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Comparison of software accuracy to estimate the bed grain size distribution from digital images: A test performed along the Rhine River

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Abstract

The quantification of the bed grain size distribution (GSD) of river surfaces is primarily conducted through manual approaches in the field. These methods are time consuming and not able to accurately represent the spatial diversity of the grain size distribution of rivers. Recently, several software programmes and procedures have been developed using semi-automatic and automatic methods to estimate bed GSD from digital imagery. The purpose of this study is to compare softwares accuracy between reference GSDs and estimated GSDs using geometric approches (Basegrain software and a procedure developed on ImageJ), statistical approaches (Digital Grain Size (DGS) and PebbleCounts softwares) and a machine learning framework (SediNet). This study evaluates ten digital images recorded along the Rhine River downstream of the city of Basel. The results showed that all software programmes considerably underestimated the manually measured GSDs. Nevertheless, it is possible to significantly improve the estimation of bed GSD by applying calibration laws. Both DGS and Basegrain softwares are reliable to estimate the GSD,while the three others softwares are accurate for percentiles equal and

higher than the D_{50}. After linear regression correction, the mean NRMSE of percentile errors did not exceed 13% for DGS and Basegrain software, while the others not exceed 22% for percentiles coarser than the D_{50}.

Key words: bed grain size, digital images, software accuracy, river, Rhine

1. Introduction

Riverbed grain size is a key parameter in geomorphological and ecological studies of rivers. This parameter allows researchers to evaluate physical habitat quality , sediment transport dynamics and restoration action effects. The quantification of the bed grain size distribution (GSD) of river surfaces is mostly conducted through manual approaches in the field, such as Wolman sampling, the paint-and-pick approach or grid sampling (Bunte & Abt, 2001). These methods are time consuming and obtained punctual measurements are not representative of the spatial diversity of a river's grain size distribution (Graham et al., 2010). Currently, new remote sensing methods have been developed to semi-automatically or automatically estimate the bed GSD of bar surfaces. These approaches are divided into two classes: (i) two-dimensional approaches using terrestrial and aerial imagery (Baptista et al., 2012; Chang & Chung, 2012; Chardon et al., 2021; Graham et al., 2005; Lejot et al., 2011; Purinton & Bookhagen, 2019; Rubin, 2004; Strom et al., 2010; Sulaiman et al., 2014; Turley et al., 2017) and (ii) three-dimensional approaches using photogrammetry, laser scanning or LiDAR datasets by estimating roughness as a proxy of bed GSD (Brasington et al., 2012; Chardon et al., 2020; Heritage & Milan, 2009; Vázquez-Tarrío et al., 2017; Woodget et al., 2018). Although the photographic sampling method does not enable the mapping of surface GSD over a large area as usually with a three-dimensional approach, it requires only a simple camera and thus is less costly than the precendently mentionned. Moreover, terrestrial photographic sampling requires fewer preprocessing steps for correcting raw data than three-dimensional approaches, which can

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be difficult and technical (e.g., cleaning and georeferencing of raw point clouds, roughness metric calculation and calibration with the manual field GSD) (Brasington et al., 2012; Heritage & Milan, 2009; Vázquez-Tarrío et al., 2017; Woodget et al., 2018). However, the accuracy of two-dimensional approaches is extremely sensitive to environmental conditions such as sun illumination, the presence of vegetation or biofilms, and sediment petrography or/and mineralogy. In addition, for suhtwo-dimensional approaches, bed sediment structures (burial, overlapping and foreshortening) also influence the accuracy of the obtained results (Graham et al., 2010; Hodge et al., 2009).

Two methods were used to estimate the bed GSD from digital images via morphological approaches and statistical approaches (Buscombe, 2013). Morphological approaches use thresholding and segmentation processing to define the outline of each visible particle, while statistical approaches tend to estimate the grain size through image texture analysis from the semi-variance approach (Carbonneau et al., 2004), autocorrelation approach (Warrick et al., 2009), the wavelength approach (Buscombe, 2013) and recently following the k-means approach (Puriton et al., 2019). Deep learning methods were also developed to estimate automatically the GSD using digital images as SediNet (Buscombe, 2020) and GRAINet (Lang et al., 2021). Although Basegrain (morphological approach) and DGS (statistical approach) programs are frequently used to estimate the GSD from digital images, a question still remains: which software provides, using default parameters, the most accurate estimation of bed GSD from digital imagery? The objective of this study is to compare the software accuracy of reference GSDs and estimated GSDs from DGS, Basegrain, SediNet, PebbleCounts software and a procedure using ImageJ. The analysis was based on ten digital images sampled along the Rhine River downstream of the city of Basel.

2. Methodology

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2.1 Study area

Photographic sampling was performed on the Old Rhine River between the cities of Kembs and Ottmarsheim over five above-water deposits. The Old Rhine River is a bypassed and regulated reach in the Alsacian Plain. An instream flow is maintained in the Old Rhine between 52 and 115 m^3/s from the Kembs derivation dam, depending on the natural hydrological regime of the Rhine River (Fig. 1b). Spills occur in the Old Rhine River when the Rhine River discharge exceeds 1400 m^3/s in Basel, which is the maximum flow capacity discharge of the Grand Canal d'Alsace (GCA). The channel bottom of the study reach is composed mainly of gravel and cobble (Arnaud et al., 2015). The mean slope and mean width are equal to 0.09% and 100m, respectively (Fig. 1b).

