



Siri' na Pacce cultural transformation and blue economy for social and cultural resilience towards the golden generation of 2045

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ABSTRACT

Background: This study develops a conceptual model that integrates maritime cultural revitalization and indigenous ethics with digital transformation and sustainable economic strategies to address the socio-ecological threats faced by the Patorani fishing community. By bridging traditional values and modern innovations, this study provides a strategic framework for coastal resilience that is aligned with Indonesia's Golden Generation 2045 vision. **Methods:** This article employs a structured, integrative literature review that synthesizes existing scholarship on maritime heritage, community ethics, digital innovation, blue economy frameworks, and coastal sustainability. Relevant theoretical perspectives were identified and analyzed to establish linkages between cultural systems, technological adaptation, and socioeconomic development. Unlike empirical studies, this conceptual work aims to consolidate theoretical components, identify gaps in current literature, and propose an interdisciplinary framework for coastal resilience. **Findings:** The review reveals that maritime traditions are experiencing significant erosion due to environmental pressures such as declining fish stocks, pollution, and coastal degradation, as well as socio-cultural challenges including shifting generational preferences and the commodification of cultural symbols. Despite these pressures, the indigenous ethical framework of *Siri' na Pacce* remains a strong yet underutilized form of moral capital that can guide ethical innovation, social cohesion, and community-based governance. Digital technologies such as e-commerce, digital storytelling, virtual cultural festivals, and online knowledge platforms offer new opportunities to strengthen youth engagement, expand economic access, and revitalize cultural identity. The integration of technologically driven practices with cultural ethics and blue economy principles shows strong potential to enhance livelihood sustainability and ecosystem stewardship. **Conclusion:** The study concludes that sustainable coastal development must be culturally grounded, technologically adaptive, and environmentally responsible to remain relevant in the contemporary era. **Novelty/Originality of this article:** The primary novelty of this research lies in its formulation of the Patorani 5.0 model, which for the first time unites cultural revitalization, ethical values, digital transformation, and blue economy strategies into an integrated conceptual framework, addressing scholarly gaps that previously treated these domains in isolation.

KEYWORDS: *Siri' na Pacce*; blue economy; coastal cultural sustainability.

1. Introduction

Indonesia is the world's largest archipelagic country with a coastline of over 108,000 kilometers and a marine area covering approximately two-thirds of the nation's total area. This potential makes Indonesia a center of marine biodiversity and a global maritime

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economy (Fauzi et al., 2023). Its strategic location between two oceans and two continents strengthens Indonesia's position as the world's maritime axis, as emphasized in the Golden Indonesia 2045 vision, which positions the maritime sector as a pillar of national economic, cultural, and social development (Wattimena et al., 2025; Ujiti et al., 2024). However, the reality on the ground shows a contradiction between the enormous potential and actual conditions. Coastal ecosystem degradation, declining marine environmental quality, and overexploitation of fishery resources pose serious challenges to the sustainability of the blue economy (Kusumadewi, 2024 ; Widayanti et al., 2022).

Beyond its quantitative potential, Indonesia's maritime domain also holds strategic qualitative value as a foundation for long-term national resilience. Marine ecosystems provide essential ecosystem services, including food security, coastal protection, climate regulation, and livelihoods for millions of coastal residents. Coral reefs, mangroves, and seagrass meadows function not only as biodiversity hotspots but also as natural infrastructure that supports fisheries productivity and mitigates climate-related risks such as storm surges and coastal erosion. In this sense, the sustainability of Indonesia's marine resources is inseparable from broader economic stability, social welfare, and national security. However, the acceleration of extractive activities without adequate governance frameworks has weakened these ecological support systems, reducing their capacity to sustain both environmental balance and human well-being.

Moreover, the contradiction between Indonesia's maritime potential and on-the-ground realities reflects structural governance challenges in the management of marine resources. The fragmentation of marine policy implementation, limited coordination between central and regional authorities, and the dominance of growth-oriented development paradigms have often prioritized short-term economic outputs over long-term sustainability. As a result, marine development initiatives frequently fail to integrate ecological considerations with socio-cultural dimensions, particularly the needs and values of coastal communities. This condition undermines the core principles of the blue economy, which emphasize efficiency, inclusivity, and ecosystem integrity as mutually reinforcing goals rather than competing interests.

In addition, global environmental change has intensified these internal challenges. Climate change-driven phenomena such as rising sea surface temperatures, shifting fish migration patterns, extreme weather events, and sea-level rise increasingly disrupt traditional fishing practices. These dynamics disproportionately affect small-scale and traditional fishers who rely heavily on predictable ecological rhythms and possess limited adaptive capacity. Consequently, the promise of Indonesia's maritime vision cannot be realized solely through technological advancement or economic expansion, but requires a holistic approach that strengthens ecological governance, social inclusion, and cultural resilience simultaneously. In this context, the sustainability of the blue economy depends not only on resource availability, but also on the capacity of coastal societies to adapt, innovate, and preserve their maritime identity within a rapidly changing global environment.

As a result, poverty levels in coastal areas remain high, with small-scale fishers facing limited access to capital, technology, and markets (Diantara et al., 2021; Hanri et al., 2023). In addition, social transformations resulting from modernization and climate change have weakened the younger generation's attachment to local maritime culture, including the loss of traditional practices such as sea sasi and coastal customs (Ridwan et al., 2025). Several studies highlight the importance of a local wisdom-based coastal community empowerment approach and economic diversification through sustainable marine tourism and blue jobs to strengthen community welfare while maintaining ecosystem sustainability (Hatidja & Sulana, 2025.; Mortelliti & Meng, 2025). This situation emphasizes the gap between the wealth of Indonesia's marine natural resources and the socio-economic capabilities of coastal communities to manage them inclusively and sustainably. Therefore, an adaptive, ecosystem-based, and local-community-friendly blue economy policy is a key prerequisite for realizing Indonesia's maritime resilience towards *Indonesia Emas 2045* (Jokhu et al., 2025; Pangabean et al., 2025).

The persistence of poverty and cultural erosion in coastal communities indicates that economic constraints and socio-cultural vulnerabilities are deeply interconnected. Limited access to capital and markets not only restricts income opportunities for small-scale fishers, but also reduces their capacity to invest in sustainable practices, technological adaptation, and intergenerational knowledge transfer. When livelihoods are unstable, younger generations tend to perceive maritime occupations as economically unviable and socially marginal, accelerating occupational shifts toward urban and non-maritime sectors. This dynamic weakens the continuity of local maritime knowledge systems and erodes collective identities that once functioned as adaptive mechanisms in managing coastal resources.

