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Farmers' Perceptions of Saltwater Intrusion and Its Impacts on Rice Production: A Comparative Study of Coastal and Riverine Communities in The Gambia

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Abstract

Saltwater intrusion is an escalating environmental stressor affecting agricultural productivity in coastal and riverine areas of The Gambia. This study examined farmers' perceptions of its impacts on rice production in the communities of Abuko and Saro, Banjul, through a structured questionnaire survey of 60 randomly selected rice farmers (30 per community). The study assessed farmers' socio-demographic characteristics, production practices, awareness of saltwater intrusion, perceived impacts on rice cultivation, and adaptation measures using descriptive statistics and chi-square tests of independence (SPSS v26, JASP v0.19, $p \leq 0.05$). All impact data are farmers' self-reported perceptions; no soil, water, or crop measurements were taken. Rice farming was undertaken predominantly by women (73%), with most farmers aged 50 years and above (55%) and 48% having no formal education. Irrigation water came directly from the Gambia River for 58% of farmers, from wells for 27%, and from rainfall for 15%. Although 78% of respondents reported observing physical evidence of intrusion, 65% did not monitor soil salinity. Before intrusion, 58% of farmers reported harvesting at least 600 kg of rice per season; this fell to 22% afterwards. Leaf burn (82%) and root damage (18%) were the symptoms most reported by farmers, and 72% reported increased pest and disease incidence. Yield losses over the previous two seasons were reported by 85% of farmers, 63% reported reduced income, and 65% reported declining household food security. Adaptation measures included salt-tolerant varieties (72%), raised-bed cultivation (58%), and extension engagement (72%), but

limited access to agricultural credit (73% with no access) constrained their effectiveness. The findings indicate that farmers perceive saltwater intrusion as a significant, multi-dimensional threat to rice production, household livelihoods, and food security in coastal Gambia. The findings nevertheless underscore the need for expanded salinity monitoring, salt-tolerant seed systems, irrigation infrastructure, and agricultural credit, and for measurement-based studies to verify the reported effects.

Keywords

Saltwater Intrusion, Rice Production, Smallholder Farmers, Food Security, Adaptation Strategies, The Gambia

1. Introduction

The Gambia is a small West African nation with a land area of approximately 11,360 km^2 and a Sahelian climate defined by a long dry season (November-May) and a short wet season (June-October) [1]. The Gambia River, which stretches 1130 km from its origin in the Fouta Djallon highlands of Guinea to its mouth at the Atlantic Ocean, is the main water body and supports the wetlands on which most of the population relies for farming [2]. Agriculture is one of the major livelihoods, with almost half of Gambia's households involved in farming and the sector employing about two-thirds of the labor force and generating a similar proportion of household income [3]. Rice is the country's preferred staple food and is mainly grown as a subsistence crop in lowland swamps along the river stretching from the Lower River to the Central River, which is identified as the national food basket [4]. The importance of rice to the food security of the household and to the livelihood of the rural people makes the sustainability of lowland swamp production a direct concern of the nation [5].

Yet, despite this centrality, The Gambia remains highly reliant on rice imports, and interventions ranging from colonial-era rice farming schemes to the post-independence assistance agreement involving the Taiwan region and the Gambia have not closed the structural gap between production and consumption. One of the most enduring threats to domestic rice production is the intrusion of saltwater into freshwater surface and groundwater resources [6] [7]. Apart from the highest proportion of the population residing in the Low Elevation Coastal Zone (LECZ), The Gambia's topography of a narrow, low-lying stretch across a single major river makes it structurally vulnerable to the impacts of sea level rise, freshwater discharge reductions, and tidal effects [8] [9]. Salinization has already spread a long way up into the River Gambia, affecting the quality of water for irrigation and human use, and making vast tracts of what was once productive tidal swamp unsuitable for rice cultivation [10] [11]. Saltwater intrusion is not a future climate challenge, but a current, growing threat to the food production system that is the

foundation of national food security, and the impact at the farm level is a priority empirical and policy question [12].

A significant number of studies have documented the biophysical processes affecting rice production under saline conditions. At the plant level, salt stress causes ion imbalance, impacts photosynthesis, and stunts tillering, grain filling, and yield in rice (Oryza sativa), a crop with high sensitivity to salt stress during germination and early development [13]-[15]. This sensitivity has been explained by complementary physiological and molecular studies that explain how plants stressed by salinity accumulate reactive oxygen species and have reduced defence responses, compared to those that lead to higher susceptibility to pests and diseases [16] [17]. Cultivar comparison studies have demonstrated that conventional varieties generally yield significantly poorer germination, establishment, and yield responses than salt-tolerant varieties under saline conditions [18] [19]. This literature can help determine whether adaptation options exist, such as using agronomically suitable salt-tolerant seeds. Research on smallholder adaptation indicates that salt-tolerant varieties are one of the most accessible and cost-effective options available to resource-constrained farmers [20]. However, this body of work is predominantly experimental or controlled environment in design, and there is little indication of the actual perception, experience, and management of salinity stress by farmers under real field, labor, and credit constraints.

A second strand of research focuses on saltwater intrusion in the Gambia context, specifically from a hydrological and water quality perspective. There are studies on the River Gambia that report long-term increases in conductivity and upstream salt intrusion, especially in the dry season [21], and regional assessments of deltaic and estuarine systems in West Africa that identify the general impacts of upstream salt intrusion on mangrove ecosystems, fisheries, and rural hydrology [22] [23]. In The Gambia, however, there is no socio-economic evidence at the farm level, although there is in other parts of the world, such as [24] on the impacts of salinity on the livelihoods of coastal smallholders in Bangladesh, which are not necessarily relevant to The Gambia because of the distinctiveness of the smallholder sector in terms of farming practices, particularly the involvement of most smallholders in lowland rice cultivation systems where women play a key role.

