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Assessing Vulnerability and Resilience to Climate-Induced Saltwater Intrusion of Smallholder Vegetable Farmers in The Gambia

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Abstract

Saltwater intrusion represents an increasingly significant challenge for smallholder vegetable farmers in The Gambia, particularly in the Lower River Region (LRR) and North Bank Region (NBR). This study therefore examines the demographic, vulnerability of agricultural landscape to saltwater intrusion, and the resilience of 35 smallholder vegetable farming households in the North Bank (NBR) and Lower River (LRR) regions, using the Composite Index of Climate Resilience (CICR) specific to saltwater intrusion and the Resilience Index Measurement and Analysis (RIMA) framework. Given that 91% of households derive their livelihoods from agricultural production, the study identifies high levels of awareness regarding climate change (94%) and indicate that 89% of farmers have experienced a decline in crop yields and income as a result of saltwater intrusion. There are regional and gender differences, the NBR exhibits a higher Resilience Capacity Index (RCI) than the LRR. While female-headed households demonstrate greater access to essential services, yet face more significant barriers to agricultural assets. In contrast, male-headed households exhibit stronger adaptive capacities. In sum, the findings indicate that saltwater intrusion exacerbates vulnerabilities and threatens food security. This highlights the necessity for targeted, region-specific, and gender-sensitive interventions, including improved agricultural inputs, social safety nets, and literacy support, to strengthen resilience among Gambian smallholder farmers and support sustainable livelihoods.

Keywords: saltwater intrusion, resilience, climate change, vulnerability, agriculture, household

1. Introduction

Globally, farmers are critical actors in climate change adaptation (Burnham & Ma, 2016). Agriculture is fundamental to global food security and economic stability, with approximately 12% of the world's land area, or 1.6 billion hectares, used for crop production (Benneyworth et al., 2016). In West Africa, arable land accounts for between 62% and 95% of the total land surface (MacDonald *et al.*, 2012). In The Gambia, agriculture is the primary source of livelihood for nearly 72% of the poor rural households, contributes 25% to the GDP and accounts for 32% of primary agricultural production (Ceesay *et al.*, 2021). With 70% of Gambians engaged in agriculture, the sector is responsible for meeting about half of the nation's food needs (Agriculture and Natural Resource (ANR) Policy, 2017). Therefore, optimizing the use of arable land, especially for staple crops such as rice and vegetables, is crucial for sustainable income and food security (ANR, 2017). However, climate change is having a significant impact on the salinity of the Gambia River, with rising temperatures, decreasing rainfall, and sea-level rise increasing the salinity of aquifers, rivers, and estuaries (Yaffa & Bah, 2018). Saltwater intrusion, extending up to Central River Region (CRR) of the country impacting farmer livelihoods (M'koumfida *et al.*, 2018). This problem is especially pronounced in the NBR and LRR, areas particularly susceptible to tidal influences that introduce saltwater into arable lands, leading to soil salinization, reduced crop productivity, and food insecurity (Yaffa *et al.*, 2016).

The Gambia, ranked 174th out of 189 countries in the 2018 UN Human Development Index

(HDI), faces significant socio-economic challenges, with approximately 20.8% of its population living on less than USD 1.25 per day (GBoS, 2019). The Gambian government has in recent years prioritized securing food production, providing adequate shelter, and ensuring access to safe water for both agricultural irrigation and domestic needs (ANR, 2017). However, how adequate are these measures in building the resilience and reducing the vulnerabilities of these smallholder farmers? Conceptually, vulnerability and resilience are related but distinct; while vulnerability examines a community's exposure, sensitivity, and adaptive capacity to climate shocks, resilience measures the ability to recover and adapt following a shock (Joakim *et al.*, 2021). Therefore, developing an adequate measure of both vulnerability and resilience is therefore critical to support adaptation strategies that reduce the impacts of climatic change and variability among smallholder farmers (Kumar *et al.*, 2020). This study fills an information gap by systematically quantifying resilience and vulnerability among Gambian smallholder farming households, examining socio-demographic and economic factors that influence resilience to food insecurity and saltwater intrusion.

The Composite Index of Climate Resilience (CICR) model by Yessoufou *et al.* (2024) has been adapted in this study to measure vulnerability and resilience specific to saltwater intrusion, emphasizing the need for an integrated approach that considers direct climate impacts on agricultural livelihoods. Complementing the CICR, the Composite Index of Climate Resilience (CICR) specific to saltwater intrusion and the Resilience Index Measurement and Analysis (RIMA) framework provide a valuable framework for identifying and addressing these complex challenges, capturing and quantifying resilience dimensions such as asset ownership, access to essential services, and social safety nets (FAO, 2016).

Specifically, the study aimed to:

i. Construct a CICR tailored to saltwater intrusion risks.

ii. Quantify household resilience to food insecurity using the RIMA framework.

iii. Identify key determinants of household vulnerability and resilience to climate change-induced saltwater intrusion.

2. Literature Review

The vulnerability and resilience of smallholder vegetable farms in The Gambia to climate-induced saltwater intrusion are increasingly critical in the context of climate change impacts on tropical regions. Climate change in the tropics is marked by heightened temperatures and reduced precipitation, which exacerbate water scarcity and promote saltwater intrusion, particularly in coastal and estuarine zones. According to the sub-tropics are anticipated to face declining precipitation levels and an increase in extreme weather events, amplifying freshwater scarcity for both human consumption and ecosystems (Haider *et al.*, 2013). The Gambia, due to its geographical characteristics and significant coastal zones, is particularly vulnerable to such changes (Mikhailov, 2008).

The phenomenon of saltwater intrusion, defined as the encroachment of saline water into freshwater sources, is increasingly common in many coastal areas worldwide, including the

Gambia River region (Fatajo *et al.*, 2010; Yaffa & Bah, 2018). Sea-level rise, a consequence of climate change, is projected to intensify this intrusion, posing Intergovernmental Panel on Climate Change (IPCC), substantial challenges to The Gambia's agricultural sector, where smallholder farms dominate. The intrusion of saline water into freshwater sources is exacerbated by variables such as river runoff, evaporation, and increasingly intense weather patterns (Yaffa & Bah, 2018). In The Gambia, where approximately 72% of poor households rely on agriculture (Ceesay *et al.*, 2021), the adverse effects of salinization on crop yield, income, and household food security are significant (M'koumfida *et al*., 2018); Abdullah *et al.*, 2016). Moreover, studies predict that salinity will advance further upstream in the Gambia River, threatening larger areas of arable land, notably affecting lowland areas vital for rice and vegetable production (Werner *et al.*, 2009; Ervine *et al.*, 2007).

The literature on resilience identifies resilience as the capacity of systems to absorb shocks, adapt, and transform, enabling continuity of livelihoods amidst adverse conditions (Holling, 1973). Resilience is commonly conceptualized as multidimensional, encompassing economic, ecological, and social components, each playing a unique role in the stability and adaptability of communities (Platt *et al.*, 2016). In contrast, vulnerability, as defined by the IPCC, captures the susceptibility of systems to climate-related stressors, considering exposure, sensitivity, and adaptive capacity (Yessoufou *et al.*, 2024; Malone, 2009). Vulnerability in agricultural systems, especially those dependent on water resources, is particularly high in The Gambia, where sea-level rise threatens the stability of agricultural production through saline intrusion and freshwater scarcity (Yaffa & Bah, 2018). Vulnerability indices often integrate socioeconomic data to analyze the impact of environmental changes on household resilience, revealing that socioeconomic conditions, adaptive capacities, and agricultural practices are closely tied to resilience outcomes in rural communities (Clare *et al.*, 2017).

Resilience indices tailored to West African contexts, like the FAO's Resilience Index Measurement Analysis (RIMA), have been instrumental in assessing and promoting resilience among farming communities by evaluating coping capacities and adaptive behaviors (FAO, 2016). Recently, the Composite Index of Climate Resilience (CICR) has emerged as a valuable tool to quantify the resilience of smallholder farmers to climate-induced shocks (Yessoufou *et al.*, 2024). Despite the evident need, there is limited research on resilience specifically addressing smallholder vegetable farmers in The Gambia.

3. Materials and Methods

3.1 Study Area and Data Collection

This study was conducted in 35 rural communities: 20 located in the North Bank Region (NBR) and 15 in the Lower River Region (LRR) of The Gambia (Figure 1). These two regions were specifically selected because of their vulnerability to saltwater intrusion from the Gambia River and the Atlantic Ocean, due to their geographical location within the salt-affected areas of the country (Yaffa & Bah, 2018). The climate is characterized by two seasons, a rainy season (between June and October) and a dry season (November to April). However, the NBR has an annual rainfall of about 700 mm, making it the driest region of the country. The daily minimum temperature is 25 ^{O}C and the maximum is 45 ^{o}C (GBoS, 2013).

The LRR, on the other hand, has an average temperature range of 25 °C to 28 °C, and an average annual rainfall that varies from 600 mm to 900 mm (Sonk *et al.*, 2019).

Survey data was collected in June 2023 from 35 households in the NBR (including Essau, Nbankam, Ndunku Charen, Nema Kunku, Jufureh, Jamagen, Darufodaba, Jurunku, Dasilame, Kerewan, Banni, Salikeni, Kinteh Kunda Janneh Ya, Mandory, Minteh Kunda, India, Jalaba, Taindato, Bambally, and Farafenni and LRR (including Sankuia, Jenoi, Jabisa, Jappinneh, Bureng, Pakaliba, Sukuta, Sara Jama, Jomarr, Jasobo, Nema, Wurukang, Sankandi, Tankularr and Karantaba) with a focus on assessing smallholder farmers' food insecurity and resilience to saltwater intrusion. The Regional Agricultural Directorate provided the list of households, from which respondents were randomly selected using the Excel RAND function. Kobo Toolbox was utilized as the primary tool for efficient and accurate data management. The survey used the RIMA questionnaire (FAO, 2016). Minor adjustments were made to the RIMA questionnaire to address specific risks associated with saltwater intrusion in the target regions.

