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Ecological Development Trade-Offs

(A Delphi-Based Framework for Managing Flood Risk under Infrastructure Expansion and Oil Palm Land Conversion in Indonesia)

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Abstract. Flood risk has become an increasingly significant challenge in developing regions experiencing rapid infrastructure expansion and agricultural land conversion. In Indonesia, economic development driven by infrastructure projects and oil palm plantation growth has generated substantial benefits while simultaneously creating ecological pressures that may increase flood vulnerability. This study aims to develop an ecological development framework for managing flood risk under conditions of infrastructure expansion and oil palm land conversion. A qualitative research design employing the Delphi method was adopted to obtain expert consensus regarding the key drivers of flood risk and sustainable development indicators. The study involved nine experts representing academia, regional planning institutions, environmental agencies, disaster management organizations, watershed authorities, and plantation governance institutions. Data were collected through three iterative Delphi rounds and analyzed using thematic analysis, median scores, interquartile range, and percentage agreement. The findings indicate that forest cover loss, watershed degradation, reduced infiltration capacity, uncontrolled land conversion, and weak spatial planning enforcement are the most critical determinants of flood risk. The results further reveal that infrastructure expansion and oil palm development influence flood vulnerability indirectly through land-use change and ecological degradation pathways. Based on expert consensus, the study proposes an Ecological Development Framework that integrates environmental governance, institutional capacity, and land-use management into regional development planning. The framework provides practical guidance for balancing economic growth objectives with ecological sustainability and disaster resilience in flood-prone regions.

Keywords: Ecological Development; Flood Risk; Infrastructure Expansion; Land-Use Change; Oil Palm Land Conversion

1. INTRODUCTION

Flood disasters have become one of the most significant environmental and so-cio-economic challenges confronting developing countries, particularly in regions experiencing rapid land-use transformation. While extreme rainfall and climate variability are commonly recognized as primary triggers of flooding, recent studies emphasize that flood risk is in-creasingly shaped by human-induced alterations in landscapes, including infrastructure de-velopment, urban expansion, and agricultural land conversion (Sebastian et al., 2019; Suriya & Mudgal, 2012; Swallom et al., 2025). Consequently, flood disasters should not be understood solely as natural phenomena but rather as the outcome of interactions among hazard, exposure, and vulnerability that are strongly influenced by development decisions and land-use policies (Auliagisni et al., 2025; J. Wang et al., 2026).

Indonesia presents a compelling case for examining the relationship between economic development and ecological vulnerability. Over the past two decades, the country has expe-rienced accelerated infrastructure expansion and substantial growth in oil palm plantations, both of which have contributed significantly to regional economic development. Infrastructure

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investments enhance connectivity, reduce transaction costs, and stimulate economic growth, while oil palm cultivation generates employment opportunities and export revenues. However, these development gains are often accompanied by environmental costs that remain insufficiently internalized in policy decision-making processes (Borozan et al., 2015). The conversion of forests, wetlands, and other natural ecosystems into built environments and monoculture plantations reduces infiltration capacity, increases surface runoff, and weakens the ecological resilience of watersheds, thereby elevating flood risk (Suprayogo et al., 2020; Yimer et al., 2008)

From an ecological economics perspective, this situation reflects a classic development trade-off in which short-term economic benefits are achieved at the expense of long-term environmental sustainability. The concept of environmental externalities suggests that development activities frequently generate unintended ecological consequences that are not adequately reflected in market prices or development planning frameworks (Corkindale & Thaçi, 2012; Correia & Roseland, 2022). As a result, infrastructure projects and land-use conversion decisions may create hidden environmental costs that eventually manifest as increased disaster vulnerability, economic losses, and social disruption. Several studies have demonstrated that changes in land use significantly influence hydrological processes and flood dynamics by altering runoff patterns and watershed functions (Amini et al., 2011; Mohammady et al., 2018).

The relationship between oil palm expansion and environmental degradation has attracted considerable scholarly attention, particularly in Southeast Asia. Research indicates that oil palm development has been a major driver of deforestation and land-use change in Indonesia, resulting in significant ecological consequences, including biodiversity loss, ecosystem degradation, and increased hydrological (Breidenbach et al., 2018; Lee et al., 2014). Furthermore, empirical evidence from Sumatra suggests that land-use conversion associated with plantation expansion contributes to altered water cycles and heightened flood occurrence, especially in areas characterized by weak environmental governance and rapid economic transformation (Merten et al., 2020).

