

Determinants of Modern Rice Production Technology Adoption: The Role of Extension Services, Biophysical Factors, and Farmers' Perceptions in Bonthe District, Sierra Leone

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How to cite this paper: Koroma, B.A., Munu, I., Mabey, P.T. and Kamanda, P.J. (2026) Determinants of Modern Rice Production Technology Adoption: The Role of Extension Services, Biophysical Factors, and Farmers' Perceptions in Bonthe District, Sierra Leone. *Open Journal of Applied Sciences*, 16, 4183-4206.
<https://doi.org/10.4236/ojapps.2026.1610228>

Received: August 24, 2026

Accepted: October 27, 2026

Published: October 30, 2026

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Abstract

The study investigated the determinants of modern rice production technology adoption in Bonthe District, Sierra Leone, with particular emphasis on the roles of extension services, biophysical conditions, and farmers' perceptions. A quantitative cross-sectional survey design was employed among 325 rice farmers selected through a multistage sampling procedure. Bonthe District and five major rice-producing communities: Torma, Borlleh, Madina, Sogballeh, and Ngepehun were purposively selected, while respondents were randomly sampled from lists of registered farmers. Data was collected using a structured interviewer-administered questionnaire and analysed using descriptive statistics, chi-square (χ^2) tests, and binary logistic regression in R software, with statistical significance set at $p < 0.05$. Findings revealed significant differences in extension service delivery, biophysical conditions, and farmers' perceptions across sections and communities. Extension indicators were strongly associated with location, including frequency of extension visits ($\chi^2 = 470.2$, $p < 0.001$), access to extension services ($\chi^2 = 365.9$, $p < 0.001$), and follow-up support ($\chi^2 = 281.9$, $p < 0.001$). Logistic regression showed that participation in training and demonstration programmes was the strongest positive predictor of adoption (OR = 14.35; Adjusted OR = 7.01; $p < 0.001$), while perceived strong extension influence negatively predicted adoption (Adjusted OR = 0.11; $p < 0.001$). Among biophysical factors, drought exposure significantly increased adoption (Adjusted OR = 3.19; $p = 0.002$), whereas flood exposure reduced adoption (Adjusted

OR = 0.36; $p = 0.018$). Perceived environmental benefits positively influenced adoption (Adjusted OR = 1.69; $p < 0.001$), whereas perceived income increase (Adjusted OR = 0.52; $p = 0.007$) and crop-failure risk (Adjusted OR = 0.74; $p = 0.013$) reduced adoption. The study concludes that effective extension services, climate-related production conditions, and farmers' perceptions significantly influence modern rice production technology adoption in Bonthe District. It recommends expanding farmer training and demonstration programmes, strengthening extension delivery and follow-up services, improving access to affordable agricultural credit, and promoting climate-resilient rice production technologies to enhance adoption and improve rice productivity and household food security.

Keywords

Modern Rice Production Technology Adoption, Extension Services, Biophysical Conditions, Farmers' Perceptions, Smallholder Rice Farmers, Bonthe District, Sierra Leon

1. Introduction

The magnitude of improvement in smallholder farmers' agricultural production, which in turn depends heavily on their capacity and willingness to innovate, is a major factor in the development of agriculture. Rice is one of the world's most important staple crops, providing food and livelihoods for more than half of the global population [1] [2]. As demand for rice continues to increase due to population growth, urbanization, and changing consumption patterns, improving rice productivity has become a global priority [3] [4]. Modern rice production technologies, including improved seed varieties, appropriate fertilizer use, mechanization, irrigation, integrated pest management, and climate-smart production practices, have been widely promoted to enhance productivity, strengthen food security, and improve farmers' incomes [5]-[7]. However, despite their proven benefits, the adoption of these technologies remains uneven across many developing countries, particularly in sub-Saharan Africa [8] [9].

In sub-Saharan Africa, the low adoption of modern agricultural technologies continues to constrain agricultural productivity and rural economic development [10] [11]. Although governments, research institutions, and development partners have invested substantially in agricultural extension systems and technology dissemination programmes, many smallholder farmers still rely on traditional farming practices characterized by low yields, limited input use, and vulnerability to climate variability [12] [13]. Previous studies have shown that technology adoption in agriculture is influenced not only by farmers' socioeconomic characteristics but also by institutional support, biophysical conditions, access to information, and farmers' perceptions of the benefits and risks associated with new technologies [14]-[16].

Among the institutional factors, agricultural extension services play a critical role in promoting technology adoption by providing technical information, training, demonstration activities, and advisory support [17]. Effective extension services reduce information asymmetry, improve farmers' technical knowledge, and increase confidence in adopting improved farming practices [18]. Biophysical conditions also influence the adoption of modern rice production technologies. Variations in soil fertility, water availability, topography, rainfall patterns, flooding, and land suitability determine the appropriateness and performance of different rice production technologies. Farmers operating under favourable environmental conditions are generally more willing to invest in improved technologies because of the greater likelihood of achieving higher productivity and profitability [19] [20]. Conversely, unfavourable biophysical conditions may discourage adoption due to increased production risks and uncertainty [21]. Farmers' perceptions constitute another important determinant of technology adoption. Decisions to adopt modern rice production technologies are strongly influenced by how farmers perceive their relative advantages, compatibility with existing farming systems, ease of use, economic returns, and associated risks [22] [23]. Positive perceptions regarding yield improvement, labour efficiency, and income generation encourage adoption, whereas concerns about high input costs, production risks, limited technical knowledge, and uncertainty regarding expected benefits often reduce farmers' willingness to adopt new technologies [24].

In Sierra Leone, agriculture remains the backbone of the rural economy, with rice serving as the country's principal staple food and the primary livelihood activity for a large proportion of rural households [25]. Despite numerous government initiatives and support from development partners aimed at increasing domestic rice production through the dissemination of improved rice production technologies, national productivity remains below potential, and rice imports continue to supplement domestic demand [26] [27]. These challenges are particularly evident in rural districts where farmers face multiple constraints related to resource availability, extension service delivery, environmental conditions, and access to agricultural inputs [28] [29]. Hence, this study therefore examined the determinants of modern rice production technology adoption by assessing the roles of extension services, biophysical factors, and farmers' perceptions among rice farmers in Bonthe District, Sierra Leone.

2. Research Methodology

2.1. Description of the Study Area

The study was conducted in Bonthe District, located in the Southern Province of Sierra Leone. The district is characterized by extensive inland valley swamps, mangrove ecosystems, and rain-fed lowland rice production systems, making it one of the country's major rice-producing areas. Agriculture is the principal livelihood activity, with rice serving as the dominant staple crop. The district experiences a tropical monsoon climate with distinct wet and dry seasons, annual rain-

fall ranging from approximately 2500 to 3500 mm, and temperatures averaging between 24°C and 30°C. Five rice-producing communities Torma Bum (Torma): 7.329978°N, -12.242906°W, Borlleh: 7.502078°N, -12.115161°W, Madina: 8.166667°N, -12.066667°W, Ngepehun: 7.375013°N, -12.138402°W, and Sogballeh: 7.329978°N, -12.242906°W, were purposively selected because of their high rice production potential and the presence of extension interventions promoting modern rice technologies.

2.2. Research Design

The study employed a quantitative cross-sectional survey design. The design was appropriate because it enabled the collection of data from farmers at a single point in time to assess the factors influencing the adoption of modern rice production technologies. The approach facilitated the examination of relationships between technology adoption and extension services, biophysical conditions, and farmers' perceptions.

2.3. Sample Size Determination and Sampling Procedure

The study employed a multistage sampling procedure to select respondents from rice-producing communities in Bonthe District, Sierra Leone. In the first stage, Bonthe District was purposively selected because of its significant contribution to rice production and the ongoing promotion of modern rice technologies. In the second stage, five major rice-producing sections, Torma, Koimato, Gbondubu, Fikie, and Yagbeh, represented by the communities of Torma, Borlleh, Madina, Sogballeh, and Ngepehun, respectively (**Table 1**), were purposively selected based on their high rice production potential and active involvement in rice farming. The lists of registered rice farmers were obtained from the district agricultural extension offices, from which individual respondents were selected using simple random sampling. The sampling frame consisted of 1720 registered rice farmers identified through the Bonthe District agricultural extension offices. Because an independent estimate of the total number of registered and unregistered rice farmers in the district was unavailable, the proportion of all rice farmers represented by the register could not be established. Accordingly, the findings and inferences of this study are limited primarily to rice farmers represented in the registered-farmer sampling frame and should not be generalized to unregistered farmers without further evidence. The primary outcome was binary technology adoption. Modern rice production technologies included improved/climate-resilient varieties, irrigation, mechanisation, soil-fertility management, improved agronomic practices, and integrated pest management. Farmers were classified as adopters (1) if they had used at least one of these technologies during the most recent rice production season and non-adopters (0) if they had used none. Thus, adoption represented the use of any one or more technologies, rather than requiring simultaneous adoption of the complete technology package. The sample size was determined using a statistical formula by Yamane [30] for a finite population:

$$n = N/(1 + N(e^2))$$

where:

n = required sample size

N = total population size

e = margin of error (0.05)

where n is the required sample size, N is the total population (1720 registered rice farmers), and e is the acceptable margin of error (0.05).

