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Semi-Automatic Extraction of Stream Bed Grain-Size Classes Based on UAS Derived Data

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Abstract

A significant and challenging issue in river geomorphological research including sediment transport, hydraulic resistance, and the prediction of flow velocity, is the quantification of the river bed grain sizes. Since field sampling methods provide only pointwise information, a more representative characterization of inhomogeneous bed composition is needed, acquired in a time efficient manner. This study presents a semi-automatic methodology to gain areal information of surface grain size classes using airborne imagery and ground truth data, sampled from 11 grids (1x1 m^2) equally distributed across the stream. High-resolution RGB orthomosaic images with resolutions of 1.34 cm/px were generated from RGB images acquired with an Unmanned Aerial Vehicle (UAV). A variety of pixel-based and object-based image analyses were examined to acquire the most accurate classification. The examined river bed is not the typical case (e.g. gravel dominated, rounded particles) and consists of a mixed gravel and cobble bed material with sharp-edges. Eventually, object-based image classification and particularly a grey-level co-occurrence matrix (GLCM) was used to examine several texture parameters. Local entropy values in combination with Maximum Likelihood Classifier (MLC; pixel-based unsupervised classification method) were highlighted as a satisfactory approach to determine all existing grain classes along the stream bed. The methodology is demonstrated at the lower part of Xerias stream reach (2.2 km), Volos, Greece. The qualitative capability of the developed hybrid method to classify and map the stream bed was evaluated in two ways. Initially, 240 random points were created and equally distributed among the three known grain classes (boulder, cobble, gravel) according to field measurements. This methodology indicated that an overall 65% correct classification was achieved. Then, considering the grain shape assessment of the field measurements, the typical sediment area shape formulas were used to estimate the area percentage of each grain class for each grid. Comparing the estimated area percentage based on the field measurements with the generated surface grain size classified map provided an average overall 52% correct classification.

Methodology

Study area and ground truth data sampling

The study stream reach (Xerias stream), with a length of 2.2 km, is located at the sub-urban region of Volos city, Magnesia prefecture, Greece (Fig. 1a). This stream reach is characterized by complex river topography, bed material usually observed in mountainous and semi-mountainous streams (Figure 1b,c) and frequent flood episodes due to intense storms.

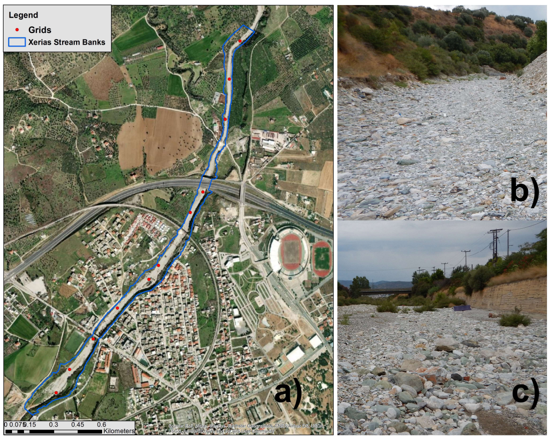

Figure 1. Xirias stream and inhomogeneous bed composition

Table 1. Grid count data classification based on Wentworth scale (Bunte and Abt, 2001)

Substrate type	Size (cm)
Sand-mud	0.0062-0.2
Gravel	0.2-6.4
Cobble	6.4-25.6
Boulder	25.6-409.6
Bedrock	>409.6

In this study, the grid sampling method that covers the 1 m^2 surface was selected for the analysis (Bunte and Abt, 2001) while 11 sampling grids were equally distributed in the entire stream reach of 2.2. km (Fig. 1). The more oversized bed materials were measured within the stream (Fig. 2a-2c) and those of smaller size were collected and measured at the laboratory facilities (Fig. 2d). The three mutually perpendicular particle axes measured, are: the longest (a-axis), the intermediate (b-axis), and the shortest (c-axis) axis. All length measurements were accomplished using a digital caliper (Fig. 2d). Finally, the grid count data were classified based on the Wentworth scale (Table 1; Bunte and Abt, 2001).

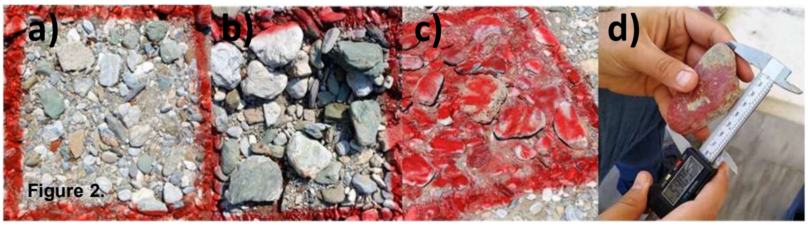

Figure 2.

Airborne Digital Imagery Acquisition and Pre-processing

The field topographic data in the study area were collected in July 2018 by using a DJI Phantom 4 V2 Professional UAV (Fig.3). Overlapping pictures were introduced in the Pix4D mapper software to develop the area's orthomosaic, the DSM and the DTM. The camera's resolution was 20 MP, and the percentage overlap for adjacent pictures was 80%. The area covered in the field survey was approximately 500 m × 120 m (length × width) along the river course, and the flight altitude was 40 m. The cell size of the produced DTM was approximately 0.013 m.

