MEANDERING CHARACTERISTICS OF CIMANUK RIVER FOCUSING ON ASPECT RATIO VARIATIONS AND GEOLOGICAL CONDITION

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ABSTRACT

Forming mechanism of meandering river is diverse and complex. Investigation of cross-sectional aspect ratio (width to depth ratio) and its variation could help to comprehend such mechanism. Cimanuk River as one of main rivers in West Java, Indonesia, was selected as main focus to study the relationship between meandering parameters and cross-sectional aspect ratio. The river has an interesting characteristic that could explain several possibilities of meandering processes. The results have shown that meandering mechanism in Cimanuk River might be affected by less variation of cross-sectional aspect ratio in the flow direction, but still has moderate to high sinuosity. Several curving reaches exist in meandering plain, but have less changing channel centerline for the past 10 years. Other meandering rivers, however, have large variation of aspect ratio that is closely related to the river widening caused by bank erosions. Geologically, meandering plain in Cimanuk River might be formed around subduction zone in the northern part of Java Island. Deposition and sedimentation process are dominant in this plain. A wider coastal deposition area could also be found in this region. In such a low and flat area, sand as bed material presents as a result from the volcanism and river sedimentation process. In some curving reaches, sand bars were found, but it has less impact to planform change because of stable bank that is composed of fine material. Meandering processes in the lower reaches of Cimanuk River might be less active due to the lack of coarser material. In other unstable meandering rivers, fine or medium gravel are contained, and gravel bar can be formed in wider channel where the aspect ratio is more than 25.

Keywords: Meandering River, Aspect Ratio, Sinuosity, Sediment, Geology

1. INTRODUCTION

Complexity of meandering river mechanism has been studied based on several approaches. Understanding aspect ratio as representative value of cross-sectional shape has been introduced in past studies to classify meandering type. Soar and Thorne (2001) revealed marked similarities between three of the most common types of meander bend found in stable single-thread channels by close examination of the broad categories in these schemes (Schumm, 1963,1977; Brice, 1975, 1984; Rosgen, 1994, 1996). The classification could be described as shown in Figure 1.

Following the categorization in Figure 1, Cimanuk River could be categorized as a "Meandering with Point Bars" river. This type refers to the channels that are generally characterized by intermediate width/depth ratio, moderately erosion resistant banks, medium grained bed material (sand or gravel), medium bed material load, medium velocities and medium stream power. Furthermore, the channel migration rate is likely to be moderate unless banks are stabilized.

The soil erosion rates to this river seems to be high due to high precipitation rates during rainy season combined with a large catchment area. The average annual rainfall is around 2,800 mm, with a monthly average river discharge varies from 21 m^3/s in the dry season (August) to about 230 m^3/s during rainy season (February). This river discharge fluctuates seasonally. At the lower reaches, the 25-year return period of a design flood was said to be about 870 m^3/s. The river catchment area is around 3,584 km^2, flowing northward into Java Sea near Indramayu city area. The river total length is approximately 240 km with gradient 1/150 to 1/500 in upper reaches, 1/2,000 to 1/3,000 in middle reaches and less than 1/5,000 in lower reaches.

