SUSTAINABLE AGRICULTURE DEVELOPMENT IN KOHISTAN REGION OF SINDH PROVINCE: AN OPTION AND OPPORTUNITIES A-CASE STUDY

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ABSTRACT

Kohistan is a harsh land depending on the rainfall, flash floods, and groundwater sources. The source of the agriculture in the study area also depends on the same sources. Sustainable development in agriculture is a challenging issue due to various factors of water availability, climate change, and prolonged dry spells. Onion was the major crop cultivated on 173.7 ha followed by wheat (82.6 ha), vegetables (65.5 ha), fodder (50.6 ha), carrot (44.5 ha), Jujube (2.1 ha), cotton (1.2 ha) mango on 0.8 ha. The crop water requirement of these crops was estimated as 201307.5 $m^{3.}$ Thus, a great loss of water was estimated due to poor water management and traditional irrigation methods i.e. flood and furrow practiced in the area. For sustainable and profitable agriculture, it is recommended that farmers should be motivated to switch over from traditional to innovative methods of irrigation such as drip, sprinkler, bubblers, and subsurface, as these are high water application and high water use efficiency methods. Nine times more area could be cultivated with innovative practices on the same water availability. However, the farmers of the area should be made aware and trained to run these systems of irrigation. In addition to this, rainwater should be harvested at its maximum by constructing delay action dams, storage dams, and ponds in the catchment area. The Government should subsidize the cost of innovative irrigation systems and give loans to poor farmers on easy terms and conditions.

Keywords: Agriculture; deep well; dug well; innovative; rain-fed; sustainable

1. INTRODUCTION

The poverty of the eco-environment and the short benefit of farmers in rustic areas have posed major challenges to achieving Sustainable agriculture Development (Hu et al., 2022; Siyal et al., 2022). Mountains are home to a tenth of the world's population and cover a fifth of the world's landmass. For most of us, mountain regions offer landscapes of spectacular scenic beauty, but we fail to see the lives and struggles of the people who exist in the mountains, numerous of whom are poor and marginalized (Hofer and McGuire 2003). The soil degradation process in the hilly track by erosion is mostly the restrictive issue linked to sustainable agriculture (Niacsu et al., 2022). On a worldwide average, one in eight people is food anxious, but in rural mountainous regions, the ratio is one in two. This means that around 300 million mountain people are fed, and half suffer from chronic hunger (Hofer and McGuire 2003). Rural-urban migration has significant socio-economic and environmental impacts in mountainous regions. In response, most rural development programs discourage depopulation because it has negative social consequences and compromises environmental sustainability (Grau et al., 2007).

Pakistan has finite water resources. Due to ever increasing population of the country, the availability of water is decreasing day by day. According to a survey, the per capita availability of water was 2961 m^3 in 2000 which decreased to 1420 m^3 in 2005, and less than about 800 m^3 per capita by 2020 (Economic Review of Pakistan, 2003; Panhwar et al., 2022). Furthermore, it has been predicted that in 2025, like other countries of the world, Pakistan will be a water scarcity country, and this would be a disastrous situation for the country (IWMI, 2000).

Water is one of the main obstacles to Pakistani agriculture, severely affecting crop yields. This situation is more acute in rainy areas (Barani), since the rains in these areas are irregular, unevenly distributed, and do not arrive on time. Besides that; drought conditions that have prevailed from time to time have exacerbated the problem. The FAO and the World Food Program (WFP) have stated in a report (2001) that the prevailing drought conditions have severely affected the rainy areas of Pakistan. Rainfall during the winter harvest season (January to March) was between 50% and 80% below average in most parts of the country, reducing rainfield production by about 70% below average production (FAO/WFP, 2001; Soomro et al., 2019).

