

Sustainable Policy Interventions for Coastal Erosion affecting Eco-Tourism and Development in Bali, Indonesia

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Abstract

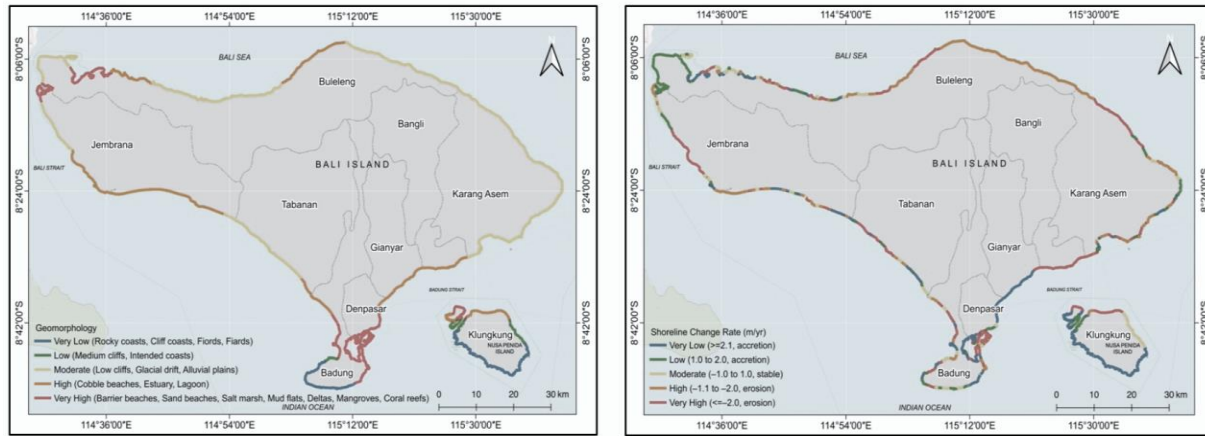
Coastal erosion imposes an looming barrier to eco-tourism and sustainable development in Bali, Indonesia. As a premier international tourist destination, Bali's economy and cultural identity are inextricably correlated to its coastal beach environments. Though, climate change increasingly stresses this island's fiscal and environmental resources. Rising sea levels compounded with anthropogenic pressures accelerates coastal erosion and degradation. This multi-facted IAPA conference paper will investigate risk and crisis management with data-informed adaptive proposals to protect environmental values. The following sustainable policy intervention approaches coastal erosion with a focus on preserving eco-tourism assets and development opportunities in Bali. The research methodology synthesizes recent literature on coastal vulnerability, greeen erosion mitigation, spatiotemporal climate projections, and preventative adaptation strategies specific to Bali and similar coastal tourism destinations. This conference paper proposes that an integrated coastal zone management approach combining organic solutions, adaptive governance, and sustainable tourism practices offers the most promising framework to address coastal erosion while promoting Bali's eco-tourism sector. The central thesis argues that effective coastal erosion management in Bali requires coordinated policy interventions across multiple scales of governance, coupling robust scientific monitoring with flexible, context-specific adaptation measures and stakeholder engagement.

Keywords:

policy; eco-tourism; coastal erosion

Context

Bali's 633 km coastline features a diverse geomorphology, including sandy beaches, rocky cliffs, coral reefs, and mangrove forests (Hastuti et al., 2022). These coastal ecosystems provide critical habitat, natural hazard protection, and the foundation for Bali's eco-tourism dependent economy. However, recent studies highlight an increasing vulnerability of Bali's coasts to erosion and flooding. Hastuti et al. (2022) found that 22% of Bali's coastline is highly vulnerable to climate change impacts, particularly in the southeastern and southwestern regions which coincidentally attract the most tourist activity: Kuta, Seminyak, Sanur, Canggu. This vulnerability stems from a combination of factors, including sea level rise, surge flooding patterns, and anthropogenic treatment of coastal resources.

Figure 1.**Vulnerability rank of (left) geomorphology; (right) shoreline change**

Source: (Hastuti et al., 2022)

Climate change projections indicate that Bali will face catastrophic coastal hazards in the coming decades. Vousdoukas et al. (2018) project that global sea level rise will lead to more frequent and intense coastal flooding events, which could exacerbate erosion along vulnerable shorelines. Similarly, Kulp and Strauss (2019) estimated that given high emission projections, over 150,000 people in Bali could be exposed to annual coastal flooding by 2050. These consequences are exacerbated by local industries like coastal development and sand mining (Wijaya & Furqan, 2018). The consequences of coastal erosion are already evident on Bali's tourism sector. Rajendra (2020) documented how incremental beach erosion has damaged coastal infrastructure and reduced the recreational value of popular tourist beaches in southern Bali. Furqan and Winandi (2018) found that coastal erosion compounded by global warming, are dissuading tourists' perceptions and decision-making, potentially threatening Bali's long-term attractiveness as a tourist destination. As coastal erosion continues, it poses risks not only to tourism assets but also to critical infrastructure, cultural sites, and local livelihoods dependent on coastal resources.

