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Abstract. The global imperative to transition towards sustainable agricultural systems is particularly acute in vulnerable, resource-scarce regions such as the Barind Tract of Bangladesh, an area characterized by a semi-arid climate, soil infertility, and acute water scarcity. Understanding the drivers and barriers to adoption is critical, with the Knowledge, Attitude, and Practice (KAP) framework serving as a vital analytical tool. This study provides a comprehensive assessment of farmers' KAP towards sustainable agriculture and examines the socio-economic and institutional factors that influence them. Data were collected through structured, face-to-face interviews with 273 smallholder farmers, selected via a multi-stage random sampling technique across the Rajshahi district. The data were analyzed using descriptive statistics and multiple regression models. The findings reveal a critical paradox: while farmers possess moderate to high levels of knowledge (Mean=19.27) and overwhelmingly favorable attitudes (Mean=56.34) regarding the benefits of sustainable practices, their actual adoption remains only moderate (Mean=16.16), exposing a significant knowledge-practice gap. Regression analyses identified Annual Farm Income (AFI) as the single most significant positive determinant across all three KAP domains, underscoring economic capacity as the fundamental gatekeeper to adoption. Farming experience and cosmopoliteness were also positive influencers, while conventional levers such as formal education, training, and agricultural extension contact showed surprisingly limited statistical impact. The study concludes that the linear KAP progression is inadequate for explaining farmer behavior in this context; instead, adoption is constrained less by cognitive limitations and more by deep-seated structural and economic barriers. Consequently, effective policy must pivot decisively from top-down information campaigns to integrated strategies that provide financial de-risking, strengthen market linkages for sustainable produce, and transform extension services into facilitative, farmer-centric learning networks to bridge the persistent intention-action divide.

Keywords: Agricultural Extension; Barind Tract; Climate-Smart Farming; Rural Development; Sustainable Agriculture.

1 Introduction

Agriculture remains the foundation of the global economy, particularly in developing countries, where it sustains livelihoods and shapes cultural and social identities (Curry et al., 2021). However, traditional agricultural systems that have supported generations are increasingly unsustainable in the face of climate change, soil depletion, water scarcity, biodiversity loss, and socioeconomic inequalities (Wijerathna-Yapa & Pathirana, 2022). As a result, a worldwide trend towards sustainable agriculture has emerged, encompassing economic profitability, environmental health, and social equity (Dönmez et al., 2024). However, the pathway to sustainability depends on farmers as major actors in agriculture, and knowledge, attitudes, and practices (KAP) contribute to decision-making for adoption (Bhujel & Joshi, 2023; Udayanga et al., 2024). Although the concept of sustainable farming practices is theoretically well-established, their practical application depends on the knowledge, perceptions, and behaviors of farmers (Sok et al., 2021). Therefore, it is essential to evaluate KAP to determine the conversion of knowledge and attitudes into sustainable agricultural practices. Worldwide, agriculture is both a cause and a solution to environmental degradation, including the release of greenhouse gases, deforestation, water shortages, and soil degradation (Mesele et al., 2025). It also features prominently in the United Nations Sustainable Development Goals (SDGs), specifically SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 15 (Life on Land), which focus on food security (Fitawek & Hendriks, 2024), water use efficiency, and ecosystem conservation. Techniques that include integrated pest management, crop rotation or multi-cropping (in which more than one species of crop is grown on the same land), organic farming, conservation tillage and agroforestry, as well as water-efficient irrigation, can yield desirable results in this regard. However, uptake remains uneven worldwide, particularly in less developed areas, where financial, institutional, and technological limitations prevail.

In Bangladesh, agriculture is not only indispensable but also highly vulnerable to various threats, including groundwater extraction, soil degradation, pesticide misuse, and climate change. Irrigation water use, primarily in the Barind tract, has overdrawn recharge, resulting in a declining groundwater table and increased irrigation costs (Md. I. Hossain et al., 2021). Excessive extraction depletes the sustainable yield and constrains farmers' potential to adopt more sustainable approaches (S. Wang & Yang, 2024). Soil deterioration compounds the problems: monocultures, excessive chemical fertilisers, and poor soil stewardship have led to the loss of nutrients, erosion, and a decrease in fertility; meanwhile, high pesticide use has weakened ecosystems as well as human health. While both government and non-governmental organizations promote sustainable practices such as IPM, organic farming, and efficient irrigation, their adoption is very low, especially among the small landholding farmers who form the majority of Bangladesh's agricultural sector. The Barind Tract is more severely affected, considering its semi-arid climate, erratic rainfall, low groundwater levels, and poor soil fertility (Md. Z. Hossain et al., 2024). Excessive pumping has exacerbated the shortage, making irrigation both expensive and challenging to implement. The continuous practice of unplanned cultivation, combined with a lack of soil conservation, has exacerbated degradation, the risks of which are heightened by climate change, including increased temperatures, erratic rainfall, and droughts (Brempong et al., 2023; Farooqi et al., 2024). Although agriculture is life-sustaining for the area, it appears not to be sustainable. Rainwater harvesting, drought-tolerant crops, soil conservation, and effective irrigation practices can enhance resilience, but these approaches are not merely a matter of information; farmers must also cultivate motivation, along with other necessary attitudes and resources.

The KAP model is a valuable tool for describing these dynamics because it connects knowledge with attitudes, and consequently, to behavior (Afzal et al., 2022; Liao et al., 2022). This will be used in this study to measure farmer's knowledge on water conservation, soil management and pest control practices, how they perceive the adoption of SCAPs (feasibility and risks) of adopting Sustainable Crop Agriculture Practices (SCAPs), as well as consistency with sustainability. Evidence from South East and South Asia also suggests that this is the right way. Farmers in India are knowledgeable about organic farming and IPM (Jaacks et al., 2022). However, adoption remains low due to high input costs, limited technical knowledge, and poor market access. Farmers in Nepal acknowledge the potential of climate-smart practices (e.g., efficient irrigation, diversified cropping) but are hesitant because their risk perception and financial support system are constrained (Sharma & Neupane, 2025). This highlights the importance of recognising that knowledge alone is not enough—attitudes influenced by socioeconomic status, experience, and institutional support also influence uptake. In addition, the majority of current studies focus on technologies rather than holistic, integrated, sustainable systems, which narrows the scope of learning broader aspects of uptake barriers. There is limited research available on the adoption of complete sustainable agricultural systems in the developing countries of South Asia, especially in the Barind Tract. Although individual practices, such as improved irrigation or the use of organic fertilizers, have been explored, far less has been studied about the influences of socio-economic and institutional factors, including education, extension services, access to finance, and supportive policies, on farmers' decision-making. That gap is critical because adoption is seldom a matter of technology alone.

