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Analysis of impact of an edge effect on efficacy of selected texture analysis methods

Analiza wpływu efektu krawędzi na skuteczność wybranych metod analizy teksturowej

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Abstract

This paper presents the comparison of efficacy of three selected methods of texture analysis: Grey Level Co--occurence Matrix (GLCM) based entropy, Laplace operations and granulometric analysis, in the context of the edge effect. This effect means identifying edges of objects in an image as places of high texture, regardless of the real nature of the texture of the objects. It can significantly decrease the efficacy of selected methods of texture analysis. The article provides a brief presentation of the principal cause of this effect and also, shortly, the basics of the tested methods of texture analysis. The experiments were carried out on the VHR satellite image Pleiades (2m GSD), on the selected samples (test areas) of four land use/cover classes having different texture. The separation of these test areas in different texture images was assessed using Jeffries-Matusita distance. The results prove the significance of impact of the edge effect on the selected methods of texture analysis (GLCM entropy and Laplace operations), but they also show that a granulometric analysis is generally insusceptible to this effect, and thereby it provides the best discrimination of land use/cover classes of different texture.

Keywords: remote sensing, texture, edge effect, GLCM, Laplace, granulometric analysis
Słowa kluczowe: Teledetekcja, teksura, efekt krawędzi, GLCM, operacje Laplace'a, analiz granulometryczna

Artykuł służy porównaniu skuteczności trzech wybranych metod analizy teksturowej: entropii opartej na macierzy współwystępowania (GLCM), operacji Laplace'a oraz analizy granulometrycznej pod kątem efektu krawędzi. Efekt krawędzi polega na oznaczaniu krawędzi obiektów na obrazie jako obszarów o silnej teksturze, niezależnie od ich rzeczywistej tekstury. Może on znacząco zmniejszyć skuteczność wybranych metod analizy. Artykuł przedstawia krótką prezentację efektu krawędzi, włączając w to analizę głównej przyczyny jego powstawania, a także podstawy teoretyczne trzech analizowanych metod analizy teksturowej. Badania *przeprowadzono na obrazie satelitarnym o bardzo dużej rozdzielczości – Pleiades (rozmiar piksela 2m). Wybrano cztery obszary testowe, przedstawiające różne klasy pokrycia lub użytkowania terenu, charakteryzujące się różną teksturą. Zbadano separatywność tych obszarów na obrazach wynikowych różnych metod analizy tekstury. Określono ją przy użyciu odległości Jeffries-Matusita. Wyniki dowodzą dużego znaczenia efektu krawędzi na niektóre metody (entropia GLCM i operacje Laplace'a), jednocześnie pokazują, że analiza granulometryczna jest w zasadzie odporna na ten efekt. Stąd to właśnie analiza granulometryczna daje najlepsze rozróżnienie wybranych klas pokrycia lub użytkowania terenu cechujących się różną teksturą.*

Introduction

Texture is an important photo-interpretation feature, essential for the analysis of various types of images. It is an example of spatial characteristics and a result of spatial organization of pixels. Thus its determination requires additional transformations of the image. Despite its importance for the diagnosis and analysis of image there is no strict definition of the texture, so there are many different methods for its determination, among which the majority is accidental (ad hoc) (Haralick 1979). The detailed view on the various types of texturing methods of analysis was presented by Haralick (1979), but since that publication several new methods have been developed. Among all the methods of texture analysis the following ones can be distinguished: an analysis based on GLCM (Grey Level Co-occurence Matrix), a granulometric analysis, a wavelet transform, or Random Markov Fields, but also relatively simple processes such as a standard deviation calculation or Laplace operations.

Previous accounts dedicated to texture analysis focus on studying selected methods for their effectiveness of distinguishing different types of texture. Weszka *et al.* (1976) compared the effectiveness of methods based on several different principles. The results of this research indicate methods based on co-occurrence matrix (GLCM) as the most effective (among the compared ones). Another study (Lewinski *et al.* 2014) showed a high efficiency in the range of indicators based on GLCM but also Laplace operators. On the other hand, a study on granulometric analysis (Pesareasi, Benediktsson, 2001; Kupidura, 2010, 2015; Kupidura *et al.* 2010; Szeszko, 2014) proved high efficiency of this method.

The analysis presented in this article differs from the ones mentioned above. It relates to the influence of the edge effect on the efficacy of the texture analysis. Edge effect is the phenomenon which consists in identifying the edges of objects in the picture as places of high texture, regardless to their actual texture. This effect can have a negative impact on the efficacy of texture analysis in the context of their use in a spectro-textural classification. In this article, three texture analysis methods have been analyzed and tested: entropy based on GLCM, Laplace filters and granulometric analysis.

The following studies were carried out on selected classes of land cover in panchromatic image of the Pleiades. The assessment of class separation in the texture images was based on Jeffries-Matusita distance (J-M).

2. Basics of selected methods of texture analysis

The following analysis concerns three different methods of textual analysis: entropy based on GLCM, filters Laplace filters and the local granulometric analysis. This section briefly explains the theoretical basis of these methods.

Entropy (GLCM). Grey Level Co-occurrence Matrix (GLCM) is the general name of one of the earliest methods of texture analysis, presented by Julesza (1962). Darling and Joseph (1968) were the first to propose its application for satellite images processing, while Haralick *et al.* (1973) used it to classify land cover (in the cited article, this method is called by the authors: Grey-Tone Spatial Dependence Matrix. The scholarship comprises many examples of GLCM applications for analysing satelite images., e.g. Peddle and Franklin, (1989), Kubik *et al.*, (2008) or Giannini *et al.* (2012). These applications present the efficacy of this method to provide an additional data in pixel-based classification or test the separability of texture images produced with GLCM (Lewiński *et al.* 2014), comparing to other methods.

According to the GLCM determine of the texture consists of two stages:

- creation of Grey Level Co-occurence Matrix;
- calculation of selected indicators on the basis of Grey Level Co-occurence Matrix.

GLCM determines the distribution of occurrence of pairs of pixels within a specified space and in a given direction (0°, 45°, 90° and 135°). In order to use the results in the classification of an image, the analysis is carried out on an artificially created image subsets defined for each pixel. As the result, each of the pixels acquires a value or values describing the texture of its neighborhood.