Policy and Governance Landscape

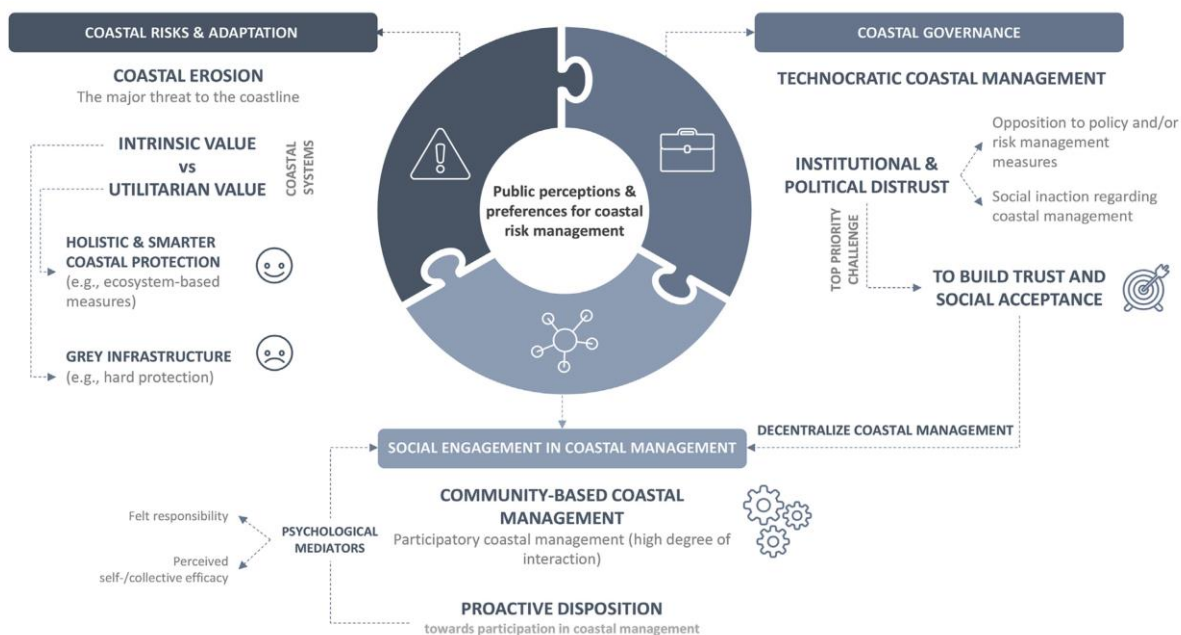
Addressing coastal erosion in Bali necessitates nuanced policy intervention. Indonesia has developed national coastal management policies, but scaling implementation and translating policy across regions proves challenging. Ferrol-Schulte et al. (2015) identified issues such as overlapping jurisdictions, limited coordination between agencies, and gaps between policy formulation and implementation as key barriers to effective coastal management in Indonesia. In Bali specifically, Widantara and Mutaqin (2024) noted that coastal management efforts are often localized and

fragmented across different scales and political domains, leading to inconsistent attention and outcomes.

Despite these challenges, there are opportunities for more integrated and adaptive governance approaches. Zhang et al. (2024) reinforce the necessity for multi-scale governance frameworks that can unite national policies with local implementation while fostering stakeholder engagement. Lodder and Slinger (2022) describe a "Research for Policy" cycle that could be adapted for Bali to promote data-informed findings inform coastal management policies. These governance innovations will be crucial for developing, implementing, and evaluating sustainable interventions.

Figure 4.

Conceptualization of public perception and preferences for coastal risk management



Source: (Areia et al., 2023)

Sustainable Intervention Strategies

To appropriately address the evolving complexity of coastal erosion and flooding and still promote a sustainable eco-tourism in Bali necessitates multifaceted approaches: nature-based solutions, green-gray infrastructure, and adaptive governance. Nature-based solutions offer promising approaches that work with organic processes to bolster coastal resilience. Mangrove restoration and conservation campaigns like Benoa Bay should be prioritized in vulnerable areas, as mangrove forests provide natural coastal protection, carbon sequestration, and support for local livelihoods (Riechers et al., 2021). Bali has opportunities to adequately expand mangrove restoration