The issue is particularly relevant in North Sumatra Province, where recent flood events have caused substantial damage to infrastructure, residential areas, and local economic activities. The province has experienced significant land-use changes due to infrastructure devel-opment, urbanization, and agricultural expansion, including oil palm cultivation. Simultane-ously, the region has recorded considerable forest cover loss over the past two decades, po-tentially reducing watershed resilience and increasing susceptibility to flood

hazards. These developments highlight the need to reconsider prevailing development paradigms and in-corporate ecological considerations more explicitly into regional planning and policy formulation.

Despite extensive research on flood risk and land-use change, existing studies predominantly focus on biophysical and hydrological dimensions, emphasizing the effects of defor-estation, urbanization, and watershed degradation on flood occurrence (Mohanty & Karmakar, 2022) .Other studies have examined the economic consequences of flood disasters and the governance challenges associated with disaster risk reduction (Koks et al., 2019; Ning et al., 2020; Tanoue et al., 2020). However, relatively limited attention has been devoted to integrating ecological, economic, and policy dimensions into a comprehensive framework capable of explaining and managing development flood risk trade-offs. Furthermore, few studies have employed expert consensus approaches to identify critical drivers and formulate operational policy frameworks for sustainable regional development.

To address this gap, the present study develops an ecological development framework for managing flood risk under conditions of infrastructure expansion and oil palm land conversion in Indonesia. Using the Delphi method, the study seeks to establish expert consensus regarding the most influential factors shaping flood risk, identify key ecological and socio-economic indicators, and construct a conceptual framework that supports more balanced and sustainable development planning. By integrating ecological economics, disaster risk theory, and regional development perspectives, this research contributes to the growing literature on sustainable development and disaster resilience while providing practical guidance for policymakers seeking to reconcile economic growth objectives with environmental sustainability.

2. LITERATURE REVIEW

The relationship between economic development and environmental sustainability has become a central issue in contemporary development studies, particularly in regions experiencing rapid land-use transformation. Traditional development paradigms have long emphasized economic growth through infrastructure investment, industrial expansion, and agricultural intensification. These activities are widely recognized as important drivers of productivity, employment generation, and regional competitiveness. However, increasing evidence suggests that development processes often generate unintended environmental consequences that undermine long-term sustainability and increase vulnerability to natural hazards (Durmaz et al., 2024; Romanyuk et al., 2019). Consequently, contemporary

development discourse has shifted toward understanding how economic growth can be pursued without compromising ecological resilience and environmental integrity.

The theoretical foundation of this discussion can be traced to ecological economics, which challenges conventional assumptions that economic growth and environmental conservation can be treated as separate domains. Ecological economics views natural ecosystems as forms of natural capital that provide essential services supporting economic and social systems (Özdemir, 2023). Ecosystem services such as water regulation, flood mitigation, soil conservation, and climate regulation contribute directly to human well-being and economic productivity. When these ecological functions are degraded through unsustainable development activities, substantial economic costs emerge in the form of environmental degradation, disaster losses, and reduced resilience to future shocks. This perspective highlights the importance of incorporating environmental costs into development decision-making processes and addressing negative externalities generated by economic activities (Sinforoso-Martínez et al., 2017; Yadav & Jain, 2024).

The concept of development trade-offs has become increasingly relevant in explaining the tension between economic expansion and environmental sustainability. Development projects often produce immediate economic benefits while simultaneously generating long-term environmental risks that are not fully considered during planning processes. These trade-offs are particularly evident in sectors involving large-scale land-use conversion, where economic gains from infrastructure development and agricultural expansion frequently occur alongside reductions in ecosystem functionality and environmental resilience (Grass et al., 2020). As a result, the sustainability of development outcomes depends not only on economic performance but also on the capacity of ecosystems to absorb environmental pressures and maintain essential ecological services.

Within the disaster risk literature, flood disasters are increasingly understood as products of both natural processes and human interventions in environmental systems. The disaster risk framework conceptualizes disasters as the interaction among hazards, exposure, and vulnerability, all of which are influenced by development trajectories and governance arrangements (Kumar et al., 2025). Vulnerability is not solely determined by physical conditions but is also shaped by socio-economic structures, institutional capacities, and land-use decisions (Grass et al., 2020). Therefore, flood risk is often regarded as a development issue rather than merely a hydrological phenomenon. Inadequate planning, environmental degradation, and unsustainable resource management may increase exposure and vulnerability, thereby amplifying disaster impacts even when hazard levels remain constant (Tasantab, 2019).

