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Mapping a Decade of Coastal Edge and Coastal Zone Dynamics in Southeast Asia: A Systematic Review of Techniques and Methodologies

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ABSTRACT

Coastal zones in Southeast Asia face escalating threats from climate change, necessitating robust monitoring techniques for effective management; however, a fragmented understanding of the methodologies used over the past decade persists. This study addresses this gap by conducting a systematic literature review, guided by the PRISMA (Preferred Reporting Items for Systematic review and Meta analysis), to comprehensively catalogue and analyse the techniques and methodologies for mapping coastal edge and zone dynamics in Southeast Asia from 2014 to 2024. The review was driven by the central research question: "What are the most commonly used techniques and methodologies for mapping coastal edge in Southeast Asia over the past decade?" Following a rigorous screening and quality appraisal process of 437 identified records, 48 high-quality articles were synthesized. The findings reveal four dominant themes: (1) the evolution and synergistic use of data sources, primarily Landsat and Sentinel constellations; (2) prevalent techniques for shoreline extraction and change analysis, notably the Digital Shoreline Analysis System (DSAS); (3) the adoption of advanced methodologies, including machine learning and integrated modeling; and (4) a synthesis of integrated workflows and a distinct geographical research bias. The study's significance lies in providing a consolidated methodological framework for researchers and a critical evidence base for policymakers, while its primary recommendation is the urgent need to address the identified geographical research gaps in under-studied Southeast Asian nations to foster equitable and informed coastal governance.

Keywords: Coastal dynamics; Southeast Asia; remote sensing; shoreline change analysis; climate change

INTRODUCTION

Climate change poses significant threats to coastal areas in Southeast Asia, particularly through sea-level rise, increased storm surges, and altered monsoon patterns (Intergovernmental Panel on Climate Change [IPCC] 2022). These changes accelerate coastal erosion, affecting densely populated coastlines, critical infrastructure, and diverse economic activities (IPCC 2022; Mentaschi et al. 2018). The region is highly vulnerable to climate change impacts, with consequences including inundation of low-lying deltas, saltwater intrusion into freshwater aquifers, and irreversible degradation of coastal ecosystems such as mangroves and wetlands (IPCC 2022). Urban coastal zones are particularly exposed due to rapid population growth, intensive land use, and increasing urbanization pressures (Yuen & Kong, 2009). To address these challenges, robust adaptation strategies involving improved coastal management, zoning, and land-use planning are increasingly emphasized (IPCC 2022; Paw & Thia-Eng 1991). In this context, vulnerability assessments play a critical role in understanding coastal risks and strengthening adaptive capacities in Southeast Asian coastal cities (Noor & Abdul Maulud 2022).

Coastal erosion mapping techniques have evolved substantially from conventional ground-based surveys and photogrammetric methods to advanced remote sensing and geospatial approaches. The integration of multispectral satellite imagery, such as Landsat and Sentinel-2, with Synthetic Aperture Radar (SAR) datasets has significantly improved shoreline mapping accuracy by overcoming limitations associated with cloud cover, tidal variability, and data continuity (Li et al. 2021; Cheng et al. 2023). More recently, shoreline extraction workflows have advanced towards semi-automated and automated approaches that leverage spectral indices, Geographic Information Systems (GIS), and machine learning algorithms, each involving distinct trade-offs in terms of accuracy, cost, scalability, and technical expertise (Li et al. 2021; García-Rubio et al. 2022). Additionally, satellite-based approaches such as JERS-1 SAR and Sentinel-1 have proven effective for coastal erosion risk mapping in data-scarce regions. By integrating shoreline dynamics indices, environmental variables, and land-use characteristics, researchers are now able to generate detailed coastal vulnerability assessments widely applied across Southeast Asia (Murooka & Haruyama 2015; Noor et al. 2023). These approaches provide cost-effective alternatives to labour-intensive field surveys and enable long-term monitoring over large coastal extents.

Despite the growing number of studies on coastal erosion and shoreline dynamics in Southeast Asia, the methodological landscape remains fragmented. Existing studies often focus on localized case studies that apply different satellite datasets, shoreline extraction techniques, analytical tools, and change metrics, making regional comparison and methodological synthesis difficult. Furthermore, the rapid evolution of remote sensing technologies including the Sentinel missions, cloud-computing platforms, and machine learning algorithms has introduced new analytical possibilities that have yet to be systematically synthesized within a Southeast Asian context. This fragmented understanding limits the development of standardized best practices for long-term coastal monitoring, shoreline change analysis, and coastal vulnerability assessment.

Systematic literature reviews (SLR) provide a rigorous and transparent approach for synthesizing methodological developments across diverse studies. Compared with traditional narrative reviews, SLRs minimize reviewer bias through a structured and reproducible search protocol, explicit inclusion criteria, and systematic quality appraisal (Robinson & Lowe 2015; Xiao & Watson 2019; Page et al. 2021). By documenting the search strategy, article selection process, and thematic synthesis procedure, SLR strengthen reproducibility and provide a robust evidence base for future methodological development.

This review is guided by the following central research question, what are the most commonly used techniques and methodologies for mapping coastal edge and coastal zone dynamics in Southeast Asia over the past decade? Therefore, this study was designed with the following research objectives To systematically identify and synthesize the remote sensing techniques and geospatial methodologies used to map coastal edge in Southeast Asia from 2014 to 2024**,** evaluate the dominant analytical tools, shoreline change metrics, and satellite datasets employed across the reviewed studies.**,** critically compare methodological trends, strengths, limitations, and emerging innovations, including machine learning and cloud-based geospatial platforms and to identify geographical and methodological research gaps that can guide future shoreline change and coastal vulnerability studies in Southeast Asia.