Substituting the values:

$N = 1720$ farmers

$e = 0.05$

Applying the formula:

$$n = 1720/(1 + 1720(0.05^2))$$

$$n = 1720/(1 + 1720(0.0025))$$

$$n = 1720/(1 + 4.3)$$

$$n = 1720/5.3$$

$$n = 324.53 \approx 324 \text{ respondents}$$

Table 1. Proportionate distribution of sample size.

SN	Section	Community	Total # of Farmers	Sample Size
1	Torma	Torma	500	94.33
2	Koimato	Borlleh	320	60.37
3	Gbondubu	Madina	300	57.0
4	Fikie	Sogballeh	300	57.0
5	Yagbeh	Ngepehun	300	57.0
GRAND TOTAL			1720	≈325

Accordingly, a sample of 325 rice farmers was selected for the study. The sample was proportionately allocated according to the number of registered rice farmers in each section to ensure fair representation. This sampling approach ensured that every eligible farmer had an equal chance of being selected while maintaining proportional representation across the study sections and respective communities.

2.4. Data Collection Methods

Primary data was collected using a structured interviewer-administered questionnaire. The questionnaire was administered through face-to-face interviews because many respondents had limited formal education. The questionnaire consisted of five sections: socio-demographic characteristics; access to agricultural extension services; biophysical characteristics of farms; farmers' perceptions of benefits, risks, and constraints associated with modern rice production technologies;

and adoption status of modern rice production technologies. The questionnaire was developed from previous adoption studies and adapted to the Sierra Leonean context. It was pre-tested among rice farmers outside the study communities, and necessary revisions were made to improve clarity and validity.

2.5. Data Analysis

Data was coded, entered, cleaned, and analysed using R statistical software (Version 4.x). Descriptive statistics, including frequencies and percentages, were used to summarize respondents' socio-demographic characteristics and perceptions. Chi-square (χ^2) tests of independence were used to determine whether extension service indicators, biophysical conditions, and perception variables differed significantly across the study sections and communities. Binary logistic regression analysis was employed to identify determinants of modern rice production technology adoption. Odds Ratios (OR), Adjusted Odds Ratios (AOR), Wald statistics, 95% confidence intervals, and p-values were reported. Statistical significance was assessed at the 5% level ($p < 0.05$). Model performance was evaluated using the likelihood ratio chi-square statistic and McFadden's pseudo- R^2 . Because some contingency tables contained sparse cells, exact or Monte Carlo simulated tests were used where the assumptions of the asymptotic Pearson chi-square test were not adequately satisfied. Where appropriate, categories with extremely small frequencies were combined only when substantively defensible. Firth's penalized likelihood method was used to estimate the logistic regression models to reduce small-sample and separation-related bias. Binary predictors were coded 1 = condition present/Yes and 0 = condition absent/No, with the latter serving as the reference category. Section was included as an adjustment variable in the adjusted models.

Key Informant Interviews (KIIs) were conducted among purposively selected respondents who had great knowledge about rice production and dissemination of new technologies in the study area to collect qualitative data for triangulation purposes. The respondents for this data included agricultural extension workers, rice farmers' association leaders, community leaders, agro-input dealers, non-governmental organization (NGO) representatives and other relevant personnel from agricultural institutions. The interview was done using a semi-structured guide to examine the existence of various resources and factors that could affect adoption of modern rice production technologies such as improved seeds, credit facilities, extension services, agro-inputs, training, markets and institutions. The interview was face-to-face and was recorded with the permission of respondents and accompanied by field notes.

2.6. Validity and Reliability

Content validity was ensured through expert review by agricultural extension specialists, rice production experts, and university researchers. A pilot survey was conducted before the main data collection to assess the suitability of the question-

naire for accurately capturing the intended information. Necessary modifications were made based on the pilot findings. Internal consistency of the perception items was assessed using Cronbach's alpha coefficient. A reliability coefficient of at least 0.70 was considered acceptable for inclusion in the final analysis.

2.7. Ethical Considerations

Ethical approval for the study was obtained from the relevant institutional authorities before data collection commenced. Permission was also obtained from district agricultural authorities, and community leaders/chiefs. Participation was voluntary, and informed consent was obtained from every respondent before the interviews. Respondents were assured that their responses would remain confidential and anonymous and would be used solely for academic purposes. Personal identifiers were removed during data processing, and respondents retained the right to withdraw from the study at any stage without penalty.

3. Results and Discussion

3.1. Demographic Characteristics of the Respondents

The demographic and socio-economic characteristics of respondents in Bonthe District reveal that rice farming is largely undertaken by middle-aged, experienced smallholder farmers who depend heavily on agriculture for their livelihoods. Male farmers constituted the majority of respondents (62.5%), with the highest proportion recorded in Ngepehun (78.9%), while Borlleh had the highest proportion of female farmers (53.3%), indicating variations in gender participation across communities. The age distribution was dominated by farmers aged 43 - 47 years (20.6%), followed by those aged 38 - 42 years (18.5%), suggesting that rice farming is primarily practiced by economically active individuals. In contrast, the youngest age group (18 - 22 years) accounted for only 2.2% of respondents (**Table 2**), reflecting limited youth participation in rice production.

Educational attainment was generally low, as nearly half of the respondents (49.5%) had no formal education, with Borlleh recording the highest proportion (68.3%). Conversely, tertiary education was the least represented category (1.9%), highlighting the generally low literacy level among rice farmers, which may constrain access to agricultural information and the adoption of improved technologies. Farming experience was relatively high, with the largest proportion of farmers having 11 - 15 years of experience (23.1%), followed by 16 - 20 years (20.9%). Ngepehun recorded the highest proportion of farmers within the 11 - 15-year category (42.1%), while only 2.2% had 41 - 45 years of farming experience, indicating that most farmers possess moderate to substantial practical knowledge of rice cultivation. Farm characteristics further demonstrate the dominance of smallholder agriculture in the district. The most common farm size was 2 acres (23.7%), followed by 4 acres (21.2%), with Borlleh recording the highest proportion of 2-acre farms (53.3%) and Madina the highest proportion of 4-acre farms (40.4%). Very large farms were rare, as farm sizes of 11, 12, 20, 22, and 25 acres each accounted

for only 0.3% of respondents. Rice farming was the principal source of household income for the vast majority of respondents (88.3%), reaching 100% in Madina, underscoring the central role of rice production in household livelihoods and food security. In contrast, only 11.7% depended primarily on other crops, while none reported livestock or non-farm activities as their major income source.

Membership in farmer organizations was nearly evenly distributed, with 49.5% belonging to farmer groups and 50.5% not affiliated with any organization. Borlleh exhibited the highest membership rate (98.3%), suggesting stronger opportunities for collective action, access to extension services, training, and agricultural inputs. Conversely, Sogballeh recorded the lowest membership level (12.3%), with most farmers (87.7%) operating outside formal farmer organizations. The findings indicate that rice farming in Bonthe District is dominated by middle-aged, moderately experienced farmers with low levels of formal education, operating predominantly small-scale farms and relying heavily on rice cultivation as their main livelihood source. The observed differences in education, organizational membership, and farm resources across communities may have important implications for agricultural productivity and the adoption of improved rice production technologies.

Table 2. Percentage distribution of respondents' demographic characteristics.