2.2 Field data collection

Photographic sampling was performed on clean substrates without vegetation or a biofilm to avoid substantial estimation errors induced by these elements (Chardon et al. 2020). According to the recommendations of Barnard et al. (2007) and Chardon et al. (2020), all digital images were taken under an umbrella in order to control solar conditions which could influence GSD estimations (Fig. 1). Moreover, all images were taken using a telescoping bar and a bubble level to capture sediment patches with a horizontal plane of view. The camera used was an Olympus TG-4, and the image resolution was equal to 16 MP (4608 x 3456 pixel). A median filter was applied to reduce error in the estimation resulting from pepper and salt phenomena (Chardon et al., 2020). As recommended by Chardon et al. (2020), the median-sized filter used in this study was equal to 5% of the Dmax value measured for each digital image.

2.3 Image processing

2.3.1 Manual digitalization

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Following the recommendations of Barnard et al. (2007), the b-axes of 80 to 100 particles were digitized manually from each digital image using a sampling grid to obtain a reference distribution. This step, which was performed using ImageJ software, allows us to achieve a reference GSD.

2.3.2 DGS software

The first software used to automatically estimate the grain size of 10 sediment patches was the DGS software developed by Buscombe and implemented in MATLAB (2013). This software is based on a statistical approach using the wavelength method which automatically provides the GSD in grid sampling (Fig. 2). . Batch processing has been proposed to evaluate the GSD of a large number of digital images. No filter was applied, and the totality of the surfaces of the digital images was considered for GSD estimation.

2.3.3 Basegrain software

The second software used in this study is Basegrain software (Detert and Weitbrecht, 2013), which was also developed for MATLAB software (Fig. 3). The approach of Basegrain is based on a morphological method. Five preprocessing steps are available for the user to compute median filter options, the minimal size of a grain area (for watershed algorithm application) and the minimal number of pixels (to determine the minimal area), which is related to grain size (Detert and Weitbrecht, 2013). This study used the default options for each step to decrease the processing time of digital images and to compare the methods between them without to not to favour one method over another. The GSD can be obtained in a grid sampling form.

2.3.4 Procedure using ImageJ software

The method using ImageJ is based on a procedure established by (Sulaiman et al., 2014), which proposed a morphological approach to automatically extract the GSD by areal

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sampling. We slightly changed this protocol as follows: (i) the digital images are transformed in 8-bit format, (ii) the substrate background algorithm is applied with mobile windows equal to 50 pixels by default, (iii) an automatic threshold for black and white transformation is applied, (iv) the watershed algorithm is applied and (v) the b-axis of all detected particles were determined via automatic measurement (Fig. 5). To compare the GSD obtained with this method (areal sampling) to the two previous estimations from DGS and Basegrain software, we collected the b-axis of 60 to 100 particles detected using a grid built with QGIS software.

2.3.5 PebbleCounts software

This software was developed in Python language and used initially to estimate the apparent GSD of above-water bar deposits using aerial imagery from a drone (Puriton & Bookhagen., 2019). This software was recently used to estimate the longitudinal bed grain size variations along 100 km of river length of the Toro watershed located in Argentina (Puriton & Bookhagen, 2021). In this study, we used the automatic procedure named as PebbleCountsAuto (AIF) which used edge detection and filter automatically suspect grains (Puriton & Bookhagen., 2019). Same as the procedure in ImageJ software, we collected the b-axis of 60 to 100 particles detected using a grid built with QGIS software from X and Y coordinates provided by the output files of the software.

2.3.6 SediNet software

This software was based on machine learning framework developed by Buscombe (2019) using python language. It allows to estimate quantitavelty and automatically the measurements from digital images and given percentiles values directly at the output. In this study, we used the trainer developed only for gravel deposits related to our dataset.

2.4 Estimation of the prediction accuracy

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To evaluate and compare the prediction accuracy of each software, we compared percentile values estimated by each automatic processing to the reference distributions. The variation between the predicted and reference values was quantified by two metrics, i.e., the NRMSE (Eq. 1) and NMAE (Eq. 2), which were calculated as follows:

$$NRMSE = \frac{\sqrt{\sum_{i=1}^{n} (x_i - x)^2}}{x_{mean}} \quad (1)$$

$$NMAE = \frac{\left(\frac{\sum_{i=1}^{n} |(x_i - x)|}{n}\right)}{x_{mean}} \quad (2)$$

where x_i is equal to the value of the predicted percentile and x is the value of the manually measured percentile. X_{mean} corresponds to the mean value of the percentile manually measured for the digital image dataset.

3. Results

3.1 Software accuracy before calibration

Fig. 6 shows that all softwares underestimated all percentiles. The results are quite similar for Basegrain software from D_{10} to $D_{50,}$ with a net underestimation of these percentiles (Tab. 1). In contrast, from D_{75} to D_{95}, an overestimation occurred using Basegrain (Tab. 1). Globally, for all software programmes, the NRMSE and NMAE decrease according to the increase in the estimated percentile (Fig. 7). However, the values of these parameters differ considerably between the compared software programmes. For DGS software, the maximal NRMSE and NMAE values of percentile errors were equal to 56% and 47%, respectively. For Basegrain software, the maximal NRMSE and NMAE values were equal to 97% and 90%, respectively (Fig. 7). For the ImageJ procedure, the maximal RMSE and

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NMAE values equal 88% and 79%, respectively. For SediNet, the maximal RMSE and NMAE values equal 67% and 58%, respectively. For PebbleCounts, the maximal RMSE and NMAE values equal 71% and 59%, respectively.

3.2 Software accuracy after calibration

Significant linear relationships were found between the manually measured and predicted percentiles by DGS and Basegrain software (Tab. 1.) Only significant statistical linear relationships were found from D_{75} between the predicted and manually measured percentiles by the procedure using ImageJ software (Tab. 1). For SediNet, significant statitical relationships where found for D_{10}, D_{16}, D_{25}, and D_{84}, respectively. Whereas for PebbleCOunts, significant relations where found from the D_{75} (Tab. 1). For the latest, no relationship was observed for the D_{10} with a R-square close to 0.

