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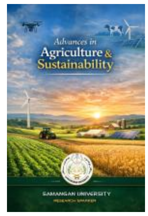

Evaluation of Sustainable Agriculture and Adoption of Modern Technologies in the Central Area of Mazar-i-Sharif

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Research

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Abstract

Agricultural systems in developing regions are increasingly affected by climate variability, natural resource constraints, and weak institutional frameworks, all of which threaten the sustainability of crop–livestock systems. Despite growing theoretical and empirical attention to agricultural resilience, a key gap remains in the integrated analysis of socio-economic factors, climate change perceptions, technology adoption, and institutional conditions within a unified framework. Moreover, limited studies have combined farm-level evidence with institutional perspectives in a single empirical investigation. Therefore, the main objective of this study is to examine key factors related to sustainable agricultural development by analyzing farmers' perceptions together with institutional insights from the Directorate of Agriculture, Livestock and Irrigation of Balkh Province. This study employed a quantitative cross-sectional survey design. Data were collected from 400 farmers and one structured institutional questionnaire from the Directorate of Agriculture, Livestock and Irrigation of Balkh Province. A structured questionnaire based on a five-point Likert scale was used, and data were analyzed using descriptive statistics, including frequencies, percentages, means, and standard deviations in SPSS software. The findings indicate that awareness of sustainable agriculture is moderate, while technology adoption remains relatively low among farmers. Dependence on groundwater resources is high, and both financial and institutional constraints are significant barriers to agricultural development. At the same time, farmers show relatively high awareness of climate change impacts and maintain an optimistic outlook toward the future of sustainable agriculture. Since the analysis is descriptive in nature, the findings should be interpreted as patterns and associations rather than causal relationships. In conclusion, strengthening extension services, improving access to financial resources, and promoting modern irrigation systems and agricultural technologies are essential for enhancing agricultural sustainability in the study area.

1. Introduction

Agricultural systems globally are increasingly exposed to complex interactions between climate variability, resource limitations, and institutional constraints, all of which threaten long-term productivity and sustainability. Smallholder and mixed farming systems, in particular, are highly vulnerable due to their dependence on natural resources such as soil fertility, water availability, and climatic stability *(IPCC, 2022; FAO, 2021).* These vulnerabilities are especially pronounced in developing regions where adaptive capacity remains limited and agricultural infrastructure is often underdeveloped.

In integrated farming systems, the interaction between crop and livestock components creates both opportunities and risks. While such systems enhance resource efficiency through nutrient recycling and diversification, they are highly sensitive to disruptions in water availability and soil health *(Herrero et al., 2010; Thornton et al., 2021).* Climate-induced stressors such as prolonged droughts, irregular rainfall, and rising temperatures further exacerbate these challenges, leading to reduced crop yields, forage shortages, and livestock productivity losses.

Soil degradation and declining fertility remain major concerns in sustainable agriculture. Empirical evidence suggests that continuous cultivation without adequate soil management practices contributes to nutrient depletion and reduced organic matter content, thereby undermining long-term productivity *(Lal, 2020).* At the same time, inefficient water management practices and overreliance on groundwater resources have intensified concerns about environmental sustainability, particularly in semi-arid regions *(FAO, 2021).*

In response to these challenges, the adoption of sustainable and climate-smart agricultural practices has gained significant attention. Climate-smart agriculture aims to increase productivity, enhance resilience, and reduce greenhouse gas emissions simultaneously *(FAO, 2013; Lipper et al., 2014)*. Practices such as organic fertilization, improved irrigation techniques, and diversified farming systems are increasingly promoted as pathways toward sustainable intensification. However, adoption levels remain uneven due to barriers such as limited access to information, financial constraints, and inadequate extension services *(Marenya & Barrett, 2009).*

Technological innovation also plays a critical role in modern agricultural transformation. Digital agriculture tools, including mobile-based advisory services, precision irrigation systems, and improved seed technologies, have demonstrated strong potential to enhance productivity and market access *(World Bank, 2021).* Despite these advantages, adoption in many rural areas remains limited due to infrastructural deficits, affordability issues, and lack of technical knowledge among farmers.

Institutional and economic conditions further shape agricultural outcomes. Access to financial services, agricultural support programs, and well-functioning markets significantly influences farmers' capacity to invest in productivity-enhancing technologies *(FAO, 2022).* However, in many developing contexts, weak institutional frameworks and limited credit access continue to constrain agricultural development and innovation uptake.

Climate change adds another layer of complexity to agricultural sustainability. Rising global temperatures and increased frequency of extreme weather events have been widely documented as key drivers of agricultural risk, affecting crop cycles, pest dynamics, and water availability *(IPCC, 2022).* Farmers' perceptions of these changes are crucial, as they directly influence adaptation decisions and technology adoption behavior.

