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Influence of flushing and other characteristics of coastal lagoons using data from Ghana

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ABSTRACT

The challenges associated with managing systems of shallow coastal lagoons along a rapidly evolving coastline are illustrated in a case study of small lagoon systems in Ghana where these important structures are relied on by a range of different stakeholders for a variety of different purposes including fishing, tourism and salt production. Results of some water quality measurements are presented, showing that these lagoons have poor ecological status where they experience either a lack of flushing by the tide, or large amounts of anthropogenic inputs, or both. A vulnerability assessment is applied to the lagoons in question and this reveals a varying degree of threat from climate change to the operation and use of the lagoons. Our understanding of these systems suggests that a set of 1D hydrodynamic models, underpinned by an understanding of the local coastal sediment transport in each case, is appropriate, and could then be used to inform stakeholders and management in decision making. Integrated, broad-ranging management strategies must adapt to the realities of climate change in order to allow the sustainable use of these lagoons in providing economic benefits, ecosystem services, and elements of coastline protection for the benefit of the local and regional population and its economy.

1. Introduction

Many coastal regions of the world contain lagoon-like structures where shallow water bodies are protected by barriers consisting of beach material. These lagoons have generally formed due to the influx of fresh water from the land, which can either escape seawards or become trapped in the lagoon, depending on the magnitude of the flow, the tidal state, and the width and cill level of the barrier. The barrier is itself controlled by the magnitude of the fresh water flow and by the nature of the coastal processes, particularly wave action, causing longshore drift or some other means of transport of beach material, which then restricts the flow of water between the sea and the lagoon, or can stop it altogether.

Many authors have contributed to our mechanistic understanding of coastal lagoon processes in general terms (e.g., Conesa and Jiménez-Cárceles, 2007; Kjerfve, 1994). Worldwide, lagoons are important for fisheries, protection from storms, washing/bathing, amenity, tourism, as well as other industries and ecosystem services. Local industries in particular may benefit from a water body that is at least partly sheltered from winds and storm events, thus providing a source of income for local people. Understanding the factors that control the level of different kinds of pollution that arise is therefore of enormous benefit to all stakeholders (Roselli et al., 2013).

Coastal lagoons are under continual threat due to climate change because they are low-lying, exposed, and generally subject to continual erosion and deposition; in most cases, however, it is not clear to what extent any of the processes associated with climate change could affect the operation of the lagoon in question for those who most wish to make use of it (Chapman, 2012; Gaertner-Mazouni and de Wit, 2012; Brito et al., 2012). Where the lagoon is being used as a nature reserve, for example (Mitchell et al., 2008), it may well be that any local sea level rise simply adds to the availability of sediment, which then gives rise to the establishment of new salt marsh areas, of benefit to a range of species. On the other hand, it is clear that issues of climate change can only be addressed provided that consistent and tested governance strategies are applied in consultation with stakeholders (La Jeunesse et al., 2015). Several authors have made some mention of the importance of using reliable and tested numerical models to predict likely outcomes in years to come.

A large body of literature from around the world is a testament to the appeal of research work that seeks to understand the

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hydrodynamics and response of such systems to coastal processes and anthropogenic change. Broadly, recent studies can be categorised into three main areas. First, a number of authors have addressed the role of morphodynamics on the changes to the hydraulic regime. This is perhaps most relevant to the present study. Of key interest are the tidal range, fresh water input, and the supply of sediment. It is this balance of processes (Moreno et al., 2010; Duck & Figueiredo da Silva, 2012; Ozturk and Sezli, 2015) that generally determines the fundamental tendency of the lagoon to be flushed by the tide. In this vein, the well-known categorisation of Kjerfve (1986) has helped to forge a better understanding of the different types of lagoons and how these respond over different time scales to different hydrological and geomorphological processes. Second, of interest to many researchers are the fundamental processes connected with the hydrodynamics and related water quality within the lagoon (Jewell et al., 2012; Dussaillant et al., 2009; Serrano et al., 2013). In deeper lagoons vertical density stratification can also be a consideration in the trapping or release of chemical species in deeper waters (Albarakati and Ahmad, 2012). Third, many researchers relate the importance of groundwater or through-barrier flow and the effect this has on the chemistry and water quality of the lagoon (Chikita et al., 2012; Stieglitz et al., 2013; Austin et al., 2013). Table 1 shows the geographical distribution of a selection of recently published studies that have informed previous debates about the local management of lagoon systems, and have helped our understanding of lagoon management generally. This list is not exhaustive but it nevertheless provides a sense of the recent diversity of interest in lagoons; the literature perhaps above all illustrates the diversity of different lagoon types, uses, threats, and opportunities.

