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Urban land use pattern identification using variogram on image

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The images of high spatial resolution leveraged remote sensing to the forefront of urban environments studies, as they better distinguish the elements that make up this very heterogeneous environment. Geostatistical techniques are increasingly being used in studies of remote sensing. The variogram is an important geostatistical analysis tool, because it allows understanding of the spatial behaviour of a regionalised variable, in this case, the grey levels of a satellite image. This study aims to identify urban residential patterns of three classes of use and occupation of land by the analysis of the parameters, graphics and results of variogram analysis. The hypothesis is that the values corresponding to these parameters represent the standard of each class spectral behaviour, and indicate that there is a pattern in the spatial organisation of each class. IKONOS 2002 images and a previous classification of land use and land cover of sub-basin in the Cabuçu river in São Paulo were used. Samples were taken from each class and the levels of grey in each pixel were used to calculate the variogram. After analysing the results, only the parameter range was considered, as it was observed that it was related with the degree of homogeneity of each sample. The range of values obtained in the calculation of variograms identified with better accuracy 'multiple dwelling unit' class rather than 'regulated dense occupation' and 'irregular dense occupation', which did not yield a good result.

1. Introduction

Although the development of large cities has been fast, there has frequently been a lack of urban planning. The uncontrolled growth of large cities generates well-known problems such as traffic jamming, poor public transportation and lack of basic sanitation; in addition, there are problems created by socio-economic disparities and high vulnerability to natural disasters, such as floods caused by the high soil impermeability and landslides due to the disorganised residential occupation in high-risk areas (Taubenböck *et al*., 2012).

The study area chosen for this study reflects the previously mentioned dynamics. The Córrego Bananal Stream sub-basin comprises the Cabuçu de Baixo river basin that is located in the far north of São Paulo city. Three classes of soil use for occupation by residences are analysed: 'multiple dwelling units (MDUs)': housing complexes as a result of government housing programs; 'regularised dense occupation (RDO)': middle/low class housing, but in an area regularised by the municipality; and 'irregular dense occupation (IDO)': lower-class houses in streets and lots not regularised by the municipality.

Since the 1980s, geostatistical methods have been applied in remote-sensing images to quantify the image structure and texture, to define optimal scales, to make estimates based on Kriging, to highlight image information, to complete missing information in pixels, to reduce image resolution and so on (Van Der Meer, 2012).

Geostatistics refers to the set of techniques for data analysis that is typically applied to regionalised variables (variables distributed in space). It is expected that these variables are spatially dependent, implying that points near each other are more similar than those far apart (Isaaks and Srivastava, 1989).

This study proposes an alternative to the land use and occupation classification in urban areas by using geostatistical techniques combined with the remote-sensing methods to understand the growth dynamics of a city, and guide urban planning actions so that these are more adapted to local needs.

This study assumes that the grey level of an orbital remote-sensing image pixel can be considered as a regionalised variable and can, therefore, be modelled by a variogram function.

The aim of this study is to present that it is possible to distinguish between the behaviour of these urban residential classes and then identify the land-use patterns using the sample variogram parameters for areas of different urban land uses.

This paper shows a similar approach to Balaguer-Beser *et al.* (2013), Brito and Quintanilha (2013), and Woodcock *et al.* (1998). The authors' first goal is 'to establish a direct link between the spatial characteristics of images and then derive the scene from the image'. This research differs from other works where the authors assumed that digital numbers expressed in the pixels are not punctual information – so all variograms are regularised – and used a non-multispectral simulated images. In this case, authors assumed that urban images are intrinsically heterogeneous and the pixels information is punctual. Brito and Quintanilha (2013) used previously defined urban patterns, as has been done here, but focused on object-based image analysis (OBIA) to classify the coverages and not to apply the variography. In Balaguer-Beser *et al.* (2013), a set off benchmark images were issued to evaluate computational approaches in order to calculate the experimental semivariograms and parameters so as to characterise spatial patterns. These authors used different types of parameters to characterise the shape of the semivariogram near the origin: the ratio between the values of the total variance and the semivariance at first lag; the ratio between semivariance values at second and first lags; and the first derivative near the origin and second derivative at third lag. These are considered as they define the changes in an image and continuous variations. These authors' contributions relate to the characterisation of the urban spatial patterns using multispectral images reduced to principal components, as well as discrimination of these patterns using the range of variograms from the different kinds of land occupation.

