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Potential impacts of climate change on agricultural production in the Long Xuyen Quadrangle, Vietnamese Mekong Delta

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ABSTRACT: Climate change and its impacts have become a serious and concerning global issue. The Vietnamese Mekong Delta, is identified as one of the deltas most adversely affected by climate change. This study aims to assess the potential impacts of climate change on seven major agricultural production systems in the Long Xuyen Quadrangle region within the Vietnamese Mekong Delta. Utilizing the Analytic Hierarchy Process (AHP) in conjunction with calculating climate change impact indices, the research classifies the degree of climate change impact on agriculture, aquaculture and forestry. The study results indicate that different agricultural production systems will experience varying impacts from climate change. For rice cultivation, flooding and drought are identified as the factors with the highest impact. Factors such as temperature increase, changes in rainfall and salinity intrusion have the most significant effects on aquaculture. In contrast, cultivated and natural forests in the research area are less affected by climate change. This assessment outcome could be highly valuable for policymakers in developing local agricultural development plans.
Keywords: climate change effects; land use; rice cultivation; saline intrusion.

Impacto potencial das alterações climáticas na produção agrícola no Quadrilátero Long Xuyen, Delta vietnamita do Mekong

RESUMO: As alterações climáticas e os seus impactos tornaram-se uma questão global séria e preocupante. O Delta vietnamita do Mekong é identificado como um dos deltas asiáticos mais afetados pelas alterações climáticas. Este estudo visa avaliar os impactos das alterações climáticas em sete grandes sistemas de produção agrícola na região do Quadrilátero Long Xuyen, no Delta do Mekong, Vietnã. Utilizando o Processo de Hierarquia Analítica (AHP), em conjunto com o cálculo dos índices de impacto das alterações climáticas, a investigação classifica o grau de impacto das alterações climáticas na agricultura, aquicultura e silvicultura. Os resultados do estudo indicam que diferentes sistemas de produção agrícola sofrerão impactos variados das alterações climáticas. Para o cultivo do arroz, as inundações e a seca são identificadas como os fatores de maior impacto. Fatores como o aumento da temperatura, as mudanças nas chuvas e a intrusão de salinidade têm os efeitos mais significativos na aquicultura. Em contraste, as florestas cultivadas e naturais na área de investigação são menos afetadas pelas alterações climáticas. O resultado desta avaliação poderá ser altamente valioso para as decisões políticas no desenvolvimento de planos de desenvolvimento agrícola local.
Palavras-chave: efeitos das alterações climáticas; uso da terra; cultivo de arroz; intrusão salina.

1. INTRODUCTION

Climate change (CC) has become a serious and concerning global issue, affecting not only natural conditions such as water sources (HUYEN et al., 2017; SÁ et al., 2018), air pollution (ALALLAWI et al., 2023) and soil erosion (ANACHE et al., 2018) but also negatively impacting various aspects of human life (BLACK, 2009). According to the Intergovernmental Panel on Climate Change (IPCC), climate change manifestations, such as temperature increase, rainfall variations, increased extreme weather events, and rising sea levels, threaten the daily lives of communities worldwide, posing the risk of pushing people into poverty (SOLOMON, 2007).

Agricultural production is considered one of the most vulnerable sectors to climate change (REILLY et al., 1996). Unpredictable natural events such as temperature rise, droughts, floods, and unpredictable weather changes have affected not only productivity but also the stability of agriculture (ANWAR et al., 2013). Studies indicate that climate change, both globally and in Vietnam, has become more severe in recent decades (SOLOMON, 2007; ADB, 2009). This exacerbates the negative impacts on agriculture - a sensitive sector to natural changes.