Through the application of linear regressions, a reduction in NRMSE and NMAE occurred for all percentiles and all procedures between the corrected-predicted percentiles and manually measured percentile due to a high reduction of the previous under-estimation of before correction (Fig. 7; Fig. 8). For DGS software, the maximal NRMSE and NMAE values of percentile errors were equal to 20% and 17%, respectively. For Basegrain software, the maximal RMSE and NMAE values of the percentile errors were equal to 20% and 16%, respectively. For the ImageJ procedure, the maximal RMSE and NMAE values were equal to 40% and 33%, respectively (Fig. 7). For SediNet, the maximal RMSE and NMAE values were equal to 33% and 23%, respectively. Finally, for PebbleCounts, the maximal RMSE and NMAE values were equal to 38% and 33% excluding the D_{10}.

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4. Discussion

4.1 Comparison of software accuracy

Our results showed that all methods underestimated the GSD with great error in comparison to the reference GSD obtained through the manual approach. This underestimation is explained by an oversegmentation of particles due to petrographic variation (Sime & Ferguson, 2003; Strom et al., 2010; Warrick et al., 2009). To reduce the error estimations, a calibration correction must be applied to improve the GSD estimation, as that proposed by Chardon et al. (2020) (Fig. 7; Fig. 8). Our results show that both DGS and Basegrain are reliable software programmes to estimate the GSD on digital images after linear regression correction (Fig. 8). The maximal value of error estimation was less than 18% (NMAE) after the linear correction (Fig. 7). The other three softwares are also reliable for percentiles estimation coarser than the D_{50} (Fig. 7). The maximal value of error estimation was equal to 22% (NMAE for SediNet) after linear correction (Fig. 7).

4.2 Software advantages and limitations

Each software presents advantages and limitations. For DGS software, the GSD was obtained quickly, and no extra preprocessing step than a median filter application was necessary. Nevertheless, this software is similar to a “black box” with no means to see the detected particles and perform error localization in digital images, which does not allow to evaluate which parameter primarily influences the particle detection. This means that there is no possible way to change the software parameters. The same limitation occurs for SediNet due to the deep learning method used. For PebbleCounts software, the advantage is that only one parameter required from the user before computation and the results of the grain identification are visible in a new window. On the other hand, Basegrain software allows you to view the detected particles and spatial errors but also allows operator intervention to modify or delete the detected particle outlines. However, in some

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cases, numerous visual checks may be necessary during the preprocessing steps (n=5) to obtain satisfying results. In our cases, to be consistent with the idea of quick and easy data processing, no calibration steps were implemented, and the GSD being estimated by the automatic object detection tool of Basegrain. For the ImageJ procedure, the main limitation is the application of step 3, which consists of applying an automatic threshold for black and white transformation that is necessary for the application of the watershed algorithm. Because pixel color values differ between each digital image, it is very difficult to find a single threshold for a set of digital images. In addition the several manual preprocessing steps of this procedure increase the processing time (Fig.5), which may be problematic for large datasets.

4.3 Future research avenues

The main advantage of using terrestrial digital images rather than aerial images or three-dimensional techniques (photogrammetric or LiDAR data) is the low required material cost. It is also a less time-consuming post-processing approach as most of the measurement errors could be avoided during the field data collection (vegetation, biofilm, sun, etc.), and less specific technical knowledge than three-dimensional approaches are needed. Thus, this method could be easily used by river managers to quickly estimate the bed GSD on both clean above and underwater bars for the planning step of river restoration projects, evaluate natural changes or integrate bed GSD spatial distribution in numerical hydrosedimentary models. However, questions still remain: what is the best sampling procedure to integrate the spatio-temporal variability of the GSD? Because digital images allows to estimate the local bed grain size quickly, how to estimate the GSD from this sampling procedure at a larger spatial scale, similar to aerial or three-dimensional approaches? Is this approach is a compromise between quantity and quality? More studies have to be conducted in this topic to determine a robust sampling protocol using digital images. Each of these sampling protocols should be guided by (i) the main objective

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of the study, (ii) the sampling effort and (iii) the precision, which must be consistent with the final use of the data.

5. Conclusion

The purpose of this study was to evaluate and compare the accuracy of GSD estimations from ten digital images recorded on the Rhine River using five software programmes. Results showed that all software programms underestimated manually measured GSDs. However, after linear regression correction, the NMAE decreased and did not exceed 18% for the DGS and Basegrain software for all percentiles. For the three other softwares, the estimation is reliable for percentiles higher than the D_{50} with a NMAE below 22%. This study shows that it is possible to estimate the bed GSD of clean substrates in a precise manner using DGS and Basegrain softwares for the entire distribution and the three other softwares for percentiles equal and higher than the D_{50}. However, a calibration step must be applied in all cases.

