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TECHNICAL NOTE

Modelling the flood vulnerability of deltaic Kuching City, Malaysia

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Abstract The main objective of this writing is to present a practical way to envisage the flood vulnerability in deltaic region, particularly on the concern of sea level rise. Kuching city of Malaysia is established on banks of Sarawak River, 30 km from the sea. Therefore, it is subjected to fluvial and tidal floods. Kuching Bay experiences the highest King Tides in Southeast Asia region. These tide magnitudes could be a glimpse of future sea level rise. By means of modelling these tides, it provides an understanding and preparation for the impacts of sea level rise on the flood mitigation infrastructures and the city itself. The modelling efforts had created an illustration that a 10% rise in tide levels would result in increase of flooding areas up to 6% relative to existing tide levels.

Keywords Flood · Infoworks RS · Kuching · River · Sea level rise · King Tides

1 Background

Kuching flat is drained by the Sarawak and Samarahan Rivers as major channels, intertwined by multiple smaller channels. In this river delta, the capital Kuching city of Sarawak State is established beside Sarawak River about 30 km from the estuary (see Fig. 1). The average elevation of the city is +5 m AD, and the mean sea level is at +4.5 m AD. Its

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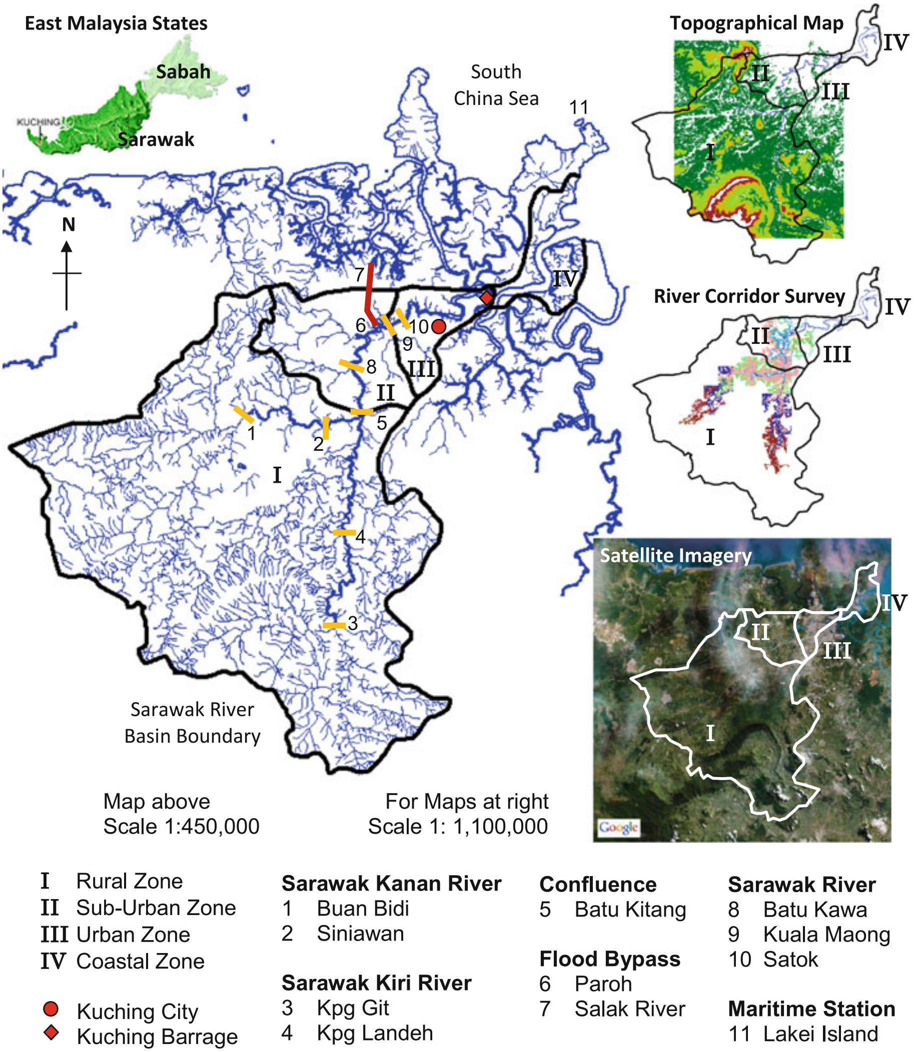

