Flood deposits characterization in Citarum Riverbank Area in Bandung Regency, West Java, Indonesia

A D Oktaviani, D N Sahdarani, J J Prayoga, A O Indraswari and A Haris
Geoscience Study Program, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok 16424, Indonesia

Corresponding author's email: dyahnindita@ui.ac.id

Abstract. Citarum River, the longest river in West Java, is one of the most strategic rivers yet one of the most polluted rivers causing a series of floods throughout history. Understanding shallow flood deposits characteristics may infer the past flooding episode and predict future flood deposits distribution. This research aims to analyze grain size and elemental distributions of flood deposits found in the Citarum Riverbank Area at several districts in Bandung Regency, West Java. Shallow coring resulted in soil samples showing that the samples were dominated by clay and silt. Element analysis revealed that Si and Al are the major elements followed by high concentrations of Fe-oxide in all soil samples. Based on these findings, it is presumed that there were two major episodes of past-floods that occurred in the research area.

Keywords: Flood deposit, Citarum river, grain size distribution, element analysis

1. Introduction
A typical tropical climate is usually affected by heavy rainfall especially during the raining season [1]. When rainfall measures at the highest intensity, the water flow will reach the highest rate and sediment discharge will take place [2]. This event may form the floodplain deposits. Indonesia, located in the equatorial zone, is strongly related to the tropical climate. Annually, the precipitation rate in Indonesia reaches up to 400 mm/month [3] causing some of the biggest flood-related disasters in several different locations. Some of the flood-related disasters in Java is caused by the heavily polluted Citarum River that runs along with West Java Province. Citarum River upstream is in Mount Wayang where the downstream of the river is direct to the Java Sea [4]. Citarum River is very prone to flooding because there have been massive land conversion projects around the river since the 1980s [5]. Citarum Riverbank Area land-use has become one of the government’s main concerns because human activities and infrastructure development has affected Citarum River as Citarum River itself is famous for the most altered river in Indonesia. Furthermore, climatic change and poor domestic waste management in the upstream area are causing floods especially in the Citarum Riverbank Area [6]. The Citarum River flood disaster caused casualties, as well as material and non-material losses [5].

This research is a fraction of a larger themed research on flood deposits characterization. The research aims to analyze grain size and elemental distributions of flood deposits found in the Citarum Riverbank Area (figure 1) that traces Baleendah District, Bandung Regency, West Java using grain distribution and fluorescence elemental analysis. This research has never been conducted in this location. The results of
this study will help to improve better understanding of past flood episodes, and to predict future flood deposits distribution that may cause flood-related disaster in Baleendah District, West Java.

2. Geological overview of the research area
The research was conducted in an area south of Greater Bandung Area, West Java, covering an area of 126 km$^2$ along with the Citarum Riverbank. This area is located between 107°32’ E – 107°43’ E and 6°58’ S – 7°10’ S. There were five different locations for sampling in Bojongsari, Sumber Sari, Bojongemas, Tegalluar, and Mekar Rayu. The research location is included in the Geological Map of Garut that was previously mapped by Alzwar [7] and also the Geological Map of Bandung that was mapped by Silitonga [8] (figure 2). Physiographically, the research area is a part of the Bandung Zone, a zone of intermontane depressions belt, which extends 20–40 km long. Bandung Zone also happens to be the topmost section of the geanticline of Java which was deformed during the Tertiary age. Bandung zone is bounded by a series of volcanoes, both on the northern and southern side [9].

**Figure 1.** Location map of the research area, showing Citarum River, West Java and the focus of the research area.

**Figure 2.** Geological map in the study area (modification from Alzwar et al. [7]) and the sampling location, positioned at the river meanders.
The area was made of lake deposits consisting of clay, silt, fine to coarse sands and gravel, which are commonly tuffaceous deposits [7]. The lithologies also consisted of limestone concretions, plant remains, freshwater mollusks, and bones of vertebrates. They were deposited in the Quaternary age.

Citarum River is bounded by Subang District in the northern part, Cianjur and Garut District in the southern part, Bandung District in the western part, and Sumedang and Garut District in the eastern part subsequently. Citarum River passes through 26 sub-districts in Bandung Area [10].

3. Floodplain and flood deposits characteristics

Overbank or floodplain is the land located between or beyond the channel deposition. This deposit composed mostly of fine-grained sediment. Besides that, the deposit also made by alluvial plains that contribute on soil formation, which can be recognized as paleosols [11]. The floodplain deposits are dominated by suspension deposits such as silt and clay deposits but if the flow of water has enough energy to transport sand in suspension, fine sand may be included. Velocity reduction may cause on the lack of suspension capability to transport sandy and silty sized grain. Hence, it can only transport clay sized grain [12].

Water flow energy or water flow velocity can be related to the size of grain that is transported. It is shown by the Hjulström diagram (figure 3) [11]. The flood deposits are located at zone of flow separation. It is related to the slow-moving flow (less than 1 cm/s) [13]. This flow has low energy and only carries clay in suspension based on the Hjulström diagram. This kind of flow velocity makes the fine-grained materials and particles settlement possible with low density that may accumulate dominated in near channel banks [14].

Floods may transport the heavy-metal materials that are related with particulate matter. Heavy metals are discharged in two phases, which are dissolved and solid phases. The element properties, river water chemistry, and pollution sources controls it discharge phase [14]. Metal content in fine-grained sediments represents the metal concentrations in a suspended load. The dissolved concentrations of metal may be increased due to the increase discharge rate. The river-water may also be changed by floods because of the reduction and oxidation conditions at the river bottom has been changed [14].

