A TIPPING-BUCKET SEDIMENT TRAP FOR CONTINUOUS MONITORING OF SEDIMENT DEPOSITION RATE

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Abstract. Characterization of horizontal and vertical sediment fluxes in rivers is required for effective river management and control. Although horizontal fluxes of suspended sediments can be monitored with various types of optical and acoustic sensors, there are no appropriate devices to monitor sediment deposition rates, one of vertical sediment fluxes. We designed and tested a new device for carrying out long-term, continuous monitoring of sediment deposition rates in rivers and coastal areas. The tipping-bucket sediment trap (TST) can be made at low cost without requiring any special manufacturing techniques, and it can be easily deployed in rivers. We conducted a simple laboratory experiment simulating the deposition of sediments in still water to check the fundamental performance of the TST. In field tests, we deployed the TST to continuously monitor sediment deposition in two rivers. The observed results indicate that the TST can perform continuous measurements of sediment deposition fluxes in two rivers. The field tests show that temporal variations in the sediment deposition rate, such as during flood events, are clearly detected in monitoring with the TST.

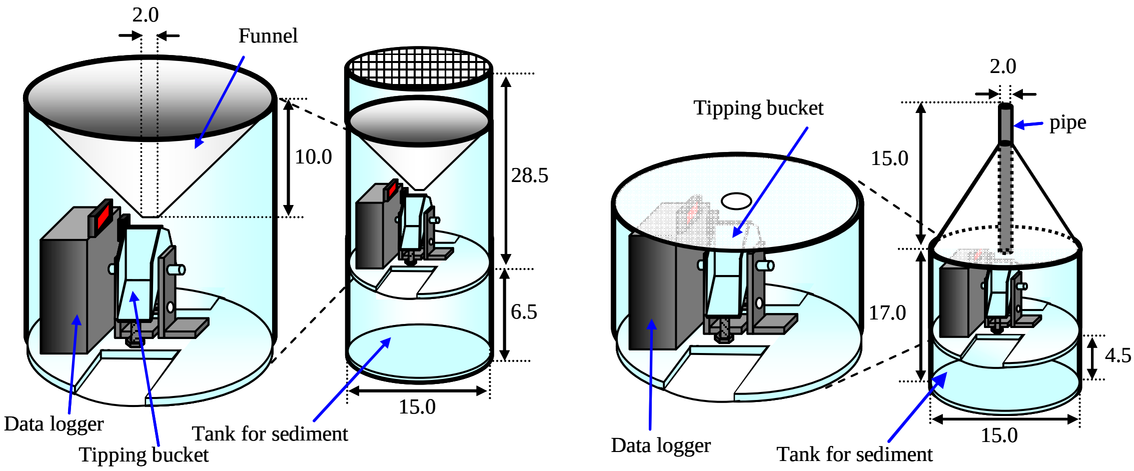
1. Introduction

Comprehensive sediment management from riverheads to coastal regions requires examination of sediment transport throughout the entire river basin. Monitoring horizontal fluxes of sediments, such as bed load, suspended load, and wash load, and vertical fluxes of sediments, such as erosion and deposition rates of sediments, is needed to understand sediment behavior. Among these fluxes, the suspended and wash loads may be measured using optical and acoustic sensors (*e.g.*, [1], [2]). In contrast, sediment deposition rate is generally measured using a sediment trap to collect particulate matter settling in water. Previously, sediment traps were mainly used in oceans to measure the total amounts of sediment deposition and to collect samples for chemical composition analysis. Thus, it is difficult to detect temporal variations in sediment deposition rates with this type of sediment trap.

In the present study, we introduce a new sediment trap in which a tipping bucket adapted from a rain gauge is applied to the measurement of sediment deposition flux. It is expected that the tipping-bucket sediment trap, hereafter referred to as TST, can provide long-term, continuous monitoring of the sediment deposition rates in rivers and coastal areas at low cost. To validate the fundamental performance of the TST, we performed a simple laboratory experiment to simulate the deposition of sediments in still water. In field tests of the TST, we applied the TST to continuous monitoring of sediment deposition in two rivers.

2. Outline of the Tipping-Bucket Sediment Trap (TST)

After several manufacturing trials, we developed two TST models, shown in **Fig. 1**, that automatically and continuously measure sediment deposition flux. The compact TSTs designed here can be made at low cost without requiring any special manufacturing techniques, and they can be easily deployed in rivers. Suspended sediments are collected into the tipping bucket through either a funnel (**Fig. 1(a)**) or a pipe mounted vertically in the upper part of the TST (**Fig. 1(b)**). As indicated in **Fig. 2**, the sediments settling through the funnel or vertical pipe are deposited on one side of the two small buckets, which are balanced against each other. When the mass of sediment required to cause the bucket to tip has been deposited, the bucket tips and empties, and the sediment falls on the other bucket. Each time the bucket tips, an electronic signal is sent to a data logger and recorded as a tipping event. The number of tipping events is referred to as the tipping number.



