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Representative agricultural pathways and socioeconomic benefits of groundwater management interventions in Punjab, Sindh and Balochistan Provinces, Pakistan

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Contents

Tables

Figures

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1 Executive Summary

This report describes three cases of using Representative Agricultural Pathways (RAPs) to explore approaches for enhancing farmer livelihoods in Punjab, Sindh and Balochistan provinces in Pakistan. The cases were part of ACIAR Project LWR/2015/036 *Improving Groundwater Management to enhance Agriculture and Farming Livelihoods in Pakistan*.

Agriculture plays an important role in global food security, and water is one of its key resources. Sustainable use of water resources is an important policy objective as set out in the National Water Policy (2018) and the Punjab Water Policy (2020). Formulation and implementation of surface and groundwater laws are linked with adoption of water conservation practices. Pakistan's farming landscapes are complex and varied in terms of water availability, distribution, quality and quantity. On-farm management practices, such as soil management, the use of fertilizer, laser levelling, irrigation methods and the selection of crops contribute in terms of water use efficiency, soil health improvement and water quality impacts. Identifying pathways to move on-farm management towards more sustainable water management is essential for the future of Pakistan.

RAPs are designed to extend global pathways to provide the detail needed for regional assessment of future agricultural systems. RAPs are formulated under the consideration of representative concentration pathways and shared socioeconomic pathways. "RAPs" are combinations of economic, technology and policy scenarios that represent a plausible range of possible futures

The RAPs framework is developed on the premise that both bio-physical and socioeconomic drivers are essential components of agricultural pathways. The RAPs methodology is based on capturing plausible farm-level improvements, such as climate change and water scarcity that affect the future of farming operations. The RAPs process relies on input from a cross section of stakeholders. RAPs are generated from a continuous engagement process among stakeholders; farmers, policymakers, academia, researchers and project team members that helps to formulate the transformative adaptation and future pathways. The iterative engagement formulates the linkages between potential stakeholders to learn about the specific critical issues. Their information is used to consider the biophysical, socioeconomic, institutional and policy related indicators. The management of groundwater is linked with existing water scenarios of the area especially water quality, availability and usage.

The RAPs process involves developing adaptations, discussion, and analysis. In this project, focus was on improved on-farm water management and poverty reduction through increased water productivity. In all three cases for this project the adaptation package was developed and parameterized from the consultation session and existing literature.

Selected adaptations were assessed with the Trade-off Analysis Model for Multi-Dimensional Impact Assessment (TOA-MD Model). This is a unique simulation tool that can use the socioeconomic data sets collected earlier in the overall project and combine them further with macroeconomic data sets of farms and then project the current and future viability of specific policy interventions proposed in research studies. In this project the model simulated various "experiments" for adaptation of new technology/interventions to estimate the impact.

Punjab

The TOA-MD model estimated the adoption rate of proposed adaptation based on net farm returns. The impact of High Efficiency Irrigation Systems (HEIS) and substitution of high delta crops with low delta crops had positive impact on net farm returns, per capita income and negative impact on farm poverty in the study area.

Results indicated that without adaptation, poverty was 17.72 percent for the survey data, whereas with interventions poverty rate would reduce by 3.6 and 3.4 percent for scenario 1 and 2 respectively. The adoption rate for sunflower and moong bean would be 49 percent and 59 percent, respectively. Results showed that proposed interventions such as crop substitution have a significant impact on farm livelihoods.

With proposed intervention of HEIS (through technology and management), there would be 23 percent decrease in poverty among small farmers and 30 percent increase in per capita income. The adoption rate of this adaptation package is 74 percent and this adoption results in the reduction of farm poverty.

Farmers are important stakeholders in control of many management interventions regarding ground and surface water. It is recommended that the policy formulation should consider and consult farmer representatives about agricultural and water related issues so that all policies can be co-ordinated. Nature based solutions are best and all the policies must be formulated for specific zones. The areas with water scarcity must be highlighted and serious efforts should be made to implement the suggested interventions.

For the upscaling of the interventions, it is recommended that the current work should be continued in the study area and other agro-ecological zones of Punjab, where the majority of farmers are resource poor, water is scarce, and poverty is high. Solving issues of communities by involving them is very important and RAPs is a novel approach to provide the solutions for critical issues and subsequently to assess the impact on livelihoods by the implemented interventions.

Sindh

Sindh and Punjab are the main provinces that contribute significantly to agricultural production and food security in Pakistan. Sindh province has potential to support intensive agriculture due to fertile soil and availability of farm labour but water is a limiting factor that hinders the growth of the agricultural sector. Currently, major cash crops, especially high water use (high delta) crops, are dominant due to established markets and processing infrastructure that ensure farm income. However, these crops are of serious concern for sustainable farming practices in the long run due to exploitation of groundwater and natural resource degradation.

To increase water productivity, important adaptations proposed are HEIS, drought resistant crop varieties, substitution of water intensive crops with less water demanding crops, mulching of soil, zero tillage and all on farm operations that can save water especially groundwater.

This interdisciplinary research process brings a holistic approach towards development pathways and adaptations at farm level. The explicit interventions shared for the study area regarding water management interventions at farm includes HEIS (ridge and bed sowing, drip and sprinkler), substitution of crops (low delta crops like Quinoa), developing the water markets, enterprise diversification (livestock farming, olericulture, fisheries, agro-forestry), crop diversification (vegetables like onion, okra, chilies, black pepper), intercropping (sugarcane and wheat; okra and onion), cultivation of high value crops and tree plantations.

The economic viability for HEIS for cash crops in the study area was estimated and results showed that water saving techniques like drip, sprinkler and bed and furrow would ensure farm returns in the long run. The water use efficiency improvement would increase the crop yields and farm returns substantially in the study area.

Balochistan

The Balochistan province is largely dependent on groundwater for its water requirements either through traditional Karezes or tubewells. The number of tubewells has increased from 5,000 to more than 40,000 since the 1970s, with groundwater levels dropping 5 meters per year in some basins. Groundwater management and reclamation could be improved by social engagement and public sector legislation. The policy domain regarding groundwater is crucial as tubewells and Karezes are two main sources for irrigation in Balochistan. It is the only province that has implemented a legal framework regarding groundwater management under the notification of the "Balochistan groundwater rights administration ordinance, 1978" and WASA Groundwater Management Act of 1989.

Pakistan is facing serious threats to food security due to climate change. Balochistan could be the leading province in terms of fruit production but due to the lack of good cultivars, proper marketing and poor infrastructure its agricultural production is not increasing substantially. Karezes and tubewells are important for the sustainable socioeconomic development of farming communities. The results indicated that farmers must adopt sustainable practices regarding groundwater extraction and recharge.

This study used data collected from Kuchlak and Pishin sub-basins of Pishin Lora basin to assess the socioeconomic impacts of groundwater management interventions. Primary and secondary data were utilized to identify the economic viability of suggested management interventions and analysed in TOA-MD model to access the economic viability of suggested interventions.

The main interventions suggested by Balochistan stakeholders are listed below.

- HEIS -Drip and sprinkler
- Low delta crops like pistachio, grapes and pomegranate instead of apple production
- Improvement in the management of existing orchards, for example weed management and plant density.
- Check bunds for water storage
- Dwarf varieties of apples, and tunnel farming.

The economics analysis for the adoption of HEIS using the TOA-MD model predicted the net farm returns, per capita income and farm poverty for the mid-century scenario (2050). The installation of this infrastructure would ensure efficient water use and increase in the net farm returns substantially. The farm poverty would reduce by 4 and 12 percent in the study area for the mid-century scenario.

2 General Introduction

This report describes three cases of using Representative Agricultural Pathways (RAPs) to explore approaches for enhancing farmer livelihoods in Punjab, Balochistan and Sindh. The cases were part of ACIAR Project LWR/2015/036 *Improving Groundwater Management to enhance Agriculture and Farming Livelihoods in Pakistan* (Punthakey et al. 2021).

2.1 Background

Agricultural production systems are complex, interlinked and play a vital role in global food security. Groundwater utilisation is an important policy domain in developing nations due to its role in achieving food security and sustainable farming livelihoods. This is particularly so in Pakistan, where irrigation plays an important role in food and fibre crops production as 90 percent of food and 100 percent of cash crops are directly dependent on irrigation (Yang et al., 2018). The use of ground and surface water resources must be used in an efficient manner (Ringler and Anwar, 2013). Intergenerational and intragenerational equity at farm resources are also important in terms of sustainable development (Fanzo et al., 2020).

Responding to calls for reform of policies regarding water and land use to ensure sustainable agricultural production in Pakistan (see, for example, Galindo et al., 2018), the sustainable use of water resources is set out in recent Policy documents such as the National Water Policy (2018) and the Punjab Water Policy (2020). The Federal National Water Policy in 2018 includes the concept of 'more crop from each drop', that is, increased water use efficiency, and encourages efficient water management on-farm. The policy also emphasises prioritising modernisation of the irrigation network, participatory irrigation management systems, use of bio-fertilizer and bio-pesticides, efficient water pricing and the use of salt tolerant crops.

Agriculture in Pakistan relies heavily on the Indus Basin, which is facing severe water scarcity conditions due to climate change. Wheat, maize, rice and sugarcane are important food crops in Pakistan and also play a vital role in food security (Ulian et al., 2020). Poor irrigation practices and lack of policy reforms are major threats for water and food security of Pakistan (Muzammil et al., 2020). Overutilisation of water creates complex problems such as waterlogging and salinisation and results in depletion of groundwater resources. There are both farm and policy level adaptations that can sustain farm income while improving water management. At the farm/irrigation system level this includes improving water productivity through re-allocation of water to higher value crops and/or those with limited irrigation requirement, and efficient use of groundwater. Policy considerations include spatial re-allocation and transfer of water and adopting policies that favour development of water markets (Culas and Baig, 2020).

This research was designed to analyse the policy impacts at the population level. The research findings could be further utilised in socioeconomic models to analyse their potential prospects at the farm level and on farmers livelihoods (Nasir et al*.,* 2020; Bakhsh et al., 2020).

Across the three provinces the aim was to develop options for increased on farm water use efficiency and or water productivity, with the ultimate twin aims of improved livelihood outcomes and improved groundwater. The exact adaptations vary across the different case studies, but in general to increase water productivity the adaptations proposed are high efficiency irrigation systems (HEIS), drought resistant plant varieties, substitution of water intensive crops with less water demanding crops (that is, substitute low delta crops for current high delta crops), protecting soil with vegetative matter, as variously described by Evans et al., (2013); Hu, and Xiong, (2014); Davis et al., (2017); Kader et al., (2019) and Ali et al., (2017). This approach, described in these three studies, specifically accesses the policy options, adoption rate and its socioeconomic impacts on farming communities, farm production and net farm returns.

2.2 Report structure

The general approach to undertaking the RAPs centred socio-economic study is provided, followed by a detailed report from Punjab, Sindh and Balochistan, including recommendations for the study areas. A general discussion concludes the report. Because the method is an important aspect of this study additional detailed material relating to RAPs events is included in the Appendix.

3 General Methodology

3.1 Representative Agricultural Pathways

RAPs are designed to extend global pathways to provide the detail needed for regional assessment of future agricultural systems. The Inter-Governmental Panel on Climate Change (IPCC) has developed the concept of Representative Concentration Pathway (RCP) to develop an understanding of impacts on the environment, water resources and society. RAPs are based on a trans-disciplinary process for designing pathways and then translating them into parameter sets for bio-physical and economic models. RAPs logically precede the definition of management scenarios that embody associated capabilities and challenges. These are designed to be part of a consistent set of drivers and outcomes from national and local developments. Teams of scientists, experts, researchers and farmers with knowledge of the agricultural systems work together through a step-wise process (Valdivia et al., 2015).

RAPs are formulated under the consideration of representative concentration pathways and shared socioeconomic pathways as described in Figure 3.1.

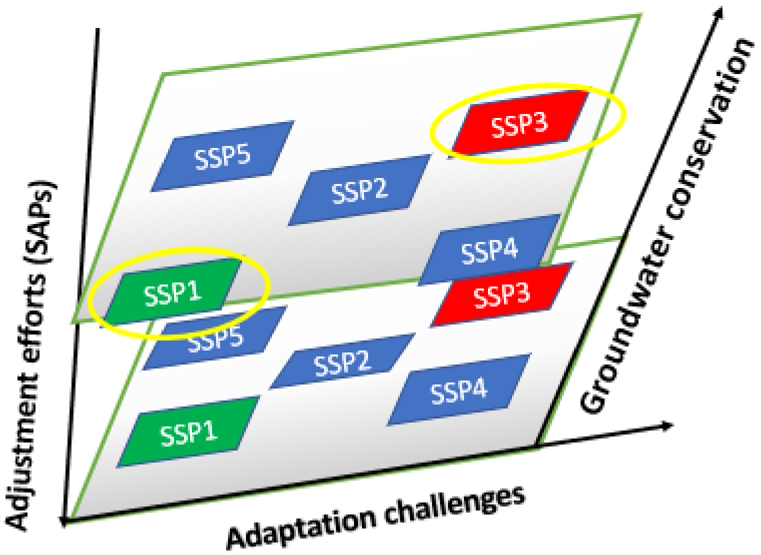


Figure 3.1 Shared socioeconomic pathways and representative concentration pathways. Source: adapted from Piontek et al. (2014).

RAPs are combinations of economic, technology and policy scenarios that represent a plausible range of possible futures. They are not intended as predictions, but rather to provide researchers with a range of plausible scenarios that can be used to simulate possible future outcomes in a consistent and transparent way (O'Neill et al., 2017). The RAPs framework reflects that both bio-physical and socio-economic drivers are essential components of agricultural pathways. RAPs can help engage stakeholders in research throughout the research process and in communication and refinement of research results (Nasir et al., 2019).

Engagement of all the possible stakeholders with agricultural policy formulation enables efficacy and better management of natural resources such as water, soil and air. The formulation of policies in the agricultural sector is interlinked with all sectors of the economy in terms of forward and backward relationships of complex farm economic hierarchy. Research organisations should analyse issues with consultation of farmers and other actors who play an important role in food value chains. The practical implementations of researchers' recommendations in the policy domain would be increased if specific technical aspects in research finding are generalized in simple, non-technical and understandable ways, and communicated with policy makers and other stakeholders (Mukherjee et al., 2020). The agricultural production system and farming livelihoods are as described in Figure 3.2.

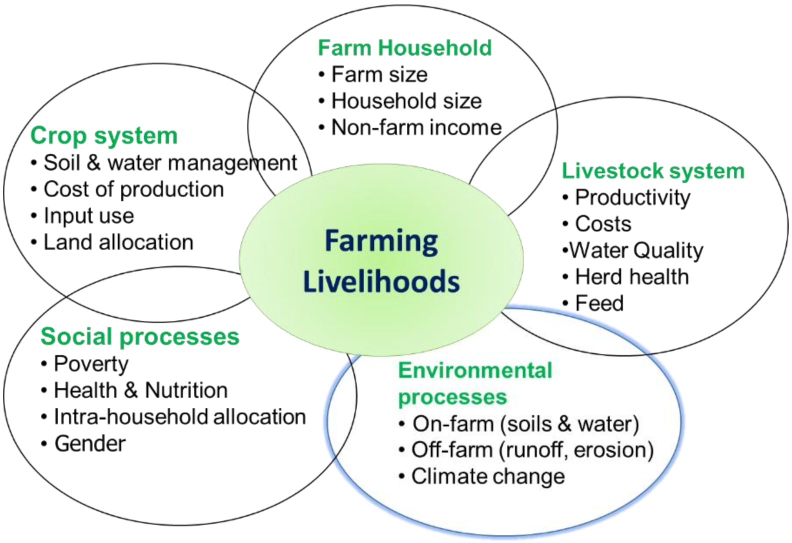


Figure 3.2: The agricultural production system and farming livelihood. (Source: Antle et al., 2015).

There are very few economic models that can be used specifically for policy evaluations. If research is to have impact, its recommendations must have socioeconomic viability, as economic rationality influence the farmers' decisions about the adoption and non-adoption of proposed interventions (Antle and Valdivia, 2011).