One of the most significant factors influencing flood risk is land-use change. Numerous studies have demonstrated that alterations in land cover significantly affect hydrological processes by modifying infiltration rates, evapotranspiration patterns, and runoff dynamics. Deforestation, urbanization, and agricultural expansion frequently reduce the capacity of landscapes to retain and regulate water, resulting in increased surface runoff and heightened flood susceptibility (H. D. Nguyen et al., 2026; X. Wang et al., 2026). Research conducted in various regions has consistently shown that changes in land-use patterns contribute to more frequent and severe flood events, particularly in rapidly developing areas where environmental considerations are subordinated to economic objectives (Hejazizadeh et al., 2026; Kasim et al., 2022).

Recent scholarship has further emphasized that flood hazards cannot be fully explained by climatic factors alone. Although climate change contributes to increasing rainfall variability and extreme weather events, anthropogenic modifications of landscapes often play an equally important role in shaping flood dynamics (Langhammer & Vilímek, 2008). Urban expansion, transportation infrastructure development, and agricultural intensification alter watershed characteristics and reduce ecological buffering capacities. Moon et al., (2024) demonstrate that green infrastructure and ecological restoration can substantially reduce urban flood vulnerability, underscoring the importance of maintaining ecological functions within development strategies. Similarly, Liu et al., (2025) argue that future flood risk assessments must integrate land-use planning, socio-economic development, and climate change considerations into a unified analytical framework.

The environmental implications of agricultural expansion have attracted significant scholarly attention, particularly in countries characterized by extensive plantation development. Indonesia provides a notable example due to the rapid expansion of oil palm plantations over the past several decades. Oil palm cultivation has contributed substantially to economic growth, export earnings, and rural employment opportunities, making it a strategic component of national development policy (Gorea et al., 2022). However, plantation expansion has also been associated with large-scale land conversion, deforestation, biodiversity loss, and ecosystem degradation (Ali et al., 2025). These environmental changes have raised concerns regarding the long-term sustainability of plantation-based development models.

Several studies suggest that oil palm expansion significantly alters hydrological systems and watershed functions. The conversion of natural forests into monoculture plantations reduces vegetation diversity, changes soil properties, and influences water retention capacity. Empirical evidence from Sumatra indicates that communities frequently associate large scale

land conversion with increased flooding and changes in local hydrological conditions (Merten et al., 2020). Similar findings have been reported in other tropical regions, where agricultural expansion has contributed to increased runoff, sedimentation, and watershed degradation. These observations suggest that flood risk should be considered among the broader environmental consequences of land-use transformation associated with plantation development.

Beyond environmental impacts, flood disasters generate substantial socio-economic consequences. Economic losses resulting from flood events include direct damage to infrastructure, housing, agricultural production, and business activities, as well as indirect losses associated with disruptions to supply chains, labor markets, and public services (Porfiriev, 2016). H. M. Nguyen et al., (2025) show that flood-related shocks may have persistent effects on economic growth, particularly in developing economies with limited adaptive capacities. Mendoza-Tinoco et al., (2020)further demonstrate that flood damage often extends beyond affected locations through interregional economic linkages, creating broader development challenges. Similar conclusions are reported by Koks et al., (2019), who emphasize the significant macroeconomic implications of flood disasters for regional economies.

The governance dimension also plays a critical role in determining the effectiveness of flood risk management. Effective governance requires coordination among multiple stakeholders, including government agencies, local communities, private sector actors, and environmental organizations. Alexander & Priest, (2019) argue that flood resilience depends on multi-layered governance systems capable of integrating risk reduction into development planning. Weak institutional coordination, fragmented policy frameworks, and inadequate enforcement of environmental regulations often undermine efforts to manage environmental risks associated with development activities. Consequently, sustainable flood risk management requires not only technical interventions but also institutional arrangements that support long-term environmental stewardship.