(a) Funnel (b) Vertical pipe

Fig. 1 Schematic view of the tipping-bucket sediment trap fitted with funnel and vertical pipe collection devices.(Unit:cm)

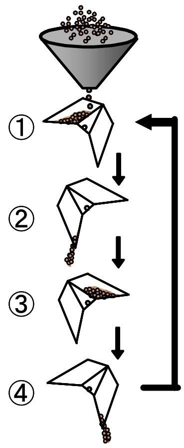


Fig. 2 Conceptual view of the measurement of deposition sediment flux using the tipping bucket.

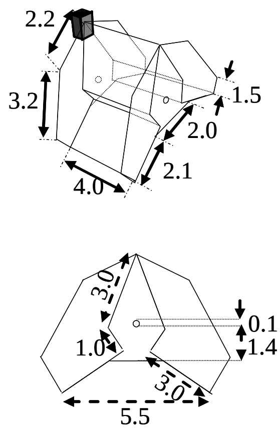


Fig. 3 Configuration and dimensions of the tipping bucket. (Unit:cm)

One of the main features of the TST is the structure for collecting the settling sediments. We first tested the use of a funnel as shown in **Fig. 1(a)** because a funnel is normally set at the upper part of rain gauge and we expected it would also be appropriate for collecting a large amount of sediment. However, the 1.0 cm diameter hole of the funnel became plugged due to fine particles settling in the water. To prevent blockage in the hole, we enlarged the hole diameter from 1.0 cm to 2.0 cm. However, in hydrologic events, the deposited sediments exceeded the storage capacity for sediments and the TST can not be used to continuously measure the sediment deposition flux. To solve these problems, we introduced a vertical pipe with a 2.0 cm diameter in place of the funnel in the upper part of the TST, as shown in **Fig. 1(b)**. The cross-sectional area of the vertical pipe (=3.14 cm^2) is much smaller than that of the main body of the TST (=177 cm^2) and the TST with the vertical pipe is expected to be able to continuously perform measurements during hydrologic events in which large amounts of sediment are deposited. The vertical positioning of the pipe on the TST may prevent the blockage. At this stage of development, the TSTs fitted with the funnel and the vertical pipe were expected to handle measurements of sediment deposition flux under low and high sedimentation conditions, respectively.

Another feature of the TST is the configuration of the tipping bucket, which is shown in Fig. 3. The triangular tipping bucket that is generally found in rain gauges does not work well in the present application. When the triangular bucket is turned, water is discharged easily from the bucket, but sediments are not. Therefore, we adopted the configuration of the bucket depicted in Fig. 3. We confirmed that the sediments are smoothly discharged from the redesigned bucket. The dimensions of the tipping bucket were adjusted in order to reduce the mass of sediments required to trigger the bucket to overturn, called the tipping mass, M_0. For a tipping bucket of this size, M_0 is actually about 1 -2 g. The deposition rate of sediments is calculated using the tipping mass divided by the time elapsed between tipping events.

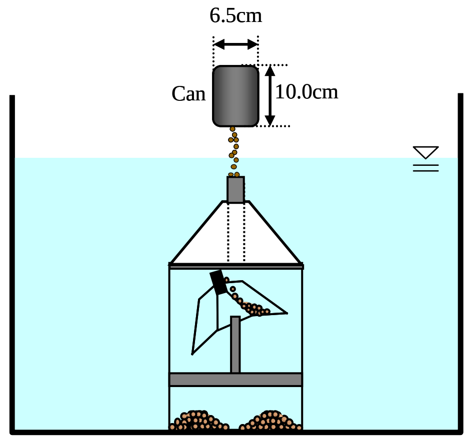


Fig. 4 Outline of the laboratory experiment in still water.

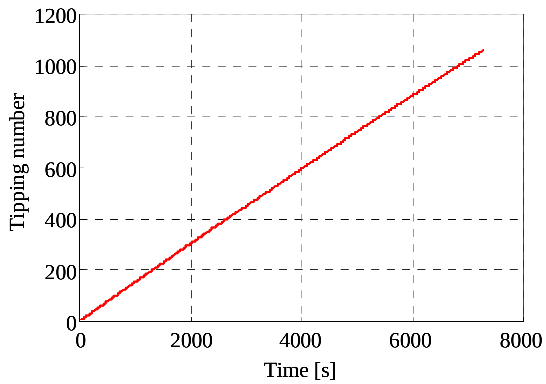


Fig. 5 Temporal variation of the tipping number using the TST fitted with the vertical pipe.

