Impact of saltwater intrusion on poverty in rural households in the Mekong Delta, Vietnam

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ABSTRACT

Purpose: The purpose of this study is to examine the causal relationship between saline intrusion and poverty in rural households in the Mekong Delta based on the 2018 Vietnam Household Living Standard Survey data.

Design/Methodology/Approach: A sample of 344 rural households in the Mekong Delta is used to analyze the causal relationship between saline intrusion and poverty through income. This study employed the Ordinary Least Squares method and the oprobit model to investigate the causal relationship between saline intrusion and rural household income. Finally, this study estimates the impact of saline intrusion on poverty using different propensity score matching methods.

Findings: 1) Saltwater intrusion has a significant negative impact on the income of rural households, making households more likely to fall into the lower income group; 2) Saltwater intrusion has a greater negative impact on the incomes of poorer households than non-poor households, while also having a negative impact on households with low education and farming; and 3) By reducing household income as well as income from farming activities, infiltration increases the risk of poverty for rural households and reduces the household's ability to escape poverty.

Conclusion: This study demonstrates how saltwater intrusion affects household poverty by reducing income and raising the likelihood that households will fall below the Vietnamese government's designated poverty income threshold.

Keywords: *Impact assessment, Mekong Delta, Oprobit model, Poverty, PSM method, Saltwater intrusion.*

1. INTRODUCTION

Natural disasters have caused global economic losses of about US$2.97 trillion with a total affected population of more than 4.2 billion people in many countries around the world in the first two decades of the 21st century (UNDRR, 2020). The increasing frequency of extreme events as a result of climate change has a significant impact on agricultural production in particular (IPCC, 2022). This poses challenges to the expansion of agricultural production. According to Moore (2020), between 1961 and 2017, anthropogenic global warming reduced the yield of major food crops such as maize, wheat, and rice, and the negative net effect was to reduce 5.7% of global production from these crops.

The poor are more vulnerable to shocks because any impact on their wealth or consumption levels threatens their livelihoods and long-term prospects, and they have fewer resources to mitigate risks or cope with shocks as they occur (Hallegatte, Vogt-Schilb, Rozenberg, Bangalore, & Beaudet, 2020). Poverty is often seen as the primary result of the impact of natural disasters on individuals and households. Poverty caused by natural disasters is always a great challenge to strengthening poverty reduction. The poor, especially in rural areas without active markets, are highly dependent on agricultural income and ecosystems, making them vulnerable to the impacts of natural disasters (Hallegatte et al., 2020). Disasters caused by climate change can directly or indirectly exacerbate poverty and form poverty traps in many ways, especially in less developed countries and regions (Leichenko & Silva, 2014). Thereby, natural disasters directly affect crop production and livelihoods of rural households, threaten income

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sources and living conditions of households, and easily push non-poor households into poverty, while those living in poverty escape from poverty and fall back into it.

Vietnam has made remarkable achievements in poverty reduction and is internationally recognized, with the poverty rate falling sharply from 57% in the early 1990s to 5.2% in 2020 (UNDP, 2021). However, Vietnam is one of the countries most affected by climate change (Espagne et al., 2021). In particular, the Mekong Delta is identified as one of the three deltas most heavily affected by climate change in the world (IPCC, 2007). Over the past three decades, the Mekong Delta has undergone significant geophysical and environmental changes, including ground subsidence, increased tidal levels, and increased saline intrusion (Espagne et al., 2021). The increasingly widespread impacts of climate disasters in recent years have made the effectiveness of poverty reduction and social security policies in Vietnam in general and the Mekong Delta in particular difficult and challenging.

This study examines the impact of a natural disaster, saline intrusion, on rural household poverty in the Mekong Delta, based on data from the 2018 VHLSS. This study contributes to the existing literature by: (1) Improving knowledge about the factors affecting the income of rural households, especially groups of households with different income levels; (2) Examine the heterogeneity of the impacts of saltwater intrusion on the income of rural households between poor and non-poor households, groups of households with different levels of education, different participation status farming livelihoods of households, to improve understanding of the heterogeneous effects of saline intrusion on poverty among rural households; (3) Clarifying the mechanism by which saline intrusion affects the poverty of rural households through income reduction, thereby suggesting policy interventions to reduce the poverty level of households rural families due to saline intrusion.

2. LITERATURE REVIEW

Disasters are characterized by abruptness, urgency, clustering, and concurrency. Natural disasters not only negatively affect households in the area but also cause serious damage to local infrastructure, leading to the collapse of the regional economy and even chaos and social disorder. Therefore, natural disasters often bring unpredictable negative exogenous shocks to individuals or households, affecting the normal course of life and the stable operation of the macroeconomy. The poor living in developing regions are particularly vulnerable to disasters, and vulnerability to disasters is a major barrier to poverty reduction (Ajibade & McBean, 2014) and economic development (Ajibade & McBean, 2014; Sawada, 2007; Skoufias, 2003).

Studies show that natural disasters are part of the reason why households fall into poverty. Research by Bui, Dungey, Nguyen, and Pham (2014) suggests that natural disasters cause direct damage to farmers' assets. When the current asset level falls below a certain threshold, farmers will fall into the "poverty trap," and it will be difficult to get out. Households affected by disasters were 25% more likely to fall into poverty during 2006–2011 in Senegal (Dang, Lanjouw, & Swinkels, 2014). Krishna (2006) found that 44% of households falling into poverty in India cited drought, water loss, or disease as one of the reasons for their loss of income.

