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Comparison of scales for faecal sludge gravimetric characterization in low-resource settings

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Physical and chemical properties of faecal sludge (FS) samples must be routinely measured for FS characterization as well as for design treatment and monitoring purposes. Many of the parameters of interest for FS rely on gravimetric methods of measurement (e.g. total solids, total volatile solids, etc.). As such, they require the use of weighing scales of sufficient reliability, accuracy and precision. Laboratory-grade analytical scales can be difficult to use in remote areas because of their bulk and price point. This study aims to compare two relatively low-cost, off-the-shelf electronic scales to a laboratory-grade analytical (reference) scale. Three scales were compared using their bias, load eccentricity errors and sensitivity errors. The comparison showed that the low-cost scales exhibit a positive bias and are more prone to eccentricity errors than the reference scale. However, they perform well enough to warrant further investigation into whether they can be an acceptable alternative to laboratory scales in field or low-resource settings for faecal sludge characterization.

Introduction

In order to develop adequate systems and technologies to store, handle and treat faecal sludge (FS), one first needs to gather information regarding its composition as well as its physical and chemical characteristics. Studies that have looked at FS characterization have found that its composition can vary greatly in accordance with many factors such as local hygiene practices, presence and type of pit lining, usage and pit emptying frequency, water table exchanges, etc. (Strande 2014). Total solids (TS) and total volatile solids (TVS) are two key parameters that can be used to characterise such variability. These parameters are assessed though gravimetric measurements (APHA 1998). However, the laboratory scales conventionally used to assess these gravimetric parameters can cost upwards of 2000 USD, which can represent a prohibitively large investment in low-resource situations. Moreover, their calibration can be altered whenever they are displaced, and their bulk makes their transport a difficult and expensive proposition.

A plethora of portable weighing scales are available on the market for a variety of other applications (e.g. gems, ammunition, etc.), and their price are spread over several orders of magnitude. The relatively cheaper scales could be a potential alternative to laboratory precision scales, but can they perform sufficiently well for FC characterization? If so, they could be a key asset in for FS gravimetric determinations when laboratory-grade scales are unavailable. To this end, this study is aimed at the comparison (i.e. response linearity, load sensitivity and load eccentricity) of two portable scales with a (reference) laboratory-grade scale.

FS management aims to develop affordable and effective sanitation solutions for communities around the world. However, such treatment strategies can only be implemented effectively if more is known about the product being treated and if monitoring data can be produced consistently and cheaply in areas where the strategies are implemented. Understanding the characteristics and limitations of low-cost field equipment can therefore contribute in its own way to the development of sustainable sanitation by enabling data collection in remote and low-resource areas around the world while remaining cognizant and critical of the resulting data's actual accuracy and reliability.

Methodology

The characteristics of the scales used in this study (Photograph 1) can be found in Table 1. All three scales are equipped with a hood to protect the weighing plate from air currents. The two “low cost” scales (A and B) were compared against the “reference” scale using three different tests (i.e. bias linearity, eccentricity, and sensitivity).

Photograph 1. Scales used for comparison (from left to right: A, B, reference)

Source: J.D. Therrien

Table 1. Characteristics of interest for different scales

Scale model	Approximate retail price (USD)	Maximum load (g)	Readability (g)	Calibration
A	20	20	0.001	Factory default
B	200	75	0.001	Factory default
Reference	2000	205	0.0001	Certified by a professional technician, less than 3 years prior to study

Bias linearity

This test indicates whether the output of the scales exhibits a bias over its operating range, and whether that bias grows linearly in relation to the load (ReliaSoft 2015). In order to assess this, test weights of known mass (5 mg to 50 g) were weighed with each scale. The scales’ biases were then plotted against the known mass of the test weights. The mass of the test weights was assessed by weighing with the reference scale in triplicates over five consecutive days. A linear regression was then performed in order to calculate the slope of the bias. A slope higher than 0 indicates a bias towards higher readings, while a slope lower than 0 shows a bias towards reading lower than the actual mass of the test weights. The test was repeated in triplicate on every day of the experiment, which lasted three days.

Eccentricity

The eccentricity test is used to assess the impact of shear (eccentric) loads exerted on the weighing plate of a scale on its output. A test mass was placed in the centre of the weighing plate, and then halfway towards the edge of the weighing plate in four different directions (towards the back of the scale, towards to front, to the left and to the right). The eccentricity error corresponds to the largest difference between the recorded weight in the centre of the plate and the recorded weight in one of the off-centre measurements (Measurement-Canada 2016). The experiment was repeated in triplicates on three consecutive days.

Sensitivity

The sensitivity test was carried out to determine whether the scale could register small variations in the weight of a live load. The scales were first loaded using test weights of known mass and their output was recorded. A 10 mg mass was then added to the weighing plate and the new reading was recorded. The difference between the reading before and after adding the 10 mg weight were compared to the latter's actual weight to determine the relative size of the error caused by the scale's lack of sensitivity. This test was carried out at a variety of initial loads across the scales' operating ranges. Each initial loading condition was tested in triplicate on three consecutive days.

