



Coastal community resilience frameworks for disaster risk management

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Abstract

Extreme weather events due to climate change and growing economic and development activities along coastlines have resulted in increased risks from natural and human-induced disasters—affecting the safety and livelihoods of coastal communities. Assessing community resilience to disasters is, therefore, an essential step toward mitigating their current and future risks. This study provides a systematic review of coastal community resilience frameworks for disaster risk management, covering their content, structure, and assessment. Sixty-four critical resilience criteria under four dimensions are identified by analyzing the convergence and divergence of the consideration of assessment indicators in the reviewed frameworks. Existing frameworks focus mostly on ‘governance and institutions,’ ‘infrastructure,’ and ‘society and the economy.’ Despite significant risks, the impacts on the environment and potential risks of climate change are not prioritized. Only 22% of the frameworks consider future risks, rendering the remainder inadequate for assessing projected risks from climate change. None of the frameworks consulted the full spectrum of stakeholders (public, government, and experts) during the development process, which compromised their applicability, acceptability, and effectiveness. 56% of the frameworks considered a single hazard type. Community resilience is inherently multi-dimensional. Therefore, the interrelationships between multiple hazards should be adequately addressed in future frameworks.

Keywords Coastal communities · Resilience indicators · Assessment framework · Coastal hazards · Disaster risk management

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1 Introduction

Coastal areas are increasingly at risk from both natural and human-induced hazards. Assessing community resilience is an essential first step toward reducing disaster risk in a community and enhancing its resilience to natural and human-induced disasters (Burton 2015). According to Lloyd et al. (2013), fast-changing climate in the recent past and have led to a greater attention being placed on the development and implementation of adaptive administrative practices to mitigate and address the unique conditions present in coastal regions. Cooper and Boyko (2010) observe that, in ideal circumstances, coastal communities and their infrastructure would be situated at a sufficient distance from the shore to guarantee adequate protection from the threat of disasters. However, in many countries, a large proportion of the infrastructure and population is located close to the shore, rendering them vulnerable to hazardous events.

Human encroachment into narrow coastal land increases the vulnerability of communities to coastal hazards. Coastal resilience entails the development and deployment of measures to minimize harm and ensure a rapid recovery during and after a disaster, which is a promising approach to mitigating disaster risks. Ewing and Synolakis (2011) report that the coastlines of the world have, for centuries, formed the epicenters of business, commerce, transportation, and industry. The diversity of resources and opportunities positioned along these coastlines have attracted a large population, leading to urban agglomerations, ranging from sizeable towns to megacities. According to Courtney et al. (2008), Ewing and Synolakis (2011), Arbon (2014), and Chelleri et al. (2015), approximately 40% of the global population resides within 100 km of the coast. Furthermore, it is estimated that, due to the increasing rate of urbanization, approximately half of the global population will live in coastal communities in the future.

Spellman and Whiting (2006) and Sharifi and Yamagata (2016) note that rising sea levels and the increased occurrence of coastal storms necessitate the relocation of communities situated close to shorelines and the establishment of infrastructures further inland. However, these strategies can prove unviable when faced by an increase in population and urbanization. Often, the only viable alternative is to devise and implement measures to facilitate coastal sustainability and resilience. Arbon et al. (2016) state that one method of reducing the vulnerability of coastal communities and their infrastructure is to improve coastal resilience. In addition, Lloyd et al. (2013) and Meerow et al. (2016) define coastal resilience as the ability for both human and natural communities to resume their normal lives; i.e., ‘bounce back,’ following events such as coastal storms, hurricanes, and flooding, rather than simply reacting to the impact of such events. Thus, coastal communities that are better prepared and informed are more likely to rebound from climate and weather-related phenomena. Cutter et al. (2014) state that preparation can facilitate rapid recovery and also minimize the negative impact on the safety of the communities and economy. Meerow et al. (2016) consider that an evaluation of community resilience not only facilitates an in-depth understanding of disasters but also assists in the formulation of informed, evidence-based strategies, capable of minimizing the impact of natural events and hasten the pace of recovery. Resilience has recently been integrated as a key element of the United Nations International Strategy for Disaster Reduction (UNISDR) (Alshehri et al. 2015).

Cimellaro et al. (2016) and Ameen et al. (2015) observe the lack of any ubiquitous model or framework for the assessment of the resilience of a community. Several researchers, including, e.g., Spellman and Whiting (2006) and Arbon (2014), emphasize the importance of focusing on community resilience, rather than vulnerability as an all-encompassing

measure. Although there exists is no universal approach to the assessment of community resilience, researchers agree that it is characterized by several dimensions of wellbeing, including political, social, economic, and physical. There exists a number of community resilience frameworks; some of which are specific to coastal areas, e.g., the community resilience index (CRI) and coastal community resilience (CCR).

Young and Solomon (2009) argue that evidence-based practices require the application of scientific findings to prevailing circumstances, by means of the appropriate selection and critical appraisal of research findings relevant to their problem. This current study, therefore, aims to broaden the understanding of CCR assessment frameworks by critically reviewing nine selected frameworks. The specific objectives are to (a) provide a detailed overview of the frameworks; i.e., their content, structure, and development/implementation process; and (b) establish common dimensions, indicators, and sub-indicators for assessing resilience.

The development and implementation of coastal community resilience (CCR) assessment frameworks are active areas of inquiry, and approaches to which are still evolving. The significance of this study lies in the fact that in addition to taking stock of the development of CCR assessment frameworks, the findings can inform future developments. The identified factors and dimensions can act as a starting point for the involvement of stakeholders and experts in the planning and preparation processes, both within and beyond the community. This, in turn, makes it possible to address the various socioeconomic and environmental challenges faced by communities in a more effective manner. The frameworks may also contribute toward ensuring that resilience becomes a ‘governable strategy,’ through the development of iterative and quantifiable frameworks for resilience implementation (Larkin et al. 2015).

This rest of the article is structured as follows. The next section describes the systematic review methodology and the criteria for selecting a framework for the detailed review. The section also describes the reviewed frameworks briefly. The following section compares the selected frameworks in terms of their characteristics and structure. The results of the review are then presented and discussed next. Findings are contextualized against the literature, while conclusions are drawn in the last section.

2 Methodology

The systematic literature review involved the selection of research publications, which were collected, appraised, and synthesized. A rigorous and documented procedure was put in place for both the search strategy and the process of selecting the research papers. Bealt and Mansouri (2018) argue that a systematic literature review requires a scientific approach enabling researchers to conduct a detailed article search while promoting transparency and relevance and avoiding bias. Moreover, a systematic literature review enhances the knowledge base of the researcher, thus having a positive impact on both practice and policy. For the current study, relevant papers were selected using a comprehensive process of planning, searching, screening, and reporting.

As the main focus of this review concerns coastal community resilience assessment frameworks, a broad-based search strategy was implemented to develop knowledge regarding current assessment frameworks and tools applied at various coastal communities (Arbon 2014). Following an extensive scoping exercise, the key trends, themes, and gaps in the chosen papers were identified and ranked in terms of importance. The following

databases were used to conduct the searches: ScienceDirect; IEEE Xplore; Google Scholar; and the Web of Science Core Collection. To increase the relevance of the results to the present study, the searches employed a range of different keywords related to ‘frameworks,’ including: (a) ‘models’; (b) ‘tools’; (c) ‘indices’; and (d) ‘toolkits,’ as given in Table 1.

The search of the databases identified 429 articles. Endnote software was used to compare the papers and delete any duplicates, resulting in the exclusion of 291 documents. This left 138 items for analysis. Figure 1 indicates that the initial searches were undertaken with the objective of extracting relevant information concerning community resilience. A manual examination of the titles and abstracts of the articles was subsequently conducted to identify information on: (a) coastal community resilience; (b) coastal hazards; (c) climate-induced hazards; and (d) multi-hazards. This examination narrowed down the number of articles to forty. The final step involved a thorough reading of each article to analyze its content, focusing specifically on how the framework was designed to examine coastal community resilience as a complete system, as well as how the resilience dimensions were structured.

Most investigated frameworks were based on the needs of a specific region of the world, which resulted in each possessing varying indicators for each dimension of resilience. The current study, therefore, excluded any frameworks that considered only one aspect of community resilience. The Australian framework designed to enhance a community’s resilience for health security threats (Chandra et al. 2011) and a framework that focused on earthquakes, a single form of natural disaster (Ainuddin and Routray 2012), were excluded. This step further narrowed down the number of frameworks to nine, all of which focused on multi-dimensional community resilience. These nine frameworks were then grouped under the following headings: (a) year of issue; (b) study location; (c) type of hazard; (d) type of assessment; and (e) assessment methods, as outlined in Table 2.

The nine chosen frameworks have been widely employed in their respective jurisdictions and varying contexts. Therefore, a body of knowledge exists regarding their effectiveness, applicability, and flexibility. Published and accompanying sources such as framework guidelines, policy documents, manuals, and peer-reviewed articles related to each of the frameworks were also evaluated using content analysis and an analytical framework.

