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Developing a framework to quantify potential Sea level rise-driven environmental losses: A case study in Semarang coastal area, Indonesia

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ABSTRACT

Climate change triggers major alterations to coastal zones worldwide. Quantification of these adverse impacts to coastal ecosystems is often done on a coarse scale of global regions. Consistent local scale estimates of physical impacts on ecosystems and monetary assessment of associated losses are scarce, especially in developing countries. With aim of facilitating such assessment, which is increasingly required, here we propose a coherent three-step framework and subsequently apply it to quantify potential sea level rise-driven alterations in the monetary value of ecosystem services in the coastal area of Semarang in Indonesia. Within this framework, we (1) quantify the present value of coastal ecosystem services by using economic valuation techniques; (2) identify the potential impacts of relative sea level rise (RSLR)-induced inundation on ecosystem services (for the year 2100 inundation scenarios); and (3) monetize these impacts by developing a novel scenario-based approach. The results show that full inundation (scenario A with 4 m RSLR) poses a median loss of 90% (US$ 2.8 – 3.5) and 25% (US$ 90 – 113) to the present art and fishery values per hectare, while amenity service is expected to lose upto 50% (US$ 3700 – 5400) of its present value. Additionally, recreation value of the coastal ecosystems in three selected sites (Marina and Maron beaches, and Plumbon estuary) will decrease by 70% (US$ 15,460 – 19,820) per hectare. However, in scenario B (RSLR of 1.1 m) with a 50% inundated area, these losses are estimated approximately 40% less than for scenario A. It is expected that researchers and policy makers may apply this approach in their areas of interest to gain a better understanding of the likely costs of sea level rise-driven environmental damages along coasts, ultimately contributing to the sustainable management of coastal environment in Indonesia and possibly in other developing countries.

1. Introduction

Climate change (CC) threatens coastal areas globally. Intensifying coastal hazards escalate damages to social, economic and environmental systems. Apart from social and economic losses, the coastal environment will undergo major physical changes triggered by coastal hazards (e.g. coastal recession, inundation, formation and closure of small tidal inlets) and CC impacts (Wong et al., 2014). The socio-economic wellbeing of coastal communities and their resilience rely considerably on the services that coastal ecosystems provide. Importantly, quantitative fine-scale physical and monetary assessments of CC driven losses – including ecosystem losses – form the basis for estimating global climate change related damages in Integrated Assessment Models. These climate science models integrate a description of greenhouse gas emissions and their associated impacts on temperature, showing how changes in temperature will affect the economic value of welfare (Pindyck, 2013). In addition, Integrated Assessment Models are used to estimate the social cost of carbon by modelling the growing change in global economic output caused by 1 t of anthropogenic carbon dioxide emissions (Sterncalls, 2016).

Available CC impact assessment studies have mostly explored the first order CC impacts on coastal and marine areas such as changes in sea level, ocean conditions and biogeochemistry, without monetizing these impacts on the services provided by ecosystems (Daw et al., 2009; Cochrane et al., 2009; Mohanty et al., 2010; Sumaila et al., 2011; Cheung et al., 2011). A few studies have performed quantitative

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analysis of physical impacts of CC on coastal ecosystem services (CES). For example, Cheung et al. (2011) demonstrated that ocean acidification (i.e. 30% reduction in oxygen demand as the H + ion concentration in the ocean doubles) in the North Atlantic reduces the growth rate of fish, resulting in a decrease of 20%–30% in potential catch.

Kuhfuss et al. (2016) conducted a valuation of CC-driven changes in CES in France, showing that a 1 m sea level rise (SLR) scenario in 2100 helps to gain additional territory to the regional coastal wetlands due to retreat of agricultural and urban areas. In this study, the transformations of ecological habitats, depending on their distance from salt water, were examined by assuming proportionality between the surface area and CES. This scenario-based approach resulted in a projected increase of total CES value (i.e. ecotourism, biodiversity, flood drainage, etc.) between €10,790,000 and €16,188,000 (2010 prices) due to 1 m of SLR by 2100 (relative to 2010) depending on different adaptive strategies considered. In a large scale study, Roebeling et al. (2013) projected coastal erosion patterns in Europe under IPCC-SRES scenarios (B1 and A1Fi), by using the Dynamic and Interactive Vulnerability Assessment (DIVA) data base, in combination with a benefit transfer approach. According to this study, SLR-induced erosion with total territory losses between 3700 km^2 and 5800 km^2 in different land cover types (coastal wetlands, agricultural areas, forests and semi natural areas) resulted in annual damages (by 2050) of approximately € 2.9 billion to associated CES. The outcomes of these studies are very diverse and sometimes conflicting, adding to the uncertainty related to the potential costs of adverse climate change impacts.