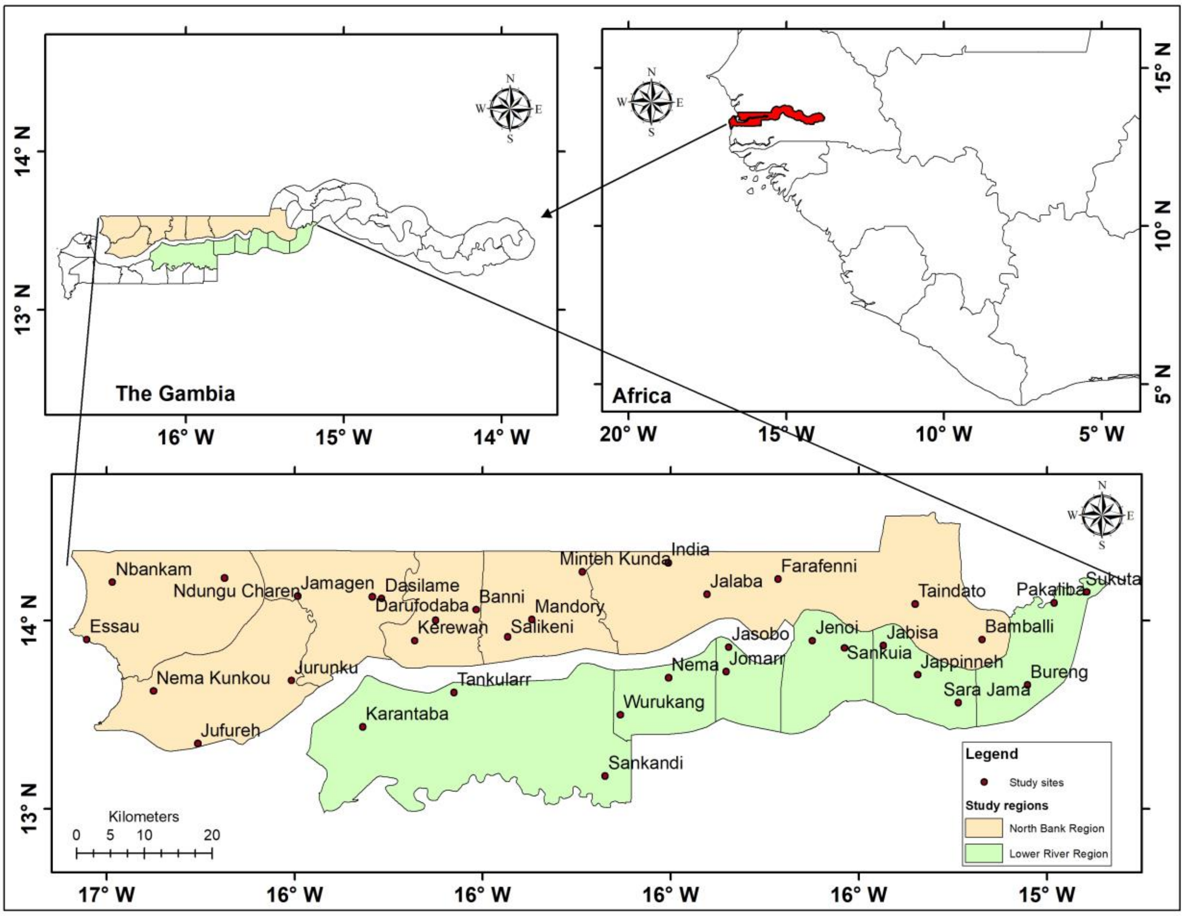

Figure 1. Map of the Gambia showing the study locations

3.2 Data Analyses

Survey data was analyzed using the CICR model which focuses on climate-induced saltwater intrusion vulnerability and RIMA, which focuses on food security. RIMA questionnaires were employed to gather data on vulnerability, which facilitated the assessment of the CICR. The CICR index, developed specifically for this study, assesses household exposure to saltwater intrusion, and examines how this climate-induced shock impacts agricultural productivity and overall well-being of the farmers. The resilience-building mechanism within the CICR framework is divided into four stages, R0 to R3.

The initial stage, **R0 (Anticipation)**, involves proactive preparation before the occurrence of a climate shock. This stage requires **anticipatory capacity**, defined as the ability to foresee, plan for, and mitigate potential impacts through access to knowledge and information. When a shock occurs, **R1 (Coping)** represents the household's immediate, short-term response to the event. This capacity is supported by **absorptive capacity** (the ability to withstand and recover from immediate impacts), as well as **social and political capacities**, which include support from networks, institutions, and governance structures. Following the coping phase, the household transitions to **R2 (Adaptation)**, where **adaptive capacity**, the ability to make systemic adjustments and behavioral changes to respond to new conditions becomes critical. Lastly, **R3 (Transformation)** reflects the household's **transformative capacity**, enabling innovation, structural reconfiguration, and the establishment of a new, more resilient equilibrium to sustainably address future shocks (Yessoufou et al., 2024). This step involves making long-term structural changes to strengthen resilience.

Building on the CICR framework, Yessoufou *et al*. (2024) incorporated seven variables in their study, while our approach used eleven questions (Q1–Q12), each aligned with at least one step of the resilience process (see Table 1). The last column of the table provides insights on the factors driving the resilience building in each step. For each question, households were asked to indicate their level of agreement based on a 3-point Likert scale: "Agree" (1), "Neither agree nor disagree" (0), "Disagree" (-1). For instance, the first question assesses the household's perception of their coping ability, corresponding to the R1 dimension.

Table 1. Questions to measure subjective resilience (Yessoufou *et al.*, 2024) to saltwater intrusion

	Questions	Factors
Q1 R1	My household can bounce back from any challenge that is caused by saltwater intrusion	Absorptive Capacity
Q 2 R1	My household is better able to deal with saltwater intrusion compared with others in our community	Absorptive Capacity
Q3 R2	If saltwater intrusion threats to my household become more frequent and intense, we would still find a way to get by	Adaptive Capacity
Q4 R3	During times of saltwater intrusion, my household can change its primary source of income or livelihood if needed	Transformative capacity
Q5 R2	If saltwater intrusion occurs, my household can afford 3 square meal it needs to survive and thrive	Financial capital
Q6 R1	If saltwater intrusion occurs my household can rely on the support of family and friends when we need help	Social capital
Q7 R1	If saltwater intrusion occurs my household can rely on the support politicians and government when we need help	Social/Political capital
Q8 R0	My household has learned important climate related hardships from the past that will help us to better prepare for the future	Learning Capacity
Q9 R0	My household is fully prepared for any future threats and challenges that is caused by saltwater intrusion	Anticipatory Capacity
Q10 R0	My household frequently receives information warning us about future extreme weather events and saltwater intrusion in advance	Knowledge and Information
Q11 R0	If any saltwater intrusion occurred tomorrow, my household would be well prepared in advance	Absorptive Capacity
Q12 R3	If any severe saltwater intrusion occurred tomorrow, my household could recover fully within six months?	Absorptive Capacity

The CICR index (Yessoufou *et al.*, 2024) is calculated:

$$CICR_i = \sum_{k}^{K} \frac{\alpha_k}{6} \sum_{j}^{J} I_{k,j}^{i} \tag{1}$$

Where CICR computes a Composite Index of Climate Resilience values between −1 and 1; $I_{k,j}^{i}$ the value of the response given by the *i*-th household for the *j*-th question on the *k*-th climate shock of the indicator, verifying:

$-2 < I_k < 2$;

- $0 < \alpha_k < 1$ and $\sum_k^k \alpha_k = 1$, the relative importance of *k*-th shock.

6 was used for normalization because J=6. In our specific context of saltwater intrusion as a shock we have *k*=1 which implies $\alpha_1 = 1$. In addition, we have nine dimensions which are the factors driving resilience in this study, each of which can be represented by one or more sub-indicators. The final resilience indicator value for household "*i*" is then calculated using the following formula:

$$CICR_i = \frac{1}{9}\sum_{j}^{J}\frac{1}{S_j}\sum_{s}^{S_j} I_{s,j}^{i} \quad (2)$$

Where $I_{s,j}^{i}$ is the value of the response given by the *i*-th household for the *s*-th question on the *j*-th dimension of the indicator, verifying: $-1 < I_k < 1$; S_j is the number of sub-indicators (questions) in the dimension j of the index.

By construction, the CICR is an increasing function of its components. That is whenever the household achieves better in terms of any of the capacities (absorptive, learning, anticipatory, knowledge and information, financial, transformative, social, and political), the index will increase to reflect this improvement.

Resilience to food insecurity was assessed at the household level, following the framework of FAO (2016) and d'Errico & Pietrelli (2017). The four resilience pillars include access to basic services (ABS), assets (AST), adaptive capacity (AC), social safety nets (SSN). **ABS** evaluates the availability and quality of essential services such as healthcare, education, water, and sanitation, which are critical for reducing vulnerability to shocks. **AST** refers to the physical, financial, and natural resources such as land, livestock, savings, and infrastructure that households rely on to sustain livelihoods and buffer against shocks. **AC** encompasses the ability of households to adjust and innovate in response to changing circumstances, often linked to education, income diversification, and access to knowledge and information. **SSN** captures the role of formal and informal support systems, including social networks, community ties, and government assistance programs, in mitigating the impacts of shocks. (FAO, 2016). The resilience outcome indicators considered are food security indicators (FAO, 2016; Brück *et al.*, 2019) such as worrying about not having enough food and not eating throughout the day. To construct the social safety nets pillar, formal and informal transfers, access to credit, and indicators of social networks were included. The FAO Shiny RIMA toolkit, is used to calculate the RIMA index. The RIMA framework evaluates resilience to food insecurity by using indicators for access to basic services (ABS), assets (AST), adaptive capacity (AC), social safety nets (SSN), food security (FS), and household demographics (FAO, 2016).

3.3 Validation of CICR and RIMA Indices

To ensure the reliability and relevance of the CICR and RIMA indices in The Gambia, the CICR index, adapted from Yessoufou et al. (2024), and the RIMA questionnaire, modified from FAO (2016), were customized to address the impacts of saltwater intrusion on resilience and food security in NBR and LRR regions. Consultations with regional agricultural directorates and smallholder farmers contextualized the frameworks to reflect local socio-environmental realities. Pretest of both indices was conducted in a subset of households from the study regions. Feedback from respondents and enumerators was used to refine the indices, ensuring the questions were easy to understand and relevance to the study objectives.

CICR is applied to interpret the level of resilience/vulnerability of the smallholder vegetable households to the climate risk of saltwater intrusion. After conducting descriptive and inferential analyses on how households' socio-demographic characteristics affect resilience to saltwater intrusion, we deepened the analysis by using chi-square tests to cross the CICR index and its dimensions with the RIMA index and its dimensions. Categories for the CICR index were obtained by using the median value as a threshold.