The current study aims to provide a comprehensive understanding of the KAP of farmers, its impact, and how ecological, economic, and institutional contexts interact with one another, with a focus on the Barind Tract. It will also highlight potential adoption barriers and recommend action pathways to improve the integration of sustainability practices. Thus, it not only aims to explain farmer behavior in one vulnerable region but also to propose insights applicable to other resource-poor agro-ecological regions. By situating the KAP framework within a sustainability narrative, this study provides insights into agricultural transformation in global discussions. It highlights the importance of farmer-centered strategies for bridging the awareness-adoption divide.

The primary objective of the study was to investigate the knowledge, attitudes, and practices (KAP) of farmers in relation to sustainable agricultural systems in the Barind Tract of Bangladesh. In the latter report, an evaluation was conducted on farmers' knowledge of sustainable farming practices, focusing on water and soil management, as well as integrated pest management. It also examines farmers' attitudes and perceptions regarding the benefits and challenges associated with adopting these practices. Furthermore, the research provides an account of current farm practices in the Barind Tract. It assesses the extent to which they meet sustainability criteria, such as coping with pressing threats of water stress, land infertility, and climate change. The study also examines the influence of socio-demographic and institutional factors (including access to resources, education opportunities, and extension services) on farmers' knowledge, attitudes, and practices with respect to sustainable agriculture.

The focus of this research will address the following questions:

RQ1: To what extent do farmers in the Barind Tract possess knowledge about sustainable agricultural practices?

RQ2: How do socio-economic and institutional factors contribute to farmers' Knowledge about sustainable agricultural practices?

RQ3: How do socio-economic and institutional factors contribute to farmers' Attitudes about sustainable agricultural practices?

RQ4: How do socio-economic and institutional factors contribute to farmers' practices about sustainable agricultural practices?

2 Literature Review

The Knowledge–Attitude–Practice (KAP) model was developed in the health sciences to critically assess the general public's view and response to interventions (Zhao et al., 2022). Examples include vaccine utilization, hygiene practices, or disease prevention programs. This model has been in use since the mid-twentieth century. The KAP model was later extended to agricultural and environmental research. It was applied to analyze how farmer' knowledge explains their attitudes and behavior in agriculture.

While initially developed and used for health interventions, the application of the KAP framework to agriculture began in the late 20th century and early 21st century, especially in areas experiencing intensified agricultural development and environmental issues (Shi & Chen, 2025). In agricultural research, the KAP framework is used to examine farmers' adoption of sustainable practices, including integrated pest management (IPM), soil fertility enhancement, water-saving irrigation technologies, and climate-smart agriculture (Thakur & Yadav, 2025). Simultaneous evaluation of KAP enables researchers to detect both awareness and barriers to adoption, thereby guiding specific intervention initiatives.

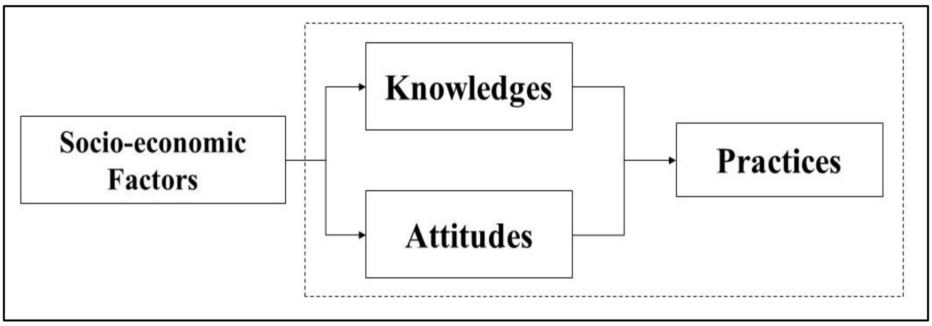
Factors influencing knowledge, attitude, and practice (KAP are multifaceted, including social and demographic, economic, institutional, and cultural influences. Socio-demographics, including age, gender, educational status, and farming experience, help establish awareness and willingness for innovation (Hassan et al., 2025). Economic variables, such as farm size, intensity of agricultural practices, family income, source of credit, and input costs, affect adoption possibilities (Lemecha, 2023). Institutional factors, such as knowledge dissemination, access to extension services, farmer training programs, cooperatives, and markets, play a crucial role in facilitating the translation of knowledge into practice (Becerra-Encinales et al., 2024).

Barind is an extensive tract of low-fertility soil with inadequate irrigation water facilities, and climate risks are the typical features for sustainable agriculture. Farmers in the area frequently experience repeated droughts, soil impoverishment, and insufficient access to modern agricultural technologies (Ahmad et al., 2022; Ruwanza et al., 2022). The KAP model could be helpful in this context to help understand the interaction between knowledge, attitude, and practices, as well as their relationship with socioeconomic conditions and the environment. Experiences from KAP studies in neighboring areas suggest that increasing knowledge alone is insufficient; interventions should focus not only on knowledge but also consider economic, institutional, and cultural barriers to support the uptake of sustainable practices.

2.1 Theoretical Framework for this Study

This study adopts a context-specific KAP framework for the Barind Tract. Sociodemographic factors (age, education, gender, and experience) and economic factors (farm size, income, and access to credit) influence farmers' knowledge of sustainable agriculture. Knowledge shapes attitudes, including perceptions of sustainability, openness to innovation, and risk–benefit assessment. Knowledge and attitudes jointly influence practices such as water conservation, crop diversification, IPM, and organic input use (Kirui et al., 2023). Sociodemographic factors, including extension services, training, organisational participation, media exposure, and policy support, strengthen or weaken the knowledge–attitude–practice relationship (Xu & Zhang, 2021). Cultural norms and risk perceptions are considered key contextual influences that affect adoption. Methodologically, this framework supports the use of regression and structural equation modelling to test direct and indirect effects within the KAP chain, while accounting for socioeconomic and institutional Variables (Y. Wang et al., 2023). Embedding the KAP model in Barind environmental and institutional realities enables both theoretical refinement and context-specific insights for policymakers, emphasizing the need for awareness-raising alongside institutional strengthening and access to resources.

