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THE USEOF CBERS IMAGE IN THE DELIMITATION OF SMALL CITIES BOUNDARIES IN THE BRAZILIAN AMAZONIA REGION

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ABSTRACT

This paper analyzes the use of CBERS (China-Brazil Earth Resources Satellite) high resolution images to map urban limits of a small city in the Amazon Region of Brazil. The use of Sino-Brazilian satellite images to study small cities of the Brazilian Amazon Region is also discussed. A HCR image was used to classify the image of the study area into four classes: urban, forest, clouds, and shadows, by visual interpretation. This map was compared with another map produced with unsupervised classification. A confusion matrix was produced to evaluate the accuracy of unsupervised classification. Comparison between the reference map (visual interpretation) and the unsupervised classification map verified that 82.8% of the areas were classified correctly. This ability to recognize and delimitate small cities in Amazonia demonstrates the quality of the CBERS – HCR image.
Keywords: CBERS- HCR image, high resolution image, urban area delimitation, Brazilian Amazon towns.

EL USO DE IMAGEN CBERS PARA DELIMITACIÓN DE CIUDADES PEQUEÑAS EN LA REGIÓN DE AMAZONIA BRASILEÑA

RESUMEN

Este trabajo analiza el uso de imágenes de alta resolución CBERS (Satélite China-Brasil de Recursos Terrestres) para establecer el límite urbano de una pequeña ciudad en la región de Amazonia en Brasil, centrándose en la ciudad de Ponta de Pedras ubicada en la Isla de Marajó, Pará. El objetivo es contribuir a la discusión del uso de imágenes del satélite chino-brasileño para el estudio de pequeñas ciudades de la Amazonía Brasileña. Se utilizó la imagen HCR del área de estudio para producir un mapa clasificado por interpretación visual y otro mapa por clasificación no supervisada, con cuatro clases: urbano, bosque, nubes y sombras, y comparar luego el resultado obtenido de ambas clasificaciones. Se calculó una matriz de confusión para evaluar la exactitud de

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la clasificación no supervisada, obteniendo un 82.8% de zonas clasificadas correctamente, lo que demuestra la calidad de las imágenes CBERS para este tipo de fines.
Palabras clave: imagen CBERS - HCR, imágenes de alta resolución, delimitación urbana, ciudades pequeñas de Amazonia brasileña.

1. Introduction

Urban form and city growth, as well as intra-urban structure, are important attributes for understanding and analyzing urban space to support urban planning. According to Villaça (1998), studying the urban form can help us understand the city as a whole. However, it is also essential to consider the relationships observed between different places inside the city to explain the urban form.

The growth of the typical city in a developing country expresses in its form and structures all social content and its conflicts (Borzacchiello apud Carlos, 1994). Therefore, it is important for decision makers to comprehend how a city grows, and how this is related to social structure, because this helps to establish prognostics and to minimize urban problems. Therefore, remote sensing data have been used as important information to study cities and the impact of urban growth on society and environment.

According to Rindfuss and Stern (1998, p.3), one motivation for linking people and remote sensing data (pixel) is that "doing so might result in better social science research." In this context, using remote sensing images, with high resolution pixels, results in better data about the social structure of a town.

High definition satellite images have been used as important sources of urban data. This technique provides the ability to monitor urban growth and intra-urban space as well as environmental problems caused by the process of urban expansion. Different authors have shown the application of these products in urban studies (Dong *et al*., 1997; Jensen and Cowen, 1999; Herold *et al*., 2002; Miller and Small, 2003; Feng *et al*., 2004; and others).

Miller and Small (2003, p. 134) indicate that

> If remote sensing is to improve our understanding of urban environments and our capacity to manage them in the future, then urban applications of remote sensing must be developed which take advantage of the unique characteristics of the data. These include (1) the self-consistent and synoptic nature of the data; (2) its capacity for routine, periodic, and unobtrusive updating and comparison; (3) its capacity for the description, classification, and measurement of critical physical properties that would be prohibitively expensive or impossible to obtain in situ; and (4) its synoptic spatial coverage. These characteristics permit assessments of cities and their hinterlands, without being constrained by the administrative or political boundaries that delimit the coverage of other types of urban data.