Fig. 1 Ground surface data for Sarawak River system modelling

low-lying landform is therefore exposed significantly to fluvial and tidal flooding. The city is subjected to Northeast monsoon from October to March with monthly rainfall up to 500 mm. Kuching Bay, on the other hand, experiences King Tides as high as 6.5 m HAT (Highest Astronomical Tide) every fortnightly, the highest in Southeast Asia region (Memon and Murtedza 1999; Sharp and Lim 2000).

Experts has cautioned that rise in sea levels would engulf deltaic regions. The sea level has been rising, and this fact had been well reported in the literatures, e.g. Douglas (1997), Church and White (2006) and Bindoff et al. (2007). Nicholls et al. (1999) had pointed out the South and Southeast Asia as the most vulnerable in absolute terms for coastal flooding, other than southern Mediterranean and Africa. Furthermore, the Intergovernmental Panel on Climate Change (IPCC 2007) estimated that the archipelagos of Malaysia, Indonesia and Thailand would experience above-average sea level rise.

As such, Kuching would be more vulnerable than before to coastal flooding. Moreover, a flood bypass channel connecting Paroh to Salak River would shorten floodwater flow to sea by 20 km (Mah et al. 2010). It also means Kuching inland is exposed 20 km nearer to sea. The structure is expected to be in full operation by 2015. Sarawak and Salak Rivers have been separate systems, until the bypass channel would combine them. The future flooding can be a totally different scenario. Due to this, there is a pressing need to estimate flood vulnerability in deltaic Kuching city, in concurrence with sea level rise.

2 Motivation

Predictions of sea level rise generally involve ocean-atmospheric modelling (Meehl et al. 2005; Thompson et al. 2008). The flow pattern at the coastal region is rather two-dimensional (2D) or three-dimensional (3D) in nature (Galperin and Mellor 1990; Horritt and Bates 2002). Such modelling is inaccessible for many. Ocean models remain strenuous to build in the lacking of expertise in ocean and climate dynamics. In the case of Sarawak State, the resolution of existing ground surface data hinders the advances to higher level modelling. However, it is evidence that one-dimensional (1D) river models are relatively accessible (Mah et al. 2011). 1D methodology is less than 15 years in Sarawak tracing back to its first use in the report of Sharp and Lim (2000) and yet reaching a mature stage.

With that, we argue that a 1D model integrated with tidal levels could function as a tool to assess the implications of rising sea level in Sarawak. It may not be providing detailed mixing processes of fresh and salt water systems, but it presents a scientific consensus on the likely effects of sea level rise in deltaic Kuching and opportunities for the possible consequences. The model would provide early prediction of longitudinal river-tide level fluctuations along the lowland river reaches for flood preparedness. This note presents a practical method of 1D modelling to incorporate sea level variations.

3 Methods

3.1 Building ground models

A MWH Soft model (formerly Wallingford Software), InfoWorks River Simulation (RS), is utilized to model Sarawak River system. InfoWorks RS involves tight coupling of GIS functionality and hydrodynamic flow simulation. Such model relies profoundly on accurate river channel and floodplain representation (Sinnakaudan et al. 2003; Sinnakaudan 2009). In Fig. 1, this project separates Sarawak River basin into four zones that correspond to four different quality levels of geographic data. These four areas are rural (I), sub-urban (II), urban (III) and coastal (IV) zones.

The rural and sub-urban zones are hilly regions (see Topographical Map in Fig. 1). A 1:50,000 topographical map covers these regions with the lowest contour line stood at 15 m (50 ft). Therefore, a river corridor survey complements the map for elevations below 15 m. The survey was carried out in year 2000 in conjunction with the Sarawak River Mitigation Options Study (Jurutera Jasa 2003) that produced contour lines of 2.5, 5, 7.5, 10, 15, 20, 30 and 40 m. These elevations better define the sub-urban zone (see River Corridor Survey in Fig. 1), where the upcoming flood bypass would be located. However, the survey exercise produced limited river cross-sectional profiles every 5 km apart in rural areas, 1 km apart in urban and sub-urban areas. Extra cross sections are computed from the surveyed profiles by means of interpolation in rural and sub-urban regions to enable routing of upland flows from its source before joining the lowland reaches. That such ground data are crude needs a further validation of its representation of the actual river conditions, discussed in later chapters.