Furthermore, modernization processes in coastal areas often unfold in a top-down manner, emphasizing infrastructure expansion, commercialization, and industrial productivity while overlooking the socio-cultural fabric of local communities. In many cases, development interventions treat coastal societies merely as economic actors rather than custodians of ecological knowledge and cultural heritage. As a consequence, traditional governance mechanisms and local wisdom practices such as customary marine tenure, seasonal fishing norms, and ritual-based ecological regulation are marginalized or replaced by standardized regulatory frameworks that are less responsive to local environmental contexts. This disconnect contributes to policy inefficiencies and limits the effectiveness of blue economy initiatives at the grassroots level.

The growing literature on coastal development increasingly underscores that economic diversification through sustainable tourism, blue jobs, and creative marine-based enterprises can only be effective when embedded within community-led frameworks. Local wisdom functions not merely as cultural symbolism, but as practical knowledge that shapes risk management, resource stewardship, and social cooperation. When integrated into development strategies, these values enhance community ownership, strengthen social cohesion, and improve adaptive capacity in the face of environmental change. Therefore, bridging the gap between marine resource wealth and socio-economic capability requires more than sectoral policy reform; it demands a governance paradigm that places local communities at the center of planning, implementation, and benefit distribution.

In this regard, the pursuit of Indonesia's maritime resilience toward the Golden Generation 2045 must be grounded in transformative approaches that align ecological sustainability with social justice and cultural continuity. Without reinforcing human capital, ethical norms, and cultural identity, investments in the blue economy risk reinforcing inequality and dependency rather than empowerment. This condition creates a critical transition point that necessitates innovative frameworks capable of harmonizing technological progress with local values setting the stage for broader systemic transformation in the era of Society 5.0.

The transformation towards Society 5.0 demands the integration of digital technology and humanitarian values, opening up opportunities for increased efficiency in fisheries production, digital marketing, and coastal economic resilience (Ordóñez de Pablos et al., 2024; Prihatiningtyastuti et al., 2025). However, unsustainable modernization risks eroding local cultural values and the maritime identity of coastal communities (Haqi et al., 2025; Latief & Wijaya, 2025). Therefore, a digital transformation based on local culture is needed to ensure that Society 5.0 also strengthens the social and cultural sustainability of Indonesia's coastal areas (Handayani & Ibrahim, 2025).

Makassar and its surrounding coastal areas, as the center of Eastern Indonesia's maritime history, are a prime example of this change. This region is known as home to traditional Bugis-Makassar fishing communities, one of which is the Patorani flying fish hunters, who inherit strong ecological knowledge and values of solidarity. However, in the past two decades, the sustainability of this tradition has been threatened. As experienced by traditional fishermen in Makassar in general, this community has been increasingly marginalized due to the pressures of industrialization of fisheries and the dominance of modern fleets that often trigger conflicts over fishing space. These challenges are exacerbated by technological modernization that is squeezing out local wisdom and

increasing pressures for resource exploitation that threaten the preservation of this maritime cultural heritage (Handayani & Ibrahim, 2025).

Behind the Patorani tradition lies the noble value of *Siri' na Pacce*, a Bugis-Makassar philosophy that includes the concept of self-esteem (*siri'*), empathy, and social solidarity (*pacce*). This value has long functioned as social capital that regulates work ethics, a sense of responsibility, concern for others, and becomes a collective mechanism in facing ecological and social challenges (Gani & Gani, 2024; Wiryadinata, 2024). A number of studies confirm that *Siri' na Pacce* plays an important role in shaping the leadership character and social integrity of the younger generation (Reski et al., 2021). In the maritime sector, this value becomes social capital that supports the sustainability of coastal resources (Rahim & Hastuti, 2023). However, studies that integrate *Siri' na Pacce* as the ethical foundation of the next generation in the digital-based Blue Economy ecosystem are still limited, so this research has a strong urgency and state of the art.

Despite its deep-rooted significance, the operationalization of *Siri' na Pacce* in contemporary development frameworks remains largely normative rather than instrumental. In many policy and academic discourses, local values are acknowledged symbolically but are rarely translated into actionable ethical guidelines that shape economic decision-making, technological adoption, or institutional governance. As a result, *Siri' na Pacce* often remains confined to cultural narratives and moral discourse, rather than functioning as a living ethical system capable of guiding adaptive responses to modernization and globalization pressures. This gap is particularly evident in maritime governance, where efficiency-driven and market-oriented approaches tend to dominate, leaving limited space for value-based considerations grounded in indigenous moral systems.

The transformation of coastal societies in the digital era further intensifies this challenge. Rapid exposure to global cultural flows, digital media, and individualistic economic models has reshaped the value orientation of younger generations, often weakening collective ethics such as solidarity, mutual responsibility, and ecological restraint. Without deliberate efforts to reinterpret and contextualize *Siri' na Pacce* within contemporary realities, local ethical systems risk losing relevance among youth who increasingly associate success with urban, technology-driven lifestyles rather than community-based maritime livelihoods. This condition underscores the importance of repositioning *Siri' na Pacce* not as a relic of the past, but as a dynamic moral framework capable of guiding ethical innovation, leadership formation, and sustainable behavior in a rapidly transforming society.

Moreover, embedding *Siri' na Pacce* into future-oriented development agendas offers an opportunity to bridge the gap between cultural heritage and modern governance. When articulated as ethical capital, these values can inform principles of fairness, accountability, environmental stewardship, and collective benefit principles that are directly aligned with sustainability discourse. In this sense, *Siri' na Pacce* provides a culturally grounded ethical foundation upon which new maritime development paradigms can be constructed. This ethical grounding becomes particularly critical when indigenous values are expected to coexist with efficiency-driven economic models, technological transformation, and global sustainability frameworks, thus creating a conceptual entry point toward the integration of local ethics with broader blue economy principles.

At the same time, the concept of the blue economy has emerged as a maritime development paradigm that emphasizes the sustainable, efficient, environmentally friendly, and welfare-oriented use of marine resources (Wuwung et al., 2024). This approach shifts the perspective from marine exploitation to conservation-based management and technological innovation. In the Indonesian context, the blue economy concept is seen as strategic for bridging the dualism between economic growth and marine ecosystem preservation, while strengthening inclusive maritime governance. However, a number of studies show that its implementation is often technocratic and tends to marginalize local knowledge, thus hindering the effectiveness of its inclusive implementation at the community level (Effendy et al., 2024; Ramadhan et al., 2025).