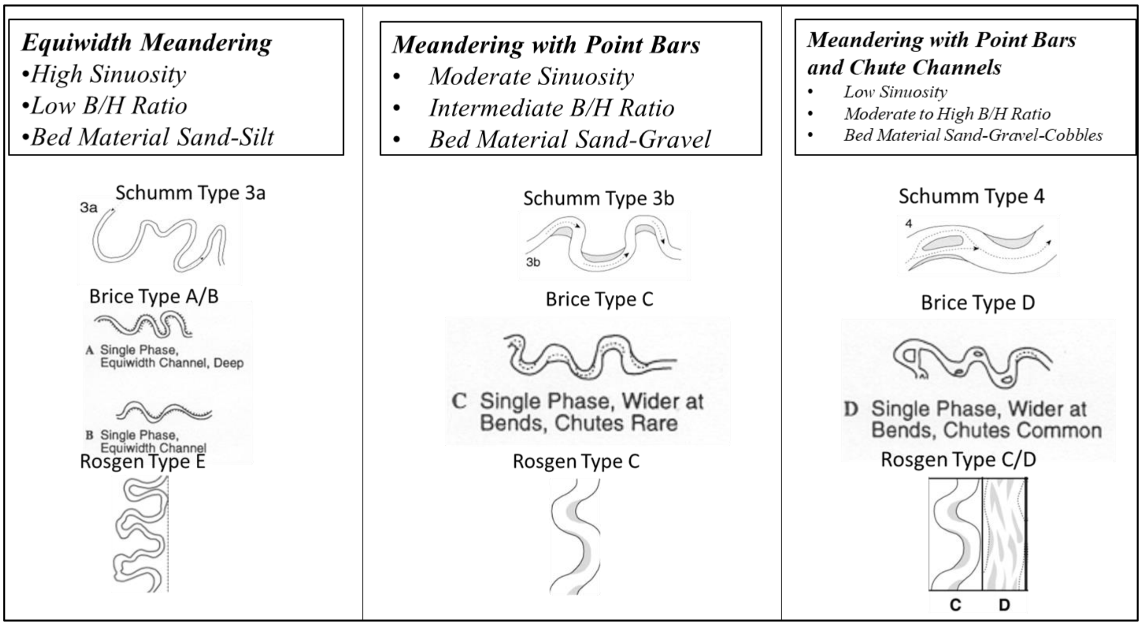


Figure 1. Meandering River Classification for Stable Single-Thread Channels
(modified from Soar and Thorne, 2001)

High rates of soil erosion in the catchment by heavy rainfall occur during rainy season. In accordance with the study report on Geo-Technical Investigation And Test for Rentang Irrigation Modernization Project (JICA Report, 2011), high sediment load was confirmed in the river with mean annual sediment yield rate at approximately 25 million tons that is equivalent to 5.3 mm/year. This condition is defined as rather critical to very critical areas from the viewpoint of erosion potential.

A soil investigation study in the Cimanuk River Basin (JICA Report, 2015) showed that major soils in the basin are latosol, regosol and alluvial. Typical soils distributed in each sub-basin are summarized below.

a) Upper basin: Regosol 32% (Clayey loam to sandy loam), Latosol 25% (heavy clay) and Andosol 17% (clay)

b) Middle basin: Latosol, 70 % (heavy clay) and Alluvial (sandy loam, loam and clay)

c) Lower basin: Gley 78%, (clay) Alluvial 18 %, (sandy loam, loam and clay) Mediterranean and Podzolic.

River sedimentation coastal area deposit seems to be dominant, as shown in the geological map in Figure 2. In the upstream part, volcanism deposition and subduction zone might also influence the sedimentation of the whole basin.