A World Bank report highlighted the vulnerability of the Vietnamese Mekong Delta (VMD), ranking it among the top three deltas globally susceptible to the impacts of climate change (WORLD BANK, 2005). According to the climate change and sea level rise scenarios announced in 2016 by the Ministry of Natural Resources and Environment, if the sea level rises by 80 cm, 21% of the VMD will be flooded, and with a 100 cm rise, 38.9% of the delta will be inundated (MONRE, 2016). In this context, the Long Xuyen Quadrangle (LXQ) - a coastal lowland located in the southwest of the Mekong Delta - is one of the heavily affected areas by climate change. This area plays a crucial role in the agricultural development strategy of the VMD, contributing approximately 20% of the region's rice output. Moreover, it is one of the largest freshwater aquaculture regions in the VMD, accounting for only 12.5% of the delta's total area (DAO & TRAN, 2020). However, recent changes in temperature, precipitation, flooding, drought, and salinity intrusion have significantly impacted agricultural production in the region (DINH et al., 2012).

Assessing the potential impact of climate change using the Analytic Hierarchy Process (AHP) provides a comprehensive initial overview of these effects. The AHP method is encouraged for adaptation assessments to climate change impacts in agriculture (LINH, 2019). However, for the VMD region in general and the LXQ in particular, studies aiming to comprehensively assess the overall impact of climate change on agricultural, forestry, and fishery production are still limited. Therefore, to initiate an assessment of the overall impact of climate change on the mentioned production activities in the LXQ region, this study selects seven key economic sectors playing a vital role in the local livelihoods. The results of this study will provide an initial comprehensive overview of the potential impact of climate change on agricultural, forestry, and fishery production activities in the LXQ. Policymakers and administrators can utilize the findings from this study to guide the development of appropriate strategies for agriculture, forestry, and fishery sectors to adapt to the impacts of climate change at the local level.

2. MATERIAL AND METHODS

2.1. Study Area

The study area, referred to as the LXQ in this research, is bounded by the Bassac River, Cai San Channel, the West Sea (Gulf of Thailand), and the Vietnam-Cambodia border (Fig. 1). The region covers a total area of 4,996.28 km2, comprising the majority of the areas of two provinces, An Giang (49.11% of the region's area), Kien Giang (47.76%), and a part of Can Tho City (3.13%). The total population of the LXQ is approximately 2 million people (2019), with around 72% of the workforce engaged in agriculture, forestry, and aquaculture. Land use patterns in the LXQ primarily include rice fields, orchards, aquaculture, upland forests, and built-up land (Figure 1) (NGUYEN et al., 2022). Therefore, it is evident that the livelihoods of the local population largely depend on agricultural production activities. To assess the potential impact of climate change in the LXQ region, we selected three main production sectors related to most local livelihoods, specifically agricultural activities, including cultivation and animal husbandry, forestry, and aquaculture. These are considered among the most vulnerable production sectors to climate change impacts (SIWRP &JICA, 2013).