Fig 1. Conceptual framework of the research

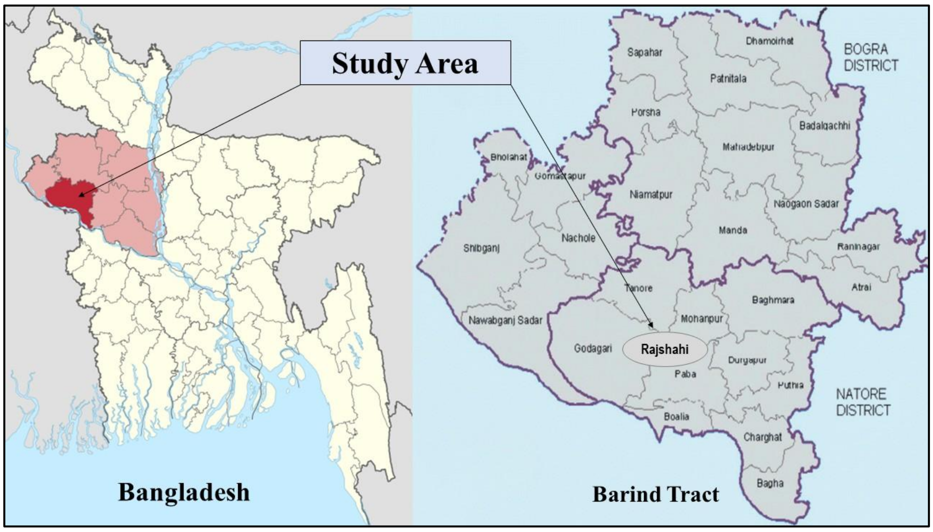


3 Materials and Methods

3.1 Study Area

The study was conducted in the Barind Tract of Bangladesh, focusing on the Rajshahi district. This region is characterized by slightly elevated, old alluvial terraces with red-yellow, clayey soils that are often low in fertility and organic matter. The climate is subtropical, with an average annual rainfall ranging from 1,200 to 1,600 mm, predominantly concentrated during the monsoon (June–September), while the rest of the year experiences water scarcity (Xiang et al., 2024). Due to the coarse texture and low water-holding capacity of the soils, farmers heavily depend on irrigation, mainly from shallow tubewells, for crop cultivation. The cropping system in the region is predominantly rice–wheat–Maize rotation, reflecting both subsistence and commercial farming practices. Rice is primarily grown in the monsoon season (Aus and Aman varieties), while grain and Maize occupy the dry winter season (Islam et al., 2024).

Fig 2. A map of the research area



3.2 Sampling and Data Collection

This study was conducted in the high Barind Tract, focusing on the Rajshahi district of Bangladesh, where the target population consisted of smallholder farmers. The sample size was calculated using the formula proposed by (Daniel & Cross, 2018). For a total farmer population of 2,915,009 in the region and a desired confidence level of 90%, a sample of 273 farmers was deemed representative. The sample size (n) is calculated according to the formula 1:

n = [z2 * p * (1 - p) / e2] / [1 + (z2 * p * (1 - p) / (e2 * N))] --------------------------(1)

Where: z = 1.645 for a confidence level (α) of 90%, p = proportion (expressed as a decimal), N = population size, and e = margin of error.

The data was interpreted from the questionnaire, which was used to collect all the data from the respondents. A multi-stage random sampling technique was employed, selecting upazilas, then unions, villages, and finally, farmers. Data were gathered via face-to-face interviews using a pre-tested questionnaire. The study period lasted between March and September 2025, which spanned the pre-monsoon, monsoon, and post-monsoon farm seasons. Trained enumerators obtained informed consent, and data quality was upheld through rigorous supervision and spot-checks by the research team to ensure the reliability and accuracy of the findings.

3.3 Measurement of the Dependent Variables

The study assessed three dependent variables: farmers' knowledge, attitude, and practices (KAP) concerning sustainable agriculture. These variables were quantified using data from the survey questionnaire. Knowledge was measured using a dedicated section of 10 Questions about sustainable practices. Responses were scored on a scale from 'Frequently' (3) to 'Not at all' (0). Attitude was evaluated using 14 questions and a five-point Likert scale on a series of statements, ranging from 'Strongly Agree' (5) to 'Strongly Disagree' (1), to gauge farmers' disposition towards sustainable methods. Finally, the level of adoption, or Practice, was determined by asking farmers about their frequency of use for eight different sustainable agricultural techniques. Responses were scored on a scale from 'Frequently' (3) to 'Not at all' (0). The individual scores for each variable were then summed to generate composite scores, which were subsequently used for regression analysis to identify the factors influencing the KAP of farmers in the Barind Tract.

4 Results

4.1 Socio-Demographic and Farming Characteristics of the Respondents

Table 1 provides a comprehensive overview of the socio-demographic and farming-related characteristics of the respondents from the Barind Tract of Bangladesh, with a total of 273 respondents. The table presents a variety of factors, categorized into distinct groups, along with the frequency and percentage distributions for each category, as well as the mean and standard deviation (SD) values for continuous variables. The measurement of the variable is also shown in Table 1.

The respondents' ages were categorized into three groups: 15.75% were in the young age category (17-35 years), 39.20% were in the middle age group (36-50 years), and 45.05% fell into the old age category (>50 years). Education levels were predominantly low, with 64.10% of respondents having received only primary education, while 35.89% had completed secondary education. The data also show a significant variance in annual family income, with 62.64% of respondents earning low incomes (up to 3 Lakhs), while only 4.4% reported high incomes (greater than 4.50 Lakhs).

