Aceh International Journal of Science and Technology
ISSN: 2088-9860
Journal homepage: http://jurnal.unsyiah.ac.id/aijst

The Spatial Distribution of Bed Sediment on Fluvial System: A Mini Review of the Aceh Meandering River

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Received : 2 August 2016
Accepted : 28 August 2016
Online : 31 August2016

Abstract - Dynamic interactions of hydrological and geomorphological processes in the fluvial system result in accumulated deposit on the bed because the capacity to carry sediment has been exceeded. The bed load of the Aceh fluvial system is primarily generated by mechanical weathering resulting in boulders, pebbles, and sand, which roll or bounce along the river bed forming temporary deposits as bars on the insides of meander bends, as a result of a loss of transport energy in the system. This dynamic controls the style and range of deposits in the Aceh River. This study focuses on the spatial distribution of bed-load transport of the Aceh River. Understanding the spatial distribution of deposits facilitates the reconstruction of the changes in controlling factors during accumulation of deposits. One of the methods can be done by sieve analysis of sediment, where the method illuminates the distribution of sediment changes associate with channel morphology under different flow regimes. Hence, the purpose of this mini review is to investigate how the sediment along the river meander spatially dispersed. The results demonstrate that channel deposits in the Aceh River are formed from four different type of materials: pebble deposited along upstream left bank; sand located on the upstream, downstream, and along meander belts; and silt and clay located along the cut bank of meander bends. Because of different depositional pattern, the distribution of the sediment along the river can be used as a surrogate to identify bank stability, as well as to predict critical geometry for meander bend initiation.

Keywords: Fluvial system; Meander river; Bed-load; Bank stability; Channel morphology

Introduction

Rivers play important roles to human life not only providing fresh water but also offering navigation and flood controlled sources. Throughout the time, rivers have been changed the shaped and flow as a consequence of erosion and sedimentation. The dynamic of the river hydrology, either natural factor or anthropogenic activities, contribute to these geomorphological changes. The connection between the dynamic of the rivers and the geomorphological changes have attracted scientists and researchers to study the trend and response of the meander channel especially when it is linked to sediment transport.

The interactions between hydrologic and geomorphologic processes in the river, especially for sediment deposition, are fundamental to the development of a fluvial landscape because of its geomorphological characteristics. The processes of weathering, erosion, and deposition are dependent on the movement of water through a complex system of a landscape including soil and vegetation development. This landscape of river controls the divergence and convergence of flow paths. However, how the dynamic processes control the physical characteristic in Aceh River, such as bed load deposition that define a fluvial system still have limited understanding. Therefore, the purpose of this review is to study how the sediment along the river meander distributes. This will show how the meander channel is dynamic by looking at erosion and deposition patterns spatially under different flow regimes.

Aceh Fluvial System

The Aceh fluvial system flows from its headwater in Bukit Barisan Mountains to the mouth at the Indian Ocean and Malacca Strait (Figure 1). The dynamic parts of the Aceh River vary in space and time in response to tropical system climatic changes, geologic changes, and to man's activities. This is because of seasonal and annual changes in precipitation and temperature, cycles of erosion and deposition (especially during floods), diversion of water (for irrigation, power, and other purposes), and the construction of public works such as dams, levees, locks, and canals (Nelson *et al.*, 2003). These changes have also altered the average flow of the Aceh River from year to year.

The flow regime of Aceh River has resulted from the changes of landscape, which control the flow regime, soil, and vegetation development. This flow also changes river morphology as consequence of alterations to the sediment supply within a drainage basin. This drainage basin is a complex environmental system where all the processes depend on the interaction between hydrologic and geomorphologic processes and development in the river system especially for sediment transport (Beven, 1996). These processes have been long studied by researchers (Walling 2006; Corenblit *et al.*, 2007; Murray *et al.*, 2008; Lee *et al.*, 2010); however, there is still limited understanding what is the spatial patterns of erosion, deposition, and transportation on the bottom channel of the Aceh River meander.