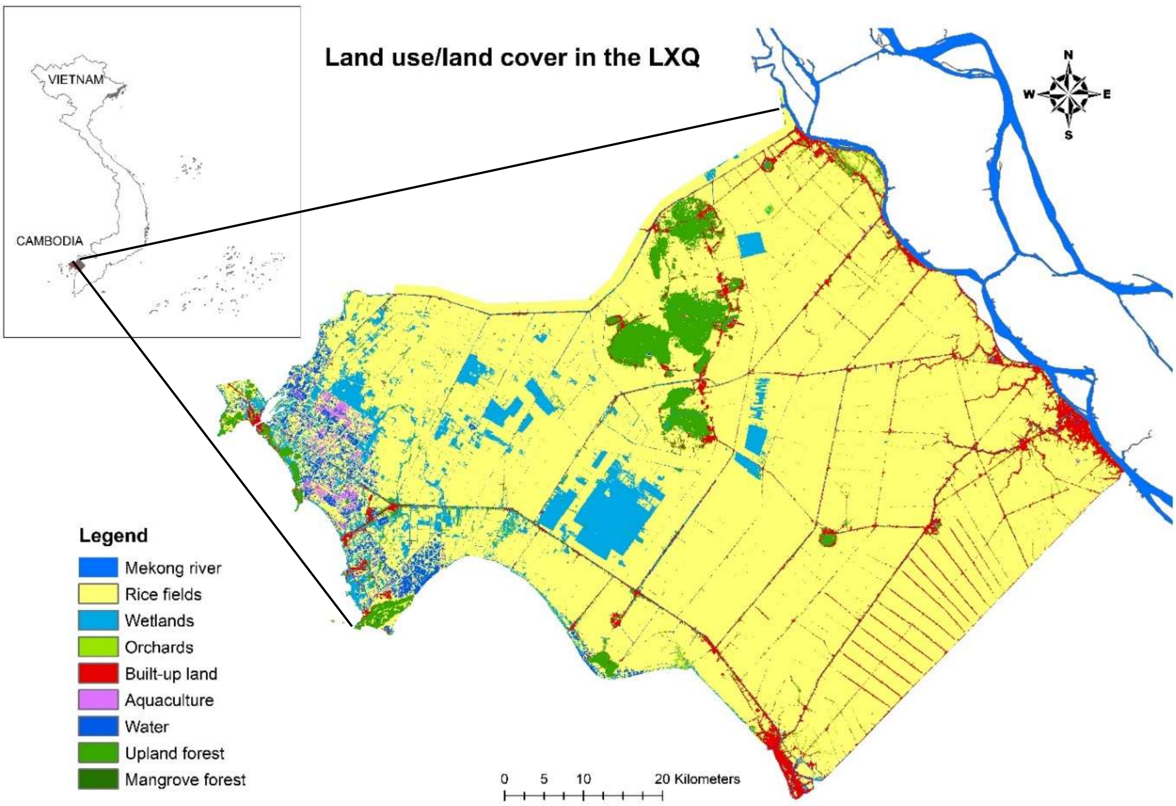

Figure 1. Land use/land cover patterns in the study area. Source: adapted from (Nguyen et al., 2022).
Figura 1. Padrões de uso/cobertura da terra na área de estudo. Fonte: adaptado de (Nguyen et al., 2022).

2.2. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a decision-making method for multiple criteria proposed by Thomas L.

Saaty (SAATY, 2008). AHP is a quantitative method used to prioritize decision alternatives and select an alternative that satisfies pre-defined criteria (SAATY, 2008). AHP has been applied in various studies related to environmental fragility (FRANÇA et al., 2019), mapping and identifying priority areas for forest recovery (DE ALMEIDA et al., 2020), food security under climate change (ALLIPOUR BIRGANI et al., 2022), and groundwater management under climate change (SCHEIHING et al., 2022). To assess the impact of climate change on different types of agricultural production, this study combines AHP with the calculation of climate change impact indices following the formula by Balica and Wright (BALICA & WRIGHT, 2010; TÍN et al., 2018) and classifies the degree of climate change impact according to Le Anh Tuan (LE et al., 2013). The specific research process is as follows:

Step 1: Determine the relative importance levels for the factors and compare the factors pairwise using the values aij (with i running horizontally and j running vertically). The importance level of each factor is recorded based on expert opinions, assigning values according to a comparison scale of importance (SAATY, 1980) (Table 1). The comparison of the importance level for each pair of factors depends on which value is examined first. For example, if factor C1 is equally important as 1/3 of factor C3, then factor C3 will be three times more important than factor C1. The comparison of pairwise components starts from the top of the hierarchy diagram (Table 2).

Table 1. AHP scale for pairwise comparisons.
Tabela 1. Escala AHP para comparações pareadas.

Scale	Numerical Rating	Reciprocal
Equally Importance	1	1
Moderate Importance	3	1/3
Strong Importance	5	1/5
Very strong Importance	7	1/7
Extreme Importance	9	1/9
Intermediate Values	2, 4, 6, 8	1/2, 1/4, 1/6, 1/8

Source: Saaty (1980).