Figure 3.

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Mapping Grain Size from Airborne Imagery-Theoretical background and Tested Methods

Prior to primary analysis, images were converted from RGB to HIS (Hue, Intensity, Saturation) and HLS (Hue, Lightness, Saturation) by using the ENVI v.5.5 software. Subsequently, the following image processing methods were explored for substrate classification, applied to the lower part of Xerias stream.

Approach	Method	Tool	Result
Pixel-based image analysis	Supervised/Unsupervised classification	ISODATA, K-Means and Maximum Likelihood Classifier (MLC)	Classification map (pixel-based)
Object-based analysis (OBIA)	ENVI feature extraction module (ENVI v.5.5)	Example and Segment only approaches	Classification map (object-based)
	Local image texture analysis (QGIS v.3.18)	Grey-Level Co-occurrence Matrix (GLCM)	Re-classified entropy values (interpreting grain size classes)

Results

The majority of the numerous classification trials resulted in ambiguous results. The following experiments presented are those characterized by the greater classification accuracy. Reclassification of entropy band (Fig. 4b) proved to be the most optimal way to interpret the grain size classes particularly of cobble, gravel and sand-mud classes (Fig. 4c).

Approach/Method	Bands	Results and set parameters
Pixel-based image analysis /Maximum Likelihood Classifier	RGB	Riparian vegetation and the vegetation detected in the middle of the stream–bed Boulders and Bedrock classes It detected their location but not their full areal extent
Object-based analysis (OBIA)/ ENVI feature extraction module	RGB	
	RGB	Boulders full lambda merge algorithm, scale value 35 and merge value 50, SVM classification method Cobbles polynomial kernel type or radial basis function
	RED and INTENSITY	Gravels SVM classification method and radial or polynomial kernel type
Object-based analysis (OBIA)/ GLCM	Haralick Texture file (Entropy band)	Cobbles, Gravels and Sand-mud

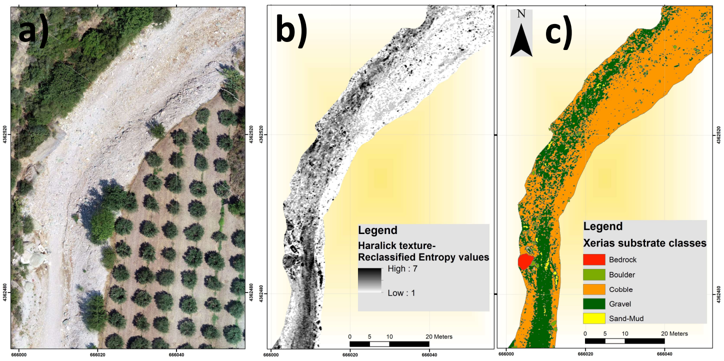

Figure 4. Orthophoto mosaic (a), Simple Haralick Texture (entropy) (b) and Stream-bed substrate classification (c) of a northern part along Xerias stream.

Validation

240 random points were created and equally distributed among the three known grain classes (boulder, cobble, gravel) according to field measurements. This methodology resulted in an overall of a 65% correct classification (0/16 points coincidence in boulders, 143/152 points in cobbles and 13/72 points in gravels). The second evaluation method involved a shape analysis to define the dominated particle shape in the entire study area (Fig. 5). Then, the typical sediment area shape formulas were used to estimate the area percentage of each grain class for each grid (field) and their comparison with the generated surface grain size based on the classified map provided an average overall 52% correct classification.

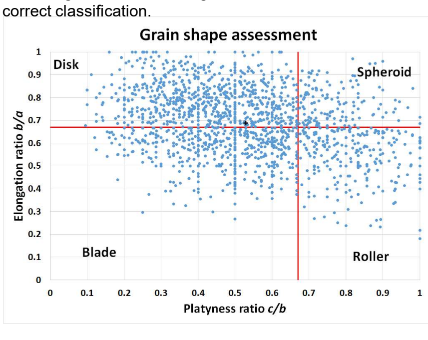

Fig. 5. Grain shape assessment results (with blue dots) and the calculated average shape (marked with black +). The meaning of the quartered is also shown.

Conclusions-Discussion

The Xerias river bed consists of a mixed gravel and cobble bed material with sharp-edges. This research highlighted the segmentation through OBIA as the most effective method of grain size analysis whereas pixel-based methods presented resolution limitations. Further problems hindering the classification accuracy were the hiding effect of neighbouring, overlapping, and interlocking classes and the presence of light-dark contact zones created by gravels and their shadow.

Selected references

Bunte, K., & Abt, S.R. (2001). Sampling surface and subsurface particle-size distributions in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics, and streambed monitoring. Gen. Tech. Rep. RMRS-GTR-74. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 428 p. https://www.fs.fed.us/biology/nsaec/assets/rmrs-gtr-74samplingsurfandsubsufpartszdist.pdf

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