A list was subsequently drawn up of the initial important and common criteria related to coastal community resilience by means of a thorough review of the criteria of each of the selected frameworks. The selected criteria were categorized into four common dimensions, and several matrices were developed, with the criteria set out in the rows and frameworks in the columns. Comparison matrices were created to ensure that all related criteria were included in the list, as well as to assess the extent of the applicability of the different frameworks across several indicators and sub-indicators within the four dimensions. Content analysis was selected as the method for all analyses discussed in this paper. All nine frameworks are introduced first in the following subsection and critiqued next.

2.1 Selected coastal community resilience frameworks

2.1.1 Coastal Community Resilience (CCR1)

CCR1 was developed in 2008 with the participation of over one hundred governmental agencies and non-governmental organizations (NGOs) in the five countries that were most affected by the 2004 tsunami, namely Thailand, Sri Lanka, Indonesia, India, and the Maldives. All contributing countries are involved in the US Indian Ocean Tsunami Warning

Table 1 Bibliometric database results against search terms and their combination using logical operators

Search operators	Search term combinations	Returns per database (count)				
		ScienceDirect	IEEE Xplore	Google Scholar	Web of science	
Boolean operators 'AND,'OR,' and 'NOT'	Coastal community resilience frameworks AND models	11	9	15	8	
	Coastal community resilience frameworks AND tools	14	11	12	5	
	Coastal community OR coastal population resilience frameworks	11	12	22	7	
	Coastal community resilience frameworks OR models	14	16	28	8	
	Coastal community resilience NOT urban resilience	11	5	25	3	
Exact phrases	Coastal community resilience frameworks	18	5	17	1	
	Coastal community resilience tools	16	8	19	6	
	Coastal community resilience models	14	1	12	2	
Truncation ^a	Coast* community resilience	8	9	8	7	
	Coastal community* resilience	6	2	2	5	
	Coastal community resilience*	9	4	1	2	
Total		132	82	161	54	

^aThe character asterisk (*) refers to any group of characters

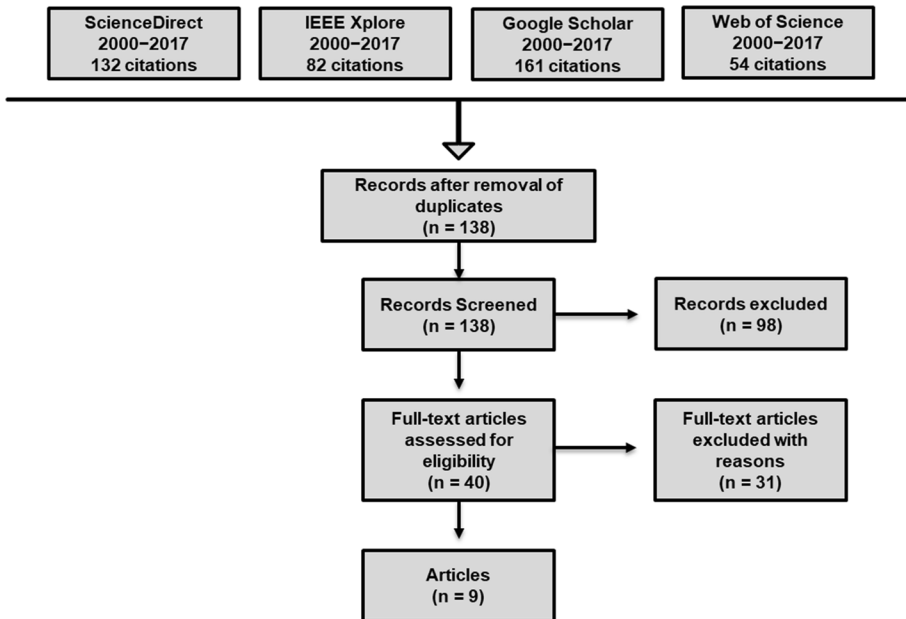


Fig. 1 Prismatic process of identification, screening, eligibility determination, and inclusion of frameworks in the study

System (US IOTWS) program. CCR1 is aimed at the assessment of coastal community resilience to natural hazards. Experience from the development of CCR1 indicates that differences exist between communities regarding the perceptions of their ability to deal with these hazards appropriately (Courtney et al. 2008).

2.1.2 Climate Disaster Resilience Index (CDRI)

Climate disaster resilience index (CDRI) was developed in 2009 by the Global Center for Education and Research on Human Security Engineering for Asian Megacities, Kyoto University, Japan. Its scope is limited to climate-induced disasters, such as cyclones, floods, heat waves, droughts, and heavy rainfall. CDRI was developed to measure the existing level of recovery from climate disasters within the targeted areas against an index titled climate disaster resilience index, from which the name of the framework was derived. CDRI provides knowledge and information to other local and national stakeholders, all of whom share the aim of enhancing community resilience (Shaw and Team 2009).

2.1.3 Texas Community Disaster Resilience Index (TX-CDRI)¹

In 2008, the TX-CDRI was developed by Texas A&M University (TAMU), Texas A&M University at Galveston (TAMUG), and the Houston Advanced Research Center (HARC)

¹ The prefixes, ‘Texas’ and ‘TX’ is our addition to the CDRI framework developed in Texas universities to differentiate between different CDRI frameworks.

Table 2 Key characteristics of the selected frameworks

Framework	Year of issue	Study location	Hazard type	Assessment type	Format	Source
CCRI	2008	Indian Ocean region (Thailand, Sri Lanka, Indonesia, India, and the Maldives)	Coastal hazard	Summative	Toolkit	Courtney et al. (2008)
CDRI	2009	South/South East Asia	Climate-induced hazards	Summative	Toolkit	Shaw and Team (2009)
TX-CDRI ^a	2010	The USA	Multi-hazard	Summative	Index	Peacock et al. (2010)
LDRI	2012	The Philippines	Multi-hazard	Formative	Index	Orencio and Fujiti (2013)
BRIC	2014	The USA	Multi-hazard	Summative	Index	Cutter et al. (2014)
IN-CDRI ^b	2014	India, Chennai	Climate-induced hazards	Summative	Index	Joerin et al. (2014)
RIM	2015	The Northern Gulf of Mexico in USA, China, The Netherlands	Coastal hazards	Summative	Model	Lam et al. (2016)
CRDSA	2015	Saudi Arabia	Multi-hazard	Summative	Index	Alshetri et al. (2015)
CCR2	2015	India	Coastal hazard	Summative	Index	DasGupta and Shaw (2015)

^aThe prefix, 'TX' is our addition to the CDRI framework developed in Texas universities to differentiate between different CDRI frameworks

^bThe prefix, 'IN' is our addition to the CDRI framework developed in India to differentiate between different CDRI frameworks

in the USA. Its aim was to focus on developing a series of indicators for community resilience that would be applicable at regional and national levels. It was developed to improve the recovery of coastal communities along the Gulf Coast and was based on data from the National Oceanic and Atmospheric Administration (NOAA). The underlying data and tools are available to the local communities, decision-makers, and stakeholders via interactive websites hosted by Texas A&M University at Galveston (coastalatlas.tamug.edu) and Texas A&M College Station (coastalatlas.tamu.edu) (Peacock et al. 2010).

2.1.4 Localized Disaster Resilience Index (LDRI)

LDRI was developed in 2012. It proposed an index for a disaster-resilient coastal community on a local level in the Philippines. The development process utilized the Delphi technique, a structured communication technique involving a panel of experts. LDRI involved twenty decision-makers in Baler, Aurora (Philippines), in identifying the criteria and elements that can be used to reduce the vulnerability of coastal communities. The identified criteria were further structured using the analytic hierarchy process (AHP) and used paired comparisons (Orencio and Fujii 2013).

2.1.5 Baseline Resilience Indicators for Communities (BRIC)

BRIC was developed in 2014 to measure the resilience of communities in specific areas of the USA. The framework was constructed by calculating the total scores for the composites of six sub-indices for resilience: social, economic, community capital, institutional, infrastructural, and environmental. The potential scores range from zero to six, with higher scores corresponding to greater resilience and lower ones to less resilience. BRIC provides a reference point or baseline for examining the current status of inherent resilience at the county level, which can be useful in guiding local policy decisions. Although the framework provides an overall measure of resilience, it does not, however, for every individual indicator (Cutter et al. 2014).

2.1.6 Indian Climate Disaster Resilience Index (IN-CDRI²)

IN-CDRI was developed in 2014 in Chennai, India, and aimed to measure, from a community perspective, a city's capability to withstand climate-related disasters. IN-CDRI focuses on a comprehensive evaluation of all sectors of a city to hasten the resilience building process in urban areas. IN-CDRI is tailored specifically to climate-related hazards such as cyclones, droughts, floods, and heat waves, which are more likely to occur in Chennai than the geophysical hazards. Engineers (experts) operating in the ten different zones of Chennai, who carry out civic works, were selected as representatives to provide responses to the IN-CDRI questionnaire. The engineers weighed the importance of each variable and parameter in terms of its influence on the overall resilience score. The IN-CDRI assessment integrates aspects related to the Hyogo Framework for Action (HFA) 2005–2015 (Joerin et al. 2014).

