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Decadal evolution of a spit in the Baram river mouth in eastern Malaysia

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ABSTRACT

We studied a newly formed spit in the Baram River mouth in Eastern Malaysia and evaluated the effects of climatic conditions and human interference over the last four decades (1974–2014). The development of a spit during a decade (1998–2008) and its maximum expansion over the period 2005–2010 is related to the erosion associated with deforestation and land use changes in the upstream region. The downstream transportation of the heavy sediment load occurred during the events of higher precipitation and flash floods. The recent spit was identified for the first time as a mud flat post the flash flooding of January 2005. It extended towards the south west of the river mouth till 2010 (six fold increase in area from 2005 to 0.29 km^2) and gradually disintegrated over the next 3 years. Depositional feature of coarse sediments and organic debris is clearly supported by the alternating thick layers in the top 25 cm of the three core samples (C1–C3) collected from the region. The non-existence of finer particles clearly indicates the supremacy of long shore currents in the region carrying away the fines to deeper regions. Gradual disappearance of the sand barrier post 2011 is due to the reduction in the amount of sediment load as a result of reduction in recent rainfall activity, land use/land cover changes mainly as reforestation, strengthening of palm plantation (controlling soil erosion in the river banks) in the upstream region. The dominant NW wind direction during the major part of the year is also one of the factors for the shift in depositional sequence and it is helped by the long shore currents which lead to the spit being partially connected to the main land.

1. Introduction

Increasing human impacts on rivers and deltas often have a strong effect on the depositional features in the nearby coastal zones. Different human intervention like building of dams, dredging in river mouth and deforestation in upstream side (causing active erosion) often decreases or increases the amount of sediments reaching the coastal zone (Panin, 1997; Giosan et al., 1999; Ungureanu and Stănică, 2000; Stanica et al., 2007). Coastal sand barrier spits close to river mouth are often extremely dynamic, which involves transport of sediments in both the longshore and cross-shore wave directions with rapid migration rates (Dan et al., 2009; 2011; Jiménez and Sánchez-Arcilla, 2004; Simeoni et al., 2007). The stability, development and evolution of the spits are often based on the amount of sediment input, wave actions in the coastal region and interactions between each process. Based on the various depositional features, the adjoining coastal region will also reflect its nature depending on the transport of sediments during different events (hurricanes or stroms) and through waves and winds. Various studies related to accumulation of sand (Hacker, 1988; Blivi et al., 2002; Medellín et al., 2009), GIS related studies (El-Banna and Frihy, 2009), growth rate of spits (Petersen et al., 2008), sedimentary structures of barrier spit (Costas and FitzGerald, 2011), sediment transport pattern on spit formation (Vinther et al., 2005) and degradation/rapid formation of spits (Aubrey and Gaines, 1982).

The purpose of this article is to report and map a newly formed spit in the Baram River mouth in Eastern Malaysia using field

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observations and satellite imageries. The possible cause for destruction and shifting of the spit is evaluated by studying the meteorological, wind data, satellite imageries of last four decades and core samples from the swampy region of the study area.

2. Study area

The Baram River is one of the major rivers in the Sarawak state in Eastern Malaysia (in Borneo Island) and Miri is one of the major cities located in the downstream side (estuarine part) of the river (Fig. 1a–c). The region is poised for a major industrial growth with various hydroelectric power plants planned in the upstream side of the Baram River. The Baram Hydroelectric Power Plant is one of the twelve major dams proposed in the Sarawak region and the proposed reservoir will cover an area of 40,000 ha. The dam construction in the upstream sides is still in its pilot stage and the proposed dams are of gravity and saddle types, which will be mainly used for hydroelectric power generation. Similarly, both deforestation and re-plantation programs are major activities in the upstream side of the river from early 1980s. In addition to the preliminary construction activities on the banks of the Baram River and its development, the effect is seen in the distribution of sediments in the river bed in the downstream side with high sediment load.