2. Literature review

Remote sensing is a powerful tool for obtaining data on land use and coverage. Recent technological advances have improved the spatial and spectral resolutions of sensor systems, and allowed for a more detailed analysis of the urban environment.

The remote-sensing applications most used on urban areas are the characterisation, identification, classification and quantification of materials, the composition and structure related to urban buildings (Weng, 2008), and environmental and economic applications such as heat islands identification, urban environmental quality characterisation and so on.

Quintanilha and Silva (2005) argue that besides the high spatial resolution of the IKONOS satellite sensors, the identification and classification of urban targets is difficult as the spectral resolution of the multispectral sensor is not enough to discriminate all different types of coverage.

In order to monitor and model the urban expansion dynamics over a time period, some authors have used remote sensing and geographic information system techniques (Jat *et al.*, 2008; Sudhira *et al.*, 2004; Taubenböck *et al.*, 2012).

Ridd (1995) explores the vegetation-impervious surface-soil model to characterise the urban environment, and to compare morphology between and within cities. Since the advent of the high spatial resolution images, many works have used the OBIA approach for urban applications. Nóbrega *et al.* (2006, 2008), Pinho *et al.* (2012), Quintanilha *et al.* (2006) and Souza *et al.* (2007, 2009) make use of object-oriented classification in high spatial resolution images in Brazilian cities. Blaschke (2010), Durieux *et al.* (2008), Giannini *et al.* (2012), Pacifici *et al.* (2009) and Tewolde and Cabral (2011) have also used OBIA for urban sprawl studies or to map urban land use.

According to Machado *et al.* (2014), comparative studies focused on global trends and patterns of urbanisation have been carried out by several researchers. For example, Esch *et al.* (2012) monitored global urbanisation through a time series based on observation data of the Earth's surface. Other studies analysed urban expansion in megacities (cities with more than 10 million inhabitants) based on remote-sensing images: Kuffer and Barros (2011) (in the megacity of New Delhi, India), Schwarz (2010) (in Europe) and Wang *et al.* (2012) (in China).

Some studies explored texture characteristics in images in order to enhance the classification of urban areas, such as

Antunes and Duarte (2012), Boucher *et al.* (2006) and Huang *et al.* (2008).

Recent and more comprehensive reviews on the use of orbital remote sensing for urban studies are in Brito and Quintanilha (2012), Machado *et al.* (2014) and Patino and Duque (2013).

Geostatistics was initially proposed in order to study the spatial distribution of minerals in evaluations of ore deposits by using Kriging models. Matheron (1971) developed the theoretical basis of geostatistics (regionalised variables theory) through the Traité de Géoestatistique Appliquée (Van Der Meer, 2012).

The variogram quantitatively represents the spatial variation of a regionalised phenomenon and is used as a starting point in many spatial studies. It is mostly used as a first step in estimation methods such as Kriging (Woodcock *et al.*, 1998). The variogram function relates the variance to the spatial separation, and provides a concise and impartial description of the scale and pattern of spatial variability (Curran, 1998). The variogram describes the spatial distribution of a regionalised variable (Woodcock *et al.*, 1998).

Variograms also have been used in order to analyse the spatial dependence on remote-sensing images in texture classification. Atkinson and Lewis (2000), for example, used the variogram in land use and occupation classification from a satellite image as a texture measure. A variogram expresses the variance changes with the increase in distance between the samples and these details are shown online (Sas Institute Inc., 2015).

According to Yamamoto (2002) and several other authors, the parameters of the variogram are the following.