The current study was conducted in Kohistan, Deh Desvi, in the Jamshoro Sindh district. It is in the Khirhar National Range in the Sindh Province of Pakistan. People and agriculture depend on rainwater harvesting (Soomro et al., 2022; Shah et al., 2020). Therefore, the area is called rain-fed. The climate of the region is arid to semi-arid. The annual average rainfall is about 250 mm (Memon et al., 2019), while evaporation ranges from 1750 to 3000 mm. The area is hot and dry in summer and cold enough in winter. June is the hottest month, with a mean maximum temperature of 44°C, while January is the coldest month, with a mean minimum temperature of 15°C. Rain falls mainly in the monsoon season (from July to August). However, there is some precipitation in March and April as well. The soils of the area are the leaching of the adjacent hilly areas and have a coarser texture mixed with small pebbles and gravel (Piedmontese soils). The workability of such soils is high, while the water retention or moisture storage capacity is low. The source of income for the people of the region is animal husbandry and small-scale agriculture. The irrigation system is mostly the Barani Nai (Spate/Rod) (Soomro et al., 2020). However, ground waters from dug wells, deep wells, and some spring waters are also used for irrigating crops. Wheat, onion, vegetables, fodder, and some fruit crops are the cropping patterns in the area. The water from dug wells and deep wells was pumped out which is used through furrow and check-basin systems of irrigation. Due to this practice, the water loss was estimated at 30-40% (Memon et al., 2010). A field survey was conducted in detail, using Rapid Rural Appraisal (RRA) techniques. This technique encourages the use of mixed study methods many of them informal in approach, with data collected through various organizations.

2. MATERIAL AND METHODS

To assess the opportunities for sustainable development of agriculture, the study was conducted on the part of Kohistan namely 'Deh Desvi', district Jamshoro was selected as a case study area. For this purpose, a field survey was conducted in detail, using Rapid Rural Appraisal and Planning (RRAP) techniques. This technique encourages the use of mixed study methods many of them informal in approach. This permits some triangulation of observation accepting the lack of quantitative accuracy in favor of a better qualitative understanding of the total system.

The field survey was carried out in the year 2021. Under this survey, 200 interviews were conducted with landowners, farmers, and field workers. The questions asked by these persons were the Landholding, Crops cultivated/cropping patterns, Source of irrigation water, Source of irrigation water extraction, Groundwater recharge, the volume of water used for the different crops, Methods of irrigation followed, and the yield of different crops.

Apart from this survey, the secondary data was collected from the (Annual Report 2005) Revenue Department of the Tehsil Headquarters, Reports of the Pakistan Agricultural Research Council (PARC), Rod-Kohi, Spate Irrigation, and the Centre Pivot projects, Surface Water Hydrology through Water & Power Development Authority (WAPDA), The data was then analyzed and tabulated and some calculations were made for interpretation on various aspects. Finally, the recommendations were made for the development of sustainable agriculture in Kohistan (hilly areas) / rain-fed areas of Sindh.

The research study is based on the following PDCA cycle, which continues the loop of planning doing, checking, and acting. It offers a straightforward method for dealing with issues and directing change.

Before revising processes and working practices, the model helps test improvement initiatives on a small-scale Figure 1.