2.1. The Baram river delta setting

The Baram river catchment area covers approximately 22,800 km^2 and discharges an estimated average of 1590 m^3/s of water and 2.4×10^{10} kg/yr of sediment load (Sandal, 1996; Straub and Mohrig, 2009). The Baram delta does not have any distributary and it has a single exit into the South China Sea. Observations from satellite imageries indicate an arcuate shape delta and the crest slopes deeply towards the offshore region. The dynamic delta is an important coastal protrusion and it has various layers of sedimentation. The coastal region has a strong southwest long shore transport and the wave action is also moderately strong (~1 m wave height in nearshore region). The depth profile in the delta region is approximately 4.5–6.5 m towards the tidal spit, and the area is dominated by softer mud in the mouth bar (Lambiase et al., 2002). An earlier facies studies in the Baram delta region indicates rapid deposition and at present the delta is in a phase of destruction due to the ongoing sea level rise during ca. 2000 BP and a large Holocene sea level high stand also peaked during ca. 5400 BP (Caline and Huong, 1992). The waves in the regions are approximately 1 m high and generally the coastal region is a relatively low energy coast. In the river mouth the tides are diurnal and the tidal height varies from 1.7 m during spring and 2.3 m during other seasons (eg. Sandal, 1996).

2.2. Processing of google and satellite images

Identification and evaluation on the formation of the spit in front of Baram river delta was carried out using the available downloadable high resolution images (Figs. 2a–e and 4a) of 1991 (Landsat 5 TM-1991) (a); 2005 (Landsat 5 TM-2005) (b); 2009 (Google Earth Image-2009) (c); 2010 (Google Earth Image-2010) (d); June 2013 (Landsat 8-2013) (e) and December 2014 (Landsat 8 OLI-TIRS) (Fig. 3a). Additionally, the 1974 topo sheet of the region was also used to identify the development and the geomorphological changes in the spit. Landsat TM data was downloaded from the Global Land Cover Facility (GLCF) website and the Landsat 8 image was downloaded from the USGS Glovis website. The coastal landform maps were prepared with the following classifications: (1) Beach, (2) Coastal plain with vegetation, (3) Mud flat, (4) Tidal Flat, (5) Spit, (6) River and (7) Sea respectively. Changes in different landforms were calculated based on the processed maps using ARC GIS software (Nayak et al., 1991; Nayak, 2002; Jayappa et al., 2006). Field visits were undertaken during dry and wet seasons of each year between 2009 and 2012 in order to observe the changes in landforms and obtain the reference points for digitizing the imageries. The field visits were compared with the satellite imageries in order to demarcate the sites of sand accumulation and evaluate the spit formation in the river mouth.

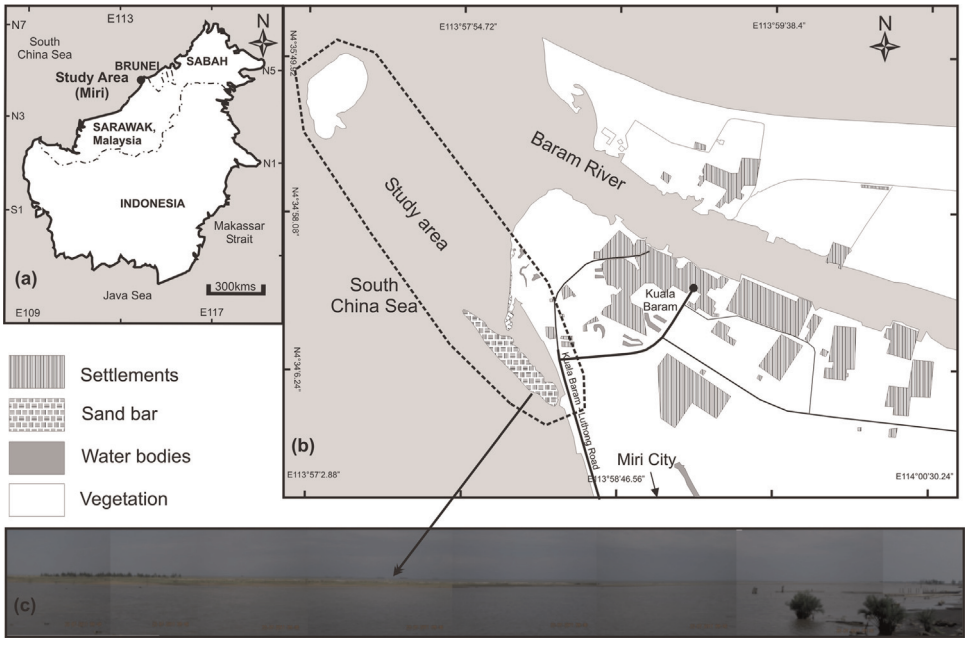

Fig. 1. (a and b) Study area map of Baram River region and spit structure in Sarawak, Eastern Malaysia. (c) A continuous camera shot of sand bar and spit formation in the southern part of the Baram River dominated by some coastal vegetation. The dotted circle area is being used for calculating the changes in spit formation.