In terms of farming practices, 9.89% of respondents owned small Farms (0.21-1.0 acres), whereas the majority (90.11%) had medium-sized Farms (1.01-3 acres). The table also highlights cosmopoliteness, where 52.01% of respondents were categorized as low cosmopolites, and 8.06% were classified as high cosmopolites, indicating varying levels of exposure to wider societal or regional influences.

Family size varied, with 38.46% of respondents coming from small families (1-4 members), while 56.04% had medium-sized families (5-8 members). Farming experience was predominantly in the medium range (39.90%), followed by high expertise (34.8%), and low experience (25.3%). Training in agricultural practices was relatively rare, as only 19% of respondents had received any formal training.

Additionally, the table examines the respondents' levels of Agricultural Extension Frequency (AEF), innovativeness, sustainable agricultural learning (SAL), and satisfaction (SAT). The results indicate that a majority of respondents had moderate to low AEF (54.95% and 32.96%, respectively), with medium levels of innovativeness (61.2%). Concerning SAL, the majority of respondents (52.40%) had moderate levels, with a significant number (41.03%) having low SAT scores. These results suggest that there is considerable room for improvement in agricultural practices, as well as in the extension provided to FFS participants in the area. This extensive information offers insight into the socio-demographic and farming-related characteristics that are possibly associated with farmers' knowledge, attitudes, and practices concerning sustainable agriculture in the Barind tract.

Table 1. Socio-demographic and farming-related characteristics of the respondents in the Barind Tract of Bangladesh (N=273).

Socio-economic Characteristics	**Categories**	**Respondents**		**Mean**	**SD**
		Fre-quency	Percent		
Age (Actual Age)	Young age (17-35)	43	15.75	48.4652	12.18242
	Middle age (36-50 years)	107	39.20		
	Old age (>50 years)	123	45.05		
Education (Year of Schooling)	Primary level (1-5)	175	64.10	4.5421	2.73980
	Secondary level (6-10)	98	35.89		
Annual family income (In Lakh BDT)	Low income (up to 3)	171	62.64	2.7707	1.04443
	Medium income (3.10-4.50)	90	32.96		
	High income (>4.50)	12	4.4		
Farm size (In hectares)	Small Farm Size (0.21-1.0)	27	9.89	1.5993	.51587
	Medium Farm Size (1.01-3)	246	90.11		
	Low Cosmopolite (4-8)	142	52.01	8.8278	2.91353

Cosmopoliteness (score)	Medium Cosmopolite (9-13)	109	39.93		
	High Cosmopolite (≥14)	22	8.06		
Family size	Small Size (1 to 4)	105	38.46	5.2418	1.93463
	Medium Size (5 to 8)	153	56.04		
	Large Family (8 to 10)	15	5.5		
Farming Experience (in Years)	Low (1-15)	69	25.3	25.5751	12.38873
	Medium (17-30)	109	39.90		
	High (≥31)	95	34.8		
Training (score)	Yes (1)	52	19	.1905	.39340
	No (0)	221	81		
Agricultural Extension Frequency (AEF) (score)	Low (0-18)	90	32.96	20.5971	5.77955
	Moderate (19-27)	150	54.95		
	High (≥28)	33	12.09		
Innovativeness (score)	Low (0-20)	64	23.4	26.5919	8.26254
	Medium (21-35)	167	61.2		
	High (≥36)	42	15.40		
Sustainable Agricultural Land (SAL) (score)	Low (≤0.22)	84	30.76	.3209	.16755
	Medium (0.23-0.45)	143	52.40		
	High (≥0.46)	46	16.84		
Sustainable Agricultural Training (SAT) (score)	Low (≤0.30)	112	41.03	.3867	.19781
	Medium (0.32-0.66)	130	47.62		
	High (≥0.67)	31	11.35		

4.2 Farmers' Knowledge on Sustainable Agricultural Systems

Table 2 presents the distribution of respondents according to their knowledge of sustainable crop farming systems in the Barind Tract, Bangladesh. The respondents are divided into three levels of expertise: mild, moderate, and reasonable. A small number (10.62%) are included in the "Mild" category, which is defined as 15 or lower, indicating that they possess a limited understanding of sustainable agriculture. This suggests that there are a handful of farmers in the locality who may have limited knowledge of sustainable agriculture. The most common group (49.82%) is Moderate, with scores ranging from 16 to 20, indicating a basic to intermediate application of SAS. This implies that 41.8% of the respondents have a fair level of awareness, which could be due to personal experience or agricultural education. Finally, 39.56% were considered to have "Good" knowledge, with a score above 20, indicating that many farmers have a good level of understanding of sustainable practices. The average score of 19.27 (±2.93 standard deviation) also shows a relatively uniform distribution of knowledge, with the majority having an average to high level of expertise.

Table 2. Farmers' knowledge score distribution on sustainable agriculture (N = 273).

Categories	**Respondents**		**Mean**	**SD**
	Fre-quency	**Per cent**		
Low (up to 15)	29	10.62	19.2747	2.92956
Medium (16-20)	136	49.82		
High (>20)	108	39.56		
Total	273	100		

The respondents' perceptions of sustainable agriculture (SA) in the Barind Tract are presented in Table 3, based on a total sample size of 273. It shows four categories of knowledge perception: Not Perceived (0), Low Perceived (1), Medium Perceived (2), and High Perceived (3), as well as their corresponding KS and the ranking of each aspect of sustainable agriculture. The highest KS recorded for the ten perceptions assessed is "Social Acceptance" (KS 557), indicating that most respondents find social acceptance significant for promoting SAS in their system. Next is "Environment Suitability," with a KS of 556, indicating that farmers prioritize environmental compatibility when practicing sustainable agriculture. In contrast, "Quantity & Quality of SA Products" had the lowest KS (466), which may suggest a comparatively lower perception of how sustainable agriculture affects product quantity and quality. The dimension "Benefits of SA" (KS=547) is perceived as the fourth, with a high proportion of farmers recognizing the benefits and valuing sustainable agriculture. The "Negative Environmental and Health Effects of Chemical Fertilization" also received a high perception score (551), indicating that the adverse environmental and health effects of chemical fertilizers were perceived.

On the other hand, "Organic Fertilizers Use" (KS 484) and "Materials in SA" (KS 508) were among the lowest ranked, indicating a lower level of perception or understanding about items related to organic inputs and materials used for sustainable practices.