These two bodies of literature leave clear and consequential gaps. Saltwater intrusion literature covers the global literature and explains why salinization is harmful to rice but does not explain how it is lived and managed by farmers, nor systematically link the advance of saltwater to production losses, livelihood outcomes, and adaptive behavior at the farm level. Therefore, evidence at the farmer level that relates saltwater intrusion to yield reduction, income loss, and food insecurity outcomes of Gambian rice farming communities is limited, and no study has previously compared the relationship between saltwater intrusion and farmer outcomes between sites with varying levels of direct marine exposure. This gap is particularly evident for Abuko and Saro (Banjul), two communities that, despite sharing broadly similar agro-ecological conditions and a shared dependence on

lowland swamp rice cultivation, differ markedly in their exposure to marine tidal influences. Saro is located on St. Mary's Island at the mouth of the River Gambia and the Atlantic Ocean, whereas Abuko is further inland along the Kombo North corridor and is influenced by salinity mostly through riverine and groundwater routes. A comparative, farmer-level analysis of these two sites provides an opportunity to distinguish site-specific vulnerability from a more general, systemic constraint and provide evidence that can be used to inform adaptation planning, not only in a generic way, but also at the site-specific level.

This study addresses this gap by assessing how saltwater intrusion affects rice production and the quality of irrigation water resources in Abuko and Saro, and by documenting how farmers in each community respond to it. Specifically, the study sought to (i) assess farmers' perceived impacts of saltwater intrusion on rice growth and yield in the two communities, and (ii) identify the adaptive strategies employed by rice farmers to manage its effects on rice production. By combining structured household-level data with a deliberate contrast between a tidally exposed and a riverine-influenced community, the study contributes the first comparative, farmer-level empirical evidence on saltwater intrusion impacts and adaptation for the Greater Banjul Area, extending a literature that has so far been dominated by hydrological modelling and single-site case studies, and providing an evidence base for differentiated, site-appropriate adaptation and policy responses.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted among rice farmers in two communities within the Greater Banjul Area of The Gambia. Abuko, located in the Kombo North/Saint Mary district, is a town approximately 5 miles southwest of Banjul (13˚24'12.2"N, 16˚38'40.7"W) and close to Banjul International Airport and the Abuko nature reserve. Saro is in Banjul (13.4697N, 16.6364W), the capital of The Gambia, on St Mary's Island at the mouth of the River Gambia, where the population is estimated at 400,000, making it the most densely populated urban centre in The Gambia (see Figure 1). The two communities share broadly similar agro-ecological and farming practices despite being distinct in administration and ethnicity: rice growing in both is predominantly women's responsibility, and the fields in which it is grown are low-lying swamp fields; farming practices in both areas are similar, and the traditional techniques for managing salinity include raised earthen ridges (locally called 'baling') or the abandonment of affected fields where such ridges are not feasible.

2.2. Research Design and Sampling

A cross-sectional comparative survey design was employed to assess farmers' perceptions of the impact of saltwater intrusion on rice production and the adaptation strategies used in Abuko and Saro. The sampling frame was established

through a preliminary enumeration of actively cultivating rice farmers in the two communities. Eligibility was restricted to farmers actively engaged in rice cultivation during the survey period.

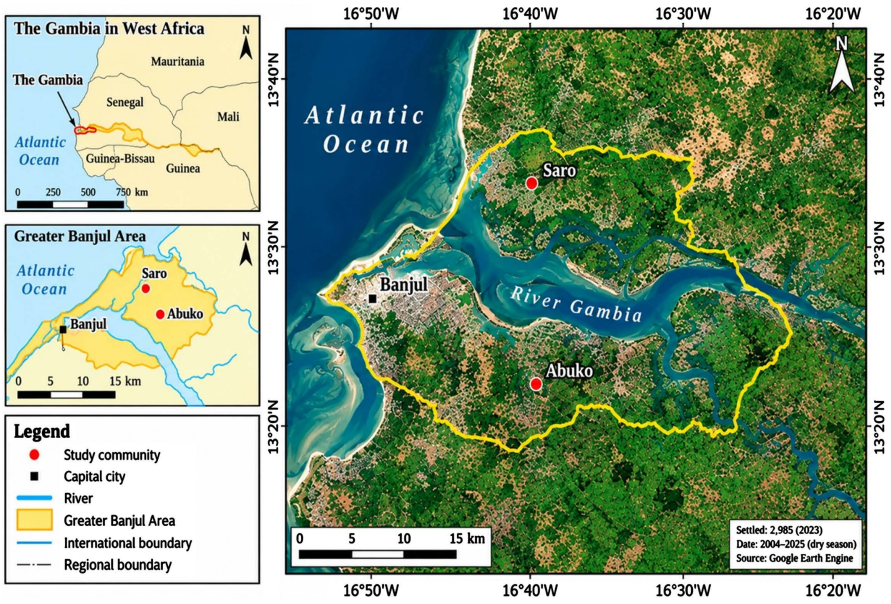


Figure 1. Study Area: Abuko and Saro rice farming communities, Greater Banjul Area, The Gambia.

The enumeration identified 30 eligible rice farmers in Abuko and 30 in Saro. Given the relatively small and identifiable population in each community, all enumerated eligible farmers were included in this study. Thus, the study adopted a **census approach**, achieving complete coverage of the enumerated target population in both communities (30/30 = 100% in Abuko and 30/30 = 100% in Saro). The final sample comprised 60 rice farmers, with 30 respondents from each community in the study. All identified farmers participated in the survey, resulting in a 100% response rate for the study.