Moreover, many studies have demonstrated that after natural disasters, poverty tends to increase and worsen (Bayudan-Dacuycuy & Lim, 2013; Karim & Noy, 2016). Beltrán, Maddison, and Elliott (2018) believe that areas with high disaster rates may experience more severe poverty because poor people prefer to settle in these areas because the cost of living can be lower. The number of poor people in the Philippines also increased by 4–5% after the impact of El Niño in 1997, according to the study by Datt and Hoogeveen (2003). Baez, Caruso, and Niu (2020) also found that experiencing a cyclone, flood, or drought in Mozambique resulted in a 12–17.5% increase in poverty rates. Poverty rates also increased from 41% in 2009 to 63% in 2010 in coastal Bangladesh after being affected by cyclone Aila (Akter & Mallick, 2013). In addition to the immediate post-disaster effects, evidence shows that disasters increase poverty in the medium and long term. Glave, Fort, and Rosemberg (2008) found that one more disaster per year increased poverty rates by 16–23% between 2003 and 2008 in Peru.

In summary, poverty is the main cause of people's vulnerability to natural disasters and other disasters. Therefore, policies that contribute to poverty reduction (if well designed) can be seen as a tool in the disaster risk management toolkit. Based on the above theoretical basis, the study proceeds to develop hypotheses about the impact of saltwater intrusion on poverty in rural households.

Many studies have shown that natural disasters have a negative impact on households income (Arouri, Nguyen, & Youssef, 2015; Bayudan-Dacuycuy & Lim, 2013; Bui et al., 2014). Natural disasters can destroy crops, houses, transport infrastructure, and arable land, thereby affecting crop yields, agricultural sales, and household incomes. The decrease in household income inevitably affects the household's risk of poverty (Walsh & Hallegatte, 2020).

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Given these factors, we propose Hypothesis 1: Saltwater intrusion can reduce household income and increase the risk of poverty in rural households. Disasters not only cause direct damage to the assets of households but also lead to loss of income and large costs of restoring physical assets. Non-poor households often experience higher losses in absolute value of income; however, poor households lose more as a percentage of income as a result of natural disasters, including property damage, loss of income, and costs of restoration and repair (Patankar, 2015). People with low income levels have more difficulty recovering from disasters (Hallegatte et al., 2020). Studies by Erman et al. (2020) find that households that have recovered from a disaster often have a higher median income than households that have not yet recovered. Therefore, Hypothesis 2 arises: Poor households are more severely affected by saline intrusion than non-poor households.

People who are well educated tend to have higher incomes (Belo, Navarro-Pardo, Pocinho, Carrana, & Margarido, 2020). In addition, people with lower education will be more affected by natural disasters than those with higher education (Zhang, Zhang, & Dai, 2022). Compared with the less educated, the well-educated possess more economic and social resources. Those with higher education are better able to cope with the negative effects of disasters, people with lower education will be more affected by natural disasters than those with higher education (Zhang et al., 2022). Compared with the less educated, the well-educated possess more economic and social resources. Those well-educated people are better able to cope with the negative effects of disasters. The effect of saltwater intrusion on household poverty may not be uniform for heads of households with different levels of education. Therefore, Hypothesis 3 arises: the impact of saline intrusion is lower for households where the head of the household has a high level of education than for households where the head of the household has a lower level of education. Hallegatte et al. (2015) argue that disaster shocks to agricultural production and health hinder households from escaping poverty. Most rural households rely on agricultural production for income; however, natural disasters can destroy crops and cause significant damage to households (Huang, Chen, Chen, & Zheng, 2022; Huigen & Jens, 2006). People engaged in farming livelihoods suffer more damage from natural disasters (Miranda & Vedenov, 2001). Compared with households that do not participate in farming livelihoods, natural disasters can be more devastating for households engaged in farming livelihoods. As the damage affects not only financial assets but also household farming livelihoods (Sawada & Takasaki, 2017), ultimately income declines, increasing the risk of poverty. The effects of saltwater intrusion on poverty can also vary depending on the household's status in farming. Based on these factors, we propose Hypothesis 4: Households with a farming livelihood are more heavily affected by saline intrusion than those not engaged in this livelihood.

3. METHODOLOGY

3.1. Data Sources

This study uses data from 344 rural households in the Mekong Delta from the Vietnam Household Living Standard Survey (VHLSS) Dataset 2018, which investigates the details of individuals and families. The wide sampling range and scientific sampling method helped ensure a representative sample by collecting personal information, such as date of birth, gender, marital status, household registration, and health status, as well as household information, such as income, expenditure, livelihood activities, and household size.

3.2. *Variable Definition and Descriptive Statistics*

3.2.1. *Dependent Variable*

This paper uses the dependent variable to measure the level of household poverty, including income. In Vietnam, income is an important criterion to determine if a household is poor if it is below the standard set by the government. Therefore, the lower the income, the higher the risk of household poverty. In this study, we used a household's one-year income to measure, and since the value of income is relatively large, we used the natural logarithm of income.

In addition, to confirm the reliability of the analysis results on the impact of saltwater intrusion on poverty, we use an alternative measure of household income, which is the quintile of households. Since the poor households in the VHLSS have been proportionally identified in each sampled area, the use of the income quintile will assess poverty more clearly than the income or poverty-dependent variable.

