Modelling of sea level rise and river system

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Abstract

Purpose – This paper aims to present a hydrodynamic river modelling by incorporating river flow and sea-level rise interactions.

Design/methodology/approach – Predicted sea levels from renowned studies are put to test on flow scenarios of the Sarawak River in the deltaic city of Kuching, Malaysia. Three cases are drawn for investigation, including one extreme flood event, one normal flow with low tide, and another normal flow with spring tide.

Findings – The model predicts a worst case that nearly 5-6 km^2 of urban land along the Lower Sarawak River would be under water due to the rise.

Practical implications – Such an indication would draw a clearer picture for strategy and mitigation planning.

Originality/value – Generally sea level estimation involves ocean-atmospheric modelling. However, the paper argues here that a river model is credible for practical hydrological site-specific analysis to include increase of sea levels.

Keywords Coastal regions, Floods, Modelling, Malaysia

Paper type Case study

1. Introduction

Sea level rise is currently a hot topic. The rise in sea level is an integrated effect due to processes associated with global warming which have changed the intensity and direction of the atmospheric circulation, ice distribution, rates of sea ice melting and freezing, temperature and salinity fields (Proshutinsky *et al.*, 2001). Predictions of such a rise generally involve ocean-atmospheric modelling (Meehl *et al.*, 2005, Thompson *et al.*, 2008). Different models of varying approaches (Jackett *et al.*, 2000, Yin *et al.*, 2009) depict concerns that land may be submerged lands (Church *et al.*, 2004), to the extent that even Google Earth is hosting one such sea level rise mapping feature of the globe (see Figure 1).

Experts have cautioned that a rise in sea levels would engulf deltaic regions, such as the Yangtze in China (Chen and Zong, 1999), Chao Phraya in Thailand (Umitsu, 2000) the Mekong Deltas in Vietnam (Wassmann *et al.*, 2004). All three deltas are primarily agricultural land where wet paddy cultivation would be affected. Nearby Southeast Asia archipelagos, including Borneo Island, are also threatened by submergence. Kuching City is in the Northwest alluvial plain of Borneo, intertwined by several river outlets, with the major channel being the Sarawak River. As shown in Figure 1, the Kuching delta of lowland peat on the eastern side and mangrove swamps in the west would be inundated under seawater. Note also that seawater would intrude through the river network to sink its riverbanks.

However, the flood map is only for public visualisation purposes. Further adaptation for local usage may still need an ocean model, which is quite difficult to build when expertise in ocean and climate dynamics is lacking. Such modelling is inaccessible for many, but there is evidence that river models are relatively accessible.

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Figure 1.
Sea level rise in the deltaic city of Kuching

Take the example of three deltaic regions mentioned above – reports of river modelling in those areas are available, such as Zhu *et al.* (2000) for the Yangtze River, and Jayawardena and Mahanama (2002) for the Chao Phraya and Mekong Rivers.

A river model integrated with sea levels could function as a tool to assess the implications of rising sea level. It presents a scientific consensus on the likely effects of sea level rise in coastal areas and opportunities to prepare for the possible consequences. The effects can have important impacts on natural ecosystems, human developments and infrastructure. Therefore, the model would provide an early diagnostic of flooded areas, the type of land cover affected, and useful information for decision-makers. Kuching City revolves around the Sarawak River. One method of utilising sea level predictions for local analysis is of particular interest in studying the interactions of the Sarawak River and sea level rise. This paper presents a simple method of river modelling to incorporate sea level variations.

2. River modelling

Kuching City is exposed significantly to fluvial and tidal actions. The region is subject to Northeast monsoon from October to March with monthly rainfall of up to 500 mm. Kuching Bay experiences spring tides as high as 6-6.5 m, known as the King Tides (Memon and Murtedza, 1999). The average elevation of the city is +5 m, and local mean sea level is +4.5 m. In order to protect the city, the Sarawak State Government had established the Sarawak River Regulation Scheme (KTA Consulting Engineers, 1994), completed in 1998. The flow of the Sarawak River was modified from a naturally tidal regime to a regulated gates system constructed just downstream of Kuching City (see Figure 2). The Kuching Barrage was the only outlet of the catchment, while two other river courses to the sea were blocked. The technical design was deprived of any pumping stations as there was confidence that the internal river storage was sufficient to reserve a 100-year return period flood (Sharp and Lim, 2000).