4. Results

4.1 Demographics of Surveyed Households

In NBR, 70% of households are headed by men, while in LRR, this figure is 67%. Educational attainment varies across regions: in NBR, 35% of households have received formal education, while 65% have non-formal education. In LRR, 33% of households have formal education, with 67% having non-formal education. Agriculture serves as the primary livelihood for 91% of households across the two regions, with 95% in the North Bank Region (NBR) and 83% in the Lower River Region (LRR). Regarding government employment, 56% of households in NBR and 13% in LRR rely on monthly government salaries (Figure 3).

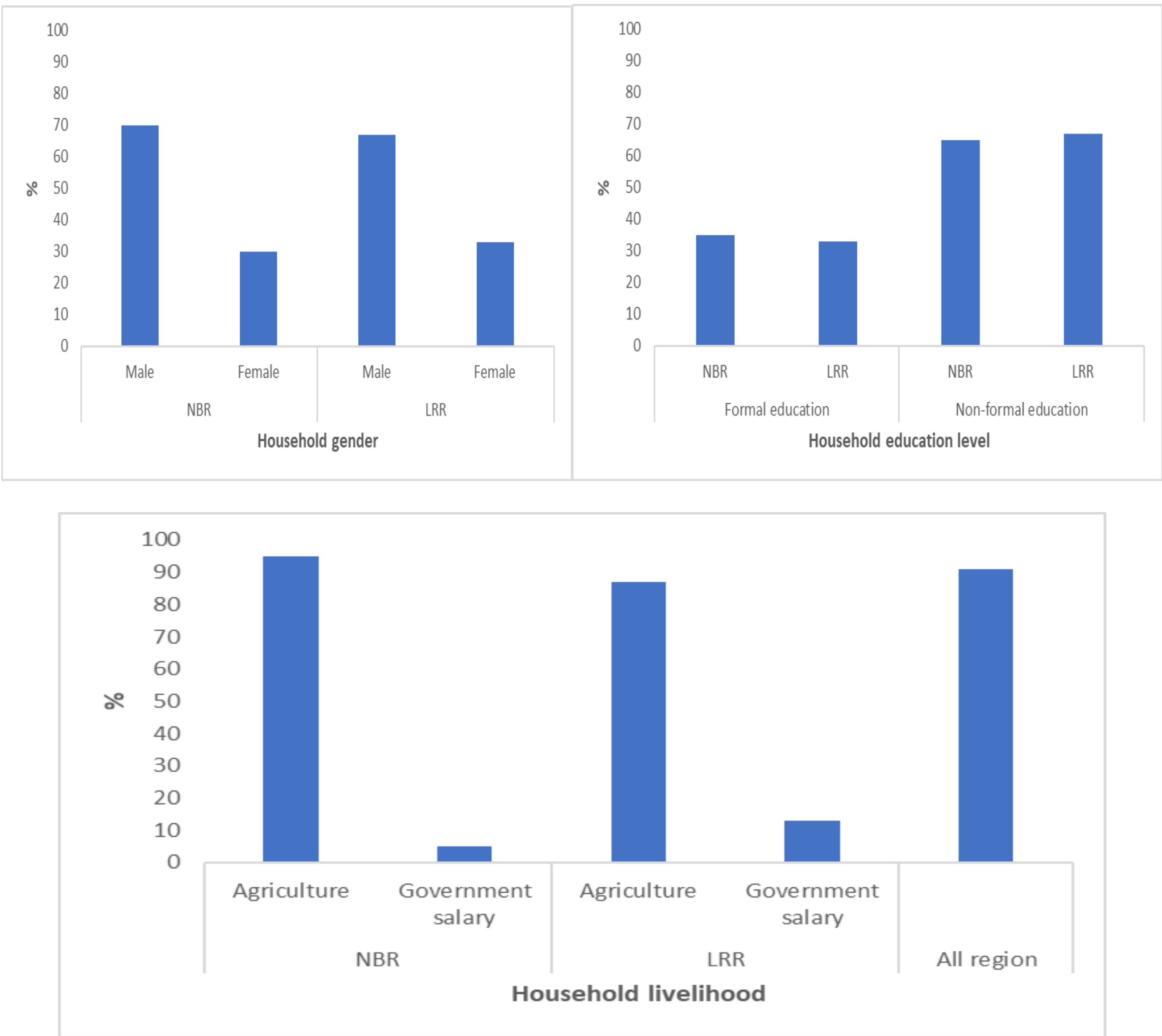

Figure 3. Household dempographics in the NBR and LRR regions

4.2 Perception of Surveyed Household to Climate Change and Saltwater Intrusion

In terms of climate risk perceptions, 94 % of the households had of climate change while 66% believed that climate change phenomenon is real and is happening. 60% saltwater intrusion as the most climate change induced risk and 89% believe that climate-induced saltwater intrusion affects their crop land, yield and income. The climate shocks perceived by the farm households are summarized below in Figure 4.

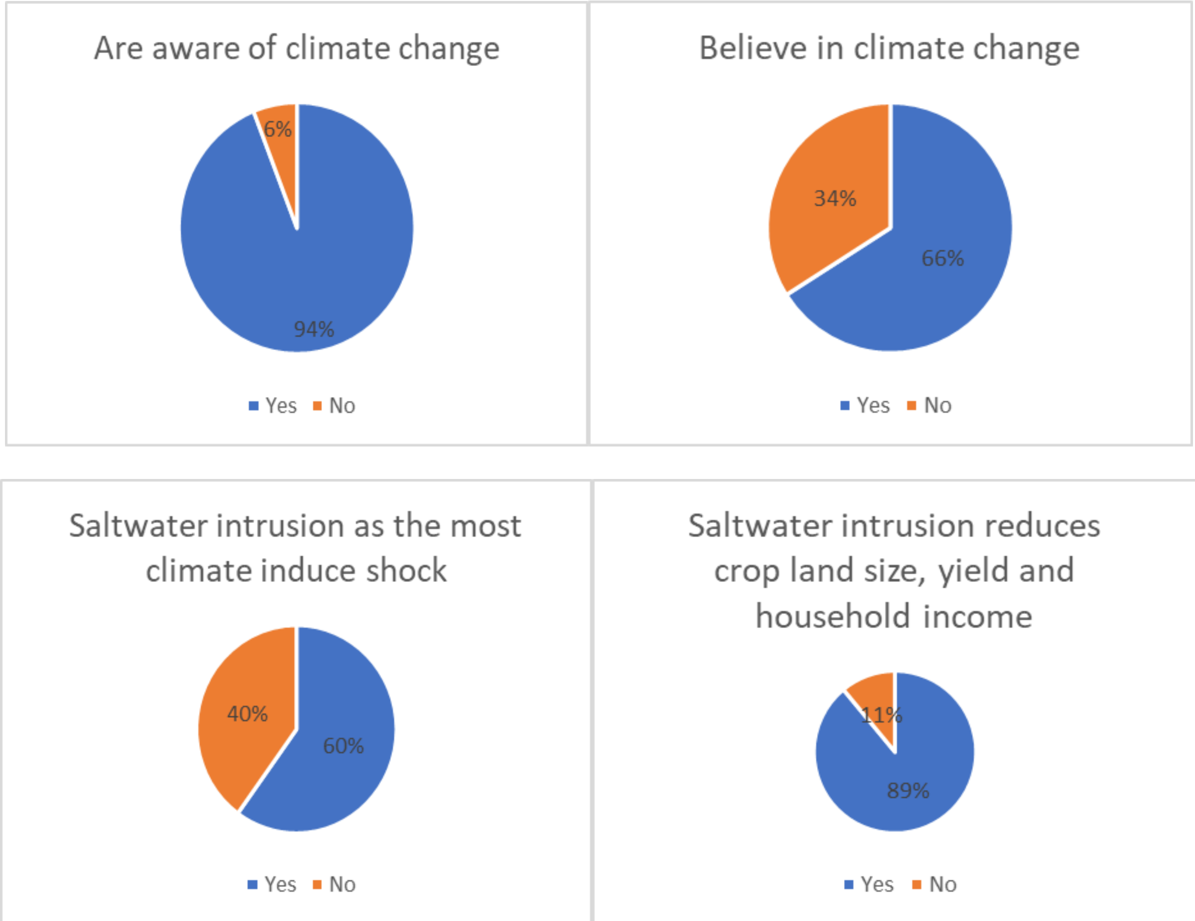

Figure 4. Perception of households to climate change and saltwater intrusion

4.3 Analysis of the Vulnerability to Saltwater Intrusion

Results of the Composite Index of Climate Resilience are presented in Table 2.

Table 2. Summary statistics on the CICR

	Mean ± SD	**Median value**
Vulnerability index	**-0.12 ± 0.4**	**-0.22**
Absorptive capacity	-0.34 ± 0.55	-0.5
Adaptative capacity	-0.29 ± 0.72	-0.5
Transformative capacity	0.03 ± 0.92	0
Financial capacity	0.66 ± 0.64	1
Social capacity	-0.34 ± 0.94	-1
Social/political capacity	-0.34 ± 0.91	-1
Learning capacity	-0.46 ± 0.85	-1
Anticipative capacity	-0.51 ± 0.74	-1
Knowledge and information	0.51 ± 0.85	1

An average vulnerability index of -0.12, indicates a general tendency toward vulnerability, although it is close to a neutral stance. However, the median value is -0.22, indicating that more than half of the households exhibit a higher level of vulnerability than resilience. The relatively low standard deviation (0.4) suggests a modest degree of variability across the dataset. An examination of the factors contributing to vulnerability reveals that both absorptive and adaptive capacities have negative values with average of -0.34 and -0.29, respectively, with median of -0.5. This implies that these capacities are generally limited among households. The higher standard deviations in these categories (0.55 for absorptive and 0.72 for adaptive) indicate more variability in the ability of households to withstand or adjust to disturbances.

In contrast, the average for transformative capacity is close to zero (0.03) and the median is also 0, indicating a state of equilibrium between the potential for transformation in response to challenges and vulnerability. Nevertheless, a high standard deviation of 0.92 indicates a considerable disparity in transformative capacity among farmers. Financial capacity is a notable exception, exhibiting a positive average (0.66) and a median of 1, indicating that a considerable number of farmers demonstrate robust financial resilience to saltwater intrusion. The relatively moderate standard deviation (0.64) indicates a certain degree of variability but suggests that financial resources are a significant contributing factor to resilience. In contrast, social and political capacities, as well as learning and anticipative capacities, exhibit negative averages and medians, indicating deficiencies in social cohesion, governance, and forward-looking capacities. The standard deviations, which range between 0.74 and 0.94, further underscore the variability observed in these critical resilience aspects. Lastly, the knowledge and information capacity, with an average of 0.51 and a median of 1, reflects a notable strength in the availability of knowledge resources. However, the standard deviation (0.85) indicates a considerable degree of variation (Table 2).

