Sediment transport pre-measurement as revealed by the hydrophone monitoring technique at a volcanic river

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Abstract. Recognizing the real-time sediment transport phenomena of rivers in the Mt. Merapi area has become an important issue, particularly in the efforts to mitigate risks of lahar flow disasters. The development of a lahar-related monitoring system in the Mt. Merapi area has currently become more challenging since contact and direct lahar flow measurement is very risky. Former techniques for lahar flow occurrences such as cable sensor and video shooting are considered good enough in terms of identifying the occurrence, but not the intensity. Furthermore, after the cable is cut, re-installation often meets its practical limit. The hydrophone measurement technique seems to be an acceptable technique subject to sufficient field calibration. This paper reports the performance of a hydrophone equipment, which can be used for monitoring bedload transport with diameters greater than 4 mm.

Keywords: Hydrophone, field measurement, bedload transport, volcanic river.

1. Introduction

Sediment transport is a phenomenon that occurs naturally in river flow. River morphology factors such as bends or changes in flow are the causes of changes in sediment transport in river basins. The changes in upstream sediment supply, both from natural processes and due to human intervention, also play a role in the process of changing sediment transport patterns and have an impact on the dynamics of riverbed configuration [1].

Due to the negative impact on river structure and river ecosystem, sediment transport needs to be considered in water resources management. Several formulas for calculating sediment transport in rivers have been developed by several researchers. However, mathematical estimation of sediment transport is often inaccurate due to the very complex interaction of water flow and sediment, making it difficult to describe mathematically [2]. Therefore, direct measurement of sediments in the field is needed, especially to verify the results of calculations performed mathematically.

Assessment of sediment transport discharges is usually performed by taking measurements directly on the river. This method is generally used to measure suspended sediments, but for bedload transport, this method is quite difficult to perform. This is caused by the gradation of basic materials that are very diverse. This conventional method is difficult to apply in rivers with supercritical flows that have very small flow depths [3].
A hydrophone is a sediment transport measurement tool that applies acoustic waves. If the bedload hits the hydrophone pipe, the microphone detects the impact as sound, which is then converted to acoustic waves and pulses. Research using hydrophones to measure sediment transport had been carried out in several countries in Japan and France. In Indonesia, this system has not been used for the study of basic sediment transport discharges. Therefore, observing the movement of basic sediments using hydrophones for some flood cases is very important.

2. Materials and Methods

2.1 Experiment Location
This research was carried out by installing a hydrophone device in Code River, Yogyakarta, Indonesia (Figure 1). In addition to the hydrophone, an automatic water level elevation station was also installed at that location. The tools were built by the Hydraulic Laboratory of the Department of Civil and Environmental Engineering, Gadjah Mada University, Yogyakarta, Indonesia. The equipment was installed for monitoring the lahar flow in Code River. To evaluate the performance of the hydrophone, a calibration experiment was conducted using sediments with different characteristics.

![Figure 1. Location of the hydrophone in Code River](image)

2.2 Equipment Setting
The experiment was performed by making a channel with a width of 15 cm and a length of 2 meters. This channel was set up with a slope of 0.05%. The hydrophone was placed at the 50-cm end (Figure 2). Tests were carried out with a flow of a certain discharge and sediment supply. Sediment supply was added at the upstream end of the channel. To find out the response of the tool to the impact of sediments, a supply of sediments with certain diameters and in certain amounts was utilized. The utilized sediment diameters were 1.18 mm, 2.36 mm, 4.75 mm, 9.5 mm and 12.5 mm. To determine the effects of sediment diameter, the experiment was carried out by making one grain of sediment material flow every minute for 15 minutes. Meanwhile, to determine the effect of sediment concentration, the experiment was carried out by supplying an amount of sediments each minute for 15 minutes.
The influence of the shape of the sediments was obtained by comparing the experiments with sediments using marbles.

When the sediments hit the hydrophone, the microphone inside the pipe detects the impact and then transmits signals that are then translated by the converter. The converter transforms the signal into an acoustic wave and forms a 100 kHz envelope frequency curve. The envelope curve is then amplified into 6 different strength scales (1, 4, 16, 64, 256, and 1024). The envelope curve is transformed into rectangular waves for each level of amplification. In each 1-second interval, the number of waves is counted as 1 unit of pulse if it exceeds the 2V limit. The unit of pulses represents the number of collisions that are then stored in the data logger.

![The actual equipment (a) and the illustration of experiment (b)](image)

**Figure 2.** The actual equipment (a) and the illustration of experiment (b)
3. Results and Discussion

To find out the sensitivity of the hydrophone, an experiment was carried out by making sediment material of certain sizes flow. In this study, three types of materials were used: gravel, glass marbles, and steel marbles.

3.1 Gravel Material

The experiments using natural materials with varying diameters produced a varying number of pulses for each amplification level (HP). This can be seen in Figure 4.1 and Figure 4.2. HP1 appeared to be more sensitive compared to other amplification levels. The hydrophone was able to read pulses generated by HP1, but could not read HP2 pulses. This is because HP1 pulses experience the greatest amplification, and thus the amplification of the waves generated at this level exceeded the 2V limit compared to lower amplification levels (HP2, HP3, and so on). Figures 4 and 5 show that HP1 is more sensitive than HP2. A zero pulse value means that there was no collision between the sediment material and the tool. Figure 6 shows that the pulse value increases as the diameter becomes larger.

Figure 4. Experimental results for gravel material with variations of diameter on HP1
3.2 Artificial Materials (Glass Marbles and Steel Marbles)
For the experiment using marbles, the hydrophone was able to record pulses starting from level 3 (HP3) to level 1 (HP1) amplification (Figure 7, Figure 8, and Figure 9). The flat line graphs show that perfectly round shapes tend to produce the same or consistent numbers of pulses at all times. Figure 10 shows that for the experiment using steel marbles, the hydrophone could only record at the highest amplification level, HP1. When using an iron marble, the impact was only able to be recorded by an HP1 amplifier. This is due to the fact that iron marbles roll perfectly and only cause very small vibrations. From the comparison between experiments using artificial materials and natural materials, it can be concluded that the generated pulses are influenced by the characteristics of sedimentary material, such as specific gravity, diameter size, and grain shape.
3.3 Experiments using a group of materials
To find out the response of the hydrophone in recording the concentration of bedload transport, experiments were carried out using a number of grains of materials that flowed from the upstream channel and were carried away by the flow, eventually striking the hydrophone pipe.
Figure 11. Hydrophone results with material in the form of a group of marbles (3, 5, and 7 items) on level 1 amplification (HP1).

Figure 12. Hydrophone results with material in the form of a group of marbles (12, 15, and 18 items) on level 1 amplification (HP1).

Figure 11 and Figure 12 show that the amount of sediment material does not necessarily produce a large amount of pulses. The grain diameter has a dominant influence on the number of pulses produced compared to the amount of sediment material [4] [5] [6] [7].

4. Conclusions
The hydrophone is quite good at reading collisions caused by sediments that have diameters greater than 4 mm. The reading results will be different for each level of amplification or strengthening of the wave. The highest amplification level of HP1 (x 1024) results in a greater pulse value when compared with HP2, HP3, and so on. In addition to the size of the sediment diameter, the sensitivity of the hydrophone is also influenced by the specific gravity of the sediment and the flow of the river.

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