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Relationships between discharge parameters and cross-sectional channel dimensions of rivers in an active margin influenced by tropical climate: The case of modern fluvial systems in the Indonesian islands

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ABSTRACT

The present study investigates (1) the relationships between discharge parameters and bankfull channel width (W_b) based on statistical analyses of hydrological data obtained from 649 sites at rivers on the Indonesian islands of Java, Sumatra, and Kalimantan, and (2) the relationship between depth parameters and W_b using channel cross sections obtained from 86 sites at rivers on these three large islands. These analyses are used to describe geomorphological and hydrological features of fluvial systems developed in a convergent margin under the influence of a low-latitude tropical climate. The relationship between mean discharge (Q_{mean}) and W_b shows distinct variation within the Indonesian rivers, and reflects regional variations in annual rainfall of a tropical climate. The relationship between bankfull discharge (Q_b) and W_b shows only minor variations across the three islands, regardless of bed and bank material types. The Q_b–W_b relationship in the Indonesian rivers has a pattern similar to that of fluvial systems in Europe and the North American continent, which are influenced by mid- and high-latitude climates. Minor regional variation in the Q_b–W_b relationship, regardless of the tectonic and climatic settings, suggests that the development of fluvial morphology is controlled mainly by flood-related episodic discharge. In contrast, the empirical equations between maximum channel depth (d_b) and W_b and between mean channel depth (d_m) and W_b show distinct regional variations not only within the Indonesian fluvial systems but also in fluvial systems of Europe and the North American continent. These regional variations are thought to reflect the fact that d_b–W_b and d_m–W_b relationships are controlled by the tectonic and climatic settings of a drainage basin, and factors such as the interrelationships between precipitation, vegetation, and slope. Consequently, selection of an appropriate d_m–W_b (or d_b–W_b) equation combined with an appropriate Q_b–W_b equation permits us to reconstruct spatial and temporal variations in hydrological features in both modern and ancient fluvial systems more precisely than applying previously proposed equations to fluvial systems formed in active margin and low-latitude climatic settings.

1. Introduction

Empirical equations between hydrological parameters, such as bankfull channel depth and width, annual mean and bankfull water discharges, have been developed for modern fluvial systems (e.g., Leopold and Maddock, 1953; Leeder, 1973; Ethridge and Schumm, 1978; Osterkamp and Hedman, 1982; Williams, 1984a, 1984b, 1986; Shibata and Ito, 2014). These equations have been used to reconstruct paleohydrological features of ancient fluvial systems together with variations in paleocurrent directions and sinuosity based on analyses of outcrops, cores, and log data of fluvial successions (e.g., Van der Neut and Eriksson, 1999; Bridge and Tye, 2000; Bridge, 2003; Adams and Bhattacharya, 2005; Ito et al., 2006; McLaurin and Steel, 2007; Hampson et al., 2013; Holbrook and Wanas, 2014).

These empirical equations have been established based on hydrological data from modern fluvial systems mainly on passive continental margin and continental-interior settings that are influenced by a temperate climate (e.g., Leopold and Maddock, 1953; Carlston, 1965; Leeder, 1973; Dury, 1976; Ethridge and Schumm, 1978; Osterkamp and Hedman, 1982; Williams, 1984a, 1986). Consequently, a better understanding of variations in hydrological parameters in fluvial systems requires the establishment of empirical equations for different tectonic