The urban and coastal zones are the flat deltaic regions that are vulnerable to sea level rise. For that reason, these zones are critical compared to the previous two. The capital city centre is surveyed in great deal since 2003 when Malaysia adjusted its mapping system to Geocentric Datum of Malaysia (GDM2000) within 1 cm accuracy (JUPEM 2009). The GIS of the Kuching city is adequate. On the other hand, a 1:25,000 bathymetric survey map of the maritime part of Sarawak River is available. The river bathymetry by side-scan sonar sounding makes up the ground data stretching from estuary (coastal zone) till Satok (urban zone).

Combining the ground data from the four zones in a GIS platform thus generates a triangular irregular network (TIN) to show its earth shape. Derived TIN model is treated as a basin-wide digital terrain model (DTM) and loaded to the InfoWorks RS environment for river network building. Since the Sarawak River basin has two mitigation structures, the first ground model has the Kuching Barrage included, while a second ground model incorporates the upcoming flood bypass channel.

3.2 Building hydrodynamic models

In the absence of more advanced earth surface observation datasets, the available topographical data are the best at the moment. These are sufficient for 1D modelling as previously proven by reports of Jenny et al. (2007) and Salim et al. (2009). Using DTM in InfoWorks RS enables the take-off of elevation data to facilitate digitization of nodes and links, forming the backbone of a river model. It also forms the basis for flood mapping.

What river modelling means in practical terms is that software incorporates the fundamental laws of moving water bodies along an open channel (in this case, St. Venant Equations) into a simulated environment where flows and stages change over time. Researchers then feed in time series of river flows and stages about the real world into the model and see how accurately the computer-generated results resemble what actually happens. In theory, models can reveal the unique conditions that will result from a given hydrological pattern and then running the model to see how events related to that pattern will unfold.

There are 24 hydrological stations along Sarawak River to record rainfall and stage data hourly. However, there is no direct measurement of flow data. Rating curves are available for two upstream non-tidal stations of Buan Bidi and Kpg Git that have been calibrated from time to time. The two upstream-ends are treated as Flow-Time Boundaries, where flow data are fed to. Two river models are developed, with and without flood bypass channel (see Fig. 2). The bypass is modelled as an extended river channel to Salak River. The downstream-ends in estuary and outlet of bypass channel are treated as tidal Stage-Time Boundaries that allow the input of stage data. No gauges are available at Salak River at the current stage. However, a tide table that referring to a monitoring station at Lakei Island is accessible from the marine department. Barrage gates are modelled as mechanical radial gates.

3.3 Sensitivity analysis

With the available hydrological data, a base river model simulating the existing conditions is calibrated and validated using channel and floodplain friction (Manning’s n) as free