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3.2.2. Explanatory Variable
The core explanatory variable in this study is saline intrusion. In Vietnam, salinity intrusion is defined as a natural disaster when the concentration threshold is 4 g/l or more, as prescribed by the Government of Vietnam. Based on the average 4 g/l salinity boundary map for many years in the Mekong Delta, we build the first core explanatory variable (salt_d) to represent the occurrence level of saline intrusion, specifically: salt_d = 1 is the household that regularly suffers from saltwater intrusion at 4 g/l, and salt_d = 0 is the household with seldon saltwater intrusion at 4 g/l. On the other hand, we have built a second salinity intrusion variable (salt_n) to measure the intensity of saline intrusion based on the average maximum salinity value measured in the dry seasons of 2014, 2016, and 2018 that the household has experienced.

3.2.3. Control Variables and Variable Statistics in the Model
To alleviate the endogeneity problem caused by omitted variables, we controlled for a range of variables at the household level, including ethnicity, household size, labor force, dependency ratio, the proportion of male workers, the highest educational level of laborers in the household, the average age of labor, and whether the household participates in farming livelihoods or not.

Table 1. Descriptive statistics of variables.

Variable	Variable description	Mean	Standard deviation
Income	Household income (million VND)	150.43	303.07
Salt_d	Dummy variable:value 1 if the household is regularly salted at 4 g/l; value 0 otherwise.	0.34	0.48
Salt_n	Highest salinity of the average dry season 2014, 2016, and 2018 that the household experienced	7.07	5.97
Ethnicity	Dummy value 1 if ethnic Kinh, value 0 if ethnic minority	0.86	0.35
Familysize	Number of members in the household (person)	3.45	1.57
Labour	Number of household members engaged in any type of livelihood (person)	2.18	0.95
Gender	Average percentage of male workers in the total labor force of the household (%)	52.39	28.90
Education	Highest degree of labor force in the household (1=illiteracy or no degree, 2=primary, 3=secondary, 4=high school, 5=college, university)	2.60	1.22
Age	Average age of a household's labor force	46.28	11.53
Farming	Household has income from farming activities (yes or no)	0.77	0.42
Farming income	Total income from farming activities of households (million VND)	43.84	194.74

Descriptive statistics of the variables used in the article are presented in Table 1, in which it can be seen that the average income of rural households is 150.43 million Vietnam dongs (VND) per year, the average intensity of saline intrusion is 7.07 g/l, and the average size of a household is 3.45 people, with 2.18 people with an average age of 46.28 years engaged in income generation. The percentage of households in the observed sample engaged in farming livelihoods is 77%.

3.3. Econometric Models
Statistical analysis was performed using Statistics and Data Science software (STATA). We report the mean and standard deviation of the variables in Table 1. Econometric modeling was performed to investigate the impact of saline intrusion on rural household poverty in the Mekong Delta through the dependent variable, household income in the year. Since income is a continuous variable, the Ordinary Least Squares (OLS) was constructed to investigate the causal relationship between saline intrusion and rural household income. In addition, we use the oprobit model to analyze the impact of saltwater intrusion on rural household poverty because the hierarchical dependent variable is made up of the quintile of household income. In testing our confidence level, we estimated the impact of saline intrusion on poverty using Propensity Score Matching (PSM) to calculate the mean effect of the treatment on subjects, which was interfered with Average Treatment Effect on the treated (ATT) by different propensity score matching methods.

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This paper not only investigates the effects of saline intrusion on rural household poverty but also examines the heterogeneous effects and mechanisms of saline intrusion on poverty. To investigate the impact mechanisms of saltwater intrusion, we estimate the impact of saltwater intrusion on farming livelihood and household head education using a probit model. In addition, we clarify the impact of saline intrusion on the income from farming activities of rural households using OLS linear regression.

3.3.1. Multiple Linear Regression Model

For the dependent variable, income, this study uses a multiple linear regression model to examine the impact of saline intrusion on household income. The OLS method was used to estimate the coefficients of the model. Two models are used, as follows:

$$Y_i = \alpha_i + \beta_1 salt\_d + \beta x + \varepsilon_i \quad (1)$$

$$Y_i = \rho_i + \beta_2 salt\_n + \lambda x + \mu_i \quad (2)$$

Where Y_i represents the dependent variable, which is the household's income (natural logarithm of income); α_i and ρ_i are the base coefficients to estimate the model; salt_d and salt_n are the core explanatory variables and reflect the occurrence and intensity of saline intrusion, respectively; x represents the control variables as ethnicity, household size, labor force, proportion of male workers, education level, working age, and whether the household participates in farming livelihood or not; ε_i và μ_i are random errors to estimate the model.

3.3.2. Ordinal Probit Model

For the dependent variable, which is the quintile of income, the oprobit model is chosen to estimate the impact of saltwater intrusion on the poverty of rural households through the probability of belonging to the household's income groups. The original model is as follows:

$$Y_i^* = X_i'\beta + u_i \quad (3)$$

$$Y_i = j \text{ nếu } \omega_{j-1} < Y_i^* \leq \omega_j$$

The model used is as follows:

$$P_{ij} = P(Y_i = j) = P\left(\omega_{j-1} < Y_i^* \leq \omega_j\right) = F\left(\omega_j - X_i'\beta\right) - F(\left(\omega_{j-1} - X_i'\beta\right) \quad (4)$$

Where Y_i represents the dependent variable, is the income quintile of the household, with j = 5 income groups ranked from low to high (from 1 to 5); X is a set of variables, including salt_d and salt_n are the core explanatory variables and reflect the occurrence and intensity of saline intrusion, respectively, x represents the control variables as ethnicity, household size, labor force, proportion of male workers, education level, working age, and whether the household participates in farming livelihood or not; P_{ij} is the probability that the ith household will be in the jth income group; F is the probability density function of the variable X.