- Sill ($C_0 + C$) is the variance stabilisation between the samples.
- Range or amplitude (a) indicates how homogeneous samples are among themselves. The greater the amplitude, the greater the homogeneity of the samples and as the distance (h) increases, the uniformity decreases. It is the range that defines the boundary between the structured field, where samples correlate, and the random field where the samples are independent.
- Nugget effect or random variance (C_0) measures the discontinuity at the origin, a result of the sampling.

Curran and Atkinson (1998) present examples of applications to explore and describe the spatial variability, and to improve the sampling scheme's sketch of images with the aim of improving the classification's accuracy. Woodcock *et al.* (1998) use the variogram to measure the spatial variance of images, to understand the nature and the cause of this variance, as well as how it relates to the imaged land characteristics. Balaguer-Beser *et al.* (2013) use semivariogram to identify regions in remote-sensing images by considering the geometric properties of the constituent elements in the target's pattern and their spatial distribution. These two articles use the variogram as pointed out in this our article.

Wu *et al.* (2006) applied the variogram-based texture analysis to classify detailed urban land-use classes, and spectral classification to separate the building class from non-building classes.

Van Der Meer (2012) presents a state-of-the-art review of the use of geostatistics in remote-sensing studies in articles published between 2000 and 2010. The author highlights some applications, such as the use of variograms to quantify picture structure, texture and observation scale optimisation besides discussing other geostatistical tools such as Kriging, co-Kriging and stochastic simulation. Two notable advances in the use of geostatistics in remote sensing are the use of variograms and Kriging estimators and simulation techniques for super-resolution mapping, and the use of simulation and other techniques to define optimal sampling schemes to link the image to the field data (see Van Der Meer, 2012).

The proposed methodology is based on studies by Brito and Quintanilha (2013) and Barros *et al.* (2013) that aimed to characterise land-use patterns using the Quickbird satellite images of a railroad suburb in Salvador (Bahia, Brazil).

3. Study area

The Cabuçu de Baixo river basin is located at the northern part of the city of São Paulo (Figure 1). It has an area that is ~42 km^2 and consists of several streams whose headwaters are at the northern part, inside the Cantareira State Park. This park, one of the most important remnants of the Atlantic Forest in São Paulo, is considered by UNESCO as a biosphere reserve and covers 30% of the entire river basin.

In the basin, there are about 150 slums (28 located in critical geotechnical risk areas, all in the northern part of the basin (Prefeitura do Municipio de São Paulo, 2002)). Figure 2 shows an example of the types of occupation in this region.

For the present study, the authors selected the Córrego Bananal Stream sub-basin as a case study. This stream is located upstream of the Cabuçu de Baixo River – a right bank tributary of the Tietê River located in the northern part of São Paulo city.

The urban heterogeneity in the basin can be observed from the several types of occupations indicated by the building standard (e.g. agglomeration, size, shape) and the road system (the

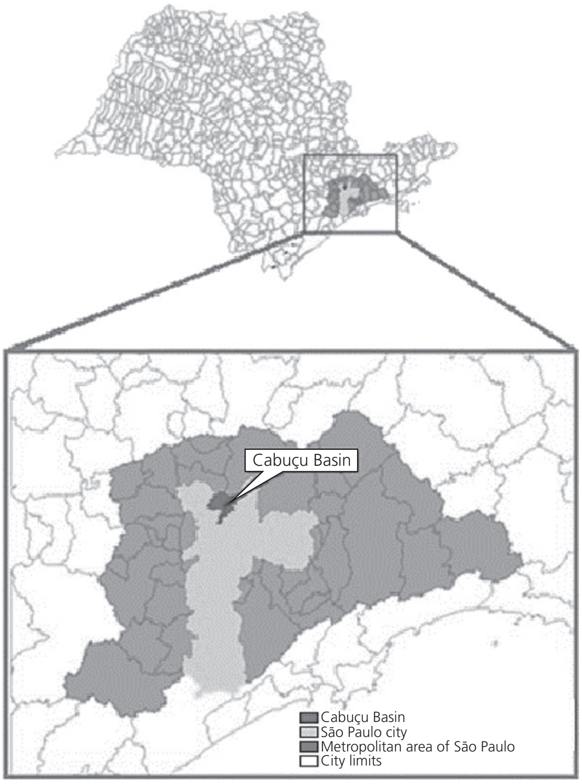

Figure 1. Location of the study area. Source: (Barros, 2004a)

presence or absence of paving, width and planning) (Barros, 2004a, 2004b).