This study contributes significantly to both the scientific body of knowledge and practical coastal management applications. By consolidating a decade of methodological developments, the review provides researchers with a structured evidence base on the evolution of shoreline extraction, coastal change detection, and vulnerability assessment workflows. For policymakers, environmental practitioners, and coastal managers, the findings offer methodological guidance for selecting appropriate datasets, analytical tools, and integrated workflows suited to different coastal settings. More importantly, the study highlights critical geographical blind spots across Southeast Asia, thereby supporting more equitable, evidence-based, and regionally representative coastal governance and climate adaptation planning.

METHODOLOGY

PRISMA

This SLR refers to PRISMA. PRISMA is developed for health and medical related review. But recently, PRISMA is often utilized within the environmental management field (Shaffril et al. 2018). This is because, according to Sierra-Correa and Kintz (2015), PRISMA offers a few valuable advantages towards the systematic review process, and it was developed with the aim of forming a comprehensive and quality-controlled of the SLR process. Based on the reference to the PRISMA, this SLR was developed based on four main steps, first is the formulation of research questions, the second is the systematic searching strategy, the third is the assessment of article quality and fourth data extraction and analysis (Figure 1).

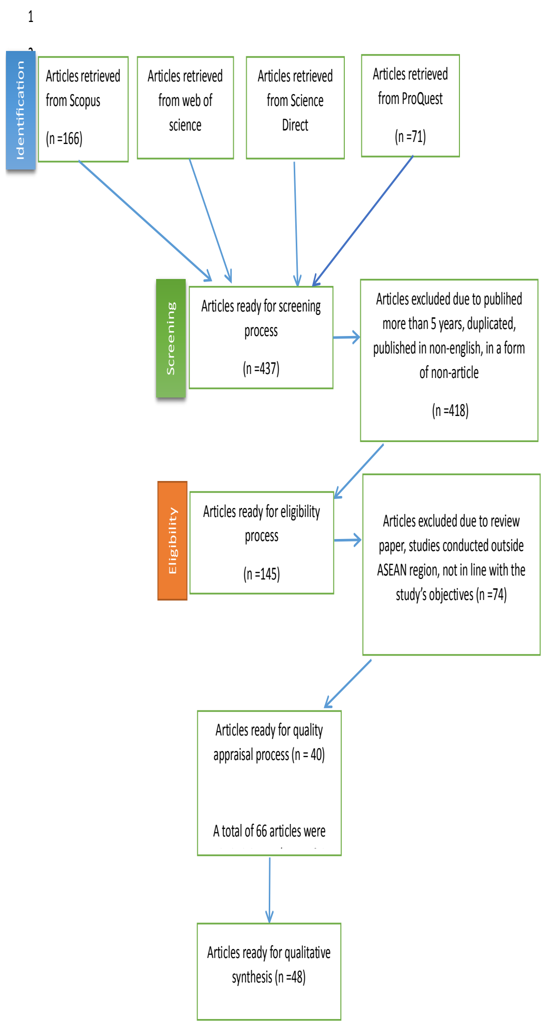

FIGURE 1. PRISMA 2025 flow diagram showing the identification, screening, eligibility assessment, and inclusion of studies in the systematic review

This SLR adopts the PRISMA framework, a robust methodology originally developed for medical research but now widely utilized in environmental management for its rigor and transparency (Shaffril et al. 2018). Its application is justified as PRISMA ensures a comprehensive and quality-controlled process, mitigating bias and enhancing reproducibility (Sierra-Correa & Kintz 2015; Page et al. 2021). The review is structured into four definitive phases, commencing with the formulation of a precise research question, followed by a systematic search strategy documented via a PRISMA flow diagram, a critical quality assessment of the identified literature, and concluding with structured data extraction and synthesis, a process aligned with established guidelines for systematic reviews in environmental science (Pullin & Stewart 2006; Page et al. 2021).

FORMULATION REVIEW QUESTIONS

This SLR establishes its research question using the Population, Interest, and Context (PICO) framework, a well-established tool for structuring systematic review inquiries. While often used in healthcare, its application in environmental systematic reviews is advocated by scholars like Lockwood et al. (2015) to ensure clarity and focus. In this context, the framework was adapted where 'P' (Population) is defined as coastal zones and edges in Southeast Asia over the past decade, 'I' (Interest) encompasses the various techniques and methodologies used for mapping and analyzing coastal dynamics, and 'CO' (Context) is specified by the geographical keyword Southeast Asia. Synthesizing these elements, the study's central research question is formulated as: What are the most commonly used techniques and methodologies for mapping coastal edge and zone dynamics in Southeast Asia over the past decade?

The formulation of a precise research question using this structured framework is a critical first step in a rigorous SLR, as it directly informs the subsequent search strategy and inclusion criteria. This approach enhances the review's reproducibility and minimizes selection bias by ensuring the literature search is targeted and comprehensive. The use of PICO in environmental contexts is supported for its utility in defining complex socio-ecological systems, thereby strengthening the methodological foundation of the review and aligning with best practices for systematic reviews in the field (Lockwood et al. 2015; Gough, Oliver, & Thomas, 2017).