The RAPs framework is developed on the premise that both bio-physical and socioeconomic drivers are essential components of agricultural pathways (Valdivia et al., 2015). The RAPs methodology is based on capturing plausible farm-level improvements as climate change and other impacts such as water scarcity affect the future of farming operations. RAPs allow for the development and adoption of new strategies which enhance adaptation mechanism by farming communities through a shared vision which is achieved through a process of continuous engagement and discussions with stakeholders.

The RAPs methodology relies on input from a cross section of stakeholders which is used to project the biophysical, socioeconomic, and institutional and policy related indicators. The impacts of efficient allocation of resources have long-term impacts that significantly improve farming family livelihoods. RAPs are generated from continuous engagement process among stakeholders; farmers, policymakers, academia, researchers and project team members that helps to formulate the transformative adaptation and future pathways. This iterative engagement formulates the linkage between potential stakeholders to learn about specific critical issues. This interdisciplinary research process brings a holistic approach towards development pathways and adaptations at farm level. Moreover, the outcome is scientifically supported with the help of existing literature. The RAPs development process is shown below in Table 3.1.

Table 3.1: Steps for the RAPs development

RAPs Development Process
Step 1: Selection of pathways
Step 2: Key indicators identification
Step 3: RAPs narratives, definitions by economic team
Step 4: Key parameters selection and review process by team members
Step 5: Direction and magnitude of change in different variables based on as discussed in RAPs meetings, rationale for rate of change and finalization of short narrative
Step 6: RAPs sharing with experts for their feedback
Step 7: Incorporation of feedback from experts and stakeholders into result of continuous engagement process
Step 8: Final RAPs drafting in DevRAP matrix and again sharing with experts for further refinement on certain variables
Step 9: Combine survey data, RAPs and secondary data in TOA-MD model to find the socioeconomic impact of policy interventions on farming populations.

3.2 TOA-MD model

The Trade-off Analysis Model for Multi-Dimensional Impact Assessment (TOA-MD) Model is a unique simulation tool for multi-dimensional impact assessment. It can utilise the socioeconomic data sets already collected and combine them with macroeconomic data sets of farms and project the current and future viability of specific policy interventions proposed in research studies (Antle and Valdivia, 2006). TOA-MD uses a statistical description of a heterogeneous farm population to simulate the change in environmental conditions and impact of new technology. TOA-MD simulates various “experiments” for adaptation of new technology and impact assessment. These experiments combined with scenarios that represent the state of the world (for example current or future technology) are the basis for Adaptation analysis.

Current = Current Technology

Future = Future (changed) Technology

Adapted = Adapted (changed) Technology

Consider the two-scenario system 1 and 2:

system 1 = Current time period, base technology

system 2 = Future time period, improved technology (Proposed interventions)

ω = v1 – v2 measures the difference in income with the base and changed technology

ω > 0 ⇒ Technology adoption causes a loss

ω < 0 ⇒ Technology adoption causes a gain

So, we can interpret the adoption model as:

Adopters = gainers from technology adoption (farmer who would like to “adopt” new technology)

Non-adopters = losers from technology adoption (farmers who would not like to “adopt” new technology

The “adoption rate” at a = 0 separates losers from gainers

3.3 Adoption rate of proposed interventions

The adoption rate for proposed interventions estimated by opportunity cost of adoption and non-adoption**.** The difference between net returns from system 1 and system 2 defines the opportunity cost.

$$\omega = \upsilon 1 - \upsilon 2$$

Where ν1= net returns from System 1; and ν2 = net returns from System 2.

ω < 0 means gain from adoption of system 2

ω > 0 means loss from adoption of system 2

Thus, the proportion of adopters is given by:

$$\mathrm{A} = 100 \int_{-\infty}^{0} \varphi\,(\omega) d\omega$$

The percentage of non-adopters or farmers that remain in System 1 is:

$$\Lambda = 100 - 100 \int_{-\infty}^{0} \varphi\,(\omega) d\omega \;=\; 100 \int_{0}^{\infty} \varphi\,(\omega) d\omega$$

3.4 Logical structure of TOA-MD: adoption analysis

An adoption process leads to selection of the population into two sub-populations of non-adopters and adopters of system 2 as presented in Figure 3.3.

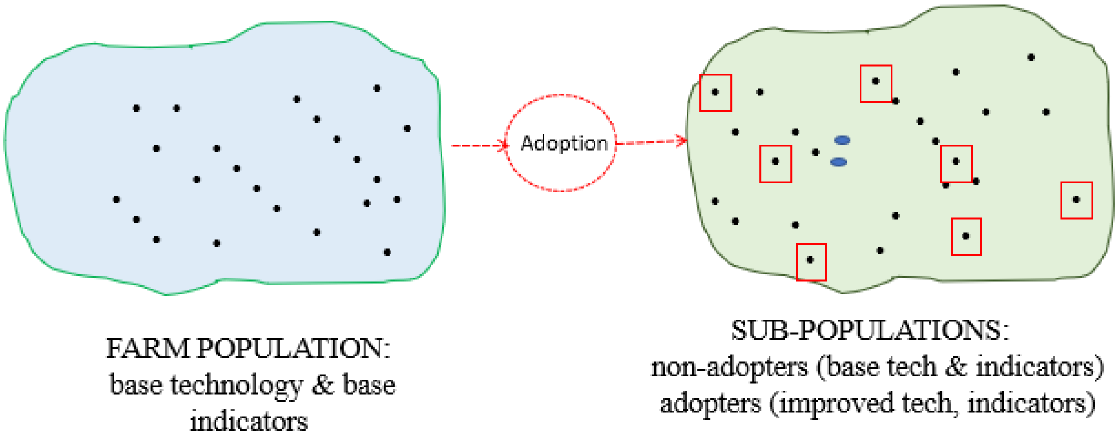


Figure 3.3: Logical structure of TOA-MD: adoption analysis. (Source: Valdivia et al., 2012)

3.5 Adoption impacts on per capita income

Per capita income is calculated by aggregating farm, nonfarm income and family size. The family size defines the number of family members fed by the same stove. Non-farm and farm income are both statistically independent similarly the sum of household income is the sum of two random variables and PCI is also the ratio of two independent variables. Thus, the approximation of mean per capita income is calculated by

$$PCI \; = (\mu_k(h,a) \; + I)/\, H + \, S_h{}^2/H^3$$

Where:

I = Nonfarm income

H = Household Size

$S_h{}^2$ = Variance of Household size

The variance of per capita income is

$$S_I{}^2 \; = (M_h + I)^2/\, H^2\{S_H{}^2 \; + \; \sigma_k{}^2(h,a)/\,(M_h + I)^2 \; + S_H{}^2/H^2 \,\}$$

3.6 Impact of adoption on farm poverty

The head count poverty indicator is the population that is below the poverty line based on a normal distribution of PCI with the mean and variances for each sub population.

k(moong) = Outcome variable:

$$\mu_k(h) \equiv mean\ of\ k(h)$$

$$\sigma_k{}^2 \equiv variance\ of\ k(h)$$

$$\sigma_\omega{}^2 \equiv variance\ of\ \omega$$

$$\rho_k \equiv correlation\ between\ outcomes\ \ k(1)\ and\ k(2)$$

$$K_k(h) \equiv correlation\ between\ outcomes\ \ v(h)\ and\ k(h)$$

The correlation between k(moong) and ω is

$$\theta_k(h) = \{\sigma_v(1)K_k(1)\rho_k{}^{h-1} - \sigma_v(2)K_k(2)\rho_k{}^{2-h}\}/\sigma_w$$

4 Punjab Analysis

4.1 Introduction: Punjab

The recent study was undertaken in Lower Bari doab (comprised of parts of Lahore, Sahiwal and Multan division). Data from two districts, District Sahiwal and District Okara has been utilised in the analysis along with secondary data about the division from government statistics. Sahiwal (Figure 4.1) is one of the most fertile divisions of Punjab and suitable for all the cash crops including wheat, maize, cotton, rice and sugarcane. Livestock rearing is also a specialty of the Sahiwal division due to famous livestock breeds and high productivity.

Figure 4.1: Sahiwal division on a map of Pakistan

The recent analysis utilised the data from the farm survey data undertaken in 2018 (Nasir et al. 2021), from 469 representative farmers, along with secondary statistics for Sahiwal division. The data were collected by multi-stage sampling techniques to ensure the availability of representative farm population based on a comprehensive site selection criterion. The distribution of farm population from head, middle and tail of the canal command ensures the heterogenous nature of farms is reflected in the data.

The RAPs methodology is based on capturing plausible farm-level improvements as climate change and other impacts, such as water scarcity, affect the future of farming operations. RAPs allows the development and adoption of new strategies which enhance adaptation mechanisms by farming communities through a shared vision which is achieved through a process of continuous engagement and discussions with stakeholders. The adoption of the RAPs approach by the stakeholder forums resulted in three kinds of interventions in Punjab:

1. Promoting the cultivation of low delta crops
2. Use of water saving technologies
3. Improving soil health through the use of organic matter

4.2 The RAPs development process

RAPs are developed to demonstrate the future agricultural production systems in a specific production system. The escalating demands of world in terms of food and fibre can be tackled with the help of technological advancement. The world is under an evolutionary process in terms of biophysical, institutional, policy, technological advancement and socioeconomic conditions (Antle et al., 2017). It has been observed that production is generally an increasing function of inputs due to productivity and technological advancements. Consistent mechanized farming, increasing crop intensity and disturbances in natural ecosystem is degrading the natural resources in agricultural production systems. Likewise, it is imperative to diversify production systems for trade advantage (Giovannucci et al., 2012; Nasir et al., 2020).

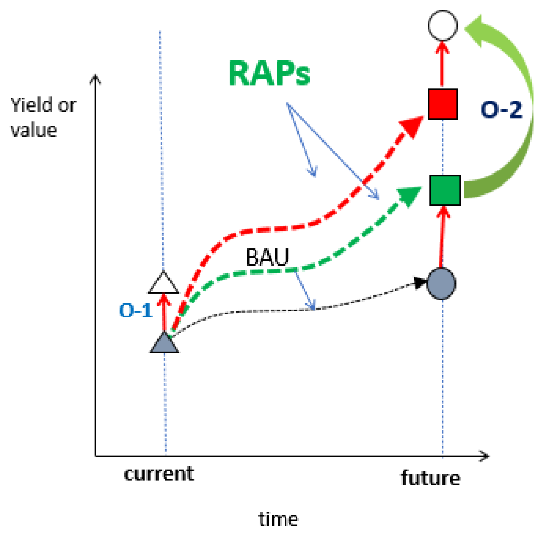


Figure 4.2: Pathways and future production systems. (Source: Antle et al., 2015)

The agricultural production pathways and future production system are described in Figure 4.2 The assessment of groundwater management on the future production system is analysed to motivate the farmers for adoption of resource conservation. The sustainable resource utilisation ensures future farm incomes. The future production system would be different from the current production system due to technological innovation and development in the agricultural sector. The RAPs were specifically designed for the future agricultural production systems for mix cropping system of central Punjab. We opt for the sustainable development pathways in the analysis. The grey pathway is the Business as Usual (BAU) pathway which describes the unsustainable use of farm resources with mechanized farming while, the green pathway describes sustainable use of farm resources and sustainable farm livelihoods. The O1 and O2 describe the current and future adaptations regarding water management that could affect the farm incomes in the current and future time periods. The current adaptations include the interventions that could be easily adopted with low capital investment.

RAPs were developed for the mix cropping system of central Punjab for irrigated agriculture. RAPs designed at national level and key indicators like policy, institutions, technology, land use pattern, trade and growth in productivity is added. After formulating the national level pathways, it is narrowed down by specifying provincial indicators or local key factors about agricultural production systems. If the cropping system, institutions, socioeconomic and policy implications vary we can devise more than one RAPs for homogenous production system.

The mix cropping system of central Punjab is homogenous in terms of the socioeconomic, technological and biophysical characteristics. For this study one developmental pathway was considered that is sustainable and due to similar socioeconomic and farm indicators we can generalize it for mix cropping system. The RAPs draft was prepared by economist and consultative sessions were planned. Experts were invited to represent the cross-disciplinary nature of the problem and sectoral diversity including economist, soil scientist, plant pathologists, irrigation and water management experts, plant and animal breeders, veterinary experts. Examples of consultative sessions with farmers, researchers and policy makers are presented in Figure 4.3Figure 4.4Figure 4.5.

Figure 4.3: RAPs consultative sessions with farmers

Figure 4.4: RAPs consultative session at University of Agriculture, Faisalabad

Figure 4.5: RAPs consultative session in the study area

There were three RAPs meetings and consultative session with experts at different times. The first RAPs meeting was arranged with the consultation of all team members. It is difficult to get the feedback on RAP indicators at the same time in the one meeting due to stakeholders from multiple fields like researchers, farmers and policy makers. Support material that reviewed the variables was prepared to assist the process. The second RAPs meeting was held to refine the first draft indicators, documentation of RAPs events in detail compiled, the same procedure was performed. It is not just the percentages that matters sometimes there are variables for which production is very sensitive, for example disease attack, impact of farm mechanization, irrigation availability, quality of irrigation water. The trend table of RAPs is presented in

Table 4.1.

Table 4.1: Trend table for RAPs in Punjab.

Variable	Sustainable development Pathway
Farm Size	Moderate Decrease ↘
Household Size	Moderate Increase ↗
Non-Agricultural Income	Small Increase ↗
Herd Size	Small Increase ↗
Input Prices	Moderate Increase ↗
Output Prices	Moderate Increase ↗
Crop Yields	Increase ↗

Source: Developed by author Nasir based on expert opinion and published information

4.2.1 Steps for RAPs development in Sahiwal

The steps for development of the RAPs process undertaken for Sahiwal is shown in Box 4.1

Box 4.1 The RAPs Development Process

Step 1: Selection of higher-level pathways (Country level) and key indicators identification

Step 2: RAPs narratives defined under different shared socioeconomic pathways

Step 3: Key parameters/indicators selection and review with consideration of existing literature

Step 4: Direction and magnitude of change in variables was shared and comprehensively discussed in RAPs meetings

Step 5: The rationale for rate of change and short narrative finalized by continuous engagement process with experts

Step 6: RAPs shared with experts for their feedback

Step 7: Feedback from experts and stakeholders in continuous engagement process incorporated in Refinement of RAPs

Step 8: Final RAPs drafted in RAP matrix and again shared with professionals for further improvement regarding important variables parameterization in the model

The RAPs parameters direction and magnitude of change is listed in *Table 4.2*.

Table 4.2: Parameterization of RAPs for sustainable agricultural production systems for the mid-century scenarios for Punjab. (Source: developed by the authors based on expert opinion and existing information from the literature).

RAPs Key variables	Direction of Change	Magnitude of Change
Farm size	Decrease	10%
Household Size	Increase	5%
Non-Farm Income	Increase	15%
Water availability	Increased	20%
HEIS adoption impact on crop yields	Increase	15 %
Cost of Production	Increase	Impact model projections with RAPs
Price	Increase	Impact model projections with RAPs
Crop Yield	Increase	Impact model projections with RAPs

4.2.2 Proposed water conservation and management practices

Water conservation and management practices are important policy domains in terms of food security and sustainable farm livelihoods. Irrigation plays an important role in production of food and fibre crops. In Pakistan 90 percent of food and 100 percent of cash crops are directly dependent on irrigation (Yang et al., 2018). Farmers tend to adopt technologies and conservation techniques as long as they can realize an increase in expected profitability. The adoption of new conservation technologies requires considerable changes in the decision-making process that include human, biophysical, institutional, and economic considerations.

Pakistan is ranked 77th out of 113 countries, with an aggregate score of 47.8 out of 100 for food affordability, availability, quality and safety, alongside a fourth factor – natural resources and resilience (The Economist's Global Food Security Index 2017). There are significant disparities between Pakistan's areas regarding food insecurity (WFP, FAO & UNICEF, 2016) as described below in Table 4.3. Despite a well-functioning agricultural production system Pakistan already suffers from food insecurity that must be considered in long term policy formulations about resource use and conservation.