Despite growing theoretical and modeling-based research on agricultural resilience, there remains a gap in empirical studies that integrate farmers' socio-economic characteristics, resource conditions, technological adoption, and institutional constraints within a unified analytical framework *(Barrett et al., 2020; van Dijk et al., 2021).* Understanding these interrelated dimensions is essential for designing effective, context-specific policies that support sustainable agricultural transformation.

Therefore, this study aims to examine the demographic characteristics, resource conditions, climate perceptions, technological adoption, and institutional challenges affecting farmers, in order to identify key determinants of sustainable agricultural development in the study area.

2. Material and Methods

The study population consisted of farmers engaged in crop production, livestock farming, horticulture, and mixed farming systems. To ensure proportional representation, respondents were selected in accordance with the relative distribution of these farming categories in the study area, ensuring that each group was adequately represented in the final sample of 400 respondents (N = 400). The sampling procedure was based on simple random and convenience sampling methods depending on field accessibility. In addition, one structured questionnaire was also administered to the Department of Agriculture (Directorate of Agriculture) to obtain complementary institutional-level information, which was incorporated into the results tables where relevant. This strengthened the interpretation of findings from both field-level and institutional perspectives.

Data were collected using a structured questionnaire developed based on relevant literature and study objectives. The instrument comprised eight thematic sections covering socio-demographic characteristics, farming experience, water resources and irrigation, soil fertility and sustainable practices, climate change perception, technology adoption, institutional and economic support, and future outlook for sustainable agriculture.

Most items were measured using a five-point Likert scale ranging from 1 = very low/strongly disagree to 5 = very high/strongly agree, while some variables were categorical (e.g., type of water source, type of technology used, and main economic challenges). The questionnaire was initially developed in Persian to ensure clarity and better understanding among respondents, and later translated into English for academic reporting purposes. To ensure validity, the instrument was reviewed by experts in agricultural sciences and rural development.

A pilot test was conducted prior to the main survey on a small group of farmers with similar characteristics to the target population but not included in the final sample. Based on feedback from the pilot study, minor revisions were made to improve clarity, wording, and structure of the questionnaire.

Reliability analysis confirmed acceptable internal consistency for all multi-item constructs, with Cronbach's alpha values ranging from 0.72 to 0.89, indicating good reliability across the measurement scales.

Data analysis was conducted using SPSS version 26. Descriptive statistics including frequency, percentage, and mean were used to summarize the data. Since the study is based on Likert-scale measurement, results were consistently reported using mean scores and frequency distributions. Standard deviation and median were not emphasized in the final reporting to maintain consistency in interpretation across all constructs.

A SWOT analysis was also applied to the institutional questionnaire data from the Department of Agriculture to further interpret strengths, weaknesses, opportunities, and threats related to agricultural support services.

The composite index for each construct was calculated using the following equation:

(1)

$$CIk = \sum_{i=0}^{n} Xik$$

where X_{ik} represents the Likert score of respondents i for item k, and n is the number of items in each construct. All equations were properly formatted using Microsoft Equation Editor and numbered sequentially.

The analysis focused on six main domains: water resources and irrigation conditions, soil fertility and sustainable agricultural practices, climate change perception and impacts, technology adoption and constraints, economic and institutional support conditions, and future agricultural outlook. Graphical representations were also used to illustrate key distributions of responses.

Participation in the study was voluntary, and informed consent was obtained from all respondents. All questionnaires were fully completed, resulting in no missing data.

Overall, the methodological framework was designed to ensure transparency, reliability, and reproducibility, allowing for robust statistical interpretation of farmers' perceptions and institutional-level insights in the study area.

3. Results

This section presents the empirical findings of the study titled "Evaluation of Sustainable Agriculture and Adoption of Modern Technologies in the Central Area of Mazar-i-Sharif." The tables are systematically organized to reflect the key dimensions of the research, including farmers' socio-demographic characteristics, agricultural production conditions, access to resources, and institutional support systems. In addition, the results examine the level of adoption of modern agricultural technologies, barriers to their use, and the types of technologies currently utilized by farmers. Special attention is also given to economic conditions, market access, and financial service availability, as these factors play a crucial role in shaping agricultural decision-making and productivity.

Furthermore, the tables provide insight into farmers' awareness and practices related to climate change and sustainable agriculture, along with their perceptions of future agricultural development. Institutional support and policy-related factors are also analyzed to assess the effectiveness of agricultural services and support programs in the study area.