The management of coastal lagoons is often governed by a multitude of considerations related to morphodynamics, hydrodynamics, water quality and ecology, all of which requires a multidisciplinary approach to a complex and rapidly changing problem. Few studies to date have considered the interaction between the physical processes that control their shape and depth, for example, and the chemical and biological interactions that control the usefulness and the economic and social value of the lagoon, for example. This is important because it is those who rely on the lagoon who most feel the effects of any change that takes place, and they themselves may or may not have a good understanding of the causes and mechanisms involved in the change. As in all such cases it is only by making management decisions based on real scientific understanding of specific systems that long term sustainable decisions can be made.

The practicalities and expense of undertaking fieldwork means that some coastal lagoon systems have received more attention than others; West African lagoons, for example, are relatively poorly understood in terms of their morphology and general ecological status. The aim of this article is to report the levels of pollution in some small coastal lagoons using case studies of lagoons in Ghana, West Africa, in relation to their state in terms of water exchanges and the degree of protection or closure from the sea. We also undertake an assessment of the present threats via a vulnerability analysis, and consider what sort of model might be best suited to the lagoons in question, with a view to making comments about the likely system response to global climate change, in terms of rising sea levels or increased severity and incidence of storms.

Table 1
Recent literature related to understanding and management of lagoon systems worldwide.

Authors	Location	Main process of interest	Date
Chikita et al.	Japan	groundwater	2012
Albarakati & Ahmad	Saudi Arabia	Water quality	2012
Moreno et al.	Spain	morphodynamics	2010
Jewell et al.	Australia	Tidal asymmetry	2012
Stieglitz et al.	France	groundwater	2013
Dussaillant et al.	Chile	Water level changes	2009
Serrano et al.	USA	Tidal hydraulics	2013
Duck & Figueiredo da Silva	Portugal	Geomorphology	2012
Pasquini et al.	Brazil	ENSO signatures	2013
Austin et al.	UK	groundwater	2013
Webster	Australia	hydrodynamics	2010
Carlin et al.	USA	Sediment resuspension	2016
Haghani & Leroy	Iran	geomorphology	2016
Ozturk & Sesli	Turkey	geomorphology	2015
Tenorio-Fernandez et al.	Mexico	Tidal dynamics	2016
Chapman	Various	Climate change	2010

2. Coastal lagoons in Ghana

2.1. Background

Despite the wide body of literature on coastal lagoons, relatively little of it relates to developing economies where subsistence-type farming or fishing may be important. Furthermore, the lack of consistent development or coordinated construction activities away from the main urban centres has precluded the detailed investigation of the coast of West Africa as a whole, or its response to the main processes that affect all coasts. Ghana's population was estimated at 27.9 million in 2015, up from the 24 million recorded in the 2010 National Population and Housing Census (Ghana Statistical Services, 2015). The country covers a total land area of 238,533 km^2 and has 540 km of coastline. The coastal zone of Ghana, defined as the area below the 30 m contour, represents about 7% of the land area (Boateng, 2009) and has about 50 coastal lagoons interspersed along the shoreline. Very little is known about many of these lagoons, though the few that have been studied (Entsua-Mensa, 2002; Entsua-Mensah et al., 2000) suggest that they provide valuable ecosystem services that support not only the wildlife and fauna, but also the subsistence economy of the rural coastal dwellers and the entire economy of Ghana.

Lagoons in Ghana provide valuable resources such as fish and crabs for sale and local consumption by fishermen. Reeds and other plants are cut for thatch and for weaving mats for sale at markets both near the lagoons and further afield. In some areas, vegetables are grown in sandy garden beds irrigated with water drawn by hand from wells along the edges of the lagoons and mangrove swamps of Ghana's coastline. Salt evaporation ponds are created along the banks of some salty lagoons (e.g., Nyanya Lagoon; Fig. 1 and Table 2) for the commercial production of salt by local people. In fact, lagoons are among Ghana's most valuable ecosystems because they are closely tied to salt marshes, mangrove swamps, and tidal flats, all of which constitute significant features of Ghana's coastline providing critical habitats for many fish and wildlife resources supporting the economy.

However, these coastal lagoons are highly fragile and vulnerable to both natural processes and anthropogenic activities. Urbanisation and land-based pollution mostly have significant impacts on the water quality, hydrodynamics, geomorphology and the biodiversity of coastal lagoons and these significantly affect the natural processes and ecosystem services provided by lagoons. Similarly, coastal lagoons in Ghana suffer from land-based pollution (domestic, industrial and agriculture), which weaken not only their ability to produce the natural services, but their resilience and their capacities to mitigate and adapt to Climate Change (IPCC, 2014).

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