This paper aims to evaluate the use of a CBERS (China-Brazil Earth Resources Satellite) high resolution image to map urban area limits of a small city in the Amazon Region of Brazil,

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focusing on the city of Ponta de Pedras, located on Marajó Island in the state of Pará. The purpose is also to contribute to the discussion about the use of Sino-Brazilian satellite high resolution images in the study of small cities in the Brazilian Amazon Region.

2. The characteristics of China - Brazil Earth Resources Satellite

According to INPE (2010), "The CBERS Program was born from a partnership between Brazil and China in the space technical scientific segment. Consequently, Brazil joined a select group of countries with remote sensing technology." The images produced by its sensors are used in different areas, such as deforestation in the Amazon Region, water resources monitoring, urban growth, education, etc.

Epiphanio (2008) stated "the main payload of the first three CBERS satellites is a CCD camera with 20-m GIFOV (ground instantaneous field of view), five bands (blue, green, red, NIR, pan), 8 bits, 113-km swath, and ±32° across-track viewing capability. The second important payload present in these three satellites is a Wide Field Imager (WFI), with two bands (red and NIR), 260-m GIFOV at nadir, 890-km swath. As part of CBERS-1 and -2, there was an Infrared Scanner (IRMS) with four bands (pan, TIR, and two in SWIR), 80-m (160-m TIR) spatial resolution, 120-km swath. For CBERS-2B, this scanner was replaced with a High Resolution Camera (panchromatic, 2.7- m spatial resolution, 27-km swath)".

The CBERS - 1 was launched in 1999, CBERS - 2 in 2003, and CBERS - 2A in 2007, which ended its operation in 2010. According to INPE (2010), due to the success of CBERS-1 and 2/2A, Brazil and China decided to continue the CBERS program by signing a new agreement to develop and launch two more satellites, CBERS-3, in 2011, and CBERS-4, in 2013. CBERS-1 and 2 are composed of two modules (INPE 2010). One module accommodates optical systems (CCD-High Resolution Imaging Camera, IRMSS - Infrared Multispectral Scanner, and WFI Camera Imaging - wide field imager); the other module known as "service" contains functions necessary for the operation of the satellite. The CBERS-2B is very similar to CBERS-1 and 2, but the IRMSS sensor was replaced by an HRC-high resolution panchromatic camera.

As stated by INPE (2010), the High Resolution Panchromatic camera (HRC-High Resolution Camera) operates on a single spectral range, which covers visible and near-infrared spectrum (0.50 - 0.80 µm). The HRC is only on CBERS-2B. It produces images with a range of 27 km wide and a spatial resolution of 2.7 m, which provides incredible details of the surface including city structures.

3. Materials, data and methods

The methodology used to develop the research for this paper followed the steps described in this section.

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3.1. Defining the study area: Ponta de Pedras - a small city in the Amazon Region

Since 1980, the Brazilian Amazon region has simultaneously been both the largest rainforest in the world and an urban region, because over 50 percent of its population was living in cities by that time. In 1985, Becker described the Region as an "urbanized forest" and supported the need to discuss how cities are an important part of this environment. In spite of the recognized importance of the topic and clear trends indicating the expansion of deprived urban conditions, there has been a lack of discussion about how these processes are expressed differently across the region. Becker (apud Costa and Brondizio, 2009) claims that "population size and rate of growth are not enough to define a level of urbanization, if attention is not paid to the values of urbanization provided to society in terms of social and economic opportunities, including services, employment, and safety (for instance against land expulsion)." No single official definition of city in Brazil exists, however, the Brazilian Institute of Geography and Statistics defines as a city all administrative seats of a municipality, regardless of population size and urban infrastructure (IBGE, 2010).