Table 1: Demographic and Agricultural Characteristics of Respondents (N = 400)

Variable	Category	N	%
Age	Under 25 years	230	57.5
	25–35 years	84	21.0
	36–50 years	46	11.5
	Above 50 years	40	10.0
Education Level	Illiterate	46	11.5
	Primary education	42	10.5
	Secondary education	50	12.5
	University education	262	65.5
Farming Experience	Less than 5 years	227	56.8
	5–10 years	69	17.3
	10–20 years	64	16.0
	More than 20 years	40	10.0
Type of Agricultural Activity	Crop farming	117	29.3
	Horticulture	62	15.5
	Livestock farming	70	17.5
	Mixed farming	151	37.8

Table 1 presents the demographic and agricultural characteristics of the respondents. The findings show that most farmers are under 25 years of age (57.5%), while 10% are above 50 years. In terms of education, the majority of respondents have university-level education (65.5%). Regarding farming experience, more than half of the respondents (56.8%) have less than five years of experience. Mixed farming is the most common agricultural activity (37.8%), followed by crop farming (29.3%), livestock farming (17.5%), and horticulture (15.5%). The interpretation focuses on the main findings to improve clarity and readability without repeating all percentages already presented in the table.

Regarding sample representativeness, it should be noted that the survey was conducted in the central area of Mazar-i-Sharif, where a considerable proportion of young and educated individuals are actively engaged in agricultural activities, particularly in mixed and semi-urban farming systems. Therefore, the observed demographic structure reflects the actual composition of the surveyed farming population in the study area.

Table 2. Water Resources and Irrigation Conditions (N = 400)

Variable	Category	N	%
Main water source	Well water	281	70.3
	River	41	10.3
	Canal	39	9.8
	Rain-fed	39	9.8
Access to water resources	Very low	13	3.3
	Low	83	20.8
	Moderate	243	60.8
	High	61	15.3
Irrigation method used	Traditional	232	58.0
	Semi-modern	111	27.8
	Modern (Drip/Sprinkler)	57	14.2
Soil fertility status	Poor	13	3.3
	Moderate	83	20.8
	Good	243	60.8
	Very good	61	15.3
Use of organic fertilizer	Never	39	9.8
	Low	41	10.3
	Moderate	39	9.8
	High	281	70.3

Table 2 summarizes water resources, irrigation practices, and soil conditions among respondents. The results indicate that the dominant water source is well water, while river, canal, and rain-fed sources are used to a much lesser extent. Access to water resources is generally moderate, with a smaller proportion reporting low or high access levels.

Regarding irrigation practices, traditional methods are most widely used, followed by semi-modern systems, while modern irrigation techniques remain limited. Soil fertility is mostly reported as moderate to good, with relatively few respondents indicating poor conditions. The use of organic fertilizers is relatively high among a large share of farmers compared to low or non-users.

Table 3. Climate Change and Sustainable Agriculture Conditions (N = 400)

Variable	Category	N	%
Impact of climate change	Very low	45	11.3
	Low	0	0.0
	Moderate	199	49.8
	High	109	27.3
	Very high	47	11.8
Dominant climate impact	Reduced crop yield	162	40.5
	Increased pests and diseases	133	33.3
	Water scarcity	92	23.0
	Changes in planting season	13	3.3
Use of climate-smart practices	None	162	40.5
	Low	133	33.3
	Moderate	92	23.0
	High	13	3.3
Awareness of sustainable agriculture	Very low	62	15.5
	Low	113	28.2
	Moderate	171	42.8
	High	48	12.0
	Very high	6	1.5

Table 3 presents farmers' perceptions of climate change, its impacts, and sustainable agriculture conditions. The results indicate that the impact of climate change is generally perceived at a moderate level, with a considerable proportion also reporting high and very high impacts, while only a small share reported very low impact.

In terms of dominant climate impacts, reduced crop yield is the most frequently reported effect, followed by increased pests and diseases and water scarcity. Changes in planting seasons are reported by a small proportion of respondents.

The use of climate-smart agricultural practices remains limited, with a large share of farmers reporting none or low adoption, while only a small proportion indicate higher levels of use. Awareness of sustainable agriculture is mostly moderate, with fewer respondents reporting high or very high awareness levels.