Despite the few applications mentioned above, little is still known about quantitative CC driven impacts on diverse CES. While most of available valuation studies have estimated the present value of CES in local case studies, this strand of literature has not explicitly quantified the changes in the value of different CES due to CC impacts (Mehvar et al., 2018a). Such quantifications are especially problematic in developing countries due to: a) a general lack of data even to asses physical impacts and associated losses (Bosello et al., 2012; Farmer et al., 2015; Burke et al., 2016); b) field work can be difficult to arrange and/or is expensive; c) willingness to pay (WTP) or willingness to avoid environmental damages (WTA) are difficult to extract in lower-income countries, especially for assessments of losses for a far-way future, while current needs are already difficult to meet. Indeed, most of the current assessments are carried out in developed countries, making it difficult to transfer these valuations into the context of developing countries. Yet, it is in fact developing countries that are likely to suffer most, given that local population is often dependent on CES to survive and adaptive capacity is low.

To fulfil this knowledge gap, particularly in the developing country context, the present study aims to quantify potential changes in the value of CES for the year 2100 inundation scenarios in Semarang coastal area, located in Central Java Province in Indonesia. The novel scenario-based approach used in this study represents a new methodology compared to previous studies by presenting a link between potential impacts of relative sea level rise (RSLR)-induced inundation with CES associated attributes. In addition, this approach bridges the potential impacts of inundation on CES with economic concepts (consumer and producer surpluses), providing a straightforward method that can be generally applied in situations where ecological and economic model simulations may not be possible due to data scarcity or other limitations.

Our study area choice is driven by the fact that Semarang provides diverse CES and large nursery habitat for coastal flora and fauna, while the area is already suffering from coastal inundation and CC impacts (KPP Nasional, 2014). To achieve the overarching objective of this study, we seek to answer the following specific questions: (1) what is the present monetary value of CES in Semarang?; (2) to what extent can climate change impacts, represented here only by RSLR (summation of mean sea level rise and land subsidence rate)-induced inundation affect the services provided by coastal ecosystems of Semarang in the year 2100?; and (3) how can the identified impacts be monetized?

The article follows three consecutive steps. Firstly, using economic valuation methods, we estimate the present monetary value of CES which is currently provided by mangrove swamps, beach, dune and pelagic systems. Secondly, by considering a ‘‘what if scenario’’ approach, we identify the potential impacts of RSLR-induced inundation on the (pre-valued) ecosystem services for different year 2100 inundation scenarios. Thirdly, these changes in CES – which could be losses or gains – are monetized using the pre-estimated values in step 1.

The outcomes of this study are expected to aid international research efforts on mapping monetary valuations of CES and RSLR impacts on CES through the quantitative assessment of a number of ecosystem services it provides within a developing country context.

2. Methods

2.1. Study area

Semarang with population of about 1.57 million people and an area of 374 km^2 (BPS, 2014) is the capital of Central Java Province in Indonesia. The whole coastal area of Semarang constitutes of 4,575 Ha (DKP, 2008). Marina and Maron beaches comprising about 33 Ha in total, and Plumbon estuary with an approximate area of 23 Ha, were selected as the study sites located in the lowland of Tugu and Semarang Barat districts (Fig. 1). The coast of Semarang mainly comprises volcanic terrain (Datema, 1989), and the soil types are generally alluvial due to fluvial sedimentation (Rahmawati et al., 2013).

There are different types of CES in the study area. Mangrove swamps mostly cover the Tugu district where the Plumbon estuary is located, while beach and dune systems are the dominant ecosystems in Maron and Marina areas. In addition, Java Sea represents another ecosystem constituting a pelagic system.

2.2. Methodology

To estimate the value of potential changes to CES, here, we develop a framework consisting of three methodological steps (Fig. 2). Firstly, we focus primarily on assessing the value of ecological services provided by coastal ecosystems (hazard impact to urban developments and infrastructure is excluded). Here we apply the available economic valuation methods to estimate the present monetary value of CES derived from the original field work. Secondly, we identify the potential impacts of RSLR-induced inundation on CES in 2100. Therefore, we use a particular scenario-based approach grounded in expert knowledge and in secondary data from literature review. Finally, we quantify the resulting losses to CES for year 2100 inundation scenarios by combining the pre-estimated monetary values with anticipated changes in quantity and quality of CES.

2.2.1. Step 1: Valuation of CES (current status)

In the first step of this study, we apply three standard economic methods (i.e. contingent valuation, net factor income and hedonic price), to estimate the present value of CES in Semarang. Semarang coastal ecosystems offer a variety of direct and indirect services such as provision of fibre and raw materials, educational opportunities, storm protection and wave attenuation, shoreline stabilization and erosion control as well as climate regulation services. In this study we focus on the four services that provide direct use values; recreation or tourism and fishery - the dominant sources of income in Semarang, together with art and amenity value - the less analysed services in current valuation studies, while are nevertheless beneficial to human well-being. Valuation of other CES is beyond the scope of this study either due to the limited time and/or resources for data collection (e.g. wood production provided by mangroves) and/or because of extensive modelling and experimental requirements (e.g. wave attenuation service). However, excluding these services in this study does not necessarily