² The prefix, 'Indian' and 'IN' is our addition to the CDRI framework developed in India to differentiate between different CDRI frameworks.

2.1.7 Resilience Inference Measurement (RIM)

The RIM framework was developed in 2015 to measure the resistance to coastal hazards of fifty-two counties along the Northern Gulf of Mexico in the USA. RIM uses exposure, damage, and recovery indicators to denote two relationships—vulnerability and adaptability. The framework utilizes both discriminant analysis and *k*-means clustering to derive resilience rankings. Five major types of coastal hazards were included in the RIM: coastal (including coastal flooding and storm surges), floods, hurricanes, thunderstorms, and tornadoes (Lam et al. 2016).

2.1.8 Community Resilience Framework (CRDSA)

In 2015, the CRDSA was developed in Saudi Arabia using a mixed-methods strategy (including quantitative and qualitative research). The CRDSA provides an assessment system, in which each criterion is weighted in order to evaluate the community's resilience in coping with future disasters. Based on a comprehensive literature search and a national survey of public perceptions of disasters in Saudi Arabia, the CRDSA was developed using the Delphi technique and AHP (Alshehri et al. 2015).

2.1.9 Coastal Community Resilience (CCR2)

CCR2, developed in 2015, aims to measure the resilience of a particular community to natural coastal hazards in rural areas in the Indian Sundarbans. The CCR methodology is divided into two parts. The first is concerned with the development of a series of criteria and variables that can be applied on a local level in rural coastal areas, while the second aims to assess, through a methodical application of the framework, the ability of the particular area under study to recover (DasGupta and Shaw 2015).

3 Comparison of the coastal community resilience frameworks

A quantitative comparison of the criteria and indicators within the nine selected frameworks can assist users and framework developers in appreciating the focus, commonality, and differences between the frameworks, and identify directions for future research and development. The assessment frameworks were compared based on key characteristics and structure.

3.1 Key characteristics

The key characteristics of the assessment frameworks are presented in Table 2. They have been organized into five major categories: year of issue, study location, hazard type, assessment type, and assessment methods. The findings of this comparison are discussed as follows.

3.1.1 Timeline

All of the selected frameworks have been developed between 2008 (CCR1) and 2015 (CCR2), thus confirming that the subject of coastal community assessment is a relatively recent development on an international level. The fact that several assessment frameworks

were published within this relatively short period demonstrates a great deal of attention paid by the scientific community on the topic in recent years (Sharifi 2016).

3.1.2 Location

The selected frameworks have been implemented in regions that are vulnerable to different types of maritime disasters, such as tropical cyclones and tsunamis. As given in Table 2, three (TX-CDRI, RIM, and BRIC) of the nine selected frameworks were purposely developed in order to assess the resilience of territories in the USA (Cutter et al. 2014; Lam et al. 2016; Peacock et al. 2010). The remaining six frameworks were used to assess resilience in Asian countries. For instance, CCR1 and CCR2 were used in India, LDRI in the Philippines, IN-CDRI in China and India, CDRI in South East Asia, and CRDSA in the Kingdom of Saudi Arabia (Alshehri et al. 2015; Courtney et al. 2008; DasGupta and Shaw 2015; Joerin et al. 2014; Orencio and Fujii 2013; Shaw and Team 2009). CCR1 is a cooperative framework (Courtney et al. 2008), and several countries (Thailand, Sri Lanka, Indonesia, India, and the Maldives) participated in its development.

The frameworks have not only been developed by international organizations but also by individual researchers. However, it is important to note that there remains a lack of assessment frameworks that have been developed by local authorities and organizations in developing countries. The frameworks that have been developed by non-local stakeholders may fail to appropriately reflect the local needs and conditions of the countries or regions.

3.1.3 Hazard type

Assessing community resilience is recognized as a fundamental step toward reducing disaster hazards and being better prepared to withstand and adapt to a broad array of natural and human-induced disasters that threaten coastal communities. Therefore, all of the selected frameworks have been used to assess the resilience of different communities across the globe to a large percentage of the different types of hazards. Hence, there exist significant differences between the selected frameworks. For instance, as given in Table 2, CCR1, RIM, and CCR2 are designed to address coastal natural hazards only (Lam et al. 2016), while TX-CDRI, LDRI, BRIC, and CRDSA are focused on multi-hazards, and CDRI and IN-CDRI address climate-induced hazards. Overall, it can be said that CCR1, CDRI, TX-CDRI, IN-CDRI, LDRI, BRIC, RIM, CRDSA, and CCR2 are broad based and address most of the risks posed by the hazards occurring in multiple domains.

3.1.4 Assessment type: formative versus summative

Additionally, the assessment frameworks can be classified as either formative or summative (Sharifi 2016). Summative frameworks measure the effectiveness of resilience interventions following the occurrence of disasters, while formative frameworks entail prior assessments and the continuous evaluation of resilience measures from their inception. Formative assessments typically contain evaluations based on forecasts rather than actual results. Moreover, they cover issues related to the constant monitoring of the conditions that started during the early steps of the planning process. In other words, they rely on methodologies that are process based and have the aim of increasing adaptive capability by conducting an incremental enhancement of the conditions (Dolin et al. 2017). The benefit of formative assessments is that they enhance the opportunities for learning. Taking

their iterative characteristics into consideration, this type of evaluation is appropriate for acknowledging dynamic challenges as well as preparing for future uncertainties.

Unlike formative assessments, summative assessments are carried out based on the actual findings of the effectiveness of the measures rather than the forecasts. Thus, summative assessments are perceived as an outcome-based assessment that assists communities in their understanding of their current stance on issues related to resilience. Furthermore, summative assessments use evidence required to formulate decision making about the importance of altering strategies of intervention. In this research, CCR1, CDRI, TX-CDRI, IN-CDRI, BRIC, RIM, CRDSA, and CCR2 can be classified as summative frameworks, while LDRI is the only formative framework that has been selected for this study. According to Cohen et al. (2016), formative frameworks, such as LDRI, are iterative. Thus, they are a suitable way of accounting for future uncertainty while at the same time addressing the dynamic present in different dimensions. Furthermore, this type of framework provides opportunities for in-depth learning. According to Norris et al. (2008), formative frameworks, such as LDRI, are vital for the assessment of community resilience against baseline conditions. This is essential for determining how communities change over time with regard to their vulnerability to hazards. As such, formative frameworks may be compared to longitudinal studies that assess changes over time to make credible inferences. Conversely, summative frameworks, which form 90% of the selected tools in this review, are outcome based. In this regard, they help communities to ascertain their standpoints concerning resilience. Sharifi (2016) notes that summative frameworks produce the evidence required for making important decisions concerning the changes needed to realign the resilience measures so that the interventions are more adaptive.

3.1.5 Assessment methods

The selected frameworks draw upon both quantitative and qualitative methods. According to Sharifi (2016), a mixed-methods approach is appropriate when data availability is problematic. Given that resilience is a value-laden concept that is influenced by attitudes and perceptions, this methodology enables the collection of ideas from community stakeholders regarding their needs in order to address concerns about the subjectivity of the assessment process.

The resilience assessment approach can be divided into four main formats: models, scorecards, toolkits, and indices (Cutter 2016).

- *Models* are used to reduce the complexity of the relationship between the risk and resilience factors, as well as to overcome any uncertainties or limitations related to predicting future events and their consequences. In this approach, past data on disasters are input into mathematical algorithms and scenario analyses in order to approximate future conditions (Cutter 2016).
- *Scorecards* allow us to obtain values for performance and assess these against each criterion within the resilience assessment framework. The values often take the form of answers to questions, calculated statistical values, or judgments/perceptions (Sharifi 2016). When using judgments in assessments, scaled questions with Likert scales are used to quantify qualitative feedback.
- *Toolkits* establish procedures for assessing resilience using one or more of the aforementioned methods (Cutter 2016). Toolkits not only provide guidance on how to conduct assessments but also outline mechanisms for identifying the assessment criteria,

collecting the required data, assigning weights, conducting assessments, suggesting interventions, and monitoring action plans.

- *Indices* rely on quantitative data, often using weighted averages or sums of scores obtained for all criteria in the assessment tool in order to get an aggregate index value (Cutter 2016). Indices are often standardized for comparison purposes, or weights are assigned to them based on contextual and temporal factors (Table 2), using methods such as the analytic hierarchy process (AHP) (Alshehri et al. 2015). Index values make it possible to assign an overall performance rating to community resilience.

As given in Table 2, most of the selected frameworks are organized in the format of indices and toolkits, and only one (RIM) is organized in a model format.