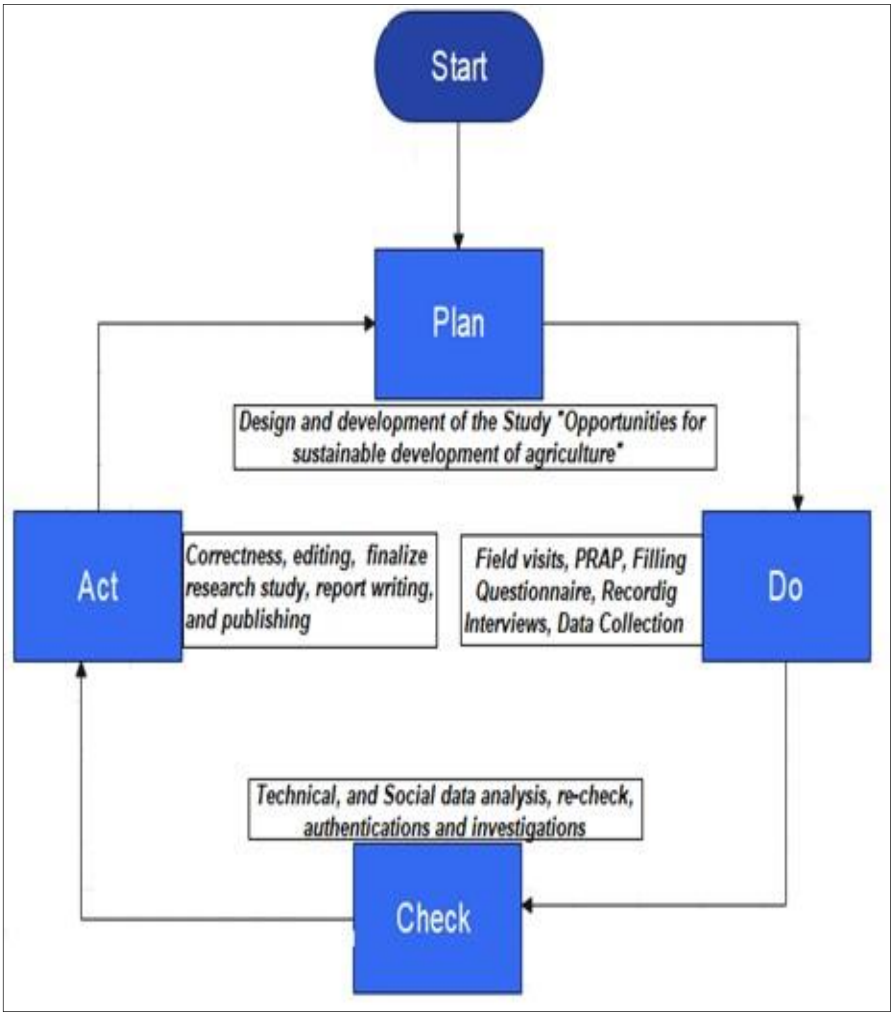

Figure 1. PDCA cycle for the study

2.1. Indicators:

The following metrics were examined to determine the validity of the experimental techniques Used to authenticate the tools used for sustainable development. Depending on the indicators of the economic, social, and environmental spheres, the socioeconomic circumstances are improved through the economy. These indicators were taken into consideration, and the sustainability indicators were also recorded using the questionnaire during the PRAP (Figure 2.).