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None

Conflict of Interest

None

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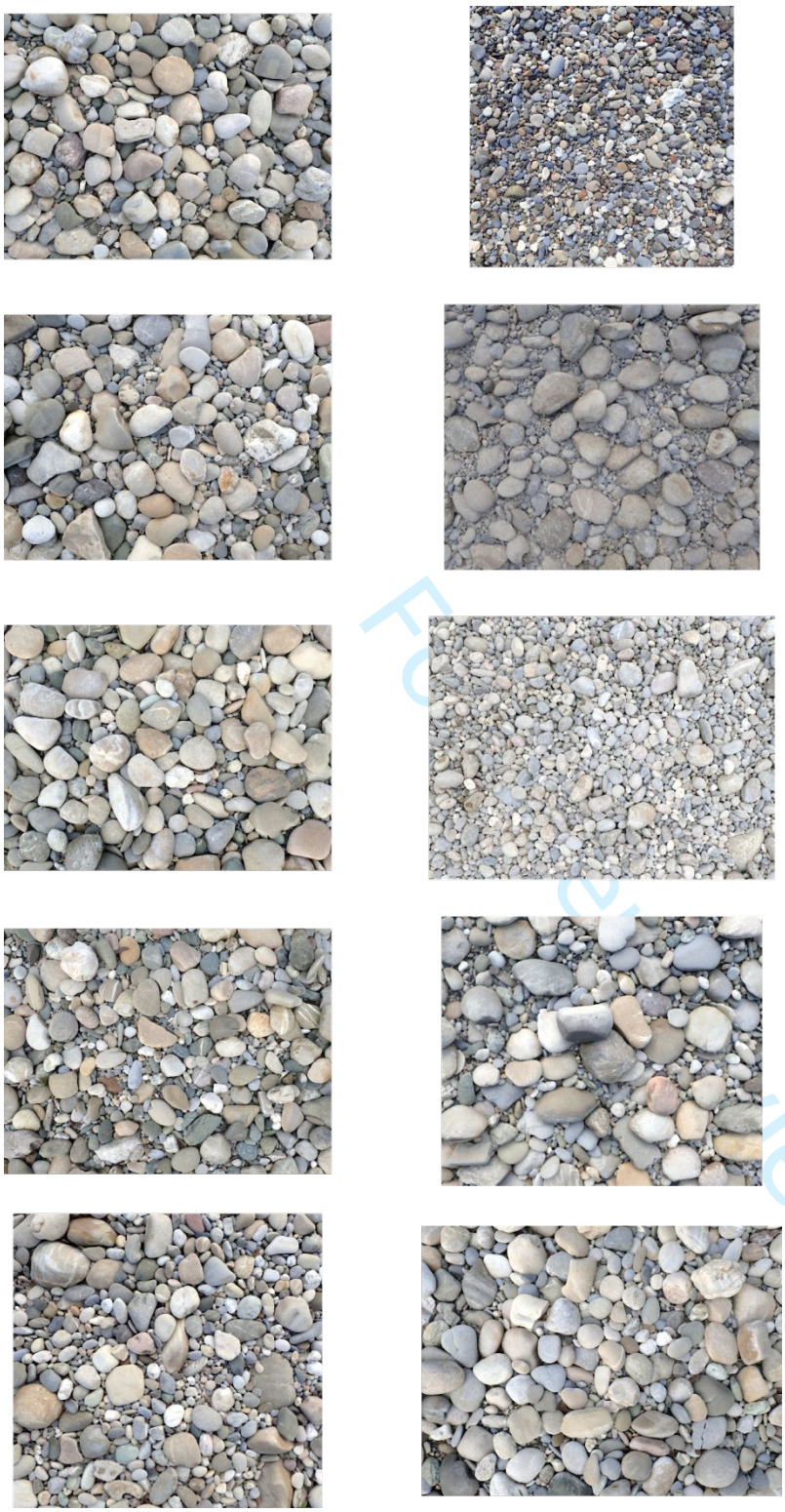


Fig. 1: Set of sediments deposits studied (n=10). A median filter was applied before analysis following the recommendations of Chardon et al., (2020).

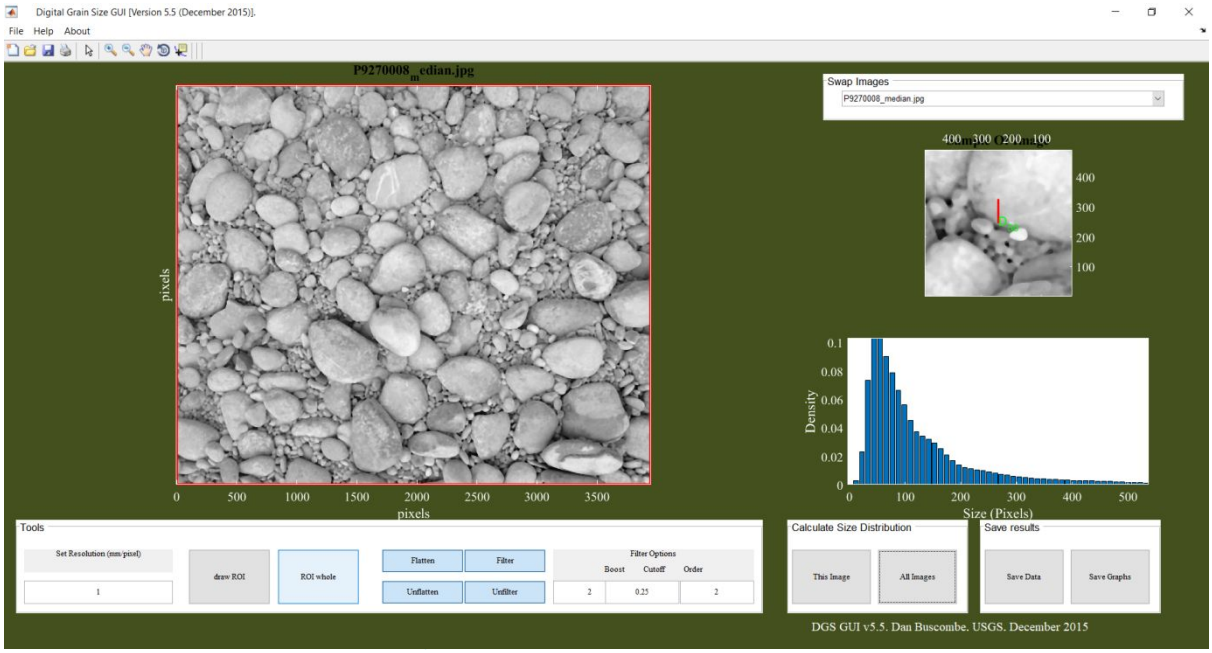


Fig. 2: Example of image processing by DGS software developed by Buscombe (2013).