Results and discussion

Bias linearity

It was found that the bias in the output generated by scales A and B exhibit a slight linearity of 0.12% and 0.10% respectively (*$p<0.05$*). This compared unfavourably to the reference scale, which exhibited no statistically significant bias (*$p>0.87$*). Figures 1-3 show the recorded biases of all three scales at different loads.

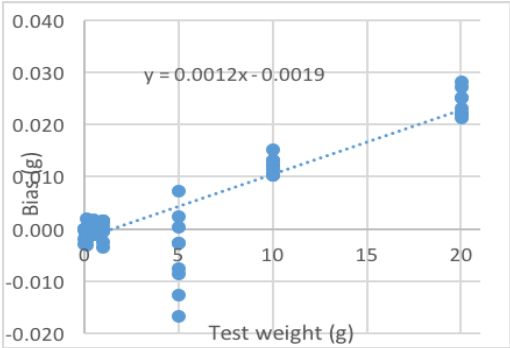

Figure 1. Response bias of scale A

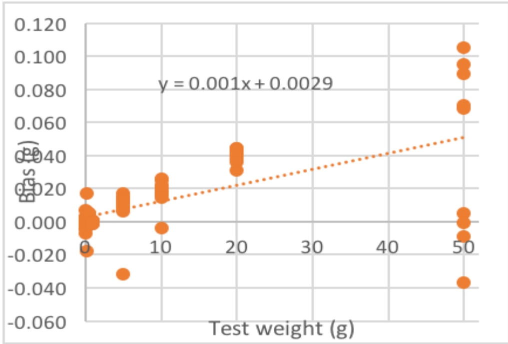

Figure 2. Response bias of scale B

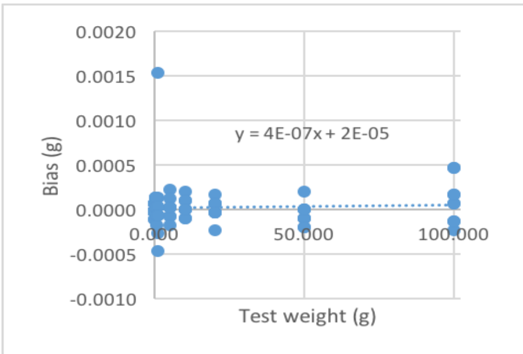

Figure 3. Response bias of reference scale

Eccentricity

The recorded eccentricity errors for the three tested scales are gathered in table 2. This table shows that scales A and B are both much more sensitive to shear loads than the reference scale, with eccentricity errors of 1 and 2 orders of magnitude larger respectively than the one observed in the reference scale. However, eccentricity errors might not negatively affect FS characterization since, as Photograph 2 demonstrates, typical crucibles cover most of the weighing plate surface of B, and scale A's plate is even narrower.

Photograph 2. Scale B with a 5 cm aluminium weighing dish completely covering its weighing plate

Source: J.D. Therrien

Table 2. Recorded eccentricity error at 30% capacity

Scale model	Test weight (g)	Eccentricity error (g)
A	6.001	0.005
B	24.996	0.068
Reference	62.0028	0.0004

Sensitivity

Table 3 shows, the average sensitivity error of scales A and B are both much higher than the reference scale's, however the scale that produced the highest error was scale B. The size of the errors produced by scale B seems to suggest that it is unsuitable for the continuous monitoring of varying live loads, especially if the variations are in the milligram range. For instance, the scale might not be reliable enough to gravimetrically measure the amount of water added to a FS sample during a dilution.

Table 3. Average error in detecting a 10 mg change in loading loading (% added weight)

Scale model	Average error (%)
A	7.0
B	24
Reference	0.5

General remarks

It was found that scale A exhibited lower eccentricity and sensitivity errors and a smaller positive bias than scale B even though it is less expensive. Its weakest point resides in its operating range, which is limited to 20g (possibly insufficient if the weight of the crucible is also considered). This limitation means that it could only be used with very small FS samples, which increases the ultimate uncertainty in the measurement of its characteristics, given the high heterogeneity inherent in FS samples (Strande 2014).

The operating range of scale B reaches 75g, which makes it more suitable for FS characterization than scale A. However, in addition to the results described above, the scale exhibited issues which may complicate its use in the field. For example, the scale's output would sometimes fail to stabilize, instead drifting continuously lower and lower. The protective hood would also exert pressure on the sensors of the scale while it was opened, which means that any object too large for the hood to contain could never be accurately measured by the scale. However, its affordable price point and small, portable, form factor might still make it an attractive alternative to a conventional laboratory scale.

Conclusion

This study was able to assess the performance and limitations of two low-cost weighing scales. While the investigated scales were shown to exhibit relatively larger sensitivity and eccentricity errors than the reference laboratory analytical scale. They were also shown to exhibit a slight but significant positive bias. More work is nonetheless needed in order to determine whether the level of performance they do offer is adequate for FS characterization in settings where serviceability is more important than razor-sharp accuracy.

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