SYSTEMATIC SEARCHING STRATEGIES

The next process is a systematic searching strategy. This process involves three main steps, namely identification, screening, and qualification. These three main steps help researchers to conduct a comprehensive search process.

IDENTIFICATION

Identification is the process of determining suitable keywords to be used in the search for relevant articles. The keywords for this SLR were identified based on the established research question. The main keyword identified for this SLR was "coastal". Subsequently, the researcher searched for synonyms, related terms, and variations of this main keyword. For this purpose, the researcher referred to several sources such as ChatGPT, online Thesauruses, keywords from past literature, expert opinions, and keywords suggested by the Scopus database. Based on this search across sources, the researcher identified several additional keywords, namely "shoreline" and "seashore".

Two main search techniques were used: manual search techniques, namely "hand searching," "snowballing," "reference tracking," and advanced searching. For the advanced search technique, a core search string was developed (please refer to the table 1). The search string was developed based on five basic functions: field codes, phrase searching, truncation, wildcards, and Boolean operators. Based on this search process, the researcher identified a total of 437 articles. Although the researcher relied not only on manual search techniques, efforts were made to ensure a comprehensive search through the use of diverse keywords, the use of four databases, and the application of various search techniques.

The process of keyword identification and search strategy development is a critical foundation for a systematic review, directly impacting its comprehensiveness, reproducibility, and ultimately, the validity of its findings. The multi-source approach for identifying keywords, as described, is a recognized best practice. Consulting diverse sources like controlled vocabularies (e.g., database thesauri), existing literature, and even AI tools help to mitigate the risk of missing relevant studies due to semantic variation or differing terminologies across disciplines (Bramer et al. 2018). This is particularly important in interdisciplinary fields like coastal management, where terms can have nuanced meanings. The combination of manual and advanced search techniques further strengthens the methodology. While advanced database searches provide a structured and reproducible primary method, manual techniques like "backward reference tracking" (checking the reference lists of included studies) and "forward snowballing" (using citation indexes to find newer studies that cite key papers) are invaluable for capturing seminal works and recent developments that may not be indexed in major databases or captured by the initial search string (Wohlin 2014).

To ensure the search was both sensitive (capturing as many relevant records as possible) and specific (minimizing irrelevant ones), the search string was constructed using precise syntax. The use of Boolean operators (AND, OR) logically combines the key concepts. Phrase searching (using quotation marks, e.g., "coastal vulnerability") ensures terms are searched as exact phrases. Truncation (using the asterisk *, e.g., coastal* to find coastal, coastals, coastline) and wildcards (e.g., organi?ation to find organization and organisation) account for variations in spelling and word endings. Finally, applying field codes (e.g., TITLE-ABS-KEY in Scopus) restricts the search to title, abstract, and keywords, increasing the relevance of results. The initial yield of 437 records, while manageable, is a promising indicator of a well-scoped search. The subsequent steps of the PRISMA protocol screening against eligibility criteria, quality assessment, and data extraction—will now refine this set into the final corpus of studies for synthesis. This meticulous approach to the search strategy aligns with the PRISMA 2020 statement's emphasis on transparency and completeness in reporting, providing a clear audit trail from the research question to the identified literature (Page et al. 2021).

TABLE 1. Advanced Search Technique

Scopus	TITLE-ABS-KEY(("coastal vulnerability" OR "shoreline vulnerability" OR "coastal sensitivity") AND ("adaptation strateg*" OR "adjustment strateg*" OR "adaptive respons*") AND (communities OR "coastal communit*" OR "seaside communit*"))
Web of Science	TS=(("coastal vulnerability" OR "shoreline vulnerability" OR "coastal sensitivity") AND ("adaptation strateg*" OR "adjustment strateg*" OR "adaptive respons*") AND (communities OR "coastal communit*" OR "seaside communit*"))
Science Direct	TITLE-ABS-KEY(("coastal vulnerability" OR "shoreline vulnerability" OR "coastal sensitivity") AND ("adaptation strateg*" OR "adjustment strateg*" OR "adaptive respons*") AND (communities OR "coastal communit*" OR "seaside communit*"))
ProQuest	("coastal vulnerability", OR "Shoreline vulnerability", OR "Coastal sensitivity") AND ("Adaptation Strategies", OR "Adjustment strategies", OR "Adaptive respons*") AND ("commumities", OR "Coastal communit*", OR "Seaside communit*")

SCREENING

The next process is screening. This process involves establishing article selection criteria. A total of three criteria were used by the researcher: year of publication (2014-2024), type of publication (focus on journal articles only), and language (focus on English only). After the screening process, a number of articles were excluded, and the remaining articles were carried forward to the next process, eligibility (Table 2). The screening phase is a critical filter in a SLR, designed to efficiently narrow down the initial search results to a manageable and relevant pool of studies based on pre-defined, objective criteria. The criteria you have selected publication date, document type, and language are standard and justifiable for ensuring the review's timeliness, academic rigor, and accessibility (Page et al. 2021). Focusing on peer-reviewed journal articles typically guarantees a baseline of scholarly quality, while the language restriction is pragmatic, though it is important to acknowledge its potential to introduce a geographical bias by excluding relevant studies published in other languages (Polanin et al. 2019).