	Borlleh (%) n = 60	Madina (%) n = 57	Ngepehun (%) n = 57	Sogballeh (%) n = 57	Torma (%) n = 94	All Total (%) n = 325
Gender						
Male	46.7	68.4	78.9	73.7	52.1	62.5
Female	53.3	31.6	21.1	26.3	47.9	37.5
Age group (years)						
18 - 22	1.7	0.0	0.0	0.0	6.4	2.2
23 - 27	6.7	1.8	0.0	3.5	2.1	2.8
28 - 32	15.0	1.8	5.3	3.5	3.2	5.5
33 - 37	15.0	10.5	22.8	8.8	10.6	13.2
38 - 42	20.0	5.3	26.3	17.5	21.3	18.5
43 - 47	15.0	29.8	19.3	19.3	20.2	20.6
48 - 52	1.7	29.8	15.8	21.1	28.8	15.7
53 - 57	10.0	17.5	3.5	14.0	11.7	11.4
58 - 62	5.0	3.5	7.0	10.5	5.3	6.2
63 - 67	10.0	0.0	0.0	1.8	6.4	4
Education level						
Quranic	15.0	24.6	22.8	15.8	23.4	20.6
No formal education	68.3	40.4	49.1	59.6	37.2	49.5
Primary	10.0	15.8	22.8	21.1	17.0	17.2
Secondary	6.7	15.8	5.3	3.5	18.1	10.8
Tertiary	0.0	3.5	0.0	0.0	4.3	1.9

Continued**Farming experience (years)**

1 - 5	11.7	14.0	3.5	17.5	10.6	11.4
6 - 10	13.3	19.3	26.3	22.8	21.3	20.6
11 - 15	13.3	22.8	42.1	22.8	17.0	23.1
16 - 20	26.7	21.1	21.1	19.3	18.1	20.9
21 - 30	16.7	12.3	3.5	12.3	12.8	11.7
31 - 35	10.0	7.0	3.5	3.5	12.8	8
36 - 40	6.7	0.0	0.0	1.8	3.2	2.5
41 - 45	1.7	3.5	0.0	0.0	4.3	2.2

Size of rice farm (acres)

1	0.0	0.0	1.8	3.5	6.4	2.8
2	53.3	5.3	14.0	8.8	30.9	23.7
3	13.3	5.3	14.0	21.1	6.4	11.4
4	18.3	40.4	15.8	14.0	19.1	21.2
5	1.7	14.0	22.8	26.3	9.6	14.2
6	8.3	15.8	12.3	12.3	6.4	10.5
7	0.0	0.0	7.0	1.8	2.1	2.1
8	0.0	12.3	8.8	7.0	5.3	6.5
9	0.0	0.0	3.5	1.8	0.0	0.9
10	5.0	1.8	0.0	1.8	8.5	4
11	0.0	0.0	0.0	0.0	1.1	0.3
12	0.0	0.0	0.0	0.0	1.1	0.3
15	0.0	3.5	0.0	0.0	2.1	1.2
20	0.0	0.0	0.0	1.8	0.0	0.3
22	0.0	0.0	0.0	0.0	1.1	0.3
25	0.0	1.8	0.0	0.0	0.0	0.3

Main source of household

Rice farming	96.7	100.0	75.4	70.2	94.7	88.3
Other crops	3.3	0.0	24.6	29.8	5.3	11.7
Livestock	0.0	0.0	0.0	0.0	0.0	0
Non-farm activities	0.0	0.0	0.0	0.0	0.0	0

Member of farmer organization

Yes	98.3	57.9	28.1	12.3	48.9	49.5
No	1.7	42.1	71.9	87.7	51.1	50.5

3.2. Role of Extension Services in Farmers' Adoption Decision by Section/Community

The chi-square analysis showed that all extension service indicators were signifi-

cantly associated with section location ($p < 0.001$), indicating substantial differences in extension service delivery across the study sections (**Table 3**) [31] [32]. The strongest variation was observed in the frequency of extension agent visits ($\chi^2 = 470.2$, $df = 12$), where Madina recorded the highest proportion of farmers receiving very regular visits (89.5%), while Sogballeh recorded the highest proportion reporting no visits (98.2%). Similarly, access to agricultural extension services ($\chi^2 = 365.9$, $df = 12$) and ease of access to extension services ($\chi^2 = 314.8$, $df = 12$) showed large disparities, with Borlleh and Madina recording the highest access levels, whereas Sogballeh consistently reported the lowest access (**Table 3**) [31] [33].

Table 3. Role of extension services in adoption of modern rice technology.

Variable	Torma (%) n = 94	Madina (%) n = 57	Ngepehun (%) n = 57	Borlleh (%) n = 60	Sogballeh (%) n = 57	χ^2	df	p	Total (%) n = 324
Access to agricultural extension services						365.9	12	<0.001	
No access	10.6	0.0	24.6	0.0	98.2				24.6
Yes, but very limited access	13.8	0.0	47.4	1.7	0.0				12.6
Yes, occasional access	42.6	50.9	12.3	96.7	1.8				41.5
Yes, regular access	33.0	49.1	15.8	1.7	0.0				21.2
Frequency of extension agent visits						470.2	12	<0.001	
Never	8.5	0.0	21.1	0.0	98.2				23.4
Occasionally (a few times a year)	46.8	10.5	26.3	96.7	0.0				37.8
Rarely (once a year or less)	16.0	0.0	49.1	0.0	1.8				13.5
Very regularly (monthly or more)	28.7	89.5	3.5	3.3	0.0				25.2
Information on modern rice technologies						274.9	12	<0.001	
No information received	11.7	0.0	28.1	5.0	100.0				26.8
Yes, basic information only	59.6	35.1	43.9	61.7	0.0				42.5
Yes, but not useful	4.3	0.0	19.3	0.0	0.0				4.6
Yes, detailed and practical information	24.5	64.9	8.8	33.3	0.0				26.2
Training/demonstration attendance						209.2	16	<0.001	
Invited but did not attend	4.3	0.0	19.3	8.3	0.0				6.2
Not Invited but attend	1.1	0.0	8.8	1.7	0.0				2.2
Never attended	30.9	3.5	29.8	43.3	100.0				40.3
Yes, once	29.8	15.8	29.8	30.0	0.0				22.2
Yes, several times	34.0	80.7	12.3	16.7	0.0				29.2
Perceived clarity of information						216.7	12	<0.001	
Clear	51.1	12.3	22.8	58.3	0.0				31.7

Continued

Not clear at all	25.5	5.3	43.9	23.3	100.0			37.8
Somewhat unclear	8.5	19.3	19.3	5.0	0.0%			10.2
Very clear and easy to understand	14.9	63.2	14.0	13.3	0.0%			20.3
Influence of extension on adoption						222.7	16	<0.001
Low influence	13.8	1.8	42.1	10.0	5.3			14.5
Moderate influence	7.4	8.8	17.5	20.0	7.0			11.7
No influence	7.4	0.0	24.6	8.3	66.7			19.7
Strong influence	40.4	71.9	7.0	13.3	10.5			29.8
Very strong influence	30.9	17.5	8.8	48.3	10.5			24.3
Most effective extension method						121.6	16	<0.001
Demonstration	45.7	36.8	49.1	11.7	1.8			30.8
Farm visit	40.4	63.2	28.1	53.3	98.2			54.8
Group meetings	8.5	0.0	22.8	31.7	0.0			12.3
Media (radio)	1.1	0.0	0.0	3.3	0.0			0.9
Other (please specify)	4.3	0.0	0.0	0.0	0.0			1.2
Ease of access to extension services						314.8	12	<0.001
No, not at all	7.4	0.0	28.1	0.0	100.0			24.6
Yes, always	36.2	40.4	10.5	16.7	0.0			22.5
Yes, rare	16.0	0.0	43.9	8.3	0.0			13.8
Yes, sometimes	40.4	59.6	17.5	75.0	0.0			39.1
Follow-up support after training						281.9	12	<0.001
No, not at all	18.1	0.0	28.1	1.7	100.0			28.0
Yes, always	21.3	38.6	1.8	18.3	0.0			16.6
Yes, rare	10.6	3.5	50.9	15.0	0.0			15.4
Yes, sometimes	50.0	57.9	19.3	65.0	0.0			40.0
Overall satisfaction with extension						267.6	12	<0.001
Dissatisfied	14.9	0.0	38.6	16.7	10.5			16.0
Satisfied	53.2	68.4	35.1	83.3	0.0			48.9
Very dissatisfied	9.6	0.0	24.6	0.0	89.5			22.8
Very satisfied	22.3	31.6	1.8	0.0	0.0			12.3

Note. Values are n (%). Chi-square statistics test association between each extension indicator and section; empty rows/columns were dropped before testing. All tests were significant at $p < 0.001$.

Other indicators, including follow-up support after training ($\chi^2 = 281.9$, $df = 12$), information on modern rice production technologies ($\chi^2 = 274.9$, $df = 12$), and overall satisfaction with extension services ($\chi^2 = 267.6$, $df = 12$) (**Table 3**), also revealed significant sectional differences [34]. Madina generally recorded the highest levels of detailed information, regular support, and positive perceptions of ex-

tension services, while Sogballeh recorded the highest proportions of respondents lacking information, support, and satisfaction. Likewise, influence of extension on adoption ($\chi^2 = 222.7$, $df = 16$), perceived clarity of information ($\chi^2 = 216.7$, $df = 12$), and training attendance ($\chi^2 = 209.2$, $df = 16$) demonstrated that farmers in Madina and Borlleh benefited more from extension interventions than those in Sogballeh [35] [36].