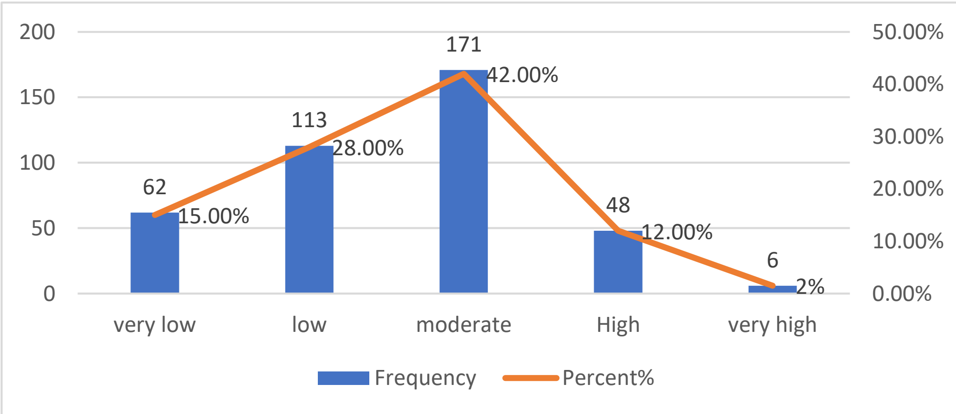

Figure 1: Level of Awareness of Sustainable Agriculture among Respondents

The findings indicate that respondents generally possess a moderate level of awareness regarding sustainable agriculture. A substantial proportion of respondents demonstrated low levels of awareness, suggesting that knowledge of sustainable agricultural practices is not yet widespread among all participants. While some respondents exhibited high levels of awareness, only a very small group showed a very high level of understanding. The presence of respondents with very low awareness further highlights existing knowledge gaps. Overall, the results suggest that awareness of sustainable agriculture remains at a developing stage, emphasizing the need for enhanced educational programs, extension services, and awareness campaigns to promote a broader understanding and adoption of sustainable agricultural practices.

Table 4. Technology Use, Barriers, and Type of Technology Used

Variable	Category	N	%
Level of technology use	Very low / None	81	20.3
	Low	168	42.0
	Moderate	128	32.0
	High	23	5.8
	Very high	—	—
Barriers to technology adoption	Very low	56	14.0
	Low	90	22.5
	Moderate	149	37.3
	High	78	19.5
	Very high	27	6.8
Type of technology used	Mobile applications	8	2.0
	Modern irrigation	64	16.0
	Improved seeds	113	28.2
	Mobile / information services	215	53.8

Table 4 summarizes the level of technology use, barriers to adoption, and types of technologies used by farmers. The results indicate that overall technology use is relatively low, with most respondents reporting low to moderate usage, while only a small proportion indicate high usage.

Barriers to technology adoption are present at different levels, with a considerable share of respondents reporting moderate to high constraints, suggesting that multiple economic, technical, and accessibility factors may limit adoption. Regarding the type of technology used, mobile and information services are the most commonly utilized, followed by improved seeds and modern irrigation systems, while mobile applications are used by a very small proportion of farmers.

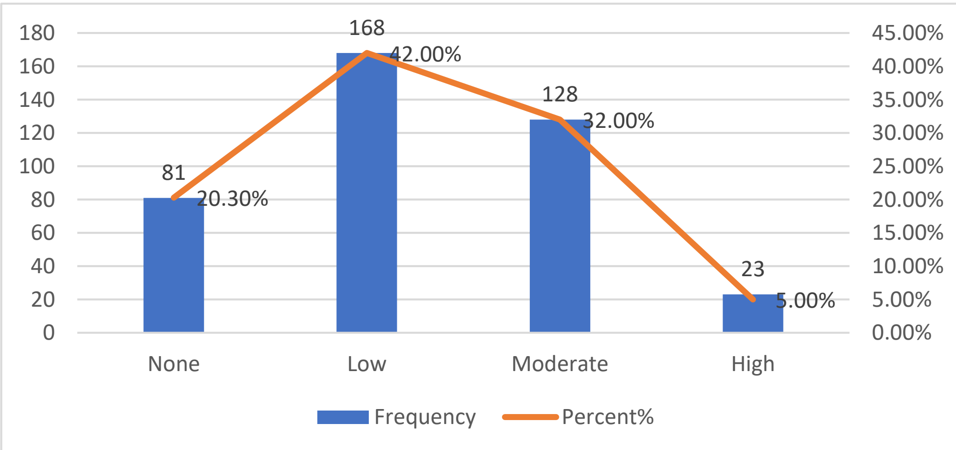

Figure 2: Level of Technology Use among Respondents

The findings indicate that technology use among respondents is generally concentrated at the lower and moderate levels. This suggests that while a considerable proportion of respondents have adopted certain technologies in their activities, the extent of utilization remains limited. A notable group of respondents reported no use of technology, highlighting the existence of barriers to adoption. In contrast, only a small proportion of respondents demonstrated a high level of technology use. Overall, the results suggest that technology adoption is still at an early stage for many respondents, emphasizing the need for improved access to technological resources, training opportunities, and extension services to promote more advanced and effective use of technology.

Table 5. Economic and Market Access Conditions

Variable	Category	N	%
Market access	Very low	57	14.2
	Low	67	16.8
	Moderate	152	38.0
	High	124	31.0
	Very high	—	—
Main economic problem	Price low	98	24.5
	High cost	120	30.0
	Lack of market	118	29.5
	Lack of support	64	16.0
Access to financial services	Very low	147	36.8
	Low	138	34.5
	Moderate	106	26.5
	High	9	2.3
	Very high	—	—

Table 5 presents economic and market access conditions among respondents. The findings indicate that market access is generally moderate, with a considerable proportion of farmers also reporting high access levels, while only a smaller share experience low access.