3.2 Framework structure

Despite the fact that a range of coastal community resilience frameworks has been developed over time in order to fulfill the same objective, these vary significantly in terms of their structure, potential, and application (Courtney et al. 2008). The nine selected frameworks have been chosen because of their similarity with regard to their organization, components, and procedures to ensure that the objectives of the review are met. Table 3 demonstrates the general structure of the tools. This structure comprises three levels—dimensions, indicators, and sub-indicators, which are discussed in the following sections.

3.2.1 Dimensions

In all of the chosen frameworks, four interrelated dimensions are covered: environmental and climate change, social and economic, infrastructure, and governance and institution, with varying degrees of emphasis on community resilience issues. This is based on local circumstances and reflects the nature of the indicators mentioned in each framework.

Resilience in terms of the environmental and climate change dimension can be roughly linked to a coastal area's exposure to specific coastal hazards (i.e., rising sea levels). Within each community, there is a different level of exposure to natural hazards. Equally, the distribution of risks to hazards is not uniform across different communities (Lam et al. 2016). This means that the level of natural/environmental resilience linked to each area will vary. Additionally, the environmental safeguarding action for each indicator has been introduced in order to incorporate specific actions that may be carried out to mitigate the threats arising from climate change. These actions are often adapted in accordance with the existing risk response mechanisms of local governments. While these factors may, at times, be considered to be negligible, they also have the potential to become highly detrimental to a society and its economy during periods of catastrophe.

In all nine frameworks, the importance of the social and economic resilience dimension has been widely emphasized. In coastal communities, social and economic resilience refers to the ability of a community to survive on limited natural resources when they are typically highly dependent on such resources (DasGupta and Shaw 2015). Table 3 illustrates that the various indicators and sub-indicators that can be categorized under 'social and economic resilience' include demographics, livelihood, awareness, training, culture, employment, safety, and security.

In terms of the infrastructure resilience dimension, utilities, communication, and public services are all essential for reducing the impact of disasters (McDaniels et al. 2008).

Table 3 General structure of the nine reviewed frameworks

Frame-work	Dimension	Indicator	Num-ber of sub-indicator	Weight (%)
CCR1	1. Policy and planning	1. Governance	10	
		2. Society and economy	6	
	2. Physical and environmental	3. Coastal resource management	6	
		4. Land use and structural design	7	
		5. Risk knowledge	4	
	3. Social and cultural	6. Warning and evacuation	7	
		7. Emergency response	4	
	4. Technical and financial	8. Disaster recovery	10	
		Subtotal	54	N/A
	CDRI	1. Physical	1. Electricity	
2. Water supply				
3. Sanitation				
4. Solid waste disposal				
5. Internal road network				
6. Housing and land use				
7. Community assets				
8. Warning system and evacuation				
		Subtotal	N/A	N/A
2. Social		1. Health status		
		2. Education and awareness		
		3. Social capital		
		Subtotal	N/A	N/A
3. Economic		1. Income		
		2. Employment		
		3. Households' assets		
		4. Access to financial services		
		5. Savings and insurance		
		6. Budget and subsidy		
		Subtotal	N/A	N/A
4. Institutional		1. Internal institutions and development plan		
		2. Effectiveness of internal institutions		
		3. External institutions and networks		
	4. Institutional collaboration and coordination			
	Subtotal	N/A	N/A	
5. Natural	1. Hazard intensity			
	2. Hazard frequency			
	Subtotal	N/A	N/A	

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)	
TX-CDRI	1. Social capital	1. Registered nonprofit organizations			
		2. Recreational centers (bowling, fitness, golf clubs) and sport organizations			
		3. Registered voters			
		4. Civic and political organizations			
		5. Census response rate			
		6. Religious organizations			
		7. Owner-occupied housing units			
		8. Professional organizations			
		9. Business organizations			
		Subtotal		N/A	N/A
	2. Economic capital	1. Per capita income			
		2. Median household income			
		3. Population in labor force, employed			
		4. Median value of owner-occupied housing units			
		5. Business establishments			
		6. Population with health insurance			
		Subtotal		N/A	N/A
	3. Physical capital	1. Building construction establishments			
		2. Heavy and civil engineering construction establishments			
		3. Highway, street, and bridge construction establishments			
		4. Architecture and engineering establishments			
5. Land subdivision establishments					
6. Legal services establishments					
7. Property and casualty insurance companies					
8. Building inspection establishments					
9. Landscape architecture and planning establishments					
10. Environmental consulting establishments					
11. Environment and conservation organizations					
12. Scientific research and development services					
13. Colleges, universities, and professional schools					
14. Housing units					
15. Vacant housing units					

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)
		22. Occupied housing units with vehicle available		
		23. Special needs transportation services		
		24. School and employee buses		
		25. Owner-occupied housing units with telephone service		
		26. Newspaper publishers		
		27. Radio stations		
		28. Television broadcasting		
		29. Internet service providers		
		30. Temporary shelters		
		31. Housing		
		32. Community food service facilities		
		33. Schools		
		34. Licensed childcare facilities		
		35. Utility systems construction establishments		
		Subtotal	N/A	N/A
4. Human capital		1. Population with more than high school education		
		2. Physicians		
		3. Population employed in health care support		
		4. Population employed in building construction establishments		
		5. Population employed in heavy and civil engineering constructions		
		6. Population employed in architecture and engineering establishments		
		7. Population employed in environmental consulting services		
		8. Population employed in environment and conservation organizations		
		9. Population employed in land subdivision services		
		10. Population employed in building inspection services		
		11. Population employed in landscape architecture and planning establishments		
		12. Population employed in property and causality insurance companies		
		13. Population employed in highway, street, and bridge construction		
		14. Population employed in legal services		
		15. Population covered by comprehensive plan		
		16. Population covered by zoning regulations		
		17. Population covered by building codes		
		18. Population covered by FEMA approved mitigation plan		
		19. Community rating system (CRS) score		

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)
		20. Population employed as firefighting, prevention, or law enforcement workers		
		21. Population employed in scientific research and development services		
		22. Population employed in colleges, universities, and professional schools		
		23. Population who speak English language very well		
		24. Population employed in special need transportation services		
		25. Population employed in community and social services		
		Subtotal	N/A	N/A
LDRI	1. Environmental and natural resource management	1. Understanding of functioning environment and ecosystems		7.42
		2. Environmental practices that reduce hazard risk		7.24
		3. Preservation of biodiversity for equitable distribution system		3.48
		4. Application of indigenous knowledge and technologies		3.89
		5. Access to community-managed common property resources		3.07
		Subtotal	N/A	25.10
	2. Sustainable livelihoods	1. High level of local economic and employment stability		5.86
		2. Equitable distribution of wealth and livelihood in community		3.39
		3. Livelihood diversification in rural areas		6.09
		4. Fewer people engaged in unsafe livelihood		5.41
		5. Adoption of hazard-resistant agriculture		5.63
		6. Small enterprises with protection and business continuity/recovery plans		4.49
		7. Local market and trade links protected from hazards		4.90
		Subtotal	N/A	35.78
	3. Social protection	1. Social support and network systems on DRR activities		8.57
		2. Cooperation with local community for DRR activities		7.47
		3. Community access to basic social services		3.30
		4. Established social information and communication channels		2.84
		5. Collective knowledge and experience of management of previous events		3.07
		Subtotal	N/A	25.24
	4. Planning regimes	1. Community decision making takes on land use and hazards		5.82
		2. Local disaster plans feed into local development and land use planning		2.79
		3. Local community participates in all stages of DRR planning		5.27
		Subtotal	N/A	13.88

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)	
BRIC	1. Social	1. Educational attainment equality			
		2. Pre-retirement age			
		3. Transportation			
		4. Communication capacity			
		5. English language competency			
		6. Non-special needs			
		7. Health insurance			
		8. Mental health support			
		9. Food provisioning capacity			
		10. Physician access			
			Subtotal	N/A	N/A
	2. Economic		1. Home ownership		
			2. Employment rate		
			3. Race/ethnicity income equality		
			4. Non-dependence on primary/tourism sectors		
			5. Gender income equality		
			6. Business size		
			7. Large retail-regional/national geographic distribution		
			8. Federal employment		
			Subtotal	N/A	N/A
	3. Community capital		1. Place attachment—not recent immigrants		
			2. Place attachment—native born residents		
			3. Political engagement		
			4. Social capital—religious organizations		
			5. Social capital—civic organizations		
			6. Social capital—disaster volunteerism		
			7. Citizen disaster preparedness and response skills		
			Subtotal	N/A	N/A
	4. Institutional		1. Mitigation spending		
			2. Flood insurance coverage		
			3. Jurisdictional coordination		
			4. Disaster aid experience		
			5. Local disaster training		
			6. Performance regimes-state capital		
			7. Performance regimes-nearest metro area		
			8. Population stability		
			9. Nuclear plant accident planning		
			10. Crop insurance coverage		
			Subtotal	N/A	N/A