Table 4.3: Food insecurity in different regions of Pakistan. (Source: World food program; 2018)

Province/ Area	Food insecurity (Percentage)
FATA	69
Gilgit Baltistan	68
Balochistan	63
Sindh	52
Khyber Pakhtunkhwah	43
Punjab	37
Islamabad Capital Territory (ICT)	32

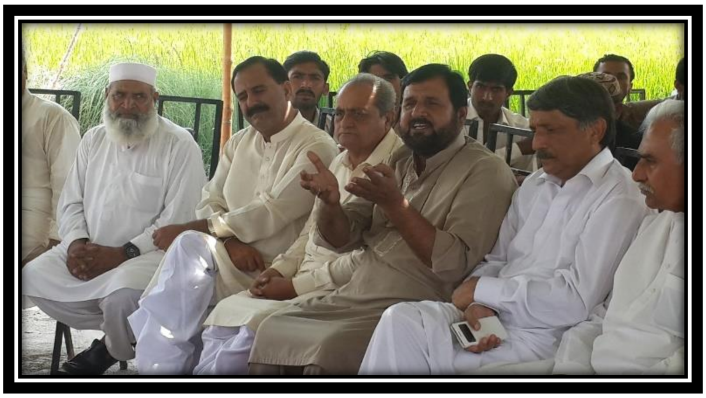


Figure 4.6. Discussions about adaptations with farmers

The agricultural production systems could be improved by educating farmers with management interventions and improved practices that can be practically possible at farm. However, slow adoption of proposed interventions is an ongoing issue. Low economic viability or practicality are constraints on on-farm adoption (McCown, 2001; Nasir, 2019; Streletskaya et al., 2020). There is, therefore, needed to involve farmers in the whole process of devising solutions towards agricultural issues, as farmers are the most important and crucial stakeholder (Farooq et al., 2019; NRC, 2010). The RAPs stakeholder consultative sessions enabled farmer involvement with already documented potential solutions. These transformative adaptations and RAPs development process is sketched in Figure 4.7

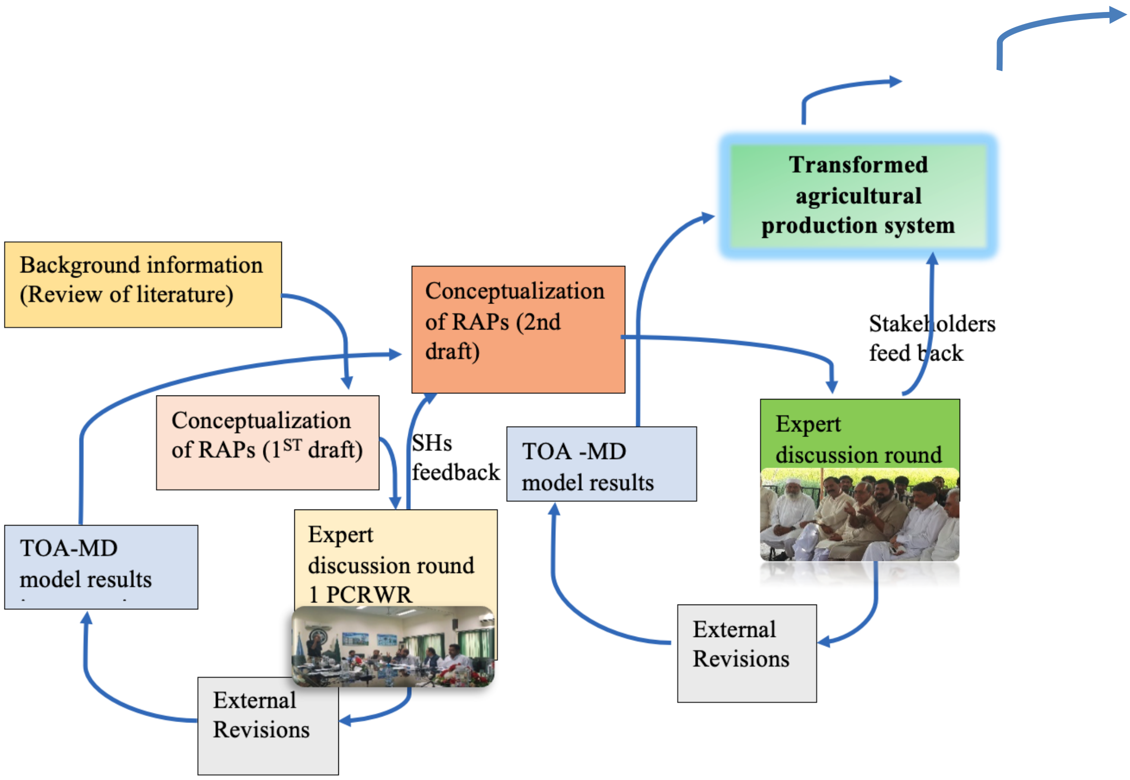


Figure 4.7: Transformative adaptations and the RAPs development process. (Adapted from: Käyhkö et al., 2020).

This project evaluated the potential adaptations in the study area and also emphasises reasons of low adoption due to lack of important stakeholders in the whole policy formation process. Generally researchers, policy makers and farmers working in their specialized fields have weak communication. During the RAPs session researchers from sociology, genetics, irrigation and drainage, economist and soil scientist were consulted to devise better projections.

The system based and problem-solving transformative process adopted in this study, builds on previous studies (Blythe et al., 2018; Gillard et al., 2016) showing that there are complexities and dynamics in the relations between different actors and contexts of action. The transformative process of adaptations followed in the study about improved water management and conservation practices suggested the following recommendations (Reeves et al., 2009; Panda, 2018; Mushtaq, 2018; Ajibade and Adams, 2019; Ju et al., 2020).

- Substitution of high delta crop with low delta crop
- Efficient Irrigation practices (HEIS, Drip Irrigation, sprinkler etc.)
- Soil conservation practices for better water holding capacity (organic manuring, mulching, conservation tillage and cover crops)
- Improved Cultivars (drought & heat tolerant varieties, short duration varieties)
- Improved Agricultural Practices (fertigation, balanced fertilizer, drainage)
- Plant Population (seed rate, no of plants)
- Construction of water storage
- Agricultural Insurance/Finance
- Water Harvesting

All of the above-mentioned strategies are important in terms of water conservation practices and expansion in farm livelihoods. However, when we want to quantify the impacts of certain on-farm adaptation strategies, we consider the adaptations that are most important and specifically linked with farmers. There are certain data and model limitations that do not allow incorporation of all the management intervention at once in the model therefore, two important interventions proposed and strongly enforced by all stakeholders were used in the model.

4.2.3 Substitution of high delta crop with low delta crop

The foremost intervention was substitution of high delta crops with low delta crops in the study area. Sustainable farming largely depends upon a farm's natural resource capabilities, especially soil fertility, and water availability and quality; all play vital roles in farm productivity and income. Most of the farmers are very concerned about rational use of these resources. Perceptibly, farm tenancy status plays a crucial role regarding farm management and resource conservation practices. Although farmers are sensitive to water use and climatic implications, their decisions are largely influenced by market signals and public policies. In Pakistan, the government is directly intervening in the wheat market and provide incentives to wheat farmers in the form of support prices. Wheat is a suitable crop for most of irrigated and rainfed areas of Punjab as it suits well in the cropping pattern and has a stable market with high returns.

Table 4.4: Current water consumption by five major crops in Punjab (Source: Khan, & Khan 2018).

Crop Water Consumption	Million Acre Feet (MAF)
Wheat	39
Cotton	29
Rice	26
Sugarcane	23
Maize	5

Table 4.4 above indicates that water consumption under wheat is highest, as wheat is preferably grown by farmers due to better returns, proper marketing, efficient value chain and seed availability. Pakistan agricultural policy mainly concentrates on wheat, especially in terms of support price and procurement. That ensures the farm returns to some extent but creates inefficiencies in the wheat market. Wheat is a suitable crop all over Pakistan, fits well in all cropping systems and competes with main oilseed crops and pulses. Research studies describe that sunflower is suitable for cultivation and highly profitable crop, however farmers are reluctant to grow it (Anwar and Saeed, 2014; Rani et al., 2018). The adoption is low mainly due to seed unavailability, high cost of production especially seed cost, inefficient marketing, lack of farm machinery for small farms and lack of competition among buyers (Amjad, 2014; Muhammad et al., 2017).

4.2.4 Efficient irrigation practices (e.g. HEIS, drip irrigation, sprinklers)

The allocation of water resources is crucial in terms of sustainable agriculture, consequently policies must be formulated for water conservation and management that could be implemented. Formulation and implementation of ground and surface water laws are linked with adoption of water conservation practices like implementation of micro irrigation technologies and to grow high value crops can boost the water economy (Kahlown et al., 2003). Pakistan's farming graphics are complex and varied in various regions in terms of water availability, quality and quantity. Therefore, it is recommended to provide water related information that is authentic and with reference to all those indicators specific policies devised and implemented in the short run and long run to achieve sustainability in farming practices (Qureshi, 2018). The on-farm management practices like use of fertilizer, soil management, laser levelling, irrigation methods and selection of crops contribute to water use efficiency, soil health improvement and mitigation of climate change impacts (Shah et al., 2019; Talib et al., 2019).

4.3 Input of TOA-MD model

This section provides the details of data that is used as an input in TOA-MD model that could be helpful in better understanding of results and farming system. The yield and price factors, secondary and primary level farm statistics that are used in the analysis to project the farming system.

4.3.1 Yield and price trends

The analysis utilises the yield and price trends from IMPACT (The International Model for Policy Analysis of Agricultural Commodities and Trade) models in the analysis as described in Table 4.5. These trends describe the future price and yield projections for specific crops in specific countries.

Table 4.5: Trend table for yield and price in mid-century scenario 2050 in Punjab. Source: based on the international model for policy analysis of agricultural commodities and trade (IMPACT) models and RAPs.

Crops	Sustainable Agricultural Pathways	
	Price trend	Yield trend (Irrigated)
Wheat	1.26	1.45
Maize	1.691	1.367
Rice	1.289	1.348
Cotton	1.24	1.48
Sugarcane	1.416	1.244

4.3.2 Secondary farm level descriptive analysis

Table 4.6 describes the farm survey information regarding total farmland and historical yields of major cash crops in Sahiwal division. These data sets are utilised as secondary information in TOA-MD model to capture the bigger picture in generalization of our research outcome for policy perspective. The farmland is given in hectares and yields are added in kg per hectare. Wheat is intensively cultivated in Punjab due to its comprehensive value chain that insures farm returns. It is the most important crop regarding policy perspective as government is focused on wheat production and prices due to its crucial role in country's food security. Farm statistics of major cash crops in Sahiwal Division describes in Table 4.6.

Table 4.6: Farm statistics for the major cash crops in the Sahiwal Division. (Source: GOP, 2017)

Crop	Total farmland (Ha)	Yields from historical data (Kg/ha)
Wheat	493710	3925.19
Maize	212400	5930
Rice	217700	2300
Cotton	96300	2162
Sugarcane	19420	45572
Moong bean	1112	780
Sunflower	68	1520

Table 4.7 describes the farm size, crop yield, crop prices, total cost of production, revenue and net income that incorporated in model as an input from survey data. This information is specifically linked with the farmers that are within our sample and represent all the farmers in a heterogenous farm population.

Table 4.7: Descriptive statistics of current production system of study area in Punjab.

Crop	Farm size (Ha)	Yield (Kg)	Price (PKR)	Total cost (PKR)	Total revenue (PKR)	Net income (PKR)
Wheat	2.94	1585.33	28.93	21387.83	46044.5	55943.17
Maize	2.69	2508.00	24.63	41164.83	61753.5	17599.75
Rice	2.48	1443.00	35.37	33497.5	51097.75	14613.67
Cotton	2.16	844.00	59.38	35655.33	50269.33	14613.67
Sugarcane	1.52	24022.67	3.93	49639	94589	44950

4.4 Results of TOA-MD model (socioeconomic analysis of management interventions)

The results of the TOA-MD model describe the adoption rate based on economic viability of proposed adaptation strategies in the study area. The important aspect of this analysis is formulation of adaptation package, and further selection of those management interventions that could be analysed for economic viability. TOA-MD model was used to analyse the adoption rate of proposed management interventions based on economic analysis and cost benefit analysis. The input for the model is based on survey data and projections of RAPs. The model outputs are mainly adoption rate of adaptations based on impact on per capita income, net farm returns and farm poverty.

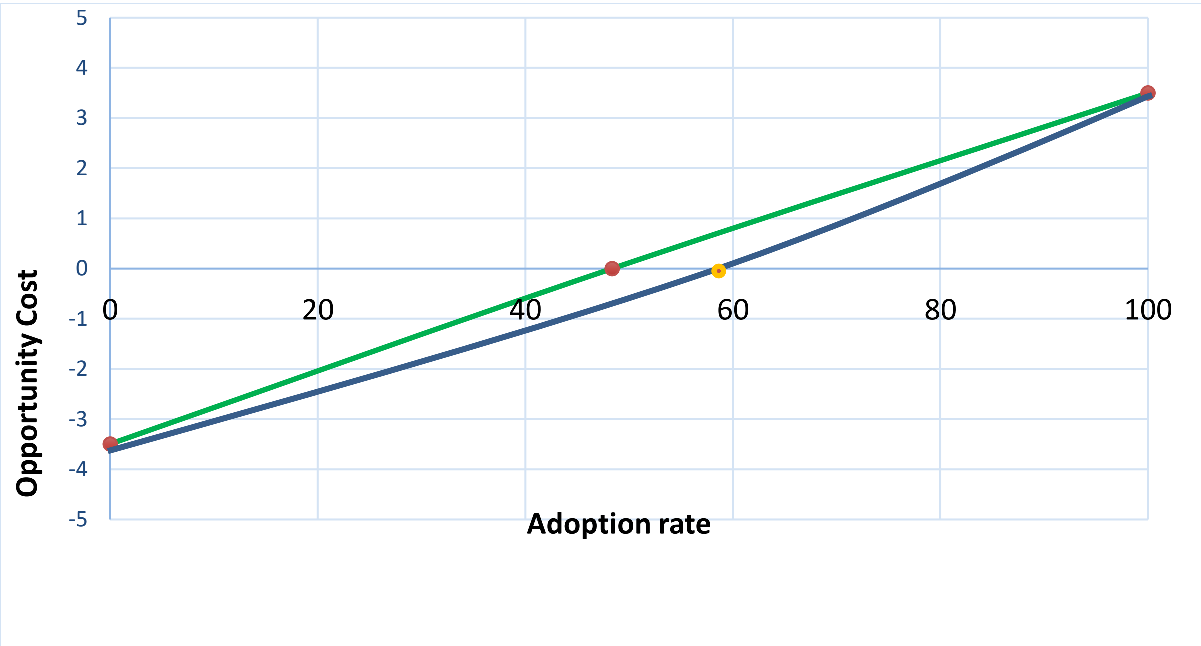
The TOA-MD model was used to estimate the adoption rate of proposed adaptation based on farm returns. Impact of Substitution of high delta crops with low delta crops on net farm returns, per capita income and poverty in study area.

4.4.1 Economic benefits of adoption of low delta crops

The proposed adaptation package includes substitution of high delta crop with low delta crops. According to the cropping pattern of the study area the proposed crops are oilseed and pulses to increase water productivity, farm livelihood and to reduce the import burden on the economy. The suggested management interventions include the crop diversification and 5-10 percent of area under wheat crop is replaced by sunflower likewise 5-10 percent maize area could be replaced by moong bean. Sunflower and moong bean are highly recommended crops according to climatic and biophysical condition of study area. Additional data sets were collected for the alternative crops in the same area for analysis of the socioeconomic impacts of crop substitution. These could be added to other oilseed and pulses, but this study focused on the existing crops that are available marginally in the study area. The rationale of crop substitution is highly recommended based on resource conservation and export bills, likewise, crop diversification also protects farmers from risk and uncertainty, and legume crops if adopted can improve soil fertility and crop productivity. There are certain risks involved especially market, financial and institutional risks that act as barrier to adoption of alternative crops (Joshi et al., 2004). The proposed interventions include the replacement of 5-10 percent of land under alternate crops that increase the returns and ensure the farm incomes. Although wheat is a staple crop and utilizes a greater proportion of water resources however, wheat has huge socioeconomic, food security and political importance. The consultative session suggested that the surplus wheat production each year could be replaced by oilseed and pulses. However, farm size is already small so it was suggested that 5 percent of land for small land holdings and 10 percent of land for large land holdings could be allocated for alternate crops. The economic benefits for adoption of low delta crops are described in Table 4.8.