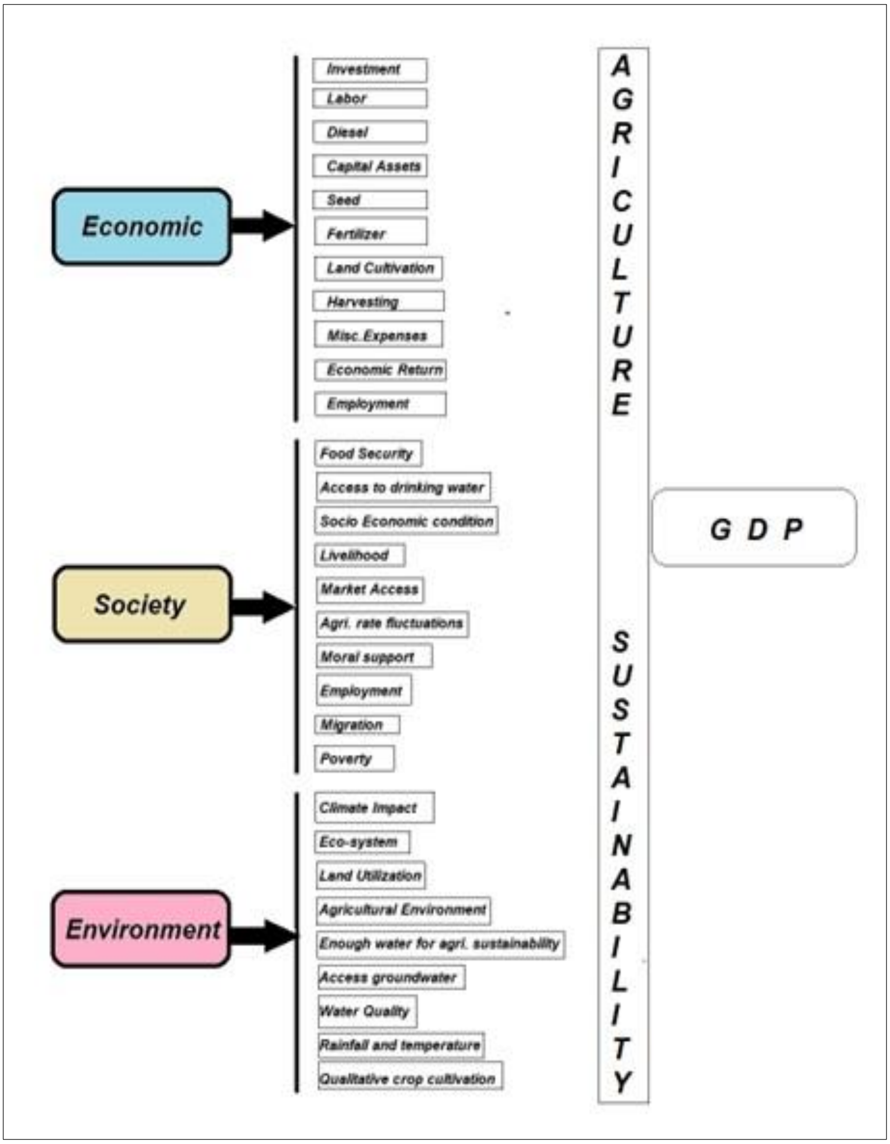

Figure 2. Economics, society, and the environment indicators

2.2. Irrigation efficiency (Ea):

By dividing the total water usage by the crop irrigation requirement (CIR), irrigation efficiency (Ea) was computed. Irrigation efficiency should, wherever feasible, be computed rather than assumed because it largely depends on the kind of system, the farmer's irrigation practices, and other case-specific considerations. In the current case study, farmers are using furrow and flood irrigation systems. The flow of irrigation for incoming and outgoing was estimated using the cut-throat flume (Picture 1, the entire amount of water used was determined using the empirical equation 1.

$$\boldsymbol{Ea} = \frac{\boldsymbol{CIR}}{\boldsymbol{Total\,Water\,Use}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Picture 1. Measuring Discharge through cut-throat flume

3. RESULTS AND DISCUSSION

Table 1 represents that 421 hectares of land were being cultivated by underground water resources through different water pumping sources like dug wells, deep wells, and Persian wells different sources of irrigation at different locations of the deh Desvi. The survey was conducted from different locations within the study area. In addition, the total number of 36 dug wells, 11 deep wells, and 4 Persian wheels (dug ponds) cultivated 178.6, 237.4, and 5.0 hac respectively, a total of 421 hec of land under various modes of groundwater sources. However, about 4745 hectares were cultivated under flood irrigation through the Spate/Rod-Kohi irrigation system.

Table 1. Location-wise Area Cultivated Under Different Sources of Irrigation in 2021

Location	**Mode of Groundwater Extraction**				**Land Cultivation under rainwater Harvesting (flood/spate)**
	Dug wells	**Deep wells**	**Persian wheel**	**Total**	
Number of sources	36	11	4	51	
	Land area Cultivation (hectares)				
Baro Road	14.3	72.9	-	87.2	837
Desvi Nai (Left)	92.3	-	2.5	94.8	655
Desvi Nai (Right)	72.0	-	-	72.0	880
Mandir (Left)	-	64.8	-	64.8	220
Mandir (Right)	-	99.7	2.5	102.2	135
Gadooro Hills	-	-	-	-	2018
Total	178.6	237.4	5.0	421.0	4745

Table 2. Water Available at Different Sources and Areas Cultivated under Different Crops in Rabi and Kharif in the Year 2021

