middle and tail areas. This ensured an even distribution of sites at head, middle and tail regions where availability of water differed. For the PRAs a list of indicators/determinants such as general description of sites, underground water and its quality, crops and technologies, drinking water availability and quality was generated with reference to project needs.

PRAs were conducted at the head, middle and tail areas of selected minor irrigation systems within the SBA and the Naushahro Feroze districts. Based on the data collected from the PRAs, two minors (i) Malwa in the SBA district (ii) Cheeho in the Naushahro Feroze were selected as project case study sites for Sindh. Some key points of criteria for selection of research sites were:

- Water availability
- Conjunctive use of surface and groundwater
- Water requirement of crops
- Cropping pattern
- Groundwater level and quality
- Soil salinity
- Easy access and approach to road
- Prior knowledge/work/data availability

3.2 Sampling methodology and sample size

Two research sites, the Cheeho and Malwa Minors, were selected for the project. Based on the information collected during PRAs, it was identified that availability of groundwater at head, middle and tail areas of minors was markedly different. At the head of the systems, availability of groundwater was greater than in the middle and tail of the systems. Farmers living in tail areas mostly rely on tube-wells for irrigation. In total six villages were selected: three villages at head, middle and tail of Malwa minor and three villages at head, middle and tail of Cheeho minor. As irrigation is done by male farmers and it is farmers who are the head of the household and the decision makers, all the respondents surveyed were male.

The three villages selected for the Cheeho Minor were - Bahram Marivillage at head, Cheeho village in the middle and Muhammad Ibrahim Brohi village at the tail (Table 3.1). The three villages selected for the Malwa minor were Choteeh Hazar Mori village at head, Mitha Khan Dharejo village at middle and Deran village at tail (Table 3.2). A stratified random sampling method was used to select respondents. Farmers were placed into one of three categories based on the size of the land that they own: (i) small farmers (own 1 to 12.5 acres of land) (ii) medium farmers (own 12.5 to 35 acres of land) and (iii) large farmers (own more than 35 acres of land).

Before conducting the surveys, the research team visited each village and collected information regarding the number of small, medium and large farms in each village. 75 farmers from each village were selected and this was proportional based on the relative number of farmers from small, medium and large farms in that village. Stratified random sampling was then used to select the farmers from each category of farm (Tables 3.1and 3.2).

Table 3.1 Sample size at head, middle and tail of the Cheeho minor irrigation system in Naushahro Feroze. Count = number of people, Propn (proportion) = count / population size.

	Head (Bahram Mari village)			Middle (Cheeho village)			Tail (Muhammad Ibrahim Brohi village)		
	Count	Propn	Sample size	Count	Propn	Sample size	Count	Propn	Sample size
Small	80	0.684	51	46	0.41	31	26	0.29	22
Medium	33	0.282	21	48	0.43	32	45	0.5	37
Large	4	0.034	3	18	0.16	12	19	0.21	16
Total	117	1	75	112	1	75	90	1	75

Table 3.2: Sample size at head, middle and tail of Malwa minor irrigation system in SB.A Count = number of people, Propn (proportion) = count / population size.*

	Head (Bahram Mari village)			Middle (Cheeho village)			Tail (Muhammad Ibrahim Brohi village)		
	Count	Propn	Sample size	Count	Propn	Sample size	Count	Propn	Sample size
Small	50	0.46	35	31	0.34	26	38	0.39	29
Medium	48	0.44	33	54	0.6	45	37	0.38	28
Large	10	0.09	7	5	0.06	4	23	0.23	18
Total	108	1	75	90	1	75	98	1	75

Figure 3.1: Enumerator's workshop and data collection using the skills of mobile acquired data

3.3 Capacity building and data collection

Literature suggests that good research is based on good data that is collected properly in accordance with the need of research study goals and with accuracy and transparency (Rajasekar, 2013). Data collection was a significant component of current research therefore the activities done before conducting survey were (i) literature review and preparation of survey tool, (ii) capacity building of research team about Mobile Acquired Data (MAD), (iii) selection of enumerators and facilitators and (iv) enumerators and facilitator's training workshop. Both primary and secondary data were used in the study. Secondary data were collected by conducting a literature review and discussions with various stakeholders and experts. After the literature review and consultation with research team members and other stakeholders, a well-structured questionnaire was prepared and pretested to conduct socio-economic survey.

Some of the key components of the questionnaire were about information regarding:

a. Socio-economic characteristics of the household
b. Land resources
c. Irrigation sources used at head, middle and tail of minors
d. Methods of irrigation
e. Cropping patterns
f. Data regarding cost of production and revenues generated by main crops
g. Sources of energy
h. Income sources

As capacity building is the one of the main objectives of the ACIAR funded groundwater project, a three-day workshop to train data collectors in using a mobile phone app for conducting the socio-economic survey was held in 2018. This training workshop was conducted by Agricultural Impact International (Ag Impact) and the trainees were the people leading the socio-economic surveys. A great contribution from the project was the capacity building of the team arising from the training in using Mobile Acquired Data (MAD) technology. This technology was new for the researchers from Pakistan and they were all were very excited to understand and use this technology. After using MAD technology for conducting socio-economic survey the research team found the below mentioned benefits as compared to a paper-based survey:

a. It saves up to 50 percent of time during field work
b. It helps the research team to enhance accuracy in data collected during the survey
c. Use of MAD improves data quality
d. It saves the time of data cleaning

The household socio-economic surveys were undertaken by an experienced and qualified team. Enumerators were selected based on their experience in conducting surveys and using android mobile phones. Two facilitators, one at each site were also engaged from local communities Facilitators were engaged based on their knowledge regarding the study area, the farming communities and local contacts. The names and education levels of survey supervisor and enumerators who participated in the Sindh socio-economic survey are outlined below:

1. Prof. Dr. Tehmina Mangan (PhD. Supervised the survey)
2. Mr. Shakeel Ahmed Siyal (B.A, Survey facilitator, Cheeho minor)
3. Mr. Niaz Ahmed (B.Com, Survey facilitator Malwa minor)
4. Ms. Mehrunisa Sial (Enumerator, M.Sc. Agri-Business Management)
5. Mr. Abdul Shakoor Jamro (Enumerator, M.Sc. Agricultural Economics)
6. Mr. Muzamil Memon (Enumerator, M.Sc. Plant Breeding and Genetics)
7. Mr. Muhammad Hassan Channa (Enumerator, M.Sc. Agricultural Economics)
8. Mr. Ghulam Nabi Dahri (Enumerator, M.Sc. Agricultural Economics)

Dr. Tehmina Mangan conducted a two-day workshop for enumerators and facilitators with the aim of explaining the questionnaire and downloading and using the Commcare app for conducting surveys, using MAD technology. Facilitators were invited to the Sindh Agriculture University Tandojam for two days. Facilitators were also trained in using stratified random sampling methodology. Facilitators learned what needed to be adopted for data collection and helped them understand what type of information was needed about the research sites and respondents. A two-day training workshop for the groundwater project research team from Sindh was also conducted with the aim of discussing and understanding the data analysis methodologies with reference the objectives of the project.

3.4 Data analysis methodology

Farm level technical, economic and water use efficiencies for various crops (wheat, cotton, rice and sugarcane) cultivated on farm was estimated with the Data Envelopment Analysis (DEA) method using efficiency measurement system (EMS) software. DEA is a non-parametric approach and the relationship between inputs and outputs is defined by making a linear piecewise frontier. In the analysis we followed input-oriented Data Envelopment Analysis (Fatima et al., 2020; Lohano et al., 2011), assuming variable returns to scale (VRS) to estimate the technical, economic and water use efficiencies for farms located at the head, middle and tail of the selected canals for both districts. Multi-crops and multi-inputs models were developed to measure the technical and economic efficiencies of farms.

3.5 Technical Efficiency

For estimating technical efficiency of a given firm *j* focused on input resources, the following linear programming problem was solved. An input oriented variable return to scale DEA technique was applied for the estimation of technical efficiency as followed by Coelli et al., (1998). It is specified as:

$$\min \theta$$
$$\theta, \{\lambda_i\}_{i=1}^{n} \quad (1)$$

Subject to:

$$\sum_{i=1}^{n} y_i \lambda_i \geq y_j \quad (2)$$

$$\sum_{i=1}^{n} x_{ki} \lambda_i \leq \theta x_{kj}, \text{for} k = 1, 2, \ldots, K \quad (3)$$

$$\sum_{i=1}^{n} \lambda_i = 1 \quad (4)$$

$$\lambda_i \geq 0 \quad (5)$$

where $\theta$is the input-oriented estimates of firm *j*technical efficiency, *yi*is the production of *i* firm produced by, where i = 1, 2,…, j,…, n, and n is the number of firms, *xki* is the *k* input quantity applied by *i* firm (for i =1, 2,…, j, …, n) for k = 1,2,…, K, where K is the number of inputs used by the firms, and $\{\lambda_i\}_{i=1}^{n}$ are the weights to be estimated. Note that there are *K* equations in Equation (3). The above model, given in Equations (1) – (4), is solved for *j* firms to get the optimum level of defined function, θ^*, which is an estimate of the input-oriented technical efficiency of j firm (TEj):

$$TE = \theta^* \quad (6)$$

3.6 Economic Efficiency

To calculate the input-oriented cost efficiency of *j* firms, the given linear programming problem is explained:

$$\min_{\{x_{kj}\}_{k=1}^{K},\{\lambda_i\}_{i=1}^{n}} \sum_{k=1}^{K} w_{kj}\, x_{kj} \quad (7)$$

Subject to:

$$\sum_{i=1}^{n} y_i \lambda_i \geq y_j \quad (8)$$

$$\sum_{i=1}^{n} x_{ki} \lambda_i \leq \theta x_{kj}, \text{for} k = 1, 2, \ldots, K \quad (9)$$

$$\sum_{i=1}^{n} \lambda_i = 1 \quad (10)$$

$$\lambda_i \geq 0 \quad (11)$$

Where $w_{kj}$is the input price k which is applied by *j*[th] firm. In Equations (7) – (11) model is given, and it is calculated for *j* firms to get the optimal solution: $\{x_{kj}^{*}\}_{k=1}^{K}$ and $\{\lambda_i^{*}\}_{i=1}^{n}$.

Cost efficiency of j (EEj) firm estimated is given below:

$$EE_j = \sum_{k=1}^{K} w_{kj} x_{kj}^{*} / \sum_{k=1}^{K} w_{kj} x_{kj} \quad (12)$$

Equation (12) indicates that $EE_j$is the ratio of minimum cost of production to the actual observed cost of production.

3.7 Water Use Efficiency

The efficiency of specific inputs in non-parametric research is measured by two approaches: the DEA sub-vector efficiency Model and slack-based DEA method (Watto and Mugera, 2014, Imran et al., 2019). The current study opted to use the input oriented variable return to scale model, as the objective was to find out the impact of water on farm output. Hence, the selected model given below is best suited for the data in hand. Whereas water use efficiency equals farm productivity with respect to water use by keeping other inputs constant.

$$Min_{\theta,\lambda}\theta \quad (13)$$

Subject to:

$$-y_i + Y\lambda \geq 0, \quad (14)$$

$$x_i - X\lambda \geq 0, \quad (15)$$

$$\frac{N1}{\lambda} = 1, \quad (16)$$

$$\lambda \geq 0, \quad (17)$$

Equation (13 to 17) indicate x_i as an input vector for the i^{th} farm and y_i as an output vector. For the selection of optimal weights, we used equations from Coelli et al. (1998). The equation is iterated *n* times to get efficiency scores of farms and some weights are selected for maximization of efficiency scores. Farms with efficiency scores of 1, are efficient farms, and successfully reach optimum level of farm output on available water resources. While a score of less than 1 shows inefficient farms(Fatima et al., 2020).

3.8 Allocative Efficiency

Using Equations (6) and (12) we computed the allocative efficiency of firm *j* (AE_j) as given below:

$$AE_j = \frac{EE_j}{TE_j} \qquad (18)$$

3.9 Estimation of gross margins and net returns from different crops

Gross margins of farm enterprises provide a simple method for comparing the performance of different enterprises that have similar requirements for labour and capital. The gross margin of an enterprise refers to the total income less the variable costs incurred in the enterprise during the cropping season. Gross margin analysis for the different crop enterprises was undertaken. Gross margins and net returns from different crops (wheat, rice, cotton and sugarcane) were computed. The estimation of gross margins (GM) was done using the following formula:

Gross margin (GM) = Total Revenue (TR) – Total Variable Costs (TVC)

Where;

$$TR = (P_a \times Y) + (P_b \times Z) \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

P_a = price of main product;

Y = quantity of output;

P_b = price of by-product;

Z = by-product quantity.