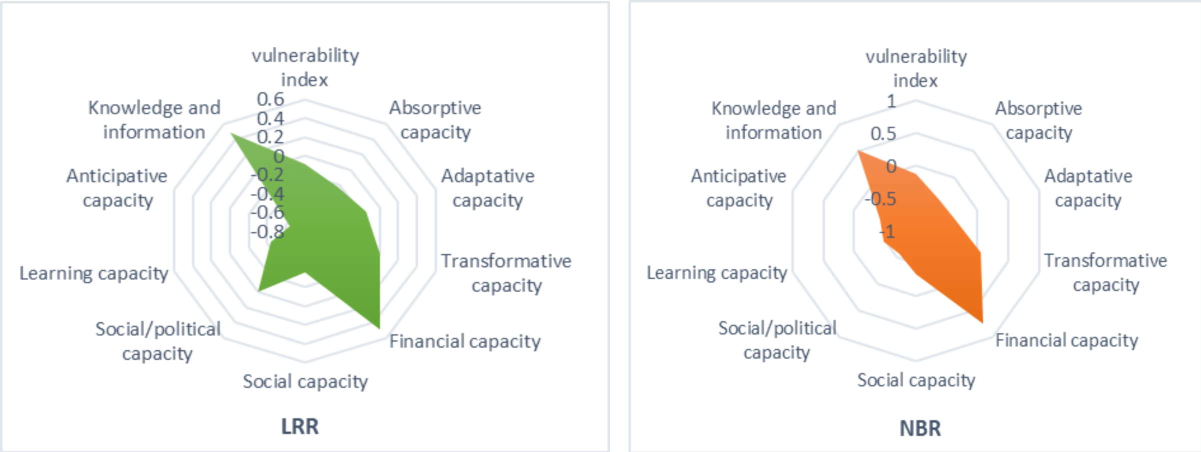

Figure 5. Vulnerability to saltwater intrusion by region

Both the LRR and NBR regions show robust financial and knowledge capacities. However, they are both significantly vulnerable in social, social/political, learning, and anticipative capacities, with values approaching -1, particularly in LRR. Absorptive, adaptive, and transformative capacities are moderately negative in LRR, while NBR displays a more balanced profile with slight positive trends (Figure 5).

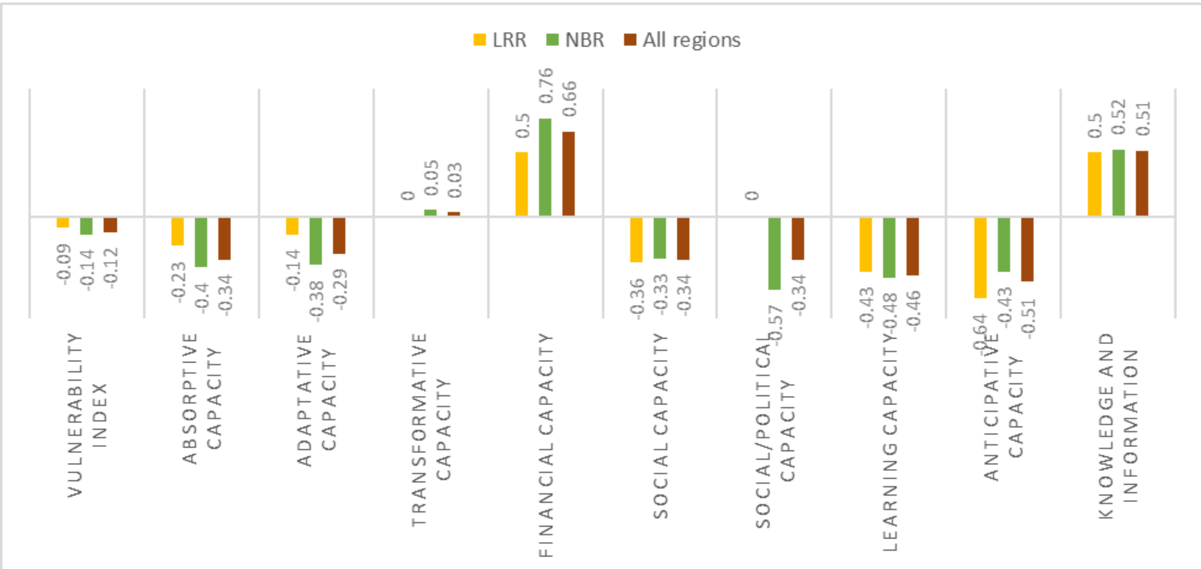

Figure 6. Vulnerability to saltwater intrusion by region and vulnerability dimension

The observed trends in the analysis of CICR across all regions are also reflected by region. We can clearly see in Figure 6 that while financial capacities, transformative capacities as well as knowledge and information contribute to an improvement in the resilience status of farmers, the other dimensions display an opposite trend, resulting in an overall low index value.

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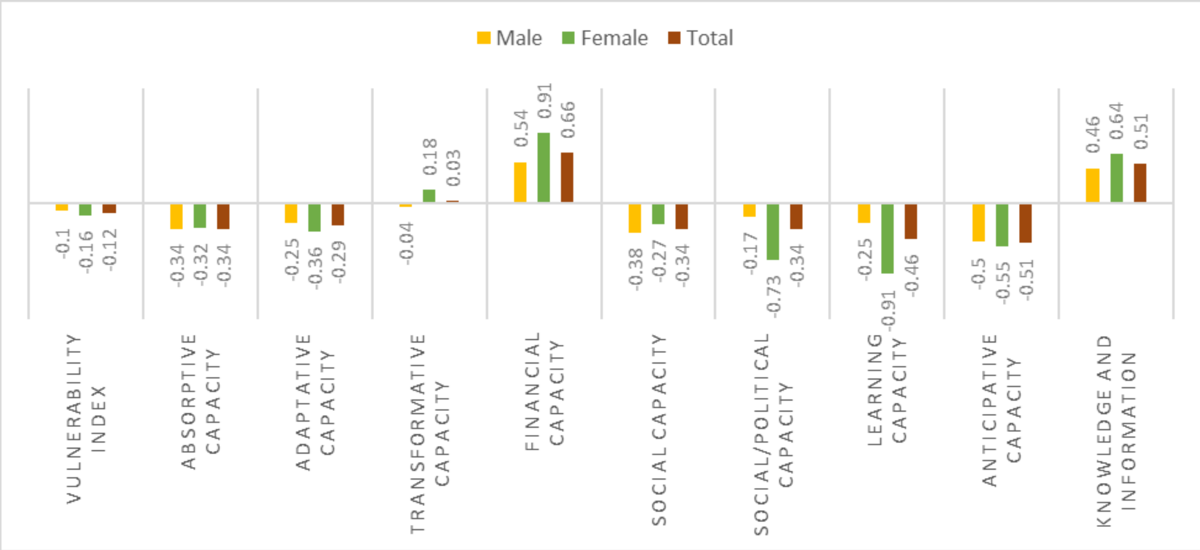

Figure 7. Vulnerability to saltwater intrusion by gender and dimension-wise

4.4 Gender Considerations in Vulnerability of Agricultural Households to Saltwater Intrusion

Figure 7 presents a comparison of the various CICR dimensions based on the gender of the head of the household. In general, male-headed households show a slightly lower degree of vulnerability (higher vulnerability with value of -0.1) than female-headed households. However, when examined in details, female-headed households demonstrate higher financial capacity (0.91) and more access to knowledge and information (0.64) compared to male-headed households (0.54 and 0.46 respectively). In other dimensions, female-headed households exhibited a markedly negative performance in social/political capacity as well as learning capacity, which collectively contributed to a reduction in the overall value of their CICR index.

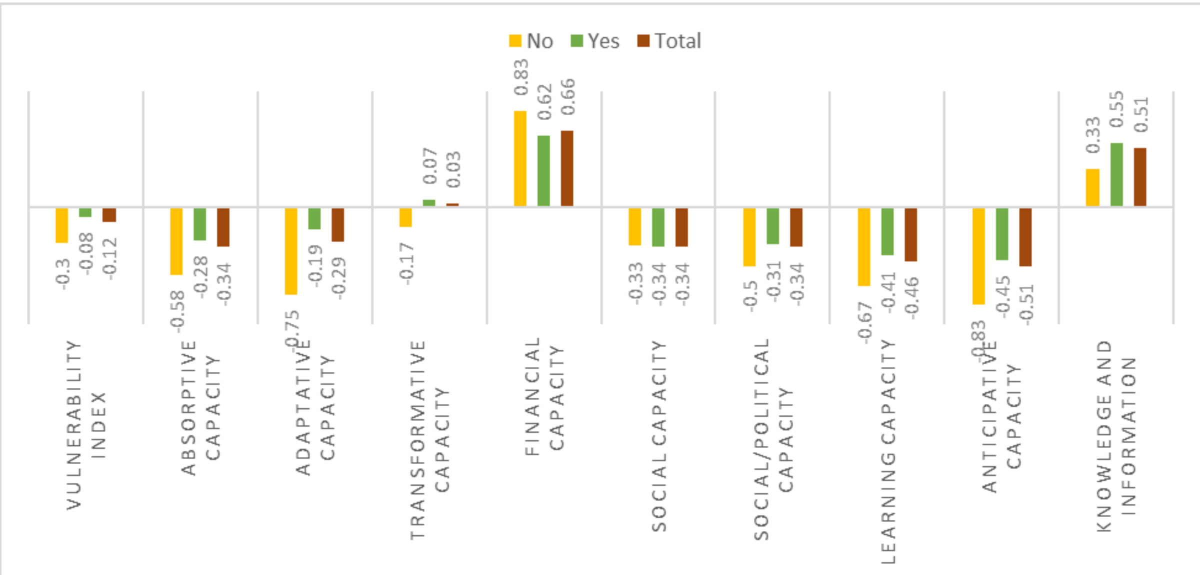

Figure 8. Vulnerability to saltwater intrusion and education level

Figure 8 illustrates the impact of the head of the household education level on resilience/vulnerability level across various dimensions. Households where the head cannot read ("No") show higher vulnerability, particularly in absorptive, adaptive, and anticipative capacities, with consistently more negative values compared to those with a literate head ("Yes"). Financial capacity stands out, as illiterate household heads demonstrate much stronger financial resilience (0.83) than literate ones (0.62). Knowledge and information capacity also show a clear advantage for households with literate heads. Overall, the ability of the head to read is strongly linked to higher resilience or lower vulnerability.