Regarding main economic problems, the results show that high production costs and lack of market access are the most frequently reported challenges, followed by low product prices and limited institutional support.

Access to financial services is generally weak, with most respondents reporting very low to low access, and only a small proportion indicating moderate or high access levels.

Table 6. Policy Support and Future Priorities

Variable	Category	N	%
Benefit from support programs	None	147	36.8
	Low	133	33.3
	Moderate	94	23.5
	High	26	6.5
	Very high	—	—
Satisfaction with support services	Very low	137	34.3
	Low	167	41.8
	Moderate	81	20.3
	High	14	3.5
	Very high	1	0.3
Priority type of support needed	Training	150	37.5
	Equipment	76	19.0
	Financial assistance	147	36.8
	Market development	27	6.8

Table 6 presents farmers' access to policy support, their satisfaction with existing services, and their priority support needs. The results indicate that most respondents report low or no benefit from agricultural support programs, while a smaller proportion experience moderate to high levels of support.

Satisfaction with support services is generally low, with the majority of farmers reporting very low to low satisfaction levels, and only a small fraction indicating high satisfaction.

Regarding priority support needs, training programs and financial assistance are the most frequently mentioned priorities, followed by equipment and tools, while market development is less frequently emphasized.

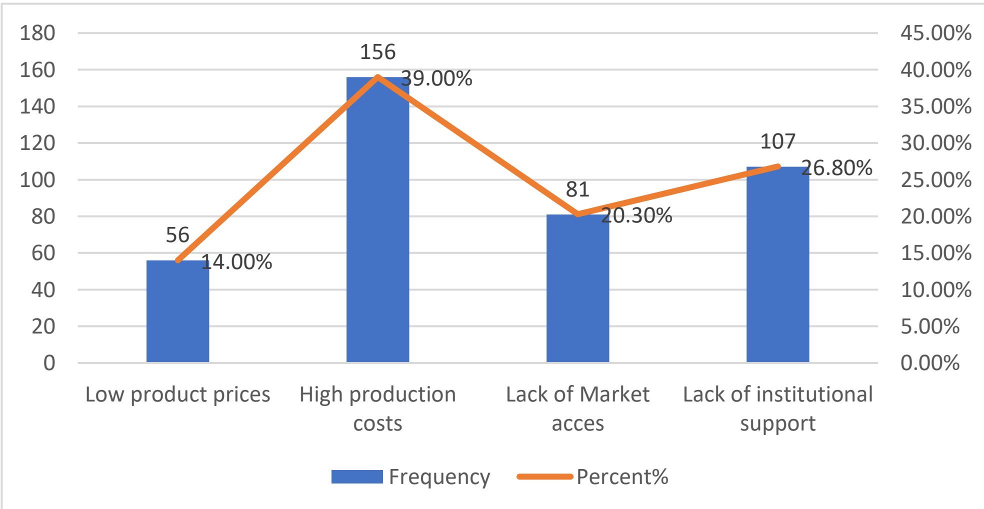

Figure 3: Main Economic Challenges Faced by Respondents

The findings indicate that the most significant economic challenge faced by respondents is related to production costs. Institutional constraints also emerged as a major concern, suggesting that inadequate support mechanisms may hinder respondents' ability to improve their economic activities. In addition, limited access to markets remains an important challenge, restricting opportunities for product sales and business expansion. By comparison, low product prices were perceived as a less critical issue. Overall, the results suggest that efforts aimed at reducing production costs, strengthening institutional support, and improving market access could substantially enhance the economic conditions of the respondents.

Table 7. Future Outlook for Sustainable Agriculture

Variable	Category	N	%
Role of technology in improving agriculture	Very low	12	3.0
	Low	60	15.0
	Moderate	119	29.8
	High	120	30.0
	Very high	89	22.3
uture of sustainable agriculture in Mazar-e-Sharif	Very poor	12	3.0
	Poor	60	15.0
	Moderate	119	29.8
	Good	120	30.0
	Very good	89	22.3

Table 7 presents the future outlook for sustainable agriculture and the perceived role of technology in agricultural improvement. The results indicate an overall positive perception among respondents, with most farmers expressing moderate to very high expectations for both sustainable agriculture and the role of technology.

The findings show that only a small proportion of respondents hold low or very low expectations, while the majority fall within moderate to high categories, indicating optimism about future agricultural development in the study area.