3.3.3. Propensity Score Matching Method (PSM)

Propensity Score Matching (PSM) is used to correct possible selection errors. First, the probit model was used to estimate the propensity score of each group based on the observed variables. Second, this study used four methods to match two groups, including k-nearest neighbor matching, local linear matching, radius matching, and kernel matching. If the result estimates obtained by the above matching methods are consistent, the estimated results are determined to be certain and reliable. The two groups are compared, namely the group of households with frequent saline intrusion at 4 g/l (treatment group) and the group of households with occasional saline intrusion at 4 g/l (control group).

Finally, on the basis of matched samples, we calculate the mean therapeutic effect (ATT).

$$ATT = E(Y_{1i}|salt\_d = 1) - E(Y_{0i}|salt\_d = 1) \quad (5)$$

Where $salt\_d$ is the core explanatory variable reflecting the occurrence of salinity intrusion; Y_{1i} and Y_{0i} are the incomes of rural households, respectively, when the sample group is regularly affected by saline intrusion at 4 g/l and when the sample group is not regularly affected by saline water intrusion at 4 g/l, respectively.

4. RESULTS

4.1. Regression Results

Table 2 reports the estimated impact of saline intrusion on rural household poverty through household income. Columns (1) and (3) only include the assumption about the extent of saltwater intrusion and the intensity of saline intrusion, respectively, and do not include other control variables. The estimated coefficients of the two core

explanatory variables are -0.313 and -0.025, respectively. Both are negative at the 1% significance level, indicating that saline intrusion has a significant negative impact on household income.
A set of control variables affecting household income is included in columns (2) and (4), but the estimated coefficients of the impact and intensity of saltwater intrusion on household income still have a negative connotation. This indicates that saline intrusion is an important predictor of rural household income by negative correlation. The above results are in agreement with Hypothesis 1.
In addition, when analyzing the estimated coefficients for the control variables, we find that household size has a positive sign at the 1% significance level. This shows that the larger the household size, the higher the income source. The same positive effect is also found in the household labor force variable. This means that the more members a household has engaged in livelihood activities, the more income it generates. Results for education level report positive signs, showing that education has a positive impact on household income. If the education level of the laborers in the household is higher, it will provide a better source of income for the household.

Table 2. Present OLS results on the effects of saline intrusion on rural household poverty: natural logarithm of income-dependent variable.

Variable	**Dependent variable: natural logarithm of income**			
	(1)	**(2)**	**(3)**	**(4)**
	OLS	**OLS**	**OLS**	**OLS**
Salt_d	-0.313***	-0.282***	-	-
Salt_n	-	-	-0.025***	-0.021***
Ethnicity	-	0.163	-	0.157
Family size	-	0.138***	-	0.134***
Labor	-	0.190***	-	0.198***
Gender	-	0.176	-	0.175
Education	-	0.200***	-	0.203***
Age	-	-0.002	-	-0.001
Farming	-	0.097	-	0.065
Constant	11.517***	9.870***	11.591***	9.927***
Observations	344	344	344	344
F test	9.95***	27.69***	10.75***	27.53***
Adjusted R2	0.025	0.384	0.028	0.382

Note: *** is significant at the 1% level.

When investigating the causal relationship between saline intrusion and rural household poverty, the high correlation between the variables raises concerns about multicollinearity, which can lead to significant bias in estimates. We use the Variance Inflation Factor (VIF) to check for multicollinearity in our model. Table 3 reports the VIF of each variable. In each case, the VIF is less than the rule of thumb value by 10, indicating that the model does not have a multicollinearity problem.

Table 3. Coefficient of exaggeration of variance for each variable.

Variable	**VIF**	**VIF**
Ethnicity	2.12	2.12
Familysize	1.73	1.72
Labour	1.31	1.30
Gender	1.24	1.24
Education	1.19	1.20
Age	1.15	1.18
Farming	1.06	1.09
Salt_d	1.05	-
Salt_n	-	1.05
Mean VIF	1.36	1.36

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4.2. Endogeneity

4.2.1. Estimate by propensity score matching method

The study sample may have endogenous selection problems because households choose their place of residence according to the natural environment, climate, and soil characteristics. Referring to existing research (Yang, Xu, Xie, Sohail, & Gong, 2023; Zhang et al., 2022), we used propensity score matching (PSM) to reduce this source of bias. We use a dummy variable equal to 1 if the household regularly suffers from saline intrusion at 4 g/l (treatment group) or 0 otherwise (control group).

This study uses two methods to test the covariate balance of the two groups. First, we compare the mean (after matching) of the observable covariates between the treatment and control groups. Second, we test the propensity scores of the treatment and control groups in the same range after matching.

Table 4 shows the mean values of the observed covariates in the two groups. In column 5, the results show that a p value (after matching) of more than 0.1 shows that there is no systematic difference between the treatment group and the control group after matching.

Table 4. Balance test between treatment group and control group.