4. Materials and methods

This research used a scene from a multispectral mode 11-bit orbital image IKONOS II taken on 24 September 2000, with 4 m spatial resolution and the following software: SPRING 5·1·6. – Geo-referenced Information Processing System (Camara *et al.*, 1996); ArcGIS 10 (Esri); Microsoft Excel.

The land use and occupation classification from the Environmental Atlas of São Paulo City Municipality (Prefeitura do Municipio de São Paulo, 2002) was used, as a first approach, to identify urban occupation patterns.

The classification of land use and occupation used in this work have eighteen classes. Three of these are related to the land use and residential occupation, namely: MDUs, IDO and RDO. These are the subject matter of this article. For this study, ten áreas from each of the three above considered classes are randomly selected (see Figure 3).

The MDUs class consists mainly of housing complexes from the housing programmes of São Paulo city by Cohab (Companhia Metropolitana de Habitação – Metropolitan Housing Company). These are low-income housing units in building condominiums of up to four floors in height.

The IDO class covers a significant area of the Córrego Bananal Stream sub-basin. It constitutes the invasion of un-occupied land to form irregular settlements (a housing pattern typical of slums or substandardised housing); these are located in flooding or landslide risky areas without any basic sanitation. Another important characteristic of this land occupation class is the irregular street layout – that is, streets that are not recognised or approved by relevant government agencies. The streets are narrow, unpaved and have no block planning.

The RDO class is characterised by the presence of totally urbanised areas and high soil waterproofing rates. The term ‘regulated’ refers to the fact that these areas are meant to be legalised; however, this legalisation did not occur because there was some urban plan for the demarcation of the lots and the streets. By analysing satellite images and photographs, the authors noted that the streets are paved and a bit wider than the streets of the IDO class, but there is no uniform standard and in many areas the two classes get confused – both with regard to street widths and lot size.

The principal component was applied to the covariance matrix of the IKONOS image four multispectral channels using the software SPRING 5·1·6. The goal was to reduce the number of bands so as to get their variograms and to preserve most of the original band information.

Figure 4 shows the IKONOS image with the polygons of the classes to be analysed, extracted from the land use and occupation map of the Cabuçu de Baixo river basin: the MDUs class is the areas with black stripes; IDO in flat gray; and RDO class is the areas with black points.

The variograms are calculated on the grey levels of the first principal component of each of the selected samples (using ArcGIS software). The model that presents the best adjustment is the spherical one. The number of lags was determined from empirical testing and by analysing variogram results. For the class RDO, seven 4 m lags are used; for class IDO, six 4 m lags, and for MDU class, twelve 4 m lags are used.

5. Results

The results are summarised in Table 1 and in Figure 5. In these, the variogram parameter values – range, sill and nugget effect of each test sample – are defined. The variogram

Figure 2. Typical urban configuration of the analysed area

maps are generated by the ArcGIS Geostatiscal Analyst and in the picture, when the ellipse is more prominent, it indicates that the variability is prevailing in some direction(s); in other words, the larger is the anisotropy. If the figure was a circle, it would indicate the opposite, isotropy, which would mean that the phenomenon would variate homogeneously in all directions. The ellipse also indicates the direction with the highest variability.

Some observations are picked from the analysis of the variogram parameters of the three classes.

The MDUs class shows anisotropy in most cases; of the ten samples, nine have anisotropy, and it is interesting to observe that the modal direction of the variance follows the orientation of the elements arranged on the land (Figure 5). The MDUs are diagonally arranged in the first two cases and vertically arranged in the third case, corresponding to the direction shown in the variogram map.