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)
IN-CDRI	5. Housing/infra-structural	1. Sturdier housing types		
		2. Temporary housing availability		
		3. Medical care capacity		
		4. Evacuation routes		
		5. Housing stock construction quality		
		6. Temporary shelter availability		
		7. School restoration potential		
		8. Industrial re-supply potential		
		9. High-speed internet infrastructure		
		Subtotal	N/A	N/A
	6. Environmental	1. Local food suppliers		
		2. Natural flood buffers		
		3. Efficient energy use		
		4. Pervious surfaces		
		5. Efficient water use		
		Subtotal	N/A	N/A
	1. Physical	1. Electricity	4	5.83
		2. Water	4	3.88
		3. Sanitation and solid waste disposal	3	3.32
		4. Accessibility of roads	5	4.85
		5. Housing and land use	5	4.24
		Subtotal	21	22.12
2. Social		1. Population	4	3.11
		2. Health	4	4.66
		3. Education and awareness	5	3.99
		4. Social capital	4	3.45
		5. Community preparedness during a disaster	5	4.12
		Subtotal	22	19.33
3. Economic		1. Income	4	3.77
		2. Employment	5	3.83
		3. Household assets	5	4.11
		4. Finance and savings	5	4.11
	5. Budget and subsidy	5	3.80	
	Subtotal	24	19.62	

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)	
	4. Institutional	1. Mainstreaming of disaster risk reduction and climate-change adaptation	3	4.13	
		2. Effectiveness of a zone’s crisis management framework	4	4.62	
		3. Knowledge dissemination and management	5	3.88	
		4. Institutional collaboration with other organizations and stakeholders, during a disaster	4	4.90	
		5. Good governance	4	4.36	
		Subtotal	20	21.89	
	5. Natural	1. Intensity/severity of natural hazards	5	3.84	
		2. Frequency of natural hazards	4	2.98	
		3. Ecosystem services	5	3.17	
		4. Land use in natural terms	5	3.27	
		5. Environmental policies	5	3.77	
		Subtotal	24	17.03	
	RIM	1. Demographic	1. Percent African American		
			2. Percent Hispanic		
			3. Percent under 5 years old		
4. Percent over 65 years old					
5. Average number of people per household					
Subtotal			N/A	N/A	
2. Social		1. Percent of the population over 25 with no high school diploma			
		2. Percent of the workforce that is female			
		3. Percent female-headed households			
		4. Percent of homes that are mobile homes			
		5. Percent of the population that rents			
		6. Number of houses per square mile			
Subtotal		N/A	N/A		
3. Economic		1. Percent of the population living below poverty			
		2. Percent of the workforce that is employed			
	3. Median value of owner-occupied housing				
	4. Median rent				
	5. Percent rural farm population				
Subtotal	N/A	N/A			
4. Government	1. Local government finance, revenue per capita				
	2. Local government finance general expenditure per capita				
	3. Percent of the population that voted in 2000 presidential election				
	4. Local government finance expenditure on education				
Subtotal	N/A	N/A			
5. Environmental	1. Mean elevation of the county				
	Subtotal	N/A	N/A		

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)			
CRDSA	6. Health	1. 5-year average infant mortality per 10,000 births					
		2. 3-year average chronic illness deaths per 10,000 individuals					
		3. Disabled and nonworking labor forces per 10,000 individuals					
		4. 3-year total low-birth-weight babies per 10,000 live births					
		5. Households with no fuel used per 10,000 house units					
		6. Households with no plumbing per 10,000 house units					
		7. Non-federal active medical doctors per 10,000 individuals					
		Subtotal		N/A	N/A		
	1. Health and well-being		1. Access to clean water and adequate sanitation		1.91		
			2. Food security		1.89		
			3. Availability of trained health workers		1.8		
			4. Medical resources such as the availability of hospital beds		1.79		
			5. Infection control		1.79		
			6. Access to health assistance		1.76		
			7. Hygiene		1.76		
			8. Immunization programs		1.75		
			9. Effective biosecurity and biosafety systems		1.74		
			10. Disease surveillance		1.74		
			11. Family health education and training programs		1.66		
			12. Identification/definition of special needs		1.65		
			13. Access to mental health care and psychological support programs		1.64		
			14. Medical intelligence gathering		1.63		
				Subtotal		N/A	24.51
			2. Governance		1. Disaster plans and policies including mitigation and evacuation emergency management plans		1.82
					2. Unity of the leadership after the disaster		1.74
					3. The application of standards and regulations regarding buildings and infrastructure		1.7
					4. Shared information (transparency)		1.68
5. Considering scientific analysis of risk assessment		1.64					
6. Integration with development policies and planning		1.63					
7. Institutional collaboration and coordination		1.62					
8. Clear partnership modalities defined and cooperation between concerned entities including private sector		1.61					
9. Participation of community members (volunteerism) including women and children		1.56					
10. Integrating populations with special needs into emergency planning and exercises		1.54					
11. International collaboration and coordination framework		1.46					
	Subtotal		N/A	18			

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)
3. Physical and environmental		1. Lessons learnt from previous disasters		1.9
		2. Capacity of infrastructures to withstand extra pressure such as floodwater		1.84
		3. Integration of services such as transportation systems, electric power and telephone		1.82
		4. Shelter availability during emergencies such as schools and stadiums		1.79
		5. Accessibility to critical infrastructure		1.78
		6. Management of waste created by natural hazards		1.74
		7. Mobile resources for reconstruction including trained workers		1.73
		8. Location of built environment (probability of exposure to hazards)		1.72
		9. Monitoring of current built environment and existing services A		1.68
		10. Brown field treatment (contaminated land with low levels of hazardous waste and pollutants)		1.4
		Subtotal	N/A	17.4
4. Economic		1. Funds available for reconstruction after disaster		2.67
		2. Access to financial services		2.35
		3. Level and diversity of economic resources		2.32
		4. Insurance coverage		2.27
		5. Home ownership status (homeowner/renter)		2.17
		6. Income and employment situation		2.17
		7. Size of Gross Domestic Product (GDP) per capita		1.94
		Subtotal	N/A	15.89
5. Information and communication		1. Early warning system		1.81
		2. Reliability of communication systems		1.69
		3. Trusted sources of information		1.67
		4. Backup of critical data		1.62
		5. Responsibility of media		1.58
		6. Use of community platforms, e.g., mosques		1.54
		7. Visual alerting systems		1.5
		8. Ability to exploit social media		1.47
		9. Ability to cascade information from international through regional to local communities		1.42
		Subtotal	N/A	14.3

Table 3 (Continued)

Frame-work	Dimension	Indicator	Number of sub-indicator	Weight (%)		
CCR2	6. Social	1. Risk awareness and training		1.02		
		2. Risk perceptions		0.98		
		3. Sense of community		0.97		
		4. Personal faith and attitudes		0.96		
		5. Trust in authorities		0.95		
		6. Previous experience		0.94		
		7. Social networks		0.91		
		8. Faith organizations		0.88		
		9. Education level		0.78		
		10. Demography (age and gender)		0.77		
		11. National language non-speaking (percentage)		0.74		
		Subtotal		N/A	9.9	
	1. Socio-economic	1. Demography	1. Demography	5		
			2. Livelihood	5		
			3. Health	5		
			4. Social capital	5		
			5. Education and awareness	5		
			Subtotal		25	N/A
		2. Physical	1. Transportation	1. Transportation	5	
				2. Residential infrastructure	5	
				3. Electricity	5	
				4. Telecommunication	5	
				5. Water and sanitation	5	
				Subtotal		25
		3. Institutional	1. Laws and policy	1. Laws and policy	5	
				2. Coordination	5	
				3. Emergency response	5	
				4. Adaptive action	5	
				5. Governance	5	
		Subtotal		25	N/A	
	4. Coastal zone management	1. Embankment and shoreline	1. Embankment and shoreline	5		
			2. Mangrove management	5		
3. Coastal biodiversity conservation			5			
4. Coastal pollution control			5			
5. Coastal land use			5			
	Subtotal		25	N/A		

Table 3 (Continued)

Frame- work	Dimension	Indicator	Num- ber of sub- indi- cator	Weight (%)
	5. Environ- mental	1. Frequency of natural disasters	5	
		2. Climate components	5	
		3. Geophysical components	5	
		4. Biogeochemical components	5	
		5. Environmental safeguard measures	5	
		Subtotal		25

When essential public services are discontinued, this has a negative impact on any rescue and relief operations, which, in turn, can affect recovery. A lack of modern infrastructural facilities, including potable water, reliable public transportation, and electricity, all leave a community vulnerable in the aftermath of a disaster. Robust and dynamic public services are thus necessary for infrastructure resilience. The assessment indicators that fall under infrastructure resilience were all drawn from the nine frameworks that have been assessed. These include transportation, health, utilities, communication, embankment, and shoreline.