There are a large number of indicators that can be calculated basing on GLCM, defining various aspects of the image. One of the most widely used for the determination of texture is the entropy, which is a measure of disorder. It is calculated by the following formula:

$$entropy = \sum_{i,j} P_{i,j} \left(-lnP_{i,j}\right)$$

where $P_{i,j}$ is the value of the corresponding element in the normalized symmetric matrix of co-occurrence.

Laplace operators. Laplace operators (laplacians) have been developed for detection and amplification of edges on images (Jensen, 1996). However, as indicated Lewiński *et al.* (2014), they may provide the analysis of image texture with high efficiency. In digital image they take the form of an arithmetic filter. For size 1 (3x3 pixels), Laplace operator mask may take the following form (this mask has been used in the following studies):

$$\nabla = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

It has to be mentioned though, that there is a number of different kernel types and because of that, the results of their application might vary.

In this study laplacians of masks with sizes from 1 to 5 pixels were analyzed.

Granulometric analysis. Granulometric analysis is one of the first applications of mathematical morphology, presented by Haas *et al.* (1967).

It involves performing a sequence of morphological openings (or closings) using structuring elements of gradually increasing size.

Morphological opening can be defined as a sequential combining of two fundamental morphological operations: erosion followed by dilation (Haralick *et al.* 1987):

$$\gamma_B\left(f\right) = \delta_B(\varepsilon_B\left(f\right))$$

whereas the closing, as a sequential arrangement of dilation followed by erosion (and thus, in the reverse order than in the case of opening; Haralick *et al.* 1987):

$$\gamma_B\left(f\right) = \delta_B(\varepsilon_B\left(f\right)) .$$

Erosion and dilation of the function (image) f using a structuring element B can be defined, following the notation Sternberg (1986) respectively as:

$$\varepsilon_B\left(f\right) = inf\left\{g\left(f - y\right),\ y \in B\right\}$$

and

$$\delta_B\left(f\right) = sup\left\{g\left(f + y\right),\ y \in B\right\}$$

Thus, the result of erosion of f is the function of the smallest value amongst all the shifts of function f by $-y$, which are elements opposing to elements forming a structuring element B (which is a subset of the image defining the scope of the operation), and the result of dilation is the function of the greatest values of all the shifts of functions f by elements y, belonging to the structuring element B (Nieniewski, 1998; Kupidura *et al.*, 2010). It should be noted that in granulometric processing one can use various kinds of operations of opening and closing of: straight – described above, but also operations by reconstruction or with multiple structuring element. This allows to obtain information about various aspects of the analyzed texture (Kupidura, 2015).

As mentioned earlier, the granulometric operations consist of a series of morphological openings or closings with increasing size of structuring elements. The differences between the results of successive morphological operations are analyzed. Such differential images contain information about deleted objects of a certain size. Calculation of the cardinality of these images (i.e. the sum of all pixels in the image) allows to specify a parameter called the size distribution. The granulometry based on the opening operation, the size distribution for *n-th* step of the opening may be calculated using the following equation (Haas *et al.*, 1967 after Dougherty *et al.*, 1992):

$$SD_n^g = \frac{S\left(X_0\right) - S\left(X_n\right)}{S\left(X_0\right)}$$

where $S\left(X_n\right)$ is the cardinality of the resulting image of the *n-th* step of opening. On the basis of the size distribution of the density the granulometric density can be calculated:

$$dSD_n^g = SD_n^g - SD_{n-1}^g$$

Since the closing operation is extensive, as opposed to the opening, which is an anti-extensive operation (Nieniewski, 1998) for a granulometry based on the said first operation (sometimes called anti-granulometry) size distribution is calculated as follows:

$$SD_n^q = \frac{S\left(X_n\right) - S\left(X_0\right)}{S\left(X_0\right)}$$

and (anti) granulometric density may be described as:

$$dSD_n^q = SD_n^q - SD_{n-1}^q .$$

In the classification (either pixel-based or object-based), where it is crucial to relate appropriate characteristics (in this case associated with the texture) to individual pixels, the local granulometry should be calculated. It consists in calculating the density of grain size not for the whole picture, but for each pixel – in its specific neighborhood (Dougherty *et al.*, 1992; Vincent, 1996; Kupidura, 2015) called granulometric window (Kupidura, 2015). This way, the operation creates a series of images – granulometric maps, each of which contains information regarding the presence of bright objects (in the case of granulometry, based on operation) or dark objects (in the case of granulometry, based on closing) in a specific environment of each pixel.

Edge effect. Edge effect concerns the majority of methods of texture analysis. It means identifying the edges of the objects in the image as areas of high texture, disregarding the real texture of the objects. This results from the principle of operation of those methods of texture analysis: they base on the analysis of the spatial frequency of the selected fragments of the image. Edges of objects, including homogeneous ones, by definition are places of a high spatial frequency, so in accordance with the principles of selected methods they are determined as places of high texture.

Two test methods: GLCM and Laplace filters are based on these principles. In contrast, granulometric analysis consists in the removal of objects of a certain size. Therefore, the existence of the edge is not critical to the outcome of the analysis, if the object described by the said edges is not removed and recorded as part of the analyzed texture.

Figure 1 shows the result of the processing of the simulated digital image (Fig. 1a) using entropy GLCM (Fig. 1b) and granulometric analysis based on the opening operation for reconstruction (Fig. 1c). As it can be seen, both methods allow to mark the fragment from the right side of the image, characterized by high texture. However, in the image based on entropy GLCM also the edges of the object on the left side are marked as places of high texture. In the context of the classification, this edge effect may be an important disadvantage, since both the object itself and its immediate surroundings are characterized by poor texture. As shown in Fig. 1c, there is no edge effect in the granulometric map.