Table 2. Comparison of pairwise importance levels of factors.
Tabela 2. Comparação dos níveis de importância dos fatores aos pares.

Factor	C1	C2	C3	…	Cn
C1	1	1/3	1/5	…	1/7
C2	3	1	1/2	…	1/5
C3	5	2	1	…	1/2
…	…	…	…	1	…
Cn	7	5	2	…	1

Step 2: Calculate weights for factors by summing the values of the matrix by column. Then, each value in the matrix is divided by the total of the corresponding column. The obtained values are substituted into the calculated value position (Table 3). The weight of each factor (C1, C2, C3, … Cn) will be equal to the average of the values in each horizontal row. The result is a one-column, n-row matrix (highlighted column).

To enhance the objectivity and reliability of the weights (wi), the Consistency Ratio (CR) is calculated following Saaty:

$$CR = \frac{CI}{RI} \quad (01)$$

In which, CI (Consistency Index): the consistency index, is calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (02)$$

where: λ_{max} (eigenvalue): the eigenvalue of the comparison matrix, is calculated as:

$$\lambda_{max} = \sum_{i=1}^{n} wi * \sum_{j=1}^{n} aij \quad (03)$$

RI (Random Index): the random index, is determined from the index given below (Table 4):

Table 3. Component weights and average weights of factors.
Tabela 3. Pesos dos componentes e pesos médios dos fatores.

Factor	C1	C2	C3	…	Cn	Weights (wi)
C1	w11	w12	w13	…	w1n	w1
C2	w21	w22	w23	…	w2n	w2
C3	w31	w32	w33	…	w3n	w3
…	…	…	…	…	…	…
Cn	wn1	wn2	wn3	…	wnn	wn

Table 4. Random index corresponding to the number of factors under consideration.
Tabela 4. Índice aleatório correspondente ao número de fatores considerados.

n	1	2	3	4	5	6	7	8	9	10	…	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	…	1.59

If CR ≤ 0.1: Consistency condition is satisfied in the assessment.
If CR > 0.1: Inconsistency in the assessment, reevaluation is required.

Step 3: Compare the degree of influence of each factor on different types of agricultural production. The study must conduct n matrices for n different factors, resulting in a table of weights representing the degree of influence of each factor on different types of agricultural production (Table 5).

Table 5. Synthesis of the importance level of each factor with types of production.

Factor / Types of production	C1	C2	C3	…	Cn
LH1	x11	x12	x13	…	x1n
LH2	x21	x22	x23	…	x2n
LH3	x31	x32	x33	…	x3n
…	…	…	…	…	…
LHn	xn1	xn2	xn3	…	xnn

Step 4: Calculate the Climate Change Impact Index (TIN et al., 2018):

$$VI = \sum_{j=1}^{n} wij * xij \quad (05)$$

where VI: Climate Change Impact Index, with the condition $0 \leq VI \leq 1$; wij: factor weights; xij: weights representing the degree of impact of each factor on different types of agricultural production.

Step 5: Classify the degree of climate change impact. According to Le Anh Tuan, the impact degree of climate change can be classified into three levels (LE et al., 2013):

High impact: Significant economic, environmental, and social losses;

Moderate impact: Causes some livelihood difficulties, and with support, impacts can be mitigated;

Low impact: Restricts livelihood activities, but can be self-supporting and recoverable.

3. RESULTS

3.1. Determining the importance of climate change factors in the LXQ

Based on the manifestations of climate change in the LXQ, the study selected five climate change factors affecting agricultural, forestry, and aquaculture production in the region, including temperature increase (C1), changes in precipitation (C2), flooding (C3), drought (C4), and saltwater intrusion (C5). The research employed the Analytic Hierarchy Process (AHP) to determine the importance level of these climate change factors on agricultural, forestry, and aquaculture production.