Table 3. Farmers' perceptions of knowledge dimensions towards sustainable agriculture (N = 273).

Knowledge towards SA	**Not Perceived (0)**	**Low Perceived (1)**	**Medium Perceived (2)**	**High Perceived (3)**	**KS**	**Rank**
Sustainable Agriculture	8	85	84	96	541	5

Benefits of SA	0	81	110	82	547	4
Limitations of SA	0	82	118	73	537	6
Environment Suitability	1	86	88	98	556	2
Social Acceptance	3	84	85	101	557	1
Practices	1	93	115	64	515	7
Materials in SA	1	107	94	71	508	8
Harmful Effects of Chemical Fertilizers	1	89	87	96	551	3
Organic Fertilisers Use	2	116	97	58	484	9
Quantity & Quality of SA Products.	9	119	88	57	466	10

4.3 Farmers' Attitude Towards Sustainable Agriculture

The distribution of respondents by their level of understanding of sustainable agricultural systems across the Barind Tract of Bangladesh is represented in Table 4 (n = 273). The knowledge scores of the respondents were classified into mild, moderate, and good categories based on their level of knowledge. The category "Mild" (from 0 to 50) encompasses the percentage of farmers with a lower comprehension of sustainable agriculture, which is approximately 17.59%, indicating that a small percentage of farmers possess limited knowledge of sustainable agriculture. The "Moderate" option (51-60) is where the answer lies for most respondents (52.01%). This sector comprises a significant portion of the population, demonstrating an acceptable, although not extensive, understanding of sustainable agriculture concepts. In the "Good" ranking, represented by scores above 60, 30.40% of farmers have a reasonable level of knowledge on sustainable agriculture. The average score (56.34, standard deviation = 5.48) reveals that the general level of awareness falls between moderate and most respondents fall within this range. These findings suggest that although some farmers in the Barind Tract possess good or moderate awareness of sustainable agricultural systems, a significant number still lack sufficient knowledge and therefore require educational interventions or outreach programs to enhance their understanding and knowledge about sustainable agriculture.

Table 4. Farmers' Attitude score distribution on sustainable agriculture (N = 273).

Categories	**Respondents**		**Mean**	**SD**
	Frequency	**Per cent**		
Mild (up to 50)	48	17.59	56.3370	5.48226

Moderate (51-60)	142	52.01		
High (>60)	83	30.40		
Total	273	100		

Table 5 describes the attitudes of individuals in the Barind Tract, Bangladesh, regarding sustainable agriculture, based on a survey of 273 respondents. Attitudes are measured on a five-point scale anchored by "Strongly Disagree" (1) and "Strongly Agree" (5), with the AS for each attitude item as well as the rank. The highest-ranked attitude, AS = 1119, is "Efficient Resource Use", indicating the respondents' desire to use resources efficiently in a sustainable form of farming. Second, "Stable Yields" (AS 1118) is also high on the list, indicating that farmers are highly concerned about maintaining stable agricultural production, which is essential for long-term sustainability. Ranked third and fourth, "Lower Cost & Inputs" and "Community Cooperation" (both as of 1116) demonstrate the significance farmers have given to lower input costs and creating community cooperation for sustainable agricultural development. The other attitudes, 'Safe & Nutritious Food' (AS 1105),' 'Household Food Security' (AS 1103), and 'Income & Livelihood Security' (AS 1102) also get better scores, indicating that the farmers practice in the Barind Tract linking sustainable agriculture with enhanced food security, nutritious food consumption, and livelihood. On the smaller end of the spectrum, "Lower Market Risks" (AS 1070) and "Linked to Tradition" (AS 1071) have weaker loadings, implying that although farmers perceive market stability and tradition are important, they are not significantly related to sustainable agriculture from a farmer's perspective.

Furthermore, "Gradual Adoption" (AS 1091) and "Practice Difficulties" (AS 1097) indicate some doubt or difficulty in adopting sustainable practices. However, the ratings demonstrate only fair agreement on the gradual adoption of practices over time. In general, the table reveals that respondents have a positive attitude towards sustainable agriculture, with a focus on resource conservation, yield stability, and community coordination. There are some barriers to adopting these practices.

Table 5. Farmers' perceptions of Attitude dimensions towards sustainable agriculture (N = 273).

Attitudes towards sustainable agriculture	**Strongly Disagree (1)**	**Disagree (2)**	**Uncertainty (3)**	**Agree (4)**	**Strongly Agree (5)**	**AS**	**Rank**
Lower Cost & Inputs	1	15	48	104	105	1116	3

Income & Livelihood Security	1	16	62	87	107	1102	7
Lower Market Risks	4	18	79	67	105	1070	14
Efficient Resource Use	1	17	50	91	114	1119	1
Support Long-Term Sustainability	3	15	61	105	89	1081	12
Community Cooperation	2	12	59	87	113	1116	4
Household Food Security	0	23	62	69	119	1103	6
Stable Yields	2	19	48	86	118	1118	2
Safe & Nutritious Food	9	18	51	68	127	1105	5
Farmers' Well-Being	0	21	70	68	114	1094	10
Pride & Satisfaction	4	18	50	98	103	1097	8
Gradual Adoption	5	16	51	104	97	1091	11
Practice Difficulties	5	25	40	93	110	1097	9
Linked to Tradition	9	24	41	104	95	1071	13

4.4 Farmers' Practices of Sustainable Agriculture

Table 6 shows that the respondents' typification of sustainable agriculture in the Barind Tract of Bangladesh was based on a sample size of 273. The respondents are grouped into three levels of practice: low, moderate, and high, corresponding to their involvement in adopting sustainable agriculture practices. The "Mild" group (n = 205;

17.94%), characterized by individuals who do not typically participate actively in sustainable practices, with scores of 15 or less. It implies that a minimal number of farmers in the area are not using sustainable farming practices. The majority of the participants, 56.78%, fall in the Moderate group (16–20). This indicates that the farmer had moderate involvement in sustainable agriculture activities rather than being fully engaged. The "Good" type (whose 25.28% score is above 21) represents farmers of sustainable methods. The practice score (mean = 16.16; standard deviation = 0.88) also indicates that a large number of respondents are concentrated at the moderate level, suggesting that most respondents who are partially practicing are sustainable in the Barind Tract.