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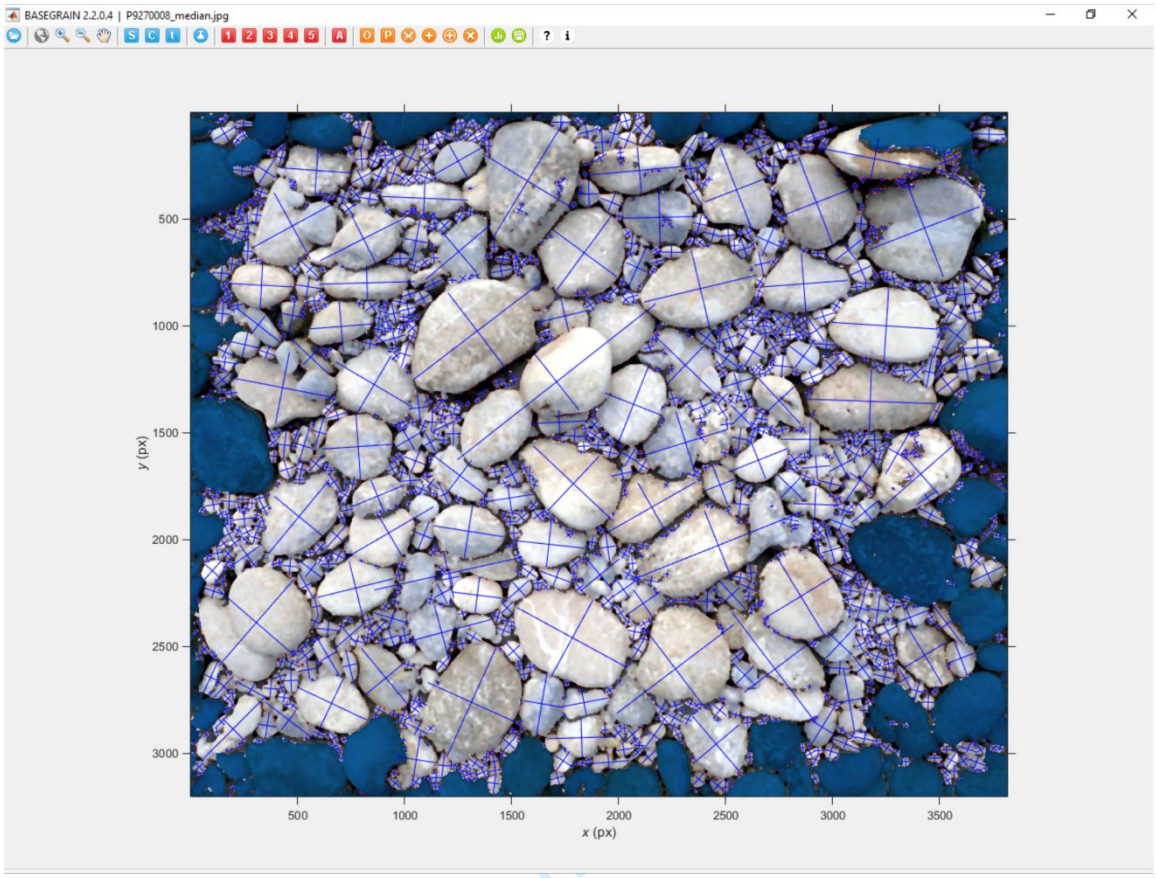


Fig. 3: Example of image processing by Basegrain software developed by Detert and Weitbrecht (2013).

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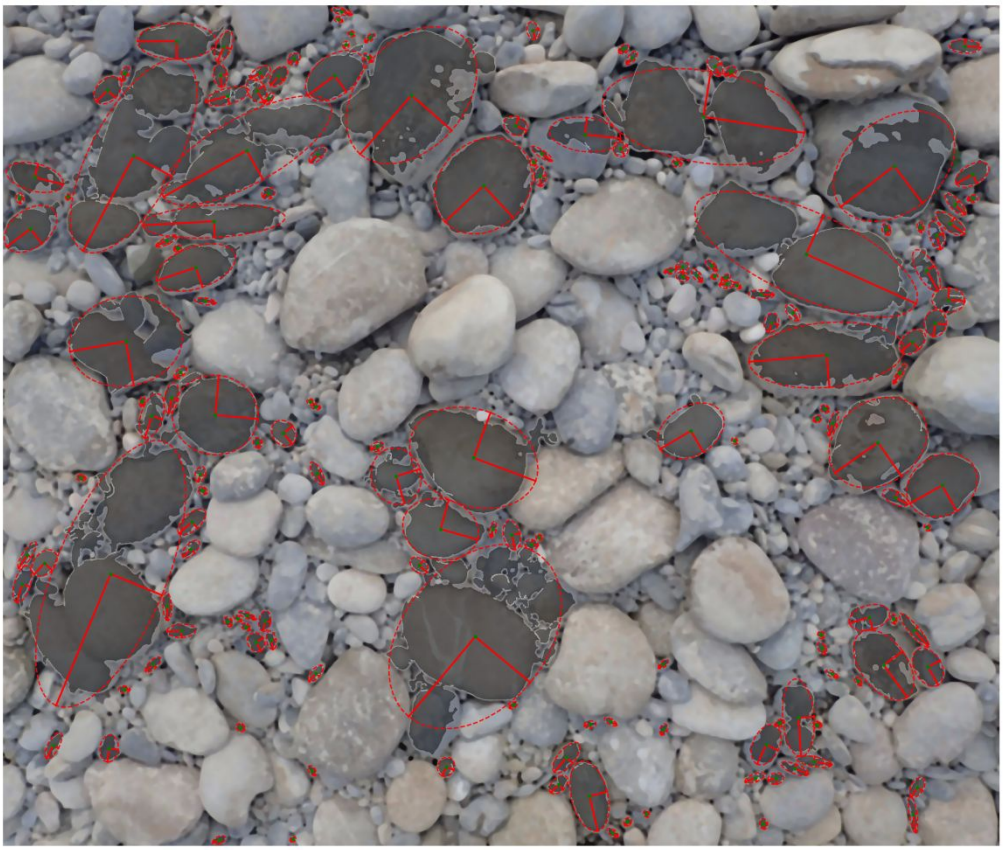


Fig. 4: Example of image processing by PebbleCounts software developed by Puriton & Bookhagen (2019).