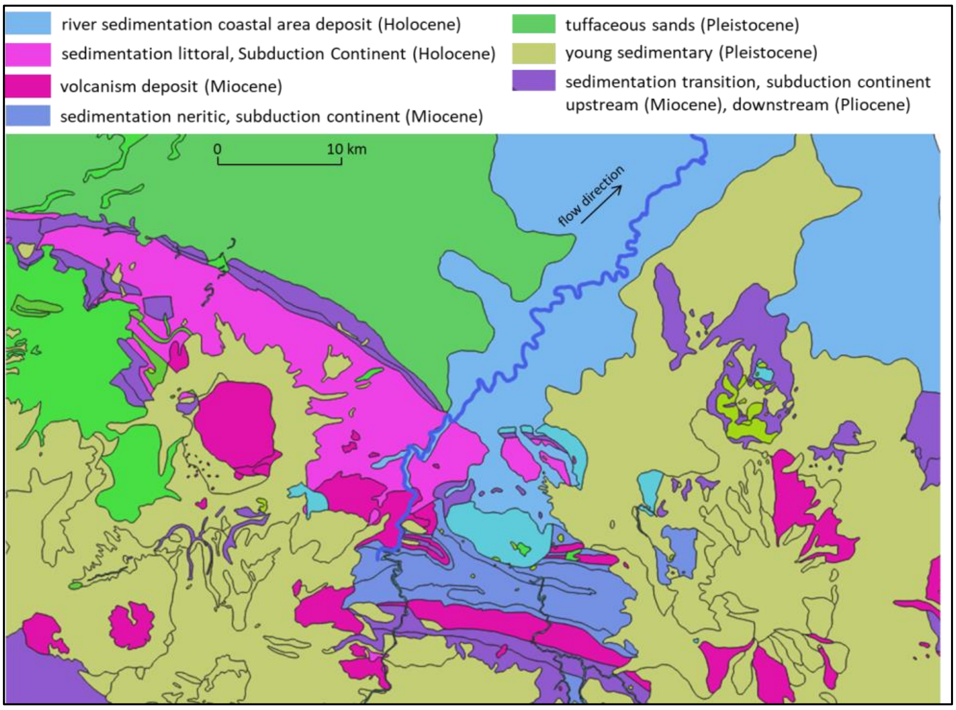


Figure 2. Geological Map of Cimanuk River
(Data Source: Indonesian Regional Geological Map, Indonesian Geology Research Center)

The condition described above could shows that the sediment dynamics in Cimanuk River are considered to be very active and the existence of bars can prove the dynamics. Several curving reaches exist in the meandering plain as is shown in Figure 3, however as shown in the figure, the river channel of Cimanuk River has less changing centerline for the past 10 years based on satellite imagery observation despite no hard bank protection. This phenomenon seems to be different from “Meandering with Point Bars” in Figure1. In order to understand the characteristics, detail conditions were analyzed and compared with other rivers.

Figure 3. Cimanuk River Curving Reaches

2. TARGET AREA AND METHODOLOGY

2.1 Data Collection

Study area for this study is located in the lower reach of Cimanuk River: from Rentang Barrage to Rambatan Weir (Figure 4) which is around 56 km length and riverbed slope around 1/8000 – 1/10.000. 20 cross sections were analyzed to obtain the aspect ratio information. Other river data have also been collected for the comparison. Those data are from several countries such as Japan (Iruma River, Oppe River, Old Ara River, Kano River and Watarase River), Cambodia (Sangkae River) and Indonesia (Ciliwung River). Old Ara River is the oxbow lake adjacent to the current Ara River.