A hydrodynamic model is utilised to model the hydraulics of the Sarawak River system (see Figure 2). Generally all hydrodynamic models require the input of boundary conditions. Flow data is required for the upstream end boundaries, while

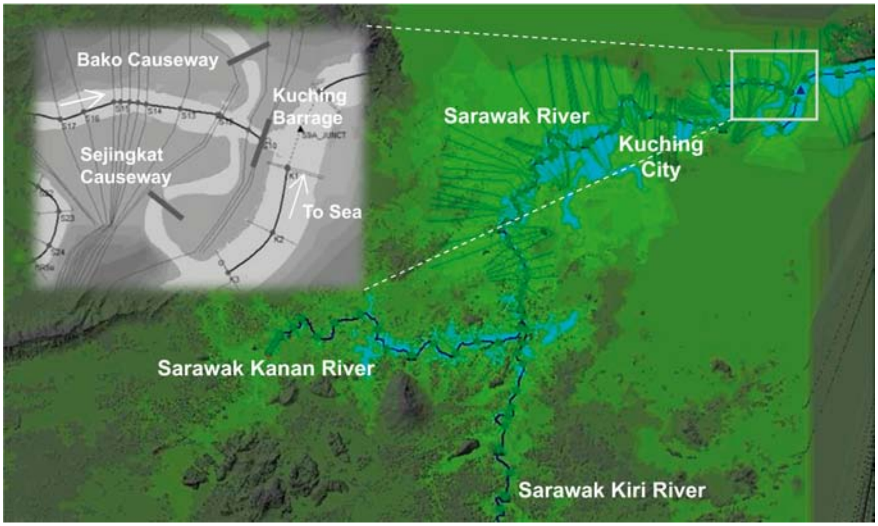

Figure 2.
Modelling of Sarawak River and coastal zone

water level data is required for the downstream end boundaries. This is the most common combination to compute an essential rating curve for model routing. Man-made structures like barrages are represented by mechanical radial gates.

Hydrological monitoring stations are distributed along the river corridor; these provide the necessary flow data for the upstream boundaries (Department of Irrigation and Drainage, 2009). No tide measuring gauge was available, but the Kuching Barrage operator records the tidally influenced water level fluctuation up- and down-river of the structure. Furthermore, a predicted tide table is easily accessible from the Sarawak Marine Department (2009). Tidal water level boundaries are imposed at the barrage and the estuary. With that, a base model representing the existing conditions has been calibrated and validated to at least 80 per cent confidence. Predicted sea levels are added for investigation.

It is common today that hydrodynamic models tie up with geographical information systems (GIS) that support flood mapping. The model calculates water levels in the river network and interpolates to points away from the network, taking account of natural barriers and available flow paths. Subtracting the ground elevation thus results in these points to obtain flood depths and the associated extent of flooding (Jenny *et al.*, 2007, Mah *et al.*, 2007). What emerges is a basin-wide Sarawak River flood map in conjunction with sea level rise.

3. Sea level rise

The Intergovernmental Panel on Climate Change (IPCC) is the most notable source for this issue. The IPCC estimates that global average sea level will rise by 0.18-0.59 m by 2100 relative to 1980-1999 under a range of scenarios. The IPCC cautions that these rates could increase or decrease in the future. If ice flow were to increase linearly, in step with the average global temperature, the upper range of projected sea level rise by the year 2100 would be 0.48-0.79 m (Intergovernmental Panel on Climate Change, 2007). Another study warns that sea level could rise much faster than previously expected, and that the global sea level could rise by between 0.75 m and 1.9 m (Vermeer and Rahmstorf, 2009).

These unfavourable conditions would exacerbate the natural variability in sea level and local tides (Macaulay, 2008). Based on this, the estimated statistics are superimposed to the Kuching Barrage and estuary to represent such rises. In the case of Kuching Bay, high astronomical tides would occur once every two weeks, and would create a very strong current, turbulence and a flushing effect at the estuaries and coastal zones. Its key characteristic would result in high waters that are higher than average and low waters that are lower than average, consistent with Macaulay's (2008) prescription. The river model can assist in shedding some light on the effects of in-stream flow collision with sea level rise.