Small cities are predominant throughout the Brazilian Amazon Region: 85% of the total administrative seats in the region had less than 20,000 inhabitants in 2000. Costa and Brondizio (2009) stated that "the regional urban population is greatly polarized, as 41% of the region's urban population reside in 1% of Amazonian municipalities, or those considered large (>200,000 inhabitants)". These authors also stated that small cities in the Amazon Region "have, in general, fragile and weak transformative economies, high dependency on federal subsidies, jobs located predominantly in public service, low competence in offering basic services such as infrastructure, education and public security, and predominance of rural activities functioning largely as part of an informal economic system" (Idem, p. 216). Throughout their development cycles, small cities "have received waves of small farmers leaving disregarded agrarian settlements for urban areas and groups of migrants attracted often predominately by public institutions and subsidies and also by a tertiary sector in development" (Costa and Brondizio, 2009, p. 214).

Ponta de Pedras is located on Marajó Island in the state of Pará, in the estuarine region of the Amazon River, and approximately 60 km by boat from the state capital Belém (figure 1). This area of the Amazon Region has very particular urban characteristics:

> "Since the 1970s, the process of urbanization of the floodplains has heralded trends which have progressively shaped the region as a whole. Conversely, in spite of a growing road transportation network in the region, a large number of small floodplain towns maintain a network of people and resources primarily through the river system ... Faster modes of transportation and communication have greatly increased these interconnections, not only between rural and urban areas, but also between urban areas along the floodplains. While the strong rural resource economy of the region supports a wide range of markets, industries, and employment (particularly informal employment), cities offer more opportunities for education, health, and employment. Again, the floodplain cities are heralding a new concept of the urban in the Amazon Region: cities with ever stronger links to the surrounding rural environment and to each other. As in other parts of the Amazon, floodplain cities are increasingly embedded within a growing network of people and resources, marked by increasing inter-dependency between rural and urban, and urban and urban" (Costa and Brondizio, 2011, p. 90).

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The characteristics mentioned before can be found in the city of Ponta de Pedras. Between 1980 and 2000, the number of urban and rural households increased 130% and 53%, respectively. Contrary to regional trends, Ponta de Pedras had an impressive growth of its rural population (a 30% increase), while at the same time experiencing declining deforestation and an increasing forest economy based on the production of açai fruit (Brondizio, 2008), which is the most important product and main source of the population's income. The 2010 census (IBGE, 2010) counted 25,989 inhabitants living in the whole municipality of Ponta de Pedras: 47.8% of them were living in the urban area. Between the 2000 and 2010 Censuses, the urban population grew almost 44% and rural population 35%. Building in the urban area and spatial growth reflect this increase.

Between 1960 and 2007, the town of Ponta de Pedras experienced a growth of 0.89 km^2 of its urban area, representing an increase of 248% compared to the urban area in 1960. The spatial pattern of urban development also evolved during this time. The number of streets increased outward from the original city area in a highly variable manner as axes of urban growth, and expansion has followed both floodplain and upland areas. This small city is important in terms of urban network of açai fruit trading. The municipality is the third most important producer of this product in Brazil (IBGE, 2010), which has been one of the important causes for the urban growth in the last 10 years.

Ponta de Pedras is growing despite limitations imposed by environmental characteristics of the floodplain and is import in the urban network of the Region. Monitoring trends of urban growth of Ponta de Pedras, as well as other small cities in the Brazilian Amazon Region, is important for public policies and planning.

3.2. Satellite image used and mapping procedures

3.2.1. Correcting HCR image

The image of Ponta de Pedras was selected using the CBERS homepage (http://www.dgi.inpe.br/CDSR). figure 2 shows the homepage layout, where the user selects the CBERS sensor, period desired, and cloud cover. After this procedure, the user can select the image to be processed and made available by INPE, and then, the image is downloaded with no charge. In China, Brazil, and some other South America countries, it is freeware data, with high quality spatial resolution. In this case, the image selected was obtained by CBERS 2, sensor HCR, on July 17, 2009, orbit/point 162/102, which had a 10% cloud cover (figure 3).