Water flow and sediment deposition are simultaneous and interactive processes in rivers, floodplains, and coastal areas (Pederson *et al.*, 2014). Predicting the response of the meander channel either naturally or man-mad to impose the water and sediment supply is very challenging problem addressed by geomorphologists. They are trying to understand why channel has a certain general form and how specific channel evolved in response to alter water and sediment supplies to the channel (Davidson *et al.*, 2013). In the river, the interaction among these processes will result in aggradation and degradation in channels, deterioration of water quality and fisheries among other environmental effects, and many other forms of ecological disturbance. The disturbance is complex because of uneven and changing bottom topography, irregular boundaries, rapid and strong erosion with abrupt bed, flow variation, and uncertain flow of sediment transport mechanism (Li and Duffy, 2011).

In general, the flow field, the movement of sediment making up the bed, and morphology of the bed are intricately linked. The flow in the channel moves the sediment, the bed is altered by erosion and deposition of sediment, and the shape of the bed is critically important for predicting the flow characteristic (Nelson *et al.*, 2003). These complex linkages in forming and processing channel morphology have been long studied by geomorphologists. Hence, by understanding the interaction of the flow field and sediment deposition in the channel and the geometry of the channel bed and bank, the local details characteristic of velocity, depth profile and sediment distribution can be predicted. Therefore, several studies have been conducted to address the problems. The studies can be accomplished by direct field investigation, laboratory experiments or physical and mathematical modeling.

In Aceh River, geomorphological processes depend on the hydrological processes with all its complications of dynamic surface and subsurface contributing areas that are forced by an unpredictable sequence of events of different magnitude (Beven, 1996). Study about the dynamic of channel flow and sediment transport have been done by researchers (Bridge 1992; Howard, 1994; Liu *et al.*, 2002; Schwartz, 2003; Vasquez, 2005; Wu, 2007). Generally their research is able to handle the cases in certain area by using their own characteristic data.

In numerical modeling technique, most of the models used in river engineering are one dimensional; especially those used for long-term simulation of a long river reach because it is most stable and required less computational time and least amount of field data for testing and calibrating. Under the condition where the disturbance on meander channel is complex, the one dimensional model is generally not sufficient (Li and Duffy, 2011). However, for simulating the effects of curvature, channel width and multiple reaches or other local phenomena, the two dimensional model can be suitable to answer the above questions. Some papers have suggested that two-dimensional flow models should offer significant improvement over one-dimensional modeling in determining sediment transport as a function of flow (Merwade, 2004). Because two-dimensional model results are spatially explicit and can be mapped, they are ideally suited for computation of landscape changes.

In this study, direct field investigation and laboratory analysis is applied. The result from this study will provide the basis for understanding the hydrodynamic and geomorphic condition in river meander environment. Furthermore, the result can also be used to provide solutions to existing problems and to simulate future issues before they occur.