4.4 Impact of Saltwater Intrusion on Farm Household's Livelihoods

Vulnerability to saltwater intrusion and vulnerability to food insecurity analysis considered categorized versions of the overall RCI index and its dimensions (ABS, AST, AC, SSN) separated by median value and computed a series of chi-square statistical tests. The results are presented in Table 3 below.

Table 3. Dependency between saltwater intrusion vulnerability and RIMA RCI index

		Saltwater intrusion			
		Not Vulnerable	Vulnerable	Total	***p*-value**
ABS	Not vulnerable	44.44	55.56	100	**0.358**
	Vulnerable	29.41	70.59	100	
AST	Not vulnerable	33.33	66.67	100	**0.631**
	Vulnerable	41.18	58.82	100	
AC	Not vulnerable	33.33	66.67	100	**0.631**
	Vulnerable	41.18	58.82	100	
SSN	Not vulnerable	47.37	52.63	100	**0.172**
	Vulnerable	25	75	100	
RCI	**Not vulnerable**	**38.89**	**61.11**	**100**	**0.826**
	Vulnerable	**35.29**	**64.71**	**100**	
	All	**37.14**	**62.86**	**100**	

The analysis demonstrates that none of the dimensions or the overall RCI index exhibit statistically significant correlations with vulnerability to saltwater intrusion. To further elucidate this relationship, we investigated the potential associations with the specific dimensions of saltwater intrusion.

Table 4. Chi-square *p*-value matrix between various components of saltwater intrusion resilience and RIMA index dimensions

		RIMA (Food insecurity and livelihoods)				
	Dimensions	**RCI**	**ABS**	**AC**	**AST**	**SSN**
Saltwater intrusion	**Absorptive capacity**	0.044*	0.903	0.404	0.122	0.728
	Adaptative capacity	0.877	0.404	0.877	0.877	0.371
	Anticipative capacity	0.404	0.555	0.555	0.903	0.076**
	Financial capacity	0.581	0.512	0.512	0.062**	0.446
	Knowledge and Information	0.476	0.927	0.476	0.476	0.782
	Learning capacity	0.328	0.328	0.227	0.227	0.452
	Social & Political capacity	0.631	0.631	0.06**	0.358	0.149
	Social capacity	0.555	0.555	0.555	0.903	0.288
	Transformative capacity	0.581	0.407	0.89	0.89	0.072**
	Overall CICR categories	**0.826**	**0.358**	**0.631**	**0.631**	**0.172**

**Significant at 5%; ** Significant at 10%*

The chi-square matrix (Table 4) illustrates the interrelationships between the various components of resilience to saltwater intrusion and resilience to food insecurity, as indicated by the RCI dimensions. In this analysis, the resilience to saltwater intrusion is divided into several categories: absorptive, adaptive, anticipative, financial, knowledge and information, learning, social and political, social, and transformative capacities. The chi-square tests were conducted to examine the associations between these components of saltwater resilience and the overall resilience to food insecurity (RCI), along with specific dimensions: access to basic services (ABS), adaptive capacity (AC), assets (AST), and social safety networks (SSN). The results revealed that a single relationship was significant at the 5% level of risk, while four relationships were significant at the 10% level.

4.4.1 Absorptive Capacity and Overall Resilience to Food Insecurity

The analysis of the relationship between the absorptive capacity dimension of resilience to saltwater intrusion and the overall RCI (livelihood index) reveals a statistically significant dependency, as indicated by a chi-square *p*-value of 0.044 (Table 4). As illustrated in Figure 9, households identified as vulnerable to saltwater intrusion in their absorptive capacity exhibit a higher prevalence (60.87%) of non-vulnerability to food insecurity compared to those deemed not vulnerable (25%).

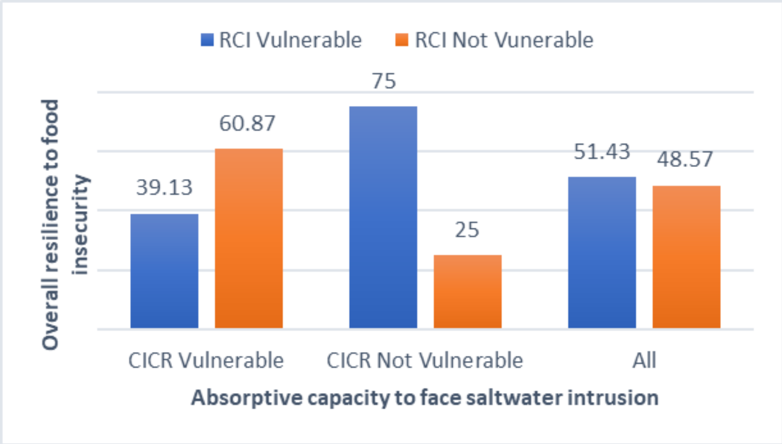

Figure 9. Relationship between absorptive capacity and overall vulnerability to food insecurity

4.4.2 Anticipative Capacity to Saltwater Intrusion Risk and Social Safety Network (SSN)

The analysis of the relationship between the anticipative capacity dimension of CICR (ability to plan for future risks) and the social safety network dimension of livelihood index (Table 4), shows a marginally significant relationship (10% level) with SSN vulnerability ($\chi^2 = 3.1574$, $p = 0.076$).

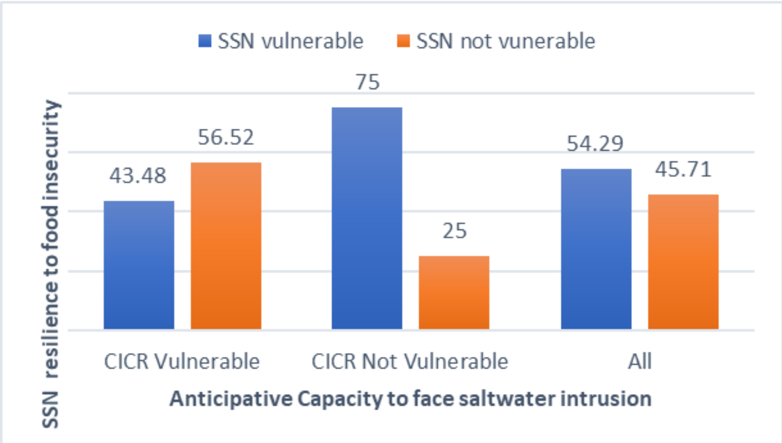

Figure 10. Relationship between anticipative capacity and vulnerability to food insecurity in the social safety network dimension

Figure 10 shows that households with higher anticipative capacity (CICR not vulnerable) tend to exhibit more weakness in their social safety network dimension (75% of SSN vulnerability) compared to those with lower anticipative capacity (CICR vulnerable), where SSN vulnerability is lower (43.48%).

4.4.3 Financial Capacity and Assets

The analysis in Table 4 indicates a significant relationship (at 10% level) between the ability of households to access, manage, and effectively utilize financial resources to cope with, adapt to, and recover from shocks (financial capacity) to face saltwater intrusion and assets ownership dimension of livelihood index ($\chi^2 = 3.4743$, $p = 0.062$).

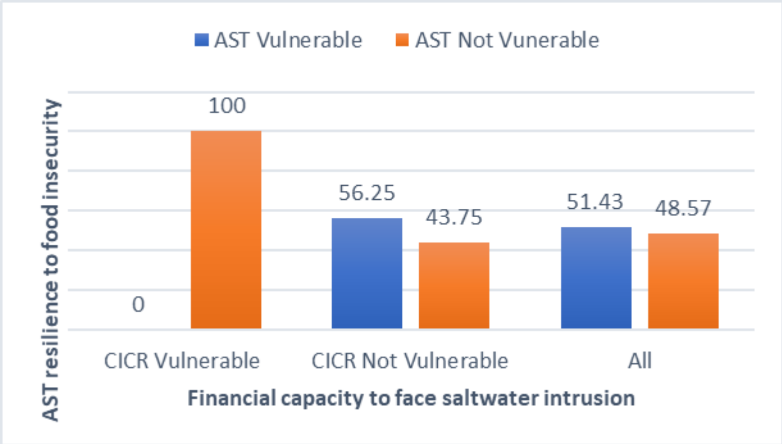

Figure 11. Relationship between financial capacity and vulnerability to food insecurity in the assets dimension

It is evident that among the financially vulnerable households affected by saltwater intrusion, none are vulnerable with respect to the assets dimension of the livelihoods index. Among the financially non-vulnerable households, less than half (44%) are vulnerable with respect to assets (Figure 11).

4.4.4 Social & Political Capacity and Adaptive Capacity

The data in Table 4 reveals a significant relationship at 10% level between social and political capacity to face saltwater intrusion and adaptive capacity dimension of livelihood index ($\chi^2 = 3.5338$, $p = 0.060$).

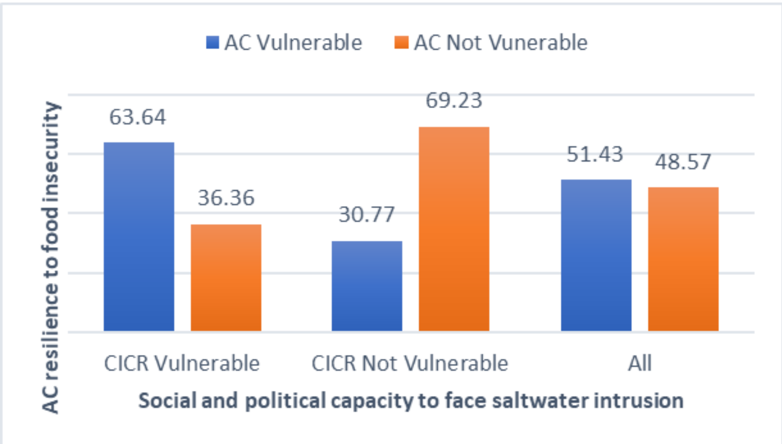

Figure 12. Relationship between social and political capacity and vulnerability to food insecurity in the adaptative capacity dimension

As illustrated in Figure 12, a significant proportion of households classified as vulnerable in their social and political capacity to saltwater intrusion (CICR vulnerable) also exhibit vulnerability to food insecurity in the adaptive capacity dimension (AC vulnerable). Amongst CICR non-vulnerable households, the majority are also classified as AC non-vulnerable (69.2%).