Incorporating these features, the TST is expected to support continuous and long-term monitoring of sediment deposition flux with high accuracy and high stability.

3. Fundamental Performance of the TST in Laboratory Experiment

3.1. *Outline of Laboratory Experiment*

To examine the fundamental performance of the TST, a simple laboratory experiment exploring the deposition of sediments in still water was set up, as shown in Fig. 4. During the experiment, the TST was installed horizontally in still water and sand was fed at a constant speed from a can suspended above the TST. We used Toyoura standard sand, which has uniform particle size, and we confirmed that the sand was dispensed from the can at a constant rate. To determine whether the bucket in the TST tips at constant time intervals, we calculated the time interval from the recorded time between when the bucket tips until the bucket tips again. For the laboratory experiment, we used the TST with the funnel and vertical pipe indicated in Fig. 1. There were no appreciable differences between the results for the TSTs fitted with the funnel and the vertical pipe intake, and the experimental results for the TST fitted with the vertical pipe are displayed in Fig. 5.

3.2. *Experimental Results*

Figure 5 shows the time series of the tipping number of the bucket in the laboratory experiment. The relationship between the tipping number and time is linear, indicating that the bucket tips at constant time intervals. In the experiment, the total tipping number is 1060, corresponding to a total sedimentation mass of 1242 g. The average M_0 and its standard deviation are 1.17 g and 0.067 g, respectively. The ratio of the standard deviation to the average is about 5 %, showing that the TST can measure the deposition flux of sand with high accuracy and high stability. The

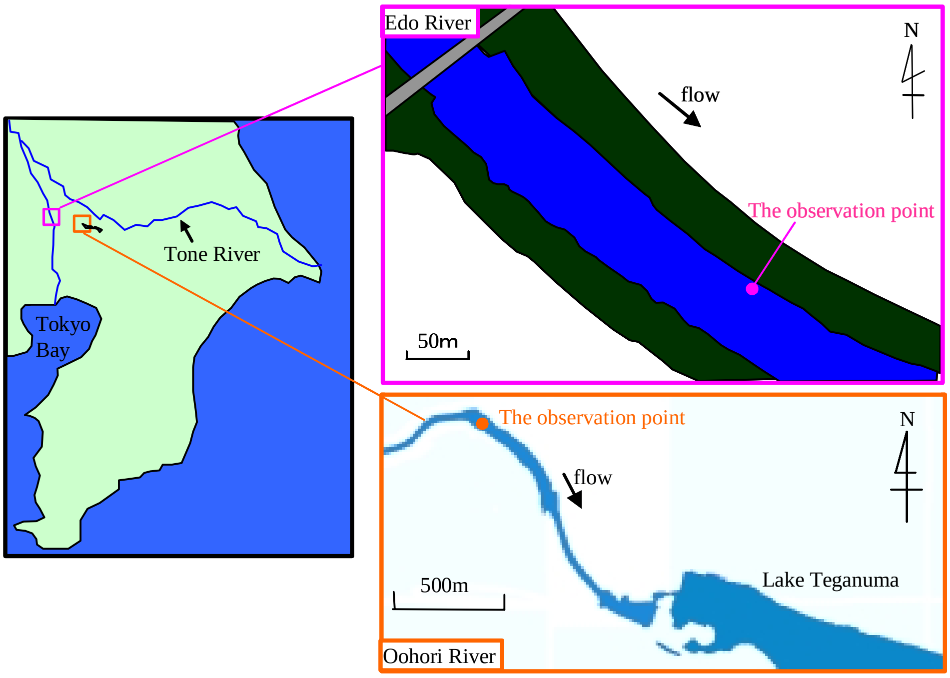


Fig. 6 Map of field sites.

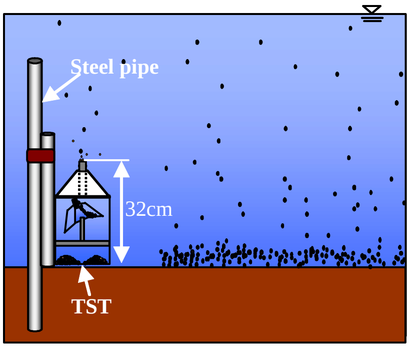


Fig. 7 Schematic view of the TST mounted in the rivers.

above experimental results confirm the accuracy of the fundamental TST performance for measuring the deposition flux of sediment.

