A modified Imhoff cone method for estimation of suspended sediment concentration at river

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Abstract: The requirement for monitoring of suspended sediment concentration (SSC) with good temporal and spatial resolution has led to the development of methods for sediment measurement. Imhoff cone method is practical and cheap alternative but moving the water samples to the laboratory and allowing them to settle can be time consuming. In this study, polyacrylamide (PAM), which is a soil conditioner and a flocculant, was tested as an accelerant of sediment settling in Imhoff cones. PAM concentrations of 0.05 and 0.1 ppm were used in water samples. PAM not only flocculates suspended sediment particles for settling, but also provides stable conditions in the settling material. Finalisation of this process in a short time, like 10 min, increases the usability of this method in field conditions without having to move samples to the laboratory. However, this method has the disadvantage that it causes errors at low concentrations and where sensitive measurements are required due to the graduation of the cone. This problem could be solved with better graduated cones or digital sensors for use with the cones.

Keywords: Suspended sediment, Imhoff cone, polyacrylamide

1. Introduction

The measurement of suspended sediment at river has crucial important for hydrological studies. Sediment movement varies spatially and temporally depending on many factors, such as the hydraulic characteristics of the stream, the climatic regime, soil and the vegetation properties of basin. Generally sediment measurements are determined under laboratory conditions by means of water samples taken using special equipment and methods. This method has some difficulties and restrictions such as; the number of samples requirement to represent a cross-section of the river's conditions (Nakato, 1990; McBean and Al-Nassri, 1988).

Different methods can be used for continuous monitoring of sediment transport. But a practical alternative indirect method, is free settleable solids (FSS) analysis using Imhoff cones, is investigated in this study. Settleable solids are defined as the solids that settle in a sample of liquid after a specific time period. This technique is very common in wastewater analysis, and its units are usually expressed in mL/L (APHA,1999).

Pavanelli and Bigi (2005) reported that Imhoff cones, which are usually used to estimate settleable matter for sewage, can be used for estimating suspended sediment concentrations in stream water and are notable for their characteristics of simplicity, cost competitiveness and reliability. They prepared water samples with 12 different sediment concentrations between 1.5 and 30.0 g/L at laboratory to compare turbidity meter and Imhoff cone measurements. After the sample cone is taken, the material that settles down (free settleable solids, FSS) in 1 h and in 24 h is measured in units of ml. It is especially well established that there is a good relation between the 24 h reading and SSC.

Sediment settling velocity depends on specific gravity, density and diameter of the sediment (Jimenez and Madsen, 2003). (Xia et al. 2004) measured sediment settling velocities between 0.001 – 0.02 cm/s depending on particle size. In the clay class (<0.002 mm particle size), sediment settling velocity was less than 0.005 cm/s. In addition, particles finer than 0.0001 mm in water remain continuously in motion due to an electrostatic charge that causes them to repel each other.

For that reason, measurements of sediment samples that include high clay or fine silt take a long time by the Imhoff cone method. Although the Imhoff cone method is practical, cheap and simple to use, transporting these samples to the laboratory and the process of settling can take a long time. Reducing the settling time can increase the effectiveness of this method. Several chemicals known as flocculants can be used to increase the settling velocity of particles in water. Many flocculants are multivalent cations such as aluminium, iron, calcium or magnesium (Gregory, 2006).The anionic form of polyacrylamide (PAM) is frequently used as a soil conditioner on farmland and for erosion control. It also helps to protect the water quality of nearby rivers and streams (Lentz and Freeborn, 2007; Ajwa and Trot, 2006**).** Furthermore, PAM can be used as a flocculant for wastewater treatment. Given these properties, it can be concluded that the Imhoff cone method can be accelerated using PAM.

This study aimed to investigate the use of the Imhoff cone method over short time periods for adoptation of field conditions. Therefore, different amounts of PAM were tested for accelerating the settling of sediment. Soils with different textures were collected from catchments as sediment material, and different concentrations were considered.

2. Materials and Methods

The suspended sediment solutions were prepared with three soil types (passed through a 250-µm sieve) in black plastic buckets to prevent the ambient light in the laboratory from disrupting the turbidity measurements. Soil properties are shown in Table 1. Twenty-five concentrations between 0.0 and 16 g/L were chosen. Homogeneity was maintained with continuous mixing during the measurement process. Available running water was used for preparing samples (0.415 ds/m and pH of 7.6).