And

$$TVC = \sum_{i=1}^{n} P_{xi} \times X_i \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where,

X_i = quantity of input X_i for $i=1$…………*n*

P_{xi} = price of input *xi* for $i=1$……………...*n*.

3.10 Water productivity

Water productivity can be defined as “the amount of production per unit volume of water used” (Guerra 1998). It is sometimes synonymous to water efficiency. Economic water productivity is defined as the value derived per unit of water used, and thus has also been used to relate water use in agriculture to nutrition, jobs, welfare and the environment (Sharma, et al., 2015). Improving water productivity is important where water is scarce and one needs to realize the full benefits of the productive inputs (fertilizer, high quality seed, tillage etc.). A good understanding of the measurement and improvement of water productivity can thus constitute a strategic response to growing water scarcity (water demand) and optimisation of other production inputs to enhance farm incomes and livelihoods (Sharma et al*.,* 2015). Moreover, water use efficiency, in a broad sense relates to the net socio-economic and environmental benefits or deficits achieved through the use of water in agriculture. Increasing water productivity is particularly important where water is scarce compared with other resources involved in production (Sharma et al*.,* 2015).

Water productivity/Water use efficiency (WUE) is generally defined as marketable yield/evapotranspiration, but economists and farmers are most concerned about the yield per unit of irrigation water applied. Thus, the WUE is calculated as yield (kg/ha) divided by irrigation water (m^3/ha). Thus, water productivity = Agricultural benefits/Water use (Cook et al., 2006). The economic measure of productivity at field scale can be measured by Gross Margin for a single product during a single phase of the crop rotation (Sharma et al*.,* 2015).

3.11 Probit model

A probit model was used to investigate the resource conservation technologies adopted by the respondents. Due to the binary nature of the outcome variable, Ordinary Least Square (OLS) regression cannot be applied (Ullah et al. 2015). The probit model may be written in form of a latent variable:

$$Y^* = X'\beta + \varepsilon \qquad (1)$$

Where, Y^* is a latent variable which represents the benefits/technology that farm household achieved by adopting the resource conservation method. X' is the vector of explanatory variables that may affect dependent variables, β_i is the vector of unknown parameters which are to be estimated and ε_i is the error term. As we cannot observe latent variables, what we can observe is defined as:

$$Y_{ij} = \alpha + \sum X_i \beta + \varepsilon \qquad (2)$$

Where Y_{ij} is the dependent variable (such as Furrow, HIES, laser levelling) having the binary outcome. It shows that households adopt the technology only if there are some benefits at farm level. Hence, it takes value 1 if Y* is greater than zero and takes zero if Y* is less than zero. X_i is the vector of explanatory variables including demographic characteristics and perceptions that may influence farmers' decision to adopt the conservation technology.

$$Yi = \begin{cases} 1 & if Y^* > 0 \\ 0 & otherwise \end{cases}$$

4 Results and discussion

This chapter describes the results of the research from analysing the data collected during survey. It includes section 4.1 which is about farm and household characteristics, section 4.2 which explains mode of purchase of inputs and credit availability and section 4.3 which is about livestock farming and income from livestock in study areas. Section 4.4 describes crops (including cropping patterns), while section 4.5 provides results regarding the sources of energy and irrigation water. Section 4.6 highlighted ranking of strategies to reduce groundwater salinity and major problems faced by the farmers, this section is followed by section 4.7, which is about training available to farming communities and section 4.8 about economic analysis of wheat, cotton, rice and sugarcane in study areas. The last two sections,4.9 and 4.10, provide the results from the resource use efficiency analysis and econometric analysis related to irrigation methods and water saving technologies used by the farmers respectively.

4.1 Farm and household characteristics

The socio-economic characteristics of farmers in the study area is shown in Table 4.1. Both districts show similar socio-economic characteristics. The average ages of respondents are very similar in the Naushahro Ferozeand SBA districts, 43 and 42 respectively. This is because middle aged farmers had more knowledge about cropping patterns, prices of inputs and outputs of crops and timings of the irrigation water compared to very old or young farmers. Family size is also similar between the districts and irrigation systems (11 people). This is higher than the average household size of Pakistan which is 6.7 people (GoP, 2020). The average years of schooling of farmers in both districts was 7, which is close to the average years of schooling in Sindh province more broadly(6.5 years)(UNDP, 2019). Differences are seen across head, middle and tail of minors in years of education and years of farming experience. The education level of farmer respondents at the head of the system (12 years in Naushahro Ferozeand 10 in SBA) is higher as compared to tail end farmers (6 years in Naushahro Ferozeand 4 SBA).

Table 4.1: Socio-economic characteristics of respondents

	Naushahro Feroze				SBA			
	Head	Middle	Tail	District	Head	Middle	Tail	District
Average age	44	42	43	43	43	41	42	42
Average number of years of formal education	12	6	5	7	10	5	4	7
Average number of years of farming experience	21	19	21	25	21	21	27	21
Average family size	11	11	11	11	10	11	11	11
Average number of adults per household	4	4	4	4	3	4	4	4
Average number of youth per household	3	4	4	4	4	4	4	4
Average number of children per household	4	3	3	3	3	3	3	3

Table 4.2 shows the per annum, average number of working days of respondent’s family members. In the Naushahro Feroze district the household head worked an average of 167 days a year. Other adults worked an average of 81days a year, while on average, the youth were contributing around 39 days a year. In district SBA the household head was working an average of 141 days a year.

Other adults were working an average of 63 days a year and the youth were contributing an average of 29 days a year.

Table 4.2: Average number working days per year by members of the households

	Naushahro Feroze				SBA			
	Head	Middle	Tail	Overall	Head	Middle	Tail	Overall
Head	132.96	174.00	150.08	166.77	151.04	118.08	155.04	141.39
Adults	68.64	106.88	68.32	81.28	91.68	26.08	72.00	63.25
Youth	18.71	76.89	22.48	39.36	41.28	18.19	28.61	29.36
Total	220.31	357.77	240.88	287.41	284.00	162.35	255.65	234.00

Table 4.3 shows the average distance between farms and markets, main roads and canals. The distance of the farm from a main city in both districts is similar (3 kilometres). On average farms in district Naushahro Ferozeare closer to the Cheeho minor canal (3.49 kilometres) but in comparison to that distance, farms in SBA are at higher average distance i.e.8.2 kilometres from Malwa minor canal. There is variation in average distances between the nearest market and farms at head, middle and tail of minors. In Naushahro Feroze, farms of villages located at the head of the system are closer to market (0.45 kilometres on average) while the distance between the farms of villages located at the tail end of the system and the market in Naushahro Ferozeis higher (3 kilometres). Similar trends in average distance between market and farms at head and tail are observed in SBA district.

Table 4.3: Farm from market, main road and canals distance (in average kilometres)

	Naushahro Feroze				SBA			
	Head	Middle	Tail	Overall	Head	Middle	Tail	Overall
Main city	2.05	3.75	4.02	3.27	3.18	1.39	5.79	3.45
Canals	4.48	2.96	3.03	3.49	5.76	11.96	6.88	8.2
Main road	6.92	3.58	4.19	4.9	12.9	17.16	7.6	12.5
Market	0.45	2.02	3	1.8	3.77	4.53	5.03	4.44

Results regarding farm characteristics are shown in Table 4.4. Findings from the Naushahro Feroze district indicate that on an average, farmers own 6.34, 11.45 and 6.65 acres of farmland at head, middle and tail reaches respectively. The farmers from head, middle and tail reaches also rented an average of 2.34, 2.01 and 3.32 acres of farmland respectively. Flood irrigation was used for irrigating 7.71, 10.92 and 7.83 acres in the head, middle and tail reaches respectively. A smaller number of farmers indicated that they used furrow irrigation and other water saving irrigation technologies. This is similar to the characteristics of farms throughout Sindh, with the majority of farmers in the province using the flood irrigation (Qureshi et al*.,* 2016).

Results from the SBA district show that on an average, farmers owned 16.19, 7.43, and 6.75 acres of farmland in head, middle and tail reaches. In the SBA district, irrigation practices were similar to those in the Naushahro Feroze district; the majority of respondents used flood irrigation on an average of 15.17, 9.32 and 6.75 acres in head, middle and tail reaches. This represents a major proportion of land. Farmers indicated that a minor proportion of their land, 3.59, 0.97 and 0.39 acres on average, is laser levelled in the head, middle and tail reaches respectively and the use of water saving technology is limited.

Table 4.4: Farm characteristics at research sites (average acres)

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Own farming land (avg. acres)	6.34	11.45	6.65	16.19	7.43	6.75
Rented farming land (avg. acres)	2.34	2.01	3.32	4.67	2.87	2.01
Operational landholding of farming land (avg. acres)	8.68	13.46	9.97	20.86	10.3	8.76
Flood irrigated farming land (avg. acres)	7.74	10.94	7.89	15.29	9.32	6.75
Furrow irrigated farmland (avg. acres)	0.93	1.89	1.29	4.89	-	0.29
Water saving technology used on farmland (avg. acres)	0.01	0.63	0.79	0.68	0.99	0.97
Laser land leveller area (avg. acres)	0.45	1.67	0.79	0.95	0.37	1.64
Average number of years since laser levellers were used on farmland	0.6	0.36	0.01	0.15	0.12	0.25

4.2 Mode of purchase of inputs and credit availability

Table 4.5shows the mode of purchase for crop inputs, across different locations in the study areas. In the Naushahro Ferozedistrict, most of the farmers used credit for purchasing inputs like seed, fertilizer, pesticide and diesel. Likewise, in SBA district the majority of the farmers were also purchasing their inputs on credit. Only a few farmers were also purchasing inputs with cash. There were various reasons for the dependency of farmers on credit, such as lack of savings, low revenue from agricultural output, higher cost of production and dependency on middlemen.

Table 4.5: Mode of inputs purchase across the minors (percent)

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Seed						
Cash	21.3	14.7	24	22.7	22.7	18.7
Credit	48	82.7	61.3	72	60	33.3
Both	30.7	2.6	14.7	5.3	17.3	48
Fertilizer						
Cash	21.3	10.7	18.7	22.7	21.4	17.4
Credit	48	86.7	66.7	72	61.3	33.3
Both	30.7	2.6	14.6	5.3	17.3	49.3
Pesticide						
Cash	21.3	17.3	40	22.7	22.7	21.3
Credit	48	78.7	52	72	77.3	36
Both	30.7	4	8	5.3	0	42.7
Diesel						
Cash	40	21.3	17.3	21.3	22.7	22.7
Credit	52	48	78.7	36	72	77.3
Both	8	30.7	4	42.7	5.3	0

Table 4.6shows the sources of credit used by the farmers across the head, middle and tail locations of both systems. Generally, farmers from Naushahro Ferozedid not prefer (formal) institutional credit. They preferred to seek credit from friends/ relatives and shopkeepers/ arthis (traders). In the SBA district there was a similar pattern of credit use; the farmers had a distinct preference for informal credit. However, this situation may be due to the low literacy of farmers, or because the formal credit process to borrow money from formal institutions is lengthy and difficult.

Table 4.6: Source(s) of credit across various locations on minors (percent). ZTBL is the Zarai Taraqiati Bank Limited, an agricultural development bank. Arhti is a commissioning agent.