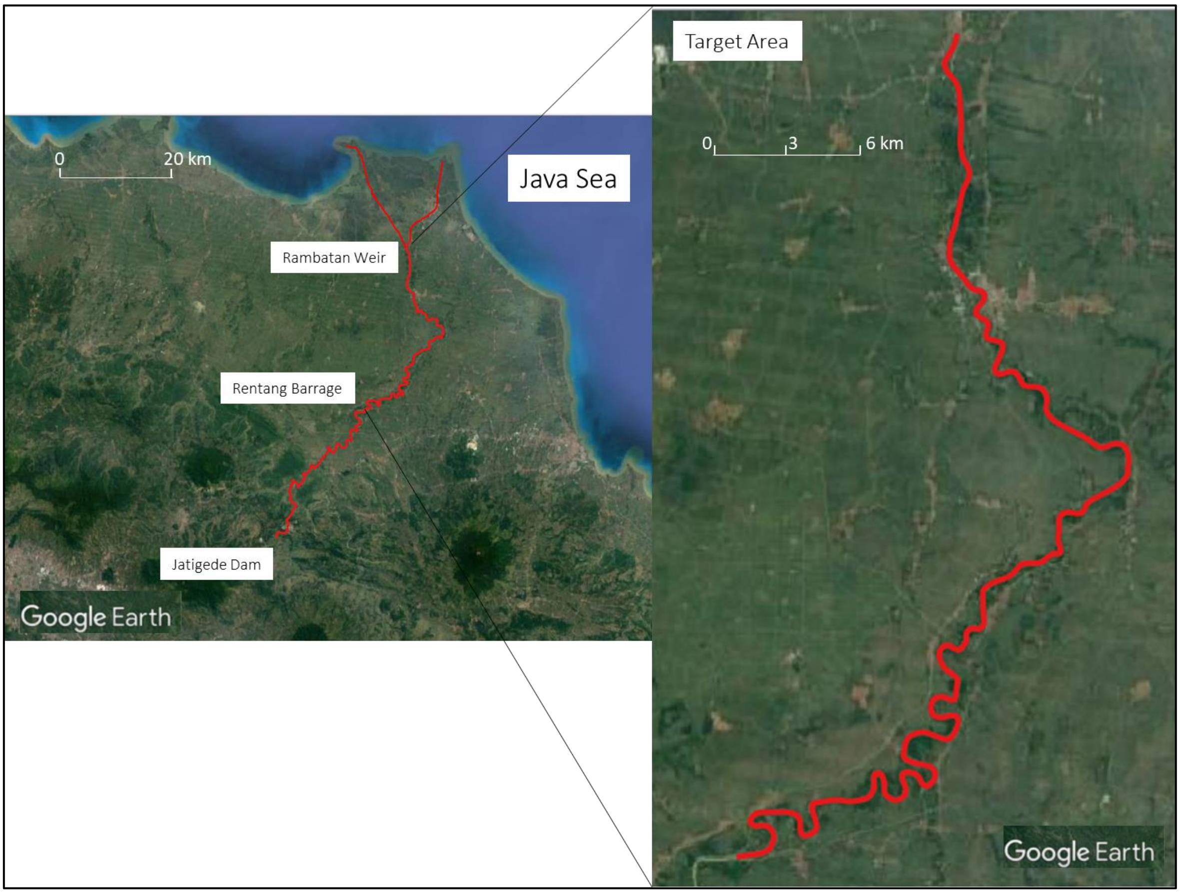
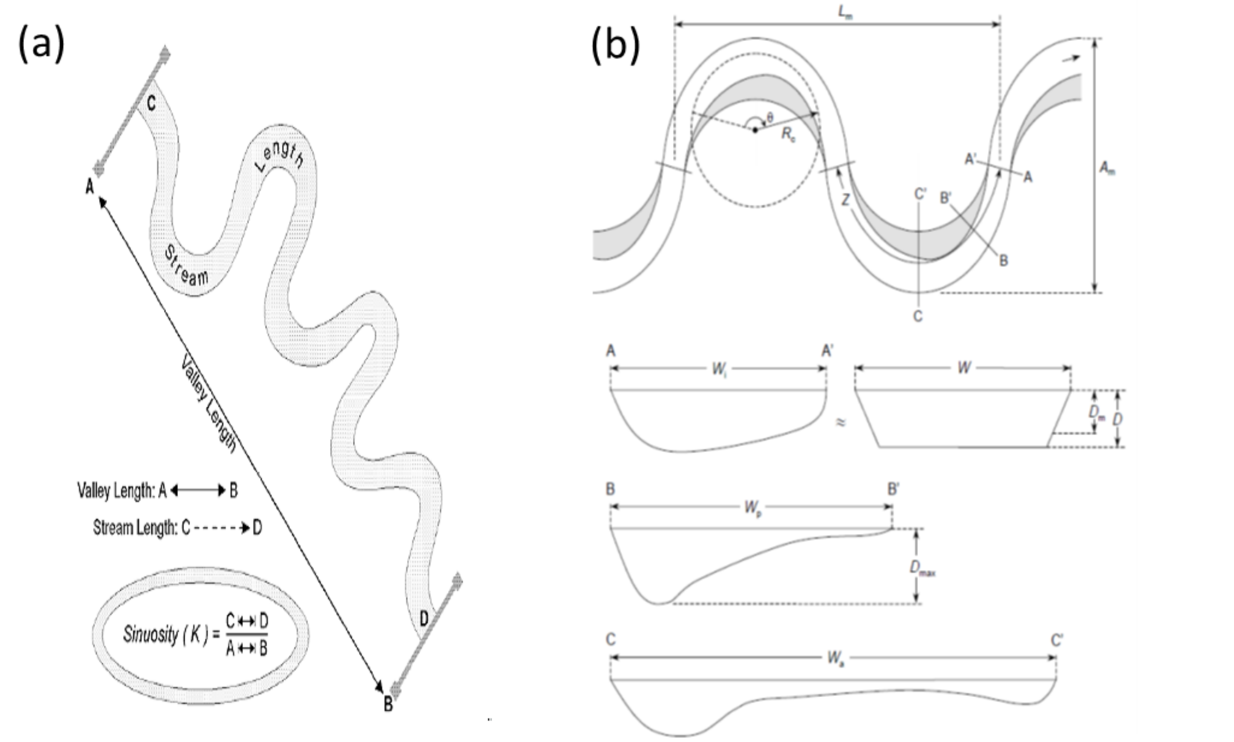


