

*Water Resources Research*

Supporting Information for

**Effects of sand addition and bed flushing on gravel-bed surface microtopography and roughness**

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**Introduction**

This supporting information provides details on the method used for evaluating the performance of DEMs of Differences (DoDs) for detecting sand accumulation on a gravel bed. The method relies on a comparison with results obtained using image analysis.

Text S1.

In this paper, changes in gravel-bed topography resulting from sand addition and bed flushing are assessed using DEMs of differences (DoDs) by subtracting DEMs collected at different epochs. A minimum level of detection (*minLOD*), dependent on measurement accuracy and a chosen Confidence Interval (CI), is necessary to distinguish real topographic changes from the inherent noise or errors in measurements. However, this limits the capacity to detect small changes, such as shallow sand deposits, which may be important expressions of sand addition in gravel-bed rivers.

To evaluate these effects, we developed an image analysis technique to determine sand content (i.e., the percentage of the bed-surface area covered by sand) from top-view photographs of the bed surface. This provided ‘truth measurements’, against which sand contents determined from DoDs, were subsequently compared.

The same high-resolution photographs of the bed surface used for producing the DEMs were used as inputs for image analysis (Figure S1B). Photographs were collected using a Nikon D5100 camera (16.4 Mpixel, 23.6 × 15.6 mm2 sensor size, 20 mm fixed focal lens), placed approximately 0.7 m above the flume centerline using a carriage and looking down vertically at the bed surface, resulting in a ground pixel size ~0.15 mm.

Image analysis consisted in i) using GIMP (GNU Image Manipulation Program) to manually color in red (Figure S1C) areas of the bed covered by sand (this required zooming in to achieve the best results); ii) reading the resulting image in Matlab to determine the percentage of the image area colored in red, which in return provided the percentage of the bed-surface area covered by sand (Figure S1D); and iii) resampling the image (1 x 1 mm pixel size) to enable comparison of sand cover determined using a DoD and image analysis, respectively. With a ground pixel size ~0.15 mm, the photograph used in the image analysis warranted high precision sand detection, with the possibility to identify individual sand grains (D50,sand = 0.9 mm). For this reason, using the results of the image analysis as benchmark was considered

C:\Users\sber081\Desktop\Gravel+Sand\Analysis\minLOD\Image processing vs DoD\Run 3\Pulse 1 (tested)\Crop 336x181 (tested)\Output\Comparison_Image_DEM.tifFigure S1. Measurement of sand cover on the gravel bed following the passage of the second sand pulse in run 3 using (a, e, f, g, h) a DoD and (b, c, d) image analysis. (a) is the DEM of the bed surface - the inset shows the region where sand content was measured; (b) is the through-water photograph of the bed cropped to the region of interest; (c) is the same photograph as in b with sandy areas manually colored in red; (d) is the result of automatic identification of red color in c using Matlab; (e, f, g, h) show different sand covers resulting from varying the measurement accuracy (SDE) in the DoD. The ‘true’ measurement accuracy of photogrammetric DEMs in our study was estimated as 1.1 mm.

appropriate. Limitations of the method lie in the long processing time and manual intervention required for inspecting the photograph and coloring sandy areas. This is unavoidable as sand grains are characterized by a spectrum of colors that largely overlapped that of natural gravel (Figure S1B), which restricts the automatic identification of sand from gravel particles based on pixel intensity. Manually coloring sandy areas in red was an effective (but not necessarily efficient) solution (Figures S1C and S1D).

In the following, the bed after the passage of the second sand pulse in run 3 is used as an example to compare sand contents determined using a DoD and image analysis, respectively. To ensure a timely application of image analysis, the comparison is done over a portion of the bed only (Figure S1A). Manually coloring sandy areas required several hours. When measuring sand content with the DoD, the effect of different measurement uncertainties on geomorphic change detection was evaluated by changing the value of the Standard Deviation of Error (SDE) and CI in Eqn. 6. This produced different *minLODs*, with values ranging from 0.18 mm for SDE = 0.1 mm and CI = 80% to 4.16 mm for SDE = 1.5 mm and CI = 95% (cf. Table S1). It should be noted, however, that SDE characterizes the DEM accuracy and is normally assigned with a fixed value (DEM accuracy was represented by SDE = 1.1 mm in our study). To test, we found that varying SDE was a worked well to assess the capacity of a DoD for detecting small geomorphic changes and to determine what would be the required DEM accuracy to achieve sand detection comparable with image analysis.

Visually, it is clear that the higher the DEM accuracy (i.e., small SDE), the better the sand detection using the DoD (Figure S1), since high DEM accuracy also means a small *minLOD* (Table S1). Only for SDE = 0.1 mm did sand cover measured with the DoD amount to a quantity equivalent to that measured using image analysis (i.e., sand cover ~40% of the bed surface, Figure S2). However, a more detailed analysis shows that improving sand detection was counterbalanced by a decrease in the reliability of the results. For instance, values of SDE below 1.1 mm resulted in a significant increase in the percentage of DoD cells wrongly indicating erosion, rising to more than 40% for SDE = 0.1 mm (Figure S2). In reality, bed erosion amounted to less than 1% of the bed surface; DoD cells indicating erosion were the result ofa *minLOD* too low given the measurement uncertainty. Likewise, a reduction in SDE below 1.1 mm resulted in an increase in DoD cells wrongly identified as sand deposition (Figure S3). These observations suggest that SDE = 1.1 mm correctly characterizes the DEM accuracy in our study, since increasing detection errors for values of SDE below 1.1 mm meant that the level of detection was inadequate given the accuracy afforded by the measurements.

In terms of the effect of CI on geomorphic change detection, Figures S2 and S3 confirm the findings presented in the paper that CI = 80% improves change detection compared to CI = 95%, which is shown by an increase in the areas of sand deposition correctly detected without an increase in detection errors.

**Table S1.** Effect of DEM accuracy (represented by Standard Deviation of Error, SDE) and Confidence Interval (CI) on the minimum level of detection (*minLOD*) afforded by the measurements.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SDE  (mm) | 0.1 | | 0.3 | | 0.5 | | 0.7 | | 0.9 | | 1.1 | | 1.3 | | 1.5 | |
| CI (%) | 80 | 95 | 80 | 95 | 80 | 95 | 80 | 95 | 80 | 95 | 80 | 95 | 80 | 95 | 80 | 95 |
| minLOD (mm) | 0.18 | 0.28 | 0.54 | 0.83 | 0.91 | 1.39 | 1.27 | 1.94 | 1.63 | 2.49 | 1.99 | 3.05 | 2.35 | 3.60 | 2.71 | 4.16 |

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**Figure S2.** Effect of DEM accuracy (represented by Standard Deviation of Error, SDE) and Confidence Interval (CI) on geomorphic change detection (deposition and erosion) using DoD analysis. The horizontal dashed line represents sand cover determined using image analysis, which here represents the ‘truth value’. The vertical line shows the SDE estimated for the study (SDE = 1.1 mm).

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**Figure S3.** Effect of SDE and CI on the reliability of DoD analysis for sand detection. The vertical line shows the SDE estimated for the study (SDE = 1.1 mm). Filled markers correspond to CI = 80%, empty markers to CI = 95%. ‘Cells correctly picked up’ and ‘not picked up’ by DoD are expressed as a percentage of the number of cells identified as covered by sand using image analysis. ‘Cells wrongly picked up by DoD’ are expressed as a percentage of the number of cells identified as covered by sand using the DoD.