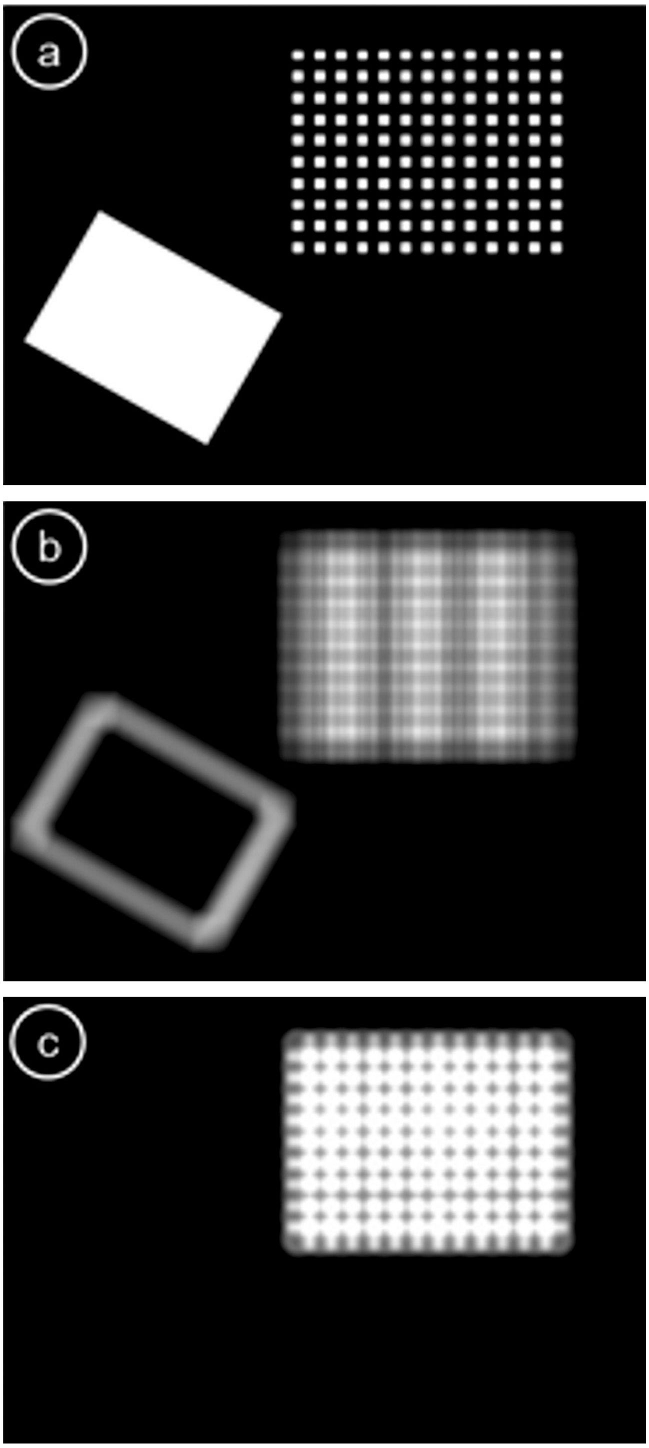

Fig. 1. A – Input image; B – GLCM entropy image; C – Granulometric map.

Ryc. 1. A – Obraz wejściowy ; B – Obraz przetworzony według metody entropii opartej na macierzy współwystępowania GLCM; C – Obraz przetworzony na podstawie analizy granulometrycznej.

Data and methodology

The study was carried out on a fragment of the satellite scene Pleiades (date of acquisition: 22.05.2012; GSD: 2m). We analyzed four test areas of different classes of land use/cover (shown in Figure 2), characterized by a different texture to the image:

a) a built-up area (3588 pixels; Fig. 2a) – an area with a high texture, resulting from the presence of buildings with different roof cover, vegetation, roads, sidewalks, etc.,
b) a forest (11135 pixels; Fig. 2b) – an area with a high texture, resulting from the lighted and shaded parts of crowns of trees,
c) a cornfield, covered with well developed vegetation (31768 pixels; Fig. 2c) – homogeneous area with a low texture,
d) a mosaic of parcels covered with vegetation and bare soil (13200 pixels; Fig. 2d) – an area consisting of land cover classes with a low texture, with a significant number of edges between parcels of width from ca. 8m to 40m.

Theoretically, a texture analysis of the areas with low texture: (c) and (d) should result with values allowing a clear differentiation from areas of high structure: (a) and (b), regardless of their spectral values. The most interesting, however, is the case of the area (d) – the mosaic of cornfields. From the point of view of the classification of land use/cover, it represents an area with low texture. However, frequently occurring edges – boundaries of parcels covered (or not) with different types of crops can result in high values of texture images. According to the assumption underlying this study, texture analysis methods susceptible to edge