TABLE 2. Inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Literature type	Research article journal	Review article journal, book, book chapter, book series, conference proceedings
Language	English	Non-English
Time line	Between 2014 and 2024	< 2014
Countries and region	Southeast Asia countries	Non southeast asia countries

ELIGIBILITY

The eligibility process serves as a second, more rigorous screening phase to ensure the selected articles are relevant and aligned with the study's objectives. This process was conducted by meticulously examining the title and abstract of each article retained from the initial screening. In cases where relevance could not be determined from the abstract alone, the full text was reviewed. Based on this process, a total of 58 articles were excluded. The primary reasons for exclusion were: (1) the study's geographical context was outside Southeast Asia; (2) the article focused on coastal policy or socio-economic impacts without detailing the specific geospatial techniques or methodologies for mapping coastal dynamics; and (3) the full text was not accessible or was a review article without original methodological data. This meticulous eligibility assessment, guided by pre-defined inclusion and exclusion criteria, ensured that only the most pertinent studies advanced to the final stage of data extraction, thereby strengthening the validity and focus of the systematic review's findings (Page et al. 2021).

QUALITY APPRAISAL

To ensure the methodological rigor and credibility of the findings, the 48 articles that passed the eligibility screening underwent a formal quality assessment. This process was guided by a checklist of six criteria adapted from Abouzahra et al. (2020), designed to evaluate key aspects of research quality (Table 3). The assessment was carried out independently by both the lead researcher and a co-researcher to mitigate bias. Each criterion was scored on a scale of 1 ('Yes'), 0.5 ('Partially'), or 0 ('No') (Table 3). Articles were retained for the final synthesis only if they met a pre-defined quality threshold of a minimum score of 3.0 out of 6.0. This rigorous appraisal resulted in the exclusion of several articles, leaving a final corpus of 48 high-quality studies for data extraction and analysis."

TABLE 3. Quality Assessment Criteria

Questions	Assessment Criteria
QA1	Is the purpose of the study clearly stated?
QA2	Is the interest and the usefulness of the work clearly presented?
QA3	Is the study methodology clearly established?
QA4	Are the concepts of the approach clearly defined?
QA5	Is the work compared and measured with other similar work?
QA6	Are the limitations of the work clearly mentioned?

DATA EXTRACTION AND ANALYSIS

Following the quality assessment, data were extracted from the selected articles by the lead researcher using a standardised extraction matrix. The extraction focused primarily on the results and discussion sections, while other sections such as the abstract, methodology, and conclusion were consulted when additional clarification was required. The extracted data were systematically organised into a structured table containing author(s), publication year, study location, datasets used, analytical methods, shoreline change metrics, key findings, and methodological insights

(Table 4). This structured extraction process ensured consistency across studies and provided a strong basis for cross-study comparison.

The extracted information was subsequently analysed using an inductive thematic analysis guided by the six-phase framework of Braun and Clarke (2006). This analytical approach was selected because the reviewed studies employed highly diverse datasets, geospatial tools, and analytical workflows, making statistical meta-analysis less suitable. Through repeated reading and systematic coding, recurring methodological patterns, dominant workflows, and emerging analytical innovations were identified and grouped into broader themes and sub-themes. Importantly, the analysis was designed not only to summarise frequently used techniques, but also to critically compare methodological differences, including variations in datasets, shoreline metrics, validation procedures, and suitability for different coastal environments.To strengthen the depth of analysis, particular attention was given to identifying cross-study inconsistencies, contrasting methodological choices, underutilised techniques, and geographical research gaps across Southeast Asia. This enabled the review to move beyond a purely descriptive synthesis towards a more critical evaluation of strengths, limitations, and contradictions in the regional literature. The final themes were subsequently validated by an independent expert to ensure conceptual clarity, methodological relevance, and direct alignment with the research objectives. This approach enhanced the credibility of the findings and ensured that the synthesis effectively addressed both dominant methodological trends and unresolved research gaps.

TABLE 3. Scoring System for Quality Assessment

Study	QA1	QA2	QA3	QA4	QA5	QA6	Number of criteria fufilled	Inclusion in the review
Nurul Khakhim et al. 2024	/	/	/	/	/	0.5	5.5/6	/
Muhammad Dimyati et al. 2021	/	/	/	/	0.5	0.5	5/6	/
Haris Abdul Rahim et al. 2023	/	/	/	/	/		5/6	/
Widya Prarikeslan et al. 2022	/	/	/	/	/		5/6	/
Muchammad Farid et al. 2024	/	/	/	/	0.5		4.5/6	/
Gaby Nanda Kharisma et al. 2024	/	/	/	/	/		5/6	/
Pujianiki et al. 2024	/	/	/	/	0.5	/	5.5/6	/
Nor Aizam Adnan et al. 2021	/	/	/	/	0.5	0.5	5/6	/
Hardianto Paputungan et al. 2024	/	/	/	/	0.5	0.5	5/6	/
Vu Dinh Cuong et al. 2024	/	/	/	/	/		5/6	/
Chakrit Chawalit et al. 2025	/	/	/	/	/	0.5	5.5/6	/
RC Maudhi et al. 2023	/	/	/	/	/		5/6	/
H A Rachman et al. 2024	/	/	/	/	0.5	0.5	5/6	/
Haris Abdul Rahim et al. 2022	/	/	/	/	0.5		4.5/6	/
Ronja Lappe et al. 2022	/	/	/	/	/	/	6/6	/