After downloaded, due to the haze and clouds in the image, an atmospheric correction was made using Quick Atmospheric Correction Module (QUAC), available from ENVI - software application. This method is "an in-scene approach to atmospheric correction and determines parameters directly from the information contained within the scene using the observed pixel spectra" (ENVI, 2011). Subsequent to this correction, a subset of the image was selected, with the urban perimeter of Ponta de Pedras as the image center, and it was saved as a new image. This subset was registered, using as the pattern image an IKONOS image, obtained in 2002,

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geometrically corrected, in UTM coordinates. These procedures prepared the image to be used as the data source for the proposed study.

3.2.2. Mapping the urban area

Two mappings of the urban area of Ponta de Pedras were produced using the same CBERS-HCR image (figure 4):

- One map was produced with Arc-Map software, using the method of visual interpretation to extract four classes: urban area, forested area, shadow, and cloud. We decided to use four classes because the objective was to draw up the boundaries of the city not to identify land use classes, which could be very difficult considering the city size.

- Another map was produced using the ISO data command for unsupervised classification available in ENVI. The CBERS image was also classified in four classes (urban area, forested area, shadow, and cloud). However, the image obtained from this classification could not differentiate clouds from urban area (more comments about this result are presented in section 4).

These mappings were compared using two procedures: 1) overlay process with intersect command of Arc-Map, which permitted quantification of the misclassified area as a result of unsupervised method; 2) elaboration of contingency table to compare the performance of unsupervised classification. The aim of these comparisons was to verify the quality of CBERS and HCR images in terms of urban area delimitation, using the unsupervised (ISO) process and to determine if the result represents reality as accurately as possible. Due to the spatial resolution of the HCR image, the authors of this paper assumed unsupervised classification could produce a high quality and accurate classification and rapidly generate urban mapping useful to decision makers.

According to NRCN (2010), a contingency table (or error matrix) is a method to compare two thematic maps. "In remote sensing image analysis, the two thematic maps are often a "ground truth" map (the reference map) and a map derived from automated image classification (the classified map). The error matrix permits the calculation of a range of measures that describes the accuracy of the classified map with respect to the reference map." Also known as the confusion table or error matrix, this table shows statistics for evaluating image classification accuracy, with the degree, in terms of percentage, of misclassification between classes. The visual interpretation map was used as the reference map and 62 field samples were plotted on the unsupervised classification image. These samples were designed using ENVI command to produce a contingency table. Their location was randomly defined, but related to the dimensions of area occupied by each class of land use; 5% of samples were related to shadows, 57% to forest, 35% to urban area, and 3% to cloud.

The contingency table evaluated the performance of the unsupervised classification in terms of mapping. Overlaying these products made it possible to visualize the main differences between visual and unsupervised classification. The error matrix was used to compare and quantify the level

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of similarity of land use in maps elaborated with visual interpretation and unsupervised classification. figure 5 shows some pictures of field samples, taken by the authors in July 2010, which supported, as ground truth, visual interpretation, and were helpful in obtaining the contingency table.

In figure 5, letters a and b, are examples of the urban area. This very small city is comprised of a center and streets made with wood and concrete. Letter c, d, and e, illustrate examples of streets with home gardens of açaí palm tree, rain forest trees; they also illustrate the very flat landscape of Amazon River floodplain. The exact location of these areas can be seen in figure 6.

4. Results and discussion

One of the most important problems in studying urban areas using remote sensing data is the spatial resolution of an image. Urban space has a mixture of targets, which makes mapping the urban land use a complex process. Nevertheless, mapping urban areas is an important process that produces essential information to urban planners. These maps can illustrate how a city is growing, the occupied areas, the main axes of growth, the environmental conflicts, and so forth.