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Commercial bank						
No	100.0	98.7	100.0	96.0	97.3	97.3
Yes	0.00	1.3	0.0	4.0	2.7	2.7
ZTBL						
No	98.7	100.0	98.7	100.0	100.0	100.0
Yes	1.3	0.00	1.3	0.00	0.00	0.00
Neighbour						
No	90.7	100.0	96.0	100.0	100.0	96.0
Yes	9.3	0.00	4.0	0.00	0.00	4.0
Friend/relative						
No	58.7	80.0	81.3	78.7	61.3	94.7
Yes	41.3	20.0	18.7	21.3	38.7	5.3
Shopkeeper/arhti						
No	44.0	77.3	77.3	74.7	57.3	88.0
Yes	56.0	22.7	22.7	25.3	42.7	12.0

4.3 Livestock farming and income from livestock

Table 4.7 illustrates the livestock owned by the farmers and the monthly income earned from the livestock. In most of the rural areas of Sindh, livestock is a significant part of agriculture income (Abedullah et al*.,* 2009). Particularly in those areas where there is shortage of irrigation water. Our data confirms this pattern in both the SBA and the Naushahro Feroze districts, particularly at the tail areas of systems. As there is a shortage of water at the tail end of the systems, farmers dependence on livestock is in these areas than in the middle and head of the system for both Malwa in SBA and Cheeho in Naushahro Feroze.

In Naushahro Feroze, the average number of milking animals owned at tail areas was higher (2.35) compared to head (0.64) and middle (1.92) areas, and per day average milk production was also significantly higher in tail areas. In Naushahro Feroze, farmers living in tail areas obtained an average of24.20 liters per day, while; at head and middle areas farmers obtained less milk (averagely 18.04 and 17.69 litres at head and middle areas respectively).

At both sites, farmers from tail areas owned a higher number of milking animals and were getting higher average per day milk production. However, they were earning less income from selling milk. This is likely due to the tail farmers selling milk mostly to shopkeepers in local villages to avoid high transport costs to markets (tail farms were furthest from markets). Farmers at the head and middle areas mostly sell milk at the nearest local markets at comparatively higher prices.

Differences in average monthly income from livestock were observed across head, middle and tail areas of the SBA district. At the head, a farmer's average monthly income from livestock was Rs. 12816.18, while, at the middle, respondents on average earnt Rs.27615.56 and at the tail reach farmers average monthly income was Rs.21814.55. This indicates that farmers from the tail of the system are obtaining more benefit compared to the head areas farmer's income. This is due to the higher milk production observed at farms in tail areas. The data also revealed that farmers living in middle of the systems are getting higher incomes from livestock compared to tail and middle farmers for both systems. This may be due to farmers at the middle of the systems capturing better milk prices due to selling milk in markets.

Table 4.7: Livestock farming and income from livestock farming in study areas

		Naushahro Feroze			SBA		
		Head	Middle	Tail	Head	Middle	Tail
Cattle owned	Avg. number	2.33	2.25	3.79	2.29	2.25	4.13
Buffalo owned	Avg. number	0.31	1.17	2.16	0.76	0.19	0.39
Sheep owned	Avg. number	2.95	1.47	3.72	2.52	4.51	3.24
Goats owned	Avg. number	0.05	0.72	0.88	1.21	0.15	2.19
Meat animals owned	Avg. number	0.20	0.53	0.35	0.36	0.07	0.17
Sold animals during a year	Avg. number	3.46	4.65	6.48	4.89	3.3	5.42
Milking animals owned	Avg. number	0.64	1.92	2.35	1.39	0.23	2.68
Milk production	Avg. liter/ day	18.04	17.69	24.20	18.66	16.05	23.75
Milk market price	Avg. PKR/ liter	63.36	64.88	62.76	56.59	64.72	59.99
Milking period of animals	Avg. months	6.65	5.69	6.28	6.20	6.19	6.08
Income from selling milk	Avg. PKR/ month	16,680.72	15,188.90	14,306.61	17,119.09	15,526.86	14,086.59
Income from selling animals	Avg. PKR/ year	28,795.96	54,893.87	39,577.56	37,039.76	27,785.26	26,566.89
Income from livestock	Avg. PKR/ month	21,286.53	24,410.97	22,956.57	12,816.18	27,615.56	21,814.55

4.4 Crops (including cropping patterns) of research sites

Table 4.8showsthe number of farmers cultivating major crops. Results suggest that the majority of farmers in Naushahro Feroze were cultivating cotton (195 respondents) and wheat (197 respondents), while only 11 respondents were growing sugarcane. Rice is not grown in the Naushahro Feroze district. Different results are found in SBA with the majority of farmers (140) growing wheat. There were76 farmers growing cotton, and rice was also grown (35) in SBA.

Table 4.8: Number of farmers grows cotton, wheat, rice and sugarcane

	Naushahro Feroze				SBA			
	Head	Middle	Tail	Total	Head	Middle	Tail	Total
Cotton	4 69	60	66	195	3	10	63	76
Wheat	74	67	56	197	29	37	74	140
Rice	0	0	0	0	20	15	0	35
Sugarcane	3	4	4	11	66	57	7	123
Overall	146	131	126	403	118	119	137	374

Table 4.9 shows the average acres of land under cotton, sugarcane, rice and wheat crops in the study areas. In Naushahro Feroze, cotton and wheat occupy major areas of cultivation and sugarcane is the third major crop. Rice is the fourth number major crop, but it is not grown in middle and tail areas of Naushahro Feroze and tail areas of SBA, as in tail areas especially, there is significantly less irrigation water and rice needs more water than cotton and wheat.

Table 4.9: Area under major crops at research sites

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Cotton (Avg. acres of land)	7.46	7.16	6.26	5.00	4.90	15.63
Wheat (Avg. acres of land)	7.73	6.66	6.11	9.97	7.08	22.89
Rice (Avg. acres of land)	0.00	0.00	0.00	8.69	6.44	00
Sugarcane (Avg. acres of land)	6.33	3.00	3.00	18.88	17.86	9.57

Table 4.10shows the time of sowing for the different crops. For both systems, Malwa and Cheeho, a vast majority of growers (> 80 to 90%) of wheat and cotton were of the opinion that sowing wheat and cotton at the appropriate growing time was best. Similarly, the majority of growers (69% to 73%) at both study sites were of opinion that sowing of sugarcane at the appropriate growing time was preferred. Rice crops are grown only by the farmers of Malwa minor and a significant number of rice growers (81%) explain that they are unable to sow rice crops at the preferred time due to shortages of water.

Table 4.10: Sowing time of major crops across districts of study area

Sowing Time	Naushahro Feroze				SBA			
	Wheat	Cotton	Rice	Sugar-cane	Wheat	Cotton	Rice	Sugar-cane
Early sowing (% of respondents)	2	1	0	18	12	3	1	15
In time (% of respondents)	98	96	0	73	88	97	18	69
Late sowing (% of respondents	0	3	0	9	0	0	81	16
Total	100	100	0	100	100	100	100	100

4.5 Sources of energy and irrigation water

Table 4.11 reveals the sources of irrigation used by the farmers at head, middle and tail of irrigation systems. It was observed that farmers of tail areas of both systems are highly dependent on groundwater compared to canal water, and the majority of farmers at head areas use canal water for irrigation. About 73% of the 75 respondents from head areas in Naushahro Feroze and 64% in SBA use canal water for irrigation. Conversely, about 59%of the75 respondents from the tail areas of irrigation system in Naushahro Ferozeand 83% in SBA use groundwater for irrigation. This shows that there is a large difference across the two systems in the availability of canal water.

Table 4.11: Source of irrigation in the study area (in average numbers)

Source of irrigation	Naushahro Feroze				SBA			
	Head	Middle	Tail	Total	Head	Middle	Tail	Total
Number of farmers use canal water for irrigation	55	38	28	121	48	48	12	108
Number of farmers use owned tube well	19	28	44	91	26	22	62	110
Number of farmers use purchased water	1	9	3	13	1	5	1	7
Total	75	75	75	225	75	75	75	225

Table 4.12 reveals the proportion of groundwater and canal water used for irrigation for growing different crops. Results indicate that increased or decreased use of canal and groundwater mainly depends on the location in the system. At head of both systems (Cheeho in Naushahro Feroze and Malwa in SBA), the percentage of canal water usage is higher compared to tail areas.

Table 4.12: Proportion of groundwater and canal water in total irrigations of crops (perception of farmers as a percentage)

Crop	Type of irrigation	Naushahro Feroze			SBA		
		Head	Middle	Tail	Head	Middle	Tail
Wheat	Groundwater	32.22	38.06	69.28	9.44	23.43	73.60
	Canal	67.78	61.94	30.72	90.56	76.57	26.40
Cotton	Groundwater	58.65	60.00	64.85	12.40	63.83	69.67
	Canal	41.35	40.00	35.15	87.60	36.17	30.33
Rice	Groundwater	0.00	0.00	0.00	18.60	66.00	78.00
	Canal	0.00	0.00	0.00	81.40	34.00	22.00
Sugarcane	Groundwater	62.73	75.25	85.43	17.80	76.50	89.50
	Canal	37.27	24.75	14.57	82.20	23.50	10.50

Table 4.13shows the number of hours canal water was used on a weekly basis. Results indicated that at the head, middle and tail reaches the allocated time was 9.32, 12.37 and 20.47 minutes per acre respectively, in Naushahro Feroze district. Likewise, in the SBA district, farmers indicated that in the head, middle and tail reaches the allocated time is 7.97, 11.13 and 15.29 minutes per acre respectively. More time is allocated for tail area farmers compared to the head and middle reach farms. However, the flow of water is reduced by the time it reaches tail areas therefore, even if at tail areas are allocated more time the availability of canal water is less.

Table 4.13: Total allocated time for canal water turn (average minutes /acre) on weekly basis

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Total allocated time for canal water turn during the day (warabandi/acre)	9.32	12.37	20.47	7.96	11.13	15.29
Total allocated time for canal water turn during the evening/night	0.00	1.83	14.32	15.20	0.00	0.43

Table 16showsthe sources of power used in farming activities. The majority of farmers used tractors for farm activities because of time savings compared to traditional practices. Findings indicate that in both at Malwa and Cheeho minor, more than 70 to 90% of farmers use tractors for their farm activities while bullocks are used less (4 to 26%).

Table 4.14: Power sources used in farming (percent of sample respondents)

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Tractor	92	74.1	95.5	95.3	89.3	73.3
Bullock	8	25.9	4.5	4.7	10.7	26.7
Both	0	0	0	0	0	0
Total	100	100	100	100	100	100

Table 4.15shows that in the Naushahro Feroze district, the majority of the farmers owned tractors. At head areas of both minors 47 to 61%of farmers owned tractors while fewer farmers at tail areas owned tractors and depend on rented tractors for irrigation.

Table 4.15: Proportion of tractor ownership across the minors

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Percentage of respondents who own tractors	51.7	45.5	46.6	53.6	61.6	47.3
Percentage of respondents who rent tractors	48.3	54.5	53.4	46.4	38.4	52.7
Total	100	100	100	100	100	100

Table 4.16 reveals farmers' perceptions regarding water shortages across head, middle and tail sections of the systems. In the Naushahro Feroze district, at head and middle areas, the majority of the farmers were of the opinion that there is huge water shortage in the Kharif season. In the tail region, more than 62%of farmers perceived that there is a shortage of water. However, a similar proportion of farmers reported water shortages in the Kharif season at head, middle and tail reaches of the SBA district. During the Rabi season, a lower proportion of farmers from both districts reported seasonal water shortages.

Table 4.16: Perception of seasonal water shortage across the minors(percent)

Season	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Rabi	27.87	6.7	8.09	17.67	9.3	8
Kharif	56.18	57.3	62.93	56.49	52	56
All year	15.95	36	28.98	25.84	38.7	36
Total	100	100	100	100	100	100

Table 4.17 depicts the sources of energy used to power tube-wells in the study area. In Naushahro Feroze diesel engines were the main source of energy for tube-wells and more than 80 tube-wells had diesel engines. The other four tube-wells depend on electricity and there were seven tractor-powered tube-wells. In the Malwa minor in SBA, diesel engines were the source of energy for more than 94 tube-wells. In addition, 10 tube-wells depended on electricity and 6 were tractor driven tube-wells.

Table 4.17: Irrigation tube-wells by source of energy (numbers)

Source of energy	Naushahro Feroze	SBA
Number of tube-wells operated by diesel engine	80	94
Number of tube-wells operated by electricity	4	10
Number of tube-wells operated by tractor	7	6
Total	91	110

Characteristics of the tube-wells in the study area are shown in Table 4.18. Results indicate that farmers are using 4.7 to 5.8 inches and 4.5 to 5.87 inches diameter pipe for tube-wells in Naushahro Feroze and SBA districts. The average screening length ranged from 11.33 to 12.43 feet. The horsepower of the tube-well motors ranged from 18.36 to 20.36 horsepower. The bore depth in both districts at the head reach was less than in middle and tail reaches. This shows that the water table in head areas is higher than at the middle and tail. The time required for water extraction varies from an average of 150 to 186 minutes in head and tail regions in Naushahro Feroze.The time required for water extraction in SBA is an average of 90 to 120 minutes from head to tail regions.

