The importance of spatial scale in the evaluation of the environment of coastal areas

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Abstract. The index-based method constitutes one of the most common methods for the evaluation of coastal vulnerability. The spatial scale used each time determines the type of data collected and the level of coastal vulnerability. There is not any “one size fits all” index that can be applied to all scales. The spatial scale can determine the final result. A region can be considered susceptible to a particular scale and viable in another. Additionally, there is not only one scale that is suitable for all needs. Different scales reflect different priorities and the influence of a given variable will increase or decrease accordingly as scale changes. The aim of this paper is to present studies conducted in the past in order to create a multi-scale index. Their conclusion on the role of spatial scale in the application of an index methodology are about to be reported and evaluated. Finally, the creation of a new multi-scale index is proposed which will assess coastal vulnerability through an environmental perspective by evaluating not only the geographical features of the coastal area but also the socio-economic characteristics in order to assess the potential impact of these on natural environment of coastal zone.

Keywords: index-based method, spatial scale, multi-scale index, coastal vulnerability

1. Introduction

Coastal vulnerability assessment focuses mainly on dimensions related to the sea level rise and less on non-climatic dimensions, such as environmental and socio-economic changes (Nicholls *et al*., 2008). Due to the rich natural resources and attractiveness, coastal areas have been inhabited and vastly exploited all over the world. The coastline is affected by a multitude of human activities, industry, urbanization, tourism development, agriculture, fisheries and overexploitation of natural resources. These factors have led to increase in pollution, loss of species and habitats and also degradation and fragmentation of ecosystems. Consequently, a conflict between coastal areas and the increasing demand for coastal resources has been observed (Kiousopoulos, 2008).

According to Kiousopoulos (2008), studies of coastal areas through indicators are strongly recommended by international organizations and are available for integrated coastal zone management and environmental assessment.

Various methods, tools and approaches have been developed thus far to assess coastal areas and optimize their management process. Recent research has focused on the development of risk assessment tools for the coastal area. Incorporation of socioeconomic factors in addition to physical characteristics appears to be a more holistic approach to coastal vulnerability. However, the adoption of such an approach is still limited mainly due to lack of data. Recent attempts to assess the vulnerability of coastal areas used data derived from GIS, remote sensing and dynamic computing models (Harik *et al*., 2017). However, the use of these models is also limited by the lack of spatial data and expertise (Harik *et al*., 2017). Four main categories of tools and methodologies that have been developed so far (Ramieri *et al*., 2011): i) Methodologies based on dynamic computer models. These methods aim to model current and potential future conditions of geophysical, biological, and/or socioeconomic processes; ii) Visualization tools, which attempt to simulate possible future conditions to be caused by climate change. Visualization tools are easy to use and do not require specialized software or hardware; iii) Index/indicators based methods based on qualitative or quantitative variables or combination of both. They express coastal vulnerability through a group of indicators which identify the key advantages and disadvantages of each coastal area; iv) GIS-based decision support tools. These tools aim to build scenarios resulting from potential climate change impacts to support coastal decision makers to make the best management decisions. They require specialized knowledge and advanced technical skills.

The Coastal Vulnerability Index (CVI) is one of the most commonly used indicator as it follows a simple methodology to assess coastal vulnerability to sea level rise, due to erosion and/or inundation (Gornitz *et al*., 1991). The first step of the above methodology for calculating the CVI is the identification of key variables that affect significantly the coastal vulnerability and coastal development in general. It includes six or seven variables, which according to the U.S. Geological Survey (USGS) are geomorphology, shoreline change rates, coastal slope, relative sea level rate, mean significant wave height, mean tidal range. The second step includes the quantification and rating of key variables based on a scale from 1 to 5. Then the key variables are aggregated into an index using a mathematical formula. Finally, the resulting values are classified into several groups (3-4) using n-1 percentiles as limits.

Over the last years, there has been a significant increase in the coastal vulnerability indicators for the evaluation of the coastal area (McLaughlin *et al*., 2002). The aim of these indicators was the grouping of the coasts based on common characteristics. This grouping will help to develop coastal management policies (Jana and Bhattacharya, 2013). Most of CVI applications have been based on Gornitz (1990) formula. Thereafter CVI assessment was advanced by modifying the parameters depending upon the availability and geographical area. The evolution of CVI led to a complex coastal vulnerability index and multi-scale index. The latter uses several indices depending on the scale used and constitute the final CVI.

McLaughlin and Cooper (2010) developed a multi-scale CVI, specifically addressing erosion impacts. In particular, the authors applied the index to a multi-scale system, including: Northern Ireland (national scale), Coleraine Borough Council (regional scale) and Portrush east Strand (local scale).

Another multi-scale coastal risk index has been developed on the basis of the Multi-scale Vulnerability Index (McLaughlin and Cooper, 2010) by integrating the revised IPCC approach and focusing on risk. The Coastal Risk Index applied to assess risk related to climate variability and change at the regional and local scale in the Mediterranean area.