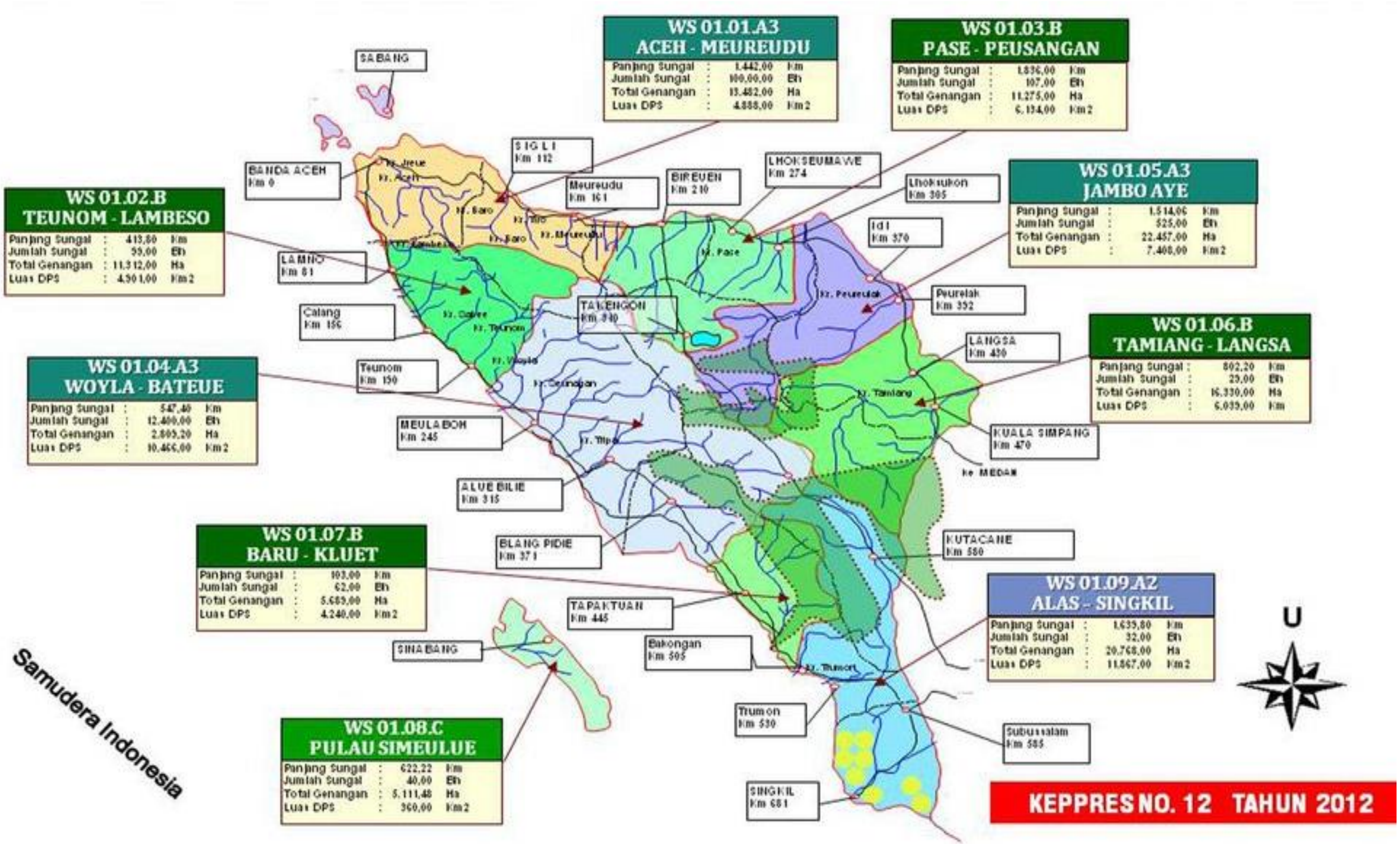

Figure 1. Map of Aceh River that flows from Bukit Barisan Mountains to Indian Ocean and Malacca Strait (http://loketpeta.pu.go.id/wilayah-sungai-provinsi-aceh)

Sieve and Spatial Analysis

The development of methods suitable for the collection of sediment data that contribute to understanding these processes is a still-evolving science because sediment erosion, transport, and deposition in fluvial systems are complex processes. Sediment data are fundamental requirements for the proper management of river systems, including the design of structures, the determination of aspects of stream characteristics and processes, ascertaining the probable effect of removing an existing structure, estimation of bulk erosion, transport, and sediment delivery to the to the oceans, ascertaining the long-term usefulness of reservoirs and other public works, tracking movement of solid-phase contaminants, restoration of degraded or otherwise modified streams, and assistance in the calibration and validation of numerical models (Hareland, 1994; Lee *et al*, 2010; Corenblit,2007; Wu *et al*., 2007).