Table 4.18: Tube-well characteristics at both minors (averages)

		Naushahro Feroze			SBA		
		Head	Middle	Tail	Head	Middle	Tail
Diameter of pipe	Inches	5.43	4.58	5.22	5.34	4.75	5.87
Screening length	Feet	10.43	10.47	11.35	12.43	11.39	12.82
Tube-well horsepower	Horsepower	18.55	16.23	19.36	19.24	20.11	18.36
Bore depth	Feet	130.23	140.23	145.23	70.53	80.32	127.34
Suction pipe	Inches	5.63	4.37	5.24	5.76	4.81	5.92
Time required per irrigation	Minutes	150.23	160.32	168.32	90.23	96.32	120.43

Table 4.19 depicts the irrigation cost per acre using diesel engines, tractor operated pumps and electric tube-wells. This table also includes the maintenance and lubrication costs of irrigation. Results across districts show that, in the case of diesel engine operated tube-wells, there was no big difference in the per acre irrigation cost across the districts of Naushahro Feroze (Rs. 2368.18) and SBA (Rs. 2221.74). There were differences in the per acre irrigation cost across the head (Rs. 568.92), middle (Rs. 866.15) and tail (Rs. 933.11) in Naushahro Feroze and head (Rs. 415.79), middle (Rs. 813.79) and tail of SBA (Rs. 992.16). This highlights that the per acre irrigation cost at the tail is higher when compared to head regions at both research sites. This is likely because tail farmers usually purchase diesel and lubricants on credit, therefore they pay a higher price for diesel as compared to head farmers who purchase diesel and lubricants with cash. It was observed that the per acre per irrigation cost of using tractor operated tube-wells was higher (Rs. 4444.54) compared to diesel operated tube-wells at Naushahro Feroze (Rs. 2368.18) and at SBA(Rs. 2221.74). In addition, tractor operated tube-wells were used only by the farmers who owned their tube-wells, therefore the use of tractor operated tube-wells was not common. It was observed that tube-wells that are operated by electricity have lower cost (Rs. 1281.58) compared to all of the

above tube-well's irrigation costs. In spite of that, the number of diesel operated tube-wells was higher in both study areas as compared to electricity powered tube-wells because the initial cost of installation of electric tube-wells is very high and unaffordable for the majority of farmers.

Table 4.19: Per acre per irrigation cost of using tube-wells operated by diesel, tractor and electricity

		Naushahro Feroze			SBA		
		Head	Middle	Tail	Head	Middle	Tail
Per acre per irrigation cost of using tube-well operated by diesel (peter engine)							
Diesel used	Avg. litre/hour	2.22	2.28	2.54	2.05	2.8	2.31
Diesel cost/litre	Avg. PKR/litre	93.61	101.92	106.35	94.33	95.4	99.22
Diesel cost / irrigation	Avg. PKR/ irrigation	207.81	232.38	270.13	193.38	267.12	229.19
Lubrication cost /irrigation	Avg. PKR/irrigation	186.11	295.27	255.41	97.91	346.67	457.03
Maintenance /irrigation	Avg. PKR/irrigation	175	338.5	407.57	124.5	200	305.94
Per acre, per irrigation cost	Avg. PKR /irrigation	568.92	866.15	933.11	415.79	813.79	992.16
Per acre per irrigation cost of using tractor operated tube-wells							
Diesel used	Avg. Litre/hour	4.02	5.33	4.22	0.00	0.00	0.00
Diesel cost /litre	Avg. PKR/litre	96.73	89.00	106.25	0.00	0.00	0.00
Lubrication cost /irrigation	Avg. PKR/ irrigation	243.31	333.33	264.06	0.00	0.00	0.00
Maintenance /irrigation	Avg. PKR/irrigation	963.31	833.33	864.06	0.00	0.00	0.00
Per acre, per irrigation cost	Avg. PKR/irrigation	1346.62	1466.67	1631.25	0.00	0.00	0.00
Per acre per irrigation cost of using electric motor operated tube-wells							
Electricity used /hour	Units/ hour	0.00	13.61	14.21	0.00	0.00	12.61
Electricity cost /unit	PKR/ unit	0.00	11.91	13.91	0.00	0.00	10.91
Lubrication cost /irrigation	PKR/ irrigation	0.00	34.54	33.54	0.00	0.00	44.54
Maintenance /irrigation	PKR / irrigation	0.00	52.67	45.67	0.00	0.00	55.67
Per acre, per irrigation cost	PKR / irrigation	0.00	746.79	534.79	0.00	0.00	654.79

Table 4.20 shows farmers perceptions on the need for watercourse improvements at various locations on the canals. The results show that 90 to 100% of farmers from the head, middle and tail areas in both districts indicated that there is need for improvement of watercourses.

Table 4.20: Perceptions of farmers about need of watercourse improvement

Farmer's perceptions	Naushahro Feroze(%)			SBA (%)		
	Head	Middle	Tail	Head	Middle	Tail
No improvement in water courses	100.00	96.00	92.00	98.67	100.00	100.00
Improvement in water courses	0.00	4.00	8.00	1.33	0.00	0.00

Figures 4.1 and 4.2 demonstrate the average per acre/cubic meter of groundwater that is applied for irrigation by the farmers. In SBA for wheat plantations at head, mid and tail reaches a similar cubic meter per acre groundwater was applied. This ranged between 2000 to 2800. Similarly, for cotton crops, the average ranged from 2000 to 3000. In both districts' sugarcane is the major groundwater consuming crop among four major crops of area.

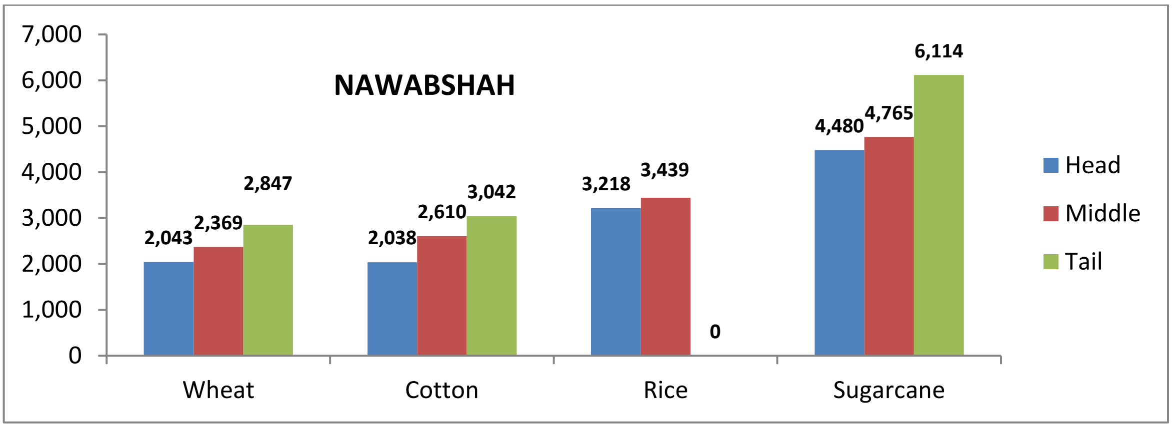

Figure 4.1: Quantity of groundwater used for irrigation in SBA (m³/acre) (Average). Note: (SBA) Nawabshahis the former name of the Shaheed Benazirabad (SBA) province.

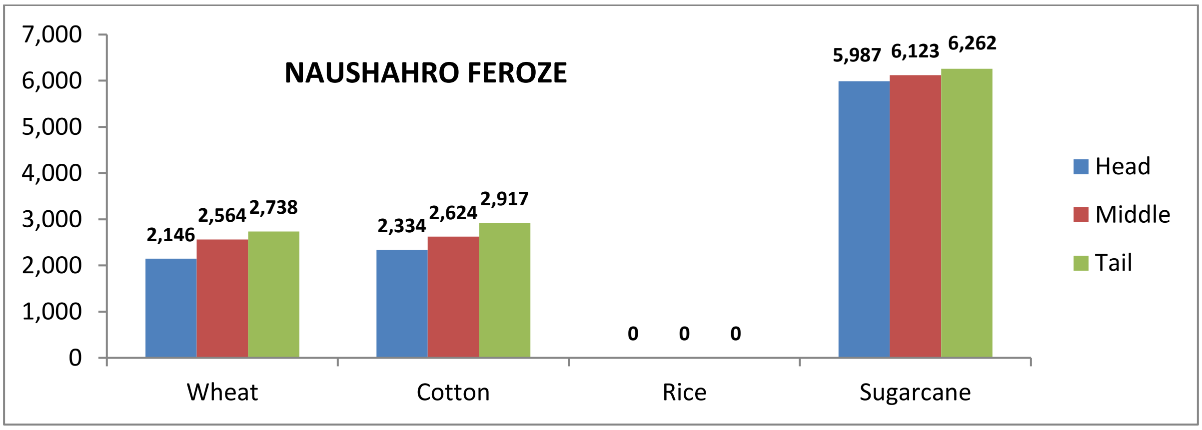

Figure 4.2: Quantity of groundwater used for irrigation in Naushahro Feroze (m³/acre) (Average)

Figures 4.3, 4.4, 4.5 and 4.6 (other details of the analysis are also represented in tabular form in Table B1 (in Appendix B)show the gross margin earned per unit of water used for irrigation of the four major crops. A higher gross margin per cubic meter water was earned by the wheat growers at the head and middle areas compared to the tail. Similarly, for the cotton crop in both districts, tail farmers earned less gross margin per unit of water compared to head and middle farmers. Rice continues this trend where farmers from head areas are earnt a higher gross margin per unit of water compared to mid region farmers. In the case of sugarcane, different results were found in Naushahro Feroze, where the gross margin earned per unit of water was higher at the tail areas compared to head areas. Similar trends were found for the SBA district for the other crops.

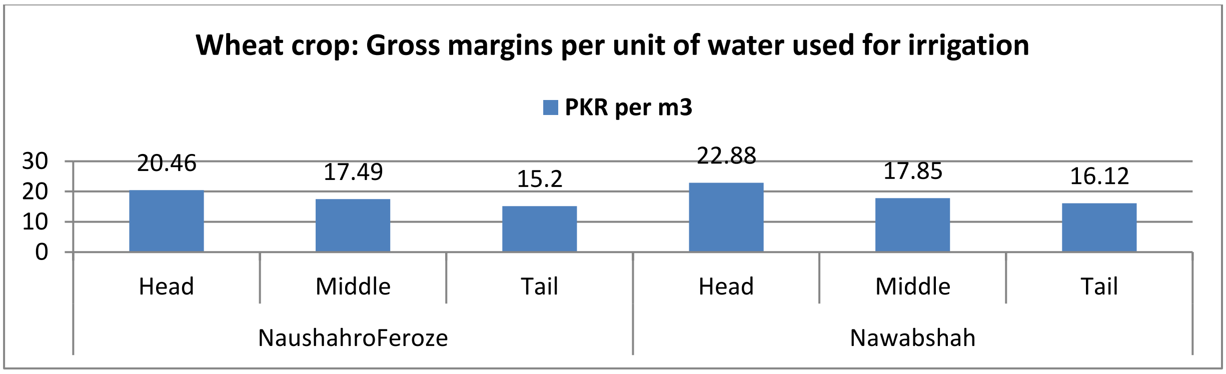

Figure 4.3: Gross margins per unit of water used for irrigation by wheat crop growers in study areas