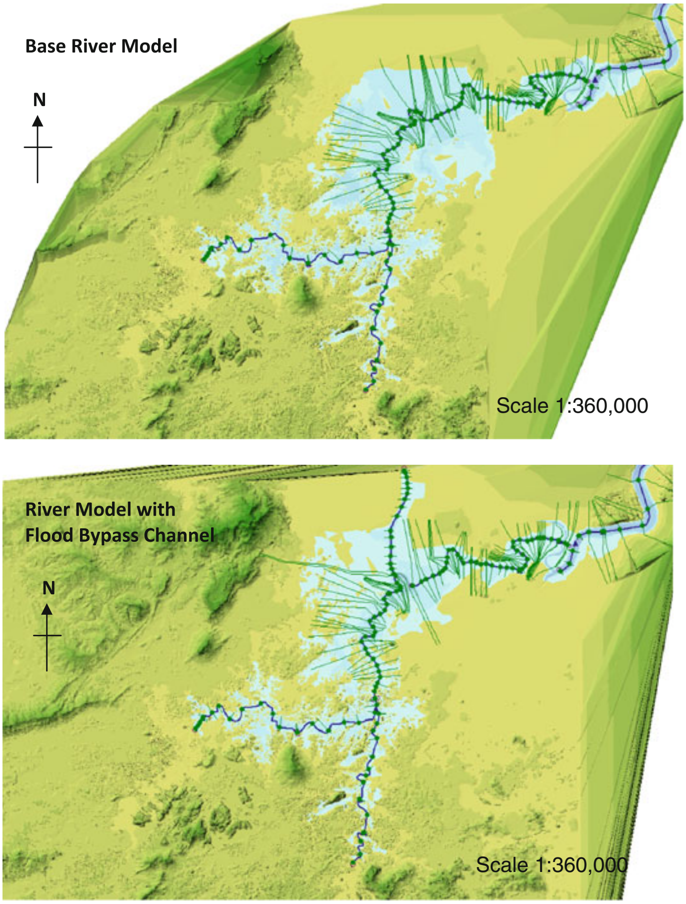

Fig. 2 Sarawak River models with and without flood bypass channel

parameters, against recorded and modelled hydrographs of Sarawak River to obtain a correlation coefficient of at least 0.80 (Wallingford 2008). Flood events of January 2004 and January 2009 are shown in Fig. 3 to prove the generated hydrographs tally well with the recorded river stage data. Those stations are located in the rural and sub-urban zones. The model is capable of mimicking the real behaviours of the river, and it reflects that the crude ground data used in the zones is thereby agreeable.

Both floods were 100-year return period events coincided with King Tides. During the most recent January 2009 flood, Sarawak River overflowed into the city centre causing traffic jams. The inundations also reflected the effects of high tides on the city. Field observations had photographs of those flooded streets captured. GIS model of the city assists in pinpointing the exact locations in the photographs with known elevations, to which observed flood depths are compared to computer-generated flood levels, as shown in Table 1. The two sets of data bear differences ranged from 0.1 to 0.2, which is tolerable. Some guidelines command strict sensitivity analysis of ±0.1 m between observed and modelled data (Whitlow 1999), while some are moderate at allowing ±0.3048 m (1 ft) (USACE 1993).