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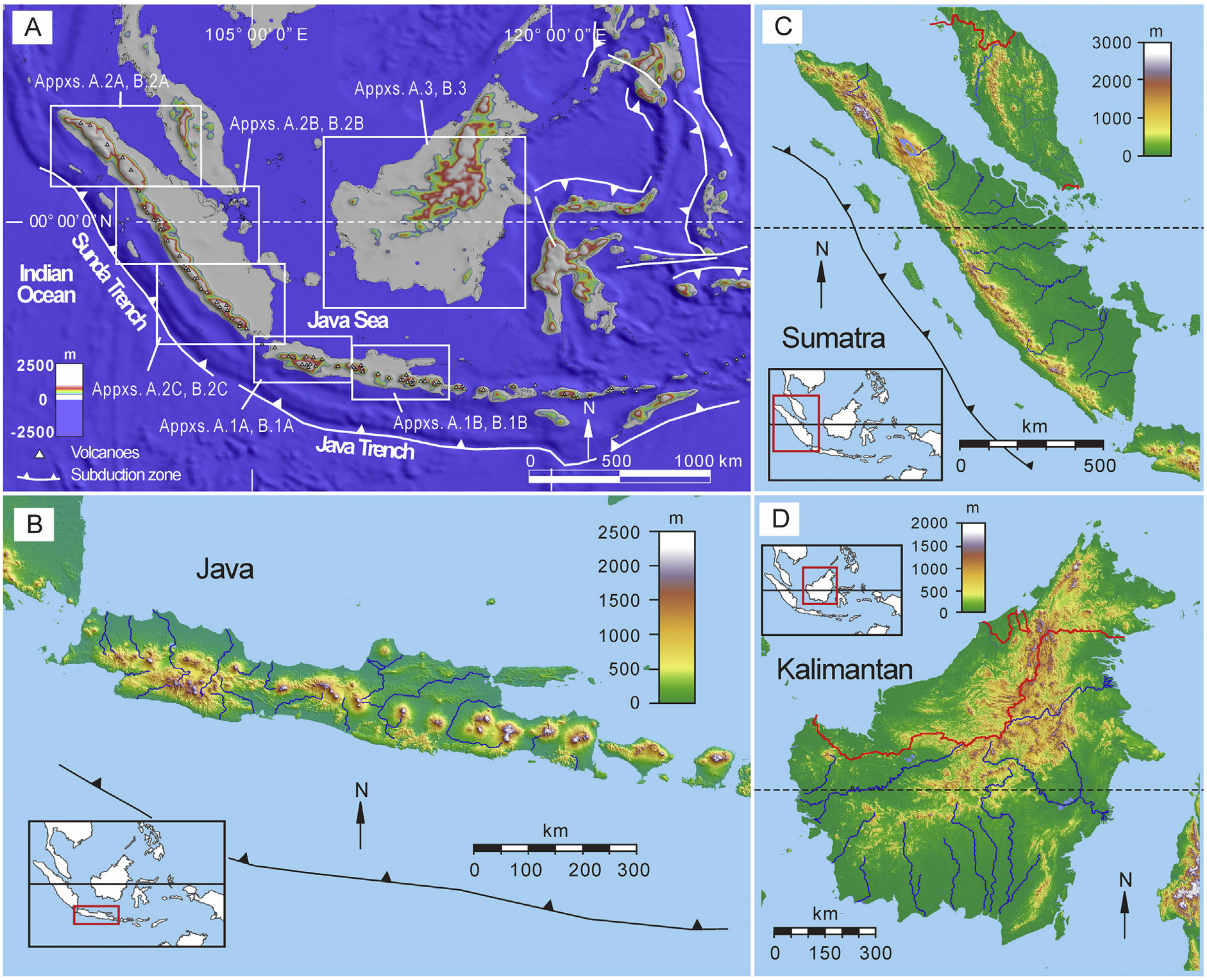

Fig. 1. The tectonic and geomorphological settings of the Indonesian islands. (A) A plate-tectonic framework of the Indonesian islands. Simplified from Hall (1997). Rectangles show locations used for the collection of hydrological and geomorphological data. (B) Hypsometric distribution of Java. (C) Hypsometric distribution of Sumatra. (D) Hypsometric distribution of Kalimantan. Figs. B, C and D are simplified from wikimedia.org (2007), and inset maps show the locations of the islands in the Indonesian archipelago.

and climatic settings (Shibata and Ito, 2014; Shibata et al., 2018). This enables us to understand spatial and temporal variations better in the paleohydrological features documented in ancient fluvial successions, and how these are related to global environmental change and the tectonic setting of sedimentary basins.

Hydrological equations have not yet been developed for active-margin settings influenced by low-latitude and equatorial climates with thick vegetation, intense rainfalls, and active sediment yield (Sinha et al., 2012; Syvitski et al., 2014), although hydrological parameters have been analyzed in modern fluvial systems in the Pacific coast of the U.S.A., which is represented also by convergent margin tectonics (e.g., Castro and Jackson, 2001; Modrick and Georgakakos, 2014). These equations are a crucial step for identifying similarities and differences in the hydrological and geomorphological parameters of fluvial systems formed in different tectonic and climatic settings.

The present study develops empirical equations for hydrological and geomorphological parameters in modern fluvial systems in the three main islands (i.e., Java, Sumatra, and Kalimantan) of the Indonesian archipelago (Fig. 1 and Appendices A–C), where these hydrological analyses have yet to be attempted. These equations are established based on relationships between mean and bankfull discharge, bankfull channel width, and mean and maximum bankfull depth. Although the bankfull channel width and mean and maximum bankfull channel depth have also been analyzed as a function of drainage area (e.g., Dunne and Leopold, 1978; Wohl et al., 2004; Modrick and Georgakakos, 2014), this study mainly analyzed the relationships between bankfull width and depth data and discharge data. The analyzed relationships were compared with some empirical equations proposed by the previous studies, which have been used to reconstruct paleohydrological features of ancient fluvial successions. The results provide a case study for modern fluvial systems developed in an active low-latitude convergent margin setting under the influence of a tropical climate.

2. Geomorphological and climatic setting

Indonesia is an archipelagic nation with more than 18,000 component islands, including 5 large islands: Sumatra, Java, Kalimantan (Borneo), Sulawesi (Celebes), and West Papua. The present study focuses on fluvial systems in the three largest islands: Sumatra, Java, and Kalimantan. The Indonesian archipelago spans the equator from latitudes 6°N to 11°S (Fig. 1A). It is characterized by mountain ranges and plateaus with volcanoes in Sumatra and Java and Paleogene and older sedimentary, volcanic, and metamorphic rocks in Kalimantan. The volcanic ranges form the Sumatra–Banda arc, and extend nearly 7,000 km along the archipelago from the northwest to southeast.

The Sumatra and Java islands are situated in front of the Sunda–Java arc subduction zone (Fig. 1A), and are characterized by active deformation processes including intense seismicity, active faulting, and relatively higher rates of tectonic uplift (e.g.,