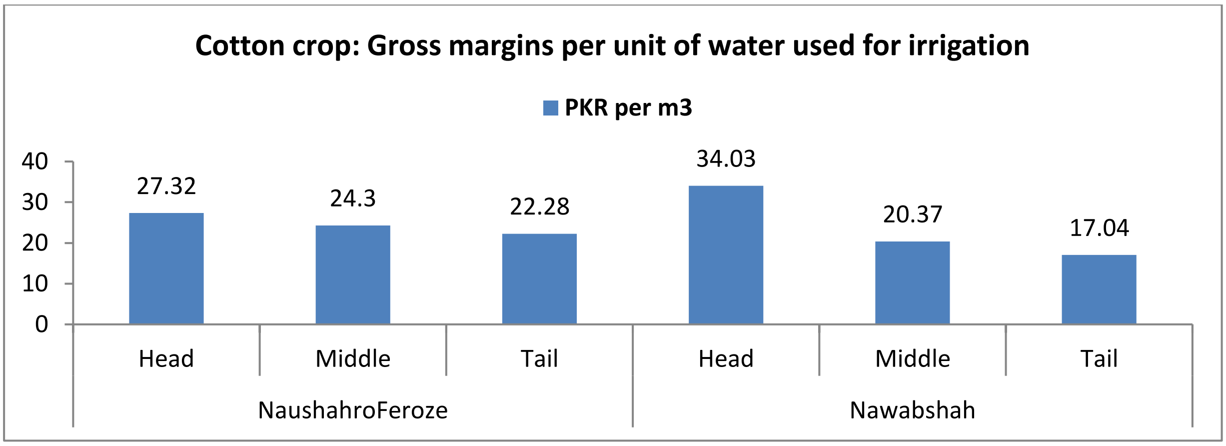

Figure 4.4: Gross margins per unit of water used for irrigation by cotton crop growers in study areas

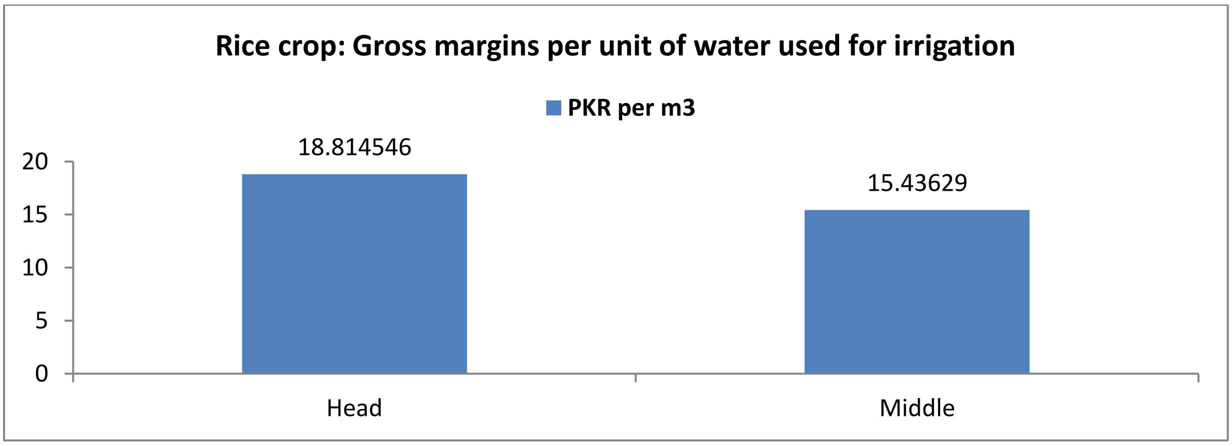

Figure 4.5: Gross margins per unit of water used for irrigation by rice crop growers in study areas

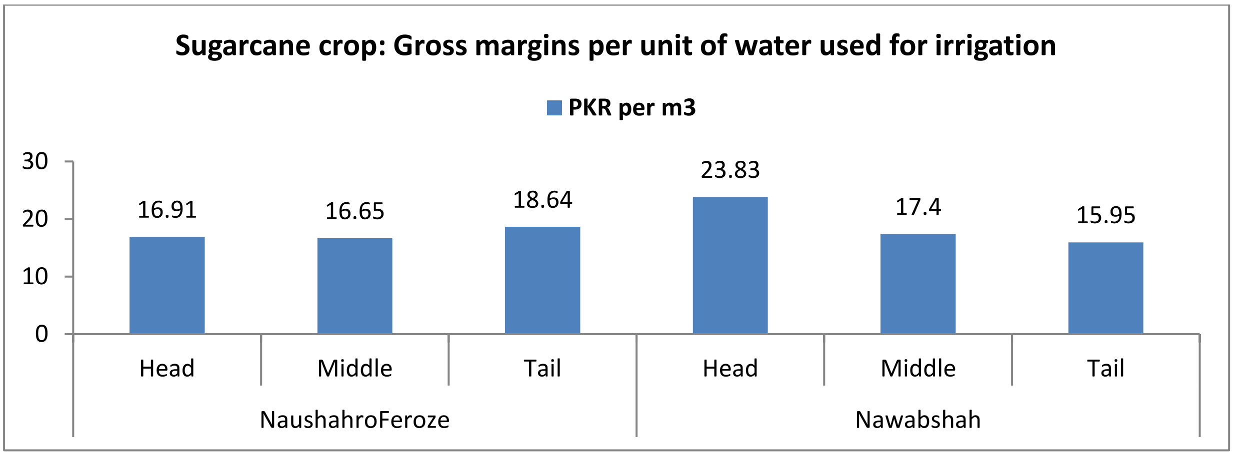

Figure 4.6: Gross margins per unit of water used for irrigation by sugarcane crop growers in study areas

4.6 Ranking of major problems and solutions

Table 4.21shows the major problems faced by farmers at both research sites. Results show that storage of water was ranked first, as a major issue in Malwa SBA and Cheeho Naushahro Feroze (29% and 38% respectively). The second major issue at both sites is about the high cost of purchasing inputs. In Naushahro Feroze salinity was ranked as the fourth major problem in the area and water storage (14%) as the fifth major problem faced in the area. The sixth problem faced by farmers was pest and disease (10%) of plants. Farmers ranked unimproved irrigation facilities at seventh place, while water logging was placed last by the farmers in district SBA.

Table 4.21: Major problems reported by farmers of both research sites (multiple answers)

Naushahro Feroze				SBA			
Problem	N	Percent	Rank	Problem	N	Percent	Rank
Water shortage	85.00	37.78	I	Water shortage	67.00	29.78	I
Purchasing of fertilizer	57.00	25.33	II	Expensive inputs	58.00	25.78	II
Salinity	33.00	14.67	III	Purchasing of fertilizer	56.00	24.89	III
Water storage	27.00	12.00	IV	Salinity	34.00	15.11	IV
Unimproved irrigation facilities	25.00	11.11	V	Water storage	32.00	14.22	V
Expensive inputs	22.00	9.78	VI	Pest/diseases	24.00	10.67	VI
Pest/diseases	12.00	5.33	VII	Unimproved irrigation facilities	23.00	10.22	VII
Water logging	11.00	4.89	VIII	Water logging	14.00	6.22	VIII

Table 4.22 shows the ranking of resource conservation methods to address saline groundwater problems, in the Naushahro Feroze and SBA districts. Farmers from the Naushahro Feroze district

ranked changes in sowing date as the first resource conservation strategy, followed by market support price. Market support may contribute to prevention of financial shocks from fluctuations in the market price. Subsidies on purchasing raised bed machines as a resource conservation strategy was ranked third by the farmers. This is because this machine helps farmers to prepare raised beds at their farms, which helps combat salinity. The use of drought resistant varieties and salt tolerant species were ranked on fourth and fifth respectively.

Farmers from the SBA district ranked drought resistant and salt tolerant varieties as their first and second priorities respectively as resource conservation strategies. Subsidies on purchasing raised beds machine was ranked third, market support was ranked fourth and changes in sowing date was ranked as fifth as a resource conservation strategy in the SBA district.

Table 4.22: Ranking of strategies to reduce groundwater salinity (ranked from 1 to 5)

Particulars	Naushahro Feroze		Particulars	SBA	
	Percent	Rank		Percent	Rank
Sowing date	52.48	I	Drought resistance varieties	50.39	I
Market support/price	50.43	II	Salt tolerant varieties	50.25	II
Subsidy on raised bed machine	50.20	III	Subsidy on raised bed machine	49.79	III
Drought resistance varieties	49.60	IV	Market support/price	49.56	IV
Salt tolerant varieties	46.74	V	Sowing date	47.51	V

4.7 Training used by farming communities

Table 4.23shows the proportion of farmers who obtained training from NGOs and Agriculture Extension workers in the study area. The NGOs working in Naushahro Feroze provided various training to the farmers from the head, middle and tail reaches. About 25 to 33%t of farmers in Naushahro Feroze and 10 to 18% of farmers in SBA had the opportunity to obtain training from NGOs. In the Naushahro Feroze district, a very small proportion farmers at head, middle and tail reaches (5, 12, and 4%) indicated that the Agriculture Extension workers had provided training to them. Likewise, in the SBA district, a very small proportions of farmers (2, 10 and 10%)in the head, middle and tail reach respectively, reported receiving training from Agriculture Extension workers regarding cultivation and new plot demonstrations.

Table 4.23: Training of farmers across the districts and minors (in percent)

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Training by NGOs						
Yes	25	30	33	22	10	18
No	75	70	67	78	90	82
Training by extension workers						
Yes	05	12	04	02	10	10
No	95	88	96	98	90	90

4.8 Economic analysis of wheat, cotton, rice and sugarcane

Table 4.24 shows the economic analysis for wheat crops. Findings indicate that the cost of production incurred by the wheat farmers in both districts is similar; Naushahro Feroze (Rs. 29,263.75) and SBA (Rs. 29,304.76. Net revenue earned by the wheat farmers in Naushahro Feroze (Rs. 14,369.31) is less than in SBA (Rs. 16,271.61). Variations across the head, middle and tail areas are also seen in costs, yields and revenues.

Table 4.24: Economic analysis of wheat crop (average per acre at study side). All costs are in PKR

Wheat	Naushahro Feroze				SBA			
	Head	Middle	Tail	All	Head	Middle	Tail	All
Cropped area (acres)	572.0	446.5	342.0	1360.5	289.0	262.0	1694.0	2245.0
Proportion of acre under rice crop (%)	42.0	33.0	25.0	100.0	13.0	12.0	75.0	100.0
Ploughing (No.)	2.9	3.3	3.0	3.1	3.3	3.2	3.5	3.5
Seed rate (kg)	56.2	56.4	57.2	56.5	51.9	57.2	59.0	57.9
No. of bags of fertilizer	4.2	4.5	4.4	4.4	4.8	4.3	4.4	4.5
No. of chemicals	2.4	2.2	1.7	2.4	0.5	1.5	1.7	1.5
No. of groundwater applications	2.5	2.0	1.0	2.0	0.3	1.5	5.1	1.3
No. of surface water applications	1.9	2.1	1.4	1.9	2.3	3.9	1.8	1.8
Land preparation cost	3404.9	4855.4	3747.4	3967.0	4591.0	4203.1	3972.9	4079.3
Sowing cost	3057.3	2618.2	2603.4	2799.1	2228.3	2834.5	3341.4	3138.9
Fertilizer cost	9052.8	9487.0	9866.4	9399.8	10231.5	9074.4	934.5	9193.2
Chemical cost	2171.1	2165.1	1474.9	1994.1	1329.1	2147.0	1922.7	1872.5
Irrigation cost	3264.1	841.3	6391.8	4896.1	2868.5	5550.3	5967.8	4608.8
Harvesting Cost	3548.3	3059.7	1959.4	2988.5	2833.9	3411.8	4076.2	3838.8
Threshing cost	2303.1	2624.2	2443.0	2443.7	2714.8	2155.6	2330.4	2359.5
Total Cost	27346.2	31993.8	28906.6	29263.8	25678.0	27162.1	30254.9	29304.8
Yield (40kg)	37.5	38.3	35.8	37.3	39.2	35.2	38.8	38.5
price/40kg	1170.8	1178.3	1162.4	1171.1	1192.4	1204.0	1180.3	1184.6
Total Revenue	43903.1	44835.4	41611.7	43633.1	46745.3	42288.0	45885.5	45576.4
Net revenue	16556.9	12841.6	12705.1	14369.3	21067.3	15125.9	15630.7	16271.6
BCR	1.6	1.4	1.4	1.5	1.8	1.6	1.5	1.6

Table 4.25 shows the farm budget for sowing one-acre of cotton in the study area. Cotton yield obtained in Naushahro Feroze was 21.90 mds (40 kg) while in SBA the average yield was higher (23.97 mds; 40 kg). Net revenue earned by the cotton farmers in Naushahro Feroze (Rs. 27,176) is also less as compared to SBA (Rs. 23,638). Variations across the head, middle and tail are also seen in the data in costs, yields and revenues.