Table 6. Farmers' practice score distribution on sustainable agriculture (N = 273).

Categories	**Respondents**		**Mean**	**SD**
	Frequency	**Per cent**		
Mild (up to 15)	49	17.94		
Moderate (16-20)	155	56.78		
High (>21)	69	25.28	1.6154	.87996
Total	273	100		

The results of one analysis on respondents' behavior towards sustainable agriculture in the Barind Tract of Bangladesh, with a sample size of 273, are given in Table 7. The table classifies various sustainable agriculture practices and indicates the frequency with which farmers employ each, using a five-point Likert scale ranging from "Not at all" (1) to "Always" (5). We also display the Rank Perception Score (PS) for each practice, along with its ranking, indicating how essential or usual respondents considered those practices.

The most highly ranked practice is "Intercropping" with a PS of 691, indicating that many farmers are actively intercropping at various levels. Intercropping, that is, the simultaneous cultivation of more than one crop type in a single field, is the most commonly employed sustainable agriculture practice within the region. This is second only behind "Agroforestry," with a PS of 677. Agroforestry, which combines trees and crops on the same land, is also widely used, albeit to a lesser extent than intercropping. Crop Rotating" (PS 662) is third, in accordance with the practices of intercropping and agroforestry, which are preventive measures for maintaining soil fertility and pest buildup, although it is less frequently practiced. "Integrated Weed Management (PS 648), Application of Organic Fertilizers (PS 638), and Integrated Pest Management (PS 639)" rank fourth, fifth, and sixth in their scores. These are key sustainable soil management practices aimed at reducing chemical inputs and enhancing soil health, biodiversity, and other benefits.

Table 7. Farmers' perceptions of practice dimensions towards sustainable agriculture (N = 273).

Practicing	Not at all (1)	Rarely (2)	Occa-sionally (3)	Fre-quently (4)	Al-ways (5)	PS	Rank
Intercropping	59	75	82	49	8	691	1
Crop Rotating	70	72	80	47	4	662	3
Integrated Weed Man-agement	73	79	71	46	4	648	4
Application of Organic Fertilizers	73	83	72	42	3	638	6
Integrated Pest Manage-ment	72	80	82	34	5	639	5
Integrating Livestock and Crops	69	93	72	34	5	632	7
Agroforestry	75	60	76	56	6	677	2
Soil Health Management	120	109	44	0	0	470	8

4.5 Determinants of Farmers' Knowledge on Sustainable Agriculture

Table 8 presents the results of a regression analysis examining the relationship between various independent variables and farmers' knowledge of sustainable agriculture in the Barind Tract of Bangladesh. The model demonstrates a strong fit, with an R-squared value of 0.772, indicating that the independent variables explain 77.2% of the variance in farmers' knowledge. The findings reveal that Experience and Annual Farm Income (AFI) are the most significant predictors of farmers' knowledge, with AFI having the highest positive impact (B = 2.288, t = 24.192, p = 0.000), suggesting that greater exposure to agricultural extension services and training programs significantly enhances knowledge. Experience (B = 0.053, t = 3.179, p = 0.002) also has a positive influence on knowledge, indicating that farmers with more years of experience tend to have a higher level of understanding of sustainable practices. Age (B = -0.040, t = -2.413, p = 0.017) negatively correlates with knowledge, suggesting that older farmers, who may rely more on traditional farming methods, generally possess less knowledge of sustainable agriculture. Additionally, Cosmopoliteness (B = 0.073, t = 2.376, p = 0.018) is positively associated with knowledge, indicating that farmers with greater exposure to external agricultural influences tend to have a better understanding of sustainable practices. The model also indicates that multicollinearity is not an issue, as all Variance Inflation Factor (VIF) values are below 10.

Table 8. Relationship between independent variables and farmers' knowledge of sustainable agriculture in the Barind Tract of Bangladesh.

Coefficients'							
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	12.337	.820		15.048	.000		
Age	-.040	.017	-.167	-2.413	.017	.182	5.501
Education	.049	.035	.046	1.407	.161	.814	1.229
Family Size	-.004	.049	-.003	-.081	.936	.822	1.216
Farm Size	.218	.180	.038	1.209	.228	.867	1.154
Experience	.053	.017	.222	3.179	.002	.179	5.594
Annual Farm Income (AFI)	2.288	.095	.816	24.192	.000	.770	1.299
Training	-.092	.229	-.012	-.403	.687	.929	1.077
Agricultural Extension Frequency (AEF)	-.006	.015	-.012	-.398	.691	.941	1.063
Innovativeness	-.003	.011	-.007	-.233	.816	.914	1.094
Cosmopoliteness	.073	.031	.073	2.376	.018	.928	1.078
Sustainable Agricultural Land (SAL)	.401	.537	.023	.747	.456	.927	1.079
Sustainable Agricultural Training (SAT)	.231	.455	.016	.507	.612	.926	1.080
a. Dependent Variable: Knowledge of SAS							
R=0.879, R^2=0.772, Adjusted R^2=0.762, F=73.553							

4.6 Determinants of Farmers' Attitudes on Sustainable Agriculture.

Table 9 presents the results of a regression analysis examining the relationship between various independent variables and farmers' attitudes towards sustainable agriculture in the Barind Tract of Bangladesh. The dependent variable in this analysis is farmers' attitudes towards sustainable agriculture, with the table providing coefficients, standard errors, standardized coefficients, t-values, significance levels, correlations, and collinearity statistics for each independent variable. The model has a good fit, with an R-squared value of 0.697, indicating that the independent variables explain 69.7% of the variation in farmers' attitudes. The adjusted R-squared value of 0.683 suggests that the model is robust and explains a substantial portion of the variance in attitudes. The overall F-statistic (49.833) is highly significant, confirming the model's relevance. Among the independent variables, Annual Farm Income (AFI) has the highest positive influence on attitudes towards sustainable agriculture ($B = 3.983$, $t = 19.504$, $p < 0.001$). This suggests that farmers who have more frequent and quality interactions with agricultural extension services and training programs tend to have significantly more positive attitudes toward sustainable farming. Experience also has a significant positive impact ($B = 0.084$, $t = 2.351$, $p = 0.019$), indicating that farmers with more years of experience tend to have more favorable attitudes towards sustainable agriculture. The collinearity statistics indicate no issues with multicollinearity, as the Variance Inflation Factor (VIF) values are all below 10. Overall, the analysis highlights the significant roles of experience and Annual Farm Income in shaping farmers' attitudes toward sustainable agriculture, emphasizing the importance of hands-on experience and access to agricultural extension services in fostering positive attitudes.