Figure 4. Cimanuk River and Target Area

2.2 Data Analysis

Schumm (1963) stated that sinuous streams on the Great Plains are characterized by relatively narrow and deep channels (low aspect ratio value), and the higher percentage of silt-clay ratio formed the perimeter of the channel. Sinuosity is defined as stream length divided by valley length (Rosgen, 1996) and it is calculated for each 3km along the river valley. Based on the classification by Rosgen (1994), river course is considered as low sinuosity if the value is lower than 1.2. A value between 1.2 – 1.5 is considered moderate sinuosity, while river with sinuosity value more than 1.5 is categorized as high sinuosity. Additionally, Rosgen (1994) divided a single thread channel into several categories based on the aspect ratio, low value (less than 12) and high value (more than 40). On the other hand, Church and Rood (1983) explained that 50 percent of distribution from cumulative frequency of aspect ratio is about 25. In this study, an aspect ratio of 25 will be considered as intermediate value of aspect ratio. Based on this condition, the aspect ratio will be classified into four categories: Low Aspect Ratio (<12), Low-Moderate (≥ 12 - < 25), Moderate – High (≥ 25 - < 40), and High (≥ 40).

Hydraulic geometry and sediment transport relations rely heavily on the frequency and magnitude of bankfull discharge (Rosgen, 1994). Related to that bankfull condition, it is necessary to consider which section can represent bankfull width for all meandering reach because large width variation appears on meandering reach. The cross section at the inflexion point approximates a trapezoidal shape and width at meander inflexion point could be used to represent bankfull width (Soar and Thorne, 2001). To represent the depth value, mean depth was used in this study to represent irregular shape of riverbed condition. Sinuosity and meandering river cross sectional shapes is shown in Figure 5.



Note: point bars are defined by shaded regions; L_m = meander wavelength, Z = meander arc length (riffle spacing); A_m = meander belt width, R_c = radius of curvature; θ = meander arc angle; W = reach average bankfull width; D = depth of trapezoidal cross section; D_m = mean depth (cross sectional area / W); D_{max} = maximum scour depth in bend way pool; W_i = width at meander inflexion point; W_p = width at maximum scour location; W_a = width at meander bend apex. (Soar, 2001)

Figure 5. (a) Sinuosity (Rosgen, 1996). (b) Meandering Rivers Cross Sectional Shapes (Soar and Thorne, 2001)

3. RESULTS ANALYSIS

Comparison of aspect ratio variation among several rivers shows that Cimanuk River has a low-moderate aspect ratio. The value is higher than 12 but lower than 25. Figure 6 explains that setting up intermediate value for aspect ratio could describe the variation more detail than the classification of low and high aspect ratio. This graph also explains that Cimanuk river has less aspect ratio variation compare to other rivers in Japan (Watarase River, Kano and Old Ara River).

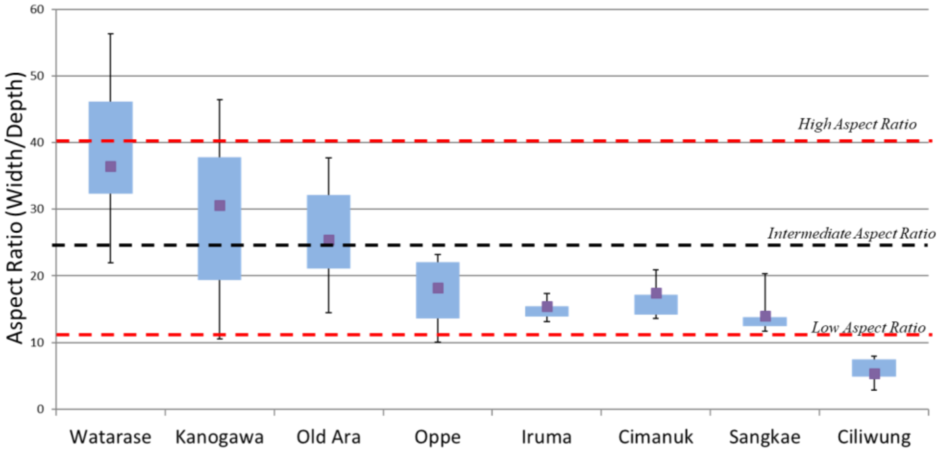


Figure 6. Aspect Ratio Comparison

Cimanuk River shows that bankfull width, aspect ratio, and sinuosity shown in Figure 7 could explain several characteristics. The width ranging from around 80 m to 140 m, and aspect ratio has less variation from upstream to downstream. The sinuosity, however, becomes lower and lower from upstream to downstream, and transition from high, moderate and low sinuosity are clear in the flow direction. This might be related to the bar condition on that area. The riverbed configuration in this river starts from stable bar and gradually becomes unclear bar in the downstream part. More stable bar was created in more sinuous channel in upper part of study area. In the downstream part, gradually bar becomes unclear and less sinuous channel was created.