The launch of SPOT 4 and IKONOS has partially solved the difficulties associated with urban mapping. However, the costs to obtain a scene can still be a problem. Social science researchers often do not have enough financial support to acquire high-resolution images to study cities in different places in the world, with very specific characteristics, such as small population size, localization, and surrounding environment. CBERS images, especially those acquired by an HCR sensor, can produce high resolution images with low cost compared to other commercial products.

Ponta de Pedras is a typical Amazonian small city, surrounded by rainforest and home gardens with açaí palm trees. Its population and economy have an intense connection with the river and forest resources. The urban structure is unique. For instance, the main streets are made of concrete to support high rainfall indexes, and many streets are wood, especially in floodplain areas. The poorest population lives in these areas, without infrastructure, where it is common to find wooden houses, as showed in figure 5c. The houses located at upland areas are usually made by brick. These characteristics make the process of image interpretation very important because the açaí home gardens can create confusions between urban area and forest. In addition, the urban area of Ponta de Pedras has grown rapidly as a function of migration from the rural to the urban areas. This migration is result of the açaí economy, which during the last decade improved family income. This process has also been caused by the population's desire to access basic services offered by the city, although these services are still considered deficient to attend residents' demands.

It is important to monitor urban growth to verify cities' performance in terms of land occupation. The CBERS - HCR image made it possible to discriminate urban characteristics without difficulty. Urban areas could be differentiated from forest with both visual (figure 6a) and unsupervised classification (figure 6b). The land use map produced as a result of visual

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interpretation indicated that forest constituted 71.6% of the area, urban area 26.2%, and cloud or shadow covered 2.3% of the image subset (table 1).

Although unsupervised classification was able to observe four classes of land use, the class "clouds" was confused with urban areas. Some pixels misclassified as clouds can be detected inside the urban area and the two clouds were classified as urban area and/or forest. This occurred because these clouds look more like haze than heavy clouds, making the process of class discrimination more complicated than usual.

The result of the overlaying process of visual interpretation and unsupervised classification (figure 7) verified that 82.8% of the land use classes by either visual interpretation or unsupervised classification mappings were classified as the same category. This process showed that only 17.2% of both classifications did not correspond.

The aim of this paper was to verify if CBERS-HCR images can be a good product for application in urban studies. By comparing the results of visual interpretation with unsupervised classification, it was possible to develop a contingency table, which shows an index of accuracy for the unsupervised classification. This table, as mentioned before, was elaborated using ground truth samples about land use (figure 8). The contingency table showed that the overall accuracy of unsupervised classification was 82.3% and 11 samples were misclassified. This accuracy is considered a high score of classification accuracy, especially for urban studies (Congalton, 1991) and emphasizes the quality of the CBERS - HCR image, considering their application to urban studies.

The contingency table (table 2) shows that 100% of samples in areas covered by cloud were misclassified as urban area, and 33% of shadow samples were associated to forest, which can be observed at the upper right corner of the map (figure 8). In this case, unsupervised classification could not separate properly these classes of land use. Otherwise, urban area and forest samples were properly classified; 86.4% and 85.7% of samples in urban area and forest, respectively, were classified accurately. The unsupervised classification enhanced in detail the lines of streets in Ponta de Pedras, which followed the main characteristics of Amazon estuarine cities.

It is also important to emphasize that HCR high resolution images, even with the data transmission problems, can be a very important data source for researchers and public administrators to study and monitor towns located at Amazon Region or any other region. Studies of urban growth can obtain good results, reinforcing observations of Rindfuss and Stern (1998) and Miller and Small (2003) about relationship between remote sensing and social sciences.

5. Final remarks

This research tested a methodology to evaluate the performance of CBERS - HCR images in terms of urban area delimitation. It also compared visual and unsupervised classification of this remote sensing product. The results obtained in this simple test showed us the performance of HCR

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- CBERS images for urban targets discrimination by mainly considering the Amazonian environment and the urban reality prevailing in this region.