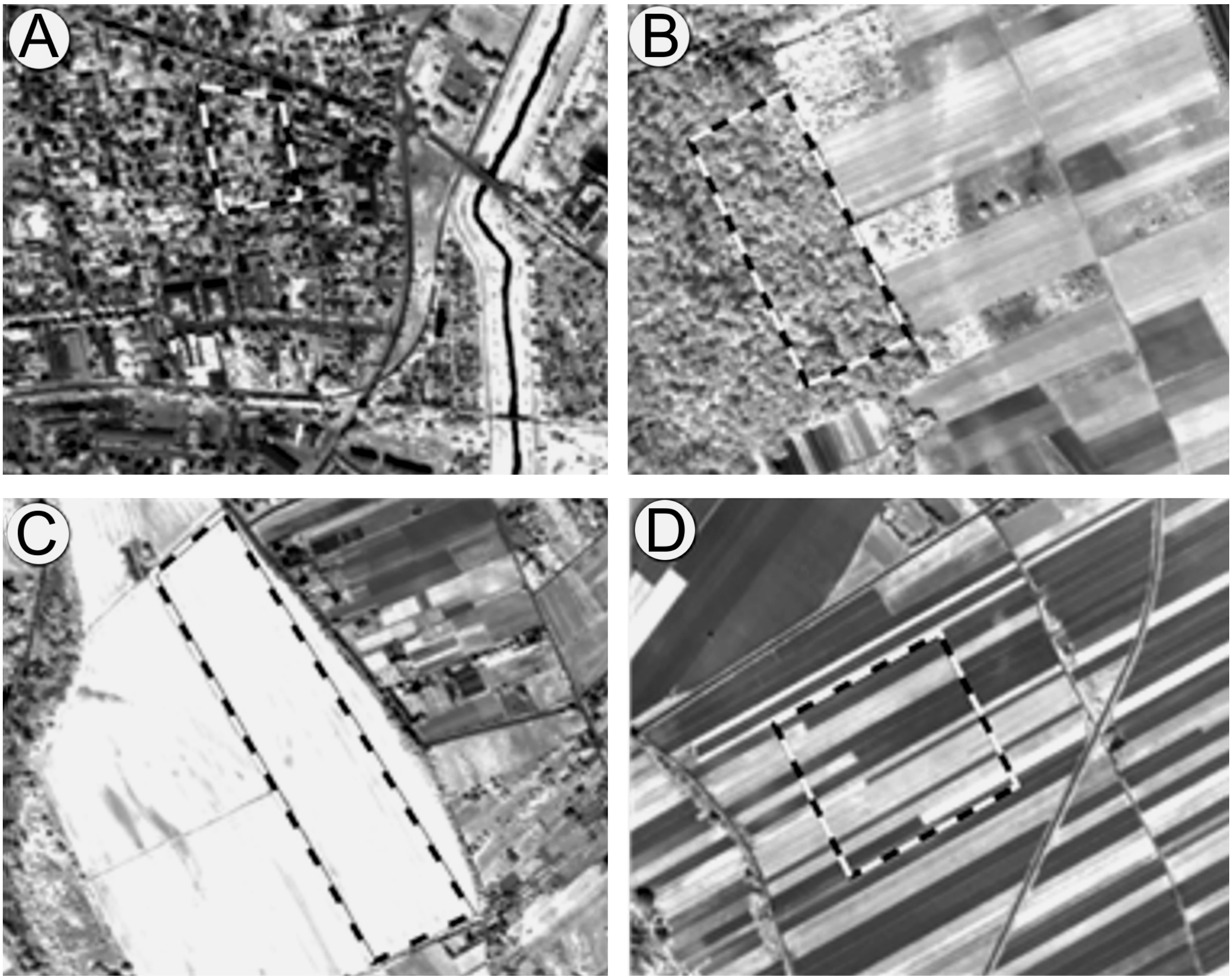

Fig. 2. Test areas presented in the near-infrared images: A – Built up area; B – Forest; C – Cornfield; D – Mosaic of fields.

Ryc. 2. Obszary badań przedstawione na zdjęciach w bliskiej podczerwieni: A – Obszar zabudowany; B – Las; C – Pola uprawne; D – Mozaika pół uprawnych.

effect can indicate such places as of high texture. It can reduce a separation of areas of different texture, and, in result, also an efficacy of texture analysis itself. In order to study the edge effect, we compared separation between the areas of high texture: (a) and (b), and the area (c), wherein the edge effect should not matter, with separation between the first said areas and (d), where, due to the frequent occurrence of edge, the said effect can have a significant impact on the results of a texture analysis.

Texture analysis can be performed on a single grayscale image. For multispectral images one can select one of the spectral images (Pleiades multispectral image contains 4 spectral ranges: B, G, R and NIR), or images artificially generated, e.g. vegetation indices (NDVI or other) or the principal components. Kupidura (2015) points out that near infrared images have somewhat higher usefulness comparing to principal components for texture analysis of very high spatial resolution images (QuickBird, pixel size 2.44 m). Therefore, in the following experiments we used near-infrared spectral image as a basis for the texture analysis.

Experiments were carried out using different parameters of selected methods of texture analysis. GLCM entropy was calculated in 5 variants – for 5 different neighborhood sizes of radius from 1 to 5 pixels. Laplace operations were also calculated in five variants –for 5 filter mask of size from 1 to 5 pixels. Granulometric analysis was carried out for 5 structuring element size – with a radius from 1 to 5 pixels for both: opening and closing operations. Thus, a total number of 10 different granulometric maps were calculated: 5 for opening and 5 for closing.

Separation of the results based on selected methods of texture analysis was assessed using Jeffries-Matusita distance (J-M). J-M is commonly used to determine separation of training fields in the supervised classification. In this study we used the following formula (Swain, Davis, 1978):

$$JM_{ij} = \sqrt{2\left(1 - e^{-\alpha}\right)}$$

where α is a Bhattacharay distance, being calculated in a following manner:

$$\alpha = \frac{1}{8}\left(\mu_i - \mu_j\right)^T \left(\frac{C_i + C_j}{2}\right)^{-1} \left(\mu_i - \mu_j\right) + \frac{1}{2} ln \left(\frac{\left| \frac{\left(C_i + C_j\right)}{2} \right|}{\sqrt{\left|C_i\right| \times \left|C_j\right|}} \right)$$

where i and j means two group of pixels being compared, C_i – covariance matrix for group i, μ_i – mean vector for group i, and $|C_i|$ – a determinant of matrix C_i.

J-M obtains values within a range from 0 to √2 where the value of √2 (approximately 1,414) indicates full separation of two groups of pixels.

All texture analysis operations were performed using free software: Bluenote (granulometric analysis and Laplace operations) and Orpheo Monteverdi 1.20. (GLCM entropy). J-M calculations J-M were carried out in Erdas Imagine 9.3.

Results

Below we present the analysis of J-M values obtained for selected texture analysis methods.

GLCM Entropy. Separation degree of pairs of classes of distinctly different texture (forest – cornfield and built up area – cornfield) is largelysatisfying: J-M values received for these class pairs are close to the maximum value indicating a full separation (table 1). It should be noted that they increase with the size of the GLCM mask size. However, in the case of an area representing the field mosaicwith frequently occurring edges between different crops (forest – mosaic, built up area – mosaic), J-M values are significantly lower. This demonstrates the significance of the edge effect: large values at the edges of objects make the distinction between these types of land cover and areas with high texture difficult basing on GLCM analysis. It can also be seen in Figure 3, showing the selected test areas on the images entropy (neighborhood size 5 pixels).

Table 1. J-M values for selected pairs of classes in the GLCM-based entropy image.

Tabela 1. Wartości J-M wybranych par klas na obrazach przetworzonych według entropii GLCM.

Pair of classes *Para klas*	**GLCM mask size [pixels]** *Rozmiar maski GLCM [piksele]*				
	1	2	3	4	5
	J-M				
Forest – Cornfield *Las – pola uprawne*	1,115	1,321	1,380	1,398	1,405
Built-up – Cornfield *Zabudowania – pola uprawne*	1,176	1,364	1,405	1,412	1,413
Forest – Mosaic *Las – Mozaika użytków*	0,723	0,838	0,895	0,934	0,963
Built-up – Mosaic *Zabudowania – Mozaika użytków*	0,779	0,928	1,023	1,087	1,133

Figure 4 shows feature space and values obtained of areas (a) – built up area, (c) – cornfield and (d) – mosaic of fields, using GLCM-based entropy (area (b) – forest has not been included to increase the clarity of the diagram). It confirms the results shown in table 1: the test areas (a) and (c) are easily distinguishable in this space, but the region (d) is characterized by a great diversity of values: the high ones in the edges and in their direct neighborhood,and the low ones in the spaces between them. As a result, the pixels of this area have values typical of both areas of low and high texture.