In response to this gap, this study proposes the concept of Patorani 5.0, a conceptual model that synergizes the cultural values of *Siri' na Pacce*, Patorani maritime traditions, the blue economy, and digital technology. This concept emphasizes that cultural preservation needs to shift from mere symbolic protection to adaptive revitalization through the integration of digital media and the creative economy (Yudistia et al., 2025). Strengthening the competitiveness of coastal communities is carried out through an integrated digital blue economy ecosystem (Perdana et al., 2025) with innovations such as digital cultural storytelling, a marine product e-commerce platform (E-Blue), and the transformation of traditions into value-added products (Nugraha et al., 2025). The sustainability aspect is also strengthened through a maritime educulture model that instills local wisdom in coastal entrepreneurship (Zamzami et al., 2025).

Although several studies have discussed the blue economy or maritime cultural revitalization separately, (Wuwung et al., 2024) no study has comprehensively developed an integrative framework linking maritime culture, *Siri' na Pacce* values, character education, and the blue economy in the context of Society 5.0. This creates an important research gap, namely the absence of a conceptual model that integrates cultural transformation and technological innovation to strengthen the socio-cultural resilience of coastal communities towards the vision of the Golden Generation 2045. Thus, this article aims to analyze the relevance of Patorani culture and *Siri' na Pacce* values in the context of modern maritime development; offer a conceptual model of Patorani 5.0 as a transformative approach in developing a culture-based blue economy; and explain how the integration of culture, technology, and the blue economy can strengthen the social and cultural resilience of coastal communities towards the Golden Generation 2045. This article contributes to the literature by providing a new conceptual framework that connects local culture and the sustainable development paradigm within the Society 5.0 framework, and shows how local wisdom values can become the foundation of inclusive and sustainable maritime development policies.

2. Methods

This study uses a systematic-conceptual review approach *that* aims to synthesize and integrate various theoretical and empirical knowledge regarding maritime culture, blue economy principles, and the philosophical values of *Siri' na Pacce* in the context of coastal resilience and the development agenda towards the Golden Generation of Indonesia 2045. This approach does not involve primary data collection, but rather relies entirely on literature synthesis as a methodological strategy to bridge fragmented concepts into a new integrative framework (Jaakkola, 2020). Methodologically, this study is based on an interpretivist paradigm, which views cultural identity, maritime traditions, and community resilience as constructive and contextual social realities, formed through historical, ecological, and local value interactions. Within this framework, an interpretivist ontology is used to understand the meaning of maritime culture as a result of social construction, while a constructivist epistemology is adopted to enable the integration of various cross-disciplinary theoretical perspectives in building a new conceptual framework (Alharahsheh & Pius, 2020)

The literature review in this study was compiled through a systematic literature search and identification process to obtain various scientific works relevant to the research focus. This process involves the stages of searching, filtering, and evaluating literature based on the suitability of the theme, contribution to concept development, and relevance to the conceptual direction of the study. The keywords used in the search include various terms that represent the main topics of the research, including maritime culture, *Siri' na Pacce*, blue economy, coastal resilience, and cultural transformation. The search results were then critically reviewed to ensure reliability, academic validity, and theoretical relevance to the research objectives. Overall, 50 scientific works published between 2010 and 2025 were selected as the main conceptual basis in compiling this literature review.

Data analysis was conducted interpretively by referring to the interactive model (Miles et al., 2014). which includes data condensation, data presentation, as well as drawing conclusions and verification. This process is in line with the interpretivist–constructivist paradigm that emphasizes meaning through contextual interpretation. Literature data was coded into main themes such as maritime culture, *Siri' na Pacce*, blue economy, coastal digital innovation, and cultural transmission, then arranged in a conceptual matrix to map the interrelationships of cultural, ecological, technological, and socio-economic dimensions, resulting in a new conceptual framework that reflects the integration of cultural values and coastal sustainability.

Next, conclusions were drawn through an iterative verification process by comparing patterns emerging from various sources and theoretical perspectives. This interpretive synthesis resulted in the development of the Patorani 5.0 conceptual model, which integrates cultural revitalization, digital transformation, and blue economy principles. Throughout the methodological process, the accuracy and reliability of the results were maintained through strict citation practices and adherence to the review protocols established at the outset of the study. Because this research is entirely based on a literature review, ethical approval was not required. However, all sources used have been appropriately cited, and methodological transparency has been maintained to allow for replication or development by future researchers. The narrative presentation of the methods follows the IASSSF template, which does not require numbered subsections but emphasizes a coherent and integrated methodological explanation within a well-structured narrative.

3. Results and Discussion

3.1 Overview of maritime cultural dynamics

Makassar has long been known as a major maritime center in Eastern Indonesia, with a strong seafaring tradition in communities such as the Patorani and fishermen in the Sangkarrang Islands, which reflects the Bugis-Makassar cultural identity based on local ecological knowledge (Nur et al., 2023). This maritime culture not only supports the coastal economy, but also forms the foundation of social cohesion in the community (Syafruddin et al., 2024). However, modernization, urban migration, and shifting job preferences have triggered a transformation of cultural values and practices, resulting in a decline in the participation of the younger generation in traditional sailing and fishing activities, thus demanding a revitalization of the identity and socio-cultural resilience of coastal communities (David & Adi, 2025; Saputra et al., 2024).

Environmental pressures are accelerating the decline of this maritime culture. Coastal erosion, changing fish migration patterns, marine pollution, and coastal resource degradation have disrupted traditional fishing routes and weakened the ecological foundations that underpin maritime practices (Nguyen et al., 2024; Siriwardane-de Zoysa et al., 2025). As ecological systems become unstable, the cultural systems that depend on them also lose continuity and sustainability. At the same time, cultural rituals and maritime symbols are increasingly commodified in the coastal tourism industry, making preservation more symbolic than substantive (Ramadhani et al., 2025).

Despite facing various challenges, the results of this review indicate the emergence of new adaptive practices that reflect cultural resilience. The younger generation is beginning to reinterpret maritime identity through digital storytelling, community-based environmental initiatives, and creative economic activities rooted in relationships with the sea. These changes indicate that maritime culture is not completely disappearing, but rather transforming into new forms that integrate tradition with contemporary values. These cultural dynamics emphasize the need for a strategic framework such as Patorani 5.0 to revitalize maritime heritage in the context of the blue economy and the demands of the 5.0 era.