Because of the limited financial support provided for public organizations in Brazil to monitor urban areas, it is important to use methodologies and products that permit the study of urban environment efficiently, accurately, and with low cost. The use of CBERS - HCR image achieves these aims. This comparison highlighted the quality of HCR images, showing they can be an excellent alternative for decision makers to use for remote sensing data in urban studies.

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TABLES

Table 1. Classes of land use

	Area (Sq Km)
SHADOW	0.04
FOREST	2.78
URBAN	1.02
CLOUD	0.05
TOTAL	3.88

Table 2. Classification accuracy (contingency table)

		Map derived from unsupervised classification			
		shadow	**forest**	**urban**	**cloud**
Map of reference of ground truth data	**shadow**	66.7	33.3	0.0	0.0
	forest	0.0	85.7	14.3	0.0
	urban	0.0	0.0	86.4	13.6
	cloud	0.0	0.0	100.0	0.0

Overall

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FIGURES

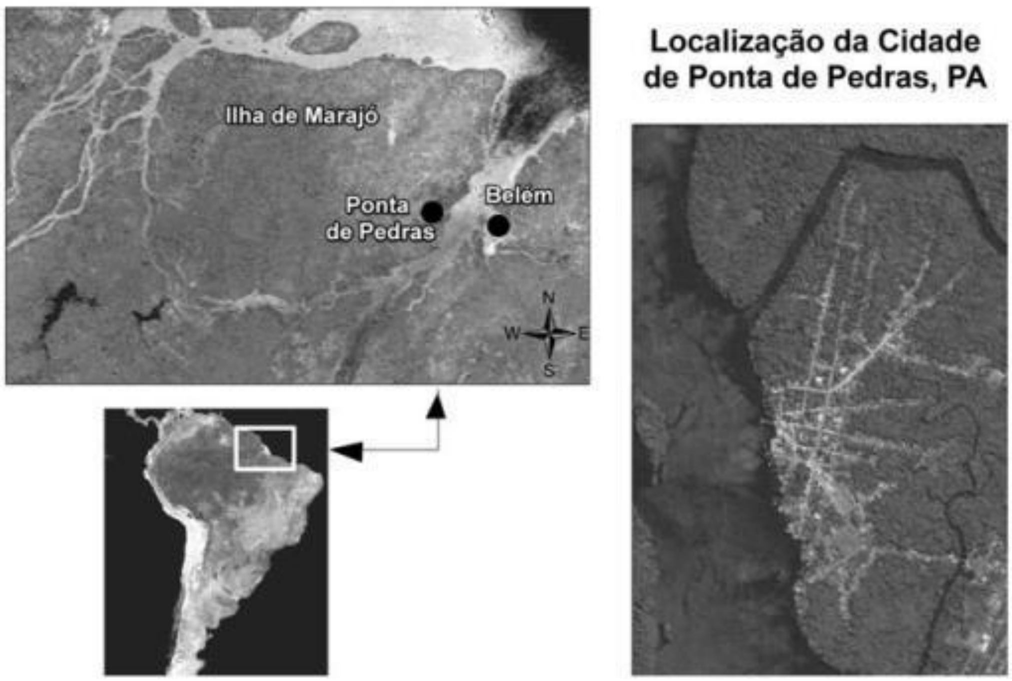

Figure 1. Location of study area.