Table 9. Relationship between independent variables and farmers' attitudes towards sustainable agriculture in the Barind Tract of Bangladesh.

Coefficients'							
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	41.605	1.770		23.499	.000		
Age	-.052	.036	-.115	-1.441	.151	.182	5.501
Education	.066	.076	.033	.877	.381	.814	1.229
Family Size	-.044	.107	-.016	-.417	.677	.822	1.216
Farm Size	.673	.390	.063	1.728	.085	.867	1.154
Experience	.084	.036	.190	2.351	.019	.179	5.594
Annual Farm Income (AFI)	3.983	.204	.759	19.504	.000	.770	1.299
Training	.204	.494	.015	.413	.680	.929	1.077
Agricultural Extension Frequency (AEF)	.062	.033	.065	1.854	.065	.941	1.063
Innovativeness	-.009	.024	-.013	-.365	.716	.914	1.094
Cosmopoliteness	.124	.067	.066	1.858	.064	.928	1.078
Sustainable Agricultural Land (SAL)	1.491	1.160	.046	1.285	.200	.927	1.079
Sustainable Agricultural Training (SAT)	.680	.983	.025	.692	.490	.926	1.080
a. Dependent Variable: Attitude of SAS							

$R=0.835$, $R^2=0.697$, adjusted $R^2=0.683$, $F=49.833$

4.7 Determinants of Farmers' Practices on Sustainable Agriculture

Table 10 presents the results of a regression analysis examining the relationship between various independent variables and farmers' practices towards sustainable agriculture in the Barind Tract of Bangladesh. The dependent variable in this analysis is the farmers' engagement with sustainable agricultural practices. The model explains 57.7% of the variation in farmers' practices, with an R-squared value of 0.577 and an adjusted R-squared value of 0.557, suggesting that the independent variables account for a substantial portion of the variance in farming practices. The overall F-statistic of 29.497 is highly significant, indicating that the model is effective in explaining the dependent variable. Among the independent variables, Annual Farm Income (AFI) ($B = 2.065$, $t = 15.326$, $p < 0.001$) exhibits the most substantial positive impact on sustainable agricultural practices. This suggests that farmers who interact more frequently with agricultural extension services, training programs, or other agrarian experts tend to engage more in sustainable practices. Experience ($B = 0.032$, $t = 1.366$, $p = 0.173$) shows a positive but marginal effect, indicating that while more experienced farmers may engage in sustainable practices to some extent, the effect is not statistically significant. Variables like Cosmopoliteness ($B = 0.042$, $t = 0.964$, $p = 0.336$), Sustainable Agricultural Land (SAL) ($B = 0.726$, $t = 0.948$, $p = 0.344$), and Satisfaction (SAT) ($B = -0.894$, $t = -1.377$, $p = 0.170$) also do not significantly influence sustainable agricultural practices, further suggesting that factors such as exposure to external influences and satisfaction with current farming methods may not be the primary drivers of practice adoption in this region. The collinearity statistics show no signs of multicollinearity, as all Variance Inflation Factor (VIF) values are below the critical threshold of 10. In summary, the analysis emphasizes the central role of Annual Farm Income in fostering sustainable agricultural practices, while highlighting that other factors, such as experience, training, and external feedback, may require more targeted approaches to significantly influence farming practices in the Barind Tract.

Table 10. Relationship between independent variables and farmers' practices towards sustainable agriculture in the Barind Tract of Bangladesh.

Coefficients[a]							
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	12.506	1.168		10.706	.000		
Age	-.018	.024	-.070	-.743	.458	.182	5.501

Education	.079	.050	.071	1.583	.115	.814	1.229
Family Size	-.051	.070	-.032	-.727	.468	.822	1.216
Farm Size	.195	.257	.033	.760	.448	.867	1.154
Experience	.032	.024	.130	1.366	.173	.179	5.594
Annual Farm Income (AFI)	2.065	.135	.705	15.326	.000	.770	1.299
Training	.038	.326	.005	.117	.907	.929	1.077
Agricultural Extension Frequency (AEF)	-.025	.022	-.048	-1.149	.252	.941	1.063
Innovativeness	.003	.016	.008	.180	.857	.914	1.094
Cosmopoliteness	.042	.044	.040	.964	.336	.928	1.078
Sustainable Agricultural Land (SAL)	.726	.765	.040	.948	.344	.927	1.079
Sustainable Agricultural Training (SAT)	-.894	.649	-.058	-1.377	.170	.926	1.080
a. Dependent Variable: Practices of SAS							
R=0.759, R^2=0.577, adjusted R^2=0.557, F=29.497							

5. Discussion

The findings of this study reveal that farmers in the Barind Tract of Bangladesh possess moderate to high levels of knowledge and generally favorable attitudes toward sustainable agricultural practices, yet their actual adoption remains moderate, exposing a persistent gap between cognition and action that is emblematic of the "knowledge–practice divide" widely reported in sustainability research. This outcome both aligns with and challenges Hey Cortana's (2021) Knowledge Dynamics in Sustainable Farming in South Asia, which posits a linear and sequential relationship among knowledge, attitude, and practice (KAP), suggesting that greater awareness naturally fosters positive attitudes and, subsequently, behavioral change. The Barind evidence suggests a more nuanced, nonlinear interaction in which socio-economic status, institutional support, and perceived risk mediate the transition from knowledge to action. Farmers demonstrated a substantial awareness of environmentally friendly techniques, such as intercropping, crop rotation, agroforestry, and integrated pest management; however, they exhibited a weaker understanding of soil fertility management, organic fertilizer application, and water conservation practices that require higher capital investment and technical skills. This asymmetry is reflected in findings from Hassan et al., (2025) observed that farmers in northern Bangladesh often rely on low-cost, tradition-compatible sustainability measures while avoiding resource-intensive innovations. Such selective adoption suggests that sustainability awareness, though growing, remains conditioned by economic pragmatism rather than ecological consciousness alone.

