Analysis of the relation between meander river transformation and soil classification in urban area

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Abstract. In general, the profile of longitudinal river flow can be divided into 3 zones i.e. source zone is the headwater or upstream part of the river, transition zone or middlestream and floodplain zone or downstream zone. Urban area usually located at downstream zone which is river section has a meander pattern therefore its many problem prone to this area, for instance, bank erosion, flood disaster at the housing area along the meander curve. Once of approach to solve this problem, especially minimize of flood disaster, is normalized the river with cutting off meander curve. However, there are several studies show that cutting off the curve of meander results in channel instability on sediment transport and environment problem. Therefore, the study of the relation between meander transformation and riverbed soil classification should be needed to avoid a misstep. Area of study is Pesanggrahan River located at the western part of Jakarta Province. When viewed from the entire river section, Pesanggrahan River passing through an urban area that has been developed and riverbed material composition at downstream zone usually are clay, silt and sand. The previous research findings concluded that soil composition with a high percentage of silt, i.e. sandy silt, would be change rapidly compare than soil composition with a low percentage of silt, i.e. clayey silt. Hence, the hypothesis of this research is meander curve with soil classification low percentage of silt are more stable than soil composition of high percentage of silt and meander curve that have not transform for a long time and it’s not recommended to cutting off to maintain the watershed ecosystem as a whole.

1. Introduction

In general, the profile of longitudinal river flow can be divided into 3 zones i.e. source zone is the headwater or upstream part of the river which has a steeper slope, transition zone or middlestream which has low elevation streams merge and flow down gentler slope and floodplain zone or downstream zone that has an even lower elevation a river wanders and meanders slowly across a broad (Figure 1).
Figure 1. A schematic diagram of a river corridor showing three zones and their upstream downstream relationships. (Miller and Spoolman 2012).

Urban area usually located at downstream or floodplain zone which is river section has a meander pattern therefore its many problem prone to this area, for instance, bank erosion, flood disaster at the housing area along the meander curve. Jakarta is the Capital city of Indonesia with a high population density of around 10 million people with an area of around 661.5 km² and crossed by 13 rivers (Figure 2).

Figure 2. Water Management System in Jakarta. (Ministry of public works and housing Indonesia, 2012).

Most of the river pass in Jakarta province has a meander bend such as Pesanggrahan River, Ciliwung River, Cipinang River (Figure 3).
Hence, from 2011 to 2015, Ministry of Public Works and Housing Indonesia, to do normalization to avoid flood disaster that almost every year occurred in several areas of Jakarta. However, to normalize, many factors must be considered, including erosion and sedimentation, changes in habitat in the watershed, and the amount of cost to maintain changes in the channel especially if any cut-off the meander curve. There are several studies show that river normalization has several disadvantages. Brookes is one of researcher who suggested that normalization has disadvantages which one of them is channel instability in sediment transport. Instability occurs because of the disruption of the natural process of channel formation resulting an imbalance between sediment supply and its capacity [1]. For instance, as a result of straightening channel with cut-off the meander bend, the length of the new path will decrease as the river's slope increases and sediment transport change in the upstream, middle and downstream river channel. Due to the energy flow, the riverbed grains that will break down from upstream to downstream from large rocks into gravel and eventually become sand, clay and silt. It is possible that in the future there will be flooding in the downstream area.

2. Problem identification

Pesanggrahan River located at the Western part of Jakarta Province as Figure 2 is one of the river has been normalized in year 2011-2015. The upstream of the river is located in the Bogor area south of Jakarta and ends at Cengkareng Drain at the Java Sea. The catchment area of Pesanggrahan River as seen as Figure 4 created with ArcGIS 10.

The Pesanggrahan watershed over the last 30 years has experienced very significant land-use changes that have resulted in a continuous flow stabilization process that has changed the shape of the transverse and longitudinal channel. According to the Head of the Center for Information and Public Relations Data of the National Disaster Management Agency, the floods that occurred as a result of the water catchment areas that are not comparable with the built up areas in the watershed. As many as 70% of the built area of the watershed consist of 45% of dense settlements scattered in the downstream areas, from Kebayoran Lama, Kebon Jeruk and Kedoya West Jakarta, while the green area is only about 7%. To solve this problem, the Provincial Government of DKI Jakarta in year 2011-2015 normalized 26,7 km Pesanggrahan River by, widening, built a retaining concrete-walls and straightening the river through cut-off some of meander, that its expected 50% of flooding can overcome.
In this research the segment to be observed is ± 10.127 km starting from the South Grogol area, Kebayoran Lama as upstream area of study to sub-district Cengkareng area, Central Jakarta, as downstream area of study. When viewed from the entire river section, the river is the middle river, passing through an urban area that has been developed and has a meander pattern which shows that the river channel in the middle area is winding sharply with a bend angle ($\phi$) less than 90° (ninety degrees) while the downstream tends to be straight with a bend angle ($\phi$) greater than 90° (Figure 5).