The study also considers the dimension of governance and institutional resilience. This can be described as the role that governments and associated institutions play in helping to build resilient communities. A proper understanding of governance must incorporate the roles and responsibilities of all levels of government (local, state, and federal), as well as the extent to which these either impede or facilitate community resilience. For example, farmers' groups, fishermen's groups, and faith-based organizations can also have a strong impact on communities. They can play a role in promoting disaster risk education and community-based support measures. With this in mind, the institutional indicators and variables were created based on an understanding of sociopolitical issues within the study area. The general aim of these variables is to measure the institutionalization of disaster risk reduction.

3.2.2 Assessment indicators and sub-indicators

In order to assess coastal community resilience, several methodological approaches have been adopted. Many of these assessment indicators have been used within a framework that aims to generate relevant, usable information that will increase the size of the current database, which draws information from a variety of sources (Cutter et al. 2014). Indicators can be described as parameters that help to explain the conditions or circumstances within a specific region that cannot be obtained directly. Indicators can also be used to assess the success and performance of these evaluation systems. They can also estimate qualitative data and assess quantitative data and are also suitable for application in a range of different contexts. This means that indicators can be referred to by various names (i.e., categories, indicators, and sub-indicators). Furthermore, indicators can cover a range of aspects, such as demographics, employment, livelihood, community awareness, land use, and warning and evacuation systems (DasGupta and Shaw 2015).

Each chosen framework is made up of indicators that are associated with aspects that can be used to assess community resilience when coastal disasters occur. As Table 3 shows, these indicators generally consist of one or more sub-indicator (Alshehri et al. 2015) to illustrate their multifaceted nature. Community resilience indicators and sub-indicators can be associated with particular values or roles that enhance a community's resilience to a maritime disaster (Courtney et al. 2008). These can include infrastructure and public facilities, the accessibility of roads, education level, voluntary groups, marine pollution, and the frequency of natural hazards. There are two main categories of indicators: common indicators for all frameworks and specific indicators for particular countries or regions. Examples include mangrove management and sea rise level in CCR2, mean elevation of the area in RIM, and DRR strategies in IN-CDRI and LDRI.

4 Results and discussion

In ideal circumstances, the coastal community resilience frameworks should provide a holistic framework to incorporate multiple dimensions and aspects of resilience during the assessment process (Kafle 2012). The different dimensions of resilience addressed in each of the selected frameworks are given in Table 3. A thorough review of the criteria for each framework led to the identification of four common dimensions: society and economy, environment and climate change, infrastructure, and governance and institutions. Table 4 illustrates each dimension, split into indicators, which are then further divided into resilience sub-indicators.

However, all of the frameworks suffer from various shortcomings in terms of their design and implementation, as alluded to by Spellman and Whiting (2006). This study has identified two pertinent issues that need further deliberation, as provided in the following subsections.

4.1 Disparities regarding the community resilience dimensions and indicators

The metric can be described as applicable to the integration and assessment of the compatibility of the frameworks. Table 5 provides a detailed analysis of the selected frameworks and their magnitude of relevance or applicability within different dimensions and relative to specific indicators and sub-indicators. Superficially, it can be inferred that nearly all of the frameworks are incompatible or loosely integrated. For example, in the society and economy dimension, nearly all frameworks fail to capture vital factors that determine the capacity of a coastal community to overcome the effects of natural disasters to their ordinary lives. For example, under the 'demography' indicator, most frameworks loosely or fail to capture the population growth rate. For example, the CCR1 framework is 67% inapplicable, 24% semi-applicable, and 10% applicable in the social and economic dimension.

It is important to assess the extent of the integration of the frameworks on an individual basis. Table 5 reveals that the CCR2 framework is the most broadly integrated across the four dimensions, accounting for 61% of fully applicable indicators, followed by CRDSA, which comprises 39% of the identified indicators that are fully applicable. It can be said that the CCR2's comprehensive coverage across all dimensions of this study is because of the fact that the framework is specifically designed for application to coastal hazards.

Table 4 Common indicators and sub-indicators for coastal community resilience assessment frameworks

Society and economy		Environment and climate change	Infrastructure	Governance and institutions
Demographic	Livelihood	Costal pollution control	Health	Laws and policy
Population density	Costal resources	Water quality	Hospitals	Regulations and policies
Age dependency	Household income	Marine pollution	Hospital beds	Environmental regulation
Disability	Poverty	Mangrove cover	Number of physicians	Participation in DRR planning
Level of education			Number of ambulances	DRR strategies
Property ownership and type			Health insurance	
			Health care support workers	
Awareness and training	Culture	Land use	Transportation	Institutional action
Disaster exercised and drills	Social capital	Agricultural land	Roads accessibility	Observation and monitoring
DRR training	Religious organizations	Urban greed space	Vehicle ownership	Institutional and collaboration and coordination
Awareness of disaster and climate change risks		Building code	Special need transportation services	Voluntary groups
Multilingual awareness programs		Mean elevation of the area	School and employee buses	
Awareness campaigns		Vulnerable built up area		
Employment	Safety and security	Slow onset disaster	Utilities	Warning and evacuation
Employment dependence on coastal resources	Riots, conflicts and homicide incidents	Exposure and risk to increasing temperature	Infrastructure and public facilities	Early warning system
	ISPS code compliance	Sea level rise	Renewable energy	Availability of evacuation center
	Safety and security system		Fire stations	Emergency aids
				Hotel and motels
			Embankment and shoreline	
			Vulnerable shoreline	
			Age of embankment	
			Maintenance of embankments	

Table 5 Coverage of indicators and sub-indicators in the nine selected frameworks

Dimension	Indicator	Sub-indicator	Framework									Average	
			CCR2	CRDSA	RIM	IN-CDRI	BRIC	LDRI	TX-CDRI	CDRI	CCR1		
Society and economy	Demographic	Population growth rate	●	○	○	●	○	○	○	○	○	○	○
		Population density	●	●	○	●	○	○	○	○	○	○	○
		Age dependency	●	●	●	○	○	○	○	○	○	○	○
		Disability	○	●	●	○	○	○	○	○	○	○	○
		Level of education	●	●	○	●	○	○	○	○	○	○	○
		Property ownership and type	●	●	●	○	○	○	○	○	○	○	○
Livelihood		Coastal resources	●	○	○	○	○	○	○	○	○	○	○
		Household income	○	●	○	○	○	○	○	○	○	○	○
		Poverty	●	○	○	○	○	○	○	○	○	○	○
		Employment	○	●	●	○	○	○	○	○	○	○	○
Employment		Employment dependence on coastal resources	○	○	○	○	○	○	○	○	○	○	○
		Disaster exercises and drills	●	○	○	○	○	○	○	○	○	○	○
Awareness and training		DRR training	●	○	○	○	○	○	○	○	○	○	○
		Awareness of disaster and climate change risks	●	○	○	○	○	○	○	○	○	○	○
		Multilingual awareness programs	○	●	○	○	○	○	○	○	○	○	○
		Awareness campaigns	○	○	○	○	○	○	○	○	○	○	○

Table 5 (continued)

Dimension	Indicator	Sub-indicator	Framework								Average		
			CCR2	CRDSA	RIM	IN-CDRI	BRIC	LDRI	TX-CDRI	CDRI		CCR1	
Culture		Social capital	●	○	○	●	●	○	○	○	○	●	●
		Religious organizations	○	●	○	○	●	○	○	○	○	○	●
		Riots, conflicts and homicide incidents	●	○	○	○	○	○	○	○	○	○	○
		ISPS code compliance	○	○	○	○	○	○	○	○	○	○	○
		Safety and security systems	○	○	○	○	○	○	○	○	○	○	○
		○ Not applicable	43%	43%	62%	29%	33%	62%	57%	57%	67%	50%	
		○ Semi-applicable	0%	14%	14%	24%	33%	19%	24%	10%	24%	18%	
		● Fully applicable	57%	43%	24%	48%	33%	19%	19%	33%	10%	32%	
		Water quality	●	○	○	○	○	○	○	○	○	○	○
		Environment and climate change	Coastal pollution control										
Land use		Marine pollution	●	○	○	○	○	○	○	○	○	○	○
		Mangrove cover	●	○	○	○	○	○	○	○	○	○	○
		Agricultural land	●	○	○	●	○	○	○	○	○	○	○
		Urban green space	●	○	○	○	○	○	○	○	○	○	○
		Building code	○	○	○	○	○	○	○	○	○	○	○
Mean elevation of the area	○	○	○	○	○	○	○	○	○	○	○		
Slow onset disasters		Vulnerable built up area	○	○	○	○	○	○	○	○	○	○	○
		Exposure and risk to increasing temperature	○	○	○	○	○	○	○	○	○	○	○
		Sea level rise	●	○	○	○	○	○	○	○	○	○	○

Table 5 (continued)