Table 1. Properties of the soil used for suspended sediment solutions

Soil Type	Soil texture			OM, %	pH	EC, ds/m	Bulk density, g/L
	% clay	% silt	% sand				
Soil-1	12.03	26.18	61.79	1.033	7.893	1.072	1.42
Soil-2	13.10	24.33	59.67	1.116	8.093	1.221	1.17
Soil-3	35.83	26.60	37.57	2.272	7.557	1.450	1.22

For -this analysis, a 500-ml water sample was used, and 0.05 ppm and 0.1 ppm PAM (charge density of % 20, molecular weight of 14-18 million mg.mol^{-1}) by water volume were added, respectively, to accelerate settling. The sample was then stirred. After this process was complete, the sample was deposited into an Imhoff cone. Sediment settling time has been determined to be 10 and 20 min after deposition into the Imhoff cone. Settled amounts of sediment were measured in mL at predetermined time intervals. Measurements were repeated three times for each sediment concentration. The highest determination coefficient R^2 values were obtained between settling sediment (mL) values versus suspended sediment concentration (SSC) values.

3. Results and Discussion

Measurements of settled solids in Imhoff cones were taken after allowing the samples to settle for 10 and 20 min. The aim of this procedure was to determine the minimum time required for the best settling. Obtained average values in mL units for each waiting time are given in Fig.1. The results obtained show that there was no difference between the readings at 10 min and 20 min ($P<0.05$). The applied PAM immediately adsorbed to soil particles and aggregate surfaces and became irreversibly bound to the soil (Lentz and Sojka, 2000). Thus, PAM not only flocculates suspended sediment particles for settling, but also provides stable conditions in the settled portion. The completion of this process in as little as 10 min increases the usability of this method.

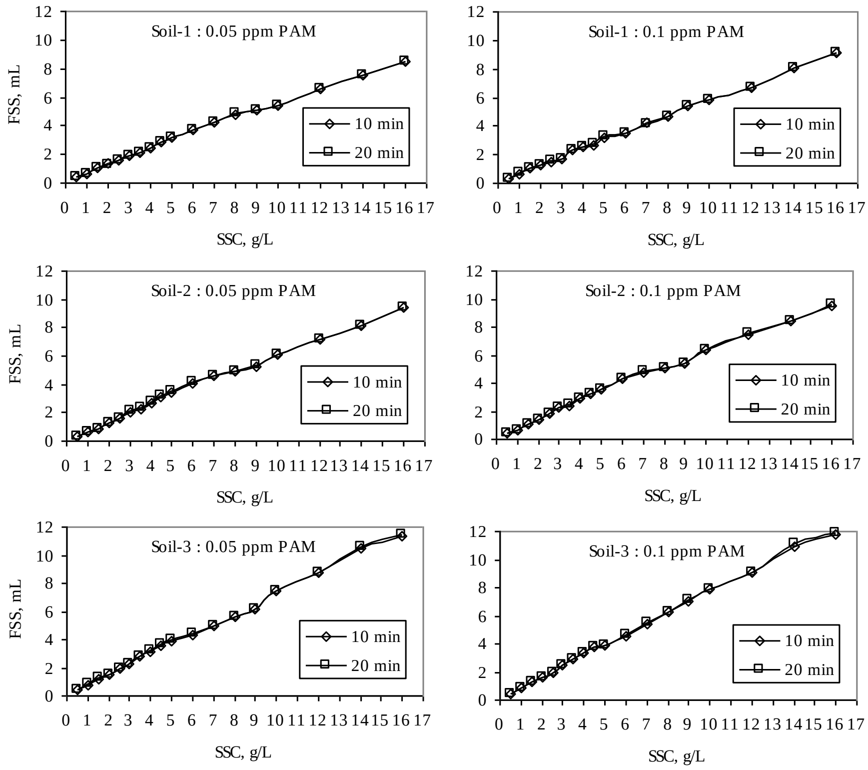

FIGURE 1. Free settled solids (FSS, ml) results for all soil types and PAM concentrations

The other variable to be investigated regarding using PAM in the Imhoff cone method is its concentration. The aim in this study was to use the minimum concentration that caused settling. In this study, 0.05 and 0.1 ppm applications were chosen. Increasing the PAM concentration did not affect observed FSS values in Soil-1, which had a low concentration (<9 g/L), but it increased the FSS value about 5.6% in soils with high concentration. The observed increase was about 7.4% in Soil-2 and about 6.0% in Soil-3. The data gathered after 10 min of settling for each PAM concentration were used for evaluating results. The relationship between SSC and FSS values with the correlation coefficient (R^2) and root mean squared error (RMSE) values were given in Table 2.

