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Coastal risk adaptation: the potential role of accessible geospatial Big Data

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ABSTRACT

Increasing numbers of people are living in and using coastal areas. Combined with the presence of pervasive coastal threats, such as flooding and erosion, this is having widespread impacts on coastal populations, infrastructure and ecosystems. For the right adaptive strategies to be adopted, and planning decisions to be made, rigorous evaluation of the available options is required. This evaluation hinges on the availability and use of suitable datasets. For knowledge to be derived from coastal datasets, such data needs to be combined and analysed in an effective manner. This paper reviews a wide range of literature relating to data-driven approaches to coastal risk evaluation, revealing how limitations have been imposed on many of these methods, due to restrictions in computing power and access to data. The rapidly emerging field of 'Big Data' can help overcome many of these hurdles. 'Big Data' involves powerful computer infrastructures, enabling storage, processing and real-time analysis of large volumes and varieties of data, in a fast and reliable manner. Through consideration of examples of how 'Big Data' technologies are being applied to fields related to coastal risk, it becomes apparent that geospatial Big Data solutions hold clear potential to improve the process of risk based decision making on the coast. 'Big Data' does not provide a stand-alone solution to the issues and gaps outlined in this paper, yet these technological methods hold the potential to optimise data-driven approaches, enabling robust risk profiles to be generated for coastal regions.

1. Introduction

Decision-making in coastal regions needs to be based on sound science and accurate information. Access to appropriate 'information' has been outlined as comprising a vital component within the coastal management process [1]. Data and information form the basis of comprehensive mapping and analysis of coastal risk [2–5]. However, there exists a vast body of data for coastal zones, and the volume and variety of datasets requiring collation, organisation, and subsequent analysis can prove overwhelming. If progress is to be made in this area a new paradigm must be developed for data, information and knowledge management. Emergent information and computational techniques hold potential benefits in the realisation of this goal. The rapidly evolving field of 'Big Data' and associated analytical approaches are proposed to be well-suited to facilitate such decision-making.

This paper focuses on coastal risk adaptation, the role of information, and potential application of Big Data solutions within this domain. This is addressed through assessment of literature dated from 2000[1] to 2017, focussing especially upon the application of data-driven approaches to coastal zone management. This has permitted emergent themes to be highlighted and investigated, providing a new understanding as to the efficacy of these methods. As yet, there have been only limited studies completed in relation to coastal Big Data approaches, yet those which do exist suggest there is considerable scope for application of these technologies to enable the generation of robust environmental risk profiles for coastal regions [3,6–8].

At the outset, it must be stated that this work cannot represent a comprehensive evaluation of all materials published concerning coastal decision support approaches, within the seventeen-year time-period reviewed. This work instead sets out to characterise and reflect upon emergent developments and, in so doing, presents a discerning representation of relevant key works, providing a structure to support an appraisal of developing opinion concerning the complexities surrounding coastal risk assessment. The publications addressed are categorised within three themes, namely: coastal risk adaptation, data-driven approaches, and the application of Big Data to coastal management. Table 1 (in Section 7) provides an overview of issues addressed within this research in relation to these three themes. It is considered that these themes provide a useful foundation for addressing the developments in this new area, with each selected publication exemplifying pertinent issues from the current debate.

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[1] The cut-off point, of the year 2000, was selected so to incorporate some important coastal management developments made in the early years of the new millennium.

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2. Coastal risk and adaptation

2.1. Vulnerability/hazards

Sustainable management approaches in coastal zones are challenged through the wide-ranging, dynamic hazards threatening the status quo in these regions. Hazards have been defined by authors, such as Kron [12, p. 1369], as representing 'the threat posed by natural forces that cannot be influenced….. beyond mankind's control'. Muro et al. [13, p. 4] define a hazard as 'the potential to cause harm (or intrinsic capacity to cause damage)'. In an anthropocentric sense hazards are seen in general as exerting a potential threat to humans and their welfare. Of the naturally occurring coastal hazards, flooding and erosion are the two most significant, and are therefore focused on primarily within this paper. Flooding of coastal systems in particular is considered 'one of the most frequent and damaging natural hazards, affecting countries across the globe' (UNISDR [32] cited in [11]). Nevertheless, impacts are also generated from human activity in coastal areas and the ocean. Unsustainable overuse of maritime resources represents a significant concern, and land-based pollutants (such as sewage and industrial wastewater) are major threats to coastal ecosystems [12].

Coastal hazards lead in turn to societal vulnerabilities, affecting properties, persons and infrastructure. Smit and Wandel [13, p. 284] state the term vulnerability is used to describe 'the estimated net or residual impacts (being the initial impact costs, minus net adaptation savings)'. For England and Wales, Defra [17, p. 104] estimated that approximately '100,000 properties, having a total value of £8 billion, in areas without protection could be eroded in the next century' with 1 million coastal properties being at risk of flooding, with an estimated value of £130 billion.