Table 4.8: Economic benefits of adopting low delta crops in Punjab. Note: the poverty line was calculated based on (Rupees/ person/ time) that was 21900 rupees for one season.

Scenarios	Crop Substitution	Change in Net returns (%)	Change in per capita income (%)	Change in Poverty (%)	Potential adoption rate (%)
Scenarios 1	Maize replaced by moong bean	32.51	28.75	-3.6	49
Scenarios 2	Wheat replaced by sunflower	33.89	30.05	-3.4	59



Scenarios 1	Maize replaced by moong bean	49
Scenarios 2	Wheat replaced by sunflower	59

Figure 4.8: Potential adoption rate of low delta crops in the study area for the mid-century scenario.

The results indicated that without adaptation poverty was 17.72 percent for survey data, whereas with interventions poverty rate would reduce by 3.6 and 3.4 percent for scenario 1 and 2 respectively. The adoption rate for sunflower and moong bean would be 49 percent and 59 percent respectively as described in Figure 4.8. Results showed that proposed interventions such as crop substitution have a significant impact on farm livelihoods.

The moong bean has great potential as a cash crop in Pakistan in wheat systems but there are certain interventions that can turn constraint into opportunity in adoption of its production in irrigated areas (Rani et al., 2018). Availability of water, high yielding cultivar, improved management practices and improvement in value chain is the crucial factor in moong bean cultivation. The cultivation of pulses especially moong bean is low manly due to marketing issues and inconsistent policies. The benefit cost ratio of moong bean is higher than all major cash crops in certain areas as reported by the National Agricultural Research Centre but due to marketing factors farmers do not grow this crop and are reluctant to substitute wheat for moong (Anwar and Saeed, 2014). The percentage change in net farm returns per capita income and farm poverty due to crop substitution is shown in Figure 4.9.

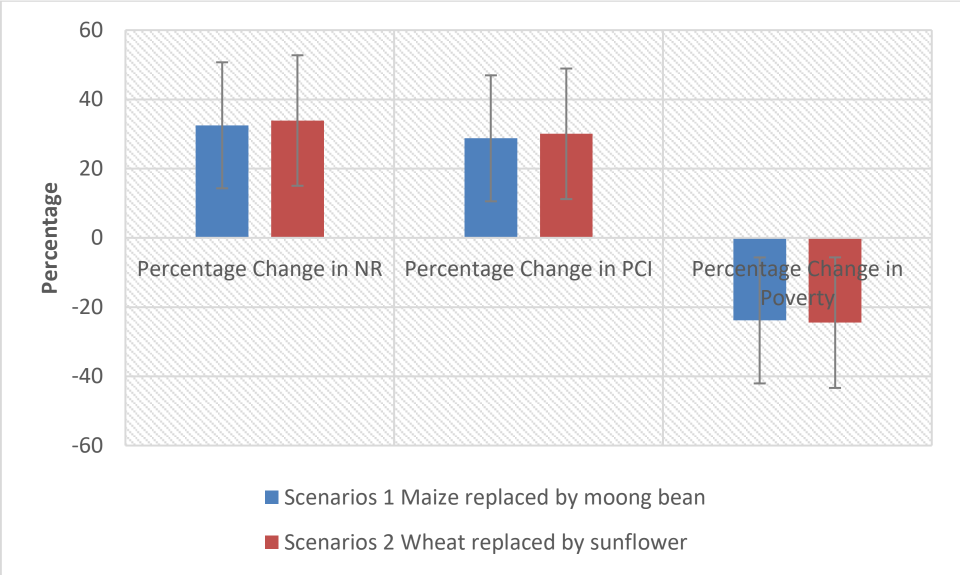


Figure 4.9: Percentage change in net farm returns (NR), per capita income (PCI) and poverty due to crop substitution in Punjab.

4.4.2 The socioeconomic analysis for adoption of high efficiency irrigation systems

Farmers tend to adopt technologies and conservation techniques as long as they can realize an increase in expected profitability. The decision to adopt technologies and techniques is also influenced by a farmer's socioeconomic status, cultural background, and access to natural resources. Moreover, the adoption of new conservation technologies requires considerable changes in the decision-making process, including a wide range of human, biophysical, institutional, and economic considerations.

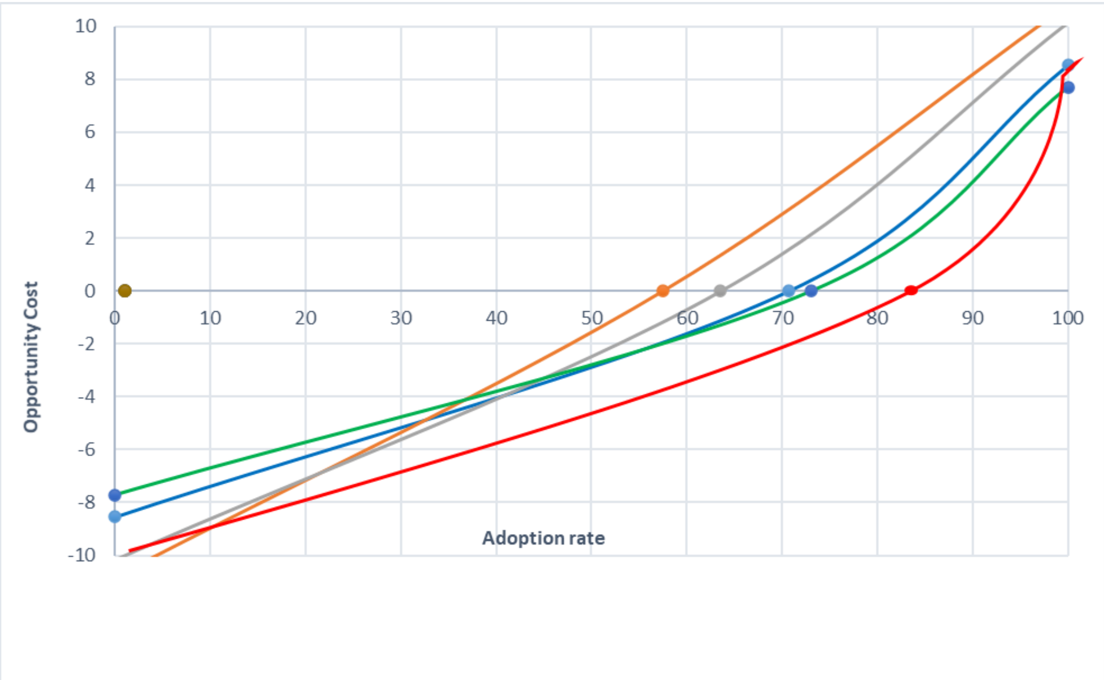
The improvement in yield is substantial in terms of adopting efficient irrigation system especially in maize crop (Amin et al., 2015). The biological and grain yields increased substantially with HEIS and raised bed systems. Water quality and mode of irrigation could approximately increase the crop yields by 15 percent. Improvement in water quality increase the crop yields substantially by improving the soil fertility in the long run. It is projected that better on farm water management increases the net farm income substantially by increasing the crop yields and reducing the cost of production, it is estimated that it increases the farm income by 75,000 rupees per acre per annum (On Farm water management, 2018). The socio-economic impacts of adaptations benefit of HEIS is presented in

Table 4.9.

Table 4.9: Socioeconomic impacts of adaptation benefits of high efficiency irrigation systems in Punja. Note: calculations are based on RAPs and TOA-MD calculations.

Crops	Change in Net returns (%)	Change in per capita income (%)	Change in Poverty (%)	Potential adoption rate (%)
Cotton	28.307	23.002	-4.7	72.000
Maize	40.804	36.586	-4.6	76.026
Wheat	19.821	18.052	-1.0	63.128
Rice	37.947	31.410	-5.3	87.036
Sugarcane	37.943	35.362	-3.6	55.775
Overall	34.893	30.564	-4.7	73.800

The proposed interventions include substitution of conventional methods of irrigation with HEIS. With proposed intervention of HEIS (through technology and management) there would be 4.7 percent decrease in poverty and 30 percent increase in per capita income. The adoption rate of this adaptation package is 74 percent and this adoption resulting in the reduction of farm poverty as presented in Figure 4.10. It is evident that substantial reductions in water consumption are possible through changes in cropping patterns and suggested crops increase the farm income and livelihood as well. Low delta crops must be prioritized as compared to high delta crops considering the demand for staple food to ensure food security issues. Adoption Rate of HEIS for major cash crops have positive impact on NR, PCI and farm poverty as shown in Figure 4.11.



Crops	Cotton	Maize	Wheat	Rice	Sugarcane
Adoption rate (%)	72.000	76.026	63.128	87.036	55.775

Figure 4.10: Adoption rate of high efficiency irrigation systems for major cash crops in Punjab.

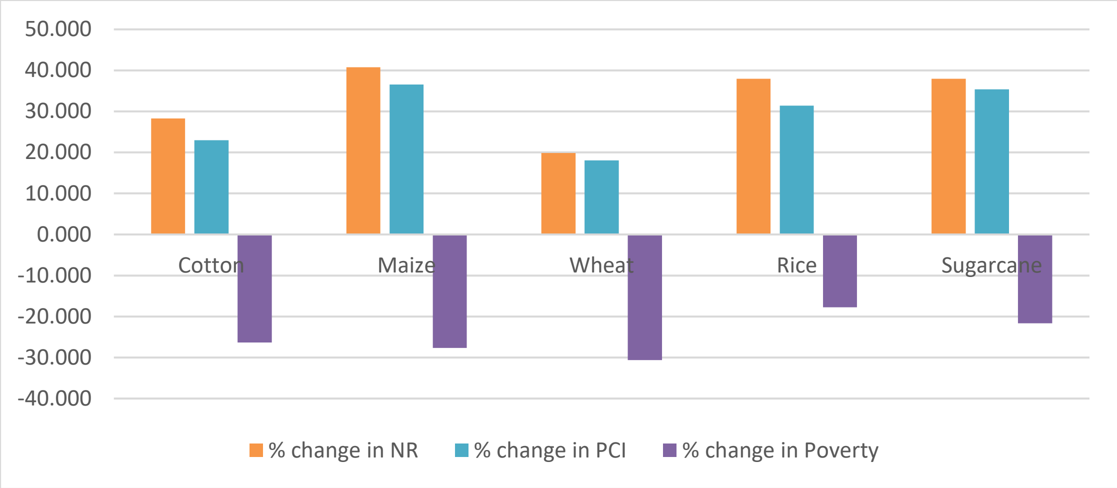


Figure 4.11: Impact of adoption of HEIS on net farm returns (NR), per capita income (PCI) and percent change in poverty in Punjab.

The result further describe that water savings and high NR are possible by shifting from conventional irrigation to improved irrigation technologies (sprinkler and drip irrigation). Public policies must consider resource conservation and sustainable livelihood. Policies must be formulated in favour of institutional development as compared to export taxes, domestic support and price control policies. On the basis of the following results, it is recommended that apart from the proposed water-saving strategies, other alternative management techniques, directed off-farm (i.e., improved infrastructure to reduce water losses due to poor conveyance efficiency) and on-farm (e.g., deficit irrigation or soil mulching) management, should be evaluated in future studies as they play an important role in sustainable use of farm resource and farm livelihoods.

4.5 Conclusions: Punjab

Agricultural production system largely depends on natural resources especially water and soil. On farm water conservation and management practices is needed and measures like re-allocation of water to higher value crops. We found that reducing irrigation requirements, spatial re-allocation and transfer of water improve water productivity could have positive impacts on farm livelihoods. The adaptations formulated during the engagement process that could increase the water productivity includes HEIS, drought resistant varieties, substitution of water intensive crops with less water demanding crops, mulching of soil, zero tillage and improved farm cultivation operations.

The TOA-MD model estimates the adoption rate of proposed adaptation based on net farm returns. Impact of HEIS and substitution of high delta crops with low delta crops had positive impact on net farm returns, per capita income and negative impact on farm poverty in study area. The results further describe that water savings and high NR are possible by shifting from conventional irrigation to improved irrigation technologies (sprinkler and drip irrigation). Overall 75 percent of farmers have economic feasibility to adopt the management interventions. Although wheat, maize, rice, sugarcane and cotton are the most important cash crops, there is a need to calculate the social cost of these water loving crops. Oilseed and pulses are the potential sectors in terms of resource conservation and crop diversification.

The Farmer and the Professor – a story of change

The Punjab economics team headed by Professor Ashfaq from University of Agriculture Faisalabad and Professor Irfan Baig from MSN University of Multan introduced the RAPs framework to the stakeholder forums at 11-L Sahiwal and 1R Okara. The RAPs framework is developed on the premise that both bio-physical and socioeconomic drivers are essential components of agricultural pathway. The RAPs methodology is based on capturing plausible farm-level improvements as climate change and other impacts such as water scarcity affect the future of farming operations. RAPs allows the development and adoption of new strategies which enhance adaptation mechanism by farming communities through a shared vision which is achieved through a process of continuous engagement and discussions with stakeholders. The adoption of the RAPS approach by the stakeholder forums resulted in three kinds of interventions in Punjab:

1. Promoting the cultivation of low delta crops
2. Use of water saving technologies
3. Improving soil health through the use of organic material

Promoting the cultivation of low delta crops: To achieve these objectives, the team engaged with farmers in 11L to move from high delta crops to low delta crops. Smallholder farmers have trialled the following crops:

- 2 acres of sunflower crop
- 8 acres of moong bean

Both crops are being promoted by the Government of Pakistan because of the excessively high cost of imports associated with edible oil and pulses. The sunflower crop at vegetative growth stage and the crop stand was excellent. The crop is now being harvested. The moong bean crop has also grown very well and will be harvested in June.

Trials are also planned for garlic which is a cash crop and also saves on water. It requires 50% less water as compared to sugarcane. Garlic will be planted in the coming season. Similarly sesame crop is being promoted, which requires only 3-4 irrigations and will be planted after wheat harvest.

Use of water saving technologies: Use of water saving methods such as bed and furrow cultivation was promoted for planting sunflower and moong bean. Before planting these two crops the land was laser levelled which decreases irrigation time and allows more even irrigation applications.

Improving soil health through the use of organic matter: Farmers in the stakeholder forum have agreed to adopt interventions that promote sustainable agriculture and to improve soil health by incorporating crop residues. Incorporating organic matter improves soil texture and soil fertility. This process will begin after harvest by using the stubble and residue as manure.

A similar process will be replicated for Sindh and Balochistan involving RAPs sessions with stakeholders to identify appropriate interventions for saving groundwater and improving farming family livelihoods.

4.6 Policy recommendations

Based on current analysis there are certain recommendations that could be helpful for researchers and policy makers for further insight about water management.

- The policy formulation must consider and consult farmer representative about water issues so that suitable policies could be implemented at farm. Farmers are important stakeholders for all sort of management interventions regarding ground and surface water.
- The most crucial factor for agricultural development is agricultural finance especially for the adaptation of technological advancements regarding water management like sprinkler, drip and farm mechanization. If the Central Bank policies enforce commercial banks to provide special financing schemes for sustainable agricultural practices, the adoption would increase substantially.
- The water allocation at farm must be equitable across head, middle and tail reaches and there must be efficient water markets so that malpractices and overutilization of water resources can be managed.
- Nature based solutions are best and policies must be formulated for specific agro-ecological zones. The areas with water scarcity must be highlighted and serious efforts should be made to implement the suggested interventions.
- Integrated farms system model is a proposed concept to increase the farming systems efficiency in a sustainable manner. Livestock, crops, fisheries, agroforestry and poultry sector all must be considered as one integrated system. Public policies that are in favour of one crop could suppress the cultivation of other crops.
- For the out scaling of the interventions, it is recommended that the current work should be continued in the other agro-ecological zones of the country where majority of farmers and non-farmers are resource poor, water is scarce, and poverty is high. Solving issues facing communities by involving them is the central focus of the novel RAPs l approach which allows appropriate solutions of critical issues and for assessing the impact on livelihoods of farmers adopting specific interventions.