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Study	QA1	QA2	QA3	QA4	QA5	QA6	Number of criteria fufilled	Inclusion in the review
Amandangi Wahyuning Hastuti et al.	/	/	/	/	/	/	6/6	/
Pannee Cheewinsiriwat et al. 2024	/	/	/	/	/	0.5	5.5/6	/
T Solihuddin et al. 2021	/	/	/	/	/	0.5	5.5/6	/
S Sugianto et al. 2018	/	/	/	/	0.5	0.5	5/6	/
T A Tarigan et al. 2024	/	/	/	/	0.5	0.5	5/6	/
Nafla Aulia Miranda et al. 2023	/	/	/	/	/	0.5	5.5/6	/
Milad Bagheri et al. 2019	/	/	/	/	0.5	0.5	5/6	/
Liana Najib et al. 2017	/	/	/	/	0.5	/	5.5/6	/
Dian Adhetya Arif et al. 2020	/	/	/	/	0.5	0.5	5/6	/
Anh T.K. Do et al. 2018	/	/	/	/	0.5	0.5	5/6	/
Bachtiar W. Mutaqin et al. 2024	/	/	/	/	/	/	6/6	/
Iswana Adela et al. 2019	/	/	/	/	0.5	0.5	5/6	/
Azman Azid et al. 2015	/	/	/	/	0.5	0.5	5/6	/
G Aliyuddin and A Damayanti 2019	/	/	/	/	0.5	0.5	5/6	/
Dian N. Handiani et al. 2022	/	/	0.5	/	0.5		4/6	/
A. Anandkumar et al. 2019	/	/	/	/	0.5	0.5	5/6	/
Febriandi et al. 2019	/	/	/	/	0.5	0.5	5/6	/
Husnayaen et al. 2018	/	/	/	/	0.5	0.5	5/6	/
Muhammad Irham et al. 2021	/	/	/	/	0.5	0.5	5/6	/
Tengku Ahmad Imran Ku Yusoff And Mohamad Shaufi Sokiman, 2017	/	/	/	/	0.5	0.5	5/6	/
I A Kurniawan and and M A Marfai 2020	//	/	/	/	0.5	0.5	5/6	/
Eva Louise den Boer et al. 2018	/	/	/	/	0.5		4.5/6	/

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F A Mohd et al. 2021	/	/	/	/	0.5	/	5.5/6	/
Fazly Amri Mohd et al. 2019	/	/	/	/	0.5	0.5	5/6	/
Max Rudolf Muskananfola and Supriharyono, Sigit Febrianto	/	/	/	/	/	0.5	5.5/6	/
Study	QA1	QA2	QA3	QA4	QA5	QA6	Number of criteria fufilled	Inclusion in the review
Hai-Hoa Nguyen et al. 2015	/	/	/	/	/	0.5	5.5/6	/
Janneli Lea A. Soria et al. 2021	/	/	/	/	0.5	0.5	5/6	/
Ratna Sari Dewi et al. 2017	/	/	/	/	0.5	0.5	5/6	/
Pratama et al. 2021	/	/	/	/	0.5	0.5	5/6	/
Muhammad Zakwan Anas Abd Wahid and Mohamed Syazwan Osman, 2023	/	/	/	/	0.5	0.5	5/6	/
Mubarak et al. 2024	/	/	/	0.5	0.5		4/6	/
Basa T. Rumahorbo et al. 2023	/	/	/	/	/	0.5	5.5/6	/
Arief Wicaksono et al. 2019	/	/	/	/	0.5	0.5	5/6	/

TABLE 4. Summary of methodologies, analytical tools, and remote sensing datasets (e.g., DSAS, CVI, LRR, GIS, ML, and satellite imagery) employed across the reviewed studies on shoreline change and coastal vulnerability assessment.

Authors	Methodology																			DATA							
	DSAS	CVI	NSM	LRR	SCE	EPR	WLR	GIS	ENVI	GT	ML	OSD	HYSR	MASW	NDVI	NDWI	DEM	CEI	MLG	S1	S2	L9	L8	L7	L5	S5	PLANET SCOPE
Nurul Khakhim et al. 2024	/		/	/		/	/															/	/		/		/
Muhammad Dimyati et al. 2021	/							/	/														/		/		
Haris Abdul Rahim et al. 2023										/																/	
Widya Prarikeslan et al. 2022	/		/			/		/	/														/	/	/		
Muchammad Farid et al. 2024													/	/									/				
Gaby Nanda Kharisma et al. 2024	/	/						/															/	/			
Pujianiki et al. 2024	/							/												/							
Nor Aizam Adnan et al. 2021								/			/	/									/						
Hardianto Paputungan et al. 2024	/	/				/									/		/										
Vu Dinh Cuong et al. 2024	/			/	/											/					/						
Chakrit Chawalit et al. 2025	/		/			/											/		/			/	/	/	/		
RC Maudhi et al. 2023		/						/									/						/				
H A Rachman et al. 2024		/						/									/	/			/						/
Haris Abdul Rahim et al. 2022								/									/									/	
Ronja Lappe et al. 2022	/			/	/																		/	/	/		

