Investigation of Suspended Sediment Samplers: A Review

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Abstract. The flow of rivers and streams carries many particles like sand and silts due to erosion phenomenon which are commonly termed as sediments. Sediments transported along the water flow distributes into either bed load or suspended load. The heavier particles settle down the river bed and form the bed load. While the lighter particles gets suspended along the surface of the water body and are termed as suspended load. The change in sediment concentration affects the hydromorphology of rivers to a great extent. The current study focusses on the measurement of the suspended sediment and reviews the various suspended sediment samplers based on different technical parameters such as working principle, accuracy and specifications. Different mechanical samplers such as bottle and trap samplers, pump samplers; electronic samplers such as Acoustic backscatter profiling sensors (ABS), etc. and optical samplers such as Optical backscatter point sensor (OBS), Optical Laser diffraction point sensors (LISST) and many more sensors such as impact sensors, nuclear sensors and conductivity sensors are reported and compared in this review.

1. Introduction

The sediments flowing along the river and deposited at the bed of river sums up the total load of sediments [1]. Future natural calamities that can occur due to river can be easily predicted by studying the total sediment load on river. The use of mechanical samplers is usually carried out for bed load sampling due to its robust design and body [2]. But for suspended load, mechanical as well as modern electronic and optical sensors are available which can measure with a good accuracy. Still, in some isolated locations and for cost feasibility, bottle-trap samplers and pump samplers are still in use along with calibration curves [2]. Van Rijn and Moustafa [2] designed a sampler which can be used to measure both bed load and suspended load and thus reduce the use of two different instruments. Some researchers like Arman et al. [3] have also made use of transport formulae and artificial neural networks to measure the suspended sediments. But still, the use of devices for suspended load is still
in existence due to its ease of operation and accuracy. The devices are also used for measurement of suspended load of alluvial streams [4] and sediment concentrations under the waves [5]. Although the mechanical samplers are widely used, the main limitation of mechanical devices are the incomplete extraction of settled sediments in the device [6]. Thus a well maintained sampler is suggested for good results. The current study reviews some of the widely used mechanical samplers as well as optical and acoustic sensors used in suspended load measurements. Both the direct method instruments and indirect method instruments are reported in the review.

2. Bottle and Trap Samplers

The bottle and trap samplers work on a simple phenomenon of collection of water using a container and trapping it with the help of a valve [7]. These devices can be used for freshwater as well as seawater [8]. For still water bodies such as lakes, bottle samplers are considered as a cost saving device [9]. For both traps and automated valve, the intake velocity with which sample is collected in sampler should match the kinetic velocity of water for precise results [10]. Difference in these velocity may result in computational errors. The water thus collected using these samplers are tested in laboratories and sediments by weight are measured.

2.1. USP-61 Suspended Load Sampler

A USP-61 suspended load sampler is shown in figure 1. It is made up of a heavy bronze metal weighing up to 50 kg in which a 500 ml container is embedded [11].

![Figure 1. USP-61 Suspended load sampler [12]](image)

A hinge is provided on the device head for accessing the container [13]. As seen in Fig. 1, a small nozzle points in the forward direction [14]. This nozzle is operated electronically [15]. For 500 ml sample collection, 10 to 30 seconds is required depending on the flow velocity [16]. Due to its heavy weight, it can go deep without getting disrupted by flow velocity [17]. A vent hole is provided on the upper side of the body for release of trapped air while the water is entering the container [18]. It is recommended to collect at least 70-75 % of the container for accurate results [19]. The hydraulic coefficient which compensates for the error of the velocity is approximately equal to 1 for this sampler [20]. Although a simple and accurate result fetching sampler, its use is limited due to its weight and manufacturing limitations [21].

2.2. Delft Bottle Suspended Load Sampler

A schematic view of Delft bottle sampler used for suspended sampling is shown in figure 2. The water entering through the nozzle exits from the back of a small go-through passage due to which the heavy sediment particles settle down in the sampler body [22]. The working of the Delft bottle is based on
speed reduction principle [23]. Delft bottle can be used for shallow streams [24] due to its heavy body. Its accuracy is quite low but can be used due to its simple manufacturing design [25].

![Figure 2. Schematic diagram of Delft bottle sampler [21]](image)

2.3. **USD-49 Depth Integrating Sampler**

USD-49 is similar to USP-61 sampler in design [26]. It also consists of a heavy casting with a bottle container fitted into its body. A USD-49 depth integrating sampler is shown in Fig. 3. The term depth integrating means the sampler continuously collects the sample while going deep the water body and again while coming up towards the surface [27]. The sampler has a maximum working depth of 5 meters [28]. Also, it is suitable only for a water flow having maximum velocity of 2 m/s [29]. A USD-49 sampler is shown in figure 3.

![Figure 3. USD-49 Depth integrating sampler [30]](image)

2.4. **Collapsible-Bag Depth Integrating Sampler**

Davis and Carnet [31] made use of collapsible bag sampler for sediment sample collection. It consists of a collapsible bag with nozzle fitted on it enclosed in a metal chamber. The purpose of metal chamber is to dip the sampler deep in the water. The sampler works on the principle of hydrostatic pressure surrounding the nozzle. As the bag is lowered, the hydrostatic force opens up the nozzle and enters the bag and once the bag is filled with sample water, the nozzle closes. This sampler is also of depth integrating type [27].
3. Pump Samplers
A pump sampler is used in conjunction with either filter, sedimentation or bottle sampler [32]. A pump is used along with a tube at the end of which a nozzle is fitted [33]. The weight of the nozzle helps in to take the hose or tube to the required depth [34]. For accurate results, the hose length should be maximum 7 meters [35]. A pump sampler installed on a river is shown in figure 4. The sample water sucked using a pump is collected in either container or bottle [36]. The sample is passed through a sieve or filter of appropriate size [37] and the combined setup is known as pump-filter sampler. Or the water collected using pump is stored in a big container and the sediments are allowed to settle down whose density is measured using an optical sensor [38]. Another method of pump sampling is to create a suction vacuum in a bottle [39]. The sample is pumped into the container using a pump directly connected to it [40]. Different bottles are used for each sample collection [41]. The sediments in the sample are then measured in laboratory by using sensors [42] or filters [43].