For certain phenomena, knowledge of some other single sediment parameter may be adequate. However, for other cases, knowledge of the entire size distribution, and especially of its tails, may be essential (Konert and Vandenberghe, 1997). For example, channel grain roughness is typically associated with the coarser sizes of the bed material, e.g., D_{90}, whereas for spawning habitat studies the size of the finer portions, e.g., D_{10}, is more critical (Lee *et al*., 2010). Because bed-material load is that part of the total load that is composed of particle sizes present in appreciable quantities in the shifting portions of the streambed, the analysis of the sampled material should render an unbiased grain-size distribution (Kwan, 2009), such as that typically provided from a volumetric sample analyzed in terms of weight through the use of a series of sieves. It is required to determine various sediment sizes with a certain accuracy or degree of precision (Konert and Vandenberghe, 1997). For this purpose, the sieve analysis method will be used. This method is used for coarse-grained soils and is the most direct method for determining particle size. The weight of material retained on each sieve is converted to a percentage of the total sample. The resulting data are presented as a particle-size distribution curve plotted on bar chart coordinates.

For further study the spatial analysis is used. This analysis is applied to explain pattern and geographically distributed in relation to other features in terms of geometry; that is locational analysis. On this case, the spatial analysis method is focused on bed load distribution and its properties to channel morphology because the aim of this spatial analysis is to recognize and understand patterns and regularities.

Result Review and Discussion

To review the preliminary result, some samples have been taken in the field to test the characteristic of bed load. The sample was taken in three locations (left bank, river center, and right bank) across the rivers along the meandering curve. The preliminary result can be seen in Figure 2 by applying the sieve analysis method. In this figure, the groups of bed sediment were divided into four groups; gravel (very course sand and course sand, sand (medium sand, fine sand, and very fine sand), silk, and clay based on Wentworth classification of sediment. The figure shows that in the center of river, sand gradually accumulates as the flow starts to drift the heavy sediment when it passes the curve of the river bank. It shows that the flow accelerates progressively after it leaves the curve bank. On the other hand, the distribution silk and mud gathers as flow hits the river left bank (cut bank). The buildup of very fine sediment along the cut bank area because of strong transport current that create deposition of sediment on the right bank after passing the cut bank area.

The very course and course sediment is distributed more along the upstream of meander channel on the left and gradually decrease downstream bend. Meanwhile, sand is unevenly dispersed along meander belt of the river. A very light sediment such as silt and clay much exist along the cut bank of meander bends. This depositional patter occurs because of stream flow react differently as it faces different feature of river morphology.