The growing complexity of development–environment interactions has encouraged researchers to adopt interdisciplinary approaches capable of integrating diverse forms of knowledge. One such approach is the Delphi method, which has been widely applied in environmental planning, sustainability assessment, disaster management, and public policy studies. The Delphi method facilitates systematic consensus building among experts through iterative rounds of consultation, enabling researchers to identify critical factors, prioritize interventions, and develop conceptual frameworks under conditions of uncertainty (Lyonnais,

2021). Because flood risk emerges from complex interactions among ecological, economic, social, and institutional factors, expert-based approaches provide valuable tools for synthesizing knowledge across disciplinary boundaries and supporting evidence-based policy formulation.

Although previous studies have substantially advanced understanding of flood risk, land-use change, and environmental governance, several limitations remain. Existing research has predominantly examined biophysical mechanisms linking land-use change to flooding, while relatively less attention has been devoted to understanding how development decisions generate trade-offs between economic gains and ecological resilience. Studies focusing on oil palm expansion have largely emphasized deforestation and biodiversity impacts, with limited exploration of their implications for flood risk management and regional development planning. Furthermore, research integrating ecological economics, disaster risk theory, land-use change, and governance perspectives into a comprehensive framework remains relatively scarce. This gap is particularly evident in the Indonesian context, where rapid infrastructure expansion and plantation development continue to reshape environmental conditions and disaster vulnerabilities. Therefore, a framework capable of identifying and managing ecological development trade-offs is essential for promoting more sustainable and resilient development pathways.

3. RESEARCH METHOD

Research Design

This study employed a qualitative research design using the Delphi method to develop an ecological development framework for managing flood risk under conditions of infrastructure expansion and oil palm land conversion. The Delphi method was selected because it is particularly suitable for addressing complex and multidimensional policy issues characterized by uncertainty and limited empirical consensus (Lyonnais, 2021). Flood risk resulting from land-use transformation involves ecological, economic, institutional, and governance dimensions that require interdisciplinary perspectives. Therefore, a structured expert-based approach was considered appropriate for identifying critical determinants and developing a policy relevant framework.

The study adopted an exploratory and framework-building approach. Rather than testing causal relationships statistically, the research aimed to achieve expert consensus regarding the key drivers of flood risk and the strategic elements required to balance economic development

and ecological sustainability. The resulting framework is intended to support sustainable regional planning and flood risk governance in Indonesia.

Study Area and Expert Panel

The research focused on North Sumatra Province, Indonesia, a region that has experienced rapid infrastructure development, extensive oil palm plantation expansion, and increasing flood occurrences over the last two decades. Several districts within the province have reported recurrent flood events that have disrupted economic activities, damaged public infrastructure, and affected community livelihoods. The region therefore provides a relevant context for examining development–environment trade-offs.

The Delphi panel consisted of nine experts selected through purposive sampling based on their expertise, professional experience, and institutional relevance to the study objectives. The panel included representatives from academia, regional development planning agencies, environmental institutions, watershed management authorities, disaster management agencies, and plantation governance institutions. The selection of experts followed the principle of knowledge diversity to ensure comprehensive assessment from economic, environmental, planning, and policy perspectives.

Table 1. Composition of Delphi Expert Panel

Expertise Area	Institutional Background
Development Economics	Universities
Regional Planning	Regional Development Planning Agencies
Environmental Management	Environmental Agencies
Watershed Management	Watershed Management Authority
Disaster Risk Reduction	Disaster Management Agency
Plantation and Land Governance	Plantation Agency

Data Collection Procedure

Data collection was conducted through three iterative Delphi rounds between January and June 2026. The first round employed open-ended questionnaires designed to identify factors contributing to flood risk under infrastructure development and oil palm land conversion. Experts were invited to provide their views regarding the ecological, economic, institutional, and land-use dimensions associated with flood vulnerability.

Responses obtained from the first round were analyzed using thematic content analysis. Similar statements and concepts were grouped into categories and transformed into measurable indicators. These indicators formed the basis for the structured questionnaire used in the second round.

During the second Delphi round, experts evaluated the importance of each indicator using a five-point Likert scale ranging from 1 (very low importance) to 5 (very high importance). Participants were also given opportunities to provide additional comments and recommendations regarding indicator relevance and conceptual relationships.

The third round was conducted to reassess indicators that had not yet achieved consensus. Feedback from previous rounds, including group responses and summary statistics, was provided to participants. This iterative process enabled experts to reconsider their judgments and contributed to a higher level of convergence among panel members.