Figure 3. The Hjulström diagram shows the relationship between the water flow velocity and the transport of loose grain [11]. The red box shows the grain size of materials that may be transported with flow velocity less than 1 cm/s which are associated with flood deposits.
These conditions are related with numerous organic matters and the content of Fe- and Mn-oxide in sediments [15]. In addition to heavy-metal material, floods may also transport the other elements such as Si, Al, Ca, Ti, etc. The Si concentrations are predominantly found as detrital material produced during weathering in sedimentary rocks.

4. Research methodology
The sampling location was narrowed down to specific points. Prior to field data collection, sampling locations selections were conducted based on aerial photos and spatial data with geographic information system (GIS). River meanders were selected as the sampling location because river meanders are presumably to hold robust flood deposits [16]. Ultimately, five borings were made manually dug using a hand auger reaching two meters below the ground. Borings were logged and described for the characteristics of contacts between different lithologies in the field. Collected samples were mostly soils (figure 4).

Laboratory work was conducted in Soil Mechanics Laboratory, in Civil Engineering Departement, Universitas Indonesia for grain size analysis and subsequently UPP IPD Faculty of Mathematics and Natural Sciences, Universitas Indonesia for X-Ray Fluorescence (XRF) analysis. The soil samples were taken to the laboratory for grain size distribution by applying repetitive sieving and drying processes. After standard grain size analysis treatment, the samples were converted into granules and underwent elemental analysis. SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, TiO$_2$ and CaO serving as major and minor elements will help provide floodplain characteristics. The results of grain size distribution and elemental analysis will then be compared and overlaid to interpret any trend within the boring facies.

![Figure 4. Field activities in the study area, (a) the soil samples that were collected; (b) collected the soils samples from hand auger; and (c) one of the sites in the Citarum River Bank Area.](image-url)
5. Results and discussion

Grain size distribution analysis revealed that the borings were dominated by clay to very fine sands. Based on the grain size distribution from west to east (MR8 to TL4, in figure 2), it is predicted that there were two major episodes of flooding in the past times. This is indicated by a border of two different lithologies of sandstone and clay (figure 5). These findings suggest that the flood episode which carried out sandstone deposits occurred in a higher energy condition subsequently reflecting higher flow velocity based on the Hjulström diagram (figure 3). On the contrary, when grain size distribution leans towards the accumulation of clay lithologies, it is presumed that a lower flow velocity occurred at those facies, sinking the area into a flood-like condition.

Samples in four sites (MR8, SS2, TL4, and BE3) consist of grain size from clay to very fine sand. Meanwhile, BS1 borings contain only sand lithologies. The predominant grain of clay to sand added up to the amount of SiO$_2$ and Al$_2$O$_3$ percentage of the soil samples at 60–65 %. SiO$_2$ concentrations made up due to the weathering in sedimentary rocks but SiO$_2$ and Al$_2$O$_3$ may also occur in river sediment [17]. In addition to SiO$_2$ and Al$_2$O$_3$, the samples are also containing a few amounts of CaO (0.75–2.7 %) and TiO$_2$ (2.3–2.6 %). Calcium elements may be interpreted as the enhancement of major ions in water occurred by volcanic minerals dissolution and weathering process [18, 19]. This result presumed that the volcanic materials affect the existence of Ca elements in samples even in small amounts. These volcanic materials may have deposited from the upstream of Citarum River which has a quaternary volcanic sequence based on the geological map of Garut.

From the elemental analysis, all samples exhibited higher content of iron oxides or Fe$_2$O$_3$ ranging from 26.48–34.37 %. Fe-oxides in flood deposits are commonly associated with plant debris [20]. However, in this case, a higher Fe-oxide content may be contributed from either plant debris, accumulation of suspended load or redox reaction which occurs due to mixing of river water and flood water carrying small, suspended particles [14]. The precipitation of Fe oxides may also occur due to the acidic water contained in rainwater which dilutes excess acidity and subsequently promotes the hydrolysis of Fe$^{3+}$ ions [21]. Further organic content analysis will be required to prove which factors contribute to the higher Fe-oxide content in all samples.

Most sedimentary stratigraphic formations in Indonesia have been mapped and clustered by each different geological process [22] where most sediment deposits characteristics are affected by tropical climates [23]. The relation between sedimentary formation and climate can be interpreted by studying the sedimentary process for-instance related to the fluvial sediment discharge, the result of sediment, and also the pigment formed-process in sedimentary [24].

![Figure 5](image_url)

**Figure 5.** Subsurface facies of flood deposits based on borings analysis (a) to (e) represent the facies from west to east. There are (a) Sample MR8, (b) Sample BS1, (c) Sample SS2, (d) Sample TL4, and (e) Sample BE3.
Figure 5 (continued). Subsurface facies of flood deposits based on borings analysis (a) to (e) represent the facies from west to east. There are (a) Sample MR8, (b) Sample BS1, (c) Sample SS2, (d) Sample TL4, and (e) Sample BE3.

Considering that sample retrieved from the research area is highly to be flood deposits, it is arguably possible that both fluvial and alluvial stratigraphic sequences can serve as evidence of geological processes such as tectonic movements and paleoclimate conditions during the time of deposition.

6. Conclusion
The flood deposits have characteristics as clay, silt or finer material as its lithologies. The Citarum River has a border two lithologies between clay and sandstone which are transported with the different flow velocity. This presumable that the research area has two major periods of past-floods. Considering the element analysis result, all samples have a higher content of iron oxides or Fe₂O₃ which may be contributed from plant debris. Higher content of silica oxide and aluminium oxide also consist of all samples of this research. These suggested that the research area is associated with flood deposits. The calcium oxide and titanium oxide may be contributed from the initial rocks in upstream of
Citarum River which consists of volcanic rocks. To support flood deposits characterization, organic carbon analysis and tree ring measurement is recommended for future studies for this research.

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