4. Results and discussion

As an example, sea level increases of 0.6 m, 0.8 m and 1.9 m are placed over the current river level and run through the model developed. The worst scenario of Kuching flooding happens when a high flow event collides with high tides. The January 2009 flood event is an example of 100-year upstream storm surges clashing with downstream 6.5 m King Tides. The impact of the flooding is depicted in Figure 3, in which the river reaches shown are tidal. Existing conditions see widespread flooding along the river corridor. The Maong River catchments are the hardest hit areas, with 2-3 m water depth being the lowest in elevation in the city. The areas surrounding the Kuching Barrage are also inundated, to a much lesser degree, with 0.1-0.2 m of floodwater.

The opening and closing of the Kuching Barrage gates are modelled as recorded. The five-day event from January 8-12 observed that the Kuching Barrage gates were fully opened for 69 hours, almost three full days. The barrage operator practises this measure when the internal Sarawak River in-stream storages saturate and water levels on both sides of the barrage reach almost equal levels. From past experience, this lessens the pressure on the barrage structures. When additional water levels are added to the lower stretches, the flood extends further from the Maong catchments to the nearby Matang areas. The extreme prediction of a 1.9 m rise only sees greater flooding in Matang. Other areas see little extra flood to the

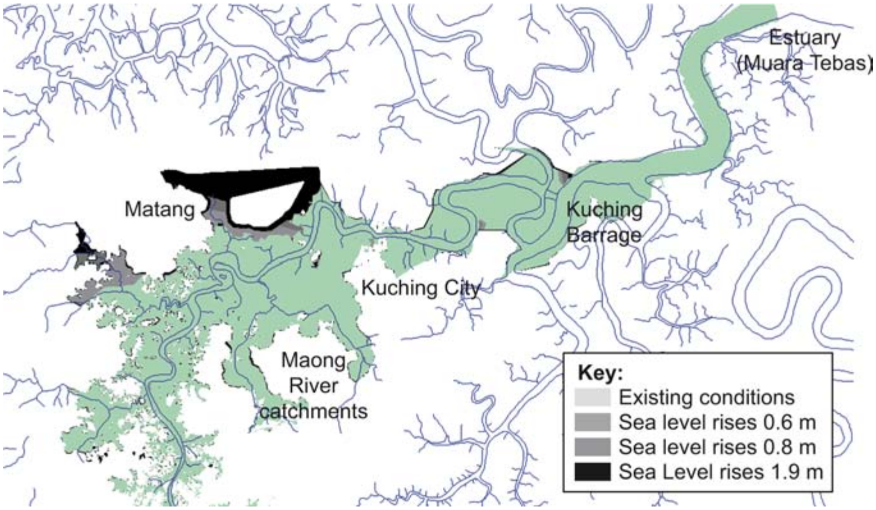

Figure 3. Running of January 2009 flood event and superimposed sea level rises

existing flood map. However, the coastal rivers north of Matang are not included in the modelling in the absence of data.

Usually the Northeast monsoon peaks in January and February, and reports of flooding often fall within this period. These two months are comparatively a short period of time, but cause the most suffering. The rest of the year consists of "normal" periods with monthly rainfall in the range of 200-300 mm. Simulations of the hydrological events of April 2007 are depicted in Figures 4 and 5. In order to synchronise with previous scenarios, the Kuching Barrage gates are modelled to be fully opened, allowing seawater to enter. An average flow of about 200 m^3/s is routed through the Lower Sarawak River. The simulation is a representation of upstream flow and tide interactions.

In the low-tide case (Figure 4), the interactions see low-lying areas like the mouth of the Maong, small parts of the city centre and Loba Belut areas inundated. Other areas are less affected by river water level rises from the sea. In another case (Figure 5), the upstream flow remains the same to interact with the spring tide. The computed maps see the flooding in the three locations worsen, but the range of the increase is less significant. It should be noted that even the extreme level of 1.9 m sees no breach in the Kuching Barrage areas for both cases. It seems that Kuching Barrage would be able to contain sea levels under normal conditions.

A summary of the results is tabulated in Table I. The predicted flooded areas are compared to those of existing conditions. However, the increases are less than 1 per cent, or about 5-6 km^2 of areas. Such an effect in an urban setting of Kuching City can be devastating. It appears that a sea level rise would exacerbate the flooding in Kuching City during the monsoon season.