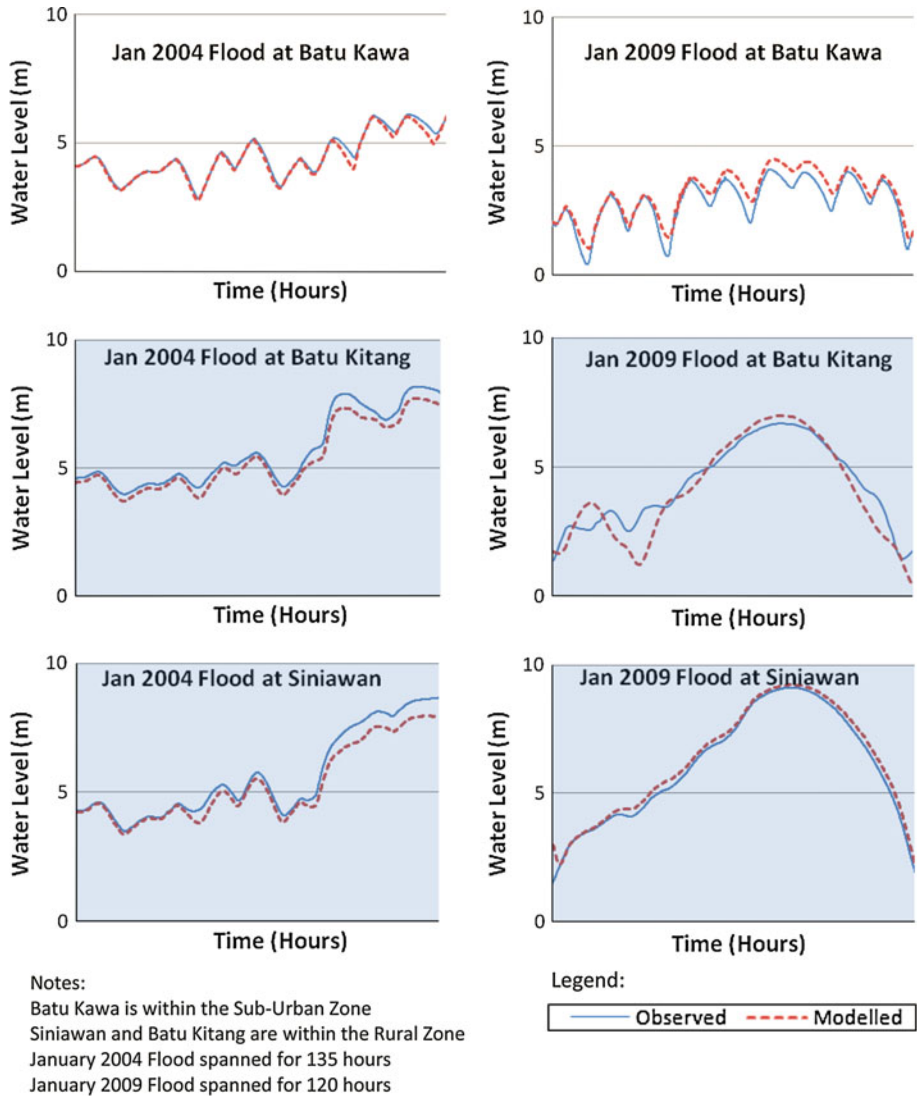

Fig. 3 Sensitivity analysis of January 2004 and January 2009 flood events

The base model carefully calibrates against discharges of one event can be utilized to predict using independent data for the second to include the flood bypass channel, a new barrage and tide levels. Constantly recurring King Tides every 2 weeks in Kuching Bay are worrisome. A King Tide event of February 7–11, 2001 that bears the highest King Tide in recent decade is elected to represent the high water conditions at coastal zone. Hypothetical rise of tide levels are added as a mean to shed some light on the effects of sea level rise. The final outputs of the model are maps showing a prediction of how vulnerable the deltaic region over tidal flooding.

Table 1 Comparison of flood depths

Flooded streets in Kuching City during January 2009 flood event			
Location	Field observation (m)	Modelled depth (m)	Difference (m)
Kuching Water Front[1]	0.6	0.5	0.1
Padungan Road[2]	0.3	0.4	0.1
Central Timur Road[3]	0.6	0.8	0.2
Satok Market[4]	0.3	0.5	0.2

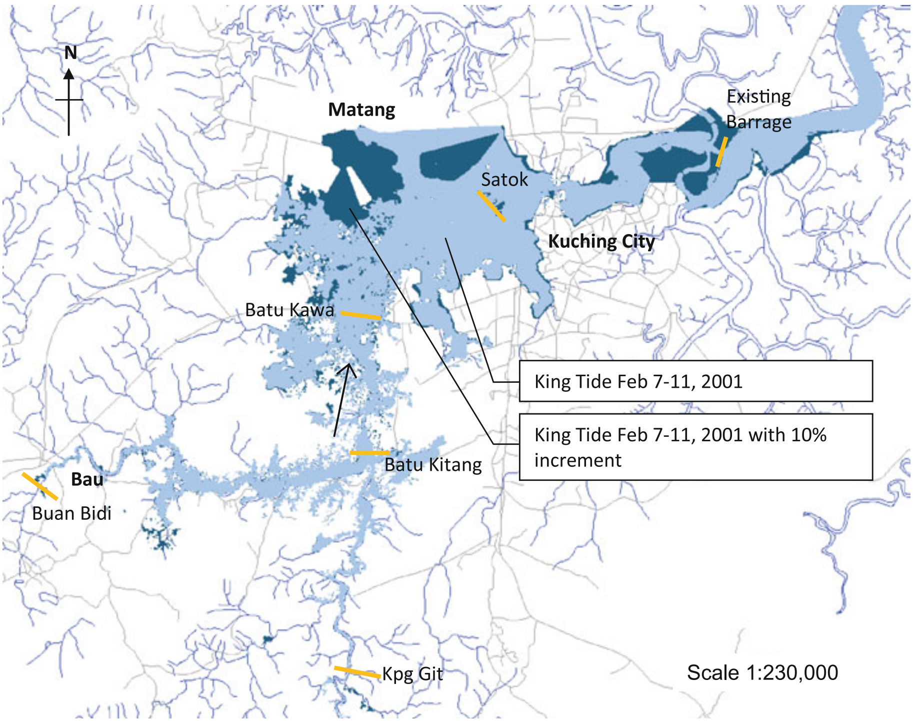

Fig. 4 Peak flood map of King Tide flood in Sarawak River from existing barrage

4 Results and discussion

The modelling results are presented in three scenarios as the following.