Laplace operators. J-M values obtained for the laplacian image show that the efficiency of individual pairs of different classes (forest – cornfield and built up area – cornfield) is small (table 2). In addition, the edge effect may significantly reduce the ability to separate different areas, at least basing on a texture (forest – mosaic, built up area – mosaic). On the basis of table 2 it can be concluded that the Laplace operations are not effective as a method of distinguishing between different land use/cover classes basing on their texture. Test areas in the laplacian images (size masks 1) are shown in Figure 5.

Table 2. J-M values for selected pairs of classes in the laplacian image.

Tabela 2. Wartości J-M wybranych par klas dla obrazów przetworzonych według operatora Laplace'a.

Pair of classes *Para klas*	**Size of mask of laplacian [pixels]** *Rozmiar maski z laplacian [piksele]*				
	1	2	3	4	5
	J-M				
Forest – Cornfield *Las – pola uprawne*	0,678	0,714	0,707	0,650	0,582
Built-up – Cornfield *Zabudowania – pola uprawne*	0,778	0,815	0,812	0,765	0,711
Forest – Mosaic *Las – Mozaika użytków*	0,271	0,114	0,066	0,081	0,114
Built-up – Mosaic *Zabudowania – Mozaika użytków*	0,418	0,271	0,196	0,126	0,089

Figure 6 shows feature space and values of areas (a) – built up area, (c) – cornfield and (d) – mosaic field obtained using Laplace'a operations. The diagram confirms the small degree of separation of the test areas, basing on laplacians.

Granulometric analysis. Separation of selected land use/cover classes on the basis of granulometric maps (based on the opening) is very good. In the case of pairs of classes: forest – cornfield and built up area – cornfield) a full separation can be observed (table 3). In the case of a second one – on all granulometric maps regardless of the SE size. This indicates multiscality of the texture of built-up areas in the VHR images. Simultaneously, the ability to distinguish field mosaic in the granulometric maps is also significant. It can be

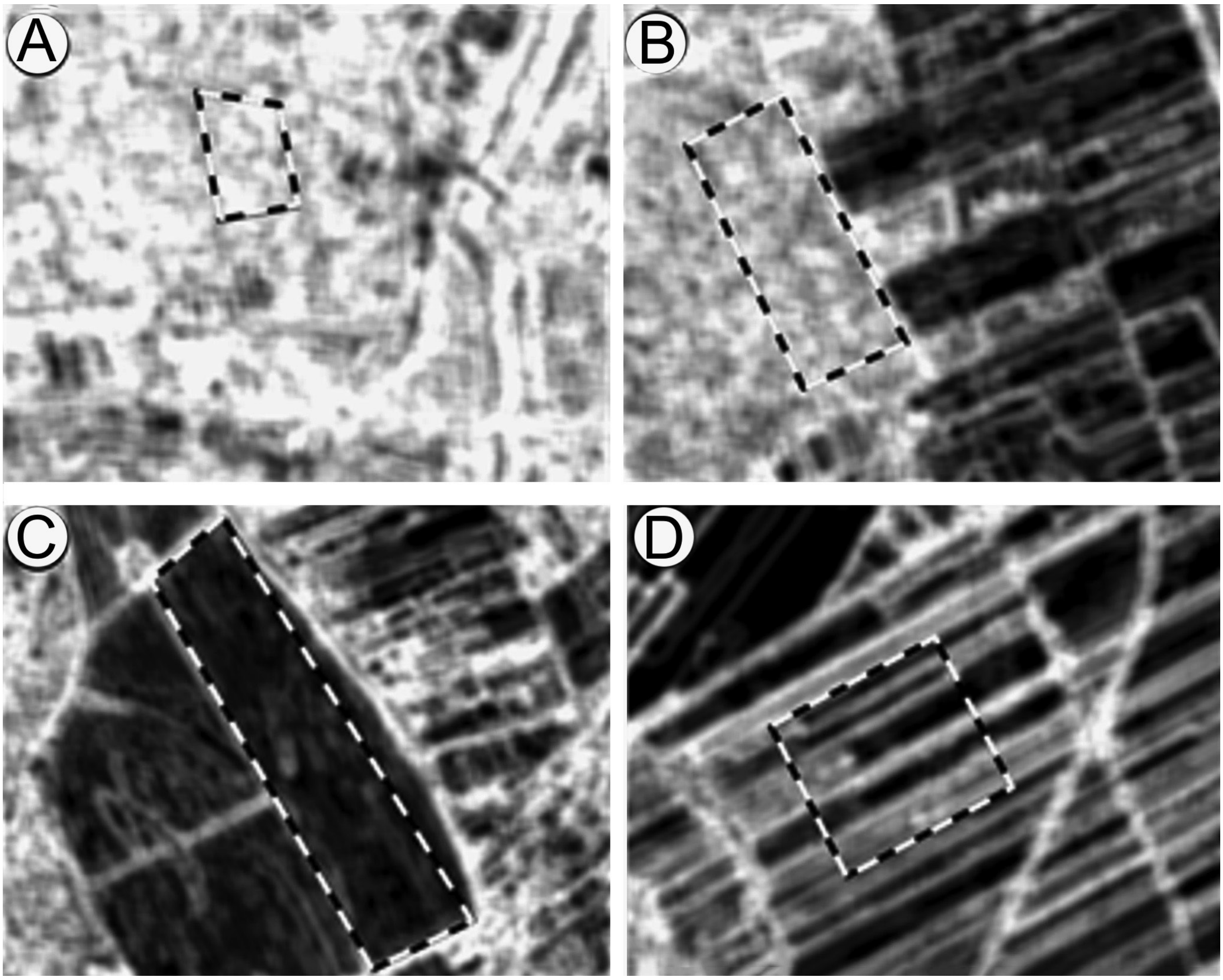

Fig. 3. Test areas presented in the GLCM-based entropy images: A – Built up area; B – Forest; C – Cornfield; D – Mosaic of fields.

Ryc. 3. Obszary testowe przedstawione na obrazach przetworzonych według metody entropii opartej na macierzy współwystępowania GLCM; A – Obszar zabudowany; B – Las; C – Pola uprawne; D – Mozaika pól uprawnych.