4.4.5 Transformative Capacity and Social Safety Network (SSN)

The relationship between the transformative capacity dimension of saltwater intrusion and the social safety network dimension of livelihood (see Table 4) is statistically significant at the 10% level ($\chi^2 = 3.2429$, $p = 0.072$). The analysis of the chart below indicates that households with robust transformative capacity in the context of saltwater intrusion (CICR not vulnerable) exhibit a higher prevalence of food insecurity in the SSN dimension (66.67%) compared to those with vulnerability in their transformative capacity in the face of saltwater intrusion (Figure 13).

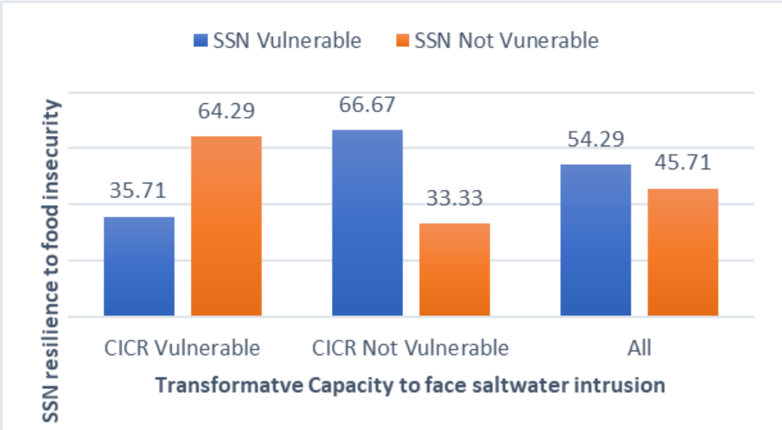

Figure 13. Relationship between transformative capacity and vulnerability to food insecurity in the social safety network dimension

4.5 Households' Resilience of Smallholder Vegetable farmers to Food Insecurity

The majority of the surveyed households demonstrated a lack of resilience to food insecurity, as evidenced by an average score below the Resilience Capacity Index (RCI) average. Figure 14 illustrates that the NBR exhibits a higher RCI of 43.94 in comparison to the LRR, which displays a markedly lower RCI of 18.59.

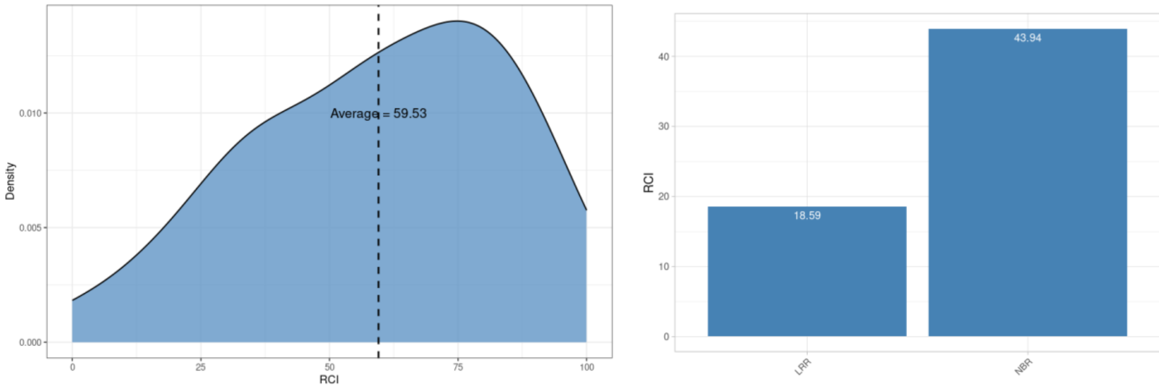

Figure 14. Resilience capacity index in Lower River Region and North Bank Region

The AC and SSN emerge as the primary contributors to household resilience in LRR, collectively accounting for 42% and 22%, respectively. In contrast, in NBR, AC, AST, and

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SSN are the primary contributors to RCI, accounting for 35%, 25%, and 24%, respectively. In both regions, the ABS pillar contributes the least to overall resilience, accounting for 18% in LRR and 16% in NBR (Figure 15). Figure 7 illustrates the disparate significance of the AST pillar in the LRR and NBR. In the LRR, over 75% of households have access to agricultural inputs, including seeds, fertilizers, and pesticides. In contrast, less than 25% of households in the NBR benefit from such inputs. However, NBR households possess greater access to agricultural land, implements, machinery, Tropical Livestock Units (TLU) (a standardized unit used to quantify the livestock owned by a household), and livestock feeds compared to their LRR counterparts.

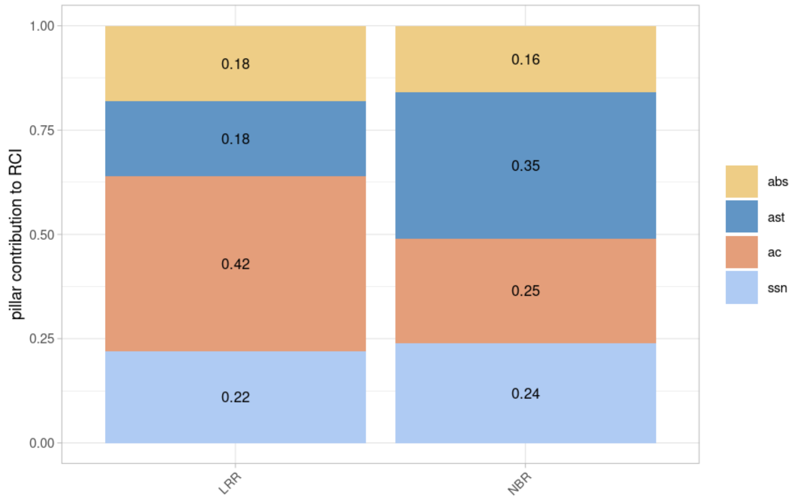

Figure 15. Resilience structure of RIMA pillars in LRR and NBR

As shown in Figure 7, AC plays a more pronounced role in the resilience of households in the NBR compared to the LRR. The proportion of household heads (HH) without formal education is nearly 75% in the NBR, whereas over 50% of household heads in the LRR have received formal education. Both regions exhibit an equal representation of household heads who can read and write, as well as members with the highest levels of formal and non-formal education. Households in LRR demonstrate a greater diversity of income sources, which may indicate enhanced access to financial opportunities, such as loans, contributing to income variability. Furthermore, LRR has superior access to animal vaccination services in comparison to NBR, underscoring the region's more robust agricultural support infrastructure. With regard to ABS, the most pivotal factors are the distance to agricultural markets (or "*lumos*") and health centers (Figure 16).

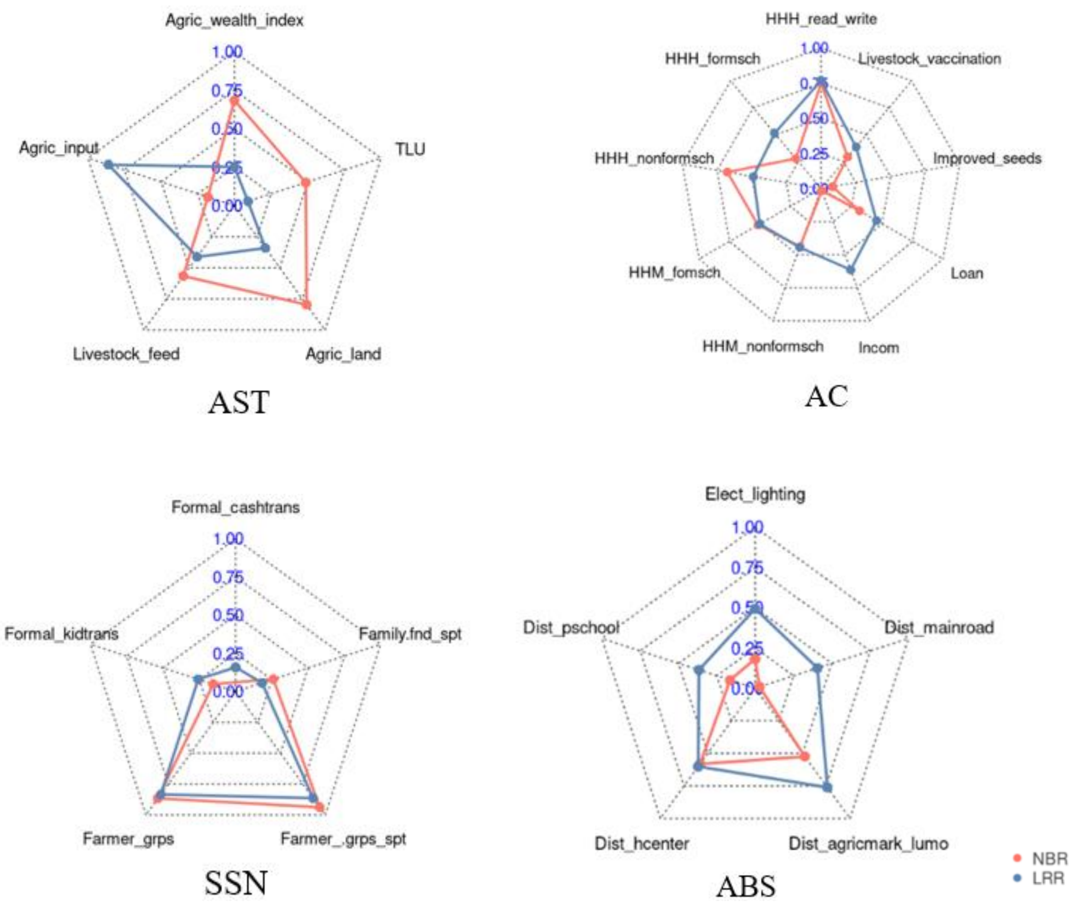

Figure 16. Variable weight in the Resilience (AST, AC, SSN and ABS) pillars

The correlation presented in Figure 16 shows that NBR households generally have worse access to basic services compared to LRR households. LRR households tend to be closer to key services, such as schools, markets, main roads, and health centers, as well as having better access to agricultural markets and electricity for lighting. Over 75% of LRR households have access to agricultural markets, and 50% have access to electricity. In contrast, only about 65% of households in both regions have access to health centers. This comparative advantage in LRR highlights the region's better positioning in terms of ABS.