The lowest chi-square value was recorded for the most effective extension method ($\chi^2 = 121.6$, $df = 16$, $p < 0.001$), suggesting comparatively smaller differences among sections regarding preferred communication approaches [37]. Farm visits were identified as the most effective extension method overall (54.8%), whereas radio-based extension was the least preferred (0.9%). Hence, Madina and Borlleh consistently recorded the highest positive extension indicators, while Sogballeh recorded the lowest values across most variables. These findings indicate that stronger extension service delivery is closely associated with greater farmer awareness, participation, satisfaction, and adoption of modern rice [38] [39].

3.3. Logistic Regression of Adoption on Extension Services

In **Table 4**, it can be seen that the logistic regression model demonstrated a good overall fit, with the section-adjusted model explaining 44.2% of the variation in modern rice production technology adoption (McFadden $R^2 = 0.442$) and a significant likelihood ratio statistic (LR $\chi^2 = 195.1$, $df = 13$), indicating that extension service variables collectively influenced farmers' adoption decisions [40]. Among the extension service variables, attendance at training and demonstration programmes was the strongest positive determinant of adoption, with farmers who participated being over 14 times more likely to adopt modern rice technologies (OR = 14.35, Adjusted OR = 7.01, $p < 0.001$) [41]. This variable also recorded the

Table 4. Logistic regression of adoption on extension services.

Predictor	B	SE	OR	z	Wald	df	p	Adj. OR (p) ¹
Access to extension	-0.99	0.82	0.37	-1.21	1.46	1	0.227	0.41 (0.271)
Regular agent visits	1.70	0.89	5.47	1.91	3.66	1	0.056	6.28 (0.053)
Useful information received	0.91	0.58	2.49	1.57	2.48	1	0.116	1.18 (0.784)
Attended training/demo	2.66	0.46	14.35	5.76	33.23	1	<0.001	7.01 (<0.001)
Information is clear	-0.15	0.46	0.86	-0.33	0.11	1	0.739	1.14 (0.793)
Strong extension influence	-2.59	0.57	0.07	-4.52	20.47	1	<0.001	0.11 (<0.001)
Easy to access service	0.23	0.73	1.26	0.31	0.10	1	0.755	0.80 (0.770)
Follow-up support provided	0.43	0.57	1.54	0.75	0.57	1	0.451	1.69 (0.372)
Satisfied with service	-0.31	0.61	0.73	-0.51	0.27	1	0.607	0.44 (0.183)

Model fit: unadjusted LR chi-square = 133.8 ($df = 9$), McFadden R-square = 0.303; section-adjusted LR chi-square = 195.1 ($df = 13$), McFadden R-square = 0.442. $n = 325$; adopters = 182. Note. B = penalized log-odds coefficient; OR = odds ratio; Wald = squared z-statistic. Predictors are binary (1 = condition present). Adj. OR (p) is the odds ratio from the section-adjusted model. $p < 0.05$, $p < 0.01$, $p < 0.001$.

largest Wald statistic (33.23), highlighting the critical role of practical training and demonstrations in promoting technology adoption [42]. Regular extension agent visits also showed a relatively strong positive effect (OR = 5.47, Adjusted OR = 6.28), although the relationship was only marginally significant ($p = 0.056$; adjusted $p = 0.053$).

Conversely, strong extension influence exhibited the strongest negative association with adoption (OR = 0.07, Adjusted OR = 0.11, $p < 0.001$), making it the least favourable predictor in the model [43]. Other variables, including easy access to extension services (OR = 1.26, $p = 0.755$), information clarity (OR = 0.86, $p = 0.739$), service satisfaction (OR = 0.73, $p = 0.607$), follow-up support (OR = 1.54, $p = 0.451$), useful information received (OR = 2.49, $p = 0.116$), and access to extension services (OR = 0.37, $p = 0.227$) were not statistically significant predictors of adoption [44] [45].

3.4. Biophysical Conditions Necessary for Modern Rice Technology Adoption

Table 5 indicates that dominant soil type showed the strongest association with the study sections ($\chi^2 = 159.2$, $df = 12$, $p < 0.001$), making it the most significant biophysical factor differentiating adoption environments [46]. The loam soil was the predominant soil type (73.2%), particularly in Madina (100.0%), Borlleh (96.7%), and Sogballeh (98.2%), while mixed soil types were concentrated in Ngepehun (77.2%). This suggests substantial spatial variation in soil characteristics that may influence the suitability and adoption of modern rice technologies [47] [48]. Regarding farming systems, the dominant rice cultivation system recorded the lowest but still significant association among the biophysical variables ($\chi^2 = 28.6$, $df = 12$, $p = 0.004$). Across all sections, rain-fed lowland farming overwhelmingly dominated (93.5%), indicating that rice production largely depends on rain-fed lowland conditions, whereas fully irrigated systems (0.9%) and both irrigated and rain-fed systems (0.6%) were rarely practiced [49] [50].

Table 5. Chi-square tests for biophysical conditions.

Variable	Torma (%) n = 94	Madina (%) n = 57	Ngepehun (%) n = 57	Borlleh (%) n = 60	Sogballeh (%) n = 57	χ^2	df	p	Total (%) n = 324
Dominant rice cultivation system						28.6	12	0.004	
Both irrigated and rain-fed systems	2.1	0.0	0.0	0.0	0.0				0.6
Fully irrigated system	2.1	0.0	0.0	1.7	0.0				0.9
Rain-fed lowland system	83.0	100.0	100.0	93.3	98.2				93.5
Rain-fed upland system	12.8	0.0	0.0	5.0	1.8				4.9
Dominant soil type						159.2	12	<0.001	
Clay soil	1.1	0.0	0.0	0.0	1.8				0.6
Loam soil	59.6	100.0	19.3	96.7	98.2				73.2

Continued

Mixed soil types	39.4	0.0	77.2	3.3	0.0			25.5
Not sure	0.0	0.0	3.5	0.0	0.0			0.6
Soil fertility rating						84.5	8	<0.001
High fertile	47.9	64.9	35.1	20.0	10.5			36.9
Medium fertility	8.5	0.0	21.1	1.7	0.0			6.5
Very high fertility	43.6	35.1	43.9	78.3	89.5			56.6
Frequency of farm flooding						214.2	12	<0.001
Frequently (almost every season)	5.3	0.0	3.5	43.3	59.6			20.6
Never	0.0	0.0	0.0	0.0	5.3			0.9
Occasionally	61.7	100.0	33.3	56.7	12.3			53.8
Rarely	33.0	0.0	63.2	0.0	22.8			24.6
Frequency of drought stress						187.9	12	<0.001
Frequently	1.1	0.0	0.0	1.7	0.0			0.6
Never	20.2	0.0	8.8	45.0	29.8			20.9
Occasionally	46.8	100.0	3.5	31.7	61.4			48.3
Rarely	31.9	0.0	87.7	21.7	8.8			30.2

Note. Values are n (%). Chi-square statistics test association between each biophysical indicator and section.

Other biophysical conditions also showed highly significant differences across sections ($p < 0.001$). Very high soil fertility was the most common fertility category (56.6%), especially in Sogballeh (89.5%) and Borlleh (78.3%). Occasional flooding was the predominant flooding pattern (53.8%), while occasional drought stress was the most frequently reported drought condition (48.3%). In contrast, frequent drought (0.6%), never experiencing flooding (0.9%), and clay soils (0.6%) were the least reported conditions. These findings demonstrate that significant differences in soil characteristics, fertility, flooding, and drought conditions exist across the sections and are likely to influence the adoption of modern rice technologies [51] [52].

3.5. Logistic Regression of Adoption on Biophysical Conditions

Table 6 shows that drought exposure was the strongest positive biophysical predictor of modern rice production technology adoption, with farmers experiencing drought being three times more likely to adopt modern technologies ($OR = 3.00$, $Wald = 14.45$, $p < 0.001$). This relationship remained significant after adjustment (Adjusted $OR = 3.19$, $p = 0.002$), suggesting that drought serves as a major driver encouraging farmers to adopt technologies that improve resilience and productivity [53] [54].