Figure 5. Area of study from upstream to downstream (± 10.127 km).
3. Methodology
The area of study is Pesanggrahan River located at the western part of Jakarta Province. When viewed from the entire river section, Pesanggrahan River passing through an urban area that has been developed and riverbed material composition at downstream zone usually are clay, silt and sand.

3.1. Literature review
In addition to changing the river in a longitudinal direction, normalization also changes the shape of the cross section of the river [2]. Those changes can be in the form of widening, deepening, and concreting around the cross section [3]. The intrinsic dynamics of meander evolution are driven by several linear and nonlinear processes which, along with external forcing (e.g., soil properties, streamflow fluctuations, and riparian vegetation), lead to the formation of typical planimetric patterns [4]. The planimetric evolution of meandering rivers is also a key process in many engineering problems. For example, the evaluation of river bank erosion and the consequent sediment transport are fundamental data for fluvial management, navigation, river restoration, and oil research [5].

3.2. Water surface profile using HEC-RAS 5.0.4 software
The Hydrologic Engineering Center - River Analysis System (HEC-RAS) is a software program developed by the US Army Corps of Engineer for modeling water flowing through systems of open channels and computing water surface profiles. The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction and the momentum equation may be used in situations where the water surface profile is rapidly varied. This software needs 3 main data which are: geometry river data, flow data and sediment data. The first step of this research is to collect secondary and primary data, where secondary data is obtained from the Central Office of River Region Ciliwung-Cisadane and literature studies related to research and primary data is obtained from direct observation to the research location to obtain an overview of the current conditions in the field.
3.3. Simulation of the meander transformation and soil classification

The relationship between meander transformation and soil classification will be simulated with a physical model built in the hydraulics, hydrology and river laboratory, University of Indonesia, using a mobile bed and visualization table equipment measuring 200 cm long, 60 cm wide and 12 cm deep. The experiment was carried out by constructing a single curve which is reflect the curvature meander radius with bend angle ($\phi$) smaller than 90$^\circ$ (ninety degrees) and moulded sampel of riverbed material.

Soil can be classified into three primary types based on its texture sand, silt and clay [6][7]. However, the percentage of these can vary, resulting in more compound types of soil such as sandy loam, sandy clay, silty loam, silty clay as shown in Figure 6.

Table 1 shown the results of the gradation test of material sampling at 5 (five) location as follow, before river normalized are cross section 152 and cross section at Cengkareng Drain, after river normalized are cross section 88, cross section 50 and cross section 13.

| Soil Type | Diameter (mm) | Cross Section 152 (%) | Cross Section 88 (%) | Cross Section 50 (%) | Cross Section 13 (%) | Cengkareng Drain (%)
|-----------|---------------|------------------------|----------------------|----------------------|----------------------|----------------------|
| Clay      | $D < 0.002$   | 31                     | 21.5                 | 14.56                | 17.5                 | 31                   |
| Silt      | $0.002 < D < 0.05$ | 27               | 48.5                 | 48.94                | 46.5                 | 67                   |
| Sand      | $0.5 < D < 2$ | 65                     | 30                   | 36.5                 | 36                   | 2                    |
| Gravel    | $D < 75$      | 0                      | 0                    | 0                    | 0                    | 0                    |
| Soil Classification: Sandy Clay Sandy Clay Loam Sandy Clay Loam Sandy Sandy Silty Loam

4. Meander transformation analysis

Based on the geometry data obtained from the Central Office of River Region Ciliwung-Cisadane, it can be seen that normalization at the area of study causes changes the longitudinal profile in river length where the length of the river before normalization is 10,127 m and after normalization becomes 9,029 m (Figure 7).

To increase the channel capacity, normalization of the channel into a uniform trapezoidal shape is carried out. Figure 8 shows the changes in the sections before and after normalization respectively as follows: at the upstream cross section number 152 changes to cross section 130, at the midllestream cross section 102 changes to cross section 88 and at the downstream cross section 14 changes to cross section 13, respectively. The part with blue stripe shows the condition before normalization and the part with yellow line shows the condition after normalization.
Figure 7. The longitudinal profile (a) before normalized (b) after normalized.