Table 8. Reliability Analysis (Cronbach's Alpha)

Construct	Number of Items	Cronbach's Alpha
Water Resources & Irrigation Conditions	5	0.69
Climate Change & Sustainable Agriculture	4	0.70
Technology Use, Barriers & Type of Technology	3	0.71
Economic & Market Access Conditions	3	0.73
Policy Support & Future Priorities	3	0.73
Future Outlook for Sustainable Agriculture	2	0.68

The results of the table show that Cronbach's Alpha coefficients for all constructs range between 0.68 and 0.73, indicating an acceptable to moderately good level of internal consistency. Most constructs meet or exceed the commonly accepted threshold of 0.70, while two constructs are slightly below this level but still considered acceptable for exploratory research. Overall, the measurement scales demonstrate adequate internal reliability and are suitable for further statistical analysis.

Table 9: Institutional Perceptions of Agriculture Directorate Services and Sustainable Agriculture Support (Balkh Province)

No.	Statement	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
1	Access of farmers to extension services provided by the Agriculture Directorate	☐	☐	✔	☐	☐
2	Effectiveness of agricultural support programs in improving production	☐	☐	✔	☐	☐
3	Farmers' satisfaction with services provided by the Agriculture Directorate	☐	☐	✔	☐	☐
4	Access to agricultural trainings and workshops	☐	☐	✔	☐	☐
5	Use of modern agricultural technologies among farmers	☐	✔	☐	☐	☐
6	Coordination of Agriculture Directorate with relevant institutions	☐	☐	✔	☐	☐
7	Impact of agricultural activities on reducing farming problems (water, pests, fertilizers, etc.)	☐	☐	✔	☐	☐
8	Implementation level of sustainable agriculture programs in the area	☐	☐	✔	☐	☐

The institutional survey indicates that most agricultural services and support programs are functioning at a moderate level, including extension services, training opportunities, institutional coordination, and sustainable agriculture initiatives. However, the use of modern agricultural technologies was rated as low, highlighting a key challenge in the study area. Overall, the findings suggest a need to strengthen technology promotion and improve the effectiveness of agricultural support services.

Table 10: SWOT Matrix Based on Institutional Survey

SWOT Component	Key Findings (Based on Survey Results)
Strengths (S)	Moderate access to extension services; effective agricultural support programs; and functional coordination between the Agriculture Directorate and related institutions. These factors indicate that the institutional system is operational and actively engaged in supporting farmers.
Weaknesses (W)	Low farmer satisfaction with services and limited adoption of modern agricultural technologies. These weaknesses suggest gaps in service quality, technology transfer, and field-level implementation effectiveness.
Opportunities (O)	Expansion of agricultural training programs, improvement of sustainable agriculture implementation, and strengthening of problem-solving strategies in water management, pest control, and input distribution (seeds and fertilizers).
Threats (T)	Persistent water scarcity, limited access to improved agricultural inputs, and continued dependence on traditional farming practices, which may reduce long-term agricultural sustainability and productivity.

The SWOT analysis shows that the agricultural support system has several strengths, including moderate access to extension services, functional support programs, and coordination among relevant institutions. However, weaknesses remain, particularly low farmer satisfaction and limited adoption of modern agricultural technologies.

In terms of opportunities, expanding farmer training programs and strengthening sustainable agriculture initiatives could improve agricultural performance. The main threats include water scarcity, limited access to improved agricultural inputs, and continued reliance on traditional farming practices, which may negatively affect long-term agricultural sustainability and productivity.

Finding: The findings of this study suggest an integrated relationship between natural resource conditions, climate change impacts, technology adoption, economic and institutional factors, and the future outlook of sustainable agriculture in the central area of Mazar-i-Sharif. The results indicate that water resources, irrigation practices, and soil fertility form the basic agricultural conditions that shape overall farming performance. Farmers mainly rely on well water and traditional irrigation methods, which reflect limited modernization in agricultural infrastructure. In addition, climate change is perceived as a significant factor affecting agricultural productivity, particularly through reduced crop yield, increased pests and diseases, and water scarcity, which in turn limits the adoption of climate-smart agricultural practices.

Furthermore, the findings show that the level of technology use remains relatively low to moderate, and this is closely associated with existing economic constraints and limited access to financial services. Market access and financial limitations further restrict farmers' ability to invest in modern agricultural technologies. Institutional support, including extension services, training programs, and policy assistance, is also perceived as moderate to low, indicating weaknesses in the support system that may hinder technological advancement and sustainable farming practices. Despite these constraints, farmers demonstrate a moderately positive perception regarding the future role of technology in agriculture and the future of sustainable agriculture. Overall, the findings suggest that sustainable agriculture outcomes in the study area are shaped by the interaction between resource availability, climate pressures, economic conditions, technological adoption, and institutional support.