This census-based approach was appropriate because the study population was small and geographically defined, allowing researchers to obtain information from the entire enumerated population rather than selecting a subsample. Accordingly, the findings are interpreted as representative of the enumerated active rice-farming populations in Abuko and Saro during the study period, rather than being generalized statistically to all rice farmers in The Gambia.

Each participant was interviewed individually using a structured questionnaire. Data were collected during a two-day field survey in the 2025 dry season.

2.3. Data Collection

Primary data were collected through a structured questionnaire administered face-to-face over a two-day field survey period, with respondents interviewed either at their farms or homes. The instrument was organised into three sections:

Section A captured sociodemographic information (age, sex, educational attainment, and years of farming experience), and Section B captured rice production information (field size, varieties cultivated, irrigation method, and water source). "Irrigation method" refers to how water was applied to the field (e.g., flood irrigation), and "water source" refers to where that water came from (river, well, or rainfall). Section C captured information relating to farmers' knowledge, observed evidence, perceived impacts, and adaptive responses to saltwater intrusion.

2.4. Data Analysis

Completed questionnaires were checked for completeness, coded, and entered into Microsoft Excel before being imported into the Statistical Package for the Social Sciences (SPSS), version 26, and JASP (Jeffreys' Amazing Statistics Program), version 0.19, for analysis. SPSS was used for data cleaning and descriptive statistical analysis, generating frequency distributions, percentages and tables that summarised respondents' socio-demographic characteristics, production practices, and perceptions of saltwater intrusion. JASP was used to perform inferential analyses: the chi-square (χ^2) test of independence was applied to examine associations between categorical variables (in particular, years of farming experience against variety choice, management practice, and knowledge outcomes), while independent-samples t-tests were used where appropriate to compare mean values between the two study locations. Statistical significance was set at the 5% level ($p \leq 0.05$) throughout.

2.5. Ethical Considerations

No formal ethical review was undertaken for this study, and no approval or exemption identifier was issued. The study was an anonymous, minimal-risk survey of adult farmers. Interviews were conducted individually at the respondent's farm or home. Before each interview, the purpose of the study, the voluntary nature of participation, the right to skip any question or withdraw at any time, and how the data would be used were explained to the respondent in Mandinka and Wolof, and written informed consent was obtained. Because 48% of respondents had no formal education (**Table 1**), the consent information was explained verbally to each respondent, and those who could not write gave their written consent by thumbprint. Confidentiality was protected by recording responses anonymously, and results are reported only in aggregate. No incentive or compensation was given for participation.

3. Result and Discussions

Sixty rice farmers, 30 each from Abuko and Saro, completed the structured questionnaire, giving a 100% response rate. The findings are presented thematically below, integrated with a discussion of their agreement or divergence with existing literature on saltwater intrusion and agricultural livelihoods in West Africa and beyond.

3.1. Socio-Demographic Characteristics of Respondents

Table 1 shows that most respondents were older farmers, with 55% aged 50 years and above (28% aged 50 - 59 and 27% aged 60 and above) and only 12% in the 20 - 29 age bracket. This pronounced ageing of the farming population is consistent with broader trends across sub-Saharan Africa, where rural agricultural labour forces are increasingly dominated by older generations as younger people migrate toward alternative livelihoods [25]-[27]. Although 40.8% of the national population is under 15 years of age [28], this youthful demographic is largely absent from active rice farming, reflecting declining youth interest in agriculture [29]. While the accumulated generational knowledge of older farmers is valuable for interpreting long-term environmental change, their capacity to adopt new adaptive technologies is often constrained by physical and financial limitations [30] [31], raising concerns about the intergenerational sustainability of rice production in these communities.

Table 1. Demographic characteristics of respondents in Abuko and Saro.

Variable	Abuko	Saro	Total
Age Range (years)			
20 - 29	3 (10%)	4 (13%)	7 (12%)
30 - 39	3 (10%)	6 (20%)	9 (15%)
40 - 49	7 (23%)	4 (13%)	11 (18%)
50 - 59	8 (27%)	9 (30%)	17 (28%)
60 and above	9 (30%)	7 (23%)	16 (27%)
Total	30 (100%)	30 (100%)	60 (100%)
Gender			
Male	10 (33%)	6 (20%)	16 (27%)
Female	20 (67%)	24 (80%)	44 (73%)
Total	30 (100%)	30 (100%)	60 (100%)
Educational Level			
No formal education	15 (50%)	14 (47%)	29 (48%)
Primary	7 (23%)	9 (30%)	16 (27%)
Secondary	6 (20%)	4 (13%)	10 (17%)
Tertiary	2 (7%)	3 (10%)	5 (8%)
Total	30 (100%)	30 (100%)	60 (100%)
Years of Farming Experience			
6 months - 2 years	1 (3%)	3 (10%)	4 (7%)
3 - 5 years	3 (10%)	3 (10%)	6 (10%)

Continued

6 - 10 years	2 (7%)	5 (17%)	7 (12%)
11 - 15 years	4 (13%)	9 (30%)	13 (22%)
16 - 20 years	8 (27%)	3 (10%)	11 (18%)
21 years and above	12 (40%)	7 (23%)	19 (31%)
Total	30 (100%)	30 (100%)	60 (100%)

Note: "Irrigation Method" refers to how water was applied to the field (all farmers used flood irrigation); "Source of Water" refers to where the water came from (river, well, or rainfall) and is independent of the application method.