Figure 8. River cross section (a) upstream section 152-130; (b) middle stream section 102-88; (c) downstream section 14-13.
4.1. Simulation of the meander transformation and soil classification.

The location of this research is in a floodplain zone with a meandering river channel pattern in the upstream and towards into widening and shallow channel in the middle and downstream area. The experiments were conducted in Laboratory Hydraulics and Hydrology University of Indonesia by using mobile bed and visualization table equipment, which is 200 cm long, 60 cm width and 12 cm deep. Channel bed had a non-erodible rigid acrylic material while the banks material and bed material were relatively uniform, homogenous, and non-cohesive as shown in Grain Size Distribution for each material classification and composition. Flow Discharge is specified as a constant at the inlet, however, water surface elevation decreases gradually along the channel [8].

Two experiment will be carried out by constructing a single curve which is reflect the curvature meander radius with bend angle (φ) smaller than 90° (ninety degrees), and moulded by the first sample was taken from the location of meander cut-off which is before normalization is cross section 152 (Figure 9) and after normalization changes to cross section 130 (Figure 10). Meanwhile the second sample was taken from Cengkareng Drain located at near estuary.

Soil classification at cross section 152 is Sandy Clay which is has high percentage of sand and soil classification at cross section Cengkareng Drain is Silty Loam which is has low percentage of sand.

![Figure 9. Cross Section 152 (before normalization).](image1)

![Figure 10. Cross Section 130 (after normalization).](image2)
Figure 11. Grain size distribution cross section 152 (Sand 65 %; Silt 27 %; Clay 8 %).

Figure 12. Laboratory experiment: material composition Sand 65 %; Silt 27 %; Clay 8 % (Sandy Clay).

Figure 13. Grain size distribution Cengkareng Drain (Sand 2 %; Silt 67 %; Clay 31 %).
Figure 1. Laboratory experiment: material composition Sand 2 %; Silt 67%; Clay 31 % (Silty Loam).

From the table 1, soil classification at cross section 152 is sandy clay with sand composition of 65%; silt 27%; clay 8% (Figure 11).

The results of laboratory research experiments for soil classification sandy clay (cross section 152) show that during 2 (two) hours experiments no significancy transformation of the curve (Figure 12).

Whereas soil classification at cross section Cengkareng Drain is silty loam with composition of sand 2%; 67% silt; Clay 31% (Figure 13) show that during the 22 (twenty-two) minutes of the experiment, the channel has experienced both transverse and longitudinal transformation (Figure 14).

5. Result and discussion
Equilibrium theory states that meandering is the process by which a river adjusts its gradient so that there is equilibrium between the erodibility of the terrain and the erosive power of the stream [9]. Thus, there is a close relationship between the transformation process of meander curve to the riverbed soil.

From the results of laboratory experiments and field observations from year 2002 to year 2016 through Google Earth (Figure 14), it can be concluded that the relation between meander transformation and soil composition of the riverbed soil with a low percentage of silt, i.e. sandy clay is relatively stable, is no significany meander curve transformation both transversal and longitudinal. Therefore, river normalization should not be carried out but it needs to be rearranged that there is a floodplain area as well as has retarding basin.
As well as the river flow downstream of the study area through Google Earth observations, it can be seen that in the 2002 to 2016 period (Figure 16) there was no significant longitudinal transformation but there was a widening cross section especially in the outer meander curve due to soil classification in that area was sandy loam which has silt percentage more than 40%. Therefore, the meander transformation relationship with the classification of sandy loam soils results in a lateral transformation. River normalization should be carried out without cut-off the meander curve but its should be built bank protection and maintaining the stability of the river cross section considering that the area is a densely populated area.

5.1. Impact of the meander cut-off to the sediment transport along the area of study.

There are several sections of the area of study river that have been cut-off. This causes a change in the length of the channel before normalization of 10,127 m and after normalization to 9,029 m, channel slope is steeper than before (Figure 17) and has an impact on the downstream sediment transport. For instance, at cross section 152 the meander curve along ±442 m is straightened to become ±112 m (Figure 18).
Figure 17. The changes of bottom slope at area of study from upstream to downstream

Figure 18. Cross Section 152 before normalization (year 2010); after normalization (year 2015, year 2019).

Since sediment transport is one of the natural factors that forms the morphology of the channel, so that in the normalization of the river it must be known the impact on the sediment transport. Based on the problem, the present study was conducted to analyze the impact of the cutting off some of meander curve due to normalization with the location being used as a case study. The daily discharge that occurs for one year on the available data will be calculated as the dominant discharge. Dominant discharge or channel-forming discharge is defined as theoretical discharge that forms the geometry of the river channel and can be used as a long-term natural hydrograph [10]. Sediment transport calculation used the discharge before normalization (2010) and discharge after normalization (2016) as shown in the Table 2.