From a socio-anthropological perspective, the transformation of maritime culture in Makassar reflects a broader process of cultural reconfiguration shaped by structural economic change and shifting aspirations. Maritime activities that were once regarded as honorable and identity-defining occupations are increasingly perceived as labor-intensive, uncertain, and lacking upward mobility. This perception is reinforced by unequal access to education, digital infrastructure, and alternative livelihood pathways in coastal areas. Consequently, cultural disconnection is not merely a matter of declining interest, but is embedded within broader socio-economic inequalities that limit the attractiveness of maritime livelihoods for younger generations.

In addition, the weakening of maritime cultural practices has implications beyond the cultural domain, extending into environmental governance and resource sustainability. Traditional maritime knowledge systems embedded within daily fishing practices historically functioned as informal regulatory mechanisms that controlled harvesting intensity, protected spawning grounds, and maintained ecological balance. As these practices erode, coastal communities increasingly rely on external regulatory systems that are often less adaptive and less sensitive to local ecological contexts. This shift reduces community autonomy in resource management and weakens the feedback loops between cultural norms and environmental stewardship.

The literature reviewed also indicates that cultural resilience is not a spontaneous process, but one that requires supportive institutional and policy environments. Grassroots initiatives such as digital documentation of maritime heritage, community-based conservation programs, and creative marine enterprises demonstrate promising adaptive responses, yet their sustainability remains fragile without structural support. When cultural revitalization is not systematically linked to economic incentives and governance frameworks, adaptive practices risk remaining isolated and symbolic. Therefore, sustaining maritime culture in Makassar necessitates an integrated strategy that aligns cultural expression, livelihood security, and ecological responsibility.

These conditions highlight that the transformation of maritime culture should be understood as an arena of negotiation between tradition and modernity rather than a linear process of decline. The emergence of hybrid cultural forms where digital media, youth creativity, and ecological awareness intersect suggests the potential for reimagining maritime identity in ways that resonate with contemporary social realities. This dynamic context reinforces the relevance of a framework such as Patorani 5.0, which conceptualizes cultural revitalization as a transformative process that integrates heritage, innovation, and sustainability within the blue economy paradigm.

3.2 Cultural values of *Siri' na Pacce* as social and moral capital

The *Siri' na Pacce* value system forms the ethical foundation of Bugis–Makassar society, fostering communal solidarity, moral responsibility, and social integrity. *Siri'* emphasizes self-respect and honor, while *Pacce* reflects empathy and collective resilience. These values function as social capital and economic morality that strengthen group cohesion and guide ethical behavior in the socio-economic life of Bugis–Makassar society (Damayanti et al., 2024). In maritime communities, *Siri' na Pacce* plays a crucial role in maintaining cooperation and fishing ethics. Among Patorani fishermen, *Pacce* fosters solidarity during risky voyages, while *Siri'* encourages honesty and respect for ecological boundaries (Ahmadin, 2025). These values not only maintain the sustainability of fishing grounds, but are also adaptive to modern environmental challenges, reflecting traditional ecological ethics that align with blue economy initiatives, such as culture-based marine waste management (Prusdianto et al., 2025).

Various aspects of *Siri' na Pacce* are now experiencing cultural erosion, especially among the younger generation who are influenced by digital lifestyles, urban culture, and individualistic values. The weakening of intergenerational cultural transmission has caused the fragmentation of collective mindsets that once supported maritime life. Recent studies show that the dominance of social media has given rise to shallow and fragmented cultural

understandings, thus eroding the deep meaning of self-esteem and solidarity in *Siri' na Pacce* (Zhafirah et al., 2025). This shift has also weakened social cohesion and coastal cultural identity, marking the transformation of the meaning of *Siri' na Pacce* values from its collective essence in Bugis–Makassar society (Rahmi et al., 2025).

However, research findings indicate that revitalizing *Siri' na Pacce* values is still very possible if integrated with a contemporary framework. In the context of Patorani 5.0, these cultural values can be repositioned as moral capital to strengthen social resilience, encourage ethical blue economy practices, and increase the participation of the younger generation. By integrating *Siri' na Pacce* into digital storytelling, community education, and cultural entrepreneurship, coastal communities can reinterpret traditional ethics to align with modern aspirations. This adaptive approach positions *Siri' na Pacce* not as a static legacy of the past, but as the foundation for the formation of a cultured, socially cohesive, and future-ready generation.

From a theoretical perspective, *Siri' na Pacce* can be understood as a form of endogenous moral governance that regulates behavior through internalized ethical norms rather than formal institutions. Unlike externally imposed regulations, these values operate through social sanctions, collective reputation, and interpersonal responsibility, making them highly effective in small-scale maritime communities. This mechanism explains why *Siri' na Pacce* historically functioned not only as cultural identity, but also as an informal regulatory system that balanced economic activity with ecological restraint. Such characteristics align with contemporary discussions on value-based governance and community-led sustainability, highlighting the relevance of indigenous moral frameworks in strengthening social and environmental accountability.

Within the context of maritime livelihoods, *Siri' na Pacce* also contributes to risk-sharing mechanisms and collective survival strategies. Fishing activities particularly those undertaken by Patorani communities are characterized by high uncertainty and environmental risk. *Pacce* encourages mutual assistance, emotional solidarity, and collective endurance, while *Siri'* reinforces trust, reliability, and accountability among crew members. These elements reduce transaction costs, strengthen cooperation, and enhance adaptive capacity in the face of ecological shocks. Consequently, the erosion of these values has implications not only for cultural identity but also for the resilience of coastal economic systems.

The reinterpretation of *Siri' na Pacce* in the digital era offers both challenges and opportunities. While digital lifestyles may weaken traditional modes of value transmission, they also provide new platforms for ethical socialization. Digital storytelling, virtual community forums, and culturally grounded content creation can function as contemporary channels for transmitting ethical narratives rooted in *Siri' na Pacce*. When framed within creative economies and digital entrepreneurship, these values can be translated into ethical branding, trust-based market relations, and socially responsible coastal enterprises. This process transforms moral heritage into a strategic asset rather than a symbolic constraint.

In this regard, the incorporation of *Siri' na Pacce* within the Patorani 5.0 framework represents a critical shift from cultural preservation toward ethical innovation. By embedding indigenous moral values into digital ecosystems and blue economy practices, Patorani 5.0 reframes local wisdom as a functional component of sustainability and development. This integration not only strengthens intergenerational continuity but also positions *Siri' na Pacce* as a guiding ethical principle for future-oriented coastal governance. Such a repositioning is essential to ensure that technological advancement and economic growth do not occur at the expense of social cohesion and ecological responsibility.