4.6 Gendered Differences in Agricultural Household Resilience

In Figure 17, female-headed households (FHHs) in NBR and LRR have a higher RCI value of 66.89 compared to male-headed households (MHH), which scored 57.81. Figure 8 presents the contributions of various pillars to the RCI for FHHs and MHHs.

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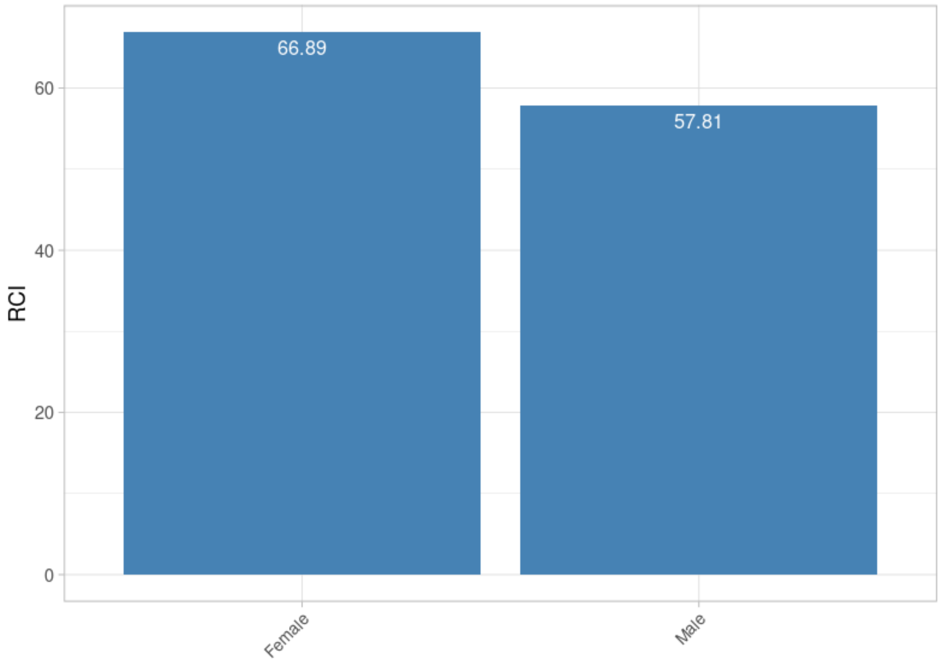

Figure 17. Gendered differences in agricultural household resilience capacity index

AST and SSN are identified as the most significant pillars for female-headed households contributing 48 and 29 % to RCI respectively. For male-headed households, AST at 46 % and AC at 22 % are the main contributors. Additionally, AC is the least contributing factor for FHHs at 11%, while ABS is the lowest for MHHs at 14% (Figure 18).

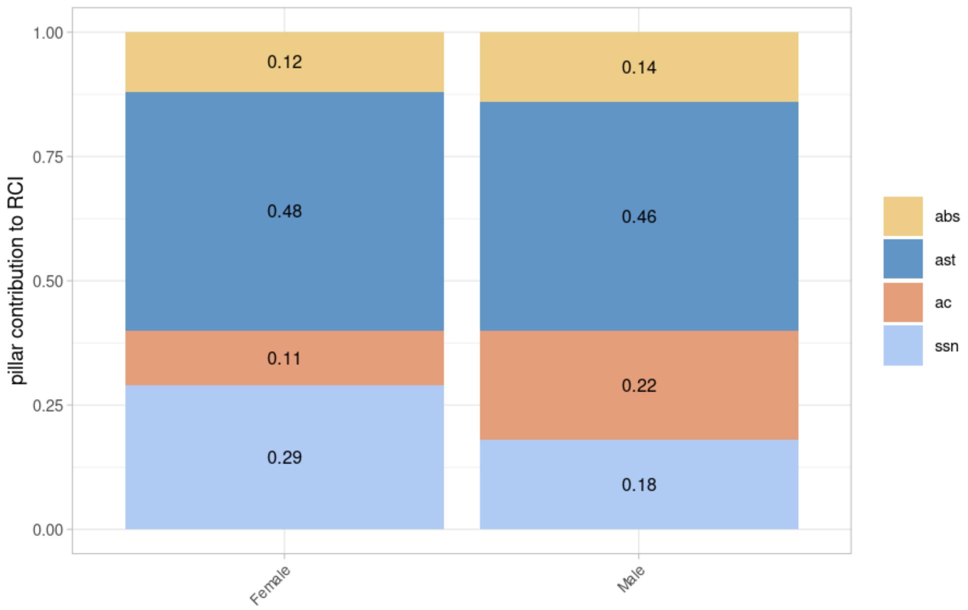

Figure 18. Gendered differences in agricultural household resilience capacity index pillars

As shown in Figure 10, female-headed households demonstrate a more favorable position in accessing essential services such healthcare facilities at more than 75 % and primary schools nearly 75% in term of ABS pillar. The correlation reveals that FHH are generally situated closer to key services, including primary schools, health centers, and main roads, highlighting the accessibility of basic resources in their communities. The AST, as shown in Figure 18, reveals that FHHs have limited access to TLU, agricultural land, and animal feed. Furthermore, FHHs exhibit lower levels of TLU and cultivated land area compared to male-headed households. Male-headed households exhibit a higher level of AC compared to female-headed households, with AC being more influential in explaining the RCI for household members (HHMs) (Figure 19). While FHHs demonstrate higher levels of non-formal education and literacy, HHMs have greater formal education. Additionally, HHMs in FHHs tend to have higher levels of both formal and non-formal education.

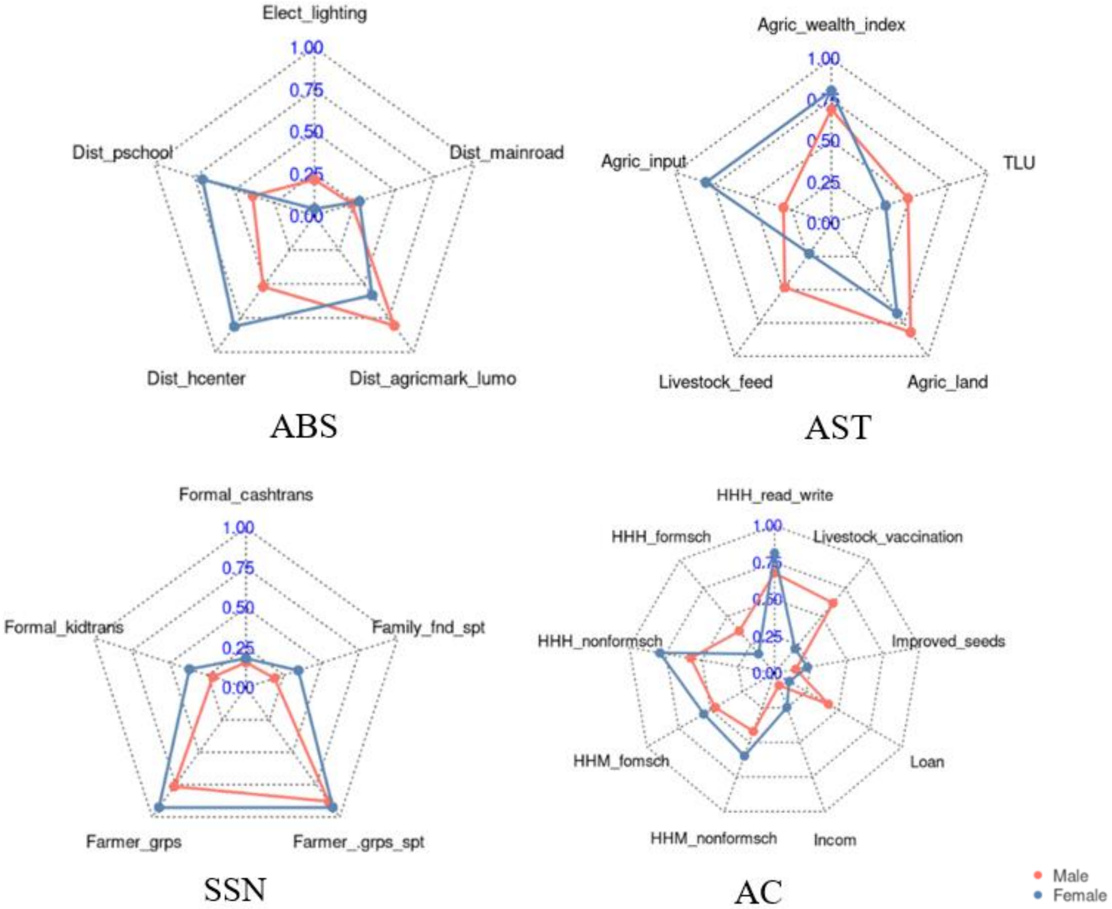

Figure 19. Gendered differences in the ABS, AST, SSN and ABS pillars

The food security indicators used in this study are worried for not having enough food, without eating the whole day and daily expenditure.

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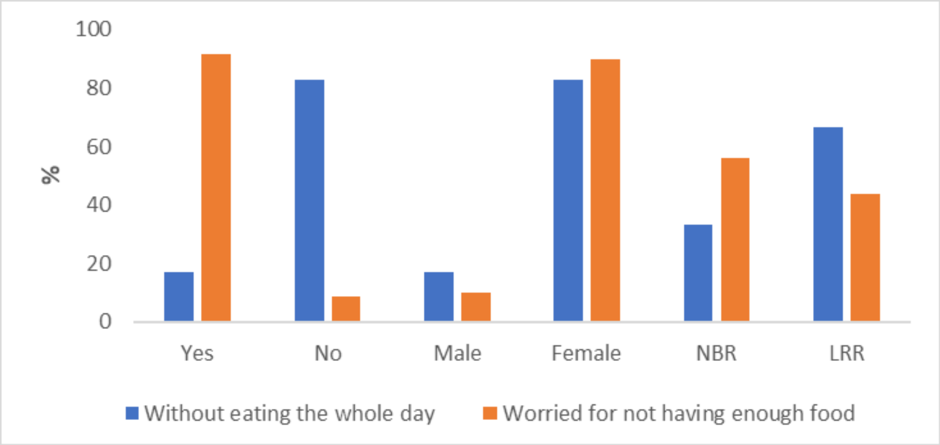

Figure 20. Resilience food insecurity indicators

The results show that more than 80 % of households are concerned about not having enough food and going a whole day without eating (Figure 20). FHHs tend to express greater worry about food insecurity compared to MHHs, with over 80% of FHHs affected, compared to less than 20% of MHHs. Regionally, the NBR recorded the highest level of concern about not having enough food at nearly 60%, while the LRR recorded over 60% of households reporting instances of going an entire day without eating.