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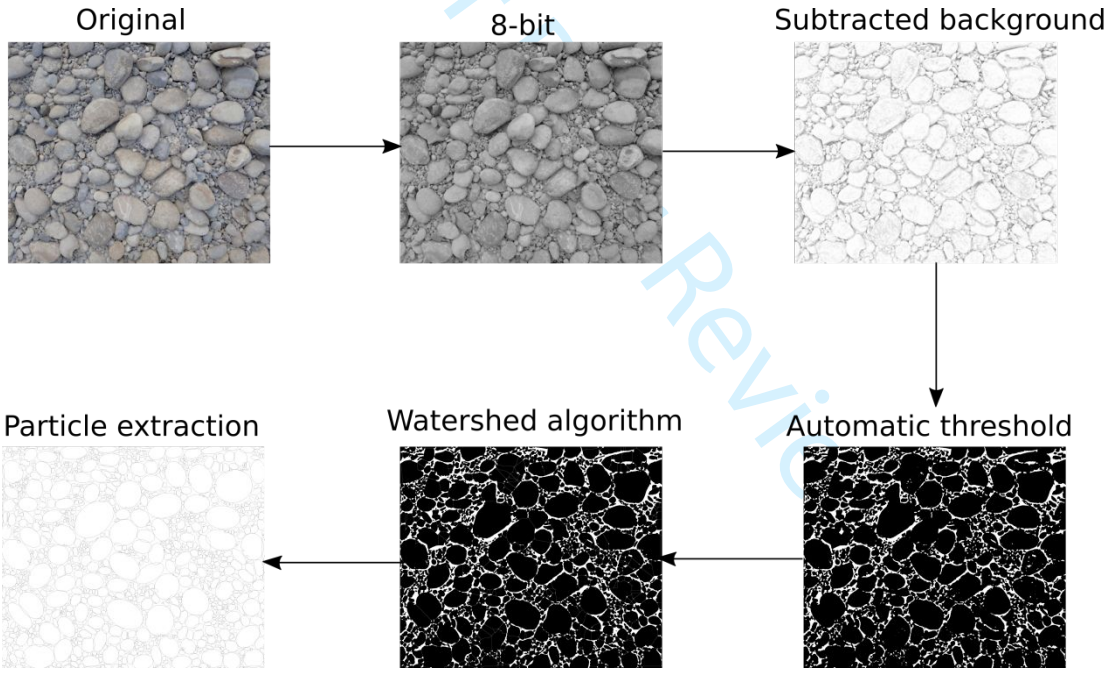


Fig. 5: Example of image processing by ImageJ software and based on the protocol developed by Sulaiman et al. (2014).