3.3 Environmental and socioeconomic pressures in coastal communities

Recurrent ecological issues such as overfishing, pollution, coastal erosion, and biodiversity decline have been linked to the socioeconomic vulnerability of small-scale fishing communities across various sources. These pressures exacerbate livelihood insecurity, which in turn reinforces the disengagement of younger generations from the

maritime sector. Findings from the literature review indicate that while government programs aim to strengthen coastal economies, the lack of a culturally rooted and community-driven approach limits their effectiveness. Therefore, the research findings highlight the need to integrate cultural identity, adaptive capacity, and sustainability principles into coastal development planning (Bennett et al., 2021; Neves et al., 2021).

Table 1. Environmental and socioeconomic pressures in South Sulawesi coastal regions (2015–2024)

Indicator	2015	2020	2024	Trend
Coastal erosion (km/year)	12.4	15.7	18.3	↑ Increasing
Poverty rate among small-scale fishers (%)	28.4	27.1	25.8	↓ Improving
Decline in pelagic fish stock (%)	-	17	34	↑ Declining
Marine pollution index (0–100)	42	48	55	↑ Worsening
Youth participation in fisheries (%)	14.2	11.7	9.5	↓ Declining

The data presented in Table 1 reinforces the interconnected nature of ecological and socioeconomic stressors affecting coastal communities. Increasing erosion, worsening pollution, and declining fish stocks directly undermine traditional fishing livelihoods, while reduced youth participation signals a broader cultural disengagement. These trends collectively highlight the urgency of adopting an integrated development framework such as Patorani 5.0 that aligns cultural values, adaptive capacity, and sustainable resource governance to strengthen resilience in coastal regions.

From an analytical standpoint, the trends shown in Table 1 reveal a paradoxical development pattern within coastal communities. While poverty rates among small-scale fishers show a gradual decline, environmental degradation indicators continue to worsen and youth participation in fisheries steadily decreases. This suggests that improvements in income metrics do not necessarily translate into sustainable livelihoods or long-term sectoral resilience. Economic assistance and short-term welfare programs may alleviate immediate poverty, yet fail to address structural vulnerabilities related to ecological instability, cultural disconnection, and limited future prospects within the maritime sector.

The decline in youth participation serves as a critical early warning indicator of systemic fragility in coastal development. Younger generations increasingly interpret environmental degradation and unstable fish stocks as signals of an unsustainable future in fisheries-based livelihoods. In the absence of adaptive pathways such as value-added marine enterprises, technology-enabled fisheries, or culturally meaningful innovation marine-based occupations lose their attractiveness. This disengagement not only threatens labor regeneration in the maritime sector, but also accelerates the erosion of traditional ecological knowledge that is vital for adaptive resource management.

Environmental pressures further compound governance challenges by increasing competition over shrinking marine resources. As fish stocks decline and pollution intensifies, small-scale fishers are forced to travel further offshore, increase operational risk, or adopt unsustainable harvesting strategies. These conditions disproportionately affect traditional communities that lack access to modern vessels, capital, and monitoring technologies. Consequently, ecological degradation and socioeconomic inequality reinforce each other in a feedback loop that weakens community resilience and undermines trust in institutional interventions perceived as distant or ineffective.

These findings underscore that coastal development cannot be effectively addressed through sectoral or technocratic approaches alone. Integrated frameworks are required to reconnect environmental sustainability with social identity and economic viability. In this context, Patorani 5.0 offers a strategic response by framing resilience as the convergence of ecological stewardship, cultural revitalization, and adaptive livelihood transformation. By embedding local values, youth engagement, and ecosystem-based management into development planning, such a framework responds directly to the multidimensional pressures identified in South Sulawesi's coastal regions and provides a pathway toward more inclusive and sustainable maritime futures.

3.4 Relevance of blue economy principles to cultural revitalization

The blue economy paradigm emphasizes the sustainable use of marine resources, ecological conservation, and inclusive economic growth. The literature demonstrates its potential to transform coastal livelihoods through innovations in fisheries, coastal tourism, renewable marine energy, and ecosystem services (Cisneros-Montemayor et al., 2021; Voyer et al., 2018). However, findings indicate that blue economy initiatives often lack cultural roots and fail to engage local communities as co-creators. Previous studies have shown that policies detached from cultural contexts tend to have low adoption rates and face community resistance (Ayilu et al., 2022). This research argues that integrating maritime culture, particularly the Patorani tradition, into blue economy strategies can enhance legitimacy and promote long-term sustainability. To summarize key findings across domains, Table 2 presents a thematic synthesis of the research findings.

Table 2. Summary of key findings from the literature review

Theme	Primary Finding
Maritime Culture	Declining practice, loss of intergenerational continuity, cultural commodification
<i>Siri' na Pacce</i>	Strong moral capital; underutilized in digital and economic frameworks
Environmental Pressures	Ecosystem degradation; livelihood vulnerability
Blue Economy	Limited cultural integration; strong potential for sustainable growth
Youth Engagement	Low interest in maritime heritage; high potential through digital tools
Education & Culture	Local wisdom improves ecological literacy and identity formation

The thematic synthesis presented in Table 2 demonstrates that maritime culture in Makassar is undergoing a gradual decline characterized by weakened intergenerational continuity and increasing commodification of cultural symbols. These findings indicate that although maritime identity remains a core historical asset, its living practice is diminishing as younger generations disengage from seafaring traditions. This pattern aligns with broader national trends in which coastal cultural systems face pressure from modernization and ecological disruptions, suggesting that cultural revitalization must extend beyond ceremonial preservation to include structural support for practice-based knowledge transmission.

At the same time, the review highlights that *Siri' na Pacce* the moral foundation of Bugis–Makassar society continues to function as strong social capital. However, its potential remains underutilized within contemporary digital, economic, and governance frameworks. This gap suggests an opportunity for recontextualizing local ethics to strengthen community resilience, especially within blue economy sectors. Environmental pressures further reinforce the need for such integration. Ecosystem degradation, declining fish stocks, and heightened livelihood vulnerability indicate that sustainable development approaches must incorporate not only technological innovations but also cultural values that historically promoted stewardship and collective responsibility.