Consensus Measurement and Data Analysis

The Delphi analysis followed established procedures commonly used in environmental and policy research. Three statistical measures were employed to evaluate expert consensus: median score, interquartile range (IQR), and percentage agreement.

The median score was used to determine the central tendency of expert assessments and identify the relative importance of indicators. The interquartile range measured the dispersion of expert opinions and served as the primary indicator of consensus. Following previous Delphi studies, consensus was considered achieved when the interquartile range was equal to or less than 1.0. In addition, percentage agreement was calculated to assess the proportion of experts assigning similar importance levels to each indicator.

Indicators meeting both criteria an IQR of ≤ 1.0 and at least 75% agreement among experts were retained in the final framework. Indicators failing to satisfy these thresholds were reconsidered in subsequent rounds until consensus was achieved or the item was excluded from further analysis.

The qualitative comments provided by experts were analyzed using thematic coding techniques. This process facilitated the interpretation of statistical results and supported the identification of causal relationships among the validated indicators.

Framework Development

The final stage of the study involved developing the Ecological Development Framework based on indicators that achieved expert consensus. Framework construction followed an iterative synthesis process integrating findings from the Delphi rounds with theoretical perspectives derived from ecological economics, disaster risk theory, land-use change literature, and sustainable development studies.

The framework conceptualizes flood risk as the outcome of interactions among infrastructure expansion, oil palm land conversion, ecological degradation, institutional capacity, and socio-economic vulnerability. These relationships were organized into a causal

structure illustrating how development decisions influence environmental conditions and ultimately shape disaster risk outcomes.

The proposed framework serves as an analytical tool for identifying critical intervention points and supporting evidence-based policy formulation. It provides guidance for integrating ecological considerations into regional development planning and offers a foundation for balancing economic growth objectives with environmental sustainability and disaster resilience.

Research Framework

Based on the literature review and Delphi design, this study proposes a conceptual framework in which infrastructure expansion and oil palm land conversion act as primary drivers of land-use change. These processes influence ecological conditions through reductions in watershed capacity, forest cover, infiltration functions, and ecosystem services. Ecological degradation subsequently increases flood exposure and vulnerability, leading to higher flood risk. Institutional capacity and environmental governance function as moderating factors that may either mitigate or amplify these impacts. Ultimately, the interaction among these dimensions determines the magnitude of development trade-offs between economic growth and ecological sustainability.

The framework developed through expert consensus is presented in Figure 1.

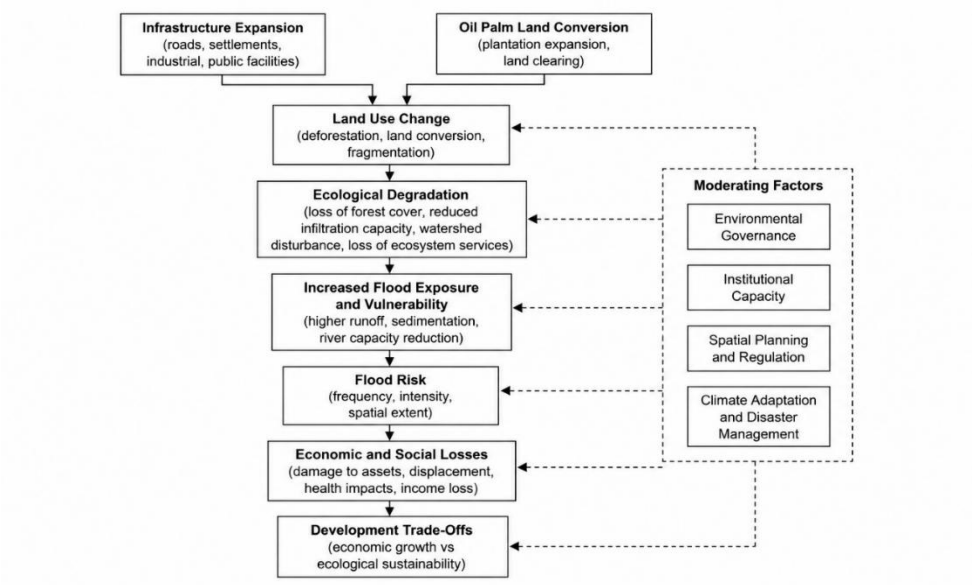


Figure 1. Conceptual Framework of Ecological Development Trade-Offs under Infrastructure Expansion and Oil Palm Land Conversion.