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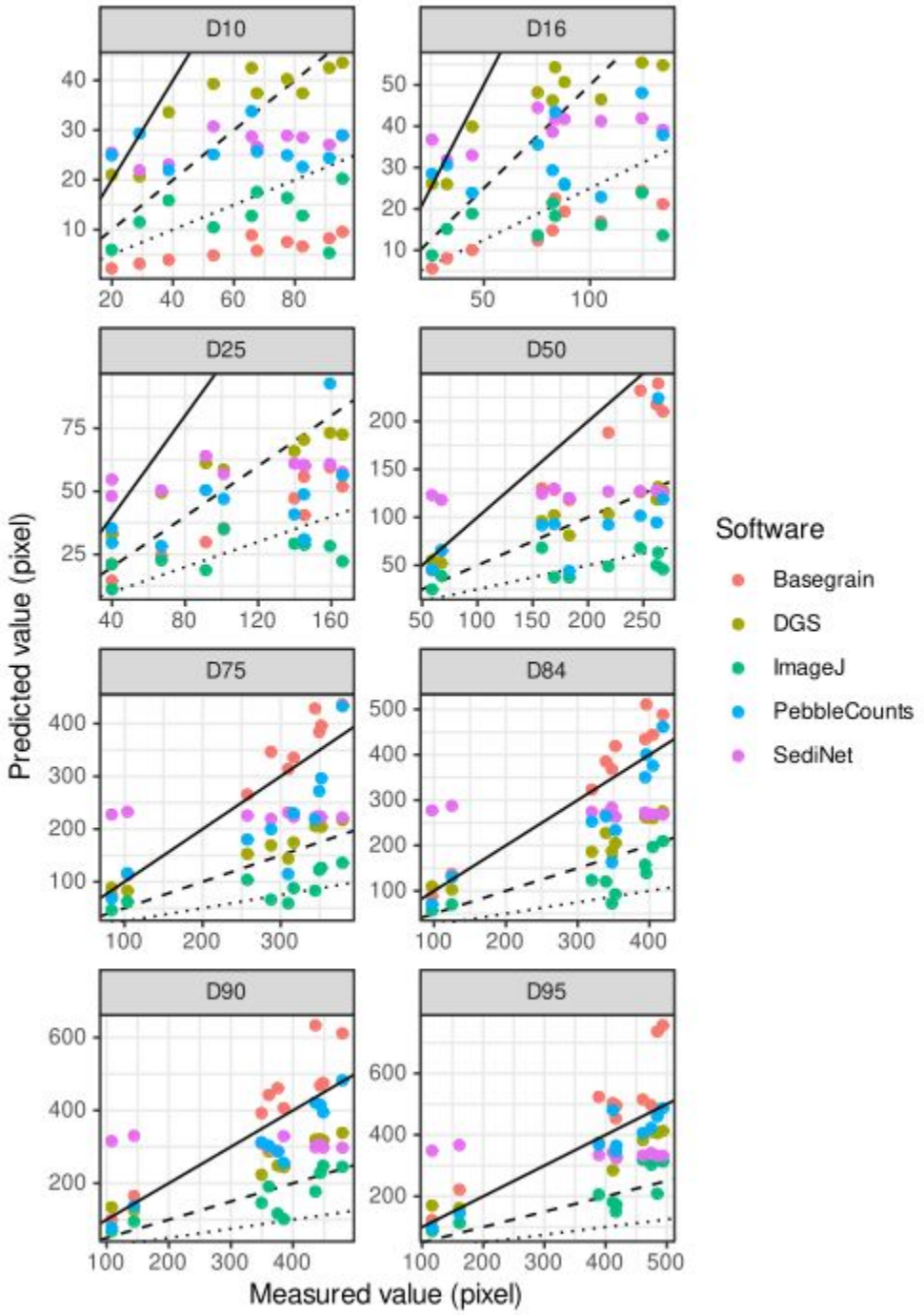
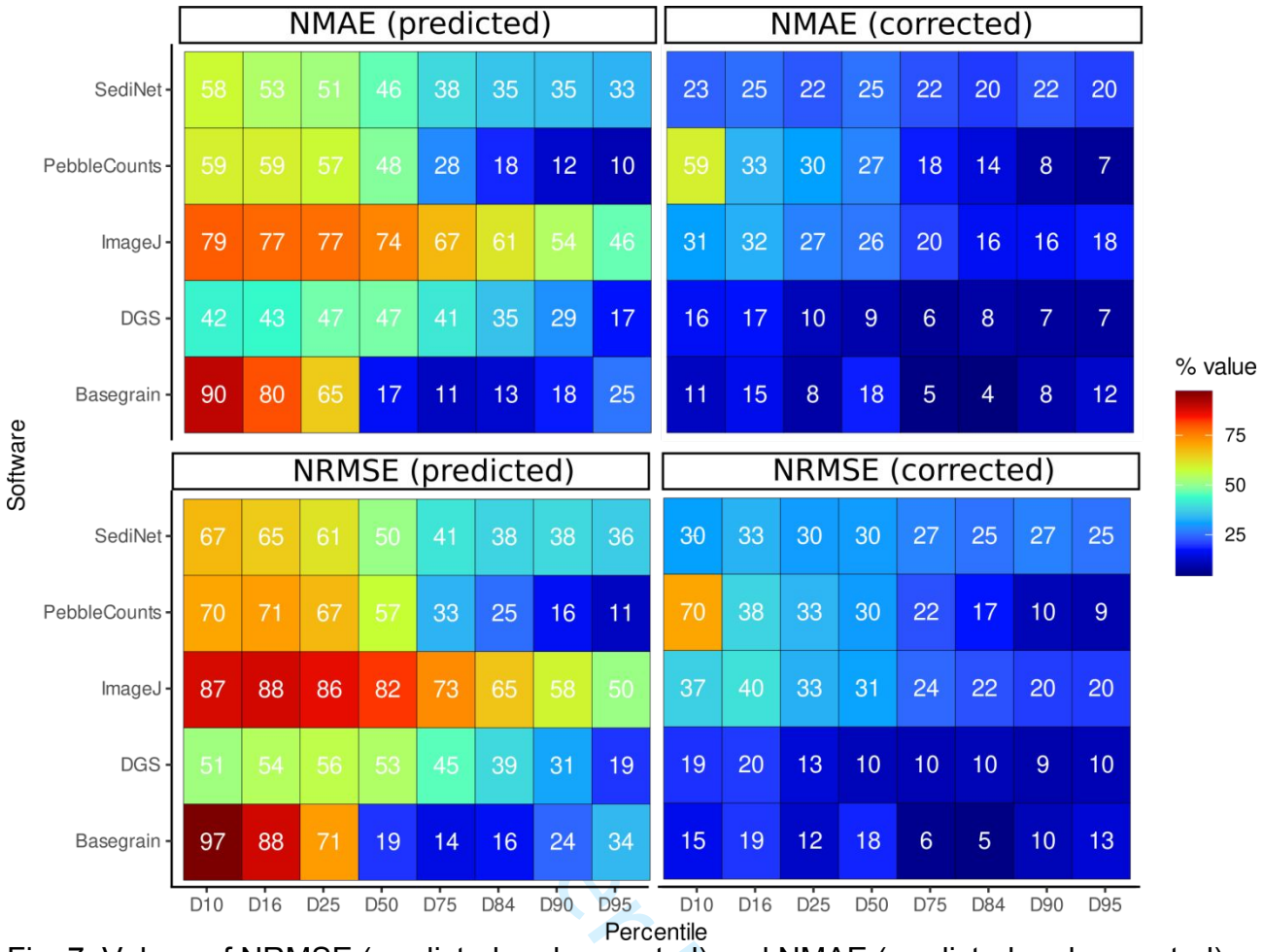


Fig. 6: Predicted percentiles of the GSD for the three methods according to manually measured percentiles before calibration. The black line and dotted black line correspond to the y=x and y = 1.5x line equations, respectively. Continuous black line, dashed black line and dotted black line corresponds to y=x equation, y=0.5x equation and y=0.25x equation, respectively.