Available Water (m^3)	**Source of Water**				
	Dug well (m^3)	**Deep well (m^3)**	**Persian wheel Ponds (m^3)**	**Rainwater* (m^3)**	**Total (m^3)**
	124648	165522	3400	1578750	1872320
Crop	**Area cultivated (ha)**				**Total (ha)**
Wheat	27.5	55.1	-	-	82.6
Cotton	1.2	-	-	-	1.2
Onion	72.9	99.6	1.2	-	173.7
Vegetable	27.5	34.4	3.6	-	65.5
Carrot	20.2	24.3	-	-	44.5
Fodder	28.3	22.3	-	-	50.6
Mango	0.8	-	-	-	0.8
Jujube (Bair)	2.1	-	-	-	2.1
Total	180.5	235.7	4.8	-	421.0

*During 2021, 375 mm of rainfall occurred in different months which has been calculated based on 421 hectares of land cultivation.

The numerous crops grown under groundwater and rainwater during the 2021 Kharif and Rabi seasons are shown in Table 2. The total available water (groundwater) in dug wells, deep wells, and under Persian wheels in 2021 was estimated as 124648, 165522, and 3400 m3 respectively. Thus, the total water at these three sources was 293570 m3, which was used for cultivating the different crops on 421 hectares in Rabi and Kharif through furrow and flood methods of irrigation. Similarly, during the reported period, about 375 mm of rainfall occurred in different months which were estimated as 1578750 m3 based on 421 hectares of different crops. Thus, the total water including rainfall used for irrigation for different crops on 421 hectares in the year 2021 was 293570 + 1578750 = 1872320 m3. However, the effectiveness of rainfall received during the crop growth period is to be considered.

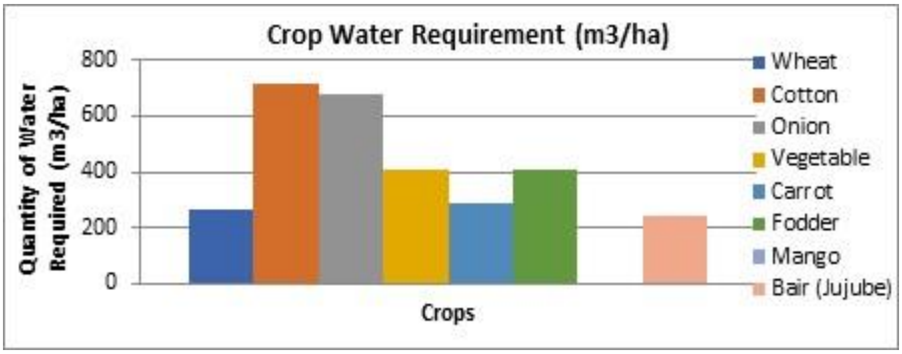

Figure 3. Crop water Requirement for each crop in the existing study area

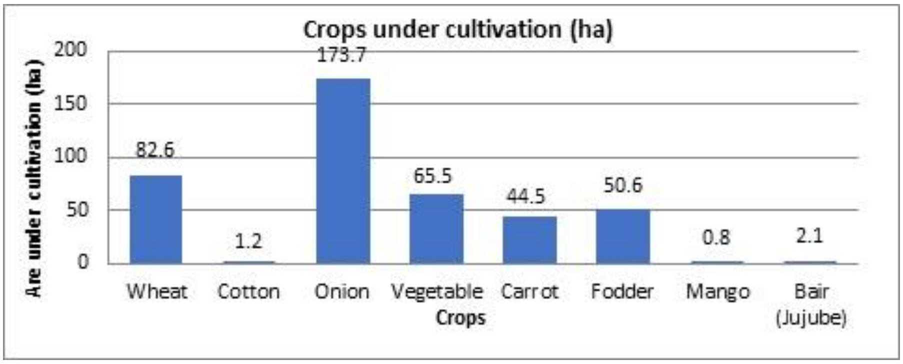

Figure 4. Cropping area in the study.