Figure 4. A Pump sampler on a river [36]

4. Optical and Acoustical Sensors
Both optical and acoustical sensors are based on same basic phenomenon of trans-mission and scattering [44]. In a wider sense, each sensors are similar as both of them measure the sediment concentration using contactless principle [45].

4.1. Optical Backscatter Point Sensor (OBS)
Optical backscatter point sensors (OBS) work on the principle of scattering of light [46]. The light after falling on sediment particles get scattered in various directions [47]. OBS absorbs the scattered light and calibrates in terms of sediment concentration [48]. OBS consists of an infrared emitter [49] and a photo receiver [50]. The sensor emits infrared light which travels through the medium, hits the sediment particles and get scattered in the fluid [51]. The scattered infra beams are collected by photodiode receiver probe and calibrated [52]. The backscattering is different for different size and materials [53], thus making calibration a tedious task. The main advantage is that the infrared easily travels in any medium [54] and size of sensor is quite small having 2 cm diameter and 5 cm length [55].
4.2. **Optical Laser Diffraction Instruments (LISST)**
LISST stands for Laser In-Situ Scattering and Transmissometery. As seen in figure 5, sample water is filled in the container and laser is emitted through it [56]. The laser light gets impinged on the sediment particles and gets diffracted through the medium [57]. Total laser beam falling on the ring detector is sensed and calibrated in terms of sediment concentration [58]. Various models of LISST are available which are designed by different manufacturers.

![Figure 5. Basic principle of laser diffraction instruments [56]](image)

4.3. **Acoustic Sand Transport Meter (ASTM)**

The working principle of acoustic sand transport meter is shown in figure 6 [59]. The device measures both sediment concentration as well as flow velocity [60]. It consists of a pipe bend in which a piezoelectric sensor is fitted. As the fluid flow bends in the pipe, the heavier particles get settled towards the bottom near the sensor and the piezoelectric sensor sends the signal to the processing unit [61]. The frequency of transmission of transducer is 4.5 MHz [59].

![Figure 6. Working principle of Acoustic Sand Transport Meter (ASTM) [59]](image)

4.4. **Acoustic Doppler Velocimeter (ADV)**
The backscattered signal and sediment concentration has a correlation between them [62]. This forms the basic principle of using Acoustic Doppler Velocimeter (ADV) for suspended load sampling. A schematic diagram showing working of ADV is shown in figure 7 [63]. The acoustic signal transmitted through a transmitter gets backscattered after colliding with sediment particles [64]. These backscattered signal is received by 3 receivers which act as a 3D probe [65]. The 3D probes help in receiving signals from all directions. The distance of sampling volume from the Velocimeter is fixed and nominally kept around 10 cm.
5. Other Sensors

Apart from the widely used mechanical, electronic and optical samplers, some other sensors such as impact sensors, nuclear sensors and conductivity sensors are also used for suspended sediment sampling. Their use is limited due to some limitations and hence not commonly used.

5.1. Impact Sensor

Impact sensors work on the principle of transfer of momentum and makes use of the momentum of the sediment density [66]. As the sediments particles are having higher momentum compared to the water particles, the impact on the sensor due to sediments is sensed and calibrated in terms of sediment density. The main problem with the impact sensor is that it inaccurately senses silt particles which are having less momentum [67]. Thus reducing the overall accuracy of the sensor.

5.2. Nuclear Sensor

Nuclear sensors work on the principle of absorption. Nuclear or radioactive energy are absorbed by the sand and silt particles flowing along the stream. This energy helps in measuring the density using nuclear counters [68]. Although having a very low inaccuracy of about 5% [69], the use of radioactive energy is governed differently for different nations, hence its use is limited.
5.3. Conductivity Sensor

Conductivity sensors work on the principle of measuring conductivity of sand and silt particles and calibrating in terms of sediment density [70]. These sensors are very rarely used as it accurately senses only higher concentration of sediments near the river bed [71].

6. Discussion

A brief review of suspended sediment samplers and sensors is carried out successfully. Based on working principles, availability, depth requirement, accuracy to be achieved and cost; the available samplers can be used for suspended load measurements. The widely used standard available samplers like USP-61 sampler, Delph bottle sampler, USD-49 sampler and collapsible bag depth integrating sampler are compared on the basis of their modus operandi. A general view of pump sampler is also noted down. Optical sensors like OBS, LISST, ASTM and ADV are also listed in the review. Using the working principles of each device, other device can easily be designed depending on the available resources to come up with in-situ samplers for measuring time-weighted average concentration of suspended sediment in rivers and streams. Also, it is quite evitable that although optical and electronic sensors are providing good accuracy, mechanical samplers are still in use due to ease in its working, simple calibration, cost and availability. A general overview of impact sensor, nuclear sensor and conductivity sensor is also highlighted.

As a generalized notion, the sampler should be able to function with the same velocity of the stream and as a future perspective, development and validation could be done for surficial sediment erodibility from time-series measurements of suspended sediment concentrations. Using this, the analysis of principal of maximum entropy could be done for the estimation of suspended sediment particles.

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