Overall, female farmers constituted 73% of respondents, with 80% in Saro versus 67% in Abuko; this site difference was not statistically significant (Fisher's exact p = 0.382, Table 2). This finding corroborates the well-documented status of rice cultivation in Gambian lowland swamp systems as a predominantly female activity, in which women form the primary labour force across all stages of production [24] [32]. Similarly, it was found that female smallholders in coastal West Africa bear a disproportionate share of the adverse effects of saltwater intrusion, given that rice is simultaneously their principal livelihood and the foundation of household food security. This gendered pattern underscores the need for agricultural policies and interventions that are explicitly responsive to the constraints and priorities of women rice farmers.

Table 2. Formal statistical comparisons between Abuko and Saro for selected outcome variables.

Outcome variable	Abuko	Saro	Test	Statistic	p-value	Effect size
Salt-tolerant variety cultivated (main variety, Table 3)	17% (5/30)	50% (15/30)	χ^2 (df = 2)	7.67	0.022	V = 0.36
Household food security affected (Table 10)	57% (17/30)	73% (22/30)	Fisher's exact	—	0.279	V = 0.17
Monitors soil salinity (Table 4)	43% (13/30)	27% (8/30)	Fisher's exact	—	0.279	V = 0.17
Female share of respondents (Table 1)	67% (20/30)	80% (24/30)	Fisher's exact	—	0.382	V = 0.15

Effect size reported as Cramér's V; indicates a Fisher's exact test, for which no χ^2 statistic applies.

Nearly half of the respondents (48%) had received no formal education, with a further 27% having attained only primary schooling, and only 8% had tertiary education. This low formal educational profile mirrors national patterns in rural Gambia and is associated elsewhere with reduced uptake of modern agronomic practices and weaker engagement with formal extension information [33]. Nonetheless, the finding that 31% of respondents possessed more than 21 years of farming experience, with a further 18% reporting 16 - 20 years, indicates that practical, intergenerational knowledge remains a dominant form of agricultural expertise in these communities, and that such experiential knowledge can substitute, in part,

for formal training in understanding long-term environmental change such as increasing soil salinity [34].

3.2. Farm Size, Rice Varieties, and Irrigation Practices

Table 3 confirms the overwhelmingly smallholder character of rice farming in both communities: 87% of farmers cultivated less than one hectare, with only 13% farming between 1.5 and 2 hectares. This is consistent with the dominance of smallholder subsistence rice production, particularly in lowland swamp areas across The Gambia [6]. Similarly, [35] notes that small individual plot sizes, combined with constrained access to credit and inputs, limit both productivity and adaptive capacity among smallholder farmers. The uniformity of small field sizes across both sites suggests that land availability is not the primary constraint on production. Rather, environmental stressors such as salinity, compounded by limited financial and technical resources, appear to be the principal drivers of low productivity.

Table 3. Field size, rice varieties cultivated, irrigation method, and water source used by farmers in Abuko and Saro.

Variable	Abuko	Saro	Total
Field Size			
Less than 1 hectare	26 (87%)	26 (87%)	52 (87%)
1.5 - 2 hectares	4 (13%)	4 (13%)	8 (13%)
Total	30 (100%)	30 (100%)	60 (100%)
Rice Variety Cultivated			
Local	15 (50%)	10 (33%)	25 (42%)
Hybrid	10 (33%)	5 (17%)	15 (25%)
Salt-tolerant	5 (17%)	15 (50%)	20 (33%)
Total	30 (100%)	30 (100%)	60 (100%)
Irrigation Method			
Flood irrigation	30 (100%)	30 (100%)	60 (100%)
Furrow/drip/sprinkler	0 (0%)	0 (0%)	0 (0%)
Total	30 (100%)	30 (100%)	60 (100%)
Source of Irrigation Water			
River	19 (63%)	16 (53%)	35 (58%)
Well	7 (23%)	9 (30%)	16 (27%)
Rain-fed	4 (13%)	5 (17%)	9 (15%)
Total	30 (100%)	30 (100%)	60 (100%)

Variety selection differed markedly between the two sites. In Abuko, 50% of farmers cultivated local varieties, 33% hybrid varieties, and only 17% salt-tolerant varieties; in Saro, the pattern was reversed, with 50% of farmers using salt-tolerant varieties, 33% local varieties, and 17% hybrid varieties. This difference likely reflects Saro's greater exposure to tidal and coastal saline intrusion because of its low-lying nature and proximity to the Atlantic Ocean. This is supported by laboratory and field tests, which have shown that the cultivars of salt-tolerant rice perform much better in saline conditions in terms of germination, establishment of seedlings, and grain yield compared to conventional varieties [15] [36], supporting the rationality of Saro farmers' variety choice and pointing to a clear seed-access gap in Abuko that targeted distribution programmes could address.

All 60 farmers (100%) in both communities relied exclusively on flood irrigation, with no farmer reporting the use of furrow, drip, or sprinkler systems. River water was the dominant irrigation source (58%), followed by well water (27%) and rain-fed sources (15%). This universal dependence on flood irrigation is consistent with the traditional lowland swamp cultivation systems that have long characterized Gambian rice farming [32], but it points to a potential vulnerability: for the 58% of farmers who draw river water directly, saline intrusion events could expose their fields to saline water. Exposure among the 27% who use well water and the 15% who rely on rainfall cannot be assessed from these data, and no water source was tested for salinity. Field-level water-quality assessments along the River Gambia have documented alarming increases in conductivity, particularly during the dry season, confirming that the primary irrigation source is itself becoming progressively less suitable for rice cultivation [37]. The complete absence of modern irrigation infrastructure across both sites reflects broader resource constraints facing Gambian smallholders and signals an urgent need for investment in irrigation infrastructure as a foundational adaptation measure.