The scale is crucial in the assessment of coastal vulnerability and in this paper the effect of scale is examined through the above studies. It also proposed the creation of a new multi-scale index that can be applied throughout the coastal area.

2. Basic Concepts

2.1. Coastal Vulnerability

Coastal vulnerability of a particular region depends on the ecological and socioeconomic characteristics (Hinkel and Klein, 2007). It is a dynamic concept as exposure, sensitivity and adaptive capacity vary based on time and depend on various environmental, social, economic, political and technological factors (ETC-ACC, 2010b).

The vulnerability assessment of different environments requires the use of different tools in different spatial and temporal scales for different purposes (ETC-ACC, 2010b).

2.2. Vulnerability and scale concept

Taking into account the complexity of the nature of coastal areas and the long-term effects of climate change, coastal policy and coastal management require a new broad scale assessment and management tools to be applied at all scales such as local, regional, national and European. Coastal vulnerability assessment at these scales provide useful information on the coastal zone management and whether studies are consistent at all these scales their use for carrying policies will maximize (Nicholls and Klein, 2005). A more detailed approach to regional and local level is essential towards understanding and managing the complexity of a specific study area and also allows the identification of areas with a greater degree of vulnerability and sectors having the need for the application of appropriate strategies (Torresan *et al*., 2008). Coastal area evaluation in a regional and local scale requires a more detailed description of coastal systems and the use of more specific indicators (Torresan *et al*., 2008). Another important factor is the time scale in the assessment of coastal area, which can last, for example, from hours up to days for a storm phenomenon and days to years on tidal ranges and in the case of regional vertical land movements from decades to millennia.

Previous studies on coastal vulnerability using indicators most often occur on a global (Gornitz, 1990) and regional (Thieler and Hammer-Klose, 1999) scale. Each indicator is driven according to which type of data is the most suitable for vulnerability assessment and what data is available in the requested spatial scale. Since coastal areas managed by bodies operating at different spatial scales, indicators can be useful only if coastal vulnerability is assessed at the appropriate scale. Coastal vulnerability assessment on a global scale enables exercising on global policies. The policies implemented based on evaluations are also carried out at national level. Nevertheless, the most suitable scale for the treatment of coastal threats is the local scale.

At each management scale, there are different approaches and data types. There is no coastal vulnerability index that fits anywhere and can be applied at all scales. The elements contributing to vulnerability, the available data and the type and the usefulness of an index vary depending on the spatial scale.

3. Literature Review

3.1 McLaughlin and Cooper

In 2010 McLaughlin and Cooper attempted to create a multi-scale coastal vulnerability index based on a common methodology and theoretical framework which will be applied to national, regional and local level. The availability of data is an important factor in the selection of parameters that will reflect coastal vulnerability at each level as well as the time required for data processing.

The McLaughlin and Cooper index integrates three sub-indices (McLaughlin and Cooper, 2010): i) a coastal characteristic sub-index, describing the resilience (e.g. age of population) and coastal susceptibility (e.g. landform, elevation); ii) a coastal forcing sub-index, characterizing the forcing variables (e.g. SLR, Storms, Heavy Rainfall); iii) a socio-economic sub-index, describing coastal targets potentially at risk, the exposure (e.g. land cover, total population).

The calculation of each sub—index is determined based on several variables, including the determination that depends on the spatial scale which is being studied. The identified variables are then classified based on a scale from 1 to 5 (5: greater degree of coastal vulnerability and 1: lower degree) in order to reflect their contribution to the coastal system vulnerability. That range allows a mathematical combination of several variables. The indices of the relevant variables are summed and the resulting number is matched in a range from 0 to 100.

The variables classification is a subjective process and criteria used should be specified precisely. The weighting of variables is also a difficult process because it is also based on subjectivity. Also, the divisions made in the coastal area do not coincide in most cases with administrative boundaries.

3.2 European Environment Agency (EEA)

In order to improve its capacity and expertise in this area, EEA has also analyzed methodological aspects of coastal vulnerability assessments. In October 2010, EEA organized a first expert workshop on methods (and data) for assessing current and future coastal vulnerability to climate change to consider complementary or alternative assessment approaches. Results of the workshop were used to finalize a technical paper on existing "Methods for assessing current and future coastal vulnerability to climate change" drafted by ETC/ACC (2010b).

The proposed multi-scale index aims to investigate effects of spatial scale in the identification of coastal risk and refers to the study of McLaughlin and Cooper (2010). Also, the possibility of using a multi-scale coastal vulnerability index based on a common methodological and theoretical framework is evaluated and applied at regional (CRI-MED) and local (CRI-LS) level.

The only difference between the two scales is the definition of the coastal unit and the selection of variable used to describe the three sub-indices. Furthermore, higher resolution is required on the local compared to the regional scale. Indeed, to include more detailed information to design appropriate strategies, introducing more and different variables for coastal vulnerability and exposure sub-indices, while forcing sub-index is the same used in regional level (CRI-MED).