In contrast, loam soil was the strongest negative predictor in the unadjusted model ($OR = 0.37$, $Wald = 9.06$, $p = 0.003$), indicating that farmers cultivating loam soils were significantly less likely to adopt modern rice production technologies [55]. However, this association disappeared after controlling for section-

level effects (Adjusted OR = 1.05, $p = 0.915$), implying that the initial effect was influenced by geographical differences rather than soil type alone. The least influential variable was irrigated cultivation, which showed no significant association with adoption (OR = 0.39, Wald = 0.78, $p = 0.376$; Adjusted OR = 0.30, $p = 0.267$). Similarly, high soil fertility and flood exposure were not significant predictors in the unadjusted model, although flood exposure became significant after adjustment (Adjusted OR = 0.36, $p = 0.018$), suggesting lower adoption among farmers exposed to flooding when section-level differences were considered [56].

Table 6. Logistic regression of adoption on biophysical conditions.

Predictor	B	SE	OR	z	Wald	df	p	Adj. OR (p) ¹
Irrigated cultivation	-0.95	1.08	0.39	-0.88	0.78	1	0.376	0.30 (0.267)
Loam soil	-1.00	0.33	0.37	-3.01	9.06	1	0.003	1.05 (0.915)
High soil fertility	-1.09	0.59	0.33	-1.86	3.47	1	0.063	0.64 (0.461)
Flood exposure	-0.29	0.34	0.75	-0.86	0.74	1	0.391	0.36 (0.018)
Drought exposure	1.10	0.29	3.00	3.80	14.45	1	<0.001	3.19 (0.002)

Model fit: unadjusted LR chi-square = 36.9 (df = 5), McFadden R-square = 0.084; section-adjusted LR chi-square = 156.7 (df = 9), McFadden R-square = 0.355. $n = 325$; adopters = 182. Note. B = penalized log-odds coefficient; OR = odds ratio; Wald = squared z-statistic. Predictors are binary (1 = condition present). Adj. OR (p) is the odds ratio from the section-adjusted model. $p < 0.05$, $p < 0.01$, $p < 0.001$.

3.6. Farmers' Perceptions of Benefits, Risks and Constraints

Table 7 indicates that farmers generally held positive perceptions of modern rice production technologies, particularly regarding their ability to increase rice yield, improve grain quality, and enhance farm income. The greatest perceived benefit was increased rice yield, with 69.8% of respondents strongly agreeing, followed by improved rice quality (62.8%) and increased farm income (58.5%) [57] [58]. Ngepehun and Sogballeh consistently recorded the highest levels of strong agreement for these benefits, while Madina showed the lowest levels of strong agreement, although most respondents there still agreed that the technologies were beneficial. Among the perceived risks, high financial risk was the most significant concern, with 38.2% strongly agreeing that adopting modern rice production technologies requires substantial financial investment [59]. In contrast, crop failure was the least perceived risk, as 48.3% of respondents disagreed that modern technologies increase the likelihood of crop failure, while environmental concerns were also relatively low, with 40.3% disagreeing that the technologies are environmentally harmful [60].

Regarding adoption constraints, limited access to credit emerged as the greatest barrier (56.6% strongly agree), followed by inadequate extension support (50.2%), high input costs (47.7%), and limited technical knowledge (47.4%) [61]. Ngepehun consistently reported the highest perceptions of these financial and technical barriers, whereas Madina recorded the lowest. Overall, the findings suggest that alt-

though farmers strongly recognize the productivity and economic advantages of modern rice production technologies, improving access to affordable credit, reducing input costs, strengthening extension services, and enhancing farmer training remain critical for increasing technology adoption across Bonthe District.

Table 7. Farmers' perceptions of benefits, risks and constraints.

Farmers' Perceptions	Borlleh (%) n = 60	Madina (%) n = 57	Ngepehun (%) n = 57	Sogballeh (%) n = 57	Torma (%) n = 94	Total (%) n = 325
Agreement that modern rice technologies increase rice yield						
Strongly agree	86.7	5.3	96.5	96.5	66.0	69.8
Agree	10.0	93.0	0.0	3.5	26.6	26.5
Moderately agree	3.3	1.8	1.8	0.0	5.3	2.8
Neutral	0.0	0.0	1.8	0.0	2.1	0.9
Disagree	0.0	0.0	0.0	0.0	0.0	0.0
Strongly disagree	0.0	0.0	0.0	0.0	0.0	0.0
Agreement that modern rice technologies improve rice quality						
Strongly agree	85.0	8.8	78.9	87.7	56.4	62.8
Agree	8.3	91.2	1.8	10.5	29.8	28.3
Moderately agree	6.7	0.0	17.5	1.8	13.8	8.6
Neutral	0.0	0.0	1.8	0.0	0.0	0.3
Disagree	0.0	0.0	0.0	0.0	0.0	0.0
Strongly disagree	0.0	0.0	0.0	0.0	0.0	0.0
Agreement that modern technologies increase farm income						
Strongly agree	73.3	12.3	66.7	86.0	55.3	58.5
Agree	13.3	87.7	0.0	8.8	31.9	28.6
Moderately agree	13.3	0.0	31.6	3.5	12.8	12.3
Neutral	0.0	0.0	1.8	0.0	0.0	0.3
Disagree	0.0	0.0	0.0	0.0	0.0	0.0
Strongly disagree	0.0	0.0	0.0	1.8	0.0	0.3
Agreement that modern rice technologies involve high financial risk						
Strongly agree	48.3	0.0	73.7	26.3	40.4	38.2
Agree	10.0	1.8	8.8	7.0	18.1	10.2
Moderately agree	10.0	0.0	12.3	14.0	14.9	10.8
Neutral	30.0	0.0	3.5	22.8	5.3	11.7
Disagree	1.7	86.0	1.8	7.0	21.3	23.1
Strongly disagree	0.0	12.3	0.0	22.8	0.0	6.2
Perception of crop failure risk in modern rice technologies						
Strongly agree	10.0	0.0	22.8	7.0	7.4	9.2
Agree	8.3	0.0	1.8	14.0	9.6	7.1

Continued

Moderately agree	3.3	0.0	1.8	3.5	5.3	3.1
Neutral	33.3	0.0	17.5	8.8	14.9	15.1
Disagree	41.7	87.7	40.4	12.3	55.3	48.3
Strongly disagree	3.3	12.3	15.8	54.4	7.4	17.2
Belief that modern rice technology is environmentally harmful						
Strongly agree	5.0	0.0	38.6	7.0	3.2	9.8
Agree	5.0	0.0	15.8	3.5	26.6	12.0
Moderately agree	1.7	0.0	3.5	3.5	5.3	3.1
Neutral	48.3	0.0	8.8	0.0	12.8	14.2
Disagree	35.0	87.7	15.8	12.3	46.8	40.3
Strongly disagree	5.0	12.3	17.5	73.7	5.3	20.6
Agreement that high input costs limit adoption						
Strongly agree	46.7	3.5	91.2	43.9	51.1	47.7
Agree	13.3	45.6	3.5	5.3	25.5	19.4
Moderately agree	8.3	0.0	3.5	1.8	9.6	5.2
Neutral	20.0	0.0	1.8	8.8	1.1	5.8
Disagree	10.0	50.9	0.0	21.1	11.7	17.8
Strongly disagree	1.7	0.0	0.0	19.3	1.1	4.0
Perception of technical knowledge as a barrier for adoption						
Strongly agree	50.0	5.3	89.5	45.6	46.8	47.4
Agree	23.3	42.1	0.0	10.5	29.8	22.2
Moderately agree	10.0	0.0	8.8	8.8	16.0	9.5
Neutral	10.0	3.5	1.8	10.5	0.0	4.6
Disagree	6.7	49.1	0.0	14.0	7.4	14.5
Strongly disagree	0.0	0.0	0.0	10.5	0.0	1.8
Perception of credit access as a barrier						
Strongly agree	61.7	10.5	87.7	82.5	46.8	56.6
Agree	30	40.4	0.0	7.0	23.4	20.6
Moderately agree	1.7	0.0	10.5	7.0	22.3	9.8
Neutral	6.7	0.0	1.8	0.0	0.0	1.5
Disagree	0.0	49.1	0.0	0.0	7.4	10.8
Strongly disagree	0.0	0.0	0.0	3.5	0.0	0.6
Perception of extension support as a barrier						
Strongly agree	55.0	14.0	70.2	77.2	40.4	50.2
Agree	33.3	36.8	8.8	7.0	33.0	24.9
Moderately agree	3.3	0.0	17.5	10.5	18.1	10.8
Neutral	5.0	0.0	3.5	1.8	1.1	2.2
Disagree	3.3	49.1	0.0	1.8	7.4	11.7
Strongly disagree	0.0	0.0	0.0	1.8	0.0	0.3

3.7. Logistic Regression of Farmers' Perceptions of Benefits, Risks, and Constraints

Table 8 shows that perceived environmental harm was the strongest positive perception influencing the adoption of modern rice production technologies. Farmers who perceived environmental benefits were almost twice as likely to adopt modern technologies (OR = 1.92, Wald = 30.58, $p < 0.001$), and this relationship remained highly significant after adjustment (Adjusted OR = 1.69, $p < 0.001$). This finding indicates that environmental considerations play a major role in motivating technology adoption [62] [63].