5 Sindh Analysis

5.1 Introduction: Sindh

This study analysed the data from Naushahro Feroze and Shaheed Benazirabad (SBA) districts. Cotton, wheat, rice and sugarcane are major crops of both research sites. Farm livelihood is closely linked with water availability for irrigation. The area is on the left bank of Sukkur Barrage and was selected based on GIS information with reference to high use of groundwater in conjunction with surface water with usable quality of groundwater.

Agricultural production systems are continuously transforming due to natural resource deterioration and climatic variations. It is evident that Sindh and Punjab provinces are mainly contributing to agricultural production and food security in Pakistan (Sardar et al., 2020; Khan et al., 2021). In the long run Sindh has the potential to support intensive agriculture due to fertile soils and availability of farm labour but water is a limiting factor that hinders the growth of the agricultural sector (Aslam et al., 2021). Moreover, mismanagement of available water resources further compounds this problem. Cultivation of major cash crops, especially wheat, is dominant due to availability of markets and processing infrastructure that ensure farm income and allow farming families to improve food security (Ho et al., 2021). However, these crops are mostly high delta crops and raise serious concerns for sustainable farming practices in the long run. The role of the government in wheat markets supports this crop, making it difficult to grow alternate crops such as oilseed and pulses. Therefore, policies must be formulated to transform agriculture and adoption of sustainable farm management practices to attain sustainable farm production and livelihoods (Ahmad and Ma, 2020).

The continuous degradation of soils due to poor quality water application threatens agriculture in the long run (Sanaullah et al., 2020). This study aims at devising management interventions especially regarding water use efficiency and strengthening farm livelihoods. The RAPs framework has been utilised to project the biophysical, socioeconomic, institutional, and policy related indicators. The impacts of efficient allocation of resources have long term impacts that significantly improves farmer livelihoods (Nasir et al., 2020; Antle and Valdivia, 2021).

The research institutions, academia and policymakers are working in a discrete sphere which creates hurdles for sustainable agricultural transformations. The RAPs process is generated from continuous engagement process among stakeholders, farmers, policymakers, academia, researchers and project team members that help to formulate the transformative adaptation and future pathways. This iterative engagement formulates the linkage between potential stakeholders to learn about specific critical issues. This interdisciplinary research process brings a holistic approach towards development pathways and adaptations at farm. However, all the outcome is supported with the help of existing literature and verified by data support and consultation of experts.

Primary and secondary data was used in the TOA-MD model to assess the socioeconomic impacts HEIS for major cash crops (wheat, cotton, rice and sugarcane) in the study area. The sample was selected according to stratified random sampling and the survey was conducted under the ACIAR funded project (Mangan et al. 2021). The sample size includes small, medium and large farmers from two research sites. The cropping pattern includes a mix of crops.

Figure 5.1: Data collection in Sindh.

5.2 RAPs development process

The first RAP session was organized in Karachi to formulate the RAPs for Sindh.

Table 5.1: Trend table for RAPs (in refinement process). Source: developed by the authors based on expert opinion during the RAPs session in Karachi and existing information in the literature.

Variable	Sustainable development Pathway
Farm Size	Decrease ↘
Household Size	Decrease ↘
Non-Agricultural Income	Increase ↗
Herd Size	Increase ↗
Input Prices	Increase ↗
Output Prices	Increase ↗

The basic RAPs framework was adopted to construct a trend table (Table 5.1) that shows the direction of change in variables for Sustainable Development Pathways. Unsustainable development would result in higher population growth, land fragmentation, and low growth in other sectors, high unemployment, unstable markets and high inflation in the economy. Sustainable development policies will lead to moderate decreases in household size, small increase in non-farm income, small increase in herd size, stable markets and low inflation in output and input markets. Table 5.2 shows the quantification of various indicators, their directions and the logics behind those changes.

Table 5.2: Quantification of RAPs for Sindh.

Indicators	Direction of change	Narrative
Farm Size	Decrease	Land fragmentation is unavoidable in the presence of Law of Inheritance, without land policy it will decrease at large scale
Household Size	Decrease	Socioeconomic historical trends determined that it will remain the same or decrease due to nuclear family system evolution.
Non-Agricultural Income	Increase	Industrialization, Urbanization, High returns on investment in other sectors, migration and increase in literacy rate will increase the non-farm income but at the same time population pressure and unemployment rate will also increase the nonfarm income
Herd Size	Increase	Agricultural land will decline and there will be intense competition between cash crops and fodder. Livestock will emerge as an enterprise and large farms on commercial basis will establish, it will be non-profitable to operate at lower scale due to easy access of farm machinery, new breeds and progressive farm management.
Variable Cost of Production	Increase	Variable cost of production will increase with the same rate as output price will increases.
Output Prices	Increase	For output prices we will use the global projections and according to our regional conditions will rationalize the output prices

The RAPs parameters direction and magnitude of change is listed in Table 5.3.

Table 5.3: Parameterization of RAPs for sustainable agricultural production systems for the mid-century scenario in Sindh. Source: developed by the authors based on expert opinion and existing information in the literature. Note: this mid-century scenario 2050 assumes surface water decrease and increased pumping of groundwater to replace it.

RAPs Key variables	Direction of Change	Magnitude of Change
Farm size	Decrease	10%
Household Size	Decrease	5%
Non-Farm Income	Increase	10%
Water availability	Increased	10%
HEIS adoption impact on crop yields	Increase	15 %
Cost of Production	Increase	Impact model projections with RAPs
Price	Increase	Impact model projections with RAPs
Crop Yield	Increase	Impact model projections with RAPs

5.2.1 Adaptation package

The adaptation package was formulated by continuous engagement with all stakeholders in the study area, especially farmers. Adaptation options already available in the literature were accessed and consultative sessions were designed to formulate adaptations for future agricultural production systems in the study area.

The suggested management interventions include adoption of HEIS, substitution of crops, developing the water markets, livestock farming and cultivation of high value crops. However, these management interventions are not adopted due to technical, financial, economic and market issues. The explicit interventions shared for the study area regarding water management interventions at farm includes the following aspects.

- HEIS (ridge and bed sowing, drip and sprinkler)
- Substitution of crops (low delta crops like Quinoa)
- Developing the water markets
- Enterprise diversification (livestock farming, olericulture, fisheries, argo-forestry)
- Crop diversification (vegetables like onion, okra, chilies, black pepper)
- Intercropping (sugarcane and wheat; okra and onion)
- Cultivation of high value crops

The consultative sessions developed certain interventions. It was noted that sugarcane is a major crop in the study area which needs more water however, due to limited surface water supplies groundwater is now an important supplementary source for irrigation. The increased pumping can create scarcity of groundwater and particularly in Sindh the quality of groundwater can deteriorate rapidly as the thin freshwater lenses overlie marginal to brackish groundwater. After consultation with farmers of the study area, different suggestions such as intercropping, sowing wheat on raised beds, sugarcane cultivation intercropped with okra and onion were explored. Results of these cropping patterns are beneficial for farmers as they allow them to grow more crops together with sugarcane taking advantage of irrigation applications, fertilizer, and land preparation inputs for sugarcane. These methods of cultivation are not only water efficient but also cost effective. Another intervention that was introduced is nursery growing for gap filling in sugarcane. Due to poor germination, gaps are always a serious issue in this area resulting in reduced crop yields. It was also highlighted that new low delta and high nutritional value Quinoa crop can be grown at large scale.

Our findings indicate ridge sown wheat has comparative advantage over traditional wheat cropping. Grain yields are higher for ridge sown wheat and fodder crops for animals. In ridge sowing less irrigation and seeds are required. Vegetables are cash crops with more benefit, but vegetables need hard work and skills. Intercropping with onion and okra is suitable for this area. It was demonstrated that by intercropping of onion and okra, both crops are in good condition and farmers will get double benefits from this land and water.

The consultative sessions were arranged by the Sindh project team and were aimed at finding the solutions of groundwater issues in the light of project findings regarding groundwater and socioeconomic impacts in the study area. The results of research projects could be further strengthened by dissemination and sharing of information with experts, policy makers and farmers. It provides a strong foundation and projections for societal impacts. The main adaptations in Sindh province includes HEIS, improved management practices, substitution of high delta crops with low delta crops, improved cultivars, seed availability, plantation of trees, water storage and equitable water sharing and regulation. Equitable canal water distribution, laser levelling, crop zoning, crop rotations, HEIS, intercropping and mulching could increase crop yields substantially.

Figure 5.2: Intercropping of onion and okra in Sindh Province

Figure 5.3: Farmers and stakeholder visit to the intercropping demonstration field site

Figure 5.4: Consultative session in the field with farmers in Sindh

High delta crops such as sugarcane and rice must be constrained by crop zoning and through policies that encourage resource conservation as it is evident that these high delta crops are are adversely impacting sustainable farming. However, increased adoption of intercropping would increase water productivity and net returns of farmers. The depletion of water and soil resources are linked with choice of cropping pattern. In Sindh province the zero tillage crops and oilseed crops are trending due to water scarcity. Chilies, orchard farming and vegetable growing are also important aspects regarding crop substitution. The cultivation of fodder is also a potential crop considering livestock profitability and mechanized farming along with other contingent benefits of fodder crops. Onion, chilies and wheat are important for intercropping. Moong bean, oilseed (sesame seed) and guar (fodder) are important in terms of crop substitution.

The suggested management interventions include adoption of HEIS, substitution of crops, developing the water markets, livestock farming and cultivation of high value crops. The data sheets and the analysis of cost of production were formulated for TOA-MD analysis. The economic analysis will describe the adoption rate, impacts of suggested interventions on net farm returns, per capita income and farm poverty.

5.3 TOA- MD model

The (TOA-MD) model was developed for impact assessment (Antle and Valdivia, 2011). The TOA-MD model was used to assess the impacts of management intervention on socio-economic indicators like farm net returns, income and poverty. TOA-MD model utilized RAPs, interventions data set, farm data along with secondary information to project the long-term impacts (Mangan et al., 2021).

TOA-MD model estimates the adoption rate of proposed adaptation options based on net farm returns. Net farm returns, per capita income and farm poverty in the study area are analysed for adoption of HEIS. The adoption rate for proposed interventions estimated by opportunity cost of adoption and non-adoption. Per capita income is calculated by aggregating farm, nonfarm income and family size. The family size was defined as the number of family members fed from the same kitchen.

5.3.1 Socioeconomic impact assessment of adoption of high efficiency irrigation systems

The results describe the socioeconomic impacts of groundwater management interventions in the mid-century (2050) scenario with a particular focus on livelihood outcomes. The suggested management interventions include adoption of HEIS, substitution of crops, intercropping vegetables with high delta crops, developing the water markets, livestock farming and cultivation of high value crops. TOA-MD model estimates the adoption rate at per farm basis for the whole farming system based on the described data sets. Cost of production, yield, price trends, returns are calculated using the primary survey data. The economic analysis describes the adoption rate, impacts of HEIS on net farm returns, per capita income and poverty (Memon et al., 2021).

Groundwater extraction is linked with cropping intensity and cropping pattern in the area. The selection of crop type and variety is linked with farm income and availability of resources. Cotton, rice and sugarcane are profitable crops and wheat is an important crop in the cropping pattern with these crops. Cash crops are important in terms of farm profit and agri-based industrial sectors in the economy. Wheat and sugarcane contribute to food security and rice and cotton crops contribute to foreign exchange earnings. The water use is high in sugarcane and rice as compared to cotton and wheat as described in Table 5.4.

Table 5.4: Gross margin per unit of water used for cash crops in Sindh. (Source: calculated from survey data in Ashfaq et al., 2021).

Crop	Gross Margin (PKR/ha)	Volume of irrigation (m3/ha)
Wheat	109246.6	6056.8
Rice	140390.6	8224.7
Cotton	151082.8	6410.1
Sugarcane	250048.6	13891.5

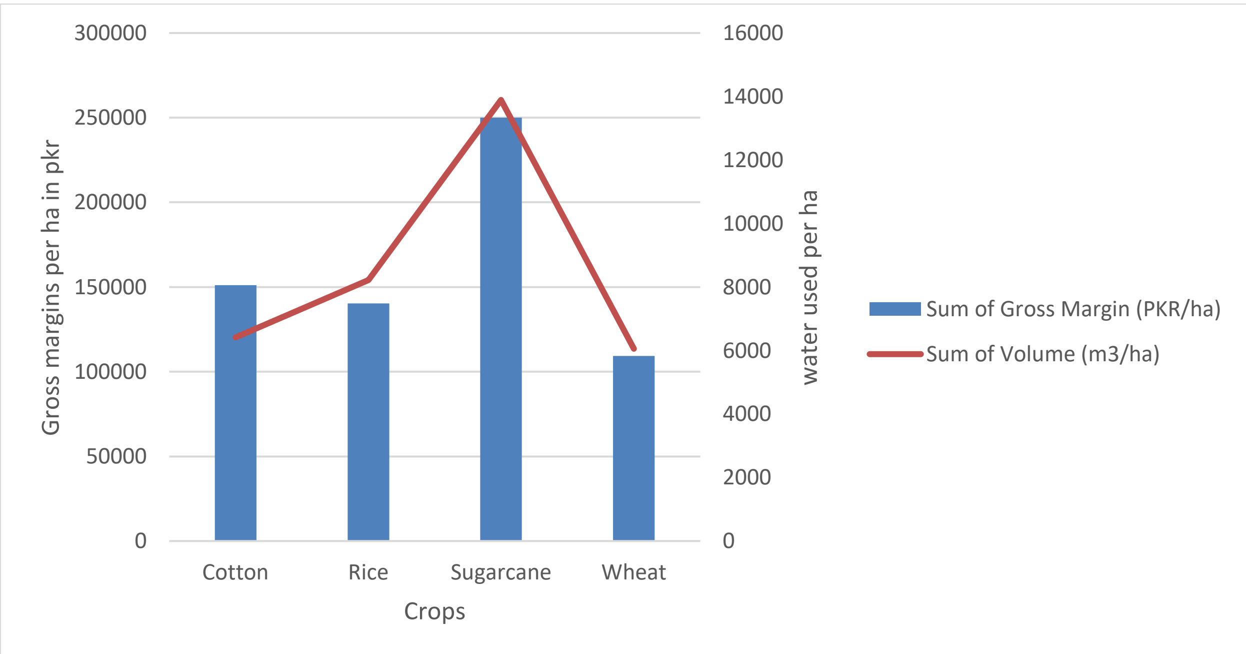


Figure 5.5: Water used for cash crops in Sindh.

Farmers are motivated by farm income and market factors at large for the selection of crops, but over time farmers are sensitive to resource conservation practices. The social cost of farm crops must be analysed and disseminated to farmers for better awareness. Rice and sugarcane are earning high incomes at external cost relating to environmental hazards and water depletion. Figure 5.5 shows the water use is high in sugarcane and rice crops, likewise the gross margins of these crops are also higher due to market factors, international prices and market distortions. The cotton crop is mostly sown on beds and is less water intensive compared to sugarcane, but the area, production and yield have declined over time due to unstable prices tied to international markets, pests, poor availability of quality seed, and climatic factors, especially temperature variability. There is a need to make changes in agricultural policies so that crops are encouraged to match agroclimatic zones to save the natural and environmental resources, especially groundwater.

Well established markets and high net returns leads towards adoption of water loving crops by farmers. These crops are also important to meet domestic food demand. The researchers, policy makers and farmers have suggested adoption of efficient irrigation practices for above mentioned crops to save water and better yields.