Dimension	Indicator	Sub-indicator	Framework										Average	
			CCR2	CRDSA	RIM	IN-CDRI	BRIC	LDRI	TX-CDRI	CDRI	CCR1			
Rapid onset disasters	Frequency of natural hazards	Intensity/severity of natural hazards	●	○	○	●	○	○	○	○	○	○	●	○
			○	○	○	●	○	○	○	○	○	○	●	●
			25%	83%	92%	42%	83%	83%	42%	75%	58%	66%		
			17%	17%	0%	25%	17%	17%	42%	8%	17%	19%		
Health	Hospitals	Hospital beds	○	○	○	●	○	○	○	○	○	○	○	
			○	○	○	○	○	○	○	○	○	○		
			○	○	○	○	○	○	○	○	○	○		
			○	○	○	○	○	○	○	○	○	○		
Transportation	Road accessibility	Vehicle ownership	○	○	○	○	○	○	○	○	○	○	○	
			○	○	○	○	○	○	○	○	○	○		
			○	○	○	○	○	○	○	○	○	○		
			○	○	○	○	○	○	○	○	○	○		
Utilities	School and employee buses	Infrastructure and public facilities	○	○	○	○	○	○	○	○	○	○	○	
			○	○	○	○	○	○	○	○	○	○		
			○	○	○	○	○	○	○	○	○	○		
			○	○	○	○	○	○	○	○	○	○		

Table 5 (continued)

Dimension	Indicator	Sub-indicator	Framework										Average		
			CCR2	CRDSA	RIM	IN-CDRI	BRIC	LDRI	TX-CDRI	CDRI	CCR1				
Communication		Access to mobile phones	●	●	○	●	●	○	○	○	○	○	○	○	○
		Access to radio/television	●	○	○	●	○	○	○	○	○	○	○	○	○
		Reliability of communication systems	●	●	○	○	○	○	○	○	○	○	○	○	○
		Internet services	●	○	○	●	○	○	○	○	○	○	○	○	○
		Vulnerable shoreline	●	○	○	○	○	○	○	○	○	○	○	○	○
		Age of embankments	●	○	○	○	○	○	○	○	○	○	○	○	○
		Maintenance of embankments	●	○	○	○	○	○	○	○	○	○	○	○	○
		○ Not applicable	25%	45%	90%	50%	50%	70%	25%	60%	85%	56%			
		● Semi-applicable	15%	10%	5%	5%	5%	20%	10%	15%	5%	10%			
		● Fully applicable	60%	45%	5%	45%	45%	10%	65%	25%	10%	34%			
Governance and institutions	Laws and policy	Regulations and policies	●	●	○	●	○	○	○	○	○	○	○	○	
		Environmental regulation	●	○	○	●	○	○	○	○	○	○	○	○	
		Participation in DRR planning	○	○	○	●	○	○	○	○	○	○	○	○	
		DRR strategies	○	○	○	●	○	○	○	○	○	○	○	○	
		Observation and monitoring	●	●	○	○	○	○	○	○	○	○	○	○	
		Institutional collaboration and coordination	●	●	○	●	○	○	○	○	○	○	○	○	
		Voluntary groups	●	●	○	●	○	○	○	○	○	○	○	○	
		○ Not applicable	25%	45%	90%	50%	50%	70%	25%	60%	85%	56%			
		● Semi-applicable	15%	10%	5%	5%	5%	20%	10%	15%	5%	10%			
		● Fully applicable	60%	45%	5%	45%	45%	10%	65%	25%	10%	34%			
Institutional action		Regulations and policies	●	●	○	●	○	○	○	○	○	○	○	○	
		Environmental regulation	●	○	○	●	○	○	○	○	○	○	○	○	
		Participation in DRR planning	○	○	○	●	○	○	○	○	○	○	○	○	
		DRR strategies	○	○	○	●	○	○	○	○	○	○	○	○	
		Observation and monitoring	●	●	○	○	○	○	○	○	○	○	○	○	
		Institutional collaboration and coordination	●	●	○	●	○	○	○	○	○	○	○	○	
		Voluntary groups	●	●	○	●	○	○	○	○	○	○	○	○	
		○ Not applicable	25%	45%	90%	50%	50%	70%	25%	60%	85%	56%			
		● Semi-applicable	15%	10%	5%	5%	5%	20%	10%	15%	5%	10%			
		● Fully applicable	60%	45%	5%	45%	45%	10%	65%	25%	10%	34%			

Table 5 (continued)

Dimension	Indicator	Sub-indicator	Framework							Average		
			CCR2	CRDSA	RIM	IN-CDRI	BRIC	LDRI	TX-CDRI		CDRI	CCR1
Warning and evacuation	Early warning system	•	•	○	•	○	○	○	○	○	•	•
		Availability of evacuation center	•	•	○	•	○	○	○	○	•	•
	Emergency aids	•	•	○	○	○	•	•	○	○	○	○
		Hotels and motels	○	○	○	○	•	○	○	•	○	○
	○ Not applicable	18%	27%	100%	18%	64%	46%	55%	45%	27%	44%	
	○ Semi-applicable	9%	9%	0%	9%	18%	27%	36%	27%	27%	18%	
	• Fully applicable	73%	64%	0%	73%	18%	27%	9%	27%	46%	37%	
	○ Not applicable	30%	48%	67%	64%	53%	66%	45%	59%	64%	55%	
	○ Semi-applicable	9.3%	13%	6%	16%	19%	20%	23%	14%	17%	15%	
	• Fully applicable	61%	39%	27%	20%	28%	14%	31%	27%	19%	30%	
Total												

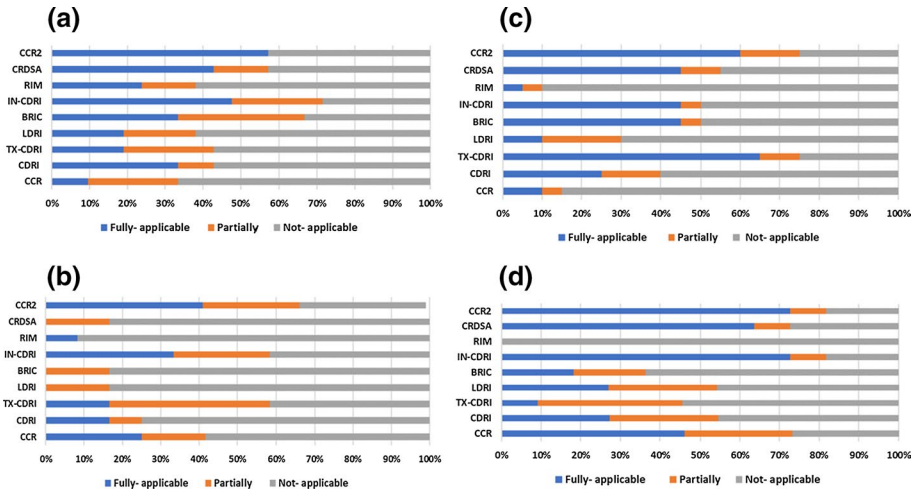


Fig. 2 Summary of the dimensional coverage in the nine selected frameworks. **a** Society and economy. **b** Environment and climate change. **c** Infrastructure and Institutions. **d** Governance and institutions

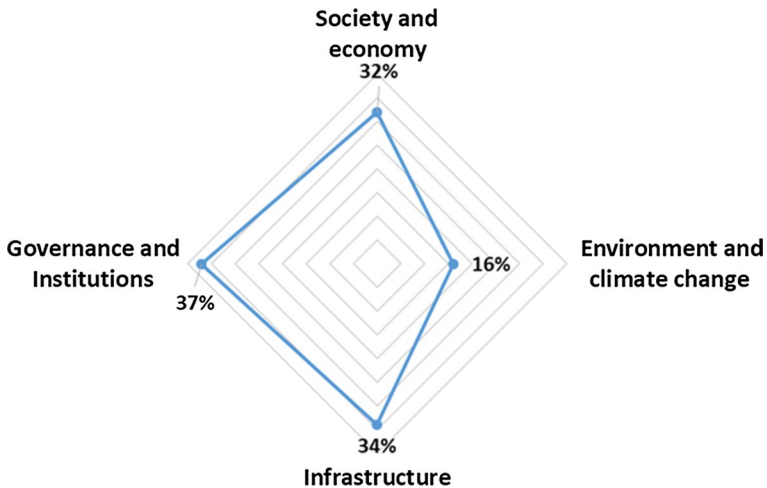


Fig. 3 Focus of the investigated coastal community resilience frameworks

However, this premise might not hold, given that CCR1, which was also designed specifically for this purpose, is highly incompatible with the dimensions included in this review. With the exception of the dimension of governance and institutions, the CCR1 framework appears to be less well integrated into the other dimensions, as shown by its high rate of irrelevance. Similarly, despite affording a specialist framework for coastal hazards, the RIM appears to be largely disconnected from the dimensions. In fact, it is wholly inapplicable in the governance and institutions dimension but, in the other dimensions, incompatible with the majority of the sub-indicators.