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Authors	Methodology																			DATA							
	DSAS	CVI	NSM	LRR	SCE	EPR	WLR	GIS	ENVI	GT	ML	OSD	HYSR	MASW	NDVI	NDWI	DEM	CEI	MLG	S1	S2	L9	L8	L7	L5	S5	PLANET SCOPE
Amandangi Wahyuning Hastuti et al.		/						/									/				/						
Pannee Cheewinsiriwat et al. 2024		/						/									/										
T Solihuddin et al. 2021	/			/											/								/		/		
S Sugianto et al. 2018								/																			
T A Tarigan et al. 2024	/																										
Nafla Aulia Miranda et al. 2023								/	/												/						
Milad Bagheri et al. 2019								/																			
Liana Najib et al. 2017																											
Dian Adhetya Arif et al. 2020	/		/			/		/															/	/	/		
Anh T.K. Do et al. 2018	/															/								/	/		
Bachtiar W. Mutaqin et al. 2024	/		/			/		/									/										
Iswana Adela et al. 2019								/																			
Azman Azid et al. 2015																											
G Aliyuddin and A Damayanti 2019								/															/	/	/		
Dian N. Handiani et al. 2022		/						/												/							
A. Anandkumar et al. 2019								/															/		/		
Febriandi et al. 2019								/																			

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Authors	Methodology																			DATA							
	DSAS	CVI	NSM	LRR	SCE	EPR	WLR	GIS	ENVI	GT	ML	OSD	HYSR	MASW	NDVI	NDWI	DEM	CEI	MLG	S1	S2	L9	L8	L7	L5	S5	PLANET SCOPE
Husnayaen et al. 2018		/						/									/										
Muhammad Irham et al. 2021		/						/																			
Tengku Ahmad Imran Ku Yusoff And Mohamad Shaufi Sokiman, 2017																											
I A Kurniawan and and M A Marfai 2020	/		/	/		/		/															/		/		
Eva Louise den Boer et al. 2018	/		/	/	/	/		/															/	/			
F A Mohd et al. 2021		/						/																			
Fazly Amri Mohd et al. 2019		/																								/	
Max Rudolf Muskananfola and Supriharyono, Sigit Febrianto	/		/			/		/																/	/		
Hai-Hoa Nguyen et al. 2015	/							/																			
Janneli Lea A. Soria et al. 2021	/		/			/																					
Ratna Sari Dewi et al. 2017																											
Pratama et al. 2021	/					/										/					/						
Wahid and Osman, 2023	/		/	/	/	/																					

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Authors	Methodology																			DATA							
	DSAS	CVI	NSM	LRR	SCE	EPR	WLR	GIS	ENVI	GT	ML	OSD	HYSR	MASW	NDVI	NDWI	DEM	CEI	MLG	S1	S2	L9	L8	L7	L5	S5	PLANET SCOPE
Mubarak et al. 2024	/							/																			
Basa T. Rumahorbo et al. 2023		/															/										
Arief Wicaksono et al. 2019	/							/								/											

*Digital Shoreline Analysis System
*Net Shoreline Movement (NSM)
*Linear Regression Rate (LRR)
*End-Point Rate (EPR)
*Weighted Linear Regression (WLR)
*Landsat 9 (L9)
*Landsat 5 TM, Thematic Mapper (L5)
*Landsat 8 OLI, Operational Land Imager (L8)
*Environment for Visualizing Images (ENVI)
*Geospatial Technique (GT)
* SPOT-5 (S5)
* National Coastal Erosion Study (NCES)
* Horizontal-to-Vertical Spectral Ratio (HVSR)
*Multichannel Analysis of Surface Waves (MASW)
*Sentinel-1 (S1)
* Maximum Likelihood (ML)
* On-Screen Digitizing (OSD)
* Sentinel-2A (S2)
* normalized difference vegetation index (NDVI)
* Digital elevation model (DEM)
* Normalized Difference Water Index (NDWI)
* Standard Error of the Coastal position estimate (SCE)
*Machine Learning (MLG)

RESULTS AND DISCUSSION

TEMPORAL ANALYSIS

The selected studies, primarily focused on Southeast Asia's dynamic coastlines from 2014 to 2024, establish a methodological foundation heavily reliant on the synergistic use of long-term Landsat data and the high-frequency Sentinel constellation for change detection. The research landscape is characterized by a dominant, integrated workflow where shorelines are automatically extracted using indices like MNDWI and their change is quantified statistically with the Digital Shoreline Analysis System (DSAS). A significant evolution is the marked shift towards advanced machine learning classifiers and multi-sensor data fusion, moving beyond simple classification to sophisticated modeling for vulnerability assessment. This progression is underpinned by an emphasis on cloud-computing platforms and rigorous ground truthing, yet it also reveals a pronounced geographical bias, with research concentrated in countries like Indonesia and Malaysia, leaving critical data gaps in other Southeast Asian nations.

THEME 1: EVOLUTION AND PREVALENCE OF DATA SOURCES

The analysis reveals that the Landsat program (L5-TM, L7-ETM+, L8/9-OLI) remains the foundational data source for decadal change studies, primarily due to its unparalleled long-term, free, and open archive providing global coverage since 1984 (Wulder et al. 2022). This legacy enables the consistent monitoring of long-term phenomena such as deforestation, urban expansion, and agricultural change over 30-year periods or more (Zhu 2017). However, the rise of the Copernicus program has significantly augmented this capability. Sentinel-2's higher temporal resolution (5-day revisit) is frequently combined with Landsat to create denser time stacks that mitigate cloud-cover limitations, while Sentinel-1's Synthetic Aperture Radar (SAR) provides critical all-weather, day-and-night monitoring capabilities, particularly in perpetually cloudy regions (Torres et al. 2012).