Among the negative predictors, perceived income increase exhibited the strongest significant reduction in adoption (OR = 0.52, Wald = 10.17, $p = 0.001$), and this effect persisted after adjustment (Adjusted OR = 0.52, $p = 0.007$). Similarly, yield benefit (OR = 0.46, $p = 0.022$), crop-failure risk (OR = 0.75, $p = 0.008$), credit-access barrier (OR = 0.63, $p = 0.020$), and extension-support barrier (OR = 0.57, $p = 0.002$) were significant in the unadjusted model, although some lost significance after controlling for section-level effects. The least influential variable was high input cost, which showed virtually no association with adoption (OR = 0.97, Wald = 0.07, $p = 0.797$), followed by grain quality benefit (OR = 0.82, $p = 0.448$) and technical-knowledge barrier (OR = 1.20, $p = 0.289$), all of which were statistically non-significant.

Table 8. Logistic regression of farmers' perceptions of benefits, risks, and constraints.

Predictor	B	SE	OR	z	Wald	df	p	Adj. OR (p) ¹
Yield benefit	-0.78	0.34	0.46	-2.29	5.26	1	0.022	0.59 (0.171)
Grain quality benefit	-0.19	0.26	0.82	-0.76	0.58	1	0.448	1.09 (0.757)
Income increase	-0.65	0.20	0.52	-3.19	10.17	1	0.001	0.52 (0.007)
High financial risk	-0.16	0.10	0.86	-1.56	2.43	1	0.119	0.74 (0.037)
Crop-failure risk	-0.29	0.11	0.75	-2.65	7.04	1	0.008	0.74 (0.013)
Environmental harm	0.65	0.12	1.92	5.53	30.58	1	<0.001	1.69 (<0.001)
High input cost	-0.03	0.12	0.97	-0.26	0.07	1	0.797	0.72 (0.055)
Technical-knowledge barrier	0.18	0.17	1.20	1.06	1.12	1	0.289	0.82 (0.427)
Credit-access barrier	-0.46	0.20	0.63	-2.33	5.44	1	0.020	0.66 (0.077)
Extension-support barrier	-0.56	0.18	0.57	-3.14	9.85	1	0.002	0.72 (0.133)

Model fit: unadjusted LR chi-square = 177.5 (df = 10), McFadden R-square = 0.402; section-adjusted LR chi-square = 250.3 (df = 14), McFadden R-square = 0.567. n = 325; adopters = 182. Note. B = penalized log-odds coefficient; OR = odds ratio; Wald = squared z statistic. Perception items are scored 1 (strongly disagree) to 6 (strongly agree); OR expresses the change in odds per one-point increase. Adj. OR (p) is from the section-adjusted model. $p < 0.05$, $p < 0.01$, $p < 0.001$.

4. Conclusion and Recommendations

This study investigated the determinants of modern rice production technology adoption among smallholder farmers in Bonthe District, Sierra Leone, focusing on extension services, biophysical conditions, and farmers' perceptions. The find-

ings showed that adoption is influenced by institutional, environmental, and behavioural factors. Farmers in Borlleh and Madina benefited from better extension services than those in Sogballeh, while participation in training and demonstration programmes emerged as the strongest predictor of adoption. Drought conditions encouraged adoption of modern rice production technologies, whereas flood-prone environments reduced farmers' willingness to adopt. Although respondents recognized the productivity, income, and environmental benefits of improved rice production technologies, limited access to credit, inadequate extension support, financial constraints, and production risks remained major barriers. The study recommends strengthening extension services through regular farm visits, demonstrations, and follow-up support, particularly in underserved communities. While climate change hazards and evidence such as drought and floods remain the factors largely influencing modern production technologies and willingness to adopt improved technologies respectively, this study also advocates promoting climate-smart rice production technologies for enhanced production and productivity, climate resilience building, and reduction of greenhouse gases emissions. Moreover, due to limited access to finance and inputs, as well as the lack of sustainable technical skills for effective and efficient farmer organizations, this study suggests the expansion of affordable agricultural credit and input subsidies to farmers and the strengthening of farmer organizations through adaptable capacity-building training and extension services for a large-scale production technology adoption. Additionally, for rigorous evidence of actual impacts, the study also emphasised the conduct of longitudinal studies to evaluate over time, including longer periods, the impacts of modern technology adoption on rice production and productivity across Sierra Leone. The study, however, calls for more robust climate-smart and climate resilience-related research for improved rice production and productivity across different ecologies in Sierra Leone.

Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Bandumula, N. (2018) Rice Production in Asia: Key to Global Food Security. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, **88**, 1323-1328. <https://doi.org/10.1007/s40011-017-0867-7>
- [2] Prasad, R., Shivay, Y.S. and Kumar, D. (2017) Current Status, Challenges, and Opportunities in Rice Production. In: Chauhan, B.S., *et al.*, Eds., *Rice Production Worldwide*, Springer International Publishing, 1-32. https://doi.org/10.1007/978-3-319-47516-5_1
- [3] Bin Rahman, A.N.M.R. and Zhang, J. (2023) Trends in Rice Research: 2030 and Beyond. *Food and Energy Security*, **12**, e390. <https://doi.org/10.1002/fes3.390>
- [4] Samal, P., Babu, S.C., Mondal, B. and Mishra, S.N. (2022) The Global Rice Agriculture towards 2050: An Inter-Continental Perspective. *Outlook on Agriculture*, **51**, 164-172. <https://doi.org/10.1177/00307270221088338>
- [5] Mallareddy, M., Thirumalaikumar, R., Balasubramanian, P., Naseeruddin, R., Nithya, N., Mariadoss, A., *et al.* (2023) Maximizing Water Use Efficiency in Rice Farming: A Comprehensive Review of Innovative Irrigation Management Technologies. *Water*, **15**, Article No. 1802. <https://doi.org/10.3390/w15101802>
- [6] Elizabeth Ojo, I., Ogunmola, A.M., Ayorinde Kolawole, E. and Chike, I. (2025) Climate-Smart Agriculture for Sustainable Rice Production: Innovations and Practices. In: *Agricultural Sciences*, IntechOpen. <https://doi.org/10.5772/intechopen.1011582>
- [7] Sandhu, N., Sagare, D.B., Singh, V.K., Yadav, S. and Kumar, A. (2021) Environment-friendly Direct Seeding Rice Technology to Foster Sustainable Rice Production. In: Wani, S.P., *et al.*, Eds., *Scaling-Up Solutions for Farmers. Technology, Partnerships and Convergence*, Springer International Publishing, 279-305. https://doi.org/10.1007/978-3-030-77935-1_8
- [8] Amponsah, S.K., Kumi, F., Akolgo, G. and Azumah, D.D. (2025) A Review of Transforming Rice Harvesting in Sub-Saharan Africa: Addressing Constraints, Leveraging Mechanization, and Enhancing Productivity. *Advances in Agriculture*, **2025**, Article ID: 5523207. <https://doi.org/10.1155/aia/5523207>
- [9] Suri, T. and Udry, C. (2022) Agricultural Technology in Africa. *Journal of Economic Perspectives*, **36**, 33-56. <https://doi.org/10.1257/jep.36.1.33>
- [10] Adenle, A.A., Azadi, H. and Manning, L. (2017) The Era of Sustainable Agricultural Development in Africa: Understanding the Benefits and Constraints. *Food Reviews International*, **34**, 411-433. <https://doi.org/10.1080/87559129.2017.1300913>
- [11] Sithole, A. and Olorunfemi, O.D. (2024) Sustainable Agricultural Practices in Sub-Saharan Africa: A Review of Adoption Trends, Impacts, and Challenges among Smallholder Farmers. *Sustainability*, **16**, Article 9766. <https://doi.org/10.3390/su16229766>
- [12] Prajapati, C.S., Priya, N.K., Bishnoi, S., Vishwakarma, S.K., Buaneswari, K., Shastri, S., *et al.* (2025) The Role of Participatory Approaches in Modern Agricultural Extension: Bridging Knowledge Gaps for Sustainable Farming Practices. *Journal of Experimental Agriculture International*, **47**, 204-222. <https://doi.org/10.9734/jeai/2025/v47i23281>
- [13] Mabey, P.T., Ngaojia, P.A., Roy-Johnson, D.S.S., Kpakima, J.S., Abdulai, J., Kalokoh, O.M., *et al.* (2026) Resource Availability and Factors Influencing Farmers' Adoption of Modern Rice Technologies in Bonthe District Sierra Leone. *Open Journal of Applied Sciences*, **16**, 3592-3614. <https://doi.org/10.4236/ojapps.2026.169199>
- [14] Manono, B.O., Khan, S. and Kithaka, K.M. (2025) A Review of the Socio-Economic,