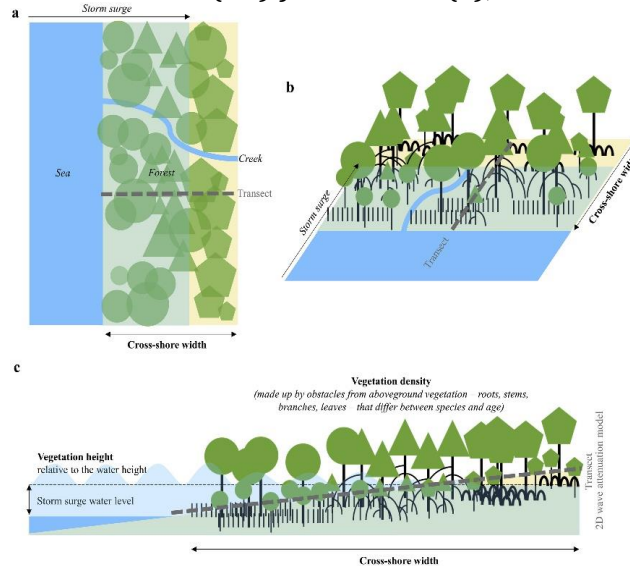
efforts, which could yield multiple ecological and economic benefits. Additionally, coral reef protection and rehabilitation must be considered, since healthy coral reefs act as natural breakwaters, reducing wave energy and erosion. Toimil et al. (2023) demonstrate the significant flood protection benefits provided by coral reefs, suggesting that enhancing protection and restoration of Bali's coral reefs could offer a cost-effective coastal defense strategy.

Beach nourishment and dune restoration present another optimistic nature-based intervention. Tactical beach nourishment can help maintain beach width and coastal protection, while dune restoration enhances natural buffers against storm surges and sea level rise. Park et al. (2023) found that nature-based solutions like beach nourishment can provide significant co-benefits beyond flood protection, including enhanced recreational value and habitat creation. However, careful design and implementation are needed to ensure long-term sustainability and minimize ecological impacts. These nature-based approaches should be complemented by green-gray infrastructure that integrate natural elements with engineered structures. Urban developers may implement permeable pavements and bioswales coastal areas to improve drainage and reduce polluting runoff, while flood-resistant building designs can enhance the resilience of coastal structures. In especially vulnerable areas, managed retreat strategies may be necessary to reduce long-term risks and create spaces for natural coastal processes (Rasmussen et al., 2021).

1. **Mangrove Restoration:** Mangrove forests provide natural coastal protection and habitat. Riechers et al. (2021) highlight the multiple benefits of mangrove restoration, including erosion control, carbon sequestration, and support for local livelihoods.
2. **Coral Reef Protection and Rehabilitation:** Healthy coral reefs act as natural breakwaters, reducing wave energy and erosion. Toimil et al. (2023) demonstrate the significant flood protection benefits provided by coral reefs. Enhancing protection and restoration of Bali's coral reefs could offer cost-effective coastal defense.
3. **Beach Nourishment and Dune Restoration:** Strategic beach nourishment and dune restoration can help maintain beach width and coastal protection. Park et al. (2023) found that nature-based solutions like beach nourishment can provide significant co-benefits beyond flood protection. However, careful design is needed to ensure long-term sustainability and minimize ecological impacts.

Figure 2.

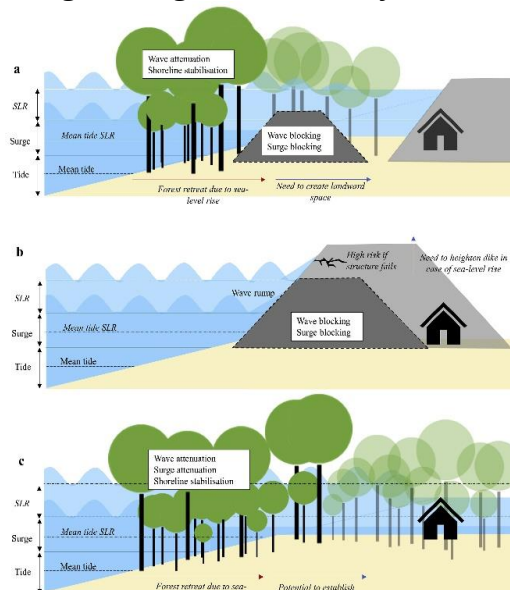
*< *left* . Simplified overview of relevant mangrove properties for wave attenuation with top-down view (a), three-dimensional (3D)-frontal view (b), and cross-shore side view (c).*



Source: (van Hespen et al., 2023)

Figure 3.

**right* > . Simplified overview of coastal protection functions by mangroves and engineering structures and potential consequences of sea-level rise (SLR) (not to scale): (a) mangrove forest and dike, (b) traditional engineering structure, and (c) only mangrove forest. In case of sea-level rise (lightest blue), mangroves may require space for landward migration (transparent forest), and engineering structures may need to be heightened (light grey)*



Source: (van Hespen et al., 2023)

The efficacy of these interventions hinges on adaptive policy and robust governance frameworks. Implementing integrated coastal zone management (ICZM) is crucial for coordinating diverse stakeholders and balancing competing interests in Bali's coastal areas. An ICZM framework ensures that tourism development, flood protection, and environmental conservation efforts are aligned and mutually adaptive. Adaptive governance frameworks should be established to enable flexible responses to changing coastal conditions and new information. This approach, as highlighted by Edwards et al. (2019), can support policy-making in complex coastal systems by incorporating diverse knowledge sources and stakeholder perspectives. Furthermore, enhancing stakeholder engagement and co-management approaches is essential for building local support and ensuring that interventions are culturally appropriate and socially equitable.