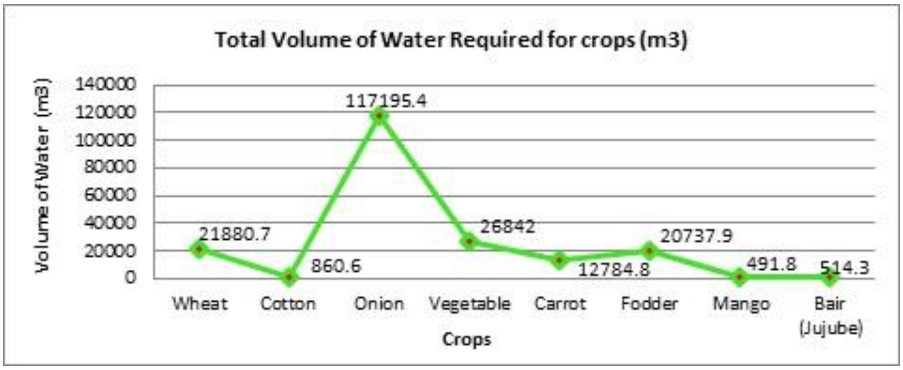

Figure 5. The volume of water required for existing crops(m^3)

It can be seen from Figures 3 to 5, that the total water demand of various cultivated crops in 2021 was 201307.5 m^3 consumed on 421 hectares of land. Whereas the total water (groundwater + rainwater) available in the respective year was about 1872320 m^3 shown in Table 2.

Table 3. Estimated Irrigation Application Efficiency

Method	Application Efficiency, Ea (%)		Total Evaporated (%)	Total Use Consumed (%)	Loss of water (%)
	Range	Average (%)			Average (%)
Actual estimated					
Furrow	-	70	8	78	22
Flood	-	55	10	65	35
As per recommendations by the literature					
Sprinkler	55-85	75	10	85	15
Centre Pivot	75-98	90	10	100	0
Lateral Move	70-95	85	10	95	5
Micro Irrigations	70-95	90	5	95	5

Table 3 depicted that the irrigation application efficiency was recorded at 70%, and 55% for furrow and flood irrigation systems respectively. Consequently, the water loss was recorded followed by 8% and 10% for evaporation, while 22%, and 36% for miscellaneous losses accounting for the seepage, conveyance, and infiltration rate. However, similar data was referenced (19), in the second part of Table 3. For Sprinklers, Centre Pivots, Lateral Move, and Micro Irrigation systems 0 to 5% losses. That means the innovative system of irrigation consumes more water with less losses.

3.1. DISCUSSION

The total area of Deh Desvi is 19578 hectares, out of which 14411 hectares (73.6%) of land may be cultivable but only 5166 hectares (26.4%) were under cultivation (Annual Report, 2005). Some locations have not dug well installation on both sides of the Mandir and in the Gadooro hills. Dug wells show the availability of shallow groundwater availability in the study area (Memon et al., 2021). Which shows the unavailability of shallow aquifers in the discussed locations? Similarly, the Desvi Nai (the channel of the natural stream), showing with no deep aquifers. The groundwater resources do not exist in the location of the Gadooro Hills. To assess the actual water requirement of the different crops cultivated in the year 2021 in the study area, their water requirements based on the consumptive use of water have been estimated following the Field Manual of On Farm Water Management (1997). These are given in Figure 3.

Therefore, it can be assumed that poor water management practice was implemented in the study area, as a loss of approximately 1671012 m^3 of water was estimated. However, the amount of rainwater could be less when calculating its impact on plants. In any case, it is a fact that the efficiency of irrigation application under flood or check basin and furrow systems irrigation systems does not exceed 40 to 60% (Chandio et al., 1995; Bureau of Reclamation, 1997).