It can thus be argued that the nine frameworks tend to concentrate more on governance and institutions and less on the environment and climate change. As such, the frameworks are highly compatible and well integrated into the legal policies surrounding the establishment of coastal community resilience interventions. This is the main reason why frameworks such as CCR2 and CRDSA exhibit impressive applicability indices in the dimension of governance and institutions. Conversely, there are few indicators in the environment and climate change dimension, which suggests that the environmental dimension is neglected within coastal community resilience interventions. However, it is essential to note that the CCR2 framework is highly effective in capturing the sub-indicators of the primary indicator, which is coastal pollution control.

From Figs. 2 and 3, it is evident that the selected frameworks place more emphasis on the government and institutions dimension (37%), followed by the dimensions of infrastructure (34%), society and economy (32%), and environment and climate change (16%), respectively. Their emphasis on government and institutions could suggest the omnipresence of external forces and factors that impede the efforts to enhance community resilience. In the ranking of the dimensions provided above, relatively less attention is paid to the environmental dimension, despite its significant role in informing and shaping community resilience. Orenco and Fujii (2013) suggest that a lack of regard for the environment when designing coastal community frameworks could stem from a lack of clarity concerning how environmental processes contribute to changes in climatic conditions. Matyas and Pelling (2015) note that research affords sufficient evidence to confirm that the presence of natural geographical assets, ecosystem protection, and resource management is vital for absorbing the shocks arising from natural disasters. Therefore, where community resilience is principally founded on environmental preservation, resilience tends to be formidable, and the likelihood of a speedy recovery is heightened. On the other hand, Sharifi (2016) observes that a failure to ensure the adequate integration of the environmental dimension increases the likelihood that coastal community resilience will be undermined.

Within the four dimensions of coastal community resilience, the ‘society and economy’ dimension’s indicators include livelihood, demography, employment, culture, awareness and training, and safety and security. As mentioned previously, the evidence regarding the environment and climate change dimension is somewhat truncated. As such, it is mainly characterized by coastal pollution control, land use, slow onset disasters, and rapid onset disasters. In contrast, the infrastructure dimension is broad, encompassing a variety of indicators and sub-indicators. The chief indicators of the infrastructure dimension are health, utilities, transportation, communications, and embankments. Finally, the ‘governance and institutions’ dimension comprises laws and policy, institutional action, and warnings and evacuations as the principal indicators of coastal community resilience, as given in Table 4.

4.2 Construction of the coastal community resilience frameworks

4.2.1 Participatory methods

The frameworks were mainly developed by identifying an initial list of indicators following an extensive literature search, and by using stakeholders and experts’ opinions and perceptions to achieve a consensus regarding the key indicators and assigning weights to each, in order to assess community resilience and the ability to cope with disasters. The majority of the frameworks employed a combination of both quantitative (i.e., numerical data) and qualitative (i.e., public opinions and expert judgments) methods (Alshehri et al. 2015). The

mixed-methods approach of building a consensus around key indicators and sub-indicators can also be found in the literature on sustainability assessment frameworks (Ameen et al. 2015; Ameen and Mourshed 2018), which are similar in concept to the CCR frameworks reviewed in this study.

When various stakeholders are involved, the benefits of using participatory methods are numerous. As Table 6 indicates, 90% of the chosen frameworks were developed using extensive literature reviews and experts’ opinions. Only one framework (BRIC) depended solely on a literature review. Although community members possess a good knowledge of the needs, vulnerabilities, and coping capacities of their areas, very few assessment frameworks have been developed with reference to public opinion. Consequently, the local needs and conditions are frequently not reflected appropriately in these frameworks.

Sharifi (2016) claims that participatory methods can build capacity, improve the local understanding of resilience and risk, and establish a platform for sharing experiences and knowledge. They can also encourage collaborative design, and the development of techniques to enhance accuracy. Additionally, the assessment metric enables selected interventions to reflect the priorities of a community and thus improve local leadership, legitimacy, and decisions in terms of trade-offs (Cohen et al. 2016; Arbon et al. 2016).

After conducting the review, it emerged that there is currently no comprehensive method through which to develop a community resilience framework using both literature reviews and the perceptions of stakeholders and experts. Thus, there is an urgent need to develop a new framework utilizing a participatory methods approach.

4.2.2 Risk identification

It is pertinent to assess how each framework captured risk on a temporal scale. There appears to be a link between the extent to which various risks are considered and how well the frameworks integrate within the resilience-building programs. Communities are

Table 6 Methods and temporal scope of the nine selected frameworks

Framework	Research method					Temporal scope		
	Overall ^a	Literature review	Public opinion/perception	Expert opinion/perception	Expert consultation	Past	Current	Future
CCR	Qualitative	✓	✓			✓	✓	✓
CDRI	Mixed	✓		✓		✓	✓	
TX-CDRI	Mixed	✓		✓		✓	✓	
LDRI	Mixed	✓		✓	✓		✓	
BRIC	Quantitative	✓					✓	
IN-CDRI	Mixed	✓		✓			✓	✓
RIM	Mixed	✓		✓		✓	✓	
CRDSA	Mixed	✓	✓	✓	✓		✓	
CCR2	Mixed	✓	✓				✓	
Count		9	3	6	2	4	9	2
Percentage		100%	33%	67%	22%	44%	100%	22%

^aA mixed-methods approach was utilized by seven (78%) frameworks, while qualitative and quantitative methods were utilized by one (11%) framework each

spatially delineated, which may explain why the consideration of geospatial risks is more pronounced in the coastal community resilience frameworks. According to Norris et al. (2008), community resilience comprises four sets of adaptive capacities—social capital, economic development, community competence, and information and communication that together determine the disaster readiness of the community. However, the authors acknowledge the uncertainties that may be experienced during the implementation stages and stress on the flexibility of the resilience plan so that effective decisions can be made. One of the ways uncertainties can be reduced is by linking the past experiences of hazards, adaptation, and mitigation with the present and the future. The temporal scope of a framework is, therefore, an important component of resilience and should ideally be linked with the spatial scope of an assessment framework.

We evaluated the resilience of a community in a time-based continuum to assess how each phase is connected with the previous phases and succeeds with other phases, i.e., their temporal scope. Table 6 reveals that only 45% of the frameworks focus on the present conditions, while 35% consider the past, and 20% examine both the present and future. If the frameworks only encompass the past and present, they risk ignoring the changing climatic conditions. Therefore, it is evident that the frameworks must consider the past, present, and future if they are to understand the system dynamics more effectively and develop strategies for coping with potential changes in the future.

Collier et al. (2016) believe that coastal community resilience should be evaluated on a time-based continuum to guarantee that risk is captured at all times. Sharifi (2016) supports this point, arguing that all stages are linked to events that take place before or after any assessment. This may explain why risk is poorly integrated into the dimensions. Of the current frameworks, CCR2 and CRDSA offer good examples of risk capture because they consider both present and future conditions. Sharifi (2016), Cimellaro et al. (2016) and Arbon et al. (2016) all believe that monitoring changes along a time-based continuum differentiate the assessment of resilience from evaluations of vulnerability. The assessment of resilience considers the past and future, while evaluations of vulnerability focus solely on the present.

5 Conclusion

Resilience is an important goal when preparing coastal communities for natural and human-made disasters, a fact that is compounded by the increasing exposure of populations to these hazards. Community resilience to disasters is essential if an affected community is to be able to rebuild itself to pre-disaster levels. In this respect, it is essential to enhance community resilience by identifying beneficial criteria that will make this possible. In this study, nine selected frameworks were critically analyzed, and different resilience dimensions addressed in each of the selected frameworks presented. Four common dimensions were identified based on a thorough review of the criteria of each framework. These dimensions are—society and economy, environment and climate change, infrastructure, and governance and institutions. These were then divided into eighteen indicators, as well as a total of sixty-four sub-indicators.

Comparison matrices were developed with the intention of assessing the extent of the applicability of the different frameworks across several sub-indicators within four dimensions. The review found that most of the frameworks address multiple aspects of resilience and so were significantly broad in scope. Additionally, it emerged that despite the fact that

several of the frameworks were designed specifically for coastal areas, these were mostly incompatible and consequently poorly integrated into resilience programs. In addition, many of the frameworks employed a narrower scope when dealing with the environment and climate change dimension when contrasted with that for the other dimensions. In this review, it was confirmed that ecosystem protection and resource management are vital for absorbing the shocks resulting from natural disasters. Therefore, where environmental preservation is the principal foundation of community resilience, then resilience is formidable, and the likelihood of a speedy recovery from disaster is heightened.

The frameworks have also been assessed according to how well the identified indicators and sub-indicators represent the needs of the community. It can be inferred that together, the reviewed frameworks addressed the bulk of the reported issues related to coastal community resilience. However, there exists a significant mismatch between the frameworks in their coverage and focus. The variations in coverage and focus result from the varying needs of the community considering which the respective framework was developed. Local relevance is thus important for the design, development, and implementation of any framework as they are not readily transferable from one location or region to the other. Experts and stakeholders should, therefore, be consulted to identify the relevance and extent of each resilience indicator to local standards and practices to ensure that the frameworks remain sufficiently objective.

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