For fine-scale analysis, commercial satellite imagery (e.g., PlanetScope, IKONOS) is employed where high spatial resolution is paramount, though its use is often constrained by cost and limited historical depth (Tyukavina et al. 2022). Crucially, modern studies rarely rely on a single data source. There is a prevailing trend towards a synergistic multi-sensor approach, integrating ancillary data like Digital Elevation Models (DEMs) and ground truthing (GT) to correct for topography and validate results, thereby significantly enhancing classification accuracy and the overall robustness of change detection models (Kennedy et al. 2018).

THEME 2: TECHNIQUES FOR SHORELINE EXTRACTION AND CHANGE ANALYSIS

The methodological approach to shoreline changes analysis is fundamentally bifurcated into the initial step of shoreline extraction and the subsequent statistical quantification of change. Shoreline extraction is predominantly achieved through automated spectral index-based techniques, with the Normalized Difference Water Index (NDWI) and Modified NDWI (MNDWI) being the most prevalent due to their efficacy in distinguishing land-water boundaries (Xu, 2006). These automated methods are favoured for processing large temporal and spatial datasets efficiently. However, manual On-Screen Digitizing (OSD) remains a critical, often more accurate, approach for complex environments like tidal flats or urban coastlines, or for validating automated extracts, highlighting a trade-off between efficiency and precision (Boak & Turner 2005).

For the quantitative analysis of erosion and accretion rates, the Digital Shoreline Analysis System (DSAS) is the established and overwhelmingly dominant tool (Himmelstoss et al. 2018). This vector-based software automates the calculation of key change statistics by generating transects perpendicular to the shore. The core metrics employed are Net Shoreline Movement (NSM), which provides the total change distance between two dates; End Point Rate (EPR), a simple calculation of NSM divided by time; and the more statistically robust Linear Regression Rate (LRR), which calculates a rate-of-change using all available shoreline positions to minimize the impact of outlier data points. The selection of these metrics allows studies to communicate both absolute change (NSM) and averaged rates (EPR, LRR), forming the quantitative backbone of coastal change assessment.

THEME 3: ADVANCED METHODOLOGIES AND MODELLING APPROACHES

The analytical workflow in coastal remote sensing is underpinned by a robust geospatial software ecosystem, with commercial platforms like ArcGIS and ENVI alongside open-source tools like QGIS and SNAP providing the essential environment for data processing, analysis, and visualization (QGIS Development Team, 2022; Harris Geospatial, 2023). Within this environment, classification techniques have evolved significantly. While traditional parametric methods like Maximum Likelihood Classification remain in use for their simplicity, there is a marked shift towards advanced machine learning (ML) and deep learning algorithms, such as Random Forest and Support Vector Machines, which offer superior handling of complex, non-linear data relationships and higher accuracy for land cover mapping (Maxwell et al. 2018).

Beyond classification, the field employs a suite of specialized models to understand and forecast coastal change. These range from physical process models like the Bruun Rule for predicting shoreline retreat to statistical models like the Kalman Filter for integrating noisy observational data, and decision-support frameworks like Multi-Criteria Decision Analysis (MCDA) for managing coastal vulnerability (Thieler & Hammar-Klose, 1999). Crucially, the reliability of any model or classification output is contingent on rigorous field validation. The synthesis of results indicates that robust Ground Truthing (GT)—through field surveys, high-resolution aerial imagery, or existing land cover maps—is not merely supplementary but an indispensable component for training algorithms and quantitatively assessing accuracy, thereby ensuring the scientific credibility of the findings (Olofsson et al. 2014).

THEME 4: SYNTHESIS: INTEGRATED WORKFLOWS AND TRENDS

Synthesis of the reviewed literature reveals distinct methodological archetypes correlated to specific research objectives. The most prevalent workflow, particularly for geomorphic change analysis, is the "Landsat + NDWI/OSD + DSAS" chain, leveraging the long Landsat archive to extract shorelines for quantitative rate calculation (Himmelstoss et al. 2018). For broader land-use/land-cover (LULC) change studies, a "Sentinel-2/Landsat + ML Classification + GIS Analysis" pipeline dominates, utilizing the improved temporal resolution of Sentinel-2 and the power of machine learning algorithms for classification (Maxwell et al. 2018). The most complex assessments, such as multi-hazard vulnerability studies, employ a "Multi-Source (Optical+SAR+DEM) + Integrated Model (e.g., MCDA)" framework, integrating diverse data to feed decision-support models like Multi-Criteria Decision Analysis (Thieler & Hammar-Klose, 1999). A clear temporal evolution is evident from 2014 to 2024. Early studies relied more heavily on Landsat and manual digitizing, while recent publications show a marked shift towards leveraging the Sentinel constellation, utilizing cloud-computing platforms like Google Earth Engine for big data processing, and adopting machine learning for automated analysis (Gorelick et al. 2017). Geographically, research focus is uneven across Southeast Asia, with a strong concentration of studies in Indonesia, Malaysia, Thailand, and Vietnam due to extensive coastlines and significant erosion threats. Conversely, countries like Myanmar, Cambodia, and Laos are notably under-represented in the literature, highlighting a critical geographical data gap that merits future research attention.