If the above available water had been used based on consumptive use, more than 9 times the area could have been cultivated in the respective year, thereby more crop yields and more income would have been obtained. Apart from this, if the available water was used through micro irrigation systems, certainly, more area would have been cultivated as micro irrigation methods are well known for higher water use efficiency, higher application efficiency, and water saving in comparison to traditional methods of irrigation. Thus, there are bright prospects and possibilities for sustainable and profitable agriculture in the Kohistan areas of Sindh provided the recommendations made in this paper are followed seriously. These innovative systems of irrigation are not only high water use and high application efficiency systems but are also capable of saving 50 – 60% water, 25 – 35% increase in yield, better quality production, and less labor cost, etc in comparison to furrow and flood methods of irrigation as reported by (Asgari et al., 2007; Babar et al., 2008; Memon et al., 2005; WRP, 2023) and many other scientists and researchers.

4. CONCLUSION

The study area which is situated in Kohistan of Sindh is a rainfed (water-scarce) area, where people and agriculture, including livestock, depend on rain and limited groundwater. Besides spate irrigation, irrigation through dug wells, deep wells by pumping, and Persian wheel ponds (groundwater) were being practiced in a limited area by cultivating some selected crops following traditional methods of irrigation i.e. flood and furrow. The total water available in the area during the study year (2021) was about 1872320 m^3 by which 421 hectares of land were irrigated, whereas the total water requirements of crops grown were estimated as 201337.5 m^3. Thus, a great loss of water was observed, by following the traditional methods such as flood/check basins and furrow systems of irrigation.

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Author's Contribution

Each author contributed significantly to the completion of this study: Aneela Hameem Memon: Conceptualization, methodology, and data analysis. Abdul Ghani Soomro: Data collection and fieldwork in the Kohistan Region. Gohar Ali Mahar: Review and editing of the manuscript. Ambar Sanam Laghari: Writing and drafting the final manuscript. Amir Khan Jamali: Conducted field surveys, Participatory Rural Appraisals (PRA), from the Kohistan Region. All authors read and approved the final manuscript.

Ethical considerations:

This study was conducted in the Kohistan Region under the supervision of Dr. Aneela Hameem Memon. Ethical approval for the study was obtained in line with institutional and professional guidelines to ensure compliance with ethical research standards.

Data collection involved conducting physical surveys and Participatory Rural Appraisal (PRA) with residents. All participants were informed about the purpose of the study and provided their verbal consent to participate. They were assured of the voluntary nature of their participation, their right to withdraw at any time, and the confidentiality of their responses. Efforts were made to minimize any discomfort or intrusion during data collection.

The study actively engaged all authors in the data collection process to maintain transparency, ensure accuracy, and uphold ethical research practices. Participant privacy was respected, and data was anonymized to protect their identities.

REFERENCES

Annual Report. (2005). Revenue Department, Government of Sindh, Thana Boula Khan.

Asgari, K., Najafi, P., & Solyimani, A. (2007). Effects of treated wastewater on growth parameters of sunflower in the irrigation treatment conditions. Crop Research-Hisar, 33(1–3), 82.

Babar, M. M., Yaseen, S. M., & Shaikh, A. H. (2008). Assessment of water use efficiency, soil salinity, and system performance of drip irrigation. In Proceedings of the International Conference on Agriculture, Food and Animal Sciences (pp. 53–56). Sindh Agricultural University, Tando Jam.

Bureau of Reclamation. (1997). Water measurement manual (Rev.). U.S. Bureau of Reclamation.

Chandio, B. A., Yaseen, S. M., & Rao, M. I. (1995). Comparative suitability of drip irrigation over furrow irrigation. In Proceedings of the 5th International Micro Irrigation Congress for a Challenging World (pp. 526–531). Orlando, FL, USA.

Economic Review of Pakistan. (2003). Pakistan water resources, problems, and remedies. Economic Review, 33(7), 19.

FAO/WFP. (2001). Global information and early warning system on food and agriculture: Crop and food supply assessment mission to Pakistan. Special Report.

Gadehi, M. A. (2010). Water use efficiency and saving through pitcher and polyethylene bag over furrow irrigation. Pakistan Journal of Agricultural Engineering and Veterinary Sciences, 26, 16–29.