Table 2. Dominant discharge (m³/s).

|       | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2010  | 83.9| 104.8| 94.4| 78.9| 81.1| 85.5| 82.8| 84.4| 99.4| 90.3| 86.4| 85.2|
| 2016  | 94.4| 120.6| 89.8| 95.6| 95  | 92.1| 99.4| 88.5| 88.4| 87.3| 85.5| 76.6|
Sediment transport simulation is carried out using HEC-RAS to obtain results in the form of water level. Then, from the water level obtained, it can be known the wet area and circumference of the cross section of the river. The wet cross-sectional area and circumference that needed to be known is 12 (twelve), as much as data of the discharge which enter the river. It must be done to be able to calculate the rate of sediment transport per year by first calculating sediment transport per month. Therefore, from the result obtained can be calculated the sediment transport using Ackers-White equation to determine the rate of sediment transport at the 3 points of sediment sampling in the river segment reviewed [11].

From the simulation of sediment transport using HEC-RAS and the calculation of sediment transport using the Ackers-White equation, it can be seen that the amount of sediment transport in the upstream region has increased from 59.29 tons/year to 214.4 tons/year, in the middle area has increased from 12.18 tons/year to 101.82 tons/year, and downstream areas decreased from 0.74 tons/year to 0.46 tons/year as shown in Figure 19 below.

6. Conclusion and Recommendation
Research on the relationship between meander transformation and soil classification was carried out on the Pesanggrahan River in DKI Jakarta, where the segment to be observed is ± 10.127 km starting from the South Grogol area, Kebayoran Lama as upstream area of study to sub-district Cengkareng area, Central Jakarta, as downstream area of study.

From the results of laboratory experiments and field observations from year 2002 to year 2016 through Google Earth (Figure 14), it can be concluded that the relation between meander transformation and soil composition of the riverbed soil with a high percentage of sand, i.e. sandy clay is relatively stable, is no significany meander curve transformation both transversal and longitudinal. Therefore, river normalization should not be carried out but it needs to be rearranged that there is a floodplain area as well as retarding basin.

As well as the river flow downstream of the study area through Google Earth observations, it can be seen that in the 2002 to 2016 period (Figure 15) there was no significant longitudinal transformation but there was a widening cross section especially in the outer meander curve due to soil classification in that area was sandy loam which is has silt percentage more than 40%. The relationship between meander curve transformation with soil classification of sandy loam results in a lateral transformation. Therefore river normalization should be carried out without cutting-off the meander curve but its should be built bank protection at the outer meander curve and maintaining the stability of the river cross section considering that the area is a densely populated area.

The soil classification in Cengkareng Drain is silty loam which has a very low and almost zero percentage of sand. Cengkareng Drain is part of the Pesanggrahan River near the estuary. The shape of the channel is uncontrollable because the riverbed soil is mostly silt with very low cohesion. Hence, in this section an artificial channel is built to properly maintain the flow of the Pesanggrahan river from upstream to the estuary.

As a result, channel geometry was changed and longitudinal slope is become higher, consequently the sedimentation at the downstream growth rapidly. From the simulation of sediment transport...
transport (Figure 19), it can be seen that the amount of sediment transport in the upstream region has increased from 59.29 tons/year to 214.4 tons/year, in the middle area has increased from 12.18 tons/year to 101.82 tons/year. However, at downstream area of study, sediment transport decreased from 0.74 tons/year to 0.46 tons/year, the amount of sediment transport tends to be smaller after normalization, this is due to the cross section of the river widening that it reduces flow velocity and affects the amount of sediment transport. Although, it is possible that in the future there will be flooding in the downstream area because in the upstream and middle areas the sediment transport increases along with the straightening of the channel due to the cutting of meander curve.

Therefore, river managers are suggest to preserve the meander river flow which can slow down the velocity which is to maintain the balance of erosion and sedimentation along the river channel, especially for meander curve with soil classification with a high percentage of sand composition to obtain the natural flow process for sediment transport along the river channel and maintain the ecosystem as a whole. Related with these conditions, simulation of meander curve transformation with riverbed soil should be carried out before determining the reservation of river corridors (Figure 20), especially along meandering rivers in urban areas.

![Figure 20. River Corridor.](source)

Source : (The Federal Interagency Stream Restoration Working Group, 2001)

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