Youth engagement emerges as both a challenge and a strategic opportunity. While interest in maritime heritage remains low, the literature shows that digital media, creative content, and experiential education can significantly enhance cultural attachment among younger generations. These insights underscore the importance of integrating local wisdom into educational systems, as doing so enhances ecological literacy, strengthens identity formation, and aligns with the developmental trajectory toward the Golden Generation 2045. In this context, the Patorani 5.0 model appears particularly relevant, offering a holistic approach that bridges culture, sustainability, and digital adaptation.

3.5 Digital transformation and the emergence of patorani 5.0

Digital transformation has significantly changed the way coastal communities access information, participate in markets, and maintain local cultural identities. Digital platforms such as e-commerce, mobile-based fisheries information systems, and online marketing

media open up new opportunities for coastal producers to diversify their income sources and expand their market reach. Furthermore, digitalization has boosted supply chain efficiency and enabled small-scale fishers to enter previously unreachable value-added sectors (Fajriani et al., 2025). However, the adoption of digital technology in coastal areas is uneven. Limited digital literacy, infrastructure access, and technological capabilities, especially among senior fishers, remain key barriers creating a digital divide (Alhassan et al., 2025). Therefore, an inclusive approach through digital skills training and infrastructure strengthening is needed so that the benefits of digital transformation can be felt equally by all coastal economic actors (Doktoralina et al., 2025).

The concept of Patorani 5.0, as developed in this study, positions digital technology not as a replacement for traditional maritime practices, but as a medium that strengthens cultural relevance in the contemporary era. By integrating traditional values such as *Siri' na Pacce* into digital practices, this framework encourages innovation rooted in local culture. For example, digital storytelling platforms enable communities to document and disseminate maritime narratives, rituals, and ecological knowledge, thus strengthening intergenerational continuity. These digital tools help reframe maritime heritage as a dynamic and evolving identity, rather than a static cultural legacy.

Furthermore, the emergence of virtual Patorani festivals, online cultural exhibitions, and immersive digital experiences presents new opportunities to promote maritime tourism and increase cultural visibility globally. Such initiatives not only expand the reach of local heritage but also create economic opportunities related to creative industries and cultural entrepreneurship. By aligning tradition and digital creativity, Patorani 5.0 offers a transformational path that combines cultural preservation, economic sustainability, and technological empowerment, making it a strategic model for strengthening coastal resilience in the 5.0 era.

From a governance and development perspective, digital transformation within coastal communities extends beyond technological adoption and must be understood as a socio-institutional shift. The effectiveness of digital platforms depends not only on access to infrastructure but also on trust, cultural legitimacy, and ethical orientation in their use. In this context, embedding *Siri' na Pacce* within digital governance frameworks helps ensure that technological innovation does not exacerbate inequality or exploitative practices. Digital marketplaces guided by ethical norms of honesty, collective benefit, and mutual responsibility can strengthen fair trade relations and reinforce social cohesion, rather than promoting purely profit-driven interactions.

The Patorani 5.0 framework also addresses the risk of cultural homogenization commonly associated with digital globalization. Without culturally grounded mediation, digital transformation may dilute local identity by imposing standardized narratives that marginalize indigenous perspectives. By contrast, Patorani 5.0 positions technology as a culturally responsive tool that amplifies local voices and preserves contextual meaning. Digital content produced within this framework reflects lived maritime experiences, ethical values, and ecological awareness, allowing coastal communities to actively shape their digital representation rather than becoming passive consumers of external cultural models.

In addition, Patorani 5.0 strengthens youth engagement by reconfiguring maritime participation into digitally enabled pathways that align with contemporary aspirations. Digital marketing, content creation, eco-tourism promotion, and data-driven fisheries management create new roles that merge technological skills with maritime identity. These pathways not only attract younger generations but also facilitate intergenerational knowledge exchange, where traditional ecological knowledge is translated into digital formats accessible across age groups. Such interactions enhance cultural continuity while fostering innovation and entrepreneurial capacity within coastal economies.

Ultimately, the emergence of Patorani 5.0 represents a shift toward a culturally embedded digital ecosystem that integrates technology, ethics, and sustainability. Rather than treating digitalization as a neutral or purely economic process, this framework recognizes the importance of moral capital and collective identity in shaping development outcomes. By situating digital transformation within local value systems, Patorani 5.0 offers

a replicable model for other maritime regions seeking to balance technological advancement with cultural integrity and environmental responsibility in the Society 5.0 era.

3.6 Integrating culture, technology, and blue economy: The patorani 5.0 model

The synthesis of research findings supports the emergence of Patorani 5.0 as a holistic model that integrates cultural heritage, ethical values, digital innovation, and sustainable marine-based economic development. At its core, the model emphasizes that maritime culture in Makassar particularly the Patorani tradition must be revitalized not merely as symbolic heritage, but as a living practice that continues to shape identity, collective knowledge, and local resilience. Revitalization entails reintroducing cultural narratives, rituals, and community-based practices into contemporary social life, thereby restoring their relevance and strengthening intergenerational continuity.

Embedded within this revitalization is the ethical foundation of *Siri' na Pacce*, which provides a moral compass for navigating modernization. As digital transformation accelerates, these indigenous values play a crucial role in guiding responsible technology use, promoting collective well-being, and reinforcing ethical economic behavior. Rather than opposing technological change, *Siri' na Pacce* becomes an anchor that aligns innovation with community integrity, social empathy, and ecological stewardship ensuring that progress remains culturally grounded.

Digital adaptation represents the third dimension of the Patorani 5.0 model. The integration of digital tools such as digital storytelling, mobile applications, e-commerce, and virtual cultural exhibitions creates new pathways for preserving maritime heritage and enhancing economic opportunities. These technologies enable the documentation and dissemination of traditional knowledge, expand market access for coastal products, and support youth engagement through creative and educational digital platforms. Such innovations bridge tradition and modernity, demonstrating that cultural practices can evolve without losing their foundational identity.

Finally, the model incorporates sustainable marine economic principles aligned with the blue economy. This pillar promotes environmentally responsible resource use, value-added marine industries, and community-based conservation. By uniting sustainability principles with cultural ethics and technological adaptation, the Patorani 5.0 model addresses structural gaps observed in existing policy frameworks, which often overlook local identity and indigenous knowledge. In doing so, the model offers a culturally rooted, future-oriented approach to strengthening coastal resilience, enhancing livelihood security, and contributing to long-term socio-ecological sustainability.