3.3. Evidence, Monitoring, and Awareness of Saltwater Intrusion

A striking paradox emerged from the data: while 78% of farmers reported direct evidence of saltwater intrusion on their farms, most commonly a salty taste in irrigation water (58%), white salt crusts on the soil surface (28%), and stunted crop growth (13%), 65% did not actively monitor soil salinity (**Table 4**). [38] emphasizes that timely, systematic monitoring of soil and water salinity is fundamental to effective saline agriculture management, enabling farmers and extension officers to formulate appropriate irrigation, variety selection, and soil amendment strategies; without such monitoring, interventions remain reactive rather than preventive. The gap identified here between widespread sensory evidence and minimal formal monitoring points to a concrete, low-cost intervention opportunity: the distribution of simple field-level salinity testing tools accompanied by basic training for farmers.

Table 4. Farmers' monitoring practices, observed evidence, indicators, and awareness of saltwater intrusion.

Variable	Abuko	Saro	Total
Monitors Soil Salinity			
Yes	13 (43%)	8 (27%)	21 (35%)
No	17 (57%)	22 (73%)	39 (65%)
Total	30 (100%)	30 (100%)	60 (100%)
Evidence of Saltwater Intrusion Observed			
Yes	26 (87%)	21 (70%)	47 (78%)
No	4 (13%)	9 (30%)	13 (22%)
Total	30 (100%)	30 (100%)	60 (100%)
Indicator of Intrusion Identified			
Salty taste in water	20 (67%)	15 (50%)	35 (58%)
White crust on soil	7 (23%)	10 (33%)	17 (28%)
Stunted crop growth	3 (10%)	5 (17%)	8 (13%)
Total	30 (100%)	30 (100%)	60 (100%)
Knowledge of Saltwater Intrusion			
Yes	23 (77%)	25 (83%)	48 (80%)
No	7 (23%)	5 (17%)	12 (20%)
Total	30 (100%)	30 (100%)	60 (100%)
Primary Source of Information			
Radio	9 (30%)	7 (23%)	16 (27%)
Television	10 (33%)	8 (27%)	18 (30%)
Agricultural extension agent	9 (30%)	10 (33%)	19 (32%)
Personal observation	2 (7%)	5 (17%)	7 (12%)
Total	30 (100%)	30 (100%)	60 (100%)

A chi-square test of independence indicated a statistically significant association between years of farming experience and farmers' ability to correctly identify indicators of saltwater intrusion ($\chi^2 = 25.134$, $p = 0.0035$; $p \leq 0.05$; Table 5), with more experienced farmers generally being better able to recognize early physical signs. Generally, awareness of saltwater intrusion as a phenomenon was relatively high (80%; 77% in Abuko and 83% in Saro), with agricultural extension agents (32%) and television (30%) being the leading information sources, followed by radio (27%). Personal observation accounted for only 12% of primary information

sources. This is consistent with evidence that extension and broadcast media channels are key routes for disseminating climate and agro-advisory information in The Gambia [39]. However, caution that knowledge gaps regarding the underlying mechanisms of saltwater intrusion remain a significant barrier to effective community-level management in under-resourced rural regions; the 20% of respondents who remained unaware in this study represent a segment that is unlikely to adopt any adaptive practice without targeted outreach.

Table 5. Summary of chi-square (χ^2) tests of association between years of farming experience and selected outcome variables.

Association Tested (Years of Farming Experience vs.)	χ^2	p-value	Decision ($p \leq 0.05$)
Rice variety cultivated	29.381	0.00198	Significant
Soil and water management practice adopted	50.570	0.0045	Significant
Indicator of saltwater intrusion identified	25.134	0.0035	Significant
Perceived effect on farming income	17.142	0.7555	Not significant
Indigenous knowledge recommendation given	27.550	0.7308	Not significant

3.4. Impact of Saltwater Intrusion on Rice Yield and Physiological Responses

The yield data provide a notable shift toward lower-yielding brackets. Before the onset of intrusion, 58% of farmers reported harvesting 600 kg or more of rice per season; afterwards, only 22% maintained this level, while the proportion of farmers harvesting 100 - 200 kg more than doubled, from 15% to 33% (**Table 6**). Although 62% of farmers estimated their own yield reduction at less than 10%, this categorical shift, from higher- to lower-yielding brackets, suggests a perceived shift toward lower productivity rather than a marginal fluctuation, and is corroborated by the finding that 85% of farmers reported experiencing outright yield losses over the two most recent farming seasons. These farm-level findings are directionally consistent with controlled studies showing that rice yield declines proportionally with increasing salinity, with even moderate salinity levels producing statistically significant reductions in tillering, grain filling, and total grain weight [14], and align with national-level evidence that the area under rice cultivation in The Gambia has expanded even as production has declined, a paradox attributable to the progressive salinisation of lowland soils [40].

Leaf burn was the most prevalent physiological symptom, reported by 82% of respondents overall (77% in Abuko, 87% in Saro), as shown in **Table 7**, consistent with the well-established mechanism by which elevated sodium and chloride concentrations in plant tissue cause leaf-tip and margin necrosis as rice plants attempt to exclude or compartmentalize toxic ions [41] and with oxidative damage associated with reactive oxygen species accumulation under salt stress [17]. Root damage was reported by 18% of the farmers. Additionally, 72% of farmers reported an increased incidence of pests and diseases, consistent with evidence that salt-

stressed rice plants exhibit weakened physiological and defense mechanisms that heighten susceptibility to biotic stress [16]. While 52% reported changes in water availability, reflecting the broader hydrological disruption that saltwater intrusion imposes on coastal lowland systems [7].