- Institutional, and Biophysical Factors Influencing Smallholder Farmers' Adoption of Climate Smart Agricultural Practices in Sub-Saharan Africa. *Earth*, **6**, Article No. 48. <https://doi.org/10.3390/earth6020048>
- [15] Musafiri, C.M., Kiboi, M., Macharia, J., Ng'etich, O.K., Kosgei, D.K., Mulianga, B., *et al.* (2022) Adoption of Climate-Smart Agricultural Practices among Smallholder Farmers in Western Kenya: Do Socioeconomic, Institutional, and Biophysical Factors Matter? *Heliyon*, **8**, e08677. <https://doi.org/10.1016/j.heliyon.2021.e08677>
- [16] Gemtou, M., Kakkavou, K., Anastasiou, E., Fountas, S., Pedersen, S.M., Isakhanyan, G., *et al.* (2024) Farmers' Transition to Climate-Smart Agriculture: A Systematic Review of the Decision-Making Factors Affecting Adoption. *Sustainability*, **16**, Article 2828. <https://doi.org/10.3390/su16072828>
- [17] Munu, I., Koroma, B.A., Mabey, P.T., Konneh, M., Kpukumu, D.B., Fortune, D., *et al.* (2026) Available Resources and Factors Influencing the Adoption of Modern Rice Technologies among Farmers in Kambia District, Sierra Leone. *Agricultural Sciences*, **17**, 633-659. <https://doi.org/10.4236/as.2026.177038>
- [18] Priya, N.K., Patil, S.S., Vishwakarma, S.K., Saikanth, D.R.K., Mishra, I., Tripathi, S., *et al.* (2025) Digital Innovations in Extension Education: A Review of Emerging Technologies and Their Impact on Agricultural Knowledge Dissemination. *Journal of Experimental Agriculture International*, **47**, 408-423. <https://doi.org/10.9734/jeai/2025/v47i53430>
- [19] Hussain, S., Huang, J., Huang, J., Ahmad, S., Nanda, S., Anwar, S., *et al.* (2020) Rice Production under Climate Change: Adaptations and Mitigating Strategies. In: Hussain, S., *et al.*, Eds., *Environment, Climate, Plant and Vegetation Growth*, Springer International Publishing, 659-686. https://doi.org/10.1007/978-3-030-49732-3_26
- [20] Sokra, I., Somaly, S., Meta, H., Sarun, H. and Molikoy, C. (2026) Factors Affecting Rice Production: A Systematic Review. *Journal of Agriculture and Technology*, **2**, 19-46.
- [21] Gardezi, M. and Bronson, K. (2020) Examining the Social and Biophysical Determinants of U.S. Midwestern Corn Farmers' Adoption of Precision Agriculture. *Precision Agriculture*, **21**, 549-568. <https://doi.org/10.1007/s11119-019-09681-7>
- [22] Arsil, P., Tey, Y.S., Brindal, M., Ardiansyah, Sumarni, E. and Masrukhi, (2022) Perceived Attributes Driving the Adoption of System of Rice Intensification: The Indonesian Farmers' View. *Open Agriculture*, **7**, 217-225. <https://doi.org/10.1515/opag-2022-0080>
- [23] Alexander, K.S., Parry, L., Thammavong, P., Sacklokham, S., Pasouvang, S., Connell, J.G., *et al.* (2018) Rice Farming Systems in Southern Lao PDR: Interpreting Farmers' Agricultural Production Decisions Using Q Methodology. *Agricultural Systems*, **160**, 1-10. <https://doi.org/10.1016/j.agsy.2017.10.018>
- [24] Kumar, G., Engle, C. and Tucker, C. (2018) Factors Driving Aquaculture Technology Adoption. *Journal of the World Aquaculture Society*, **49**, 447-476. <https://doi.org/10.1111/jwas.12514>
- [25] Binns, T. and Bateman, J. (2017) Rural Livelihoods and Food Security: Long-Term Insights from Sierra Leone's Eastern Province. *Geographical Research*, **55**, 156-165. <https://doi.org/10.1111/1745-5871.12204>
- [26] Kolleh, J.B., Bello, L.O., Arouna, A., Akaba, S. and Sakurai, T. (2025) Impact of the Smart Valley Project in Enhancing Rice Production and Farmer Outcomes in Northwestern Sierra Leone. *Journal of Agriculture and Food Research*, **24**, Article ID: 102338. <https://doi.org/10.1016/j.jafr.2025.102338>
- [27] Kamara, L.I. (2019) The Use of Agricultural Innovation Systems Approaches in Sierra Leone: Exploring Perceptions on Innovations in Rice Production, Research and Ex-

- tension. Doctoral Dissertation, University of Reading.
<https://centaur.reading.ac.uk/id/eprint/85257>
- [28] Priya, N.K., Khatri, A., Karki, P., Samota, S.D., Vishwakarma, S.K., Sukdeve, E.K., *et al.* (2025) The Important Role of Extension Services in Strengthening the Capacity of Farmers' Resilience to Climate Change in India. *Journal of Experimental Agriculture International*, **47**, 204-223. <https://doi.org/10.9734/jeai/2025/v47i33329>
- [29] Antwi-Agyei, P. and Stringer, L.C. (2021) Improving the Effectiveness of Agricultural Extension Services in Supporting Farmers to Adapt to Climate Change: Insights from Northeastern Ghana. *Climate Risk Management*, **32**, Article ID: 100304.
<https://doi.org/10.1016/j.crm.2021.100304>
- [30] Yamane, T. (1973) Statistics: An Introductory Analysis. Harper & Row.
<https://www.gbv.de/dms/zbw/252560191.pdf>
- [31] Nzao, A.N., Katundu, M. and Muhihi, B.G. (2025) Agricultural Extension Service Accessibility under Decentralised Governance: Evidence from Smallholder Sunflower Farmers in Dodoma and Singida Regions, Tanzania.
<https://quarterlyreview.net/ojs/index.php/aqssr/article/view/269>
- [32] Abate, G.T., Dereje, M., Hirvonen, K. and Minten, B. (2020) Geography of Public Service Delivery in Rural Ethiopia. *World Development*, **136**, Article ID: 105133.
<https://doi.org/10.1016/j.worlddev.2020.105133>
- [33] Miriti, C.M. (2025) Smallholder Farmers' Satisfaction with Agricultural Extension Services in Embu East Sub-County, Embu County, Kenya. Doctoral Dissertation, UoEm.
- [34] Karki Nepal, A., Choudhary, D., Pandit, N.R. and Khanal, N. (2025) Impact of Training and Digital Extension Services on Agricultural Technology Adoption and Rice Yields. *PLOS ONE*, **20**, e0337456. <https://doi.org/10.1371/journal.pone.0337456>
- [35] Lawal, K.F. (2023) Perceived Effectiveness of Public Extension Services among Maize Based Smallholder Farmers in Kwara State, Nigeria. Master's Thesis, Kwara State University (Nigeria).
- [36] Baba, S.S. (2018) Effectiveness of Knowledge Management Approaches on Agricultural Extension Services Delivery in Selected Districts of Northern Region. Doctoral Dissertation, University for Development Studies.
- [37] Tegene, T., Wims, P., Gebeyehu, D. and Abo, T. (2023) Analysis of Communication Approaches Used in Agricultural Extension: Case of Wolaita Zone, Southern Ethiopia. *Local Development & Society*, **4**, 348-369.
<https://doi.org/10.1080/26883597.2023.2173635>
- [38] Danjumah, P.M., Asiamah, M.T., Tham-Agyekum, E.K., Ibrahim, S.A. and Mensah, L.K. (2024) Dynamics of Agricultural Extension Delivery Services to Rice Farmers in Ghana. *Heliyon*, **10**, e26753. <https://doi.org/10.1016/j.heliyon.2024.e26753>
- [39] Alzahrani, K., Ali, M., Azeem, M.I. and Alotaibi, B.A. (2023) Efficacy of Public Extension and Advisory Services for Sustainable Rice Production. *Agriculture*, **13**, Article No. 1062. <https://doi.org/10.3390/agriculture13051062>
- [40] Wang, G., Lu, Q. and Capareda, S.C. (2020) Social Network and Extension Service in Farmers' Agricultural Technology Adoption Efficiency. *PLOS ONE*, **15**, e0235927.
<https://doi.org/10.1371/journal.pone.0235927>
- [41] Mgendi, B.G., Mao, S. and Qiao, F. (2022) Does Agricultural Training and Demonstration Matter in Technology Adoption? The Empirical Evidence from Small Rice Farmers in Tanzania. *Technology in Society*, **70**, Article ID: 102024.
<https://doi.org/10.1016/j.techsoc.2022.102024>
- [42] Qi, C. (2025) The Role of Educational Science in Environmental Management and