The RDO class also shows anisotropy in most samples, but unlike the former class, the variogram map presents a less pronounced anisotropy (Figure 5); in ten samples, seven have anisotropy. It is possible to observe that there is anisotropy with a less pronounced ellipse shape than the MDUs class. Although variogram maps indicate that most of the samples show anisotropy, the variograms in the four basic directions are not calculated, as this study aims to identify patterns from the spectral behaviour. The IDO class also shows anisotropy in most samples. In ten samples, seven are anisotropic.

The most important parameter in a variogram analysis is the range as it determines the homogeneity level; the larger the amplitude, the larger the homogeneity of the samples (i.e. the grey levels of the pixels have a higher similarity among themselves). The classes RDO and IDO present similar average ranges, 17 and 18, respectively, while the MDUs class presents a higher average range value of 29. By analysing the occupation history of the study area, it is possible to understand why, in spite of being classified as two distinct classes, the classes RDO and IDO have similar average range values and, therefore, the variogram is not able to accurately distinguish between these two classes.

Unlike MDUs that are planned, the other two classes have as the main characteristic unauthorised buildings and the disorganised occupation – that is, not planned.

Although some characteristics distinguish one class from the other, such as the lot size (larger in RDO class) and the street layout with better planning (larger width in the RDO class), in several stretches this difference is not so clear.

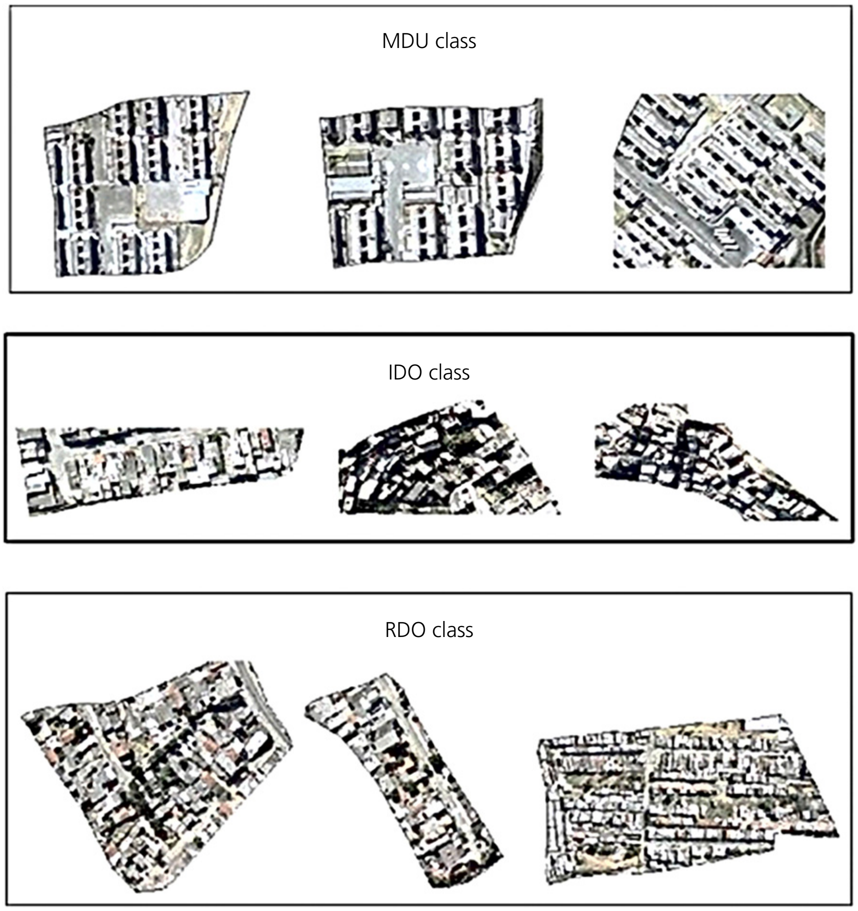

Figure 3. Samples (polygons) representing the three classes of land use and occupation considered

6. Conclusion and discussions

A city's growth dynamics is the subject of numerous studies and knowledge areas, and knowing the mechanisms involved in this process is of vital importance to managers and urban planners since the urban population is constantly growing and mega cities have steadily been appearing everywhere around the world. The present study meets the above theme to analyse a methodological proposal to identify urban development patterns using a geostatistics tool, the variogram.