4.1 Existing barrage

In this scenario, Kuching Barrage gates are assumed in failure mode (e.g. fully opened) to allow the high tides to flood in Sarawak River, while the upstream flows are remained at average flow. The 5 days 24-h King Tide data of February 2001 are utilized, with a maximum tide level stood at 6.48 m HAT. The same dataset is increased 10% in height to a maximum level of 7.13 m HAT and ran through the model. The resultant flood maps are shown in Fig. 4. The existing barrage would be submerged when tide levels increase.

4.2 Flood bypass channel and existing barrage

The same tide data are applied here. The upstream flow remains unchanged. Modelling assumption here is that the flood gates at the bypass channel would fail. Scenario of sea water gushing in through the bypass channel in Fig. 5 has predicted an increase of flooding in Matang area, but decrease in the city area due to the regulation of Second Barrage. The modelling involves the whole of floodwater would be diverted to Salak River, prohibiting excess water from entering the city by the new barrage. Kuching Barrage is predicted to be flooded by the existing high tide due to backwater effects, which would prove to be a considerable factor in the Lower Sarawak River.

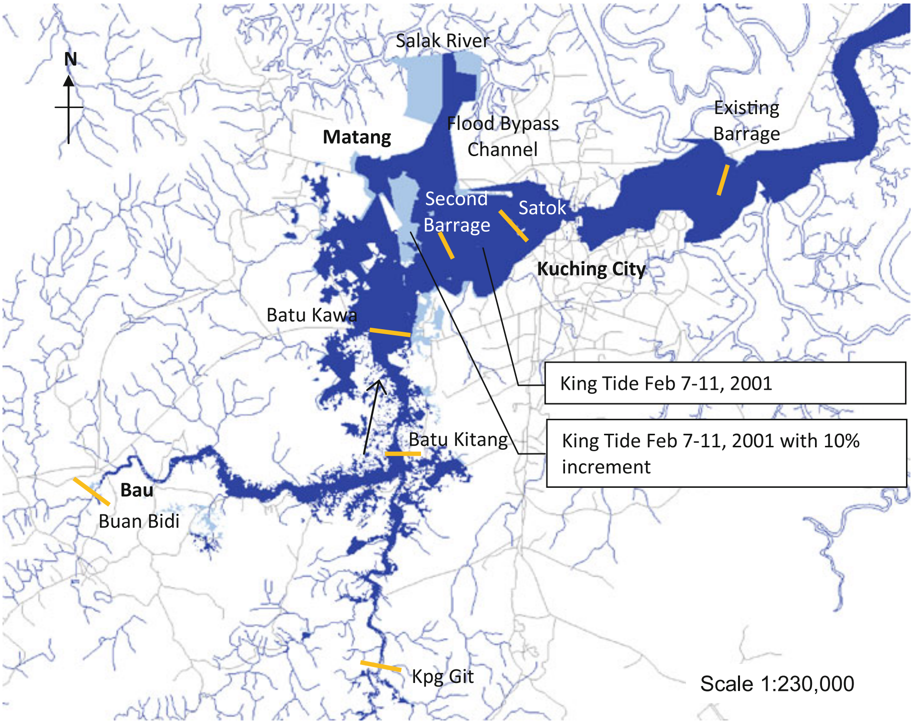

Fig. 5 Peak flood map of King Tide flood in Sarawak River from existing barrage and flood bypass channel