4. Field Tests of the TST in Two Rivers

4.1. *Outline of Field Surveys*

In field tests of the method, we deployed the TST to measure the sediment deposition rate in two rivers. The field sites were the Oohori and Edo rivers in Japan, which are typical urban and large rivers, respectively, as shown in Fig. 6. We mounted the TST in the rivers with a steel pipe hammered into the riverbed, as shown in Fig. 7. The TST fitted with the vertical pipe was used in the field tests. The height of the top of the TST was 32 cm from the riverbed. Following are descriptions of field sites and measurements that were carried out at each site.

The Oohori River flows into Lake Teganuma, one of the well-known eutrophic lakes in Japan. The width of the main channel in the Oohori River is 20-40 m at a low flow condition. The TST was mounted at the center of the main channel at a measurement station located 1.5 km upstream from the river mouth. Observations were made from 21 August to 28 September, 2006. We conducted maintenance of the TST five times during this period.

The Edo River diverges from the Tone River and flows into Tokyo Bay. The Edo River has a compound cross section width of 400 m. The TST was mounted in the main channel at a measurement station located 39 km upstream from the river mouth. Observations were made from 11 to 25 September, 2006. We did not maintain the TST in this period, in which a hydrologic event resulting in discharge exceeding 400 m^3/s occurred.

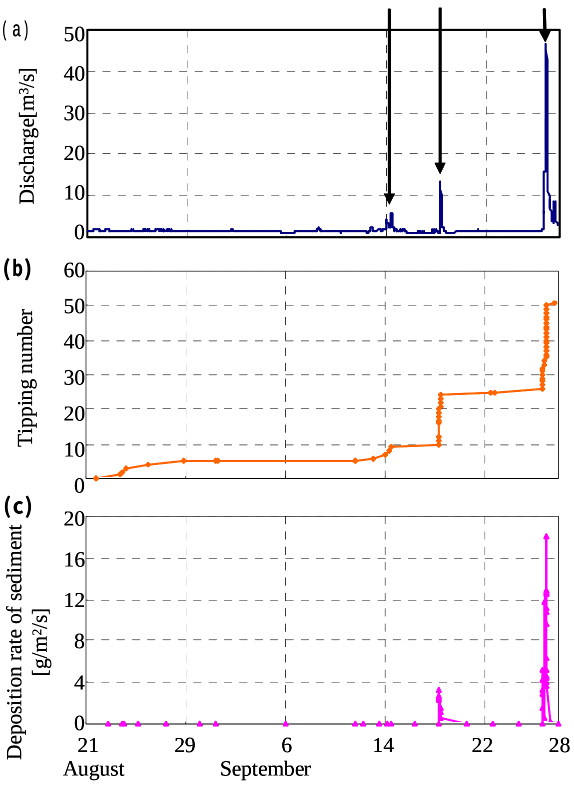


Fig. 8 Temporal variations in river discharge (a); tipping number (b); and, deposition rate of sediments (c) in the Oohori River.