Variable	Matching status	Mean		T-value	p-Value
		Treatment	Control		
Ethnicity	Before	0.780	0.898	3.018	0.003
	After	0.780	0.712	1.19	0.233
Family size	Before	3.593	3.376	-1.219	0.224
	After	3.593	3.390	0.97	0.333
Labor	Before	2.161	2.186	0.230	0.818
	After	2.161	2.229	-0.58	0.565
Gender	Before	55.212	50.914	-1.310	0.191
	After	55.212	56.836	-0.45	0.650
Education	Before	2.475	2.664	1.370	0.172
	After	2.475	2.661	-1.24	0.216
Age	Before	46.526	46.145	-0.290	0.772
	After	46.526	46.775	-0.17	0.867
Farming	Before	0.729	0.792	1.323	0.187
	After	0.729	0.780	-0.90	0.366

In addition, the probability density histograms of propensity scores before and after matching (Figures 1, 2) show that the propensity score values of both the treatment and control groups intersect and are within the range after matching. This illustrates the effectiveness of using propensity score matching.

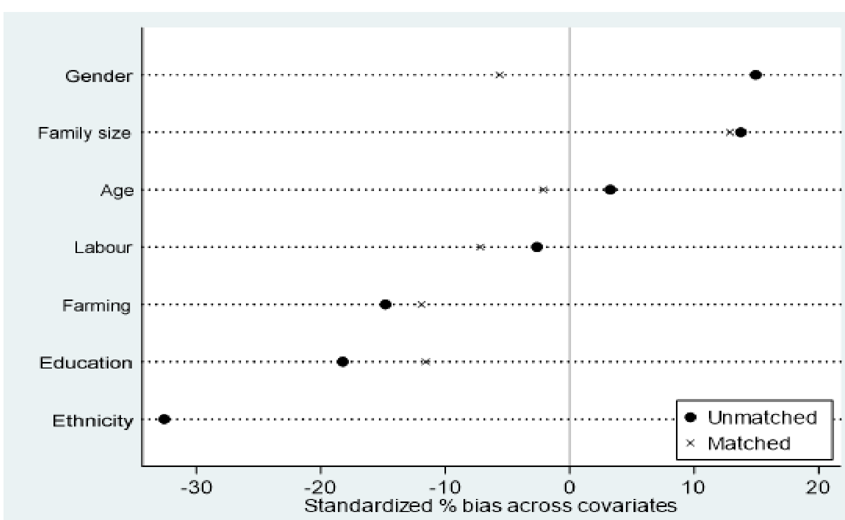

Figure 1. Normalized deviation before and after matching.

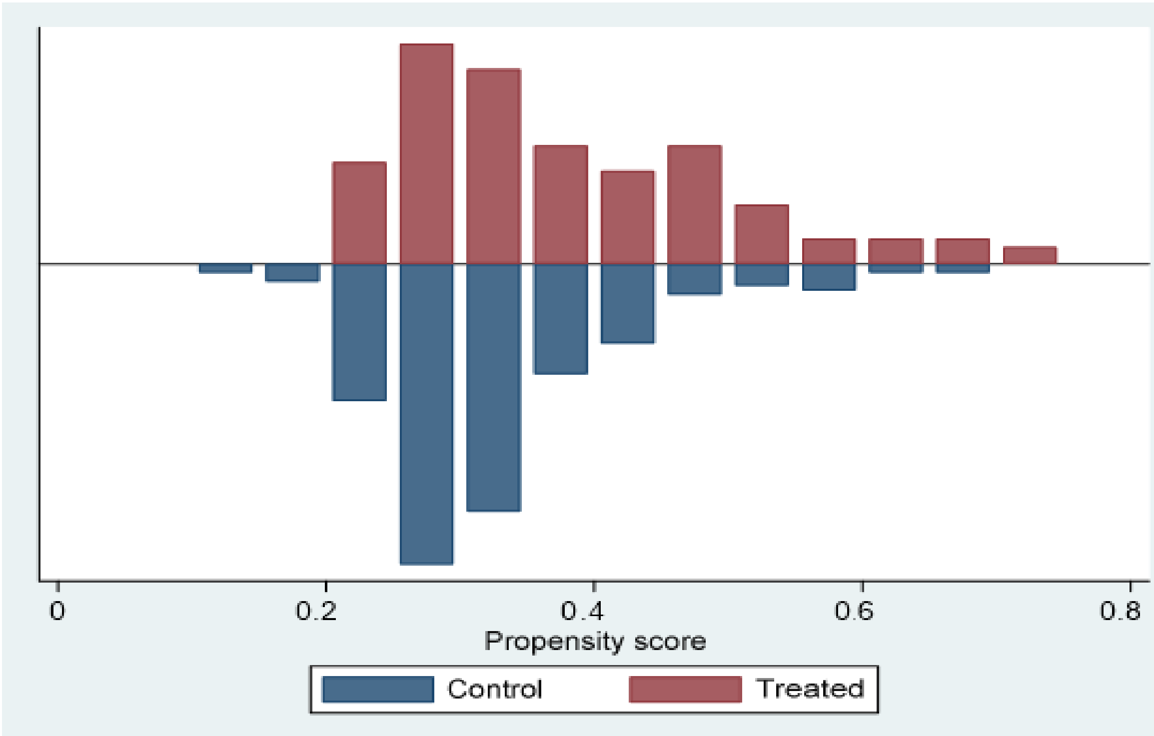

Figure 2. Distribution of general trend points and support zones.