5.3.2 Input data used in TOA-MD model

This section provides the details of data that is used as an input in the TOA-MD model that could be helpful in better understanding of results and farming systems. The yield and price factors, secondary and primary level farm statistics are used in the analysis to compute the input data for the model.

The analysis utilizes the yield and price trends from IMPACT (The International Model for Policy Analysis of Agricultural Commodities and Trade) models in the analysis as described in Table 5.5. These trends describe the future price and yield projections for specific crops in specific countries.

Table 5.5: Trend table for yield and price in the mid-century scenario 2050 for Sindh. Source: based on the international model for policy analysis of agricultural commodities and trade (IMPACT) models and RAPs.

Crops	**Sustainable Agricultural Pathways**	
	Price trend	Yield trend (Irrigated)
Wheat	1.26	1.45
Rice	1.289	1.348
Cotton	1.24	1.48
Sugarcane	1.416	1.244

The TOA-MD model includes the historical yields of crops for long term projections. This study utilizes the last five years of crop yield data on provincial basis. It could be utilized at district level also.

Table 5.6 and Figure 5.6 describe the average yield of wheat, rice, cotton and sugarcane in Sindh Province.

Table 5.6: Yields from historical data (Kg/ha) of major cash crops in Sindh. (Source: GOP, 2018)

Crop	2015-16	2016-17	2017-18	2018-19	2019-20	Yields from historical data (Kg/ha)
Wheat	3321.0	3343.8	3339.8	3589.9	3402.07	3399.3
Rice	3574.1	3546.4	3441.6	3725.3	3060.09	3469.5
Cotton	951.8	960.7	1049.7	1114.9	779.848	971.4
Sugarcane	57492.3	63052.0	61839.2	59716.2	59671.7	60354.3

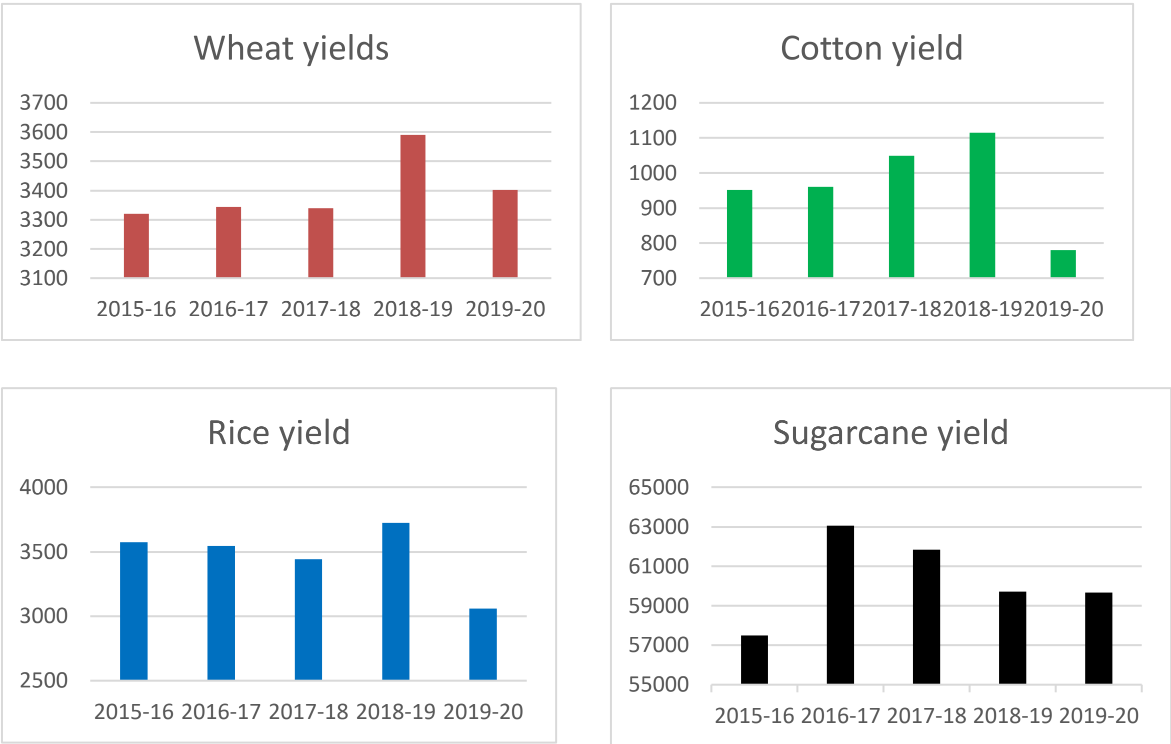


Figure 5.6: Yields from historical data (Kg/ha) of major cash crops in Sindh.

Table 5.7 describes the total farmland (ha), average household size of system (person), coefficient of variation of household size, farm size (ha) and coefficient of variation of farm size in study area. The poverty rate, per capita income, and net farm returns are linked with all these indicators.

Table 5.7: Socioeconomic information of current production system of study area. (Source: GOP, 2018 and ACIAR survey data)

Crop	Total Farmland (Ha)	Average household size of system (person)	Coefficient of variation of household size	Farm Size (Ha)	Coefficient of variation of farm size
Wheat	194453	11	47	2.9	91
Rice	19936	11	41.7	3.2	92.4
cotton	98788	10	44.7	4.3	86.99
Sugarcane	55578	10	47	7.02	106

The input data was estimated utilizing farm statistics for cropped area, variable cost, yield, price and standard deviations of cash crops in the study area. The primary and secondary statistics were used to access the aggregate impacts of HEIS in Sindh Province. Net farm returns of sugarcane are highest as compared to other cash crops. Rice also showed higher returns as compared to cotton and wheat.

Table 5.8: Descriptive statistics of current production systems in the study area. (Source: survey data).

Crop	Cropped area (Ha)	Total Cost (PKR)	Yield (KG)	Price (PKR)	Total Revenue (PKR)	Net revenue (PKR)
Wheat	5547.39	72412.06	3800.39	29.61	112619.2	40207.15
Cotton	2765.04	90571.00	2369.19	62.88	148982.7	58411.67
Rice	1299.74	78041.74	5586.43	26.57	143965.1	65923.36
Sugar cane	5759.90	144588.10	66519.3	3.65	242795.5	98207.42

The use of HEIS has had positive impacts on net farm returns, per capita income for the mid-century scenario and is shown in Table 5.9. Considering the groundwater level decline in the long run along with efficient irrigation system installation the net impacts would be positive on farm livelihoods (Zulfiqar and Thapa, 2021). The increase in net farm returns, per capita income would result in decreasing farm poverty in the study area. The adoption rate is highest in wheat crop that is 43 percent farmers would be economic gainers and increase their returns by sustainable use of irrigation. The adoption rate is 36 percent for cotton, 31 percent for rice and 19 for sugarcane in the study area (Isaev et al., 2021).

Table 5.9: Socioeconomic impacts of adaptation benefits of high efficiency irrigation systems in Sindh. Note: Calculations are based on RAPs and TOA-MD calculations. The poverty line was calculated based on (Rupees/ person/ time) that was 21900 rupees for one season (a seasonal based poverty estimate).

Crops	% Change in NR	% Change in PCI	% Change in Poverty	Potential adoption rate
Wheat	33.64	42.27	-8.6	43
Rice	23.53	31.41	-5.1	31
Cotton	21.77	29.83	-3.23	36
Sugarcane	38.06	46.65	-2.04	19
Aggregate	29.25	37.54	-4.74	32

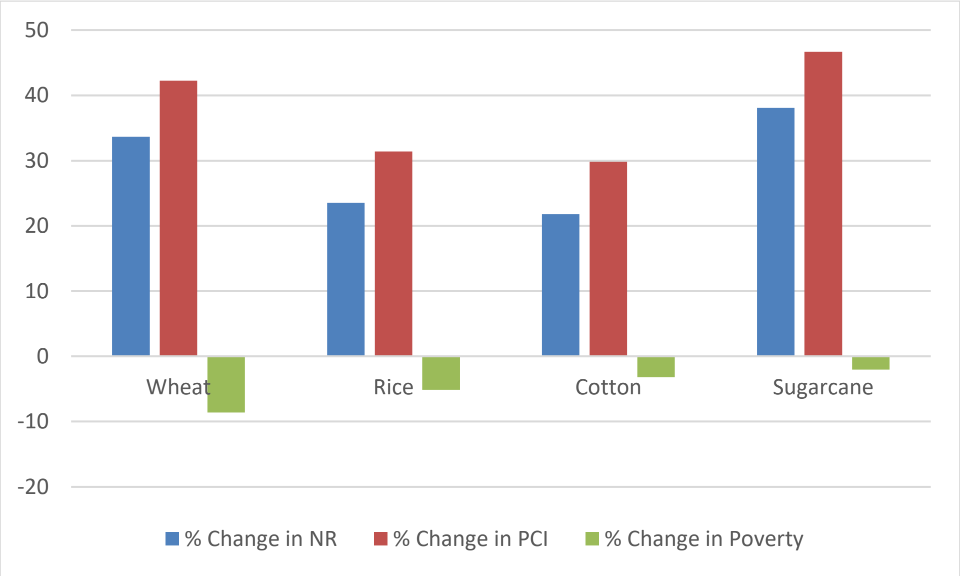


Figure 5.7: Impacts of high impact irrigation systems on net farm returns (NR), per capita income (PCI) and percentage change in poverty in Sindh.

Considering the cost benefit analysis, the adoption of HEIS would increase the farm returns and sustain the farm livelihoods in the long run. The other adaptation option such as crop substitution and cultivation of high value crops needs time for development of market infrastructure and industrial development. Due to persistent pressure on soil and water resource the cultivation of sugarcane must be on marginal lands to meet the domestic sugar demands (Malik, 2005). The rice, cotton and wheat are also important in terms of food security and foreign exchange earnings (Nasir et al., 2020). The HEIS is not a superior system of irrigation for crops like sugarcane that is water intensive especially when water is unfit for irrigation. Its high installation cost, breakage and clogging resulted in net economic loss. HEIS may be a superior system where water is fit for irrigation, free of ferrous and low installation costs (Hussain et al., 2010).

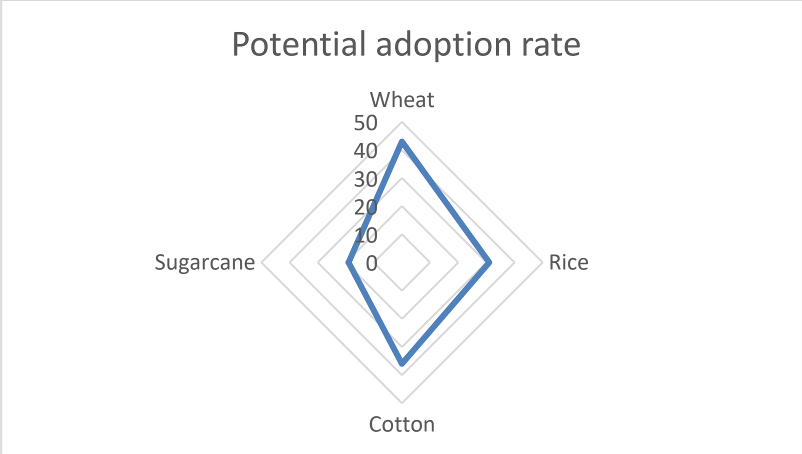


Figure 5.8: The potential adoption rates of major cash crops in Sindh.

The adoption rate of sprinkler and drip irrigation is economically viable, but farmers face technical, financial and administrative issues in terms of adoption (Chovatia et al., 2019). The analysis has provided some evidence on the potential for drip-irrigation systems to transform the agricultural landscape in Pakistan. The results are also supported by Read Bell et al., 2020

5.4 Conclusions for Sindh

The explicit interventions for the study area regarding groundwater management interventions at farm includes, HEIS (ridge and bed sowing, drip and sprinklers), substitution of crops (low delta crops like Quinoa), developing the water markets, enterprise diversification (livestock farming, olericulture, fisheries, argo-forestry), crop diversification (vegetables like onion, okra, chilies, black pepper), intercropping (sugarcane and wheat; okra and onion) and the cultivation of high value crops. The economic viability for HEIS for cash crops in the study area was estimated and results showed that water saving techniques would ensure high farm returns in the long run. The water use efficiency improvement would increase crop yields and farm returns substantially in the study area.

5.5 Policy recommendations

Water resources are important for sustainable farm incomes and must be utilized in an efficient manner to meet the escalating demand for food and fibre. The resource depletion, increasing population, urbanization and climate change poses serious threats towards food security and farm livelihoods. Groundwater in Sindh province is a limited resource as it is available from thin freshwater lenses. for farming. Groundwater over pumping has been increased at large due to shortage of surface water and increasing the cropping intensity. The policies that support the installation of tubewells and subsidized energy rates for agricultural operations leads to depletion of groundwater and its quality that also affects the soil fertility. Area specific farm policies must be devised for efficient allocation of water resources.

The provision of finance for installation of drip and sprinkler and farm machinery for bed and furrow will help farmers to increase the water use efficiency. Awareness programs towards environmental and resource depletion will also sensitize farmers to select the crops that has less external cost.

6 Balochistan Analysis

6.1 Introduction: Balochistan

Formulation and implementation of surface and groundwater laws are linked with adoption of water conservation practices, such as implementation of micro irrigation technologies, and growing high value crops, can boost the water economy (Nikolaou et al., 2020). Farming in Pakistan is complex and varies across regions in terms of water availability, quality and quantity (Angourakis et al., 2020). On-farm management practices, such as the use of fertilizer, soil management, laser levelling, irrigation methods and crop selection result in improving water use efficiency, soil health improvement and water quality (Jovanovic et al., 2020). The Balochistan province is largely affected by climatic changes and the changes in precipitation timing and intensity have badly affected its water resources. Due to a lack of water storage infrastructure, a large portion of surface water experiences rapid runoff without utilisation and is a lost opportunity for recharging aquifers. The efficient allocation of water resources and specific water regulations must be formulated to sustainably manage aquifers, but policies are difficult to implement due to the riparian nature of resources in Balochistan (Akhtar et al., 2021). During dry periods groundwater is the only option of water supply for various human activities, and it needs to be replenished by introducing artificial recharge, watershed management and an efficient irrigation system. Therefore, water related information must be provided that is authentic and workable for farming communities. Specific groundwater policies must be devised and implemented in short run and long run to achieve sustainable farm livelihoods (Nasir et al., 2020; Azhar et al., 2021).

The Balochistan province is largely dependent on groundwater for its water requirements either through Karezes or tubewells. The Karez is the water storage technology that has supported poor communities for centuries. Balochistan is focussing attention on economic growth and development. For example, the recent government has allocated 7000 million PKR for the tariff differential for agriculture tubewells in Balochistan as subsidy to KESC in FY 2021-22). The public investment will boost the productivity to some extent, but it will have long term implication on groundwater level. The number of tubewells has increased from 5,000 to more than 40,000 since the 1970s. Correspondingly, groundwater has been diminishing at an accelerated rate, with the level in some basins declining by more than 5 meters per year (Ashraf and Hasan, 2020). Public policies must prioritize the efficient use of water resources and allocate funds for better and sustainable water management in the area. The installation of tubewells must be regulated and linked with sustainable water utilisation and water recharge.

Groundwater management and reclamation can be improved by social engagement and public sector legislation. The community is already sensitized due to severe drought and water scarcity. The legal framework with public investments in specific areas had long term implications for sustainability in the agriculture sector of Balochistan. The poverty profile of Balochistan is also crucial it is the poorest province of Pakistan with low poverty zone to extreme poverty zones. The multidimensional poverty was estimated from 10 to 76.1 percent in 2015 (PPAF, 2020). The study area falls in extreme Poverty zone 2 that is 56 percent poor. Sindh and Balochistan have the highest rural poverty rates among Pakistan’s provinces (World bank, 2019).

6.2 RAPs process

The Balochistan project team were part of the RAPs training session held in Islamabad (Figure 6.1 and Figure 6.2).