The proposed interventions offer significant potential for preserving Bali's coastal assets while supporting sustainable development. However, successful implementation will depend on overcoming governance challenges, securing adequate funding, and fostering stakeholder engagement. Integrating these diverse approaches - from mangrove restoration to adaptive governance - can create a more resilient and sustainable coastal management system for Bali. This holistic strategy not only addresses immediate flood risks but also supports long-term eco-tourism development and environmental conservation goals. As climate change continues to exacerbate coastal vulnerabilities, the urgency of implementing these strategies becomes increasingly apparent. By adopting this comprehensive approach, Bali can work towards a more resilient and sustainable future for its coastal ecosystems, tourism-based economy, and traditional communities whose values derive from their environments.

Adaptive Infrastructure and Land-use Planning

Complementing nature-based solutions, adaptive infrastructure and land-use planning approaches are also essential for curbing coastal erosion risks and promoting sustainable eco-tourism development in Bali. A key strategy is the establishment and enforcement of coastal setback zones, which can reduce severely consequential exposure to erosion and even afford governments space for natural coastal processes. Rasmussen et al. (2021) found that mandated setback zones can be highly effective in reducing short-term flood damages, though only when integrated with other proactive measures. In Bali, implementing setback zones would require careful consideration of existing development patterns and cultural land uses. However, the long-term savings from preventing infrastructural damage and preserving beaches for tourism could outweigh the short-term barrier costs of implementation.

Climate-resilient infrastructure is another critical component of Bali's adaptive strategy. This includes measures such as elevating buildings, improving drainage systems, and designing flexible structures that can adapt to changing coastal conditions. Handayani et al. (2020) demonstrated the effectiveness of such approaches in reducing flood risks in coastal urban areas of Indonesia. For Bali, this could involve retrofitting existing tourist facilities and designing new developments with rising sea levels and increasing storm intensity in mind. While the upfront capital expenditure for climate-resilient infrastructure may seem prohibitive, the long-term benefits make this approach economically viable.

In highly vulnerable areas of Bali's coast, controlled retreat operations will be necessary to reduce long-term damages. This approach involves the planned mass relocation of assets and communities away from high-risk coastal zones. While politically challenging, controlled retreats may be the most cost-effective solution in areas facing severe, imminent and irreversible coastal erosion. Hino et al. (2017) found that well-planned retreat can not only reduce disaster risks but also afford new legislators political latitude to implement more expansive ecosystem restoration and new forms of coastal land use. In Bali, managed retreat could also be integrated with eco-tourism initiatives, creating new nature-based attractions in areas formerly occupied by at-risk infrastructure.

Thus, adopting an integrated coastal zone management (ICZM) approach is crucial for coordinating these diverse adaptation strategies. ICZM can help ensure that tourism development, flood protection measures, and environmental conservation efforts are aligned and mutually reinforcing. Bisaro et al. (2020) emphasize the urgency of coordinating coastal flood risk reduction measures across different levels of governance to avoid conflicting interests. In Bali, this could involve creating a dedicated coastal management authority that brings together representatives from tourism, environmental, and infrastructure sectors to develop holistic adaptation plans.

1. **Setback Zones and Managed Retreat:** Establishing and enforcing coastal setback zones can reduce exposure to erosion and create space for natural coastal processes. In highly vulnerable areas, managed retreat strategies may be necessary to reduce long-term risks (Rasmussen et al., 2021).
2. **Climate-Resilient Infrastructure:** Upgrading coastal infrastructure to be more resilient to erosion and flooding is crucial. This includes measures such as elevating buildings, improving drainage systems, and designing flexible structures that can adapt to changing conditions (Handayani et al., 2020).
3. **Integrated Coastal Zone Management:** Adopting an integrated approach to coastal planning that

considers the entire coastal system can help balance development needs with erosion management. Bisaro et al. (2020) emphasize the importance of coordinating coastal flood risk reduction measures across different levels of governance.

The effectiveness of these adaptive infrastructure and land-use planning approaches hinges on robust policy frameworks and governance structures. Implementing setback zones, climate-resilient infrastructure, and managed retreat strategies requires strong regulatory support and enforcement mechanisms. No strategy alone will suffice, and thus must build into a holistic integrated coastal zone management framework. Moreover, these approaches must be flexible enough to accommodate the uncertainties inherent in climate change projections. Adaptive pathways planning, as described by Haasnoot et al. (2013), offers a promising framework for developing flexible, long-term adaptation strategies that can be adjusted as new information becomes available.