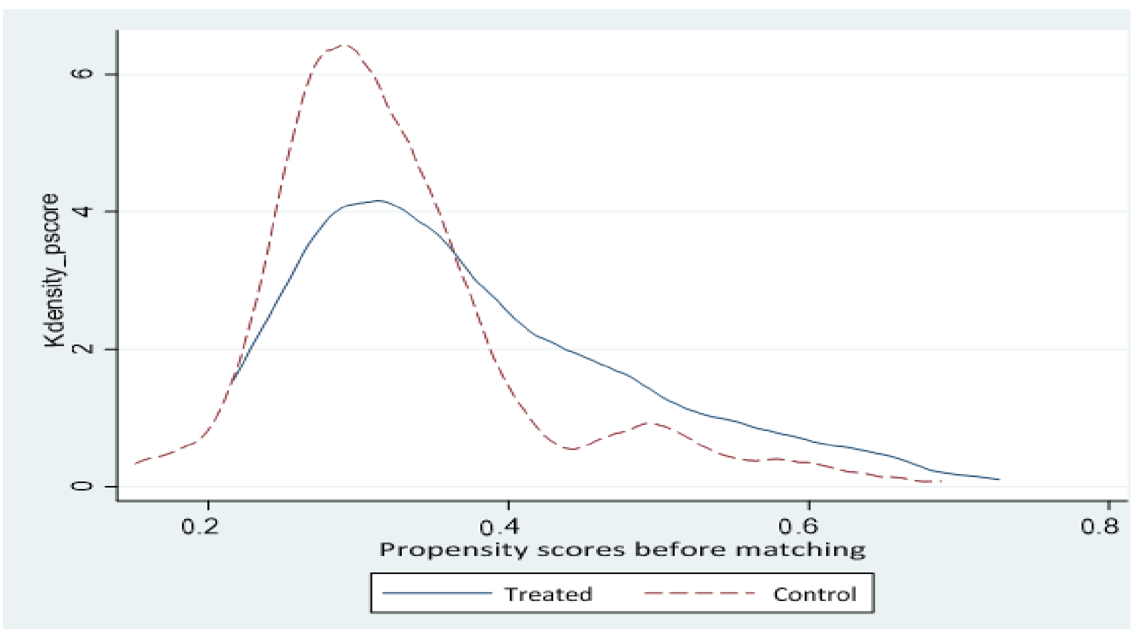

Figure 3. Density distribution of propensity scores (Before matching).

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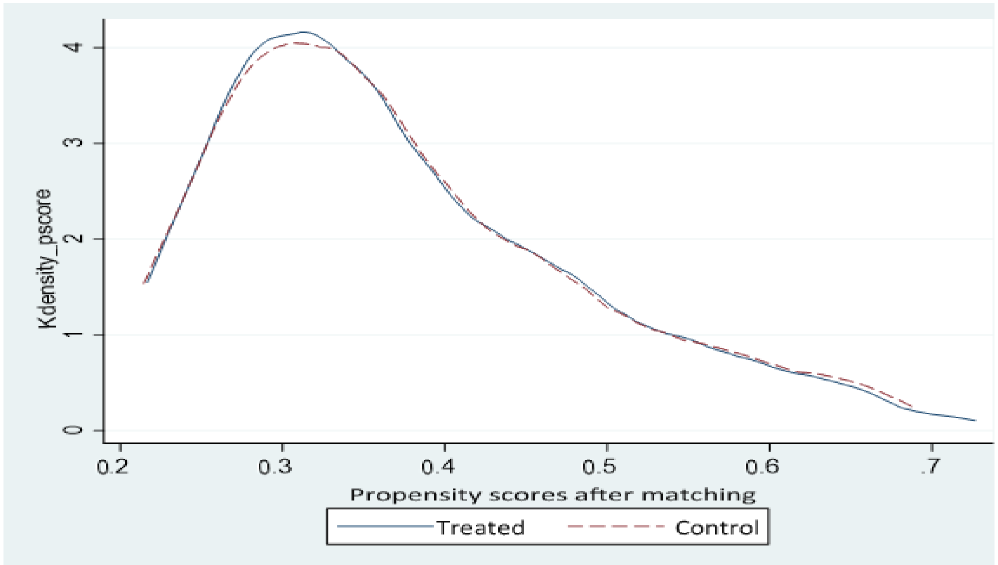

Figure 4. Density distribution of propensity scores (After matching).

An important step in applying PSM is to check for Overlap and general areas of Support between the treatment and control groups (Heckman, Ichimura, & Todd, 1997). Figures 3 and 4 report density distribution estimates in the two groups before and after matching, showing that most of the samples fall in the general support region after matching.

Building on existing research (Yang et al., 2023; Zhang et al., 2022), this paper presents different types of score matching estimators, including Kernel matching, local linear matching, radius matching, and nearest neighbor matching (k = 1, k = 4). Table 5 presents the impact of saline intrusion on household income, obtained using the propensity score matching method. The results show that the average treatment effect on the treatment of the different combined methods is both negative and significant, showing a negative correlation between saline intrusion and income in our sample. This is consistent with the above estimates, which show that natural disasters have a significant negative impact on rural household income and lead to an increased risk of household poverty.

Table 5. PSM estimation of the impact of saltwater intrusion on rural household income.