The advantages of the multi-scale CVI methodology are (Ramieri *et al*., 2011):

- Integrates physical as well as socio- economic variables
- Three separated sub-indices representing vulnerability
- Not expensive and easy calculation process
- Easily integrates the concept of risk
- Produces vulnerability maps
- Applicable both at regional and local scale.

The aim of this program was to identify the coastal hot-spots that are in extremely high risk. The CRI-MED and the CRI-LS present coastal vulnerability in an easy way and without the use of expensive tools to support policy makers for the coastal zone management.

4. Assessing coastal vulnerability at different spatial scales

The basic advantage of a multi-scale index is the choice of perspective. Users have the choice of the appropriate scale according to their needs and the management scale. By means of a multi-scale index, data is digested at different spatial scales and adapted in such a way that coastal risk illustrated in a common format for all scales. There is no single scale that can me*et al*l needs. The different scales tend to reflect different priorities and the influence of one variable will increase or decrease if the scale changes. Multi-scale indexes have the advantage that they can be used to assist stake holders to develop coastal policies at different scales and application fields.

According to McLaughlin and Cooper (2010) the main differences identified between regional and local scale. In implementation of CRI-MED no extra attention to detail is paid as sought to assess the risk of all coastal Mediterranean coasts. In contrast, the level of detail of CRI-LS is very high, but the overall perspective low (McLaughlin and Cooper, 2010). Finally it is at the discretion of the administrator of the coastal area or the institution that makes decisions to determine the most appropriate scale to be used and this will depend on whether the policies will be exercised will be in national, regional or local level.

In an ideal world, indicators should be based on local-level information. However, this is often not feasible in terms of availability of data, storage and processing with respect to the time scale required for the assessment of coastal vulnerability.

After a thorough investigation of the existing literature, a methodology that aims to create three indicator systems, one for each scale (local, regional and national scale) which will assess any coastal area where exerted by human activities is suggested.

The main steps of the proposed methodology are:

- Categorization of key issues into two groups, nature and human.
  Most studies so far at this stage categorize indicators based on 3 or 4 pillars of sustainable development (economy, society, environment). Based on the literature (Gornitz *et al.* (1990, 1994)), coastal vulnerability index (CVI) created by Gornitz (1990) for evaluating vulnerability of coastal area focuses on only six parameters relating exclusively to natural environment as mentioned in previous chapter. In an effort to improve this index, recent studies (Thieler and Hammer Klose (1999, 2000), Thieler (2000), Boruf *et al*. (2005)) have introduced other parameters relate to socioeconomic data related to human. Therefore, the two main categories that

affect the quality and sustainability of coastal areas is considered to be nature and human.

- Selection of key issues based on existing literature.
  At this stage the most important parameters that affect coastal zone were also identified and are either related to physical characteristics or to human activities. So far the new system of indicators is the same for all spatial scales. The key issues are:
  - Demography
  - Society
  - Economy
  - Infrastructure
  - Urban environment – settlements
  - Tourism – commerce
- Selection of indicators.
  The selection criteria are:
  - Relevance in terms that the results describe accurately the existing situation
  - Availability of data. Especially in Greece, it is difficult to obtain a lot of data and relate different spatial and temporal scales.
  - Ease of collection

    Based on a literature survey, multitude indicators for coastal vulnerability are collected and the most frequently used as well as those that successfully meet the above criteria are selected.

  The indicators present some variations on the three scales in order the final system to be more representative.

- Categorization of all indicators in the three pillars of sustainable development (economy, society, environment) to point out where the new policies should be implemented.
- Evaluation of indicators systems by stakeholders through questionnaires in order to select the most appropriate system.
- Selection of final indicators.
- Ranking based on the existing literature.

The final indicator system will be applied on 3 scales (local, regional, national). Diversification will be only in the indicators of each key issue depending on the scale being studied. The selected key issues will be scored by stakeholders to highlight the most important of them. Scores will be attributed as weights which will affect the final result and will help identify the key issues that have the greatest need for new appropriate policies.

The final tool will be available for use to everyone and will initially requested by the user to answer some questions such as the scale to be considered and then the appropriate system of indicators will be displayed. Then, the required data will be collected and the final result will arise on completion of the final equation will which will present the state of the environment of coastal area. The end users of the tool will be the entire academic community, stake holders and investors.

5. Conclusions

It is clear that several attempts have been made to find sustainable development indicators for the coastal area. However, due to continuous developments it is necessary to further investigate the issue of finding appropriate indicators. This will give not only a general idea of the current situation of the coastal area, but it will also identify threats and weaknesses, with final aim of selecting the best policy. Furthermore, the user according to his needs will have a choice of spatial scale.

The results of the proposed methodology can be applied to any coastal area where human intervention occurs. Comparisons either between the same scale study areas or between comparative studies on the same area at different times to evaluate the progress towards sustainability could be made.

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