Transitioning to the next section on sustainable tourism practices, it is clear that the success of adaptive infrastructure and land-use planning in Bali will depend heavily on effective tourism policy implementation and stakeholder engagement. The complex nature of coastal adaptation requires not only technical solutions but also innovative governance approaches that can shape the social, economic, and environmental challenges driven by tourism.

Sustainable Tourism Practices

Integrating sustainable tourism practices into coastal management is essential for Bali, given the island's heavy reliance on tourism as an economic driver. A key strategy is diversifying tourism offerings to limit pressure on eroding beaches. This can involve promoting alternative eco-tourism activities and inland attractions from jungles to temples and volcanoes. For example, Shang et al. (2023) discuss how eco-tourism initiatives can support both environmental conservation and economic development. In Bali, this could include developing guided tours of the island's rice terraces, promoting cultural experiences in inland villages, or creating nature trails in less-visited forested areas. Such diversification not only helps manage coastal impacts but also spreads economic benefits more evenly.

Tourist education and engagement is another critical component of sustainable tourism. Raising awareness among visitors about coastal erosion and encouraging responsible behaviors can help reduce human-induced pressures on beaches. Aziz and Niazi (2023) highlight the importance of developing tourists' environmentally responsible behavior for protecting coastal areas. In Bali, this could involve implementing educational programs at popular beach destinations, creating interactive displays about coastal ecosystems, or developing mobile apps that provide real-time

information about beach conditions and conservation efforts. These initiatives can foster a sense of accountability and stewardship among tourists to encourage more sustainable practices.

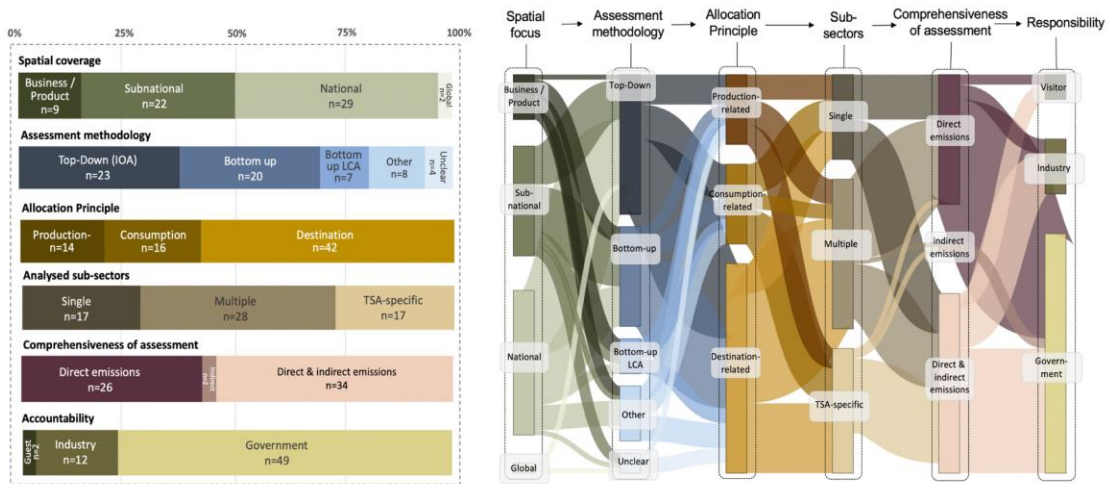
Implementing sustainable beach management practices is crucial for preserving Bali's coastal environments. This includes controlling access to sensitive areas, managing waste effectively, and limiting sediment extraction. Peeters et al. (2024) emphasize the need for comprehensive beach management strategies that balance tourism demands with environmental protection. For Bali, this could involve establishing clear zoning regulations for beach use, implementing advanced waste management systems, and strictly enforcing regulations against illegal sand mining. These measures can help maintain beach integrity while still facilitating tourism industries.

The efficacy of these sustainable tourism practices depends on their integration with broader coastal management strategies. For instance, diversifying tourism offerings can complement adaptive infrastructure approaches by reducing development pressure on vulnerable coastal areas. Similarly, tourist education initiatives can support the implementation of nature-based solutions by fostering public understanding and support. The feasibility of these practices is enhanced by Bali's existing tourism infrastructure and the growing global demand for sustainable travel.

1. **Diversifying Tourism Offerings:** Reducing pressure on eroding beaches by promoting alternative eco-tourism activities and inland attractions can help manage coastal impacts. Shang et al. (2023) discuss how eco-tourism initiatives can support both environmental conservation and economic development.
2. **Tourist Education and Engagement:** Raising awareness among tourists about coastal erosion and encouraging responsible behaviors can help reduce human-induced pressures. Aziz and Niazi (2023) highlight the importance of developing tourists' environmentally responsible behavior for protecting coastal areas.
3. **Sustainable Beach Management:** Implementing best practices for beach management, such as controlling access to vulnerable areas, managing waste, and limiting sand extraction, can help preserve beach environments (Peeters et al., 2024).