Table 6. Estimated yield reduction and rice yield levels before and after saltwater intrusion.

Variable	Abuko	Saro	Total
Estimated Yield Reduction Due to Salinity			
Less than 10%	17 (57%)	20 (67%)	37 (62%)
11% - 20%	9 (30%)	5 (17%)	14 (23%)
30% and above	4 (13%)	5 (17%)	9 (15%)
Total	30 (100%)	30 (100%)	60 (100%)
Yield Before Saltwater Intrusion (kg/season)			
100 - 200	3 (10%)	6 (20%)	9 (15%)
300 - 500	9 (30%)	7 (23%)	16 (27%)
600 and above	18 (60%)	17 (57%)	35 (58%)
Total	30 (100%)	30 (100%)	60 (100%)
Yield After Saltwater Intrusion (kg/season)			
100 - 200	9 (30%)	11 (37%)	20 (33%)
300 - 500	13 (43%)	14 (47%)	27 (45%)
600 and above	8 (27%)	5 (17%)	13 (22%)
Total	30 (100%)	30 (100%)	60 (100%)

Table 7. Observed physiological and agronomic effects of saltwater intrusion on rice production in Abuko and Saro.

Variable	Abuko	Saro	Total
Symptom Observed on Rice Plants			
Leaf burn	23 (77%)	26 (87%)	49 (82%)
Root damage	7 (23%)	4 (13%)	11 (18%)
Total	30 (100%)	30 (100%)	60 (100%)
Increased Pest/Disease Incidence			
Yes	23 (77%)	20 (67%)	43 (72%)
No	7 (23%)	10 (33%)	17 (28%)
Total	30 (100%)	30 (100%)	60 (100%)

Continued

Change in Water Availability Reported			
Yes	14 (47%)	17 (57%)	31 (52%)
No	16 (53%)	13 (43%)	29 (48%)
Total	30 (100%)	30 (100%)	60 (100%)

3.5. Seasonal Dynamics of Saltwater Intrusion

Saltwater intrusion was most reported during the rainy season (53% overall), peaking at mid-season (48%), as presented in Table 8. This pattern, while counterintuitive at first glance, is consistent with the hydrological dynamics of the Gambia River basin, where increased river flow and tidal interaction during the rainy season can push saline water further inland through overflow and flooding of adjacent lowlands, particularly where flood-control infrastructure is absent [42]. Similarly, [43] noted that in estuarine systems, saltwater intrusion is not confined to the dry season, as seasonal flooding can mobilize saline sediments and groundwater into cultivated fields during the growing season. The mid-season timing identified here is especially concerning, as it coincides with the tillering and panicle-initiation stages, when rice is most physiologically sensitive to ionic stress [44].

Table 8. Seasonal occurrence and period of peak saltwater intrusion reported by farmers.

Variable	Abuko	Saro	Total
Season of Peak Intrusion			
Dry season	11 (37%)	17 (57%)	28 (47%)
Rainy season	19 (63%)	13 (43%)	32 (53%)
Total	30 (100%)	30 (100%)	60 (100%)
Period of Intrusion within Season			
Beginning	7 (23%)	9 (30%)	16 (27%)
Mid-season	15 (50%)	14 (47%)	29 (48%)
Ending	8 (27%)	7 (23%)	15 (25%)
Total	30 (100%)	30 (100%)	60 (100%)

3.6. Adaptation Measures Employed by Farmers

The adoption of adaptive measures was relatively high: 72% of farmers had adopted salt-tolerant rice varieties, and 72% had received extension training, while raised-bed cultivation was the most common soil-management practice (58%), followed by mulching (28%), flushing (8%), and improved drainage (5%),

as indicated in Table 9. The high uptake of salt-tolerant varieties, despite farmers' considerable resource constraints, suggests that seed-based adaptation has been comparatively well disseminated, consistent with evidence that salt-tolerant crop varieties represent one of the most accessible and cost-effective adaptation strategies available to smallholder farmers facing salinity stress [20]. The predominance of raised-bed cultivation reflects a traditional, well-understood technique in Gambian lowland systems, locally known as 'baling', that creates a physical barrier between farmland and saline floodwater. Such indigenous water-management practices among Gambian women rice farmers are well documented and continue to underpin contemporary adaptation strategies [39]. However, ridge-building and similar physical barriers are, on their own, insufficient to counter the long-term advance of saltwater intrusion driven by sea-level rise and reduced freshwater flow [45]. The very low uptake of improved drainage (5%) and flushing (8%), both capital-intensive interventions, is consistent with the severely limited access to agricultural credit documented in Table 10 (73% of farmers reported no credit access) and indicates that sustainable, infrastructure-based adaptation will require institutional and policy support beyond the capacity of individual smallholders [46].

Table 9. Adaptation measures adopted by farmers in response to saltwater intrusion.

Variable	Abuko	Saro	Total
Uses Salt-Tolerant Rice Varieties			
Yes	23 (77%)	20 (67%)	43 (72%)
No	7 (23%)	10 (33%)	17 (28%)
Total	30 (100%)	30 (100%)	60 (100%)
Soil/Water Management Practice			
Raised-bed cultivation	18 (60%)	17 (57%)	35 (58%)
Mulching	7 (23%)	10 (33%)	17 (28%)
Flushing	3 (10%)	2 (7%)	5 (8%)
Improved drainage	2 (7%)	1 (3%)	3 (5%)
Total	30 (100%)	30 (100%)	60 (100%)
Received Extension Training			
Yes	23 (77%)	20 (67%)	43 (72%)
No	7 (23%)	10 (33%)	17 (28%)
Total	30 (100%)	30 (100%)	60 (100%)

Table 10. Economic impact of saltwater intrusion and farmers' priority support needs.