Table 4.25: Economic analysis of cotton crop (average per acre at study site). All costs are in PKR.

Cotton	**Naushahro Feroze**				**SBA**			
	Head	Middle	Tail	Overall	Head	Middle	Tail	Overall
Cropped area (acres)	515.0	415.0	413.0	1343.0	15.0	119.0	985.0	1119.0
Proportion of acre under rice crop (%)	38.4	30.9	30.8	100.0	1.0	11.0	88.0	100.0
Ploughing (No.)	4.7	4.6	4.1	4.5	3.7	3.6	3.6	3.6
Seed rate (kg)	6.7	8.9	8.2	7.8	6.5	7.9	6.0	6.2
No. of bags of fertilizer	5.7	4.6	4.9	5.1	4.0	3.7	4.1	4.1
No. of chemicals	1.9	2.3	2.1	2.1	2.5	2.4	1.9	2.3
No. of groundwater applications	6.7	6.9	9.2	7.5	2.9	2.8	12.1	11.0
No. of surface water applications	4.2	3.0	1.4	3.0	2.9	3.3	0.6	0.9
Land preparation cost	5897.7	6831.8	5438.5	6044.8	4993.3	5310.9	4232.2	4357.1
Sowing cost	2531.6	2817.7	2573.8	2632.9	1700.0	3560.5	2166.4	2308.4
Fertilizer cost	12488.0	9491.8	10319.9	10895.9	8746.7	9079.0	9846.6	9750.2
Chemical cost	2158.1	2232.9	3209.4	2504.6	6100.0	2514.3	2072.2	2173.2
Irrigation cost	6745.6	8991.8	11495.9	8900.5	6160.0	5046.2	11947.4	11135.9
Harvesting Cost	3938.8	4139.3	3448.7	4776.2	2620.0	3596.6	4188.8	4422.5
Total Cost	34541.4	34541.4	38644.6	36993.9	36562.8	38926.7	32629.0	36653.6
Yield (40kg)	21.7	21.7	22.3	21.9	23.0	18.3	16.3	24.0
Marketprice	2938.1	2938.1	2914.3	2930.1	3018.2	2900.0	3176.5	2515.3
Total Revenue	63755.9	63755.9	64988.4	64169.9	69357.1	53157.0	51840.0	60292.5
Net revenue	29214.5	29214.5	26343.8	27176.0	32794.3	14230.3	19211.0	23638.9
BCR	1.9	1.9	1.7	1.7	1.9	1.4	1.6	1.6

Table 4.26 shows the farm budget for sowing one-acre of rice crop in the study area. Net revenue earned by the rice farmers was Rs.26678.82. Variations across the head, middle and tail are also seen in the data in costs, yields and revenues.

Table 4.26: Economic analysis of rice crop(average per acre at study side). All costs are in PKR. Rice is only grown in the head and middle areas of SBA so no data is provided for the tail or for Naushahro Feroz

Rice	**SBA**		
	Head	Middle	Overall
Cropped area (acres)	365.00	161.00	526.00
Proportion of acre under rice crop (%)	69	31	100
Ploughing (No.)	4.30	4.25	4.29
Seed rate (kg)	11.57	9.98	11.08
No. of bags of fertilizer	3.19	3.49	3.29
No. of chemicals	2.56	2.86	2.65
No. of groundwater applications	0.00	1.28	1.28
No. of surface water applications	17.05	18.54	17.79
Land preparation cost	5083.70	5635.40	5252.57
Sowing cost	3000.85	3449.19	3138.08
Fertilizer cost	11431.96	4459.01	9297.65
Chemical cost	2438.90	2397.52	2426.24
Irrigation cost	2737.81	3797.83	3062.26
Harvesting Cost	2055.34	4962.73	2945.25
Threshing cost	3201.29	3581.37	3317.62
Total Cost	32104.30	30401.37	31583.06
Yield (40kg)	53.35	59.69	56.52
Market price	1134.47	901.24	1063.08
Total Revenue	60545.21	53085.40	58261.88
Net revenue	28440.90	22684.04	26678.82
BCR	1.89	1.75	1.84

Table 4.27 shows the farm budget for sowing one-acre of sugarcane in the study area. Findings indicate that the cost of production incurred by the sugarcane growers in Naushahro Feroze was higher (Rs. 60,347.33) compared to SBA (Rs. 58,514.00). Sugarcane yield obtained in Naushahro Ferozewas 679.00 mds (40 kg) while in SBA the average yield was lower (673.00 mds; 40 kg). Net revenue earned by the sugarcane farmers in Naushahro Feroze(Rs. 46,708.33) was less compared to SBA (Rs. 39,744.00).

Table 4.27: Economic analysis of sugarcane crop (average per acre at study side). All costs are in PKR.

Sugarcane	Naushahro Feroze				SBA			
	Head	Middle	Tail	Overall	Head	Middle	Tail	Overall
Cropped area (acres)	19.0	12.0	12.0	43.0	1246.0	1018.0	67.0	2331.0
Proportion of acre under rice crop (%)	44.0	28.0	28.0	100.0	53.0	44.0	3.0	100.0
Ploughing (No.)	5.6	4.0	3.3	4.5	5.7	6.0	6.5	5.9
Seed rate (kg)	3216.0	3200.0	3400.0	3263.0	3289.0	3288.0	3310.0	3289.0
No. of bags of fertilizer	7.1	7.5	7.3	7.3	8.0	7.5	7.5	7.8
No. of chemicals	2.6	3.3	2.3	2.8	3.5	3.8	3.3	3.5
No. of groundwater applications	29.9	31.2	34.3	31.8	0.0	2.3	29.5	10.6
No. of surface water applications	2.0	2.3	1.8	2.1	29.9	31.2	2.7	21.3
Land preparation cost	8026.0	5500.0	4150.0	6240.0	7316.0	7914.0	8234.0	7603.0
Sowing cost	13958.0	12500.0	15800.0	14065.0	15093.0	16476.0	15546.0	15710.0
Fertilizer cost	15064.0	15617.0	16367.0	15582.0	16360.0	15961.0	15701.0	16167.0
Chemical cost	2297.0	1317.0	983.0	1657.0	1394.0	2608.0	2000.0	1941.0
Irrigation cost	28505.0	27209.0	30209.0	22186.0	755.0	1755.0	27209.0	2041.0
Harvesting Cost	8211.0	8900.0	6667.0	7972.0	11116.0	10414.0	8851.0	10744.0
Total Cost	61785.0	58664.0	60593.0	60347.3	58260.0	57175.0	59379.0	58514.0
Yield	703.0	689.0	645.0	679.0	707.0	584.0	682.0	673.0
Market price/40kg	144.0	148.0	181.0	157.7	151.0	142.0	143.0	146.0
Total Revenue	101232.0	101972.0	116745.0	107055.7	106757.0	82928.0	97526.0	98258.0
Net revenue	39447.0	43308.0	56152.0	46708.3	48497.0	25753.0	38147.0	39744.0
BCR	1.6	1.7	1.9	1.8	1.8	1.5	1.6	1.7

4.9 Resource use efficiency analysis

The results of the input-oriented DEA model are presented in Table 4.28. Results regarding technical efficiency using variable returns to scale (VRS) indicate that farms in the Naushahro Feroze district were 88% efficient and that farms in the SBA district were 57% efficient. There were allocative efficiencies among the Naushahro Feroze (41%) and the SBA (71%) farms in the study area. This indicates that farmers can save some cost by more efficient allocation of inputs and that there is scope for farms from Naushahro Feroze (59%) and SBA (29%) to save costs through optimal allocation of inputs. The estimated mean economic efficiency of Naushahro Feroze and SBA was 57% and 41% respectively.

The sub-vector water use efficiency (WUE) of Naushahro Feroze was 78% and SBA was 67%t. On the basis of the above findings, it is suggested that the farms of both districts could save a significant amount of water and improve water use efficiency with the help of sustainable groundwater management practices and technologies. The results indicate that for both Naushahro Ferozeand SBA farms, the average output could have been obtained by using less water, while keeping other inputs constant. Consequently, if water use efficiency improves, it should be possible to reallocate a proportion of the irrigation to the other water demands, without compromising the production of major crops.

Many studies have found that water use inefficiencies are common in agriculture (Karagiannis et al., 2003; Lilieeld and Asmild, 2007; Speelman et al., 2008; Frija et al., 2009; Ali Chebil et al., 2012). Similarly, a large degree of water use in efficiency has previously been reported among rice and cotton growers in Pakistan (Watto and Mugera, 2014; Watto, 2013; Imran et al., 2019). Thus, it has been observed that sustainable groundwater management practices and technologies can help to improve farm productivity, resource use efficiency and ultimately farm income. A wealth of empirical evidence (Watto, 2013, Zulfiqar et al., 2017; Abedullah et al., 2006; Hussain et al., 1999; Watto and Mugera, 2014; Imran et al. 2019) shows that technical and economic inefficiencies are common among the rice and cotton growers in Pakistan.

Table 4.28: Economic analysis of Naushahro Ferozeand SBA (per farm percentage)

		Naushahro Feroze	SBA
Head	Technical Efficiency (VRS)	0.80	0.75
	Water Use Efficiency	0.64	0.82
	Scale Efficiency	0.83	0.82
	Economics Efficiency	0.44	0.29
	Allocative Efficiency	0.56	0.39
Middle	Technical Efficiency (VRS)	0.79	0.63
	Water Use Efficiency	0.65	0.62
	Scale Efficiency	0.85	0.68
	Economics Efficiency	0.44	0.45
	Allocative Efficiency	0.56	0.63
Tail	Technical Efficiency (VRS)	0.95	0.74
	Water Use Efficiency	0.86	0.62
	Scale Efficiency	0.88	0.78
	Economics Efficiency	0.48	0.52
	Allocative Efficiency	0.57	0.70
Overall	Technical Efficiency (VRS)	0.88	0.57
	Water Use Efficiency	0.78	0.67
	Scale Efficiency	0.83	0.65
	Economics Efficiency	0.57	0.41
	Allocative Efficiency	0.41	0.71

4.10 Technical, allocative, scale, economic and water use efficiency

This study found that head farms of both districts are technically less efficient than the middle and tail farms. The estimated mean technical efficiency of Naushahro Feroze and SBA head farms was 80% and 75% respectively, which means that a 20% and 25% increase in production is possible with the present state of technology. Additionally, the mean technical efficiency of middle and tail farms of Naushahro Feroze district was 79% and 84% respectively. While, in case of the SBA district it was 63% and 74%, respectively. Therefore, the majority of the middle farms of each district, were either technically inefficient or had scale inefficiencies or both.

4.10.1 Efficiency Estimates for head reach farms

Efficiency estimates for farms located on the head reaches of systems are shown in Table 4.29. Technical efficiency of most (48) farms from the Naushahro Feroze district ranged between 70-79% and the technical efficiency of the majority (38) of farms ranged between 30-39%. Scale efficiency ranged from 30-39% for most (43) farms. Most farms (43 farms) were found to be economically efficient, ranging between 60-69% efficiency. Likewise, the majority (49) of farms were found to have allocative efficiency between 60-69%. The results from the SBA district indicate that most (45) farms were technically efficient ranging between 70-79%. Likewise, for the majority of farms (47) water use efficiency ranged between 70-79%. Scale efficiency ranged between 70-79% for 35 farms. Similarly, 34 farms were found to be economically efficient ranging between 70-

79%. Many farms (35) were observed to have 100% allocative efficiency. Overall, a smaller number of farms were observed as efficient in the head reach of the system.

Table 4.29: Frequency distribution of technical, economic and water use efficiency of head farms assuming variables return to scale (VRS) (percentage) Technical efficiency=TE, Water use efficiency=WUE, Scale efficiency=SE, Economic efficiency=EE and Allocative efficiency=AE.