Analysing urban residential patterns is of great importance for management and planning of cities since the identification of these patterns helps to understand how the city is organised and can indicate in which direction the city is growing, as well as what kind of urban pattern of growth the city is experiencing.

In this study, the urban residential pattern identification is carried out from the spectral behaviour of different residential classes. The difference in spectral characteristics between residential classes occurs due to different materials, sizes and shapes of buildings found in each class.

One consequence of the pattern identification is the delimitation of the intra-urban space in homogeneous sectors that could be related initially, to its physical aspects; in a deeper analysis, this may also reflect the socioeconomic aspects of the resident population.

Although this research has achieved satisfactory results, the analysed methodological proposal presented a number of points that need to be reviewed and tested in future studies to ensure its replicability.

One of the difficulties encountered during the study was to obtain a high-resolution image that had not undergone any kind of correction or fusion, since in order to analyse the spatial variance of the target spectral behaviour it is necessary that the data be 'as raw as possible'.

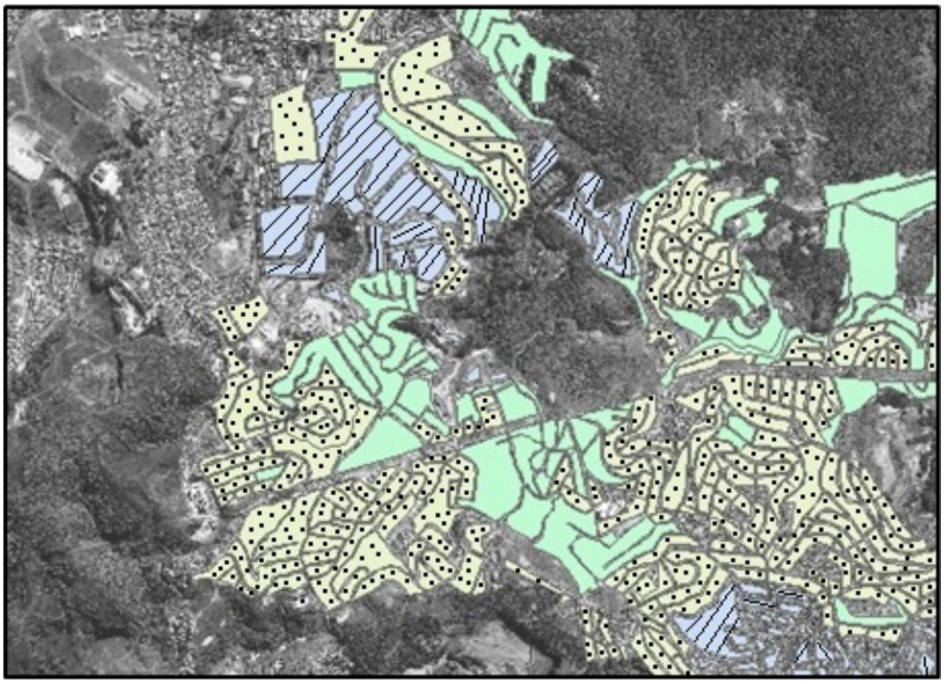

Figure 4. 2002 IKONOS image and polygons of the analysed classes

Sample	Range: m			Sill: × 10^7			Nugget effect: × 10^7		
	MDU	RDO	IDO	MDU	RDO	IDO	MDU	RDO	IDO
1	26	28	19	7	5	11	0	4	2
2	48	28	21	5	4	28	4	3	2
3	25	11	22	11	9	10	0	5	0
4	25	13	24	8	7	8	3	3	3
5	26	12	10	10	8	9	3	0	0
6	28	15	24	9	10	9	7	8	4
7	48	10	9	6	5	10	2	2	0
8	27	15	12	9	6	10	4	3	0
9	13	16	13	7	6	8	0	3	3
10	22	24	24	10	8	6	3	3	1
Mean	17	18	29	8·2	6·8	10·9	2·6	3·4	1·5
Median	15	20	26	8·5	6·5	8·5	1·5	3·5	1·5
Std. dev.	7	6	11	2·1	2·1	3·5	2·1	0·7	0·7