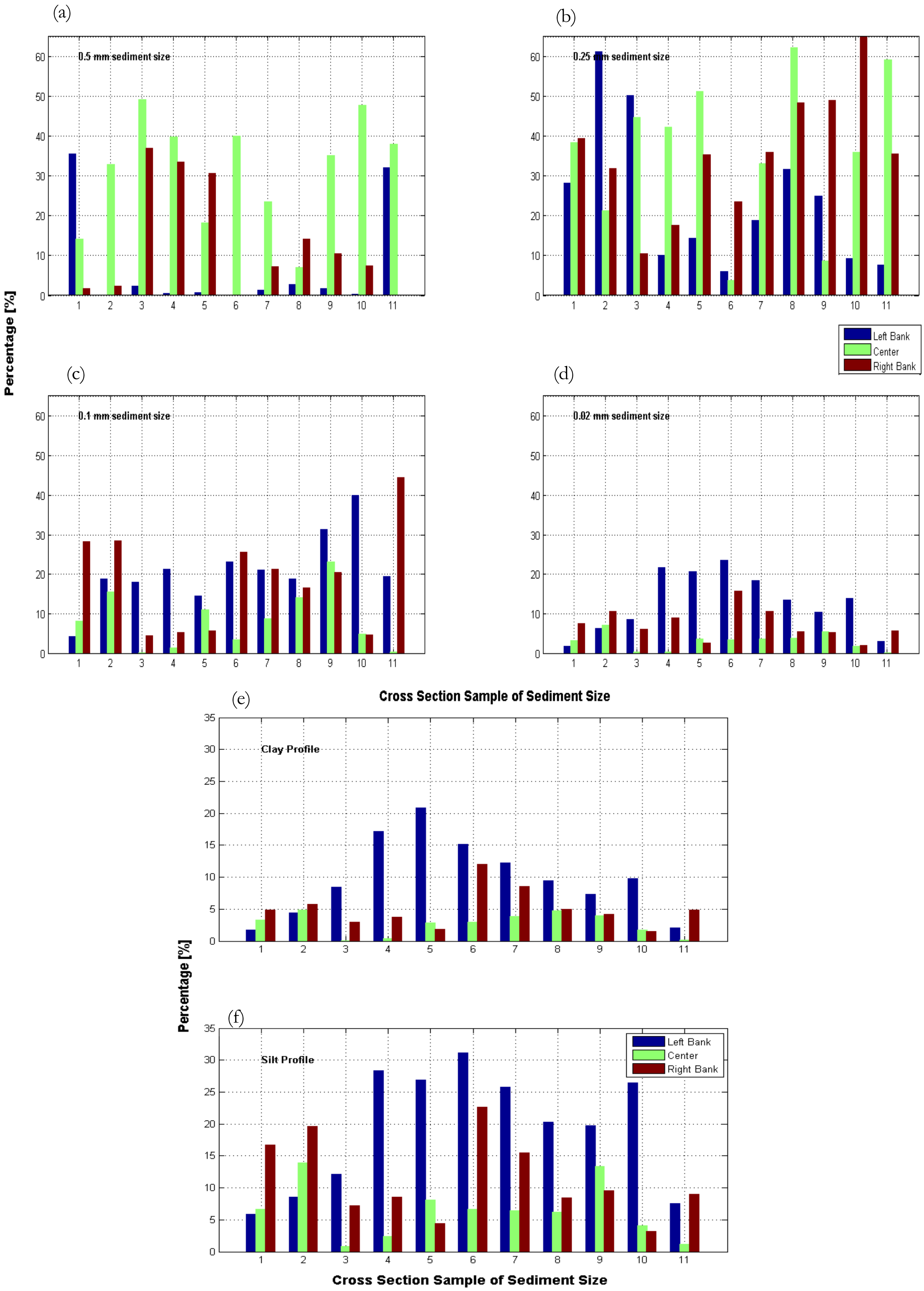

Figure 2. The bar graph of sediment profile along the river from sand, pebble, silt, and clay. This sediment was taken from upstream (left of the graph) to down-stream (right of the graph) of the river in three locations: left, center, and right bank of Aceh River. In this figure the notation in each graph represent the sediment profile distribution of: (a) course sand, (b) medium size sand, (c) fine sand, (d) very fine sand, (e) clay, and (f) silk

Conclusions

In this review, it concludes that meandering bank channel reach has greater morphological variability spatially because of flow regime and channel morphology of Aceh River. It can be seen that none of bed-loads are well distributed along the river bank because of the flow transport acts differently as it moves in different feature of channel. The study is implementing to Aceh River, where subsequent sediment deposition and channel closure in this area could possibly reduce sedimentation and lead to depletion of stream flow. Mostly the Aceh River is formed of igneous and metamorphic rocks that consist of alluvial red clay, silt, and sand. Therefore, the method employed is important if we want to study the characteristic local details of velocity, depth profile and sediment distribution. Furthermore, the continued research should be conducted in this area which provide a detailed understanding of morphology processes associated with flow regime and sediment formation, development and function in the Aceh River environment. For further purpose, the study can be used for engineering and geomorphology to study the river contaminant transport, evaluate fish habitat, and guide river training and diversion works.

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