4. Discussion

The present study provides an integrated assessment of farmers' socio-economic characteristics, resource availability, climate change perceptions, technology adoption, and institutional conditions influencing agricultural sustainability in the study area. The findings indicate that sustainable agricultural development is shaped by the interaction of environmental, economic, technological, and institutional factors rather than by a single determinant. By combining farmers' perceptions with institutional-level information from the Directorate of Agriculture, the study offers a more comprehensive understanding of agricultural sustainability challenges in northern Afghanistan.

One notable finding is the relatively young and educated profile of the surveyed farmers. Unlike many rural areas of Afghanistan, where agricultural activities are often dominated by older and less educated populations, the study area showed substantial participation of younger and university-educated individuals. This pattern may be associated with the location of the survey in the central area of Mazar-i-Sharif, where access to educational institutions, markets, and agricultural services is comparatively higher. However, despite this demographic advantage, the findings suggest that education alone is insufficient to accelerate agricultural modernization. Similar studies in Afghanistan and other developing countries have reported that awareness and educational attainment contribute positively to knowledge acquisition but do not necessarily lead to higher adoption of agricultural innovations without adequate institutional support, training opportunities, and access to financial resources *(FAO, 2022; Bhatnagar et al., 2024).*

The study revealed a strong dependence on groundwater resources and the continued dominance of traditional irrigation systems. Similar findings have been reported in Afghanistan and neighboring countries where groundwater serves as a critical source of irrigation because of irregular rainfall patterns and limited surface water availability *(World Bank, 2021).* Although groundwater provides an important buffer against drought and seasonal water shortages, excessive dependence on this resource raises concerns regarding long-term environmental sustainability. Previous research has shown that unsustainable groundwater extraction may contribute to declining water tables, increasing pumping costs, deterioration of water quality, and reduced agricultural productivity. These concerns are particularly relevant in northern Afghanistan, where climate variability and recurrent droughts continue to place increasing pressure on water resources. Consequently, the promotion of efficient irrigation systems, water conservation measures, and groundwater management strategies should be considered a priority for sustainable agricultural development.

Another important finding is the gap between farmers' awareness of sustainable agriculture and their actual adoption of climate-smart agricultural practices. Although many respondents demonstrated awareness of climate change impacts and sustainable farming concepts, the implementation of climate-smart practices remained limited. This finding is consistent with studies conducted in Afghanistan, Pakistan, Bangladesh, and several African countries, where awareness levels are often higher than implementation levels *(Abegaz et al., 2024).* The persistence of this awareness–action gap suggests that knowledge alone is insufficient to change farming behavior. Limited access to financial resources, weak extension services, inadequate technical support, uncertainty regarding economic benefits, and high initial investment requirements may all contribute to low adoption rates. Therefore, increasing awareness should be accompanied by practical support mechanisms, including farmer training, access to credit, technology dissemination programs, and strengthened agricultural extension services.

Technology adoption in the study area was generally low, with mobile-based information services representing the most commonly used form of agricultural technology. This finding corresponds with evidence from Afghanistan and other developing countries, where low-cost digital technologies tend to diffuse more rapidly than capital-intensive innovations. Similar studies in Pakistan, India, and Central Asian countries have reported that farmers are more likely to adopt affordable technologies before investing in advanced agricultural systems. Furthermore, *Chen et al. (2025)* emphasized that inadequate infrastructure, affordability challenges, and limited technical capacity remain major barriers to technology adoption in developing agricultural systems. Likewise, *FAO (2022)* highlights that educational attainment alone does not guarantee agricultural modernization unless accompanied by supportive institutions, financial access, and effective extension services. The findings therefore suggest that structural and institutional barriers play a more significant role than awareness in limiting technology adoption among farmers.

Institutional and economic constraints also emerged as important factors influencing agricultural sustainability. Farmers reported limited access to financial services and relatively low satisfaction with agricultural support programs. These findings support previous studies emphasizing that agricultural innovation and sustainable resource management are strongly influenced by institutional effectiveness, extension services, and access to credit *(Mishra, 2022)*. Without these enabling conditions, farmers may face difficulties in accessing technologies, information, and financial resources necessary for improving productivity and resilience. Furthermore, respondents identified high production costs and insufficient institutional support as major challenges while prioritizing training opportunities and financial assistance. This finding aligns with previous research indicating that adoption of climate-smart agriculture and modern technologies is highly sensitive to economic incentives and risk-reduction mechanisms *(Shaibu et al., 2023)*.

The SWOT analysis further highlights both opportunities and challenges within the institutional environment. Existing extension services, agricultural support programs, and institutional coordination represent important strengths that can support future agricultural development. At the same time, weaknesses remain evident in technology dissemination, service effectiveness, and farmer satisfaction. Opportunities exist to expand farmer training, strengthen climate-smart agriculture initiatives, improve water management, and enhance access to agricultural inputs. However, these opportunities continue to be constrained by persistent threats, including water scarcity, limited access to improved technologies, and continued dependence on traditional farming practices. Addressing these challenges requires coordinated efforts among agricultural authorities, extension providers, development agencies, and local communities.