Drawing on literature references and expert opinions, the study quantified the importance level of climate change factors for agricultural, forestry, and aquaculture production in the region (Table 6). The data were calculated using the AHP method, and the weights for each factor are presented in Table 7.

Table 6. Pairwise comparison matrix of climate change factors affecting agriculture.
Tabela 6. Matriz de comparação aos pares dos fatores das alterações climáticas que afetam a agricultura.

Factor	C1	C2	C3	C4	C5
C1	1	2	1/4	1/2	1/3
C2	1/2	1	1/5	1/3	1/4
C3	4	5	1	3	2
C4	2	3	1/3	1	1/2
C5	3	4	1/2	2	1

Table 7. Weight of climate change factors in pairwise comparisons.
Tabela 7. Peso dos fatores das alterações climáticas em comparações aos pares.

Factor	C1	C2	C3	C4	C5	Weights (wi)
C1	0.10	0.13	0.11	0.07	0.08	0.10
C2	0.05	0.07	0.09	0.05	0.06	0.06
C3	0.38	0.33	0.44	0.44	0.49	0.42
C4	0.19	0.20	0.15	0.15	0.12	0.16
C5	0.29	0.27	0.22	0.29	0.24	0.26

The reliability of the weights was assessed through the consistency index. With five factors, the random index RI = 1.12 (refer to Table 4), which yielded:

Eigenvalue of the matrix $\lambda max = 5.07$
Consistency index CI = 0.02
=> Consistency ratio CR = 0.02 < 0.1 (satisfying the consistency condition).

3.2. Analyzing climate change impacts on diverse agricultural sectors in LXQ

The study employed the Analytic Hierarchy Process (AHP) to determine the impact of each climate change factor on seven types of agricultural, forestry, and aquaculture production in LXQ. These include rice (LH1), annual crops and perennial plants (LH2), orchards and perennial plants (LH3), mangrove forests (LH4), melaleuca forests (LH5), brackish water aquaculture (LH6) and freshwater aquaculture (LH7). The results, summarizing the weights for each criterion concerning different types of agricultural, forestry, and aquaculture production, are presented in Table 8.

Table 8. Importance level of climate change factors for each type of agricultural production in LXQ.
Tabela 8. Nível de importância dos factores das alterações climáticas para cada tipo de produção agrícola na LXQ.

Types of production		Factor				
		C1	C2	C3	C4	C5
Agriculture	LH1	0.15	0.14	0.37	0.30	0.22
	LH2	0.09	0.22	0.23	0.23	0.15
	LH3	0.06	0.09	0.14	0.13	0.08
Forestry	LH4	0.04	0.04	0.05	0.05	0.05
	LH5	0.04	0.03	0.04	0.04	0.04
Aquaculture	LH6	0.31	0.41	0.08	0.13	0.34
	LH7	0.31	0.07	0.09	0.12	0.12
CR		*0.02*	*0.06*	*0.02*	*0.04*	*0.02*

3.3. Level of climate change impact on agricultural, forestry, and aquaculture activities in LXQ

To quantify the impact of climate change on various agricultural, forestry, and aquaculture activities in LXQ, the study applied the influence index formula. This involved multiplying the matrix (Table 8) with the column of average weights of climate change factors (wi - Table 6). The results, indicating the climate change impact index on different types of agricultural, forestry, and aquaculture production in the region, are presented in Table 9.

The climate change impact levels are categorized into three groups:

0 - 0.10: Low Impact
0.11 - 0.20: Moderate Impact
0.21 - 0.30: High Impact

Based on the weight results of each factor, the climate change impact index on various types of agricultural production was calculated and classified into impact levels. The degree of climate change impact on different types of agricultural, forestry, and aquaculture production is presented in Table 9.

Table 9. Classification of climate change impact levels on various agricultural, forestry, and aquaculture productions.
Tabela 9. Classificação dos níveis de impacto das alterações climáticas em diversas produções agrícolas, florestais e aquícolas.