Table 2. Regression analysis between suspended sediment concentration (SSC) g/L and free settled solids (FSS), mL.

Soil types	PAM, pm	Regression Equation	R^2	RMSE
Soil-1	0.05	SSC = 1.9035FSS-0.6238	0.9956	0.295
	0.1	SSC = 1.7756FSS-0.3198	0.9977	0.214
Soil-2	0.05	SSC = 1.7191FSS-0.3799	0.9972	0.337
	0.1	SSC = 1.6901FSS-0.5990	0.9935	0.495
Soil-3	0.05	SSC = 1.3994FSS-0.1923	0.9966	0.260

	0.1	SSC = 1.3322FSS-0.2529	0.9978	0.207

The results show a high correlation of free settled solids with suspended sediment concentration for all treatments. Furthermore, all observations used for determining the effectiveness of FSS analysis of all chosen soil types are given in Fig. 5.

It can be seen from Fig. 3 that higher FSS values depend on the clay content of soils. Differences between soil groups between 10.7% and 27.7% are observed because PAM flocculates clay particles and produces aggregates. This situation necessitates calibration of the Imhoff cone method for different sediment materials. On the other hand, the best way to obtain sensitive measurements depends on the sediment values measured in river conditions (Andrew, 2002).

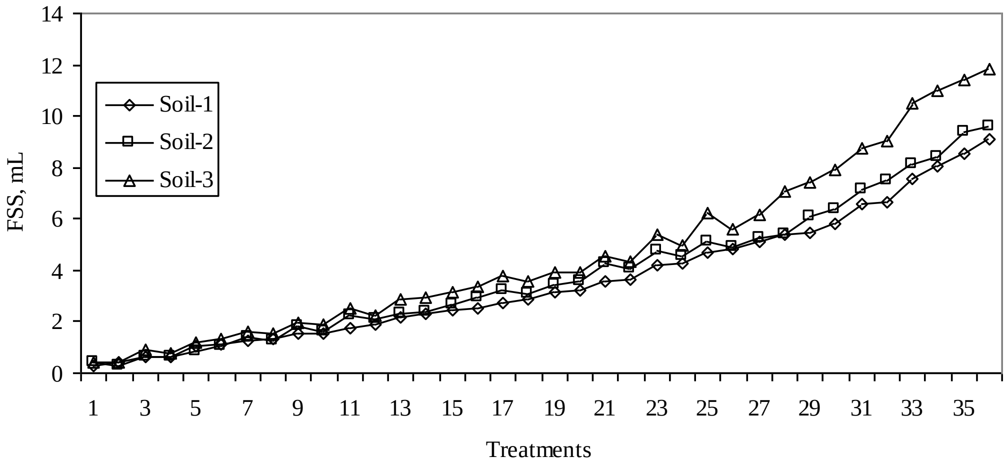

FIGURE 5. The free settled solids (FSS) results for different soil types

Several methods, such as acoustic, laser in situ scattering and transmissometry (LISST), are available for providing continuous sediment measurements. However, these methods are very expensive, require special training and experience and are still undergoing development (Thorne and Hanes 2002; Meral, 2008). Pavanelli and Bigi (2005) reported that Imhoff cone measurements are not significantly influenced by variations in particle size distribution among different samples. However, the best way of obtaining sensitive measurements depends on measured sediment values in river conditions. The use of this practical and cheap method with PAM accelerated the process and increased its usability. With this modification, the measurement results can be obtained at the sampling site without having to transport samples to the laboratory. Errors at low concentrations and measurement sensitivity can be thought of as the disadvantages of this method. The measurement precision of the graduated cone is 0.5 mL for volumes less than 10 mL; 1 mL for volumes of 10-40 mL and 2 mL for volumes ranging between 40 and 100 mL. This problem may be solved by developing digital sensors for use with Imhoff cones.

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