Figure 3.

quantitative apportionment review of spatial focus, assessment methodology, allocation principle, sub-sectors, comprehensiveness of assessment, and responsibility



Source: (Gössling et al., 2023)

However, implementing these practices requires overcoming several challenges. These include potential resistance from established tourism operators, the need for significant investment in new infrastructure and programs, and the challenge of changing long-standing tourist behaviors. Addressing these challenges will require strong policy support, innovative financing mechanisms, and collaborative efforts between government agencies, the tourism industry, and local communities.

As Bali works towards more sustainable tourism practices, it is crucial to consider the long-term implications for coastal resilience and economic sustainability. This approach not only helps protect Bali's beaches but also positions the island as a leader in sustainable tourism, potentially attracting a new segment of environmentally conscious travelers. Moreover, by reducing pressure on coastal areas, these practices can complement and enhance the effectiveness of other coastal adaptation strategies, creating a more holistic and resilient approach to coastal management.

Transitioning to the next section on monitoring and adaptive management, it is clear that the success of sustainable tourism practices, like other coastal management strategies, will depend on robust systems for monitoring their impacts and adjusting approaches as needed. Regular assessment of tourist behaviors, beach conditions, and economic indicators will be crucial for ensuring that these practices effectively contribute to Bali's overall coastal resilience strategy.

Monitoring and Adaptive Management

Effective coastal erosion management and sustainable eco-tourism development in Bali

require robust monitoring systems and adaptive management approaches. Recent advances in remote sensing and GIS technologies offer new opportunities for comprehensive coastal monitoring in Bali. High-resolution shoreline mapping using PlanetScope imagery, as demonstrated by Hastuti et al. (2024), allows for more frequent and accurate monitoring of erosion patterns up to 3-meters, providing unprecedented detail in tracking coastal dynamics. Implementing such a system across Bali's coastline would allow authorities to identify erosion hotspots quickly and prioritize intervention efforts.

Integrating multiple data sources into comprehensive vulnerability assessments is crucial for informed decision-making. Areia et al. (2023) emphasize the importance of incorporating public perceptions and preferences into coastal risk management strategies. In Bali, this could involve regular surveys of local communities and tourists to gauge their awareness of coastal risks and preferences for adaptation measures. Combining this social data with physical measurements of shoreline change, wave dynamics, and sea level rise can provide a holistic view of coastal vulnerability. Such integrated assessments can help identify areas where ecological, economic, and social vulnerabilities intersect, allowing for more targeted and effective interventions.

Developing early warning systems for extreme events and erosion hotspots is another critical component of adaptive management. Adedara et al. (2024) discuss the potential of advanced warning systems to support proactive coastal management. For Bali, this could involve implementing a network of wave buoys, tide gauges, and coastal cameras to provide real-time data on coastal conditions. When combined with predictive models, such a system could alert authorities to impending erosion events or flood risks, allowing for timely evacuation and protection measures.

Adaptive management frameworks that allow for flexible responses to changing conditions and new information are crucial. Edwards et al. (2019) discuss the potential of adaptive governance tools, such as role-playing games, to support decision-making in complex coastal systems. In Bali, this could involve regular stakeholder workshops where policymakers, tourism operators, and community leaders use scenario-planning tools to explore potential future coastal changes and adaptation strategies. These exercises can build shared understanding and facilitate more agile policy responses to emerging coastal threats.

The effectiveness of these monitoring and adaptive management approaches hinges on building local capacity and ensuring long-term commitment. This requires investment in training programs for local officials and community members on coastal monitoring techniques and data interpretation. It also necessitates stable funding mechanisms to maintain monitoring systems and

support ongoing research. Prabhakar et al. (2024) highlight the importance of integrating climate change adaptation into local development planning. For Bali, this could involve mandating that all coastal development projects include provisions for long-term monitoring and adaptive management.

1. **High-Resolution Shoreline Mapping:** Hastuti et al. (2024) demonstrated the use of high-resolution PlanetScope imagery for detailed shoreline change analysis in Bali. This approach allows for more frequent and accurate monitoring of erosion patterns.
2. **Integrated Vulnerability Assessments:** Combining physical, ecological, and socio-economic data in comprehensive vulnerability assessments can inform targeted interventions. Areia et al. (2023) emphasize the importance of integrating public perceptions and preferences into coastal risk management strategies.
3. **Early Warning Systems:** Developing early warning systems for extreme events and erosion hotspots can support proactive management and reduce risks to coastal assets (Adedara et al., 2024).

Adaptive management frameworks crucially allow for prompt and precise responses to changing conditions. Edwards et al. (2019) discuss the potential of adaptive governance tools, such as role-playing games, to support decision-making in complex coastal systems.