454 Fig. 7: Values of NRMSE (predicted and corrected) and NMAE (predicted and corrected)
455 for each softwares. Predicted and corrected correspond respectively to no calibrated and
456 calibrated results after linear regression application.

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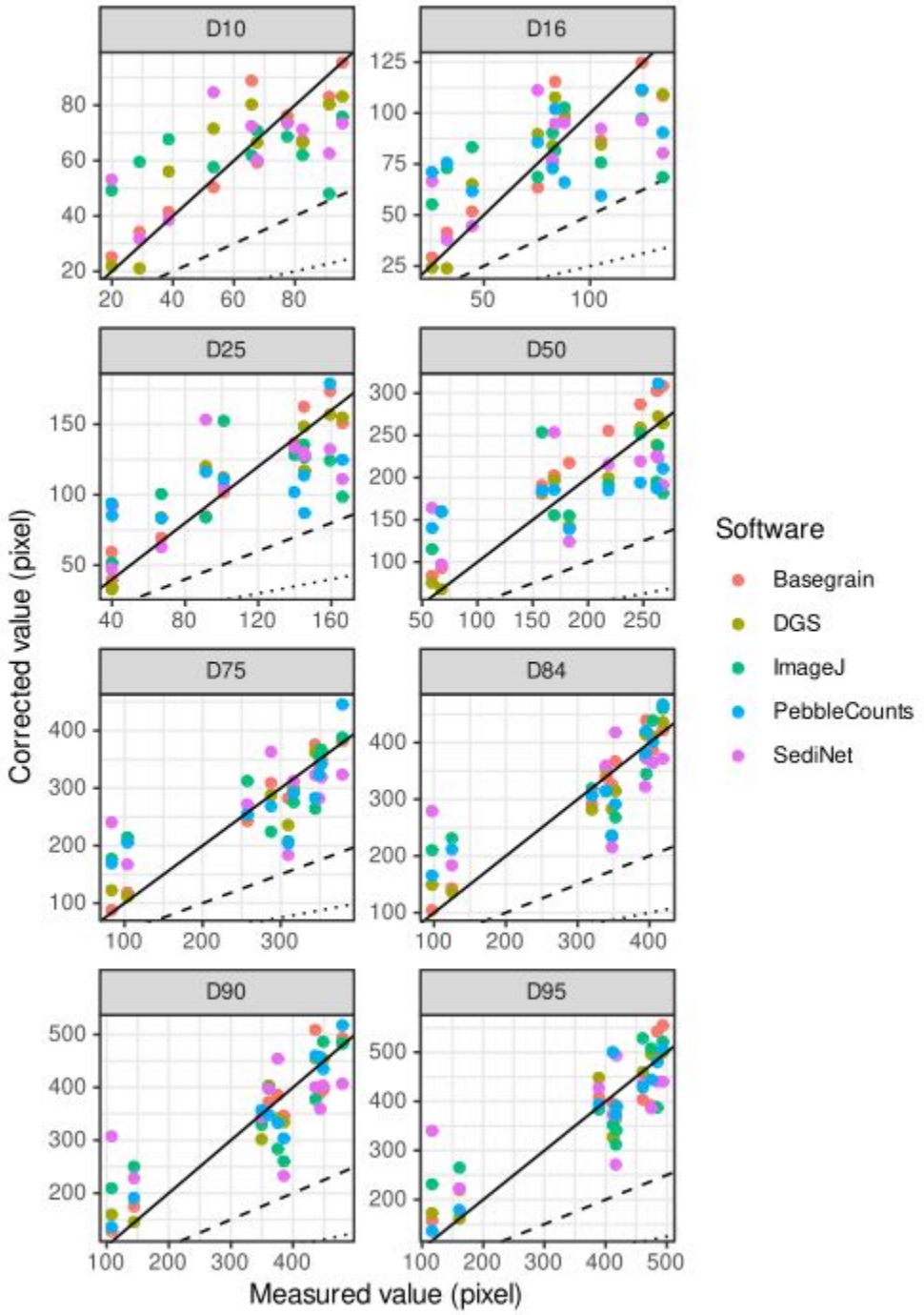


Fig. 8: Predicted percentiles of GSD for the three methods according to manually measured percentiles after calibration. Continuous black line, dashed black line and dotted black line corresponds to y=x equation, y=0.5x equation and y=0.25x equation, respectively.

	DGS		Basegrain		ImageJ		PebbleCounts		SediNet	
Percentile	R^2	P-value	R^2	P-value	R^2	P-value	R^2	P-value	R^2	P-value
D_{10}	0.76	0.00096	0.84	0.00018	0.12	0.33	0.04	0.31	0.41	0.047
D_{16}	0.79	0.00065	0.80	0.00052	0.15	0.26	0.22	0.17	0.42	0.043
D_{25}	0.89	4e-05	0.91	2.2e-05	0.37	0.061	0.35	0.075	0.48	0.026
D_{50}	0.92	1e-05	0.94	3.7e-06	0.35	0.07	0.40	0.053	0.40	0.051
D_{75}	0.92	1.4e-05	0.97	2.8e-07	0.51	0.02	0.59	0.0087	0.38	0.057
D_{84}	0.90	2.4e-05	0.96	5.3e-07	0.57	0.011	0.72	0.0017	0.42	0.042
D_{90}	0.92	9.4e-06	0.90	2.6e-05	0.64	0.0054	0.90	2.4e-07	0.36	0.063
D_{95}	0.90	2.9e-05	0.84	0.00021	0.63	0.0065	0.92	1.4e-05	0.40	0.052

Tab. 1: R-square values of linear regressions and P-value between grain size percentiles estimated for each software according to grain size percentiles estimated manually.

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Journal title	River Research and Applications
Submission ID or DOI	RRA-21-0183.R1
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