Population growth within the coastal zone has been widely cited as a catalyst factor raising levels of vulnerability [16,17]. Natural hazard losses can be related directly to the number of people living in risk prone areas, especially where a large number of people, assets and complex infrastructure are concentrated in single vulnerable locations.

2.2. Risk

In acknowledging coastal hazards and associated vulnerabilities, the nature and extent of coastal risk can be identified. Risk may be defined as the probability of a given hazard occurring, factored by the severity of its consequences [1,9,14,18–24], thus:

$$Risk = Probability\ x\ Consequence \tag{1}$$

Risk represents 'the main instrument and criteria leading to coastal zone management policy' [19]. The Tyndall Coastal Simulator project [25], identified for a case study site in East Anglia that flood risk is predicted to grow exponentially during the 21st century, whilst erosion risk is predicted to remain relatively constant. Jongman et al. [11] state that, in the Netherlands, exposure to flooding has increased by 300% over the last 50 years, as economic value in coastal areas has risen at a rate above that of the national average. Poor planning on the coast and unsustainable natural resource use has been cited as major factors exacerbating a wide range of environmental risks, such as those relating to natural processes, Climate Change induced hazards and pollution [16].

2.3. Impacts

Within the progression of the coastal risk cycle, hazards create vulnerabilities, which in turn lead to the propagation of these hazards, resulting in consequences, which can be labelled 'impacts'. The term impact 'implicitly deals with severity, intensity, or duration of the effect' [28, p. 69], Impacts can become compounded in some instances because of human attempts at adaptation. As a result 'Coastal Squeeze' can occur, as habitats and natural coastal features become caught between defences and rising sea levels and so become lost at accelerated rates [15,27].

One implication of human intervention is that many stretches of coast, lying adjacent to protected areas, have become sand-starved [28]. This concurs with the most apparent impact from physical coastal processes being the landward transition of the shoreline, becoming especially apparent when extreme events occur, such as the North Sea Storm Surges of 1953 and 2013 [29,30]. Damage arising from natural disasters has been reported to increase in recent times as a result of capital accumulation in flood-prone areas [20].

2.4. Adaptive measures

Adaptations have been termed: 'adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stress' [15, p. 282]. Conflict is almost inevitable where continued development in coastal areas requires stability, whilst natural processes involve change [31]. As a result, humans who wish to develop coastal sites are required to adapt to natural processes.

In terms of physical adaptations, conventional coastal adaptations can be split into groupings of 'hard' and 'soft' measures. Hard adaptation measures are generally regarded as semi-permanent installations on the coast. Examples of these are seawalls, revetments, groynes, and breakwater sills. Soft adaptation measures include beach feeding (recharge), dune building, and 'Managed Realignment' [28]. Soft measures are deemed to be those designed to work with natural processes [23]. In the UK, Defra [14] have outlined the need to 'work with natural processes' and to use a 'wide range of risk management options', including softer adaptation measures. Furthermore, in enacting *Making Space for Water*[2] [15], Defra is reported to be using ecosystems services in some areas, instead of relying on hard measures (in tackling flood and coastal erosion risk) [32].

In economic terms people begin to rely on coastal protection structures, making their property more valuable [31]. In this sense government can be seen to provide inverse incentives to invest in hazardous areas through the provision of protection [11]. For the right adaptive strategies to be adopted, rigorous evaluation of the available options is required [33]. This evaluation hinges on the availability and use of suitable datasets.

2.5. Coastal risk assessment – the role of information

Building on notions of coastal risk, it becomes apparent that a core driving aspect of managing the coastline is the completion of reasoned risk assessments. Within risk assessments, hazards need to be identified, together with estimations of their probability, and quantification of the impacts these hazards will have on vulnerable areas. This enables adaptive management strategies to be developed. Advances in computing power can prove critical in this process as responses to events can be altered by data-driven modelling [1]. Without this a situation of inappropriate development of coastal land can arise. Generally though, increased construction on the coast is seen to result in long-term damage to the environment and increased risk from flooding and erosion [31]. Therefore, in making decisions about future developments on the coast it is critical to evaluate the full range of risks.

In their first response to, *Making Space for Water*, Defra [14] emphasise how risk information must drive activities, highlighting the specific requirement for inclusion of better data on the consequences of coastal flooding and erosion. In relation to coastal partnerships in England, Milligan et al. [34] argue that a fresh approach should better incorporate flood and erosion risk assessments in its planning phases.

[2] Making Space for Water is a key document relating to government coastal policy in England and Wales, published in 2004 [15].