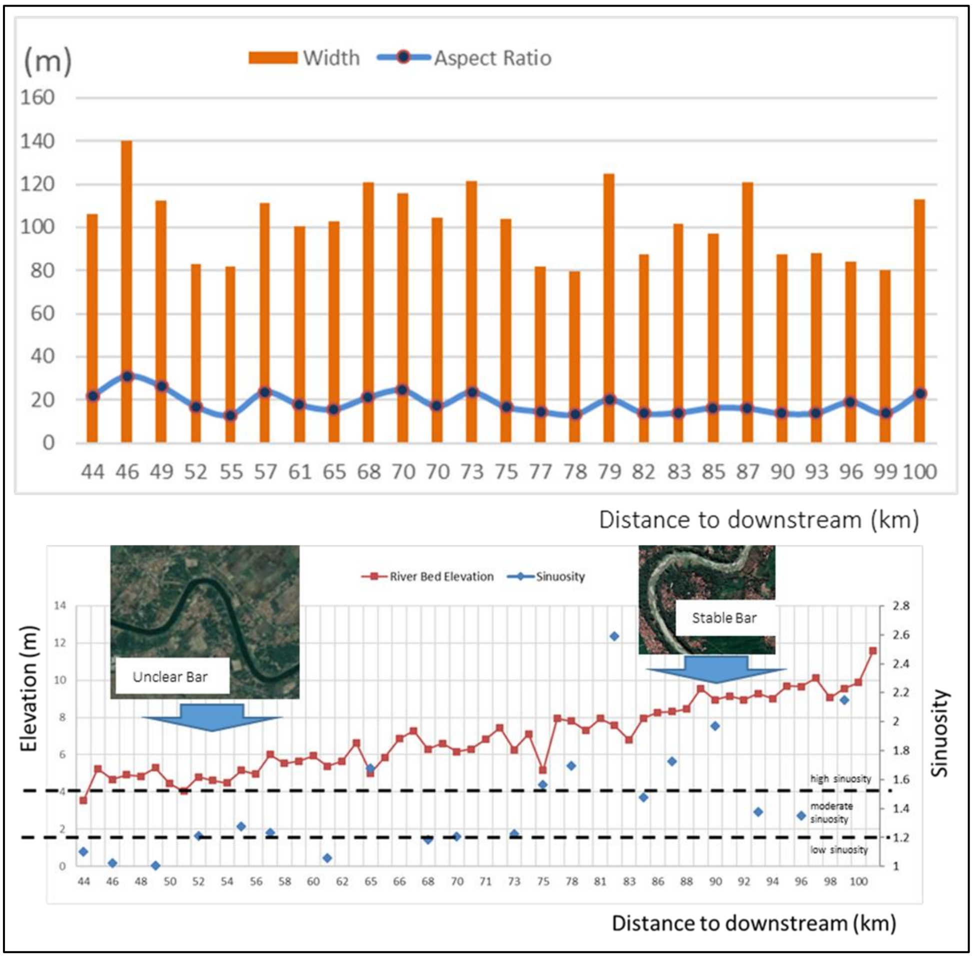


Figure 7. Comparison of Width, Aspect Ratio, Sinuosity and Riverbed Elevation

Figure 8 shows comparison of sinuosity as meander parameter with aspect ratio among the studied rivers. Along with other rivers, Cimanuk River might be classified into “Meandering with Point Bars” (Type2). The graph in Figure 8 also explains that setting up 25 as value of intermediate aspect ratio is important to investigate river with moderate sinuosity. As shown in the figure, value lower than 12, between 12 and 25, 25 and 40 could describe characteristics of each cross sections. Cimanuk River cross section appear in each type of sinuosity from low to high sinuosity, but still dominant in low- moderate aspect ratio.