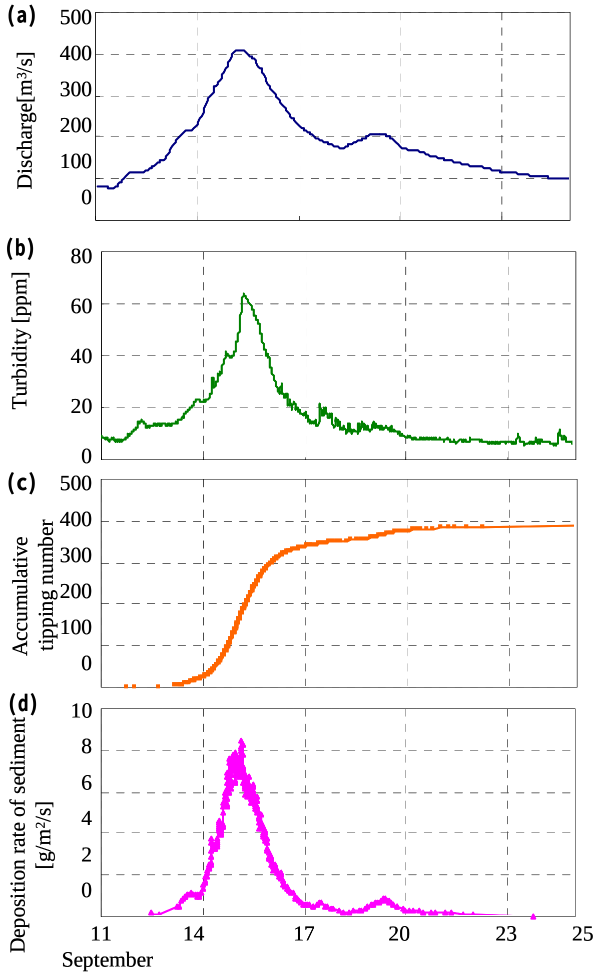


Fig. 9 Temporal variations in river discharge (a); turbidity (b); tipping number (c); and, deposition rate of sediments (d) in the Edo River.

4.2. *Measured Results and Discussion*

4.2.1. *Oohori River*

Figure 8 shows the measured results of the temporal variations in river discharge, the tipping number, and the sediment deposition rate in the Oohori River. The sediment deposition rate was determined as the M_0 divided by the time interval of each tipping. This procedure was also used to calculate the sediment deposition rate in the Edo River. The river discharge is estimated from the observed water level and the rating curve at the measurement station. During this period, three hydrologic events occurred, as depicted by arrows in Fig. 8. The observed results show that the tipping number increased most in the three hydrologic events and the increased tipping frequency was coincident with the increased flood discharge. In particular, the discharge and deposition flux exceeded 40 m^3/s and 15 g/m^2/s, respectively, during the flood event from September 26 to 27, 2006. The bucket turned five times in low-flow conditions, showing that the TST with the vertical pipe has the capability of measuring the deposition rate of sediments during flood conditions as well as in low-flow conditions.

4.2.2. *Edo River*

Figure 9 shows the river discharge, turbidity, tipping number and sediment deposition rate in the Edo River. The river discharge was calculated using the observed water level and the rating curve at the measurement station. The turbidity was measured with an optical turbidity sensor (Compact-CLW, Alec Electronics Co., Ltd., Japan) installed at the station. Flood discharge of more than 400 m^3/s was observed during the period. The TST successfully measured the deposition rate of sediments during this flood. The total tipping number reached 387. Temporal variation in the sediment deposition rate was notable during the flood and almost similar to that of turbidity. The particle size distribution of deposited

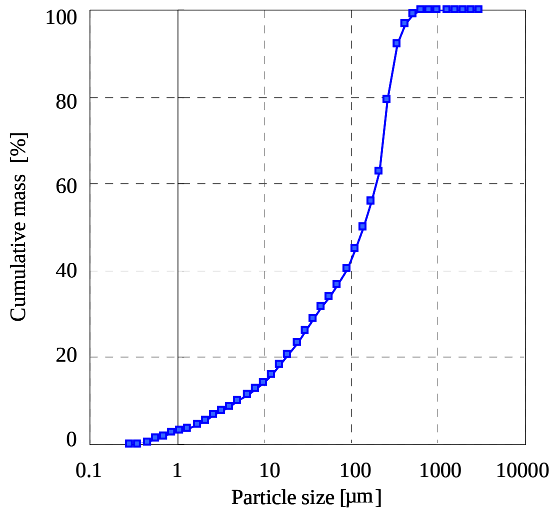


Fig. 10 Particle size distribution of deposited sediments in the TST in the Edo River.

sediments in the TST is shown in Fig. 10. We measured the particle size of the sediments with a laser diffraction particle size analyzer (SALD-3100, Shimadzu Co., Ltd., Japan). The mean diameter of the sediments collected in the TST was approximately 100 μm . These results illustrate that the TST can measure the deposition flux of fine sand. These results demonstrate that the TST can generate continuous measurements of the deposition rate of fine sediments even under heavy flood conditions, without requiring maintenance.

5. Conclusions

The main conclusions in the present study are as follows:

(1) To realize long-term, continuous monitoring of sediment deposition rate in rivers and coastal areas, in the present study, we present a tipping-bucket sediment trap (TST), in which a tipping bucket normally used in rain gauges is applied to the measurement of the sediment deposition flux.

(2) We confirmed the fundamental performance of the TST through a simple laboratory experiment for sediment deposition in still water.

(3) As a field test, we deployed the TST to perform continuous measurements to determine the sediment deposition rates in the Oohori and Edo rivers. The TST succeeded in continuously measuring the deposition rate of fine sediments under flood conditions without requiring maintenance.

(4) These observations demonstrate that the TST can perform continuous measurements needed to determine the sediment deposition rate with high temporal resolution.

Acknowledgments

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