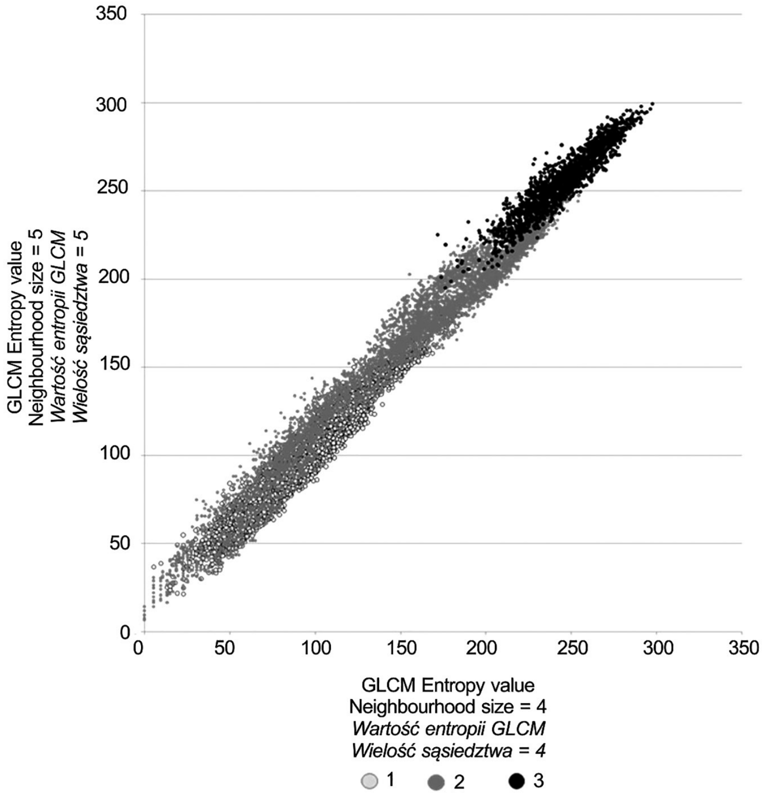

Fig. 4. Feature space based on GLCM entropy values and the selected classes of land use/cover: 1 – Cornfield; 2 – Field mosaic; 3 – Built-up area.

Ryc. 4. Wartości cech przestrzennych dla obrazów przetworzonych metodą entropii opartej na macierzy współwystępowania GLCM, dla wybranych klas użytkowania ziemi / pokrycia terenu: 1 – Pola uprawne; 2 – Mozaika pól; 3 – Zabudowania.

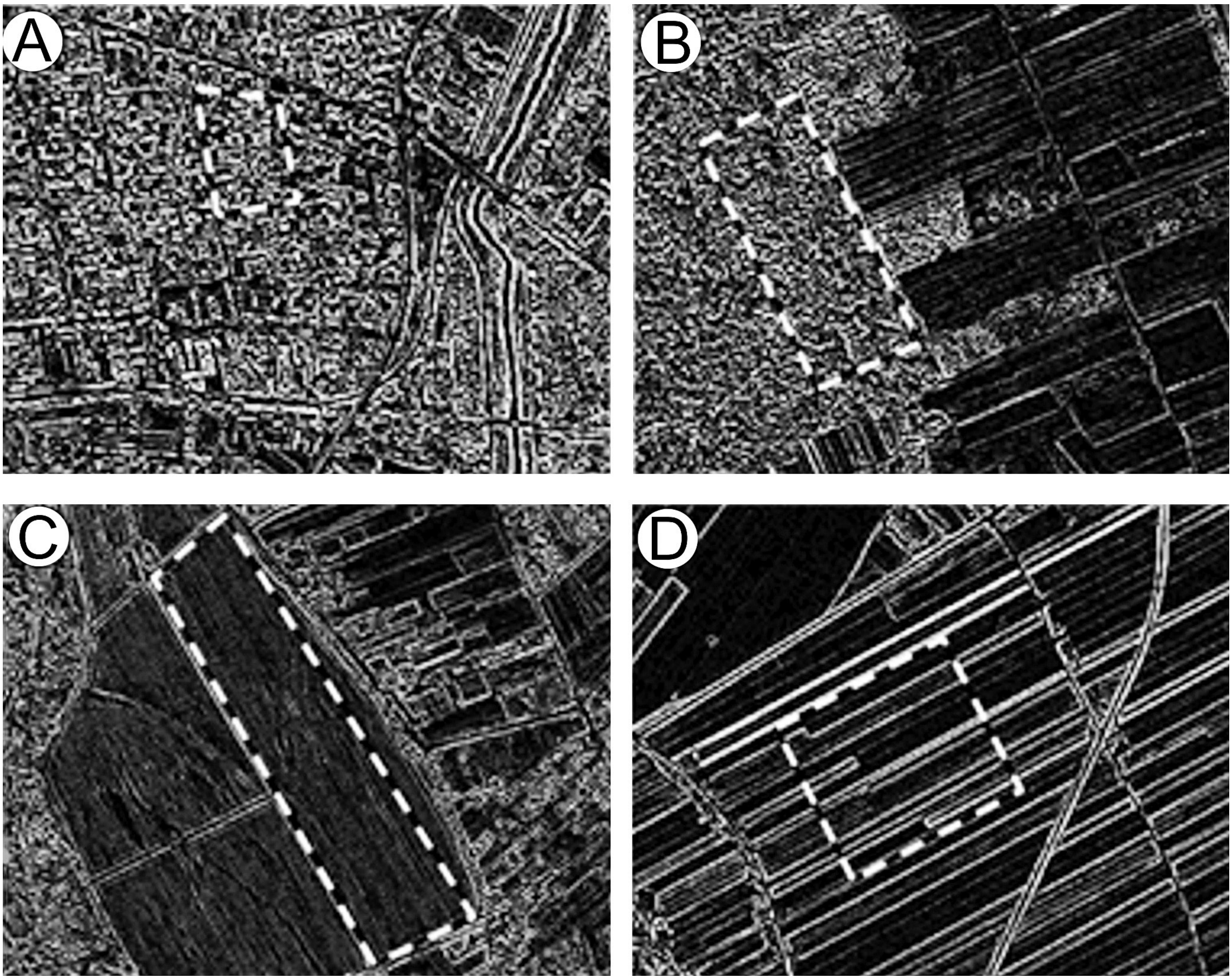

Fig. 5. Test areas presented in the laplacian imaKges: A – Built up area; B – Forest; C – Cornfield; D – Mosaic of fields.

Ryc. 5. Obszary testowe przedstawione na obrazach przetworzonych według operacji Laplace'a: A – Obszar zabudowany; B – Las; C – Pola uprawne; D – Mozaika pół uprawnych.