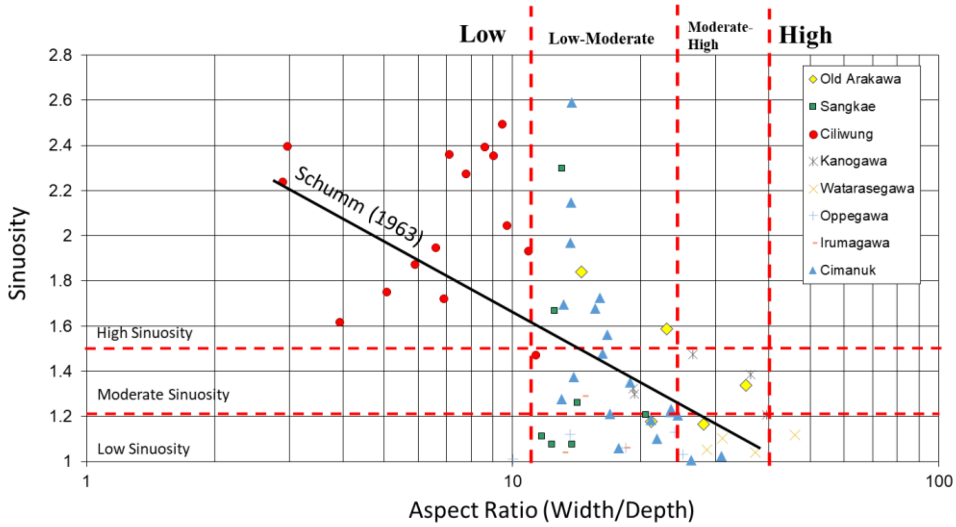


Figure 8. Comparison Aspect Ratio and Sinuosity

In order to understand a more detail characteristics of Cimanuk Rivers sinuosity, it is necessary to investigate sediment size in bed and bank material shown in Figure 9. The bed material of Cimanuk River is quite different from Sangkae River and Ciliwung River, and similar with other Rivers in Japan. The material is taken in upstream part of the study area, and this condition might also have possibility of bar existence. Some stable bars were formed, but as in flow direction it become unclear. Meandering processes in Cimanuk River might be less active due to the lack of coarser material in the lower reaches.

For bank material, however, huge amount of silt-clay material exists in Cimanuk River in comparison with rivers in Japan because of the soil characteristics in the catchment. In this case, bank erodibility may have similarity with Sangkae River and Ciliwung River that affected by cohesive material.