Variable	Before matching	Kernel Matching	Local Linear Matching	Radius Matching	Nearest Neighbor Matching (k=1)	Nearest Neighbor Matching (k=4)
Salt_d	-0.313*** (0.099)	-0.225*** (0.105)	-0.207* (0.157)	-0.313*** (0.086)	-0.277** (0.157)	-0.250*** (0.113)
Observations	337	337	337	337	337	337

Note: ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

4.2.2. Substitute a Dependent Variable

In the above model, the dependent variable, which measures household poverty through the income variable, is continuous. We then set up an alternative measure as the quintile dummy of the income variable, which is a hierarchical variable with a value between 1 and 5. If household income is in the smaller quintile compared to the rest of the quintiles in the data, that family is considered to have a relatively high degree of poverty and is coded 1. Households with higher income levels will be encoded in higher hierarchical groups as 2, 3, 4, and 5. We then use the oprobit model to examine the impact of saline intrusion on household poverty levels. As shown by the estimated results in Table 6, the coefficients for the estimation of the occurrence and intensity of saline intrusion for the household income quintile have a negative significance, indicating that saline intrusion puts households at risk of falling into the lower income group, which is consistent with the OLS results of Table 2. These results better illustrate the conclusion that saline intrusion significantly negatively affects the poverty of rural households.

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Table 6. Oprobit results on the effects of saltwater intrusion on rural household poverty: The quintile-dependent variable of income.

Variable	The quintile-dependent variable of income			
	(1)	(2)	(3)	(4)
	Oprobit	Oprobit	Oprobit	Oprobit
Salt_d	-0.329***	-0.384***	-	-
Salt_n	-	-	-0.028**	-0.030***
Ethnicity	-	0.324*	-	0.314*
Family size	-	0.262***	-	0.257***
Labor	-	0.368***	-	0.378***
Gender	-	0.308	-	0.309
Education	-	0.364***	-	0.367***
Age	-	-0.001	-	-0.000
Farming	-	0.214	-	0.171
Observations	344	344	344	344
Log likelihood	-549.894	-444.995	-549.282	-445.195
LR chi2	7.49*	217.29***	8.72***	219.94***
Pseudo R2	0.007	0.196	0.008	0.196

Note: ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

In addition, the results from Table 6 also show a positive correlation between ethnicity and income compared to the results in Table 2, which do not show any significant correlation. This shows that, although there is no significant effect on income, ethnic characteristics have an influence on the income distribution of households in the community. If households belong to the Kinh ethnic group, the probability of being in the low-income group will be lower than that of the Khmer ethnic group, which means that the poverty risk of Kinh households will be lower.

4.3. Heterogeneity

To better understand the relationship between saline intrusion and rural households, we examine the heterogeneity of the effects by dividing the sample into poverty, education, and different farming livelihoods.

First, the study divided the sample into two groups with different poverty statuses. The poverty dummy variable is built with a value of 1 if the household has been poor in the last 5 years (from 2014 to 2018) and zero if it has never been poor in the above period. The results of OLS estimation in Table 7 show that the income level of poor households is reduced more due to the impact of saltwater intrusion compared to non-poor households. This result is consistent with Hypothesis 2: that poor households in rural areas are more vulnerable to the adverse effects of climate change, leading to greater resilience and affecting their ability to escape poverty.

Table 7. Heterogeneous effects of saltwater intrusion by household poverty.

Variable	Poverty		Poverty	
	Yes	No	Yes	No
Salt_d	-0.535***	-0.171**	-	-
Salt_n	-	-	-0.039***	-0.013*
Control variable	Yes	Yes	Yes	Yes
Constant	10.281***	10.503***	10.455***	10.534***
Observations	59	285	59	285
Adjusted R2	0.434	0.328	0.424	0.327

Note: ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively.

To test Hypothesis 3, Table 8 presents the results of the heterogeneous effects of saltwater intrusion on household incomes where the heads of households have different levels of education. The dummy variable is constructed with a value of 1 if the head of the household has a low level of education (illiteracy or no degree) and a value of 0 if the head of the household has a higher education (with a degree from primary school). The results show that

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highly educated household heads cope better with saltwater intrusion than less educated household heads. These results confirm Hypothesis 3.

Table 8. Heterogeneous effects of saltwater intrusion by education level of household head.

Variable	Education		Education	
	Low	High	Low	High
Salt_d	-0.408***	-0.264**	-	-
Salt_n	-	-	-0.029***	-0.202**
Control variable	Yes	Yes	Yes	Yes
Constant	10.236***	10.669***	10.322***	10.718***
Observations	152	192	152	192
Adjusted R2	0.532	0.210	0.522	0.208

Note: ***, and ** are significant at the 1%, and 5% levels, respectively.

To test Hypothesis 4, we introduce a dummy variable to measure the status of a household's farming livelihood. The dummy value is equal to 1 if the household is engaged in farming as a livelihood; otherwise, it is 0. Table 9 reports the impact of saltwater intrusion, taking into account the status of the family's farming livelihood. The results indicate that households that participate in farming livelihoods will have a worse response to saltwater intrusion than those that do not. The results in Table 9 test Hypothesis 4.

Table 9. Heterogeneous effects of salinity intrusion by household farming livelihood status.

Variable	Farming		Farming	
	Yes	No	Yes	No
Salt_d	-0.355***	0.0723	-	-
Salt_n	-	-	-0.295***	-0.004
Control variable	Yes	Yes	Yes	Yes
Constant	9.936***	9.873***	10.007***	9.856***
Observations	265	79	265	79
Adjusted R2	0.354	0.420	0.354	0.419

Note: *** is significant at the 1% level.