- Green Technology Adoption in Rural Revitalization through Interview-Based Insights. *Scientific Reports*, **15**, Article No. 19544. <https://doi.org/10.1038/s41598-025-95791-4>
- [43] Xu, Z., Li, J. and Ma, J. (2022) Impacts of Extension Contact on the Adoption of Formulated Fertilizers and Farm Performance among Large-Scale Farms in Rural China. *Land*, **11**, Article No. 1974. <https://doi.org/10.3390/land11111974>
- [44] Suvittawat, A. (2026) Drivers of Farmers' Adoption Intention for Soil Nutrient Analyzers: Roles of Awareness, Perceived Usefulness, and Ease of Use. *Agriculture*, **16**, Article No. 390. <https://doi.org/10.3390/agriculture16030390>
- [45] Kassem, H.S., Alotaibi, B.A., Muddassir, M. and Herab, A. (2021) Factors Influencing Farmers' Satisfaction with the Quality of Agricultural Extension Services. *Evaluation and Program Planning*, **85**, Article ID: 101912. <https://doi.org/10.1016/j.evalprogplan.2021.101912>
- [46] Riar, A., Mandloi, L.S., Poswal, R.S., Messmer, M.M. and Bhullar, G.S. (2017) A Diagnosis of Biophysical and Socio-Economic Factors Influencing Farmers' Choice to Adopt Organic or Conventional Farming Systems for Cotton Production. *Frontiers in Plant Science*, **8**, Article No. 1289. <https://doi.org/10.3389/fpls.2017.01289>
- [47] Ambali, O.I., Areal, F.J. and Georgantzis, N. (2021) Improved Rice Technology Adoption: The Role of Spatially-Dependent Risk Preference. *Agriculture*, **11**, Article No. 691. <https://doi.org/10.3390/agriculture11080691>
- [48] Rezaee, L., Davatgar, N., Moosavi, A.A. and Sepaskhah, A.R. (2023) Implications of Spatial Variability of Soil Physical Attributes in Delineating Site-Specific Irrigation Management Zones for Rice Crop. *Journal of Soil Science and Plant Nutrition*, **23**, 6596-6611. <https://doi.org/10.1007/s42729-023-01513-y>
- [49] Niang, A. (2019) Rice Yield Gaps in West Africa. Doctoral Dissertation, Universitäts- und Landesbibliothek Bonn. <https://nbn-resolving.org/urn:nbn:de:hbz:5n-54666>
- [50] Thanawong, K., Perret, S.R. and Basset-Mens, C. (2014) Eco-Efficiency of Paddy Rice Production in Northeastern Thailand: A Comparison of Rain-Fed and Irrigated Cropping Systems. *Journal of Cleaner Production*, **73**, 204-217. <https://doi.org/10.1016/j.jclepro.2013.12.067>
- [51] Bwire, D., Saito, H., Sidle, R.C. and Nishiwaki, J. (2024) Water Management and Hydrological Characteristics of Paddy-Rice Fields under Alternate Wetting and Drying Irrigation Practice as Climate Smart Practice: A Review. *Agronomy*, **14**, Article No. 1421. <https://doi.org/10.3390/agronomy14071421>
- [52] Datta, A., Ullah, H. and Ferdous, Z. (2017) Water Management in Rice. In: Chauhan, B.S., *et al.*, Eds., *Rice Production Worldwide*, Springer International Publishing, 255-277. https://doi.org/10.1007/978-3-319-47516-5_11
- [53] McFadden, J., Bailey, S., Bonin, D., Paul, L. and Malacarne, J. (2026) Drought-Tolerant Crops as a Drought Adaptation Tool: Productivity, Input Complementarity, and Risk Effects. In: *Handbook on Climate Change Impacts, Mitigation, and Adaptation in Agriculture*, Edward Elgar Publishing, 200-230. <https://doi.org/10.4337/9781035344970.00019>
- [54] Pal, B.D., Kapoor, S., Saroj, S., Jat, M.L., Kumar, Y. and Anantha, K.H. (2022) Adoption of Climate-Smart Agriculture Technology in Drought-Prone Area of India—Implications on Farmers' Livelihoods. *Journal of Agribusiness in Developing and Emerging Economies*, **12**, 824-848. <https://doi.org/10.1108/jadee-01-2021-0033>
- [55] Hobbs, P.R. (2021) Tillage and Crop Establishment in South Asian Rice-Wheat Systems: Present Practices and Future Options. In: Katakai, P. and Babu, S.C., Eds., *The Rice-Wheat Cropping System of South Asia: Efficient Production Management*, CRC Press,

- 1-22. <https://doi.org/10.1201/9781003210658-1>
- [56] Midzi, M. (2026) Drivers and Perceived Sustainability of Soy-Maize Cropping among Smallholder Farmers in Central Malawi. <https://stud.epsilon.slu.se/22523/1/midzi-m-20260703.pdf>
- [57] Adisa, R.S., Ahmed, T.A., Ebenehi, O. and Oyibo, F.O. (2019) Perceived Benefits of Adoption of Improved Rice Production Technologies among Small-Scale Farmers in Kogi State, Nigeria. *Journal of Agricultural Extension*, **23**, 138-148. <https://doi.org/10.4314/jae.v23i1.12>
- [58] Casinillo, L.F., Cadenas, J.M. and Laure, A.R. (2026) Understanding the Agricultural Support Services for Rice Farmers Using Ordinal Correlation and Regression. *Ho Chi Minh City Open University Journal of Science—Economics and Business Administration*, **16**, 3-20. <https://doi.org/10.46223/hcmcoujs.econ.en.16.7.4209.2026>
- [59] Ullah, Z., Han, J., Anwar, A. and Sajjad, A. (2026) Factors Influencing the Adoption of Sustainable Rice Farming Practices in Khyber Pakhtunkhwa, Pakistan. *PLOS ONE*, **21**, e0350735. <https://doi.org/10.1371/journal.pone.0350735>
- [60] Owusu-Sekyere, E., Hatab, A.A., Lagerkvist, C., Pérez-Ruiz, M., Šarauskis, E., Kriaučiūnienė, Z., *et al.* (2024) Farmers' Willingness to Adopt Precision Agricultural Technologies to Reduce Mycotoxin Contamination in Grain: Evidence from Grain Farmers in Spain and Lithuania. *Precision Agriculture*, **25**, 2292-2320. <https://doi.org/10.1007/s11119-024-10167-4>
- [61] Taivalmaa, S.L. and Slavchevska, V. (2016) Feminization of Agriculture in the Context of Rural Transformations. https://d1wqtxts1xzle7.cloudfront.net/104659946/aga-brussels-2017-li-bre.pdf?1690824747=&response-content-disposition=inline%3B+file-name%3DFeminization+of+Agriculture+in+the+Conte.pdf&Expires=1791770585&Signature=dRkVOhbQHxAGVqbgzAerTFnhPL-KrRgXE6wTamHr0kd3Rr1FbXO7z44hmEtnpvdmBkkhzhIuxOsBzAI5jGG-FaozFI1zCk-xZoML~wsSI7n1U-4H8QvPfc4IOvP0PR12AF-BUz1CHi8MirBji7rGSecWCA64LJHDwFOLHWnaYsfnl6Orpgga-Zeb0UjvWAsISNT6lEJycslaf5b6KJtHInxQo-rMI8Algtcz7Fo6OB-Keiogi3vnw7Zfj5UkfQ53U6V5dYOIMHYCMAm5gg8AYo3W-cjMHcQ7bHRco2PalEzNuhYVGKGM9vH9fsva1xJzXteF-scMOPk1L8Rr61Fa8tpTbg_&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA
- [62] Awa, H.O., Ojiabo, O.U. and Orokor, L.E. (2017) Integrated Technology-Organization-Environment (T-O-E) Taxonomies for Technology Adoption. *Journal of Enterprise Information Management*, **30**, 893-921. <https://doi.org/10.1108/jeim-03-2016-0079>
- [63] Mouakket, S. and Aboelmaged, M. (2021) Factors Influencing Green Information Technology Adoption: A Multi-Level Perspective in Emerging Economies Context. *Information Development*, **39**, 699-719. <https://doi.org/10.1177/02666669211048489>