5. Conclusions

Sea level rise is reported on widely, but this paper outlines the interaction of sea level rise with a river system. A hydrodynamic river model is presented as a means to achieve this. Several scenarios have been run through the model and have predicted an increase of about 1 per cent in the flooded area due to sea level rise along the Lower

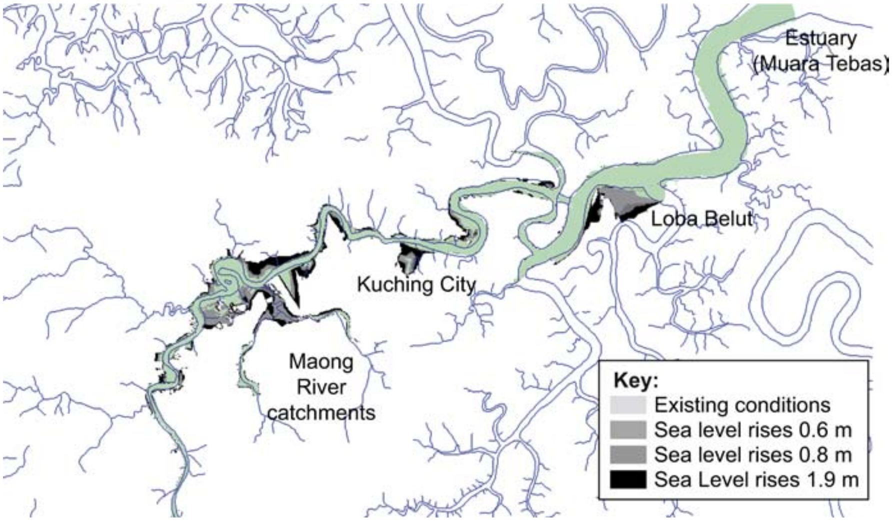

Figure 4.
Running of normal conditions and sea level rises

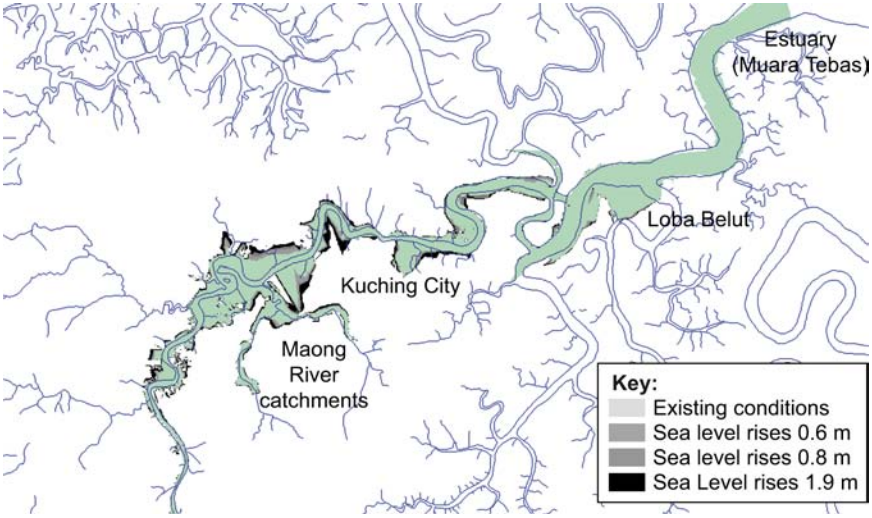

Figure 5.
Running of spring tides and sea level rises

Table I.
Percentage of flooded areas compared to existing conditions

	Flooded areas of existing conditions (km^2)	Compared to existing conditions (per cent)			
		+0.6 m	+0.8 m	+1.9 m	Remarks
Case 1: January 2009 flood event	655.53	+0.24	+0.41	+0.94	Greatest
Case 2: Normal flow and low tide	599.72	+0.42	+0.66	+0.73	
Case 3: Normal flow and spring tide	604.07	+0.33	+0.57	+0.63	Least

Sarawak River. The model is a useful tool and a practical method in helping to estimate the effect of sea level rise, and further helps in formulating a management strategy.

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