Grau, H. R., & Aide, T. M. (2007). Are rural–urban migration and sustainable development compatible in mountain systems? Mountain Research and Development, 27(2), 119–123. https://doi.org/10.1659/mrd.0906

Hofer, T., & McGuire, D. (2003). Beyond the International Year of Mountains: A preliminary assessment by the FAO, the United Nations lead agency for IYM2002. Mountain Research and Development, 23(1), 80–83. https://doi.org/10.1659/0276-4741(2003)023[0080: BTIYOM]2.0.CO;2

Hu, S., Yang, Y., Zheng, H., Mi, C., Ma, T., & Shi, R. (2022). A framework for assessing sustainable agriculture and rural development: A case study of the Beijing-Tianjin-Hebei region, China. Environmental Impact Assessment Review, 97, 106861. https://doi.org/10.1016/j.eiar.2022.106861

IWMI. (2000). Report on World Water Vision: Projected water scarcity in 2025. The Hague.

Memon, A. (2005). Performance evaluation of drip and sprinkler irrigation systems [master's thesis, Mehran University of Engineering and Technology]. Irrigation and Hydraulics, IIDE.

Memon, A. H., Soomro, A. G., Memon, R. M., Lashari, B. K., Babar, M. M., & Ansari, K. (2021). Assessment of groundwater quality and soil salinity/status under various irrigation systems in arid region of Jamshoro District. Pakistan Journal of Scientific & Industrial Research Series A: Physical Sciences, 64(3), 214–221.

Memon, A., Ansari, K., Ashraf, A., Babar, M. M., & Soomro, A. G. (2019). Projected rainfall variability based on PRECIS regional model. Mehran University Research Journal of Engineering & Technology, 38(2), 513–524.

Niacsu, L., Bucur, D., Ionita, I., & Codru, I. C. (2022). Soil conservation measures on degraded land in the hilly region of Eastern Romania: A case study from Puriceni-Bahnari catchment. Water, 14(4), 525. https://doi.org/10.3390/w14040525

Panhwar, M. Y., Khokhar, N. H., Shah, S. A., & Pathan, N. (2022). Water quality analysis of old and new Phuleli Canal for irrigation purposes in the vicinity of Hyderabad, Pakistan. Water Practice & Technology, 17(2), 529–536. https://doi.org/10.2166/wpt.2022.015

Shah, S. A., Naji, A. M., Ali, A., & Aftab, A. (2020). Investigation of climate change variability under climate change conditions over the semi-arid region. Journal of Mechanics of Continua and Mathematical Sciences, 15, 46–54. https://doi.org/10.26782/jmcms.2020.02.00005

Siyal, A. A., Siyal, Z. U. A., Siyal, P., & Bhatti, N. B. (2022). Social and ecological climate change vulnerability assessment in the Indus Delta, Pakistan. Water Practice & Technology, 17(8), 1666–1678. https://doi.org/10.2166/wpt.2022.122

Soomro, A. G., Babar, M. M., Arshad, M., Memon, A., Naeem, B., & Ashraf, A. (2020). Spatiotemporal variability in spate irrigation systems in Khirthar National Range, Sindh, Pakistan (case study). Acta Geophysica, 68(1), 219–228. https://doi.org/10.1007/s11600-020-00428-x

Soomro, A. G., Babar, M. M., Ashraf, A., & Memon, A. (2019). The relationship between precipitation and elevation of the watershed in the Khirthar National Range. Mehran University Research Journal of Engineering & Technology, 38(4), 1067–1076.

Soomro, A. G., Shah, S. A., Memon, A. H., Alharabi, R. S., Memon, D., Panhwar, S., & Keerio, H. A. (2022). Cascade reservoirs: An exploration of spatial runoff storage sites for water harvesting and mitigation of climate change impacts, using an integrated approach of GIS and hydrological modeling. Sustainability, 14(20), 13538. https://doi.org/10.3390/su142013538

Water Resources Program (WRP), Department of Ecology, State of Washington. (2023). Program guidance: Determining irrigation efficiency and consumptive use (Publication No. 20-11-076). Issued October 2005, updated April 2023.