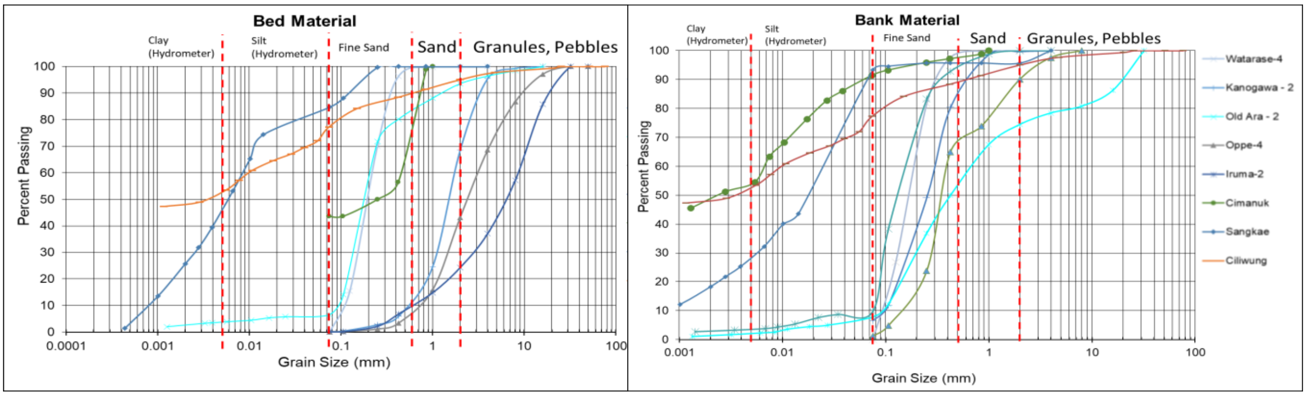


Figure 9. Bed and Bank Material

4. DISCUSSIONS

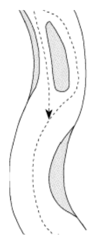
From geological point of view, meandering plain in Cimanuk River was formed around subduction zone in northern part of Java Island. Deposition and sedimentation process are dominant in this plain, and wider coastal deposition area also could be found in this region. In such a low and flat area, sand as bed material exists as a result from the volcanism and river sedimentation process. In some curving reaches, sand bar exists, but it has less impact to planform change. In other unstable meandering rivers that are considered to be Type 3, gravel or sand bar can be formed in moderate-high or high aspect ratio channel and it causes the planform change. On the other hand, in the stable meandering rivers that are considered to be Type 1, there are no sand in low aspect ratio.

One important characteristic feature is that the size of bed and bank material in Type 1 and 3 is similar, but they are quite different in Cimanuk River that is "Meandering with Point Bars" (Type 2). In that sense, Iruma and Oppe River in Japan contain pebble that is not included in bank material. The aspect ratio of these rivers also is low-moderate and stable spatiotemporally (see Figure 6), but point bars are created in curved reach. This result implies the bank and bed material moves independently in Iruma and Oppe River as well as Cimanuk River.

Downstream part of the study area in the Cimanuk River, however, the sinuosity becomes low as is shown in Figure7, and the condition is similar with Sangkae River. If downstream fining occurs in the river channel, we can imagine that the bed material size becomes similar with bank material size. In that case, it is quite reasonable that the similar condition is formed in these rivers, but this condition can be considered as "Meandering with Point Bars" (Type 2), too. One important point here is the relationship between the transition of bar shape and sinuosity. As point bars become unclear, sinuosity becomes smaller. This result implies meandering process is caused by bar formation in Type 2, but it is not so active as Type 3. Meandering process in Type 1, however, can be considered to be quite different because of the high sinuosity despite no bar formation.

This study proposed a modification for Soar and Thorne (2001) classification (Table 1). Type 2 is the intermediate condition between Type 1 and Type 3 and there are two kinds of situation whether the bed and bank material are similar or different. This modification could explain the difference among each meandering type that could be helpful for river management. Also, from this modification, it could simplify the similarity approach for river modelling for numerical or laboratory scale purpose.

Table 1. Proposed Meandering Types for Cimanuk River by Modification Classification from Soar and Thorne (2001)

Characteristics	**Type 1 Equiwidth Meandering**	**Type 2a Meandering with Point Bars**	**Type 2b Meandering with Point Bars**	**Type 3 Meandering with Point Bars and Chute Channel**
Aspect Ratio	Low (< 12)	Low-Moderate (12 to 25)	Low-Moderate (12 to 25)	Moderate-High (25 to 40) or High (> 40)
Aspect Ratio Variability	Stable	Intermediate	Intermediate	Diverse
Sinuosity (Planar Shape)	High (> 1.5)	Moderate (1.2 to 1.5) or Low (< 1.2)	High (> 1.5) or Moderate (1.2 to 1.5)	Moderate (1.2 to 1.5) or Low (< 1.2)
Bar Existence	No Bar	Unclear Bar	Stable Clear Bar	Unstable clear Bar
Bed and Bank Material	Clay – Silt	Clay - Silt	Bed contains coarse sand - Granule and is much coarser than the bank material.	Bed: Very coarse sand - Granule Bank: Sand
Planar Form				
Target Rivers	Ciliwung	Sangkae, Cimanuk (Downstream of lower reach)	Cimanuk (Upstream of lower reach), Iruma, Oppe	Old Ara, Kano River, Watarase

5. CONCLUSIONS

Meandering process in Cimanuk River seems to be affected by surrounding geological characteristics. The process might be less active because of lack of existence of coarser material in the lower reaches. Cimanuk River has less variation of aspect ratio, but has gradual change of sinuosity. The condition is considered to be "Meandering with Point Bars", but it has less impact to planform change. Setting up 25 as intermediate value for aspect ratio is important to investigate river with moderate sinuosity. It is the boundary between high and low spatiotemporal variability of aspect ratio. Understanding variation of several parameters of Cimanuk River could give new approach to modify previous classification, but still necessary to investigate more detail impact of changing sediment size and sediment supply rate.

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