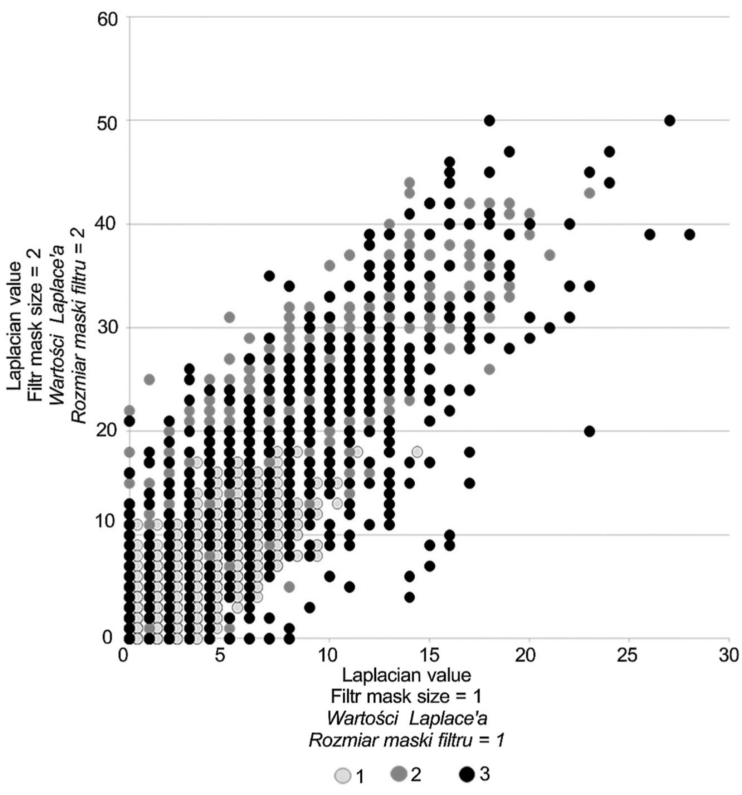

Fig. 6. Feature space based on laplacian values and the selected classes of land use/cover: 1 – Cornfield; 2 – Field mosaic; 3 – Built-up area.

Ryc. 6. Wartości cech przestrzennych dla obrazów przetworzonych według operacji Laplace'a, dla wybranych klas użytkowania ziemi / pokrycia terenu: 1 – Pola uprawne; 2 – Mozaika pól; 3 – Zabudowania.

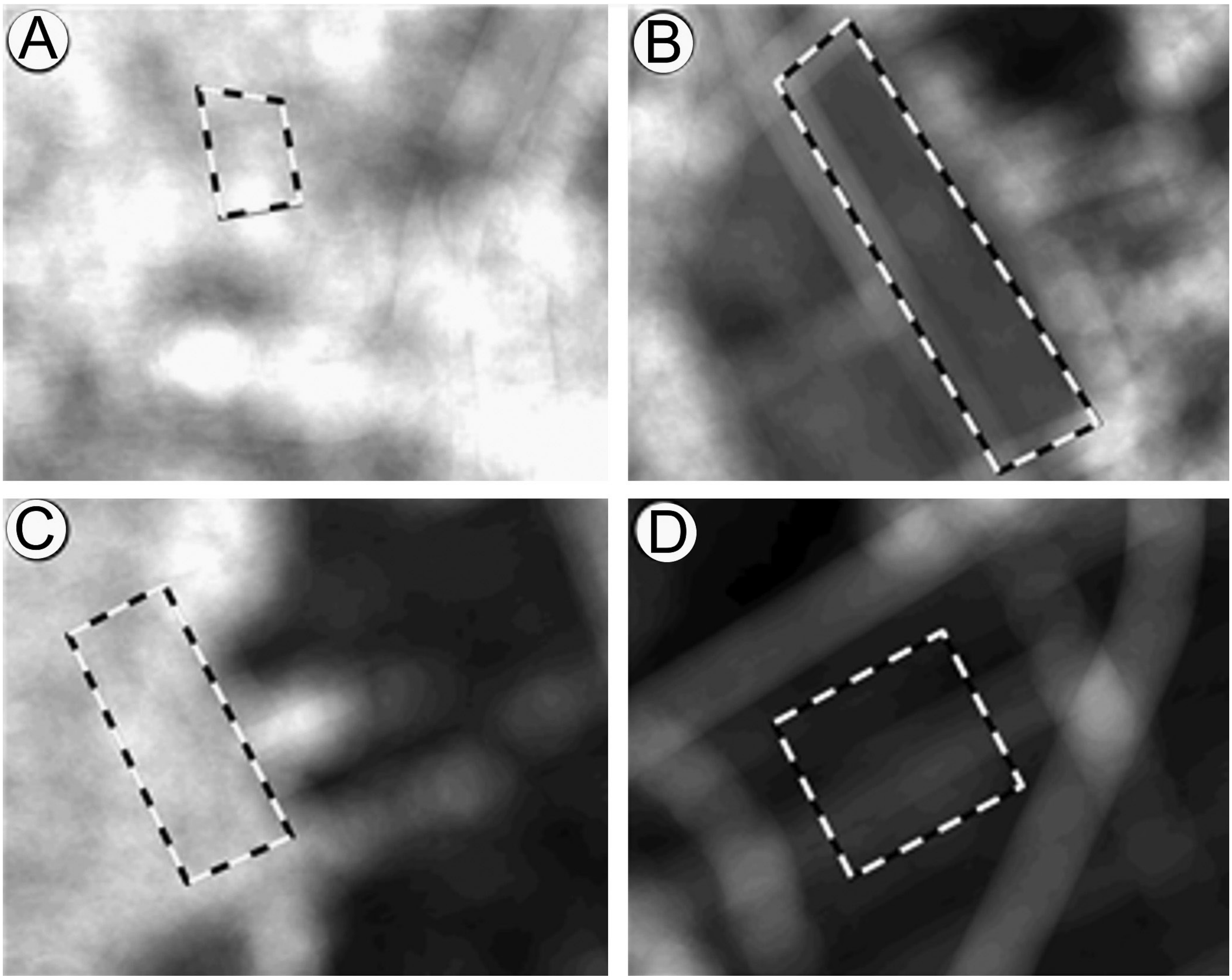

Fig. 7. Test areas presented in the granulometric maps: A – Built up area; B – Forest; C – Cornfield; D – Mosaic of fields.