4. RESULTS AND DISCUSSION

Delphi Round 1: Identification of Flood Risk Drivers

The Delphi survey was conducted between January and June 2026 involving nine experts representing academia, regional planning institutions, environmental agencies, watershed management authorities, disaster management organizations, and plantation governance institutions. The study focused on North Sumatra Province, Indonesia, where rapid infrastructure expansion and oil palm land conversion have coincided with increasing flood occurrences in recent years.

The first Delphi round aimed to identify factors perceived by experts as contributing to flood risk within the context of development and land-use transformation. Through open-ended questionnaires, experts generated a broad range of responses encompassing ecological, economic, institutional, and land-use dimensions. Thematic analysis of these responses resulted in four major dimensions consisting of ecological degradation, land-use change, institutional capacity, and socio-economic vulnerability.

Among the factors identified, forest cover loss, watershed disturbance, reduced infiltration capacity, uncontrolled land conversion, weak spatial planning enforcement, and inadequate environmental governance were the most frequently mentioned. Experts consistently emphasized that flood risk should not be viewed solely as a consequence of extreme rainfall but rather as an outcome of cumulative environmental changes associated with development activities.

These findings support the argument that flood vulnerability is socially and environmentally constructed through development processes. The results are consistent with previous studies emphasizing the role of land use change and environmental degradation in increasing flood susceptibility (Tasantab, 2019; X. Wang et al., 2026)

Delphi Round 2 and Round 3: Expert Consensus on Key Indicators

The second and third Delphi rounds focused on evaluating and refining the indicators identified during the first round. Experts assessed the importance of each indicator using a five-point Likert scale. Consensus was evaluated using median values, interquartile range (IQR), and percentage agreement.

Table 2. Consensus-Based Indicators of Ecological Development Trade-Offs

Indicator	Median	IQR	Agreement (%)	Rank
Forest cover loss	5.00	0.00	100	1
Watershed degradation	5.00	0.00	100	2
Reduced infiltration capacity	5.00	0.00	100	3
Uncontrolled land conversion	5.00	1.00	89	4
Weak spatial planning enforcement	5.00	1.00	89	5

Expansion of oil palm plantations	4.89	1.00	89	6
Infrastructure expansion pressure	4.78	1.00	78	7
Institutional coordination	4.67	1.00	78	8
Community adaptive capacity	4.56	1.00	78	9

Table 2 indicates that ecological indicators received the highest level of consensus among experts. Forest cover loss, watershed degradation, and reduced infiltration capacity emerged as the most critical factors influencing flood risk. These findings suggest that ecological degradation functions as the primary mechanism linking development activities to increased disaster vulnerability.

Interestingly, infrastructure expansion and oil palm plantation development were not perceived as direct causes of flooding. Rather, experts viewed these activities as drivers of land-use change that subsequently trigger ecological degradation. This finding highlights the importance of considering indirect causal pathways when evaluating development impacts on environmental systems.

Development of the Ecological Development Framework

Based on the Delphi consensus, an Ecological Development Framework was developed to explain the causal relationships between development activities and flood risk. The framework is presented in Figure 1. The framework demonstrates that infrastructure expansion and oil palm land conversion influence flood risk primarily through land-use change and ecological degradation pathways. These processes reduce ecosystem services, weaken watershed functions, and increase environmental vulnerability. As ecological resilience declines, exposure to flood hazards increases, resulting in greater economic and social losses.

The framework further identifies environmental governance, institutional capacity, spatial planning enforcement, and climate adaptation strategies as moderating factors capable of reducing the negative impacts of development activities. Therefore, flood risk is conceptualized not merely as an environmental issue but as a development governance challenge requiring integrated policy interventions.

Discussion: Managing Development–Environment Trade-Offs

The findings provide empirical support for ecological economics theory, which argues that economic development frequently generates environmental externalities that are not adequately reflected in planning decisions. While infrastructure development and plantation expansion contribute to regional economic growth, they may simultaneously reduce ecosystem resilience and increase disaster vulnerability when ecological considerations are neglected.

The Delphi results indicate that ecological degradation serves as the primary transmission mechanism connecting development activities to flood risk. This finding is consistent with previous studies highlighting the importance of ecosystem services in regulating hydrological systems and mitigating environmental hazards. The results also reinforce arguments that flood disasters should be interpreted as manifestations of development choices rather than solely natural events.

