Socio-Economic Planning Sciences 51 (2015) 34–45

Contents lists available at ScienceDirect

Socio-Economic Planning Sciences

journal homepage: www.elsevier.com/locate/seps

Adaptation analysis for environmental change in coastal communities

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ARTICLE INFO

Article history:
Available online 24 June 2015

Keywords:
Coastal community vulnerability
Climate change adaptation
Resilience
Adaptive capacity
Analytical hierarchy process
Group decision making

ABSTRACT

Small islands and coastal communities around the world are particularly vulnerable to climate change impacts, mainly from storm surge attributed to more frequent and severe coastal storms, and mounting sea-level rise. Coastal hazards including inundation, salinisation of the water supply, and land erosion all threaten vital infrastructure that support coastal communities. This research, part of the International Community-University Research Alliance (ICURA) C-Change project "Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean", develops and applies a multicriteria decision evaluation and support system for evaluating adaptation options for coastal communities. The paper estimates vulnerability, resilience, and adaptive capacity measures associated with adaptation strategies in coastal communities with respect to their environmental, economic, social, and cultural dimensions. Results are determined using a multi-participant formulation of the Analytical Hierarchy Process (AHP) for identifying multicriteria decisions as adaptation strategies in a specific coastal context. The application of the framework is conducted for the coastal community of Little Anse on Isle Madame, Nova Scotia. Specifically, the state of the Little Anse breakwater is analysed and adaptation options for protecting, accommodating, and retreating are presented and evaluated in the face of predicted storm scenarios. The results indicate that, in the case of Little Anse, the strategic decision to protect the community by a new breakwater arm provides preferred measures for resilience and adaptive capacity.

1. Introduction

Coastal communities around the globe are experiencing changing climate impacts from increased frequency and severity of coastal storms, e.g., Typhoon Haiyan, Hurricane Sandy, Hurricane Katrina, rising sea levels threatening island states, e.g., the Maldives, permafrost thawing in polar regions, and widespread coastal erosion [7,14,15]. Canada has the longest coastline in the world and the Atlantic region of Canada is subject to impacts from a wide range of interannual hurricanes, winter cyclonic storms, and flooding [33]. The hurricane season of 2010 was especially harsh with frequent storm incidents in the region [8,9]. The predictable and mounting impacts of changing coastal environments require further investigation of coastal vulnerability and adaptive capacity and the preparation of communities in the Canadian coastal zone to face of impacts of climate change [1,4,5].

The purpose of this paper is to present an evaluation framework for coastal adaptation decisions applied in a defined coastal community context. The evaluative process proceeds from the development of a profile of the coastal community that includes its vulnerability to environmental change, as well as the community's identified priorities. A multicriteria decision framework is formulated that accounts for the expected impacts of severe coastal storms to rank alternative adaptation strategies. The results of the strategy rankings provide support for coastal communities' efforts to adapt strategically to the pending environmental changes. This research is part of the International Community-University Research Alliance (ICURA) C-Change project "Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean" [3,19]. C-Change seeks to raise awareness of coastal climate vulnerability and promote improved adaptive capacity and coastal community preparedness in selected communities in Canada and the Caribbean region. Evaluation of adaptation decisions options and the development of measures for vulnerability and adaptive capacity are applied in this paper to the C-Change coastal community of Little Anse, Richmond County, Cape Breton, Nova Scotia, Canada.

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http://dx.doi.org/10.1016/j.seps.2015.06.003
0038-0121/

2. Methods

The evaluation of coastal communities' adaptation strategies to environmental change is a problem characterized by multiple community criteria and the participation of multiple community-based agents. This problem is modelled for decision support using a multicriteria, multi-participant framework that captures community vulnerabilities (measured by storm impacts), and the suite of community priorities embraced by contributing community leaders and decision makers.

The research process comprises the following four steps:

I) *Community Profile and Problem Formulation.* Profile the resources of the coastal community with respect to the community's "pillars of sustainability" criteria identified as: (1) Economic; (2) Environmental; (3) Cultural; and (4) Social dimensions. The "pillars of sustainability" were formally adopted by municipalities throughout Canada in the development of the 2009–2010 Integrated Community Sustainability Plans (ICSPs) [21].

II) *Community Vulnerability and Storm Impacts.* Collect historical data on severe storms impacts and damages to determine coastal community vulnerability on related indicators of the multiple criteria of the community profile.