Variable	Abuko	Saro	Total
Farming Income Affected by Salinity			
Yes, significantly	18 (60%)	20 (67%)	38 (63%)
Slight decrease	9 (30%)	7 (23%)	16 (27%)
No effect	3 (10%)	3 (10%)	6 (10%)
Total	30 (100%)	30 (100%)	60 (100%)
Household Food Security Affected			
Yes	17 (57%)	22 (73%)	39 (65%)
No	13 (43%)	8 (27%)	21 (35%)
Total	30 (100%)	30 (100%)	60 (100%)
Access to Agricultural Credit			
Yes	5 (17%)	11 (37%)	16 (27%)
No	25 (83%)	19 (63%)	44 (73%)
Total	30 (100%)	30 (100%)	60 (100%)
Priority Support Needed			
Financial	14 (47%)	16 (53%)	30 (50%)
Technical	6 (20%)	7 (23%)	13 (22%)
Infrastructural	5 (17%)	4 (13%)	9 (15%)
Policy	5 (17%)	3 (10%)	8 (13%)
Total	30 (100%)	30 (100%)	60 (100%)

3.7. Economic Impact and Food Security Implications

Farmers reported substantial economic effects. Across both sites, 63% of farmers reported that saltwater intrusion significantly reduced their farming income, and a further 27% reported a slight decrease, meaning that 90% of all respondents experienced some degree of income decline. Household food security was affected for 65% of respondents overall, rising to 73% in Saro, though the site difference was not statistically significant (Table 2). Access to agricultural credit was critically limited, with 73% of farmers reporting no access whatsoever, and when asked to identify their most urgent support need, half of all respondents (50%) named financial support, ahead of technical assistance (22%), infrastructural support (15%), and policy intervention (13%).

These findings sit within the broader macroeconomic context of The Gambia

as a Least Developed Country, where poverty remains widespread and structural economic constraints [47] [48]. Progressive salinization along the River Gambia has steadily reduced the extent of farmable land, contributing to declining national rice production and rising dependence on imports, with direct consequences for household food security in communities such as Abuko and Saro (Food and Agriculture Organization) [49]. Declining domestic production compels households to rely increasingly on imported rice, financed in turn by income from other agricultural activities, thereby further eroding household savings and net income [50]. The high prioritisation of financial support over technical or infrastructural assistance reflects a practical reality: without capital, farmers cannot access the seeds, infrastructure, or labour required to implement adaptive strategies they already know about. This finding is consistent with broader evidence that low-elevation coastal communities in developing countries face acute structural constraints, including limited access to financial resources, in adapting to climate-related stressors [50].

3.8. Comparative Analysis of Abuko and Saro

Although Abuko and Saro share broadly similar agricultural systems, formal tests of the apparent site differences (**Table 2**) yielded mixed results. Saro farmers were significantly more likely to report a salt-tolerant variety as their main rice type (50% versus 17% in Abuko; $\chi^2(2) = 7.67$, $p = 0.022$, Cramér's $V = 0.36$). The apparent differences in reported food security impact (73% versus 57%) and in soil salinity monitoring (43% versus 27%) were not statistically significant (Fisher's exact $p = 0.279$ for each, **Table 2**) and, given the small per-site sample ($n = 30$ each), should not be interpreted as established site differences. The ecological explanation that follows therefore applies most directly to the variety-choice difference: Saro, a coastal, tidally influenced zone adjacent to the Atlantic Ocean, is inherently more exposed to direct marine saline ingress, whereas Abuko experiences intrusion principally through riverine and groundwater pathways. Comparable patterns of differential vulnerability between coastal-estuarine and inland-riverine sites have been documented in West Africa, with coastal locations typically experiencing more frequent and severe intrusion events [51] [52].

As summarised in **Table 5**, chi-square tests confirmed that years of farming experience were significantly associated with rice variety choice ($\chi^2 = 29.381$, $p = 0.00198$), soil and water management practices ($\chi^2 = 50.570$, $p = 0.0045$), and the ability to identify indicators of saltwater intrusion ($\chi^2 = 25.134$, $p = 0.0035$), indicating that accumulated farming experience meaningfully shapes both adaptive behaviour and hazard perception. In contrast, farming experience was not significantly associated with perceived income effects ($\chi^2 = 17.142$, $p = 0.7555$) or with the indigenous adaptation practices recommended by farmers ($\chi^2 = 27.550$, $p = 0.7308$), suggesting that the economic burden of saltwater intrusion and the indigenous knowledge base for responding to it are broadly shared across the farm-

ing population rather than concentrated among any single experience group. Notwithstanding site-specific differences in severity, both communities exhibited comparable gaps in irrigation infrastructure and credit access, indicating that systemic, rather than purely site-specific, interventions are required to comprehensively address saltwater intrusion across the Gambia River basin farming communities.

4. Conclusions and Recommendations

4.1. Conclusions

This study investigated farmers' perceptions of the impact of saltwater intrusion on rice production in Abuko and Saro, Banjul, using structured survey data from 60 smallholder rice farmers. All impact findings are farmers' self-reported perceptions, and the survey included no soil, water, or crop measurements. The evidence gathered across the socio-demographic, agronomic, environmental and economic dimensions converges on a single central finding: farmers in both communities perceive saltwater intrusion as a severe and escalating threat to rice production, food security, and household livelihoods. These perceived consequences were reported by a sample composed mainly of women and older farmers, who form the backbone of rice cultivation in these regions. Respondents were predominantly female (73%), aged 50 years and above (55%), and had limited formal education (48% with no schooling). This is a structurally vulnerable population that possesses deep experiential knowledge of its agroecological environment but lacks the technical resources and institutional support needed to respond effectively to intensifying stressors such as climate change.