Figure 6.1: Consultative session with stakeholders in PCRWR for RAPs and interventions

Figure 6.2: Consultative session with stakeholders in PCRWR for RAPs and interventions

Following this, an interactive RAPs session was organized in Quetta, where researchers, farmers and policy makers were invited to determine the future agricultural pathways for Balochistan. Biophysical, socioeconomic, technological, institutional and policy variables trends were discussed in specific areas. Researchers, policymakers, farmers and officials from different disciplines were invited to assess the trends for important indicators which helped to formulate future projections for agricultural systems. RAPs were generated for the long-term agricultural development and intervention impact assessment. The consultative sessions and engagement process was an efficient way to determine farm specific management interventions. The socioeconomic impacts and adoption rate of interventions were assessed by using the TOA-MD model (Antle and Valdivia, 2020).

The socioeconomics team organized the interactive session to refine, calibrate and parameterize important indicators that are used in the model. The review of existing literature about specific interventions that could be estimated in TOA-MD model is important in terms of authentication. Balochistan province is significantly varied from other two provinces not only in terms of agricultural production system, geographical and institutional domain but also in terms of socioeconomic and cultural context. The important interventions regarding Balochistan involve institutional development, formulations of rules and regulations, infrastructure improvements, value addition and crop and livestock insurance to boost the agriculture sector and farming livelihoods (Antle and Valdivia, 2021). Figure 6.3 describes the RAPs framework and the projection for sustainable and unsustainable development pathways.

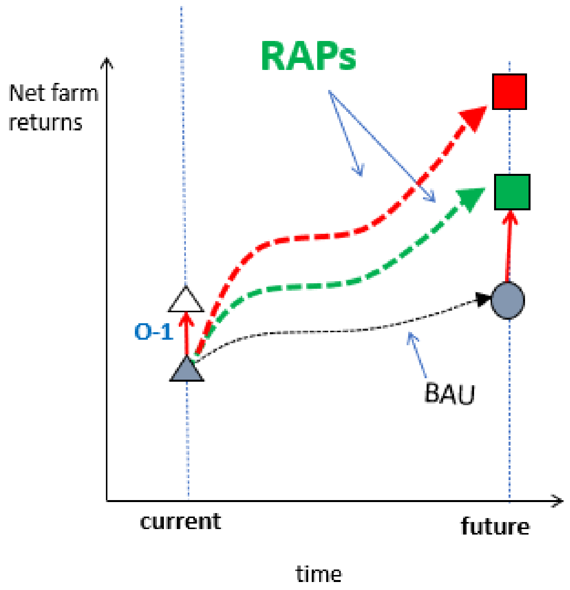


Figure 6.3: Framework for the RAPs in Balochistan.

6.3 RAPs: outcomes and trend table

RAPs were formulated first for the business-as-usual case and then developed for the sustainable development pathways. The trend table for Balochistan agricultural pathways are described below in

Table 6.1 and most interesting thing is that there is consistency among all agricultural pathways' direction. However, the magnitude and intensity could vary among provinces.

Table 6.1: Trend table for RAPs in Balochistan. (Source: developed by the authors based on expert opinion and existing information from the literature).

Variable	Sustainable development Pathway
Farm Size	Decrease ↘
Household Size	Decrease ↘
Non-Agricultural Income	Increase ↗
Herd Size	Increase ↗
Input Prices	Increase ↗
Output Prices	Increase ↗

Public policies prioritize the agriculture sector to achieve food security and sustainable development. The agriculture sector is strengthened through increased public investment to achieve self-sufficiency and improved viability. Investments are made in research, technology, infrastructure and extension services in order to gain sustainable farm productivity. Educational and health investments accelerate the demographic transition, leading to a relatively lower population growth. Government liberalizes imports of food grains, invests in food supply chains and improved research and development. Policies formulated to strengthen the farming system as in enterprise targeting resource sustainability by providing agricultural finance, insurance, improved seed, information and technology transfer through management information system. All resources are allocated efficiently by considering ecological, social and economic implications. Table 6.2 defines the rationale for the RAPs framework.

Table 6.2: Quantification of RAPs for Balochistan.

Indicators	Direction of change	Magnitude (%)	Narrative
Farm Size	Decrease	8	The law of inheritance is the major determinant of division of farms in Pakistan. Mechanization, high returns and emergence of farm business as an enterprise, will decrease at a lower scale. The orchard farms would not decrease at higher pace but division of land and increase in land use value will be evident.
Household Size	Decrease	15	Population is increasing due to religious and social reasons, multiple marriages. But nuclear families are emerging over time.
Non-Agricultural Income	Increase	25	Profitability in agriculture sector, High unemployment rate, Increase in literacy rate in urban area, awareness, emergence of new enterprises
Herd Size	Increase		Profitability, high demand of livestock products due to increase in incomes, economic potential for establishment of milk industry.
Input Prices	Increase		Variable cost of production will increase with the same factor as output price increases. The same ratio (relative prices) determine that the change in prices are real.
Apple Prices	Increase	26	For output prices we have used the global projections and according to our regional conditions rationalized the output prices.
Grapes Prices	Increase	24	

Figure 6.4: RAPs consultative session in Balochistan

6.3.1 Water conservation management interventions

Groundwater management is important in terms of sustainable development and establishment of strong foundation for long term farming practices. The management of groundwater is linked with existing water scenarios of the area especially water quality, availability, distribution and usage. The policy domain regarding water is crucial as surface and groundwater are two main sources for irrigation in Pakistan, Balochistan is the only province that has a legal framework regarding groundwater management under the notification of the “Balochistan groundwater rights administration ordinance, 1978” and WASA Groundwater Management Act of 1989 (GOB 1978; Ashraf and Hasan, 2020). Apart from legal framework there is no implementation of any sort regarding groundwater laws in true letter and spirit due to the prevailing political economy. Informal water trading markets exist in Balochistan which could be utilized for efficient allocation of water resources in the long run.

Water policy and public investments must prioritize the areas that are facing serious drought and flood conditions and the livelihoods of poor communities are linked with groundwater. Water quality is also an important policy consideration, but it is extremely complex to estimate and analyse the quality aspects. The consultative sessions were organized by project teams to better formulate the adaptations in specific regions due to different socioeconomic, geographical and distinct agricultural production systems. The water scenarios are also different in all provinces along with cropping pattern and farming systems.

Figure 6.5: Consultative session with farmers in Balochistan

The intervention regarding efficient allocation of water resources includes HEIS; in this case drip and sprinkler irrigation, cultivation of low delta crops such as pistachio, grapes and pomegranate instead of apples, improvement in current management practices, construction of check bunds for water storage, improved cultivars especially dwarf varieties of apple and tunnel farming (Kakar, 2015; Kakar et al., 2016). The important management interventions HEIS and crop substitution were analyzed and improvement in socioeconomic conditions of farmers projected for the mid-century (2050) scenario due to efficient allocation of resources in the long run. A wide range of adaptation strategies were shared by team members to get their feedback on every aspect. For Balochistan agricultural interventions were compiled in which biophysical, socioeconomic and policy parameters were assessed. A comprehensive package of interventions for improved agricultural systems is listed in

Table 6.3.

Table 6.3: Agricultural systems comprehensive interventions. (Source: based on a literature review and expert opinion).

Biophysical interventions	Socioeconomic interventions	Institutional and policy interventions
○ Improved Cultivars (drought & heat tolerant varieties, short duration varieties, low delta crops like pistachio and pomegranates) ○ Quality seed ○ Plant Population (seed rate, no of plants) ○ Improved Agricultural Management Practices (fertigation, Balanced fertilizer use, Drainage) ○ Efficient Irrigation practices (Drip Irrigation) ○ Changes in cropping patterns ○ Soil reclamation projects	○ Construction of water storage ○ Crop diversification ○ Participatory Management Approach ○ Increasing the off-farm income opportunities ○ Population control measures ○ Agro-forestry ○ Tunnel farming ○ Fisheries, sericulture, apiculture and Livestock Farms	○ Agricultural insurance/finance ○ Farm mechanization (mechanical picker for cotton) ○ Subsidies/Taxation ○ Input/output price policies ○ Trade ○ Efficient Input/ output markets ○ Govt. investments in agriculture (Infrastructure, R&D) ○ Supportive trade policies ○ Farm consolidation

The legal framework for sustainable use of groundwater in Balochistan has been initiated (see above). The public investments that are linked with installation of tubewells in the agriculture sector must be monitored and installed under a legal framework that does not harm the local Karez system. Groundwater rules must be devised considering the location, groundwater discharge and recharge rate. The installation of solar tubewells decreases the pumping cost but increases water extraction which need some regulatory mechanism. Due to water conservation and adoption of HEIS the proportion of groundwater for irrigation has reduced by 27 percent in China and 35 percent in Australia (Latif et al., 2016).

Figure 6.6: Consultative session with farmers in Balochistan

Table 6.4: The management interventions trialled to reduce groundwater pumping in Balochistan. (Source: Balochistan ACIAR team prepared based on stakeholder interaction)s.

Location	Management Interventions at Farm in Balochistan
Kuchlak sub basin	Installation of Piezometer for groundwater level measurement and monitoring Introduction of low delta crops such as pistachio, pomegranate and grapes and HEIS. The details are as follows: o Tomato planted on drip Irrigation for efficient water use in Zarghoon o Apple and Apricot orchard planted on drip irrigation to improve water use efficiency in Zarghoon o Distributed 20 tensiometers among farmers to enable them to measure soil moisture level and plan need based irrigation schedule and avoid over irrigation o Distributed EC and TDS meters to monitor water quality
Pishin sub basin	Installation of piezometer for groundwater level measurement and monitoring Plantation of low delta crops such as pistachio, grapes and pomegranate on drip irrigation to introduce low delta crops and HEIS to improve water use efficiency and promote sustainable agriculture: o Planted young vineyard with improved grape variety on HEIS in Malikyar o A mature apple orchard (14 years old trees) converted from flood irrigation method to drip irrigation to improve water use efficiency in Malikyar o Planted new vineyards with improved grapes varieties on HEIS in Huramzai o Planted new pomegranate orchard with improved grapes varieties on (HEIS) in Huramzai o Pistachio planted as intercrop in mature grapes orchard to replace them in the long run in Huramzai, that will increase farmers' incomes and improve water use efficiency o Distributed 20 tensiometers among farmers to measure the moisture level in soil and plan need based irrigation schedule to avoid over irrigation. o Distributed EC and TDS meters to monitor water quality

6.4 RAPs components

Table 6.5: Biophysical indicators

Biophysical variables	Direction of Change (Increase, decrease, intensity)
Soil Degradation	Same. Because farmers add new soils from the rivers
Groundwater Availability	Will go down. Right now, water levels are 300-800 feet and decreasing 3-7 meter per annum.by mid-century it will go down by 1400-2800 feet. New technology could resolve the issue.
Surface water?	No surface water in the study area but in 2 districts of Baluchistan i.e. Naseer Abad, Jafarabad and Suhbat pur Indus water is available but its supply is decreasing because India is controlling water. Canals are also silting.
Productivity-crops, LS, orchard	Will increase due to better inputs and improvement in technology. LS productivity will decrease due to overgrazing of area. Better breeding could increase productivity
Pest and Disease Infestation	Will increase-medium intensity
Livestock Per Household	Will decrease due to reduction of grazing areas.

Table 6.6: Institutional Indicators

Institutional Variables	Direction of Change
Input Subsidies	Either same or mildly increase due to govt policies and financial situation
Fertilizer Use	Will increase because currently farmers are using less than the recommended doses of fertilizers.
Input Prices	Will increase in nominal terms but real prices will remain either same or increase slightly. If there will be improvement in technology, then both nominal and real prices will increase.
Output Prices	Will increase in nominal terms but real prices will either decrease or remain the same.
Improved Seed Use/varieties/species	Will increase
Government Investment	Will increase both in monetary and real terms to achieve SDGs

Table 6.7: Geographical Indicators

Geographic	Direction of Change
Farm Size	Will decrease due to subdivision, law of inheritance
Cropping Patterns	Will change
Land Use Patterns	Will improve
Other Interventions	Rules of water use, how much to use? Solar system need rules, markets need to develop, value addition for fruits, insurance 1- HEIS-Drip 2- Low delta crops like Pistachio, grapes and pomegranate instead of apples, 3-improvement in the management of existing orchards, 4-check bund for water storage, 5-Dwarf varieties of apples, tunnel farming

6.5 Input of TOA-MD model

This study utilizes the data collected from Kuchlak and Pishin sub-basins of Pishin Lora basin to assess the socioeconomic impacts of groundwater management interventions (Khair et al., 2021). Primary and secondary data was utilized to identify the economic viability of suggested management interventions in the long run. RAPs and management interventions along with farm data were analysed in TOA-MD model to access the economic viability of suggested interventions.

The outcome of any research needs validation of macroeconomic data sets especially the policy domain of all scientific recommendation must have socioeconomic viability for impact. The outcome of ACIAR project and recommendations formulated in the form of intervention supported and formulated by all stakeholders of agricultural production systems. The analysis formulates a broader application of recommendation and the impact on farm livelihoods.

Table 6.8 describes the yield and price trends that are projected for the mid-century scenario.

Table 6.8: Trend table for yield and price in the mid-century scenario 205 for Balochistan. (Source: based on RAPs).

Crops	Sustainable Agricultural Pathways	
	Price trend,	Yield trend (Irrigated)
Apple	1.26	1.45
Grapes	1.24	1.48

The cropping pattern of Balochistan comprised of mainly four major crops: wheat, onion, maize, and barley. In addition to conventional cropping, large orchards of grapes and apples also exist that are well-known for being of high quality. The horticultural crops are a potential area to increase exports due to the China-Pakistan Economic Corridor (CPEC) route and climatic conditions of

Balochistan. The limiting factor is the availability of water that could not allow the upscaling of existing orchard at commercial scale.

The yield of grapes could be increased by 24 percent with a water saving of 48 percent. Drip irrigation was installed in Balochistan in a few orchards but that was not adopted on large scale due to lack of finance for initial investments. The departments/agencies must formulate practical and sustainable programs for adoption of HEIS in the country. Efforts should be made to maximize crop yield by using minimum water i.e. to achieve 'more crop per drop'. In nutshell, water use efficiency and water productivity can be increased by employing best management practices (Latif et al., 2016).

Table 6.9 provides the total farmland and historical yield for Apple and Grapes in Balochistan.

Table 6.9: Farm statistics for apple and grape crops in Balochistan. (Source: GOP, 2018).

Crop	Total Farmland (Ha)	Yields from historical data (Kg/ha)
Apple	87203.5	6466.0
Grapes	95059.3	4343.0

Table 8 describes the socioeconomic profile of apple and grape production in Balochistan which shows the average farm size of apple and grapes are 3 Ha and 2 Ha respectively. The average farm price of one kg of apple is 38 rupees and 70 rupees for grapes. The variable cost of production, yield, market price and gross margins are given below. The gross margin of apple is higher as compared to grapes due to poor marketing of grapes. The farm size, variable cost of production, income, yield, market prices and gross margin of apple and grapes are described under Table 6.10.

Table 6.10: Descriptive statistics of current production systems for apple and grape crops in Balochistan. (Source: survey data).

Crop	Farm Size (Ha)	Variable Costs (VC)	Income (Rs)	Yield/acre (kg)	Market price (PKR/Kg)	Gross Margins (GM)
Apple	3.065	100098	352953	9145.625	38.625	252855
Grapes	2.045	94748	279720	4144	67.5	184972

The agricultural production in Balochistan is largely linked with water availability and all the farming activities largely depend on groundwater. The groundwater is a limited resource and over time without any legal framework and proper management its availability declines and pumping cost has increased substantially. The rational use of water is required in such a drought prone area. The stakeholders suggested the provision of HEIS for orchards could increase the farm income in the long run. The HEIS could contribute largely in the sustainable use of groundwater in the mid-century scenario. The economics analysis done by TOA-MD model for technological interventions calculated the net farm returns, per capita income and farm poverty for the mid-century scenario. The installation of such infrastructure would ensure the efficient allocation of water use and increase the net farm returns substantially. The farm poverty would reduce by 8 percent for apple farmers and 12 percent in grape growers in the study area for the mid-century scenario. Socioeconomic impacts of adaptations benefits of HEIS in Balochistan is enlisted in

Table 6.11.