From a regional development perspective, the findings suggest that economic growth and environmental sustainability should not be viewed as competing objectives. Instead, sustainable development requires balancing economic expansion with ecological preservation. Failure to integrate environmental considerations into development planning may generate substantial long-term economic costs through increased disaster losses, infrastructure damage, and reduced social welfare.

Furthermore, the study highlights the importance of institutional quality and environmental governance. Experts emphasized that weak regulatory enforcement and fragmented institutional coordination often exacerbate the environmental consequences of land-use change. Consequently, improving governance mechanisms may be as important as technical flood mitigation measures in reducing disaster risk.

Policy Implications

The findings offer several important policy implications. First, regional planning authorities should strengthen ecological considerations within infrastructure development and land-use planning processes. Second, environmental impact assessments should incorporate flood risk indicators related to watershed conditions, forest cover, and infiltration capacity. Third, stronger institutional coordination is required among environmental agencies, regional planning institutions, disaster management organizations, and plantation authorities.

Finally, sustainable flood risk management should move beyond reactive disaster response toward proactive ecological governance. Integrating environmental protection, land-use regulation, and disaster risk reduction into development planning can help achieve a more balanced relationship between economic growth and ecological sustainability.

5. CONCLUSION AND RECOMMENDATIONS

This study aimed to develop an ecological development framework for managing flood risk under conditions of infrastructure expansion and oil palm land conversion in Indonesia. Using the Delphi method, the research identified the key factors contributing to flood vulnerability and established expert consensus regarding the relationships between

development activities, ecological degradation, and disaster risk. The findings indicate that flood risk is not merely a consequence of hydrometeorological hazards but is strongly influenced by development-induced land-use changes that alter ecological functions and reduce watershed resilience.

The results reveal that forest cover loss, watershed degradation, reduced infiltration capacity, uncontrolled land conversion, and weak spatial planning enforcement are perceived as the most critical determinants of flood risk. The study further demonstrates that infrastructure expansion and oil palm plantation development do not directly generate flooding; rather, their impacts are mediated through land-use transformation and ecological degradation processes. These findings reinforce the argument that ecological conditions constitute a fundamental component of sustainable development and should be incorporated into regional planning and development decision-making processes.

The Ecological Development Framework proposed in this study contributes to the literature by integrating perspectives from ecological economics, disaster risk theory, land-use change studies, and environmental governance into a single analytical framework. The framework highlights the importance of considering environmental externalities associated with development activities and emphasizes the role of institutional capacity, environmental governance, and spatial planning in mitigating the negative consequences of economic expansion. In this regard, the study advances understanding of development–environment trade-offs and provides a practical basis for designing more resilient and sustainable development policies.

From a policy perspective, the findings suggest that flood risk management should move beyond conventional structural interventions and adopt a more integrated ecological governance approach. Regional governments should strengthen the incorporation of ecological indicators into infrastructure planning, environmental impact assessments, and land-use management policies. Greater coordination among planning agencies, environmental institutions, disaster management authorities, and plantation regulators is also necessary to ensure that economic development objectives are aligned with environmental sustainability and disaster resilience goals.

Despite its contributions, this study has several limitations. First, the framework was developed based on expert consensus and therefore reflects informed professional judgment rather than direct empirical measurement of causal relationships. Second, the study focused on North Sumatra as a representative context, which may limit the transferability of findings to regions with different ecological, socio-economic, and institutional characteristics. Third, the

qualitative nature of the Delphi method does not permit statistical estimation of the magnitude of relationships among the identified factors.

Future research is encouraged to validate the proposed framework using quantitative approaches, such as structural equation modeling, spatial analysis, or integrated environmental-economic assessment methods. Comparative studies across different regions may also provide deeper insights into how variations in governance quality, land-use dynamics, and ecological conditions influence development–environment trade-offs. Such efforts would contribute to the refinement of the framework and support the development of more context-specific strategies for balancing economic growth, environmental sustainability, and disaster risk reduction.

Overall, the study concludes that sustainable development cannot be achieved solely through economic expansion. Long-term development resilience depends on the ability of policymakers and stakeholders to recognize ecological systems as critical development assets and to integrate environmental sustainability into the core of regional planning and governance processes.

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