Types of production		Climate change impact index	Climate change impact levels
Agriculture	LH1	0.29	High Impact
	LH2	0.20	Moderate Impact
	LH3	0.11	Moderate Impact
Forestry	LH4	0.05	Low Impact
	LH5	0.04	Low Impact

Aquaculture	LH6	0.20	Moderate Impact
	LH7	0.12	Moderate Impact

4. DISCUSSION

4.1. The dominant climate change factors affecting LXQ's agricultural ecosystem

The results from Table 7 show that flooding is the most influential factor in agriculture in LXQ (wi = 0.42). The major impact of flooding is the reduction of agricultural production space, leading to a decrease in crop and livestock yields. However, in the future, as the irrigation system becomes more complete, the effects of flooding on agriculture are expected to gradually decrease. In addition to flooding, saltwater intrusion also significantly affects the growth and productivity of crops and alters the seasonal structure in agriculture (wi = 0.26). Under the current abnormal climate conditions, the situation of saltwater intrusion may continue to increase and have adverse effects.

Factors such as temperature increase (wi = 0.10) and drought (wi = 0.16) lead to severe crop water shortages, reducing crop productivity. Moreover, drought reduces soil fertility, increases irrigation costs, and contributes to the spread of pests and diseases.

Furthermore, changes in precipitation (wi = 0.06) will decrease productivity, affect the quality of aquaculture, and alter the cropping season and structure. However, the impact on agricultural production is less pronounced than other factors.

4.2. Differential impact of climate factors across LXQ agricultural sectors

The consistency ratio (CR) for pairwise comparisons of climate change factors with the seven types of agricultural production is consistently less than 0.1, indicating that the assessment results of climate change factors for various agricultural, forestry, and aquaculture productions are reliable.

Based on the results (Table 8), the impact of each climate change factor on different types of agricultural production is as follows:

Temperature Increase (C1): Has the most significant impact on brackish water and freshwater aquaculture (C1=0.31). Extreme temperature events can substantially compromise fish growth, reproduction, metabolism, physiology, behavior, future fitness, and survival (ISLAM et al., 2022). Higher water temperatures lead to an unstable living environment, the appearance of harmful algae, and a decrease in oxygen levels, affecting the livelihood of aquatic species (AHMED et al., 2020). Moreover, the increase in temperature also affects rice production (C1=0.15). According to the Asian Development Bank (ADB, 2009), a 1°C increase in temperature can lead to a 10% reduction in rice productivity. Other types of agricultural production evaluated in this study are also influenced by the increase in temperature, although to a lesser extent.

Changes in Precipitation (C2): Has varying impacts on different types of agricultural production. Annual crops and perennial plants, orchards, mangrove forests, and melaleuca forests are not significantly affected by changes in precipitation.

Flooding (C3): Has the most substantial impact on rice production. Research by Sâm (2006) on the relationship between floods and rice yield shows that flood depth and duration are inversely proportional to rice productivity. For instance, if the flood depth is 0.5-1.0m and the duration is 10 days, rice productivity may decrease by 37-46%. If the duration exceeds 10 days, rice yield may be completely damaged (SÂM, 2006). Additionally, flooding significantly affects annual crops and perennial plants. According to the Japan International Cooperation Agency (JICA), if the flood depth is 0.25m and the duration is 1 day, flower productivity may decrease by 10%. However, if the flood depth exceeds 0.5m, annual crops may be entirely damaged. Flooding has less impact on melaleuca forests and mangrove forests, according to the Southern Institute of Water Resources Planning (SIWRP). For aquaculture, floods may inundate pond embankments, causing losses. However, most aquaculture ponds are constructed to prevent flooding, minimizing the impact on aquaculture (SIWRP; JICA, 2013).