Ryc. 7. Obszary testowe przedstawione na obrazach przetworzonych metodą analizy granulometrycznej: A – Obszar zabudowany; B – Las; C – Pola uprawne; D – Mozaika pól uprawnych.

perfectly differentiated from the areas with high texture in the granulometric map of size 1 (this granulometric map provided a perfect discrimination between all the compared test areas). It should be noted that the J-M generally decrease with increasing the size of the SE. Test areas on the maps granulometric are shown in Figure 7.

Similar conclusions can be drawn from the analysis of Table 4, showing the J-M values for the granulometric maps obtained basing on closing operations. Although in some cases, the observed separation may be slightly worse than in the case of opening, it should be noted that the effectiveness of one or the other type of particle size determination depends on, among others, the nature of the texture (whether it is mainly made up of the bright features on a dark background or vice versa). Furthermore, the combined use of granulometry based on both operations (opening and closing) can additionally increases the efficiency and reliability of texture analysis using granulometric maps.

Table 3. J-M values for selected pairs of classes in the granulometric maps (opening operation).

Tabela 3. Wartości J-M wybranych par klas dla obrazów przetworzonych według analizy granulometrycznej (operacja otwarcia).

Pair of classes *Para klas*	**Structuring element size [pixels]** *Rozmiar elementu strukturalnego [piksele]*				
	1	2	3	4	5
	J-M				
Forest – Cornfield *Las – pole uprawne*	1,414	1,414	1,398	1,408	1,398
Built-up – Cornfield *Zabudowania – pola uprawne*	1,414	1,414	1,414	1,414	1,414
Forest – Mosaic *Las – Mozaika użytków*	1,414	1,373	1,044	0,976	0,975
Built-up – Mosaic *Zabudowania – Mozaika użytków*	1,414	1,407	1,250	1,163	1,219

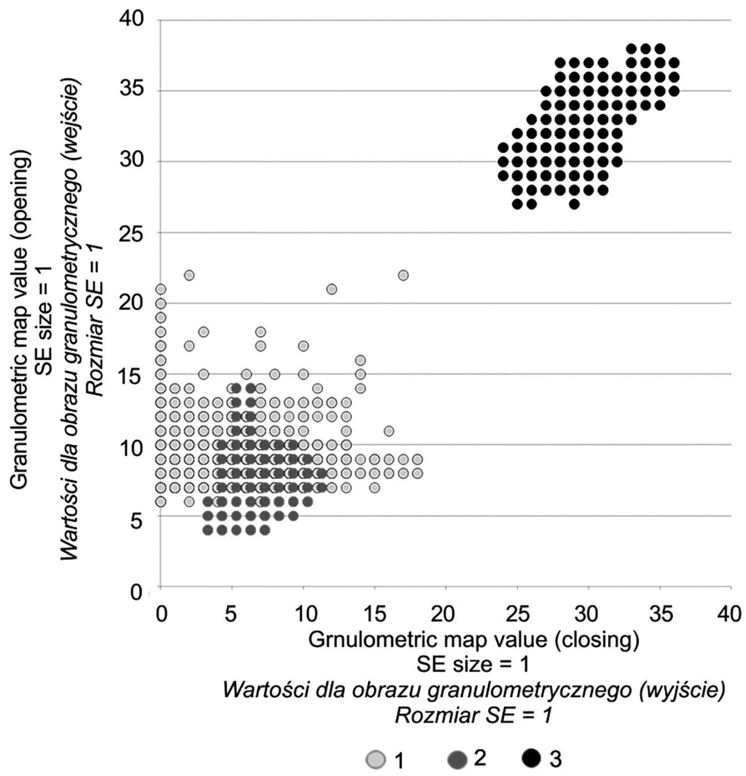

Fig. 8. Feature space based on granulometric values and the selected classes of land use/cover: 1 – Cornfield; 2 – Field mosaic; 3 – Built-up area.

Ryc. 8. Wartości cech przestrzennych dla obrazów przetworzonych metodą analizy granulometrycznej, dla wybranych klas użytkowania ziemi / pokrycia terenu: 1 – Pola uprawne; 2 – Mozaika pól; 3 – Zabudowania.

Table 4. J-M values for selected pairs of classes in the granulometric maps (closing operation).

Tabela 4. Wartości J-M wybranych par klas dla obrazów przetworzonych według analizy granulometrycznej (operacja zamknięcia).

Pair of classes *Para klas*	**Structuring element size [pixels]** *Rozmiar elementu strukturalnego [piksele]*				
	1	2	3	4	5
	J-M				
Forest – Cornfield *Las – pole uprawne*	1,410	1,408	1,414	1,413	1,394
Built-up – Cornfield *Zabudowania – pola uprawne*	1,410	1,413	1,414	1,414	1,413
Forest – Mosaic *Las – Mozaika użytków*	1,414	1,377	1,224	0,841	0,915
Built-up – Mosaic *Zabudowania – Mozaika użytków*	1,414	1,398	1,349	1,038	0,936

Figure 8 presents feature space and values of areas (a) – built up area, (c) – cornfield and (d) – mosaic field obtained using granulometric analysis. It shows a complete separation of pixels of two areas of low texture in relation to the built up area – an area with a high texture. At the same time, pixels of both test areas of cornfields have very similar values on the two presented granulometric maps. The impact of the edge effect in that case is basically irrelevant.

Summary and conclusions

In this paper we have presented the results of experiments conducted to test out the potential influence of the edge effect on 3 selected methods of texture analysis: GLCM-based entropy, Laplace operators and granulometric analysis. The results show, that a granulometric analysis is generally insusceptible to the said effect. Also, it provides a precise differentiation between land use/cover classes of different texture in VHR satellite images. The results of the texture analysis basing on entropy, under certain conditions allow to obtain distinctive values for regions with a different texture. It should be noted though, that the J-M values obtained in this case were smaller, than in the case of granulometric maps. Additionally, we observed a strong edge effect: distinction between areas of different texture can be distorted for areas with object edges occurring frequently. Laplace operators have been proved to be ineffective as a tool of texture analysis of VHR images, at least in the context of this study.

The results of the presented studies are important for the potential application of texture analysis as a source of an additional data fora classification of VHR satellite images. Granulometric analysis provides accurate separation between areas of different texture. At the same time it is insusceptible to edge effect, which is a unique feature compared to other methods analyzed in this research. It all proves granulometric analysis to be a very effective method of texture analysis in the context of a satellite images classification.

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