Table 1. Descriptive statistics of the parameters of variograms of ten samples from each class

Although it is possible to find homogeneous patterns in urban and intra-urban frameworks of cities, in certain aspects the determined patterns have heterogeneity. One example is the case of the IDO class that can be defined as slums or as sub-normal housing. There are numerous examples of this type of housing organisation that uses different materials in the

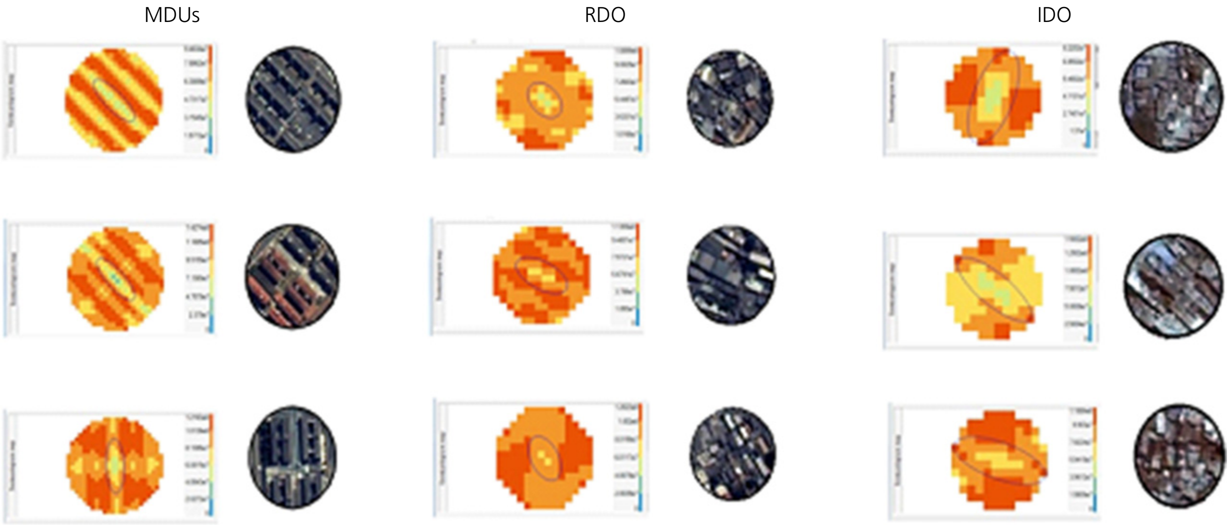

Figure 5. Image cropping of the samples of three classes and variogram map associated with the sample

construction of houses and are spatially distributed in different ways.

The point is that the classes analysed in this study are visibly and spectrally very close and this made the variograms not clearly distinguishable from each other, except for the MDUs class that is well defined and could be detected by the parameters of the calculated variograms.

This 'confusion' between the classes IDO and RDO may reflect the occupation process of the entire study area – that is, even the area that is now considered 'regulated' was in the past considered an 'irregular' occupation, showing that there was no particular type of urban housing planning for this area.

According to the results, it is concluded that the proposed methodology achieved its goal to identify homogeneous areas in high-resolution satellite images. However, it is observed that it applies best in areas with well-defined classes. In the present study, the MDUs class is clearly identified by the variograms as it shows very singular characteristics and settings. For the other two analysed classes – RDO and IDO – both present characteristics, settings and building materials are quite similar to each other and this made the identification of these classes by way of variograms not so effective.

The proposed methodology proved to be valid, and it can be a rapid and low-cost tool for urban planners who need, for example, to characterise the morphology of the city; to detect non-separable classes in the regular conditions of the images; to support the sample training set selection used in supervised classification algorithms; and to find dimension for the rules or external variables in an OBIA classification (such as the buffer size, the digital terrain modelling scale and so on).

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