In addition, to further test the heterogeneous effects of saline intrusion on the farming livelihoods of rural households, we use the OLS method to regress the impact of saline intrusion on the farming income (natural logarithm treatment) of the household. The results in Table 10 show that the negative impact of saltwater intrusion on farming income is higher than total household income. This further reinforces the hypothesis that farming is a livelihood activity heavily affected by saline intrusion in rural areas.

Table 10. OLS results on the effects of saltwater intrusion on household farming income.

Variable	Dependent variable: natural logarithm of farming income			
	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	OLS
Salt_d	-0.684***	-0.694***	-	-
Salt_n	-	-	-0.068***	-0.070***
Ethnicity	-	-0.170	-	-0.233
Family size	-	0.152*	-	0.140*
Labor	-	0.190	-	0.210
Gender	-	0.259	-	0.254
Education	-	0.158*	-	0.167*
Age	-	0.003	-	0.005
Constant	9.800***	8.257***	10.019***	8.429***
Observations	265	265	265	265
F test	11.06***	5.27***	16.34***	6.18***
Adjusted R2	0.037	0.102	0.055	0.121

Note: ***, * are significant at 1%, 10%, respectively.

In summary, starting from the difference in households, we have considered the heterogeneity of saline intrusion between the poor and the non-poor group, the different educational attainment, and the status of livelihood participation in household farming. This is beneficial for understanding the heterogeneous impact of saline intrusion on household poverty across income levels. The findings show that poor households experience a larger loss of income due to the effects of saline intrusion than non-poor households. This is consistent with the study by Patankar (2015) on the extent of the impact of natural disasters on the income of poor and non-poor households. Heads of households with higher education are better able to cope with saltwater intrusion, and therefore the income of households affected by saline water intrusion is less than that of households with low education levels, similar to the research results by Zhang et al. (2022). Saline intrusion reduces household income from farming production, resulting in the total income of households engaged in farming production being affected more than those not engaged in farming livelihood.

At the same time, this study theoretically analyzed the role of household income on the impact of saltwater intrusion on household economic status and examined the corresponding mechanism, providing empirical evidence to understand the mechanism by which saline intrusion affects household poverty. The results of the mechanism analysis show that saline intrusion can reduce household income and, at the same time, increase the risk of falling into the lower income group of rural households, thus increasing the probability of poverty for households affected by salinity. This result is consistent with the findings of Arouri et al. (2015) and Zhang et al. (2022) on the impact of natural disasters on household income.

5. CONCLUSIONS

Given the importance of reducing poverty in countries facing extreme events caused by climate change, research on the impact of saltwater intrusion on poverty is an important topic. In this paper, we investigate the causal relationship between saline intrusion and poverty through the income of 344 rural households in the Mekong Delta from VHLSS 2018. One of the most important findings emerging from this paper is that saltwater intrusion has a negative impact on household income as well as an increased risk of falling into lower income groups. This shows that saltwater intrusion has an impact on household poverty by reducing income and increasing the risk of falling below the poverty income threshold set by the Government of Vietnam.

Further analysis of heterogeneous effects was performed by subdividing the sample by poor household population, education level, and household production status. On the one hand, the results show that poor households suffer more income loss due to saline intrusion than non-poor households. That makes the ability of poor households to recover and escape poverty in the context of natural disasters even more difficult. In addition, the results also show that saltwater intrusion has stronger negative effects on household heads with lower education than on household heads with higher education. On the other hand, compared with households that are not engaged in farming production, the income of households engaged in farming production is more negatively affected by saline intrusion.

The following policy implications can be drawn from the study results: Firstly, saline intrusion has a significant negative impact on the poverty of rural households through a reduction in household income, while poor households also experience a decrease in income due to more saline intrusion than non-poor households. Therefore, it is necessary to focus on ensuring social security and policy support for affected groups to reduce the loss of household income, help affected households compensate for their income, and reduce the gap between the rich and the poor and between the poor and the non-poor. Second, our findings show that education will reduce the negative impact of saltwater intrusion on household income, so improving the level of education for households in rural areas, especially poor households, is extremely important for sustainable poverty reduction policies and disaster risk management. Third, our findings suggest that farming is a livelihood activity heavily affected by saline intrusion. Households engaged in farming livelihoods are more susceptible to damage, yield reduction, and farming failure due to the influence of salinity. Therefore, the government should focus on solving the livelihood difficulties of rural households in areas affected by saline intrusion through supporting policies on varieties, farming techniques, fertilizers, and other inputs to improve productivity. At the same time, salt-affected areas need to plan crops or change livelihoods in accordance with regular saline intrusion in order to limit risks and reduce the dependence of livelihoods on climate and soil conditions. It is important for the government to increase investment in infrastructure to prevent salinity, improve prevention and response, and strengthen early warning of saltwater intrusion, as well as take measures to prevent and mitigate salinity intrusion for households in areas

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frequently affected by saline intrusion, especially poor households. This will prevent individuals from falling into the poverty trap because of reduced income due to saline intrusion.

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INSTITUTIONAL REVIEW BOARD STATEMENT
The Ethical Committee of the Vo Truong Toan University, Vietnam has granted approval for this study on 10 April 2023 (Ref. No. 103A/QD-DHVTT).

TRANSPARENCY
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

COMPETING INTERESTS
The authors declare that they have no competing interests.

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