Irrigation water came directly from the River Gambia for 58% of farmers, a source potentially exposed to tidal saline ingress, while 27% used well water and 15% relied on rainfall. Therefore, river-borne saline exposure cannot be assumed for all farms. Evidence of intrusion was reported by 78% of farmers; however, 65% did not actively monitor soil salinity, a gap between perceived evidence and proactive management that represents one of the most actionable findings of this study. The self-reported yield data indicate a downward shift: the proportion of farmers reporting harvests of 600 kg or more per season fell from 58% before the intrusion to 22% afterwards, and 85% of farmers reported yield losses over the two most recent seasons. Because no soil, water, or crop measurements were collected, these reported changes cannot be attributed specifically to salinity. Farmers also reported that these losses affected their economic and food security situation, with 90% reporting some degree of income decline and 65% reporting compromised household food security. The contrast in variety adoption between the two sites (50% in Saro versus 17% in Abuko; $\chi^2(2) = 7.67$, $p = 0.022$, Cramér's $V = 0.36$, Table 2) suggests that adaptive capacity is not absent, but appears constrained by structural barriers, mainly limited access to credit (73% with no access) and irrigation infrastructure, rather than by a lack of awareness, which stood at 80% across both sites. These findings

reflect farmers' perceptions and do not constitute confirmed effects of saltwater intrusion on water quality, germination, crop growth, or yield in Abuko and Saro. Measurement-based studies that combine soil and water salinity data with yield records are needed to test whether the reported changes are attributable to salinity. If farmers' perceptions are borne out, the reported trajectory of decline is likely to continue without targeted multi-sectoral intervention, with consequences for national food security and the livelihoods of Gambian farming households.

4.2. Recommendations

1) Establish low-cost, community-based salinity monitoring: Given that 65% of farmers do not monitor soil salinity despite widespread evidence of intrusion, government and NGO partners should deploy affordable electrical conductivity meters and field salinity test kits at the community level, with extension agents trained to conduct seasonal salinity mapping and share results with farmers in locally appropriate formats.

2) Accelerate the distribution of certified salt-tolerant rice varieties: The significantly higher uptake of salt-tolerant varieties in Saro (50%) relative to Abuko (17%; $\chi^2(2) = 7.67$, $p = 0.022$, Table 2) demonstrates strong demand where varieties are accessible. Government agencies, in partnership with the national seed secretariat and international rice research institutions, should scale up the multiplication and distribution of certified salt-tolerant cultivars to underserved communities, such as Abuko, potentially through seed subsidies and community seed banks.

3) Invest in diversified irrigation infrastructure: Direct reliance on the River Gambia for irrigation water, reported by 58% of farmers, is a potential vulnerability, although no water source in this study was tested for salinity. Investment in small-scale groundwater wells, rainwater harvesting, and, where feasible, drip or furrow irrigation pilots, accompanied by routine water quality testing, would reduce direct saline exposure for at-risk farms.

4) Expanding access to agricultural credit and financial services is essential to achieve this: With 73% of farmers reporting no access to credit, financing remains a critical barrier to adopting such technologies. Microfinance institutions, including agricultural credit unions, government credit schemes, and development partners, should design gender-sensitive, collateral-free, group-based lending products that target female rice farmers in coastal and riverine areas.

5) Develop gender-responsive agricultural policies and programs: As women constitute 73% of the rice farming workforce and bear a disproportionate share of both the labour burden and economic consequences of yield loss, agricultural policies and extension programmes should explicitly centre on women's participation, constraints, and priorities, including equitable access to land tenure, training, credit, and inputs.

6) Strengthen extension services with a focus on adaptive practice: Although 80% awareness of saltwater intrusion has been achieved, the gap between awareness and effective practice adoption remains significant. Extension programmes should shift toward hands-on, demonstration-based training in raised-bed construction, flushing, mulching, and improved drainage, for example, through participatory farmer field school models.

7) Integrating saltwater intrusion into national climate adaptation planning: The Gambia's National Adaptation Programme of Action and Nationally Determined Contributions should explicitly incorporate saltwater intrusion in coastal and riverine agricultural systems as a priority adaptation challenge, embedding salinity risk into land use planning, early warning systems, and access to international climate finance.

8) Conduct longitudinal and geospatial research on salinity dynamics: This cross-sectional study was limited to two sites. Future research should employ longitudinal designs to track salinity progression and yield trends over time, integrating geospatial soil-salinity mapping, remote sensing, and hydrological modelling to generate site-specific risk assessments across The Gambia's coastal and riverine rice-producing zones.

4.3. Limitations of the Study

This study is subject to several limitations. The research was geographically restricted to Abuko and Saro, which may limit the generalizability of findings to other regions of The Gambia or comparable coastal environments. The cross-sectional design captured farmers' perceptions at a single point in time and may not fully reflect long-term trends in saltwater intrusion. The relatively modest sample size (60 respondents) constrains the statistical power of the analysis, and reliance on self-reported data introduces potential recall bias and subjective interpretation. Finally, the absence of direct instrumental measurement of soil and water salinity limits the extent to which farmers' perceptions could be independently validated against empirical physicochemical data, an important direction for future longitudinal and geospatial research.

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Author Contributions

Investigation, O.M.B.; data curation, O.M.B.; formal analysis, B.J.; writing: original draft preparation, B.J.; writing: review and editing, C.A.A.; supervision, P.B.; proofreading. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

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

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