III) *Community Adaptation Data and Problem Analysis.* Prepare the multicriteria problem formulation for analysis; obtain feedback from the representative community group participants on criteria priorities; design the severe storm scenarios and associated data analyses; and prepare the adaptation strategy alternatives for evaluation.

IV) *Community Evaluation of Adaptation Strategies.* For each of the storm scenarios, compare the contribution of the alternative adaptation strategies as a function of the expected storm impacts and the community priorities; rank the overall effectiveness of the alternatives; compute community vulnerability, resilience, and adaptive capacity measures.

I. *Community Profile*. Four dimensions, defined as "pillars of community sustainability" are defined to categorize the status of coastal communities' assets position through the associated values of related indicators. The indicators, i are resource asset measures expressed in monetary units (with the exception of numbers of demographic groups, i.e., seniors and children, at risk) and representing community characteristics of interest. Selected indicators by pillar are denoted below:

1) Economic pillar – $EC(i)$, $i = 1, \ldots n_{ec}$; e.g., value of built environment (residential, commercial/industrial), public works;
2) Environmental pillar – $EN(i)$, $i = 1, \ldots n_{en}$; e.g., value of land use, residential, commercial/industrial, green space;
3) Cultural pillar – $C(i)$, $i = 1, \ldots n_c$; e.g., value of community resources, historical sites, faith-based infrastructure (church grounds), schools; and
4) Social pillar – $S(i)$, $i = 1, n_s$; e.g., value of labour income, identification of vulnerable demographic groups (seniors, children).

These four community pillars and their associated indicators are the key community dimensions by which the community defines itself [27,34].

II. *Community Vulnerability and Storm Impacts*. Vulnerability is defined by local community threats from rising seas and more frequent and severe storms. Historical storms are described to provide the local coastal community context. Two primary sources are used for extracting historical storms incidences along with their impacts:

(i) National Oceanic and Atmospheric Administration (NOAA)'s HURDAT2, or "best track" database [17,18]; and
(ii) Environment Canada's Climatology of Hurricanes for Eastern Canada [9].

The HURDAT2 database reports on historical storms relevant to selected coastal communities, and provides information via an online tool to query the HURDAT2 database. Storm and wind speeds are measured in kilometres per hour and the pressure is measured in millibars. The ranges of these indicators are the basis for categorizing storm scenarios. Storm Scenarios are sorted based on the intensity of observed storms.

Storm surge is an unusual rise of water generated by a storm, over and above the predicted astronomical tides. Approximately 1500 people lost their lives as the result of Hurricane Katrina and majority of those casualties, directly or indirectly, were the result of storm surge [24]. The combination of surge with normal tides creates hurricane storm tide, which has the potential to increase the mean water level to critical heights causing significant damage to critical infrastructure and people [24]. The Canadian Tides and Water Levels Data Archive [11] provides maximum water levels at the time of storms from marine observation stations aligned with Canadian coastal communities. Fig. 1 illustrates storm surge and storm tide.

Data on historical coastal storms' tracks, severity, and water level are the drivers for coastal community impacts. GIS mapping is used in C-Change coastal community storm impact analysis [19] to analyse the community assets impact by storms of different severity. Limited data exist on the impacts of storms to coastal community assets, homes, infrastructure and businesses. Much of these data are reported in the local media [32]. However, given that there are no formal community-by-community reporting mechanisms for natural storm damage, then the impacts of storms are estimated based on aggregate values dependent on storm severity.

III. *Community Adaptation Data and Problem Analysis*. The Analytic Hierarchy Process (AHP) is adopted to formulate and analyse the multicriteria problem [31]. The AHP problem hierarchy for "Adaptation Decision Support" (top level of hierarchy) is constructed from the Community Profile and the 4 pillars of sustainability (second level of criteria in the hierarchy). The third level of the hierarchy presents the indicators associated with each pillar. Fig. 2 presents an illustration of the coastal community adaptation problem hierarchy.

Coastal communities are represented in the decision making process by stakeholders with different perspectives on the importance of the dimensions of the community profile. These stakeholder-participants are represented as follows:

1) *Community group members*: these are the representatives of the community, including community social clubs such as Community Seniors, Youth members, the Knights of Columbus, the Ladies Auxiliary, and faith-based church groups.
2) *Local Government*: representatives of local government, namely, the Regional Municipality, responsible for community services and governance, and governance liaison (municipal, provincial, and federal levels of government).
3) *Business/Industry*: delegates of the local coastal industries including fisheries industry managers, local contractors, restaurant and hotel owners, hardware and grocery store owners and operators.