Drought (C4): Strongly affects rice production, as rice cultivation requires a large amount of irrigation water (C4=0.3). Drought can reduce rice productivity by 20-30%, as reported in the synthesis report "Synthesis of some activities responding to climate change in the Mekong Delta region" by the Center for Sustainable Rural Development and the Climate Change Research Institute of Can Tho University (LE et al., 2013).

Additionally, annual crops and perennial plants are also seriously affected by drought. Furthermore, drought often leads to a short period of aquaculture and threatens the survival of aquatic species due to water scarcity.

Saltwater Intrusion (C5): One of the main environmental obstacles to brackish water aquaculture. According to Le Anh Tuan and colleagues, increased salinity seriously affects the survival, growth, and yield of aquaculture species (LE et al., 2013). Freshwater aquaculture in LXQ, distributed along the Hau River, is less affected. Moreover, it is evident that rice production in LXQ is significantly affected by saltwater intrusion. This is consistent with the research results of Vu Ba Quan, who stated that saltwater intrusion during the rice cultivation period can slow down the rice growth process by 5-10 days, and intrusion at a salinity level of 4‰ during the seedling stage without water drainage can cause most rice seedlings to die. At a salinity level of 3.5‰ during the flowering stage, rice yield can decrease by 40-60% (GIAO, 2021). Different annual crops and perennial plants have varying ecological adaptability. However, most of them have a salinity tolerance threshold in both soil and irrigation water of no more than 4‰ (HOANG et al., 2006).

4.3. Assessing climate change impact severity on LXQ agriculture, forestry and aquaculture

Rice (LH1): This agricultural type is the most affected by climate change, with a corresponding impact index of 0.29. Rice production is significantly impacted, implying a substantial reduction in productivity and output. This could have negative consequences for food security and the income of farmers.

Annual crops (LH2) and Orchards and Perennial Plants (LH3): These agricultural types are moderately affected by climate change, with impact indices ranging from 0.11 to 0.20. This indicates that climate change can affect their growth and development but not as severely as rice. Therefore, changes in cultivation seasons or production methods could mitigate the impact and enhance adaptability to future climate variations.

Mangrove Forests (LH4) and Melaleuca Forests (LH5): These forestry types are the least affected by climate change, with impact indices of 0.04 and 0.05, respectively. Due to their natural characteristics, these types exhibit high adaptability, and the risk of damage from climate change factors is low.

Aquaculture (Brackish Water - LH6, Freshwater - LH7): Similar to LH2 and LH3, aquaculture is moderately affected by climate change, with impact indices ranging from 0.12 to 0.20. This suggests that climate change has some constraints on production activities, causing certain difficulties in the livelihoods of people engaged in aquaculture. However, this sector can adapt quickly and recover with appropriate adaptive solutions.

5. CONCLUSIONS

Agricultural, forestry, and aquaculture activities in the LXQ region are currently and will continue to be influenced by the effects of climate change. However, the degree of impact varies for each type of agricultural, forestry, and fishery activity. Rice production is the most severely affected due to its ecological characteristics and widespread distribution. Flooding and drought have the highest impact levels (weights are 0.37 and 0.30, respectively). In addition, rice is also significantly affected during the dry season due to saltwater intrusion into the inland areas (weight of 0.22). Other factors, such as temperature increase and changes in precipitation, do not have a significant impact on rice production in LXQ.

Annual crops and perennial plants are also affected by climate change but at a moderate level. Orchards and perennial plants are the least affected, mainly due to their good resistance and distribution in less affected areas. Aquaculture activities are moderately affected by climate change, with brackish water aquaculture more affected than freshwater aquaculture. Factors such as temperature increase, changes in precipitation, and saltwater intrusion have the most significant impact on the growth and development of aquatic species. Floods and droughts do not have a significant impact on the production activities of the aquaculture sector. Forestry production is the least affected by climate change. Melaleuca forests and mangrove forests have a high adaptability to temperature increases, changes in precipitation, and drought.

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