DISCUSSION

This systematic review synthesizes the methodological evolution in coastal dynamics and erosion mapping across Southeast Asia, revealing a field rapidly advancing through data integration and machine learning, yet challenged by persistent geographical and technical gaps. Theme 1 highlights a strategic shift from reliance on a single data source to a synergistic multi-sensor approach. While the Landsat legacy remains foundational for long-term trend analysis, its integration with the Sentinel constellation has been a game-changer for the cloud-prone Southeast Asian region. As highlighted in a recent global analysis by Zhang et al. (2023), the combination of Sentinel-2's high revisit rate and Sentinel-1's all-weather SAR capability directly addresses critical data gaps, enabling more robust time-series analysis. However, a significant limitation persists in the underutilization of very high-resolution commercial data and unmanned aerial vehicles (UAVs) for validation, creating a resolution ceiling for regional-scale studies. To overcome this, future research must leverage cloud-computing platforms to develop automated data fusion pipelines, as demonstrated in recent large-scale coastal studies using Google Earth Engine (Amani et al. 2023). This will bridge the scale gap between satellite imagery and on-the-ground processes, ultimately leading to more precise change detection.

In Theme 2, the standardization of shoreline analysis around automated extraction and the Digital Shoreline Analysis System (DSAS) has enabled regional meta-analyses. The prevalent use of indices like MNDWI and statistics like the Linear Regression Rate (LRR) provides a consistent, comparable framework for quantifying coastal change. The move towards open-source toolkits, exemplified by the CoastSat software (Vos et al. 2023), is making these robust methodologies more accessible. Despite this standardization, a critical gap remains the inadequate quantification and reporting of positional uncertainty, which is inherent in shoreline mapping due to tidal variations and sensor limitations. This often leads to overconfident interpretations of erosion rates. Moving forward, it is imperative for studies to adopt and standardize uncertainty budgets. Furthermore, research should explore machine learning models for shoreline delineation in complex environments like tidal flats, which may outperform traditional spectral indices and reduce the reliance on labor-intensive manual digitizing. Theme 3 underscores a pivotal methodological evolution from traditional classification to advanced, predictive modeling. The adoption of machine learning algorithms like Random Forest has significantly improved land cover mapping accuracy by handling complex, non-linear data relationships. As detailed in the state-of-the-art review by Wang et al. (2024), deep learning models are now pushing the boundaries of classification performance. More importantly, the integration of these classifications into decision-support frameworks such as Multi-Criteria Decision Analysis (MCDA) represents a crucial shift from descriptive mapping to applied science for coastal vulnerability assessment. A key limitation, however, is the "black box" nature of complex models, which can hinder interpretability and stakeholder trust. To address this, the integration of Explainable AI (XAI) techniques is essential. Future work must also focus on better calibrating physical models like the Bruun Rule with local remote sensing data to improve the reliability of shoreline change forecasts.

Finally, the synthesis in Theme 4 reveals that methodological progress is unevenly distributed across the region. The identified archetypes, from the "Landsat + DSAS" chain to the "Multi-Source + Integrated Model" framework, provide a clear roadmap for study design. The temporal trend is now defined by the analysis of large, multi-sensor datasets on cloud platforms, a paradigm that has been critically reviewed for its opportunities and challenges in environmental monitoring (Amani et al. 2023). However, the most glaring gap is the severe geographical bias, with a concentration of studies in Indonesia, Malaysia, and Thailand, while Myanmar, Cambodia, and Laos remain critically understudied. This bias creates a significant blind spot in regional climate adaptation efforts. Therefore, the highest priority for future research should be to address this imbalance through targeted studies and international collaborations in data-poor countries, applying standardized regional protocols to generate a truly comprehensive and comparable assessment of coastal vulnerability for all of Southeast Asia.

CONCLUSION

This systematic review demonstrates that the monitoring of coastal dynamics in Southeast Asia has been fundamentally transformed by a shift towards integrated, cloud-based geospatial workflows. The established methodological archetype, leveraging the long-term Landsat archive with the high-frequency Sentinel-2 and all-weather Sentinel-1 data, provides an unprecedented capacity for consistent, large-scale change detection (Zhang et al. 2023). This multi-sensor paradigm is increasingly operationalized through machine learning algorithms and cloud computing platforms like Google Earth Engine, which have become central to processing these vast datasets and generating accurate land cover and shoreline maps (Amani et al. 2023). The dominance of tools like the Digital Shoreline Analysis System (DSAS) for quantifying erosion rates further underscores the field's maturation towards standardized, quantitative assessment.

Despite these significant technical advancements, the review reveals a critical and persistent challenge: a severe geographical research bias. The overwhelming concentration of studies in countries like Malaysia, Indonesia, and Thailand, as evidenced by numerous case studies, leaves the coastlines of Myanmar, Cambodia, and Laos as glaring scientific blind spots (Noor et al. 2023). This inequitable distribution of research effort creates a major barrier to developing a cohesive regional understanding of vulnerability and directly undermines the goal of inclusive climate adaptation. Without targeted studies in these data-poor regions, policymakers are left without the necessary evidence to prioritize interventions, thereby exacerbating the risks for some of the most vulnerable populations.

Moving forward, the priority for the research community must be to bridge this gap between technical capability and equitable application. Future work should focus on deploying these advanced, integrated methodologies—particularly the synergistic use of optical and SAR data and explainable AI models—specifically within the under-studied nations of Southeast Asia (Wang et al. 2024). Furthermore, there is a pressing need to transition from primarily mapping past changes towards forecasting future vulnerability under various climate scenarios. By consolidating these powerful tools into a consistent, region-wide framework, scientists can provide the comprehensive and actionable intelligence required to build resilient coastlines and safeguard communities across the entirety of Southeast Asia.

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DECLARATION OF COMPETING INTEREST

None.

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