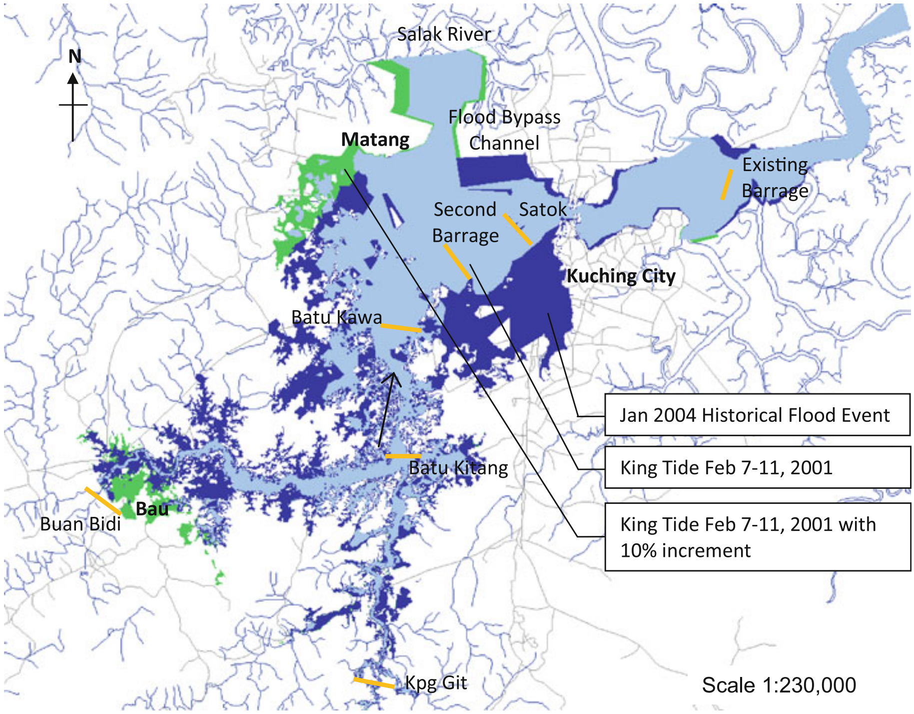

Fig. 6 Peak flood map of upstream flows coincide with King Tides from existing barrage and flood bypass channel

4.3 Upstream flows coincide with tides

This scenario is a more realistic representation of the flooding in Kuching, as historical major floods took place when upstream flows coincided with King Tides. The tide data are the same as of previous two scenarios. However, upstream peak flow of 1,300 m^3/s is routed through the model from the upstream Buan Bidi and Kpg Git catchments. Such flow is in equivalent to a 100-year design flood flow. Prohibiting any flood flow from entering the vicinity of city area is a success as shown in Fig. 6. The city centre is again less flooded compared to the upstream catchments and the imposed January 2004 flood event. Coincidence of floodwaters and tides in Upper Sarawak River-Salak River had predicted extensive flooding in Matang, Batu Kawa, Batu Kitang and the rural Bau town.

A summary of the modelling outcomes is tabulated in Table 2. The January 2004 event is shown among the statistics the least in affected area. High tides would worsen the flooding conditions. Bau town would be tidally affected as previously not and more flooded. The feature highlights that in case of breaching, the flood bypass channel would trigger floodwater congestion in the upstream reaches and substantial bank bursts.

5 Conclusion

Modelling of King Tides and assuming 10% increment of tide levels are presented in this note as a way to visualize the effects of sea level rise on Kuching city, Malaysia. A rise of

Table 2 Modelling outcomes on flooded areas in Sarawak River basin

	Flooded area (km^2)			
	Scenario 4.1 Existing barrage	Scenario 4.2 Flood bypass channel and existing barrage	Scenario 4.3 Upstream flow coincides with King Tide	January 2004 historical event
King Tide	980.63	1013.37	1021.45	926.19
King Tide with 10% increment	991.49	1074.88	1053.61	–
Remarks	+1.10%	+6.07%	+3.14%	–

10% in tide levels is predicted to result in increase of flooding areas up to 6% relative to existing tide levels. The existing barrage is revealed potentially in the brink of submerging that needs immediate counter actions. The upcoming bypass channel is predicted to increase flooded areas to 3–8% higher in Bau areas (upstream catchments) than scenario without a bypass. In short, an initial predictive expression of the future flooding of Kuching is obtained for adaptation planning.

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