As Bali moves towards more comprehensive coastal monitoring and adaptive management, it is crucial to consider the long-term implications for coastal resilience and sustainable tourism. This approach not only helps protect Bali's beaches but also positions the island as a leader in large data-centric sustainable coastal management, potentially attracting a new segment of environmentally conscious travelers. Moreover, by providing a robust evidence base for decision-making, these systems can enhance the credibility and effectiveness of coastal policies, potentially increasing public and political support for necessary adaptation measures.

Transitioning to the next section on financing and implementation, it is clear that the success of monitoring and adaptive management strategies in Bali will depend heavily on securing adequate funding and developing effective governance structures. The data and insights generated through comprehensive monitoring will be crucial for justifying investments in coastal protection and identifying the most cost-effective adaptation strategies. Furthermore, the adaptive management approach provides a framework for continuously evaluating and adjusting these investments as conditions change and new information becomes available.

Financing and Implementation

Implementing sustainable coastal erosion interventions and eco-tourism development in Bali will require significant financial resources and innovative funding mechanisms. One potential approach is the development of public-private partnerships (PPPs) that engage the tourism industry in funding and implementing coastal protection measures. As demonstrated by Toimil et al. (2023), PPPs can leverage additional resources and expertise from the private sector to complement public investments in coastal adaptation. In Bali, this could involve collaborations between local government agencies and major hotel chains or tour operators to jointly fund beach nourishment projects or mangrove restoration efforts. Such partnerships could be particularly effective given the tourism industry's vested interest in maintaining attractive and resilient coastal areas.

Another promising financing avenue is accessing international climate finance and exploring green bond issuance. Ali et al. (2024) highlight the potential of green bonds to fund large-scale coastal adaptation projects. For Bali, issuing a dedicated "Coastal Resilience Bond" could attract impact investors interested in supporting sustainable tourism and climate adaptation. The bond's proceeds could be earmarked for a portfolio of nature-based coastal protection measures and eco-tourism infrastructure improvements. This approach could tap into the growing market for sustainable finance while providing a stable funding source for long-term adaptation efforts.

Quantifying the economic value of coastal ecosystem services, including erosion protection, can help justify investments in nature-based solutions. Toimil et al. (2023) demonstrate how valuing these services can inform cost-benefit analyses of different adaptation strategies. In Bali, conducting a comprehensive valuation of beach and mangrove ecosystem services could provide compelling evidence for increased public and private investment in their conservation and restoration. This economic case could be particularly persuasive for local policymakers and business leaders concerned about the long-term viability of the tourism sector. Implementing these financing strategies will require building capacity at multiple levels of governance. Kasim (2021) emphasizes the need for enhancing local government capacity in coastal management planning and implementation in Indonesia. For Bali, this could involve targeted training programs for provincial and regency-level officials on topics such as climate finance, project evaluation, and adaptive management. Strengthening local capacity will be crucial for effectively deploying and managing adaptation funds over time.

The feasibility and efficacy of these financing approaches depend on several factors. Public-private partnerships require a supportive regulatory environment and clear mechanisms for risk-sharing between public and private entities. Green bond issuance necessitates a robust financial

infrastructure and credible reporting on the use of proceeds and impact metrics. Ecosystem service valuation demands reliable scientific data and methodologies adapted to the local context. Despite these challenges, successful examples from other coastal regions suggest that these approaches can be effectively implemented with proper planning and stakeholder engagement.

As Bali moves towards implementing these financing strategies, it will be crucial to consider their long-term implications for coastal governance and sustainable development. The influx of new funding sources and implementation partners may necessitate new coordination mechanisms and accountability frameworks. Moreover, the focus on economic valuation and market-based instruments should be balanced with considerations of social equity and cultural preservation, given the importance of coastal areas to Balinese identity and traditional livelihoods.

1. **Public-Private Partnerships:** Engaging the private sector, particularly the tourism industry, in funding and implementing coastal protection measures can leverage additional resources (Toimil et al., 2023).
2. **Green Bonds and Climate Finance:** Accessing international climate finance and exploring green bond issuance can provide funding for large-scale coastal adaptation projects (Ali et al., 2024).
3. **Ecosystem Service Valuation:** Quantifying the economic value of coastal ecosystem services, including erosion protection, can help justify investments in nature-based solutions (Toimil et al., 2023).

Successful implementation will also require capacity building at multiple levels of governance. Kasim (2021) highlights the need for enhancing local government capacity in coastal management planning in Indonesia.

It is clear that robust systems for evaluating the effectiveness of financed interventions will be essential. The success of innovative financing mechanisms will depend on demonstrating tangible improvements in coastal resilience and sustainable tourism outcomes. Establishing clear metrics and adaptive management processes will be crucial for maintaining stakeholder confidence and ensuring that financial resources are deployed efficiently to address Bali's evolving coastal challenges.

Conclusions

Addressing coastal erosion in Bali requires a holistic, adaptive approach that integrates nature-based solutions, sustainable infrastructure, and responsible tourism practices. This study has demonstrated that an integrated coastal zone management (ICZM) approach, combining organic solutions, adaptive governance, and sustainable tourism practices, offers the most promising

framework for addressing coastal erosion while supporting Bali's eco-tourism sector. The analysis of shoreline changes, flood risks, and economic impacts underscores the urgency of implementing coordinated policy interventions across multiple scales of governance.