Regression results indicate that annual farm income, farming experience, and cosmopoliteness are the most significant determinants of farmers' knowledge and attitudes. At the same time, education level, training, and extension contact exert a weaker influence. The divergence may be attributed to contextual differences between South Asia's subregions: in the Barind Tract, extension services are under-resourced, training is sporadic, and access to agricultural innovation is uneven, causing farmers to depend more on peer learning and experiential knowledge exchange. This aligns with Pretty & Bharucha, (2015) argument that informal and community-based knowledge networks often serve as the backbone of sustainable practice in resource-limited farming systems. The strong influence of income underscores that economic security enhances both cognitive openness and willingness to adopt riskier sustainable practices, a pattern consistent with studies by Li et al. (2020) and Md. I. Hossain et al. (2021), who found that income stability correlates positively with farmers' adoption of innovative practices in South and Southeast Asia. In this sense, economic empowerment functions as a precondition for sustainable agricultural transformation.

Attitudinally, Barind farmers express a clear belief that sustainability contributes to yield stability, soil health, and long-term profitability, reflecting a pragmatic, livelihood-oriented interpretation of sustainability rather than an abstract environmental ethic. This is consistent with the claim that positive attitudes toward sustainability in South Asia are driven by perceived socio-economic benefits rather than ecological idealism (Benschop, 2021). However, our findings expand on this perspective by revealing a layer of cautious optimism: farmers endorse sustainability in principle but hesitate in practice due to the high costs of inputs, labor shortages, and perceived uncertainty regarding immediate economic returns. Farmers' scepticism about institutional reliability, market stability, and government support further constrains their willingness to transition fully toward sustainable systems. Thus, while awareness and attitudes are relatively strong, behavioral intentions are moderated by perceptions of feasibility and access.

In practice, adoption patterns reveal that low-cost, low-risk sustainable practices such as intercropping and crop diversification are relatively widespread. In contrast, more complex practices, such as composting, integrated nutrient management, or water-efficient irrigation systems, which require specialized inputs or long-term investment, remain limited. These patterns align with findings from studies conducted in Sri Lanka, India, and Pakistan (Madushani et al., 2024), which attribute adoption barriers to high input costs, a lack of institutional facilitation, and limited market incentives. The regression analysis for the Barind Tract reveals that income is the single most influential factor shaping practice, surpassing both knowledge and attitude in terms of explanatory power. This challenges Benschop, (2021) assumption that knowledge and attitude directly translate into behavioral change, reinforcing instead the perspective of Pretty & Bharucha,

(2015) that sustainable practice depends on enabling economic and institutional conditions. Without financial incentives, technical assistance, and infrastructural support, knowledge remains inert and attitude symbolic.

Collectively, the study's results highlight that the adoption of sustainable agriculture in the Barind Tract is shaped less by cognitive limitations and more by structural and systemic constraints. The weak effects of education, training, and extension activities suggest inefficiencies within Bangladesh's agricultural knowledge infrastructure, echoing concerns raised by Alam et al., (2024) regarding the need for localized, participatory, and problem-oriented extension services. Moreover, the limited significance of cosmopoliteness and media exposure on practice adoption highlights the need to transform exposure into actionable guidance through on-farm demonstrations and peer-to-peer learning platforms. Consequently, the study proposes a contextualized revision of the traditional KAP model: rather than a unidirectional sequence, sustainable adoption should be conceptualized as a circular and feedback-driven process where practice outcomes reinforce or reshape knowledge and attitude through experience and observation.

6. Conclusion and Recommendation

This study provides a critical reappraisal of the conventional Knowledge, Attitude, and Practice (KAP) framework within the challenging agro-ecological context of Bangladesh's resource-scarce Barind Tract. Our findings reveal a profound paradox: while farmers possess moderate knowledge and overwhelmingly favorable attitudes towards sustainable agriculture, a significant gap exists between awareness and on-the-ground application, particularly in the areas of systematic soil nutrient management and agroforestry. This divergence fundamentally challenges the linear progression often assumed in KAP-based behavioral studies. The regression analysis identifies Annual Farm Income (AFI) as the most significant determinant across all three domains, indicating that economic capacity serves as a crucial mediator between intention and action. Consequently, awareness and positive attitudes are necessary but insufficient precursors for adoption; they are effectively gated by the financial ability of farmers to bear the perceived risks and upfront costs associated with transitioning to more sustainable systems. The limited impact of formal education and traditional extension services further corroborates that conventional, top-down dissemination models are inadequate for overcoming these deep-seated structural barriers. These insights necessitate a strategic pivot in policy, moving beyond mere information dissemination to actively dismantling the economic and institutional barriers to adoption. Firstly, enhancing the economic viability of sustainable practices is paramount. This requires a multi-pronged financial strategy including targeted subsidies for organic inputs, the establishment of micro-credit facilities tailored for sustainable technologies, and the development of robust market linkages that offer premium pricing for certified produce. Secondly, the agricultural extension service model demands a paradigm shift from prescriptive instruction to facilitative, farmer-centric learning. Establishing farmer-led demonstration hubs and formalizing peer-to-peer knowledge exchange networks can create a more contextualized and trusted learning environment. Thirdly, institutional support must be strengthened to de-risk the transition by ensuring reliable supply chains and promoting community-based mechanisms, such as cooperative resource management, to mitigate individual risks and foster collective action.

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Clinical Trial Number

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Data availability

The datasets collected during field study and analyzed are not publicly available due to privacy and ethical restrictions protecting research participant confidentiality but are available from the corresponding author on reasonable request.

Consent to Publish

Not applicable.

Consent to Participate

Informed consent was obtained from all individual participants included in the study before the face-to-face interviews. Participants were informed about the purpose of the research, the nature of their involvement, and that their data would be used anonymously for academic publication.

Ethics Approval

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Department of Agronomy and Agricultural Extension, University of Rajshahi (Date of Approval: February 17, 2025).

Competing interests

The authors declare no competing interests.

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