3.7 Implications for education and the golden generation 2045

The research also shows that education is a key mechanism in revitalizing maritime identity and preparing the younger generation towards Indonesia's 2045 vision. The concept of educulture, namely the integration of education and cultural values, has emerged as a promising approach to foster ecological awareness, digital literacy, and ethical behavior. Through project-based learning, strengthening the maritime curriculum, and community engagement, the Patorani 5.0 framework can support the achievement of SDG 4 (Quality Education) and SDG 11 (Sustainable Cities and Communities). This approach helps align the competencies of the younger generation with the needs of a sustainable maritime future (Simanjuntak et al., 2024).

The educational components summarized in Table 3 highlight how culturally grounded learning strategies can enhance the formation of a resilient and future-ready generation in coastal regions. Integrating Patorani history, maritime ethics, and ecological literacy into the curriculum strengthens students' cultural identity and environmental awareness, while digital literacy initiatives such as digital storytelling and virtual maritime exhibitions encourage creativity and technological competence. Community-based learning further reinforces empathy, social cohesion, and intergenerational connection by exposing students

to real-life maritime practices. In parallel, entrepreneurship modules equip youth with practical skills in e-commerce and maritime-based business models, promoting economic independence and innovation. Finally, embedding *Siri' na Pacce* within character education cultivates integrity, responsibility, and resilience, positioning local values as central foundations for achieving the goals of the Golden Generation 2045.

Table 3. Educational integration of maritime culture for the golden generation 2045

Educational Component	Cultural Integration Strategy	Expected Outcomes
Curriculum content	Patorani history, ecological literacy, maritime ethics	Strengthened identity & sustainability knowledge
Digital literacy training	Digital storytelling, virtual maritime exhibitions	Improved creativity & technological competence
Community-based learning	Visits to fishing villages, cultural immersion	Empathy, social cohesion, intergenerational connection
Entrepreneurship modules	E-commerce for coastal products, maritime business models	Youth empowerment & economic independence
Character education	Embedding <i>Siri' na Pacce</i> in daily learning	Integrity, responsibility, and resilience

From an educational policy perspective, the integration of maritime culture through the educulture approach represents a strategic investment in long-term human capital development. Education that is disconnected from local context often produces graduates who are technically competent yet culturally detached from their own socio-ecological realities. By contrast, culturally responsive maritime education fosters a sense of belonging, responsibility, and ethical awareness that strengthens students' commitment to sustainable development within their own communities. This alignment between education, culture, and local ecosystems is essential for ensuring that learning outcomes are socially relevant and environmentally grounded.

The findings also indicate that embedding maritime values into formal education enhances the relevance of 21st-century competencies within the framework of Society 5.0. Critical thinking, digital creativity, collaboration, and ethical judgement are not developed in isolation, but through meaningful engagement with real-world challenges faced by coastal communities. When students participate in project-based learning that addresses ecological degradation, cultural preservation, or digital entrepreneurship in maritime contexts, they acquire transferable skills while simultaneously contributing to community resilience. This dual impact strengthens the role of education as both a personal development tool and a mechanism for collective transformation.

Furthermore, the educulture-based implementation of Patorani 5.0 supports intersectoral collaboration between schools, coastal communities, cultural institutions, and local governments. Such collaboration expands learning spaces beyond classrooms and encourages knowledge co-production between generations. Elders, fishers, and cultural practitioners become knowledge bearers, while youth act as digital translators and innovators. This reciprocal learning model not only preserves maritime heritage but also revitalizes it in forms that are accessible and meaningful to younger generations in a digital society. Ultimately, positioning education as the driving force of Patorani 5.0 reinforces its strategic contribution to Indonesia's Golden Generation 2045. By integrating cultural identity, ethical values, digital competence, and sustainability principles into educational systems, this framework ensures that future generations are not only technologically capable but also morally grounded and socially responsible. Such an approach strengthens national maritime resilience by cultivating a generation that is prepared to lead inclusive, culturally rooted, and sustainable development in Indonesia's blue economy future.

3.8 Multi-stakeholder collaboration for maritime sustainability

The analysis shows that the cultural, technological, and economic transformations proposed through the Patorani 5.0 framework cannot be realized through community

efforts alone, but require coordinated multi-stakeholder collaboration. The existing literature consistently emphasizes that coastal development will be effective when government agencies, universities, traditional leaders, civil society organizations, and the private sector work within an integrated governance system that balances ecological, cultural, and economic objectives (Kismartini et al., 2023). By positioning cultural capital and digital innovation as complementary assets, Patorani 5.0 encourages joint planning, collaborative resource management, and the creation of joint solutions that reflect a blend of scientific knowledge and local wisdom. This collaborative approach aligns with global discourse recognizing culture as the “fourth pillar” of sustainable development, alongside economic, social, and environmental pillars, thus ensuring that maritime sustainability is rooted in community identity, values, and inclusive participation.

From an institutional governance perspective, multi-stakeholder collaboration functions as a mechanism to reduce fragmentation in coastal and maritime management. Government institutions contribute regulatory authority and policy alignment, universities provide scientific research, innovation, and capacity building, while traditional leaders and community organizations ensure cultural legitimacy and contextual relevance. The private sector, particularly in marine-based industries and digital platforms, plays a critical role in scaling innovation, mobilizing investment, and linking local products to broader markets. When these actors operate within an integrated framework, the strengths of each stakeholder compensate for the limitations of others, creating a more resilient and adaptive governance system.

Effective collaboration, however, requires more than formal partnerships; it depends on trust, shared values, and transparent decision-making processes. In culturally rooted frameworks such as Patorani 5.0, local values embodied in *Siri' na Pacce* can function as ethical anchors that mediate stakeholder interactions. These values encourage accountability, mutual respect, and collective responsibility, reducing power imbalances and fostering inclusive participation. As a result, collaboration becomes not only a technical arrangement, but also a moral commitment to equitable and sustainable outcomes for coastal communities.

Moreover, multi-stakeholder collaboration enhances policy coherence across sectors that are often managed in isolation, such as fisheries, education, tourism, digital economy, and cultural preservation. By integrating these sectors, Patorani 5.0 supports the co-creation of policies and programs that simultaneously address environmental protection, livelihood diversification, and cultural revitalization. This holistic approach increases the likelihood that development interventions will be socially accepted, environmentally effective, and economically viable over the long term.

In this sense, collaborative governance under Patorani 5.0 represents a shift from centralized, sectoral management toward participatory and culturally informed maritime sustainability. By institutionalizing partnerships that recognize local wisdom as a strategic asset, this framework contributes to the development of inclusive maritime governance models that can be replicated in other coastal regions facing similar sustainability challenges.