The efficacy of this integrated approach is evident in its ability to address the complex, interconnected challenges facing Bali's coastline. Nature-based solutions, such as mangrove restoration and beach nourishment, have shown significant potential in enhancing coastal resilience while providing co-benefits for biodiversity and local livelihoods (Riechers et al., 2021). These solutions are particularly feasible in Bali due to the island's rich coastal ecosystems and the cultural value placed on natural environments. Adaptive governance mechanisms, as highlighted by Zhang et al. (2024), enable flexible responses to changing coastal conditions and new information. This approach is crucial for Bali, given the uncertainties associated with climate change impacts and the dynamic nature of coastal systems. The integration of sustainable tourism practices into coastal management strategies is not only environmentally necessary but also economically viable. As demonstrated by the analysis of recreational benefits, maintaining beach width through nature-based interventions can yield substantial economic returns (Toimil et al., 2023). Bali's economic reliance on tourism and provides a strong incentive for both public and private sector investment in coastal protection. However, the successful implementation of this integrated approach hinges on overcoming several challenges. First, there is a need for enhanced coordination between different levels of government and across sectors. The establishment of a dedicated coastal management authority, as suggested by Bisaro et al. (2020), could facilitate this coordination. Second, building local capacity for coastal management and monitoring is crucial. This includes training programs for local officials and community members on coastal monitoring techniques and data interpretation, as emphasized by Kasim (2021).

Looking ahead, several key areas require further research and policy attention. First, developing high-resolution climate change projections specific to Bali is essential for improving long-term planning. This would enable more accurate assessments of future flood risks and shoreline changes, allowing for more targeted interventions. Second, evaluating the effectiveness and cost-benefit ratios of different intervention strategies in the Bali context is crucial. This includes not only immediate flood protection benefits but also long-term impacts on tourism, local livelihoods, and ecosystem services. Finally, exploring innovative governance models that can better integrate scientific knowledge, local expertise, and stakeholder perspectives in coastal management decisions is vital. This could involve developing participatory decision-making processes that engage local

communities, tourism operators, and environmental organizations in coastal planning and management. In conclusion, by adopting an integrated, science-based approach to coastal erosion management, Bali can work towards a more resilient and sustainable future for its coastal ecosystems and tourism-based economy. This approach not only addresses immediate erosion and flood risks but also positions Bali as a leader in sustainable coastal management, potentially attracting environmentally conscious tourists and investors. The success of this approach in Bali could serve as a model for other coastal tourism destinations facing similar challenges, contributing to global efforts in sustainable coastal management and climate change adaptation.

Future research directions should focus on:

1. Developing high-resolution climate change projections specific to Bali to improve long-term planning.
2. Evaluating the effectiveness and cost-benefit ratios of different intervention strategies in the Bali context.
3. Exploring innovative governance models that can better integrate scientific knowledge, local expertise, and stakeholder perspectives in coastal management decisions.

Methodology disclosure

This conference paper was drafted using a combination of human writing and AI-assisted language models. The overall structure, key arguments, and core content were developed by the human author based on analysis of the provided literature sources. AI language models (GPT-3.5) was then used to assist with expanding certain sections, generating additional supporting text, and improving the overall flow and coherence of the paper. The AI outputs were carefully reviewed, revised, and edited, and integrated by the human author to ensure accuracy and alignment with the intended arguments. This hybrid approach aimed to enhance the efficiency of the drafting process while maintaining human oversight and authorship of the substantive content and conclusions.

Discussion note from author

The findings of this study underscore the urgent need for comprehensive coastal policy interventions in Bali to prevent the island from facing consequences similar to those already evident in other Indonesian cities, most notably Jakarta. Indonesia's decision to relocate its capital from Jakarta to Kalimantan is primarily driven by compounding climate change stressors, including severe coastal erosion and flooding. Bali must heed this cautionary tale and take swift action to protect its coastlines. Bali could not resort to the option of relocating its foundations without catastrophic consequences for its eco-tourism industry and, more critically, its rich cultural heritage. The island's

identity, economy, and way of life are inextricably linked to its coastal areas. Failing to implement robust coastal protection and sustainable development policies could lead to irreversible damage to Bali's beaches, marine ecosystems, and coastal communities. This would not only devastate the tourism sector but also erode the cultural practices and traditions that are deeply rooted in Bali's coastal landscapes. The time for decisive action is now – Bali must prioritize innovative, nature-based solutions and strict coastal management practices to ensure its resilience against the mounting threats of climate change and anthropogenic pressures. Only through immediate and sustained intervention can Bali safeguard its coastal treasures for future generations and maintain its status as a world-renowned island paradise.

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