Efficiency (%)	Naushahro Feroze					SBA				
	TE	WUE	SE	EE	AE	TE	WUE	SE	EE	AE
100	13	21	16	34	31	24	22	27	29	35
90-99	15	18	23	24	41	18	16	24	21	22
80-89	25	32	24	27	24	34	44	24	32	21
70-79	48	30	32	33	21	45	47	35	34	21
60-69	32	22	33	43	49	15	23	19	15	26
50-59	35	32	12	23	32	9	1	15	13	15
40-49	29	30	34	33	8	3	0	9	8	11
30-39	23	38	43	21	24	3	0	0	1	2
Below-30	18	15	21	0	8	2	0	0	0	0

4.10.1 Efficiency Estimates for middle reach farms

Efficiency estimates for farms located on middle reaches of the system are portrayed in Table 4.30. Results for the SBA district show that most farms (23) were technically efficient with efficiencies ranging between 90-99%. Likewise, 28 farms were found to be using water 100% efficiently. 23 farms ranged between 60-69% for scale efficiency. 23 farms were found to be economically efficient ranging between 70-79%. Most farms (26) were allocatively efficient, ranging between 80-89%. In the Naushahro Feroze district, most farms (33) were technically efficient and ranged between 60-69%. Likewise, for water use efficiency, 25 farms had 100% efficiency. 15 farms ranged between 70-79% for scale efficiency. Most farms (28) were found to be economically efficient, ranging between 70-79%. Likewise, the majority of farms (36) had 100% allocative efficiency. Overall, fewer farms were observed to be efficient in the middle reaches of the systems.

Table 4.30: frequency distribution of technical, economic and water use efficiency of middle farms assuming variables return to scale (VRS) (percentage). Technical efficiency=TE, Water use efficiency=WUE, Scale efficiency=SE, Economic efficiency=EE and Allocative efficiency=AE.

Efficiency (%)	Naushahro Feroze					SBA				
	TE	WUE	SE	EE	AE	TE	WUE	SE	EE	AE
100	13	25	19	23	36	22	28	19	13	23
90-99	15	7	23	24	13	23	5	21	19	17
80-89	23	8	16	17	23	16	7	12	18	26
70-79	21	14	15	28	24	19	6	15	23	20
60-69	33	17	12	24	12	12	16	23	12	12
50-59	12	24	16	4	7	8	31	12	23	9
40-49	4	18	14	3	6	7	8	7	8	12
30-39	3	3	12	7	4	10	8	8	8	6
Below-30	6	14	3	0	5	13	20	13	6	5

4.10.2 Efficiency Estimates for tail reach farms

Efficiency estimates for farms located on the tail of the irrigation systems are portrayed in Table 4.31. Results for the Naushahro Feroze district for show that the technical efficiency of most farms (30) ranged between 70-79%. Water use efficiency for most farms (86) ranged between 80-89%. Scale efficiency was between 90-99% for 28 farms. Similarly, most farms (45) were found to be economically efficient with efficiency ranging from 80-89%. Likewise, allocative efficient for most farms (36) ranged between 60-69%.

Results for the SBA district show that that the majority of farms (36) were technically efficient with efficiency ranging between 60-69%. for the water use efficiency of 26 farms ranged between 40-49%. Scale efficiency ranged between 90-99% for 34 farms. Most farms (36) farms were found to be economically efficient with efficiency ranging between 70-79%. Most farms (26) had 50-59%allocative efficiency. Overall, fewer farms were as efficient in the tail reach of the system.

Table 4.31: frequency distribution of technical, economic and water use efficiency of tail farms assuming variables return to scale (VRS) (percentage). Technical efficiency=TE, Water use efficiency=WUE, Scale efficiency=SE, Economic efficiency=EE and Allocative efficiency=AE

Efficiency (%)	Naushahro Feroze					SBA				
	TE	WUE	SE	EE	AE	TE	WUE	SE	EE	AE
100	24	20	22	23	33	12	22	19	16	15
90-99	24	29	28	24	23	16	5	34	22	18
80-89	22	86	26	45	34	22	8	23	21	16
70-79	30	46	23	33	35	21	18	25	36	13
60-69	25	0	23	3	36	36	19	14	20	24
50-59	15	0	16	21	20	20	24	13	17	26
40-49	23	0	12	0	0	17	26	6	12	19
30-39	6	0	13	0	0	0	13	9	0	10
Below-30	12	0	18	0	0	0	9	1	0	3

4.11 Econometrics analysis

The descriptive statistics for the variables used in the regression analysis of Probit models for estimating farmers' adoption of water saving technologies in the study area are given in Table C1 in Appendix C.

The probit regression results for the head areas are provided in Table 4.32. A significant positive relationship was found between age and adoption of laser land leveling, but in the case of adoption of furrow irrigation methods there is a significant negative relationship with age. This explains why the use of laser land levelling is more common than furrow irrigation in the study areas. There was also a positive significant relationship between livestock income and the adoption of laser land leveling. It may be trickle down impact of higher earnings from livestock and farmers have more income therefore they invest to adapt laser land levelers. This shows that farmers who have a higher proportion of livestock income are more likely to use the laser land levelling. The results show that market support price of ridge making machine and adoption of furrow irrigation method have a positive significant relationship in head areas.

The results from the probit model results for the middle areas of the system (Table 4.33) show that there is a significant negative relationship between livestock income and the adoption of both laser land leveling and high efficiency irrigation technologies. This may be explained by the fact that in areas where there are more water shortages, farmers mostly depend on livestock for their livelihoods and thus, the income generated from livestock is higher and investment in high efficiency and water saving technology is less. There is also a significant positive relationship between the availability of credit and adoption of high efficiency irrigation technologies. In middle areas, as family size increases, adoption of laser land leveling also increases. Results also indicate that there is a positive and significant relationship between family size and adoption of laser land levelling.

There is also positive and significant relationship between drought resistant varieties and the adoption of high efficiency irrigation technologies. It highlights that farmers who are cultivating disease resistant varieties are also adopting HIES for to achieve better yields.

The probit regression model estimates for adoption of water saving technologies in the tail regions are shown in Table 4.34. The results highlight that tractor ownership has positive impact on adoption of furrow irrigation and that market support price also has a positive impact on adoption of furrow irrigation.

*Table 4.32: Estimates of the probit regression model for adoption of water saving technologies in the head region.HEIS=high efficiency irrigation systems*** denotes significant at 1%, **denotes significant at 5%, *denotes significant at 10%*

Variables	Furrow		HEIS		Laser leveling	
	Coef.	SE	Coef.	SE	Coef.	SE
Age	-2.675**	1.219	0.349	0.726	6.612***	2.197
Farming Experience	0.280	0.425	0.309	0.284	-0.990*	0.551
Family Size	0.615	0.454	0.014	0.399	0.481	0.640
Schooling	-0.583	0.315	-0.091	0.198	0.390	0.403
Groundwater quality	0.330	0.505	-0.564	0.358	-0.204	0.701
Land tenure ship	0.224	0.499	-0.343	0.351	-0.483	0.710
Tube well ownership	0.068	0.564	-0.020	0.406	-0.799	0.797
Training by extension	-0.626	0.978	-0.027	0.782	-0.638	1.252
Access to credit service	0.605	0.435	-0.087	0.352	-1.588**	0.799
Livestock income	-0.195***	0.063	-0.029	0.029	0.330***	0.117
Operational holding	-0.563**	0.287	-0.116	0.176	0.934**	0.389
Salt tolerant varieties	0.261	0.164	0.311**	0.139	0.141	0.241
Drought resistant varieties	0.151	0.161	-0.112	0.126	-0.349	0.268
Market support price	0.430***	0.153	-0.182	0.121	-0.327	0.233
Sowing date	0.174	0.138	0.128	0.116	-0.508**	0.241
Tractor	1.242***	0.423	-0.160	0.323	-1.755***	0.633
Labor workdays	0.515	0.363	-0.643**	0.332	-0.963*	0.508
Intercept	6.230	4.791	3.910	3.072	-21.154***	8.120
Observations	*150*		*150*		*150*	
LR Chi^2 (17)	*73.11*		*19.07*		*66.18*	
χ^2	*0.000*		*0.324*		*0.000*	
Log likelihood	*-29.393*		*-49.365*		*-17.831*	
Pseudo R^2	*0.554*		*0.162*		*0.645*	

*Table 4.33: Probit regression model estimates for adoption of water saving technologies in the middle region. Note: *** denotes significant at 1%, ** denotes significant at 5%, * denotes significant at 10%*

Variables	Furrow		HEIS		Laser leveling	
	Coef.	SE	Coef.	Coef.	SE	Coef.
Age	0.627	0.867	0.635	0.652	-0.892	0.788
Farming Experience	-0.136	0.376	-0.206	0.276	-0.330	0.331
Family Size	-1.176***	0.354	-0.007	0.272	0.882***	0.330
Schooling	0.038	0.206	-0.237	0.170	-0.190	0.197
Groundwater quality	0.452	0.333	-0.132	0.259	-0.542*	0.334
Tube well ownership	0.362	0.539	-0.078	0.357	0.183	0.467
Training by extension	-0.253	0.509	0.108	0.443	0.091	0.444
Access to credit service	-0.495	0.338	0.479*	0.271	0.166	0.312
Livestock income	-0.126***	0.049	-0.065***	0.027	0.073*	0.041
Operational holding	-0.404*	0.242	-0.146	0.159	0.201	0.223
Salt tolerant varieties	-0.073	0.113	-0.021	0.094	0.208**	0.107
Drought resistant varieties	-0.032	0.123	0.308***	0.102	0.091	0.119
Market support price	0.323	0.137	-0.183**	0.096	-0.167	0.130
Sowing date	0.104	0.109	-0.066	0.081	-0.180*	0.102
Labor workdays	-0.003	0.002	0.004**	0.002	0.000	0.002
Tractor	0.845	0.340	-0.508*	0.303	-0.837**	0.357
Intercept	2.803	3.171	-0.254	2.409	1.215	2.877
Observations	*150*		*150*		*150*	
LR Chi^2 *(16)*	*72.54*		*41.76*		*42.04*	
χ^2	*0.000*		*0.000*		*0.000*	
Log likelihood	*-47.525*		*-76.542*		*-51.183*	
Pseudo R^2	*0.433*		*0.214*		*0.291*	

*Table 4.34: Probit regression model estimates for adoption of water saving technologies in the tail region. *** denotes significant at 1%, ** denotes significant at 5%, * denotes significant at 10%*

Variables	Furrow		HEIS		Laser leveling	
	Coef.	SE	Coef.	SE	Coef.	SE
Age	-0.155	0.816	0.165	0.498	-1.032	1.008
Farming experience	0.177	0.442	0.046	0.243	-0.499	0.509
Family size	0.221	0.557	0.196	0.354	0.343	0.667
Schooling	0.230	0.284	0.091	0.192	-0.022	0.384
Tube well ownership	-0.127	0.608	-0.713**	0.365	0.242	0.904
Access to credit service	-0.409	0.492	0.506	0.329	-0.661	0.768
Livestock income	-0.089**	0.045	-0.009	0.023	0.039	0.053
Operational holding	-0.678**	0.298	-0.142	0.134	0.171	0.314
Salt tolerant varieties	0.056	0.134	0.103	0.098	0.112	0.183
Drought resistant varieties	0.078	0.146	-0.139	0.098	-0.301	0.229
Market support price	0.446***	0.170	-0.161*	0.086	-0.367*	0.226
Sowing date	-0.003	0.119	0.162**	0.080	0.126	0.164
Labor workdays	0.001	0.003	-0.002	0.002	-0.002	0.004
Tractor ownership	1.127***	0.404	-0.385	0.275	-1.114*	0.632
Intercept	1.338	3.424	0.596	2.144	3.736	4.276
Observations	*150*		*150*		*150*	
LR Chi^2 (14)	*45.31*		*19.6*		*18.16*	
χ^2	*0.000*		*0.143*		*0.200*	
Log likelihood	*-30.361*		*-71.692*		*-19.208*	
Pseudo R^2	*0.427*		*0.120*		*0.321*	

5 Conclusions and recommendations

The key objectives of this research were to examine socio-economic characteristics of farming communities, groundwater distribution, utilisation and management. This information will fill an important research gap in Sindh, about the socio-economic factors that contribute to groundwater management including groundwater availability and management with reference to head, middle and tail of the minor irrigation systems.