Table 6.11:Socioeconomic impacts of adaptation benefits of high efficiency irrigation systems in Balochistan. Note: calculations are based on RAPs and TOA-MD calculations.

Crops	% Change in Net Returns	% Change in Per capita income	Change in Poverty*	% Potential adoption rate
Apple	29.96	27.45	-8	42
Grapes	34.38	37.30	-12	48

**Farm poverty is calculated at 1 $ per person per day*

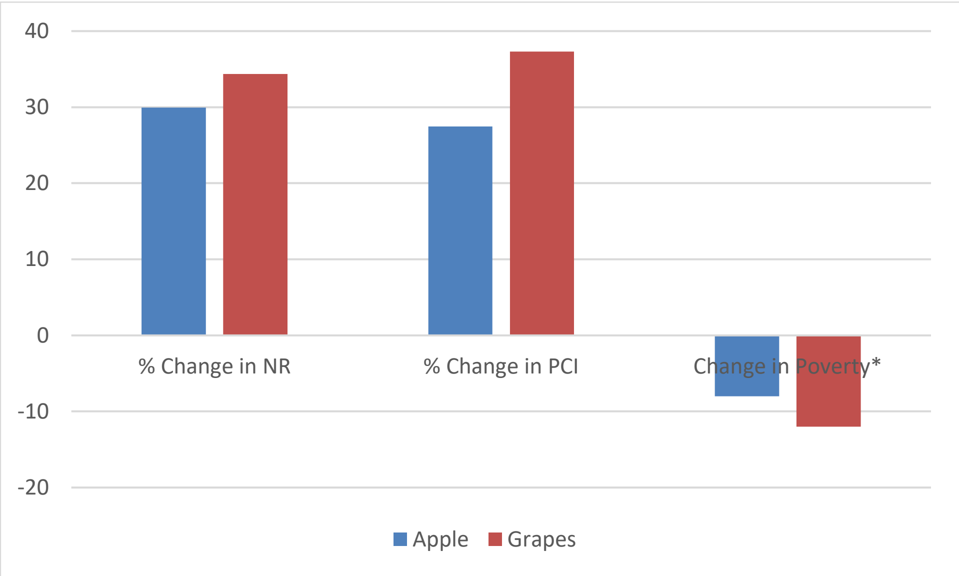


Figure 6.7: Socioeconomic impacts of high efficiency irrigation systems on apple and grape producers in Balochistan.

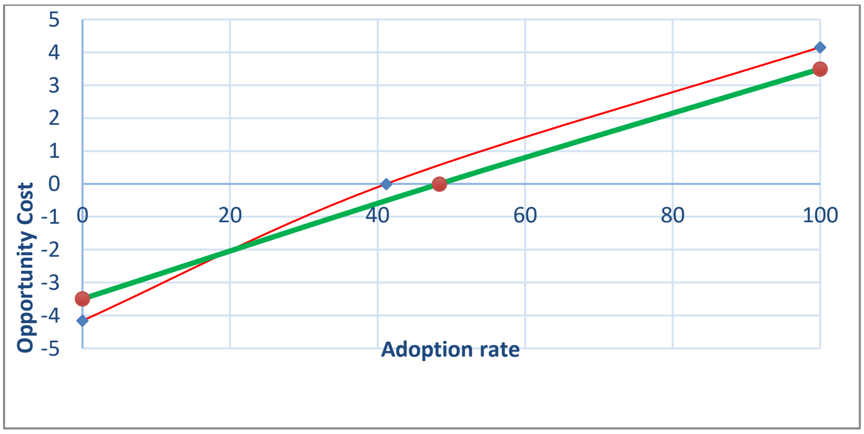


Figure 6.8: Adoption rate of high efficiency irrigation systems for apple and grape crops in Balochistan.

The poverty rate in Balochistan is higher as compared to other provinces. The 2019 household integrated economic survey (HEIS) data estimates show 56.8 percent poverty in Balochistan as compared to 36 percent of national average. Rural poverty is less than urban poverty in this area that determine the potential of agricultural economy for poverty eradication as 70 percent of the population is vulnerable to poverty (Jamal, 2021). By the adoption of water efficient practices, the farm area and production could also increase substantially. This was not included in the current analysis. The awareness about water and soil conservation in farming communities must be provided to sustain the farming livelihoods.

Figure 6.9: Cultivation of tomato crops on a drip irrigation system at Master Agha Muhammad field, Zarghoon

Figure 6.10: New plantation a grape orchard/vineyard using drip irrigation in Malikyar

Figure 6.11: New plantation of a pistachio orchard using drip irrigation in inter college Huramzai

6.6 Policy implications: Balochistan

Pakistan is facing serious food security threats due to climate change. Balochistan could be the leading province in terms of fruit production but the lack of good cultivars, proper marketing and poor infrastructure is constraining agricultural production. Karez and tubewells are important for sustainable socioeconomic development of farming communities. The results indicated that farmers must adopt sustainable practices regarding groundwater extraction and recharge. The following recommendation are formulated based on the outcome of this study.

- High efficiency irrigation system must be provided at affordable prices to farmers to increase water use efficiency and decrease the pumping rate.
- The awareness and engagement of farming communities is needed to formulate sustainable agricultural production systems in the long run.
- The poverty is a serious concern among provincial disparity and especially poverty is high in Balochistan. The agricultural production system could provide sustainable farm livelihoods and decrease the poverty in the long run. Public policies must link markets with distant places in Balochistan for efficient production.
- The suggested management intervention at farm level includes support of low delta crops like pistachio, grapes and pomegranate instead of apple, improvement in the management of existing orchards, check bunds for water storage, provision of dwarf varieties of apples, and tunnel farming.
- The provision of subsidy regarding tubewell tariff differential must link with certain regulations to protect the groundwater aquifers.

7 Reflections on This Work

7.1 Limitations

- The analysis was conducted for a mid-century scenario however, given that the future is unpredictable, there could be many development pathways and future sustainability related parameters that could change the extent of impacts. This study only considers the sustainable development pathways and assumes that there would be enough efforts for resource conservation.
- There is a lack of region and crop specific ex ante analytical impact about water quality and quantity.
- The data about alternate crops was not analysed for other livestock and horticultural crops due to lack of survey data, although it could be a potential enterprise in the study area.

7.2 Suggested improvements

This analysis could be further refined by considering adaptations regarding water harvesting, storage and water prices which are important indicators regarding efficient use of water and agricultural resources for other areas of Pakistan. In addition, the analysis could be performed using more than one pathway and price assumptions for the future.

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Appendix A: Detailed approach as described through the minutes of meetings

Minutes of meeting for Representative Agricultural pathways for Bari Dawab Punjab Pakistan

Day 1: 05-09-2019

Venue: PCRWR Conference Room, Khayaban-e-Johar, H-8, Islamabad

Participants: Dr Muhammad Ashfaq, Dr Irfan Ahmad Baig, Dr Tehmina Mangan, Dr Fateh Muhammad Mari, Dr Syed M Khair, Dr. Ishfaq Ahmad, Mr Zamir Soomro, Javaria Nasir

Time: 9:00 am to 4:00 pm

Consultative Session started with the Recitation of Holy Quran. Presentation on RAPs and process of development of RAPs was presented by Dr. Muhammad Ashfaq. The important indicator regarding model parameters were discussed in RAPs session with participants on key parameter selection regarding future scenarios.

Groundwater is important component regarding crop productivity and continuously depletion of resource threatens the future of water availability. The future is unpredictable, uncertain and it is difficult to formulate one model that can portray future scenarios. RAPs are designed to build the plausible future scenarios with the help of continuous engagement process that involves experts with sound knowledge and skills to draw the future scenarios. The important indicators to conserve water are to change the high delta crops with low delta crops, introduction of new water efficient seed varieties and sustain the oilseed crops and industry for study area. This project is efficient in terms of improved communication and outreach with farming community of research area. The ***apna pani*** app must be shared with communities. The information of peso meter was acquired by stakeholders in the session.

Biophysical Indicators:

Soil quality:

Soils degraded due to high cropping intensity in bari dawab[1] area, coupled with lack of organic manuring, decline in water quality, and high use of fertilizer. All of these resulted in to hardening of soil and degrade its texture. At the same time there are some good government interventions regarding soil testing and awareness programs regarding soil health through extension workers that works well and create awareness in farming community to sustain the soil health. All the participants were agreed that soil degradation will decrease due to farmers awareness in future

[1] A doab is the land formed between two rivers

Surface Water Availability:

Dam capacity is declining continuously due to silting and high temperature. The effect of high temperature will increase the water flow but it will be in form of floods and maximum water will be wasted due to poor management and storage capacity.

Groundwater availability:

Groundwater exploitation is high as compared to recharge options and there are maximum number of tube-wells installed to extract water. In future government will not give subsidy on tube-well installation and some regulations will be ensured by policy makers to sustain the agriculture of this area.

Livestock availability and productivity:

Livestock sector is important livelihood option for the farming community specifically in study area. Commercialization, Improved breeds, Better management practices and high demand will result into high number of animals and quality of produce.

Pest and disease attack:

Pest and disease attack will be increased due to climatic variations and resistance in pest and viruses. Crop complex in mix cropping zone faces big threat regarding pest and disease attack. Conversely policy interventions regarding land use pattern, pesticide and technological advancement, genetic revolution will control the pest and disease attack.

Livestock per household:

Technological advancement, new breeds, commercial farms, high demand of LS products, small farm lands

<u>Institutional Parameters</u>

Input Subsidy:

Efficient and sustainable farming, high competition of resources, corporate culture in farming

Improved Seed Use:

Seed availability is low at this time but with advent of technology and corporate sector in seed industry the seed availability would increase over time. Approval of Breeders act and new seed companies enter into seed market. World giants in seed industry just started their operation in Pakistan. In mid-century the seed availability would be much higher and farmers are already sensitive towards high quality seeds

Input Prices:

High demand for input will increase the price level,

Output Prices:

Global food prices are either declining or remain stagnant from last two decades. Government is not capable to increase the price level without increase in world prices.

Government Investment

Investment in agriculture will remain same in terms of GDP ratio.

Socioeconomic Parameters

Labour Availability:

Urbanization, Migration, literacy level, labour displacement, mechanization

Population Growth rate:

Population growth rate is declining continuously.

Female participation in agriculture:

Education in female, social aspects

Nonfarm Income:

Improved mobility, Connectivity, migration, education, Industrialization, value addition

Technological Parameters

Improved Cultivars:

GMO's, Corporate sector, multinational companies, farmers awareness.

Productivity trends:

Value addition, commercialization, competition, high food demands

Mechanization:

Farm implements, zero tillage machinery, DSR, labor shortage, high cost of labor, advent of latest technology

Geographic Parameter

Farm Size:

Direction: Decrease Magnitude: 8-10%

Cropping Pattern:

Cropping pattern will be changed substantially according to climatic and market situation. In the study area crops are changed quickly due to suitability of biological and climatic conditions to various crops.

Day 2: (6-09-19)

Time: 9:30 am to 1:00 pm

Participants:

Recitation of Holy Quran

Review of Day 1 RAPs activity

Difference of opinion on some biophysical variables especially regarding soil fertility and input subsidy.

Soil Fertility: (Increase)

Climatic scenarios predict the floods and huge use of fertilizers added, cropping intensity increased substantially, bad governance, and all these factors would reduce the soil quality substantially. At the same time, it will be at low pace as farming awareness and experience would guide them to sustainable practices. Soil testing facilities, extension facilities, international demands for organic farming and biological control could positively affect. Low organic matter, High temperature, Climatic conditions, rainfall intensity increased that would increase the soil erosion. Soil fertility, soil erosion and soil productivity separately addressed.

Groundwater:

Population increased and number of tubewells would also increase substantially but in future a greater number of tubewells are not possible with reference to acreage allotment. Water scenarios would be better if groundwater policy was implemented properly.

Surface Water Availability:

Diyameer Bhasha dam is only for electricity and not mainly for irrigation. So at present water availability will remain same at farm gate. Need more input from agriculture department.

Subsidy: No Change

Green box, red box, Ambre box (10 years' time period to eliminate)

Green Box subsidies (Certain level of GDP you can provide to agriculture. Fertilizer subsidy, solar subsidy, irrigation subsidy.

Gender Diversity (Female participation in agriculture)

Way Forward:

Ranges are more relevant than exact figures for model calibrations.

There must be some background data and scientific knowledge and analysis to fixing the future parameters value.

Discuss about the socioeconomic reports.

Socioeconomic team will develop RAPs for their analysis

Report and DevRAP matrix will be available by the end of September.

Minutes of meeting for Representative Agricultural Pathways for Bari Dawab Punjab Pakistan

Date: 25-11-2019

Venue: MNSUAM

Participants: Dr. Muhammad Saifulah, Dr. Khuda Bakhsh, Asad Naseer, Salman Awan, Mahreen Alam, Tayyaba Hina, Afzal Baig, Dr. Amin, Dr. Shiraz Akhter, Nabeel Ijaz, Asghar Ali, Dr. Sami Ullah, Ali Imran, Umar Farooq, Dr. Muqarrab Ali, Dr. Umar Ijaz, Rasheed Ahmad, Banish Sarfraz, Wakeel-ur-Rehman, Rida Afzal, Zeeshan Ahmad, Ihtisham Ali and Muhammad Faraz

Coordinator: Dr. Muhammad Ashfaq and Dr. Irfan Ahmad Baig

Consultative Session started with the Recitation of Holy Quran and Introduction of RAPs development process and objectives.

The main points discussed during the session comprised of Water saving technologies and methods, Socioeconomic reforms till 2050, Institutional reforms (marketing and administrative improvements) and technological factors.

Irrigation:

Hydrological efficiency could be increased by various ways and most important factor in groundwater efficiency improvement is farmer awareness about this precious resource and ways through it could be utilized on sustainable basis.

- Increased farmer awareness, knowledge and financial resources.
- Cropping technology improvements.
- Avoid over irrigation and flooding
- Water education in masses and society to aware next generations
- Decreasing the gap between research, academia, farmers and policy makers
- Better measurement tools in irrigation department for monitoring and facilitation of farmers
- Ensuring the availability of water to farmers at critical timings like sowing, fertilization etc.
- Water harvesting and improving the soil health is also important in terms of sustainable farming
- Training of target stakeholders related to water management including farmers and government officials.

Socioeconomic factors:

- Efforts to improve the human capital and growth
- Education of resource depletion resource conservation and resource management especially water.
- Maintenance of water courses in terms of lining and cleanliness

- Area specific policy formation to facilitate farming community to better combat the challenges.

Institutional Factors:

The marketing, research and infrastructure improvement are crucial for current agriculture to increase the farm returns.

Efforts to produce quality produce and strengthen the value chain to ensure the quality maintenance in whole value chain. Minimize the marketing losses

Formation, implementation and Monitoring of groundwater policies

Future scenarios:

- All input subsidies would be dissolved
- Improved seed use would be increased substantially
- Extensive variations in cropping patterns and crop shifts would be sudden and frequent
- Use of electronic markets would be increased for marketing of input and output
- Agricultural sector needs serious efforts to sustain the farm lands. Land use policy is needed to stop urban sprawl and to save the farm lands
- Recent development regarding agroecological zoning must be shared and policies must be integrated with these zones.
- Market risk of farm produce must be address to stabilize the farm incomes
- Improvements in water use efficiency like 50 percent increase in WUE
- Increase in foreign investment in agriculture sector and corporate farming
- Strengthening of agriculture department and better services and policies will be in future that would result in better management practices for irrigation, pest control, sowing, harvesting and marketing of farm produce
- Increase in green manuring due to increased demand of organic food and strict export policies. Technology improvement would also help in increasing the soil health and organic manuring.
- The future cropping pattern would be changed extensively and new cross will be introduced in farming and present cross could be interchanged in different areas according to variation in climatic and other biological factors.

Research for a changing world

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