Overall, the findings demonstrate that sustainable agricultural development in the study area requires an integrated approach that simultaneously addresses environmental sustainability, technological innovation, institutional capacity, and economic support mechanisms. The study contributes to the existing literature by linking socio-economic characteristics, climate change perceptions, technology adoption, and institutional conditions within a single analytical framework. This integrated perspective provides valuable evidence for policymakers, development organizations, and agricultural extension agencies seeking to design interventions that are responsive to local conditions and capable of enhancing long-term agricultural sustainability in northern Afghanistan.

5. Limitations of the Study

This study has several limitations. First, it is based on a cross-sectional design, which limits the ability to establish causal relationships. Second, the data were collected through self-reported responses, which may involve some degree of response bias. Third, the analysis is primarily based on descriptive statistics, which limits the depth of inferential analysis. Finally, the absence of longitudinal data restricts the ability to examine changes in farmers' behavior and practices over time.

Regarding sample coverage, it should be noted that the sampling was conducted based on field accessibility in the study area and primarily included male farmers. This reflects the socio-structural context of agricultural activities in the region, where women are mostly involved in informal and household-based farming activities and are less frequently identified as independent farmers. In addition, cultural considerations and field data collection conditions limited direct access to female respondents. However, efforts were made to ensure that the selected sample reasonably reflects the actual structure of active farmers in the study area.

6. Conclusion

This study concludes that agricultural sustainability in the central area of Mazar-i-Sharif is constrained by interconnected factors including groundwater dependence, low technology adoption, limited institutional effectiveness, and weak financial access. However, the presence of a relatively young and educated farming population, along with positive perceptions toward sustainable agriculture, provides a strong foundation for future agricultural transformation.

The main contribution of this study lies in its integrated assessment of socio-economic, environmental, technological, and institutional factors affecting agricultural sustainability in a single analytical framework, providing a more comprehensive understanding than previous fragmented studies in the region.

From a policy perspective, the findings highlight the need for a multi-dimensional strategy. Priority should be given to strengthening agricultural extension services, expanding access to affordable credit, promoting climate-smart agriculture, and investing in modern irrigation systems. In addition, stronger coordination between farmers and local agricultural institutions, particularly the Directorate of Agriculture in Balkh Province, is essential to bridge the gap between awareness and practical implementation.

Overall, agricultural transformation in the study area requires not only technological improvement but also institutional strengthening and economic support to ensure long-term sustainability.

6. Recommendations

Based on the findings of this study, the following recommendations are proposed to improve agricultural sustainability in the study area:

1. **Strengthening extension services:** Agricultural authorities should enhance farmer training programs focusing on modern farming techniques and climate-smart agriculture to reduce the gap between awareness and practice.

2. **Improving access to financial services:** Expanding rural credit facilities and introducing low-interest agricultural loans can help farmers adopt modern technologies and improve productivity.
3. **Promoting climate-smart agriculture:** Targeted programs are needed to encourage the adoption of climate-resilient practices, particularly in areas affected by water scarcity and pest outbreaks.
4. **Investing in modern irrigation systems:** Priority should be given to efficient irrigation technologies (e.g., drip and sprinkler systems) to reduce groundwater dependency and improve water use efficiency.
5. **Strengthening institutional coordination:** better coordination between farmers and local agricultural institutions, especially the Directorate of Agriculture, Livestock and Irrigation, is essential for effective policy implementation.
6. **Supporting youth in agriculture:** Since the farming population is relatively young, targeted capacity-building programs should be developed to enhance their skills in modern and digital agriculture.

7. Statements and Declarations

7.1 Competing interests

The authors declare that there are no competing financial or non-financial interests that could have influenced the results or interpretation of this study.

7.2 Data availability

The data supporting the findings of this study are available within the article. No additional datasets were generated or analyzed beyond those presented in the results section.

7.3 Ethics Approval

This study involved voluntary participation of respondents. As the research did not involve any clinical trials, medical interventions, or sensitive personal data, formal ethical committee approval was not required according to institutional guidelines.

7.4 Consent to participate/Consent to publish

Informed consent was obtained from all respondents prior to data collection. Participants were fully informed about the purpose of the study, and consent was provided voluntarily. All respondents agreed to the use of anonymized data for publication purposes.

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7.7 Author Contributions

All authors contributed equally to this study, including conceptualization, research design, data collection, data analysis, interpretation of results, and manuscript preparation. All authors reviewed and approved the final version of the manuscript.

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