3.9 Positioning of the current study in existing scholarship

A comparative examination of existing literature reveals that prior studies tend to address cultural preservation, blue economy strategies, and digital innovation as separate domains, resulting in fragmented understandings of coastal development. Research on maritime culture often centers on heritage protection, while blue economy scholarship prioritizes ecological and economic metrics, and digital transformation studies focus primarily on technology adoption. The present study offers a distinct contribution by synthesizing these three strands into an integrative conceptual framework Patorani 5.0 that positions cultural values, technological adaptation, and sustainable marine economic practices as mutually reinforcing components. This consolidation represents the primary novelty and the state-of-the-art contribution of the research. Although further empirical

validation is required, the model fills a significant gap in current scholarship by providing a culturally grounded and technologically adaptive pathway for policy planning, community empowerment, and long-term coastal resilience.

From a scholarly positioning perspective, the contribution of this study lies not only in integration but also in reconceptualization. Rather than treating cultural values, digital transformation, and economic sustainability as parallel variables, Patorani 5.0 reframes them as an interdependent system in which each component amplifies the effectiveness of the others. Cultural values provide ethical orientation and social legitimacy, digital technologies function as enablers of inclusion and innovation, and blue economy principles ensure environmental and economic viability. This systemic perspective advances existing scholarship by shifting the analytical focus from sectoral optimization to relational sustainability within coastal development discourse.

Furthermore, this study contributes methodologically to the literature by adopting a holistic analytical lens that moves beyond descriptive cultural analysis or technical economic modeling. By synthesizing insights from cultural studies, sustainability science, and digital development literatures, the research demonstrates how indigenous value systems can operate as active design principles within contemporary development frameworks. This approach responds to growing academic calls for decolonizing sustainability narratives by situating local knowledge not as supplementary data, but as foundational logic in policy and framework formulation.

In comparison with existing models of maritime development that emphasize top-down governance or market-driven digitalization, Patorani 5.0 foregrounds community agency and ethical grounding as core drivers of transformation. This distinction is particularly relevant in contexts where rapid technological adoption risks deepening inequality or eroding cultural identity. By embedding moral capital and cultural legitimacy into digital and economic processes, the framework offers a nuanced alternative that aligns global sustainability agendas with local socio-cultural realities.

Taken together, these contributions position the present study as a conceptual bridge between fragmented bodies of scholarship and as a foundation for future empirical research. The Patorani 5.0 framework invites subsequent studies to test, refine, and operationalize culturally embedded digital-blue economy models across diverse maritime regions. In doing so, it advances the discourse on coastal resilience by demonstrating that sustainable maritime futures are most effectively built when culture, technology, and economy evolve in synergy rather than in isolation.

4. Conclusions

The findings of this study demonstrate that the challenges faced by coastal communities in South Sulawesi cannot be understood through singular perspectives of culture, environment, or economic policy alone. The synthesis of literature reveals that the erosion of maritime traditions, weakening of *Siri' na Pacce*, ecological degradation, and limited youth engagement are interconnected conditions shaped by structural, social, and technological change. Through the conceptualization of Patorani 5.0, this study offers an integrative framework that unites cultural revitalization, ethical values, digital adaptation, and blue economy principles into a single coherent model. This framework represents the primary contribution of the study, advancing current scholarship by bridging previously fragmented domains and positioning culture as an operational driver of sustainable coastal development rather than a passive heritage asset. While further empirical research is required to operationalize and test the model, Patorani 5.0 provides a strategic pathway for policymakers, educators, and local stakeholders to strengthen coastal resilience, enhance cultural continuity, and support Indonesia's long-term vision for a future-ready maritime generation.

From a theoretical standpoint, this study contributes to the advancement of maritime and sustainability scholarship by proposing a culturally embedded development model that moves beyond conventional technocratic or environmentally deterministic approaches. By

positioning *Siri'na Pacce* as moral and social capital within a digitally enabled blue economy ecosystem, the Patorani 5.0 framework expands existing debates on sustainability governance and Society 5.0. It demonstrates that indigenous cultural values are not merely contextual variables, but can function as core design principles that shape ethical behavior, institutional trust, and collective resilience in coastal development processes.

In practical terms, the findings offer concrete implications for policymaking, education, and community development. For policymakers, Patorani 5.0 provides a reference framework for designing culturally responsive coastal policies that integrate digital transformation, youth empowerment, and environmental sustainability. For educational institutions, the model reinforces the importance of educulture-based curricula in preparing a maritime generation that is technologically competent, ethically grounded, and socially responsible. Meanwhile, for coastal communities and civil society organizations, the framework highlights pathways for revitalizing maritime identity through participatory digital initiatives, creative industries, and inclusive economic diversification.

Despite its contributions, this study is not without limitations. As a conceptual and literature-based analysis, the Patorani 5.0 framework requires empirical validation through longitudinal case studies, participatory action research, and policy experimentation across different coastal contexts. Future research should focus on testing the framework's effectiveness in enhancing livelihood resilience, youth participation, and ecological outcomes, as well as examining the scalability and adaptability of culturally grounded digital-blue economy models in other maritime regions of Indonesia and beyond.

In conclusion, this study underscores that sustainable maritime futures cannot be achieved solely through technological advancement or economic growth, but must be grounded in cultural meaning, ethical values, and collective agency. By integrating culture, digital innovation, and sustainability into a unified framework, Patorani 5.0 offers a forward-looking contribution that supports Indonesia's aspiration toward the Golden Generation 2045 and reinforces the role of coastal communities as active stewards of the nation's maritime heritage and blue economy development.

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Author Contribution

Conceptualization, N.R.P., and I.; Methodology, I.; Validation, M.H.; Formal Analysis, N.R.P.; Investigation, N.R.P., and I.; Resources, M.H.; Data Curation, I.; Writing – Original Draft Preparation, N.R.P.; Writing – Review & Editing, I., and M.H.; Visualization, N.R.P.; Supervision, Dr. Muhammad Hasan; Project Administration, N.R.P..

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Informed Consent Statement

Informed consent was not required for this study because it did not involve human participants or identifiable personal data.

Data Availability Statement

No additional datasets were generated or analyzed during the current study. All data supporting the findings are available within the cited sources.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Declaration of Generative AI Use

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist in refining the structure, improving clarity, and enhancing the academic tone of the manuscript. After using this tool, the authors carefully reviewed, edited, and validated all content and take full responsibility for the final version of this publication.

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