5. Discussion

The study highlights widespread vulnerability to climate change impacts among smallholder farmers in the NBR and LRR regions of The Gambia where agriculture is the predominant livelihood strategy for most of the households. In these socio-demographic landscapes, vegetable gardening can enhance resilience, especially for women, but highly vulnerable households, constrained by poor infrastructure and resources, derive minimal benefit from gardening (Yessoufou et al., 2024). Vulnerability is widespread across households, with saltwater intrusion worsening land and water scarcity and compounding climate-induced pressures on households that lack livelihood diversity, similar to observations from past researches in USA, China and Sub-Saharan Africa (Hauer et al., 2021; Rentschler & Salhab, 2020).

The study reveals significant variability in farmers' transformative capacities, reflecting their diverse adaptive responses. Some households employ adaptive strategies such as application of animal manure and lime in their gardens, while others lack the resources or knowledge. Vulnerability to climate change is significantly mitigated by adaptation strategies such as crop diversification and crop rotation, capital (natural and financial), the cultural organizational system, and collective action mechanisms (Atozou, 2023; Amuzu *et al*., 2018; Bene, 2015). Kheiri et al. (2024) observed that a variety of coping and adaptation solutions including changing planting date and weather forecasting can reduce vulnerability. However, the key enablers for effective adaptation include governance, policies, community networks, and social protection (Béné *et al*., 2012). In The Gambia, local political activism has encouraged smallholder farmers to adopt climate-smart agriculture as an adaptation to climate change. However, progress is hindered by persistent barriers such as limited national financial resources and a shortage of climate change experts (Han & Kirabaeva, 2024; Lauer & Eguavoen, 2016).

Financial and knowledge capacity emerge as resilience strengths, with financial capacity moderately consistent across households and knowledge capacity more variable. The Gambia's Climate Change and Vulnerability Strategy reflects the government's commitment to incorporating climate adaptation into national planning (Han & Kirabaeva, 2024). However, current funding of smallholder farmers are insufficient to meet adaptation needs, indicating an urgent requirement for additional funding. Increased technical assistance and knowledge-sharing, particularly on coastal adaptation, could help farmers adopt salt-tolerant crops and sustainable land management practices (O'Donnell *et al*., 2024).

Despite these strengths, weaknesses in social, political, and learning capacities impede collaboration and adaptive learning across socio-demographic divide. Gender roles add complexity to resilience-building, as women contribute significantly to agricultural labor, but are often excluded from agricultural decision-making processes (Wu *et al*., 2015). Limited land rights and access to resources further marginalize women, reducing their adaptive capacity. Political capacity is also constrained by scarce resources, centralized policies, and political interference, which stifles local adaptation (Dimelu & Anyanwu, 2008; Urhibo, 2021).

The regional comparison shows that smallholder farmers in both NBR and LRR have strengths in financial and knowledge capacities, but weaknesses in social, political, and learning capacities. Farmers in NBR shows slightly higher resilience, benefiting from a balance of absorptive, adaptive, and transformative capacities. In contrast, LRR faces greater vulnerability to saltwater intrusion with fewer adaptive resources. Targeted, region-specific interventions that strengthen governance structures and promote community-led learning could better address the challenges of saltwater intrusion. These findings are consistent with Atozou (2023), who reported greater resilience in NBR than LRR, where rural poverty and food insecurity are prevalent due to low rain-fed crop productivity (International Fund for Agricultural Development (IFAD), 2020).

Socio-demographic factors influence gender disparities, with FHHs often showing greater resilience due to social safety nets and transformative capacity, despite challenges in accessing agricultural resources. Men's economic migration often leaves women as primary household managers, making social support networks essential for their resilience. Women's participation in vegetable gardening further increases their resilience by providing food security and income, supporting findings from similar resilience studies in Senegal (FAO, 2017 & 2015).

Food insecurity remains a pressing concern, with many households reporting fears of food shortages, particularly in FHHs where women's income is critical to family nutrition (Quisumbing *et al*., 1996; Sraboni *et al*., 2014). In NBR, fewer households face severe food shortages than in LRR, where prolonged hunger is more common. Empowering women in household decision-making and improving access to rural markets could improve food security by encouraging agricultural investment (Zakari *et al*., 2014). These measures, aligned with The Gambia's National Adaptation Plan (2015) and National Climate Change Policy (Urquhart, 2016), provide a framework for translating research insights into actionable strategies to build resilience and secure sustainable livelihoods.

This study is limited by its focus on 35 rural communities in NBR and LRR regions of The Gambia, which may restrict the generalizability of findings. Data collection in a single season (June 2023) and reliance on self-reported data may have introduced biases and overlooked seasonal variations. The study only focused on saltwater intrusion excludes other climate risks like drought and flooding. Nonetheless, it offers critical insights into smallholder farmers' vulnerabilities and adaptive capacities, guiding future research and policy.

6. Conclusions and Recommendations

This study set out to investigate how saltwater intrusion, an emerging climate change-induced risk, impacts the vulnerability and resilience of smallholder vegetable farming households in The Gambia's North Bank Region (NBR) and Lower River Region (LRR). Using a tailored Composite Index of Climate Resilience (CICR) and the FAO's Resilience Index Measurement and Analysis (RIMA) framework, the findings underscore the multidimensional nature of resilience and reveal critical demographic, regional, and gender-specific disparities.

Saltwater intrusion exacerbates vulnerabilities. Indeed, the results showed that a striking 89% of farmers reported declining crop yield and income attributable to salinization, confirming the pervasive threat posed by saltwater intrusion. The calculated CICR showed an average vulnerability index of –0.12. Despite being close to neutral, the median of –0.22 indicates that most households are leaning toward vulnerability rather than resilience. Both regions demonstrate limited capacities in absorption (–0.34) and adaptation (–0.29), emphasizing the urgent need for interventions aimed at buffering against and adjusting to saltwater intrusion.

In their financial and information capacities, households exhibited relatively high financial (mean of 0.66) and knowledge/information (mean of 0.51) capacities. Over half of them seem to possess either savings or supportive financial mechanisms, and many are well-informed about climate change risks. These positive traits can be leveraged to enhance overall resilience if coupled with improvements in other weaker dimensions.

There are still critical gaps in social, political, and forward-looking capacities. Social/political (–0.34) and anticipative (–0.51) capacities are notably low in both regions, highlighting deficiencies in governance structures, community cohesion, and long-term planning against tidal influences of saltwater intrusion. Learning capacity (–0.46) also emerged as a major gap, underscoring the need for targeted education and knowledge-sharing to foster proactive climate risk management.

In terms of gender and regional disparities, the NBR shows, overall, a higher resilience capacity index (RCI = 43.94) than the LRR (RCI = 18.59), suggesting that region-specific challenges, such as differences in agricultural inputs and geographical exposure, shape resilience outcomes. Female-headed households exhibit stronger access to essential services (e.g., proximity to schools and health centers) and higher financial capacity (0.91), yet they face significant constraints in social/political spheres (–0.51) and agricultural assets.

Conversely, male-headed households have stronger adaptive capacities (e.g., diversified coping strategies) but fare less favorably in financial and knowledge dimensions.

As for food insecurity, it remains a pressing issue: Despite notable differences in access to assets and basic services, more than 80% of all households express concern over food shortages, and many have experienced going a full day without meals. Statistical tests showed limited direct linkage between overall saltwater intrusion vulnerability and the RIMA dimensions, although significant relationships emerged between specific capacities (e.g., absorptive capacity at $p = 0.044$) and food insecurity outcomes.

In sum, this study provides robust quantitative evidence that saltwater intrusion is intensifying vulnerabilities among Gambian smallholder vegetable farmers. While certain capacities—especially financial and knowledge—show promise, critical deficits in social cohesion, governance support, and forward-looking planning remain. Addressing these gaps holistically is imperative for bolstering both short-term food security and long-term adaptation to evolving climate risks.

Building on the findings, the following recommendations are proposed to enhance resilience and reduce vulnerability to saltwater intrusion among smallholder vegetable farmers in The Gambia.

- Strengthening institutional and community networks: Bolster community-based organizations, cooperative societies, and political engagement to improve households' social/political capacity, which was notably low (–0.34). This should lead to more cohesive local governance and participatory decision-making that will amplify farmers' voices in resource allocation and climate adaptation policies.

- Enhancing anticipative and learning capacities by integrating targeted training programs on climate forecasting, early warning systems, and salt-tolerant cropping techniques into existing extension services. This is expected to lead to improved anticipative capacity (currently –0.51) that will enable farmers to plan for future salinity threats, reducing income and yield losses.

- Promoting inclusive asset ownership and input distribution programs, ensuring that female-headed households, despite high financial capacity, can overcome barriers to land, livestock, and other productive inputs. Expected outcome of this action include: Greater equitable access to assets, leading to improved resilience, particularly for female-headed households that show strong potential but remain constrained in agricultural resources.

- Leveraging existing high financial capacity by establishing microfinance schemes, revolving credit funds, and saving associations specifically tailored to agricultural activities exposed to saltwater intrusion. Expected Outcome: Increased liquidity to invest in water management technologies (e.g., shallow tube wells, small-scale desalination) and infrastructure upgrades to mitigate saltwater damage.

- Investing in rural road networks, health facilities, and agricultural input markets, especially in the NBR, which demonstrates higher vulnerability in basic services (ABS =

16%). This should lead to better market access for inputs and produce, improved healthcare utilization, and reduced travel distances will fortify both livelihood and health resilience against future climatic shocks.

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Authors contributions

Prof. Dr. Yacouba Diallo, Dr. Malanding Jaiteh and Mr. Alieu Saidy were responsible for study design. Mr. Alieu Saidy and Mr. Bubacarr Jaiteh were responsible for data collection. Mr. Alieu Saidy and Mr. Adjani Nourou- Dine Yessoufou were responsible for data analysis. Mr. Alieu Saidy, Mr. Adjani Nourou- Dine Yessoufou, Dr. Malanding Jaiteh and Dr. Alpha Kargbo drafted the manuscript. Mr. Alieu Saidy and Mr. Adjani Nourou- Dine Yessoufou revised it. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Macrothink Institute.

The journal’s policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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