5.1 Conclusions

5.1.1 Water shortage is considered as major issue by farmers

Farmers at both sites ranked shortage of water as first among the issues that they face. High levels of surface water shortage are observed particularly at tail areas of the irrigation systems. This shortage enhances pressure on the groundwater resources leading to over extraction. The number of tube-wells was also significantly higher at the tail areas of the minors as compared to head areas. Dependence of tail areas farmers on groundwater resources is very high as 60 to 75% of those farmers surveyed depend on tube-wells for irrigation. At head, middle and tail reaches of the Naushahro Feroze district,the allocated timing of canal water was 9.32, 12.37 and 20.47 minutes per acre respectively. Likewise, in SBA district, farmers indicated that in the head, middle and tail reaches the allocated time was 7.97, 11.13 and 15.29 minutes to fill per acre respectively. Although time allocated at tail areas is more compared to head and middle areas, the farmers at the tail end of the system are getting less water because the allocated time for extraction starts when water starts to flow from the water course. In tail areas, the distance between farm and watercourse is greater therefore water takes more time to reach farm. Additionally, in head areas water flow is higher than in tail areas.

5.1.2 Unequal distribution and mismanagement of irrigation water

Data from the current research also revealed that the distribution of canal water across the head, middle and tail of the systems is unequal. This can be an important cause of mismanagement of water. At the head, the percentage of canal water usage is significantly higher than the tail areas. We observed that canal water used at head of both systems ranges from 68% to 90 % for wheat crops and in comparison, to that, for the same crop at the tail areas, use of canal water is just 30% to 26%. This finding was not only in wheat crops. Overall, in tail areas, the use of groundwater is significantly higher (69% to 73%). At head areas of both research sites, 73% of respondents in Naushahro Feroze and 64% of respondents in SBA use canal water for irrigation. In both areas, farms from the tail depend on tube-well water for irrigation as reported by 59% of respondents in Naushahro Feroze and 83% in SBA.

5.1.3 Increased irrigation costs

Data also shows that the per acre average irrigation cost incurred by the farmers at the tails of both systems (Rs. 6,391.81) is 100% higher than the same per acre average irrigation cost incurred by the farmers at the head of both systems (Rs. 3,264.07). Similar trends are observed for other crops. This increased irrigation cost at tail areas is due to higher dependence on groundwater. Groundwater levels are decreasing day by day and the extraction cost is increasing accordingly. Moreover, tail area farmers mostly purchase diesel and lubricants on credit which results in higher costs compared to head farmers who purchase diesel and lubricants with cash.

5.1.4 Prevailing irrigation practices enhance mismanagement of water

Irrigation practices also play a significant role in groundwater and surface water management. Results of the current study show that the majority of farmers use flood irrigation at both research sites. In head areas of both systems, flood irrigation was used to irrigate on average 8 to 15 acres of land. In comparison, furrow irrigation was used on a significantly smaller area (0.9 to

4.8 average acres). Similarly, at the middle of both systems, 9 to 11 average acres of land were irrigated by flood irrigation and only 0 to 1.89 average acres were irrigated by furrow irrigation. This shows that flood irrigation is a common practice in research areas. Literature suggests that due to the poor water efficiency, flood irrigation is an important factor contributing to the mismanagement of available water for irrigation(Qureshi et al*.,* 2016).

5.1.5 Lack of training and awareness

Training plays a significant role in capacity building for farmers in relation to efficient use of the limited water resources and creates awareness regarding the impacts of mismanagement of irrigation water. Training opportunities to increase awareness about water management options and better ways to use the available limited resources of water, were very low at research sites, as 70 to 80%of farmers had not had the opportunity to access training.

5.1.6 Livestock can be used to reduce pressure on water resources

The results of our study have also revealed that in those areas where there is a shortage of both surface and groundwater, **livestock can be a good alternative** to earn income and **reduce pressure on scarce water resources.** This is especially true where farmers can fetch better prices for livestock, dairy and livestock products. Data from the current study reveals that due to a shortage of irrigation water and the high cost of irrigation, farmers in tail areas depend on livestock as an alternate source of income. In spite of getting better milk production, the farmers of tail areas are earning less income. It was observed in the data of SBA that the average number of milking animals owned at tail areas is higher (2.68) as compared to head (1.39) and middle areas (0.23) and per day average milk production is also higher at tail area (23.75 litres) as compared to mid area (16.05 litres) and at head area (18.66). In spite of the fact that farmers from tail areas own higher numbers of milking animals and are getting higher average per day milk production, they are earning less average monthly income from selling milk This occurs primarily because tail farmers sell milk mostly to local shopkeepers in the village to avoid high transport costs to markets Therefore, they receive a lower price for milk as compared to farmers at head and middle areas, who mostly sell milk in nearest local markets at comparatively higher prices.

5.1.7 Higher gross margin per cubic meter irrigation

Data revealed that a higher gross margin per cubic meter of irrigation water was earned by the wheat growers at head and middle sections as compared to tail farmers. This was also the case for cotton and rice crops in both districts. This may be because of relatively high irrigation costs incurred by the farmers at tail areas.

5.2 Recommendations

Based on the results from this study we present the following recommendations:

1. Significant differences in the availability of canal water between the head, middle and tail areas of the irrigation systems were observed in the data. Farmers from the head and the middle areas have greater availability of canal water than tail farmers at the tail end of the systems. This leads to pressure on groundwater resources, degradation of quality and quantity of groundwater, and, because groundwater is markedly more expensive than canal water, decreasing incomes from farming due to higher cost of production at the tail end of the systems. If canal water was equitably distributed along the length of the irrigation systems, farmers in head and middle sections may be more receptive to adopting practices that lead to improved water efficiency to avoid having to use expensive, poor quality groundwater. Therefore, it is recommended that the government should create a policy to ensure equal distribution of canal water across the different parts of the irrigation systems. This policy will help to enhance sustainable use of groundwater resources by reducing the number of tube-wells installed and avoiding extra use of tube-wells that can lower the groundwater tables.

2. In consideration of the greater distance between farm and water course in tail sections, the government could increase the allocated time for accessing canal water by tail-end farmers. Head reach farmers are using more canal water, therefore measures should be taken to reduce that extra use.
3. Efficient and implementable policy measures are essential to reduce the burden of higher cost of production experienced by the tail area farmers, due to significantly high dependence on ground water resources.
4. Training for farmers should be conducted to reduce the use of flood irrigation introduce and to enhance the use of furrow irrigation and other water-efficient methods of irrigation. Flood irrigation is commonly used as irrigation method in Sindh and results in inefficient water use and low water productivity.
5. Livestock rearing can be a profitable and alternate income generating source of rural people. Diversification in livelihoods in rural areas of Sindh should be considered for reducing mismanagement and pressure on water resources.
6. Suitable (better) varieties of the major crops should be considered as options for adapting to saline-affected and water-logged areas as well as to increase the crop productivity.

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Appendix A: Research sites for PRAs

Table A.1: Research sites for PRAs

S. No.	Name of site/minor	District	Selection Criteria	Features
1	Gul Minor	Naushero Feroz	Conjunctive use of surface and groundwater, usable groundwater	DTW = 3-6 meter GWQ= Useable (0-1500 ppm)
2	Nather Detha	Naushero Feroz	Conjunctive use, having shallow with marginal quality of groundwater	DTW = 1.5-3.0 meter GWQ= 0-1500 ppm & 1500-3000 ppm
3	Chiho Minor (preferred)	Naushero Feroz	Utilizing lot of groundwater in conjunction with surface water with usable quality of groundwater, MDF-NGO has done already some work in this area, easy data availability	DTW = 1.5-3.0 meter GWQ= 0-1500 ppm Wheat, sugarcane, cotton, maize. The farmers of Chiho village in coordination with SID are managing Chiho minor.
4	Tetri Minor (optional)	Naushero Feroz	Utilizing lot of groundwater in conjunction with surface water with marginal quality of groundwater, MDF-NGO has done already some work in this area, data availability	DTW = 3.0-6.0 meter GWQ= 1500-3000 ppm Wheat, sugarcane, cotton, maize. The farmers in coordination with SID are managing Tetri minor.
5	Chanari (optional)	Naushero Feroz	Utilizing lot of groundwater in conjunction with surface water with marginal quality of groundwater, MDF-NGO has done already some work in this area, data availability	DTW = 1.5-3.0 meter GWQ= 1500-3000 ppm Wheat, sugarcane, cotton, maize. The farmers in coordination with SID are managing Chanari minor.
6	Sarkand	SBA	Useable quality of groundwater with easy access from National Highway. MUET is going to start some research work in this area by Master's student	DTW = 3-6 Meter GWQ = 0-1500 ppm Design discharge 63 Cusecs Off-taking from Rain Distry (RD40). GCA=3,261 Acres CCA=11,612
7	Village = Allah Bux Purely on solar based groundwater pumping	SBA	Area with Useable groundwater quality, purely on groundwater using solar pumping, along the Rohri Canal, not having sufficient surface water availability due to tail-end	Already visited during previous field visit to SBA. Farmers are growing sugarcane, wheat, etc Lift irrigation system
8	Malwa Minor or any other minor from Malwa Distry covering tail-end	SBA	Deep water table with marginal groundwater quality	DTW = 6-10.8 Meter GWQ = Marginal (1500-3000 ppm)
9	Manhoro Minor	SBA	Left side of Rohri Canal Mainly waterlogged area with useable quality of groundwater	DTW = 0-3.0 Meter GWQ = Useable (0-1500 ppm) It is at the border of Naushahro Feroze and SBA (Benazirabad)

Appendix B: Gross margins per unit of water for the major crops

Table B.1: Estimates of gross margins per unit of water used in Sindh

	Naushahro Feroze			SBA		
	Head	Middle	Tail	Head	Middle	Tail
Wheat						
Gross Margin (PKR/acre)	43,903.06	44,835.41	41,611.73	46,745.33	42,287.98	45,885.54
Volume (m^3/acre)	2,146.00	2,564.00	2,738.00	2,043.00	2,369.00	2,847.00
PKR per m^3	20.46	17.49	15.20	22.88	17.85	16.12
Cotton						
Gross Margin (PKR/acre)	63,755.90	63,755.90	64,988.44	69,357.09	53,157.00	51,839.99
Volume (m^3/acre)	2,334.00	2,624.00	2,917.00	2,038.00	2,610.00	3,042.00
PKR per m^3	27.32	24.30	22.28	34.03	20.37	17.04
Rice						
Gross Margin (PKR/acre)	-	-	-	60,545.21	53,085.40	-
Volume (m^3/acre)	-	-	-	3,218	3,439	-
PKR per m^3	-	-	-	18.814546	15.43629	-
Sugarcane						
Gross Margin (PKR/acre)	101,232.00	101,972.00	116,745.00	106,757.00	82,928.00	97,526.00
Volume (m^3/acre)	5,987.00	6,123.00	6,262.00	4,480.00	4,765.00	6,114.00
PKR per m^3	16.91	16.65	18.64	23.83	17.40	15.95

Appendix C: Regression variables

Table C.1: Statistics of variables used for regression analysis

Variables	Type	Mean	SD	Min	Max
Furrow acre	Binary	0.89	0.32	0	1
HEIS	Binary	0.77	0.42	0	1
Water saving technologies	Binary	0.05	0.21	0	1
Age	Continuous	3.71	0.24	2.83	4.32
Farming experience	Continuous	2.83	0.60	0.69	3.56
Family size	Continuous	2.33	0.38	1.61	3.56
Schooling	Continuous	1.58	0.79	0.41	2.77
Operational holding	Continuous	31.73	29.86	1.5	160
Labor workdays	Continuous	134.48	65.06	0	408
Livestock Income	Continuous	32072.23	56976.64	0	500000
Tube well ownership	Binary	0.17	0.38	0	1
Tractor Ownership	Binary	0.64	0.48	0	1
Groundwater perception	Binary	0.34	0.48	0	1
Access to credit	Binary	0.29	0.46	0	1
Training by extension	Binary	0.03	0.16	0	1
Salt tolerant varieties	Scale	2.31	1.31	1	5
Drought resistant varieties	Scale	2.79	1.31	1	5
Market support price	Scale	3.07	1.48	1	5
Sowing date	Scale	2.87	1.72	1	5


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