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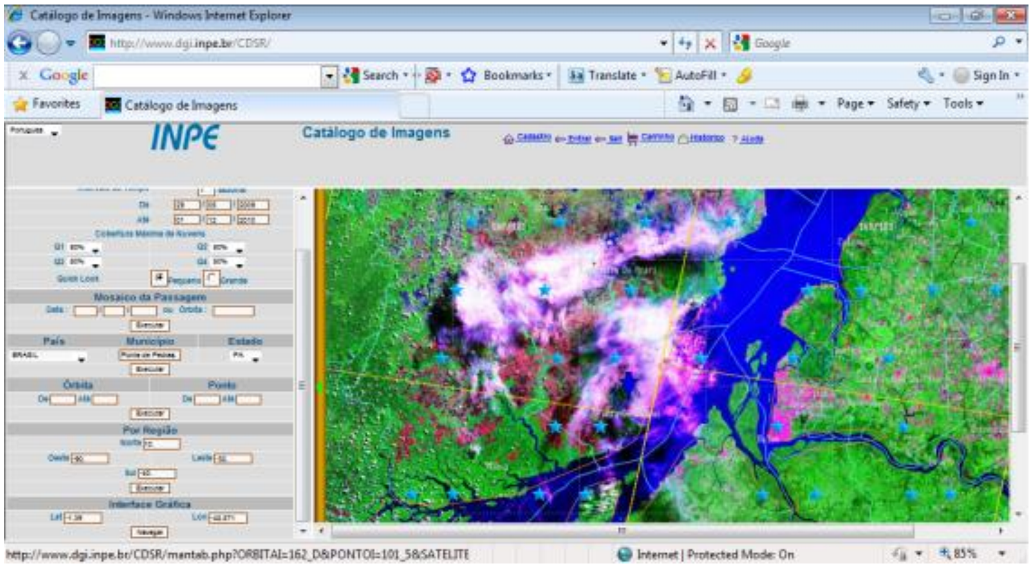

Figure 2. CBERS homepage, where user can select CBERS image, according to some parameters.

Source: http://www.dgi.inpe.br/CDSR

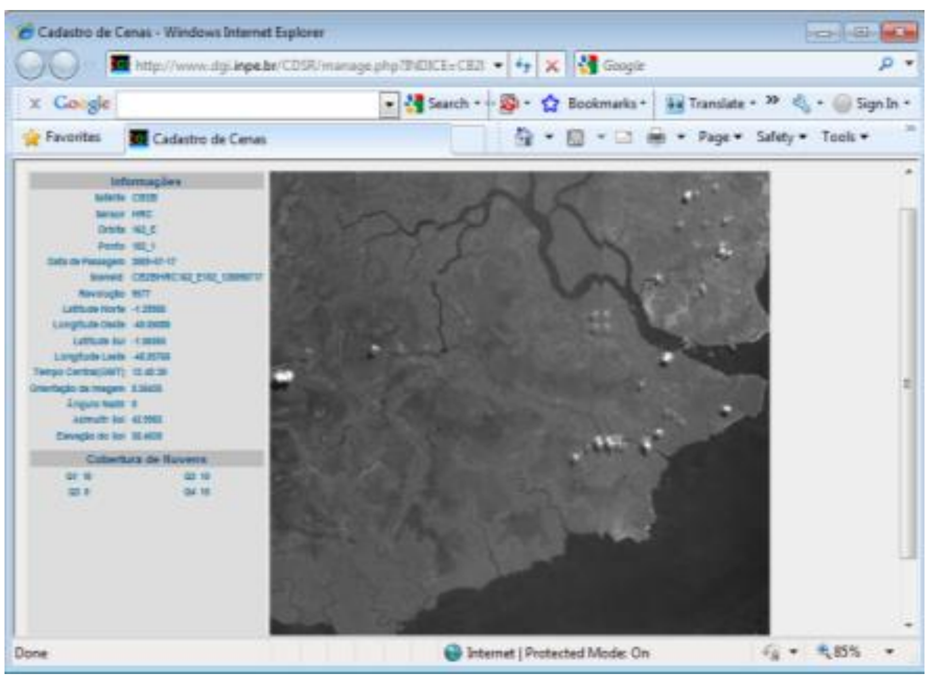

Figure 3. Original format of HCR image of Ponta de Pedras, before being available by INPE.

Source: http://www.dgi.inpe.br/CDSR

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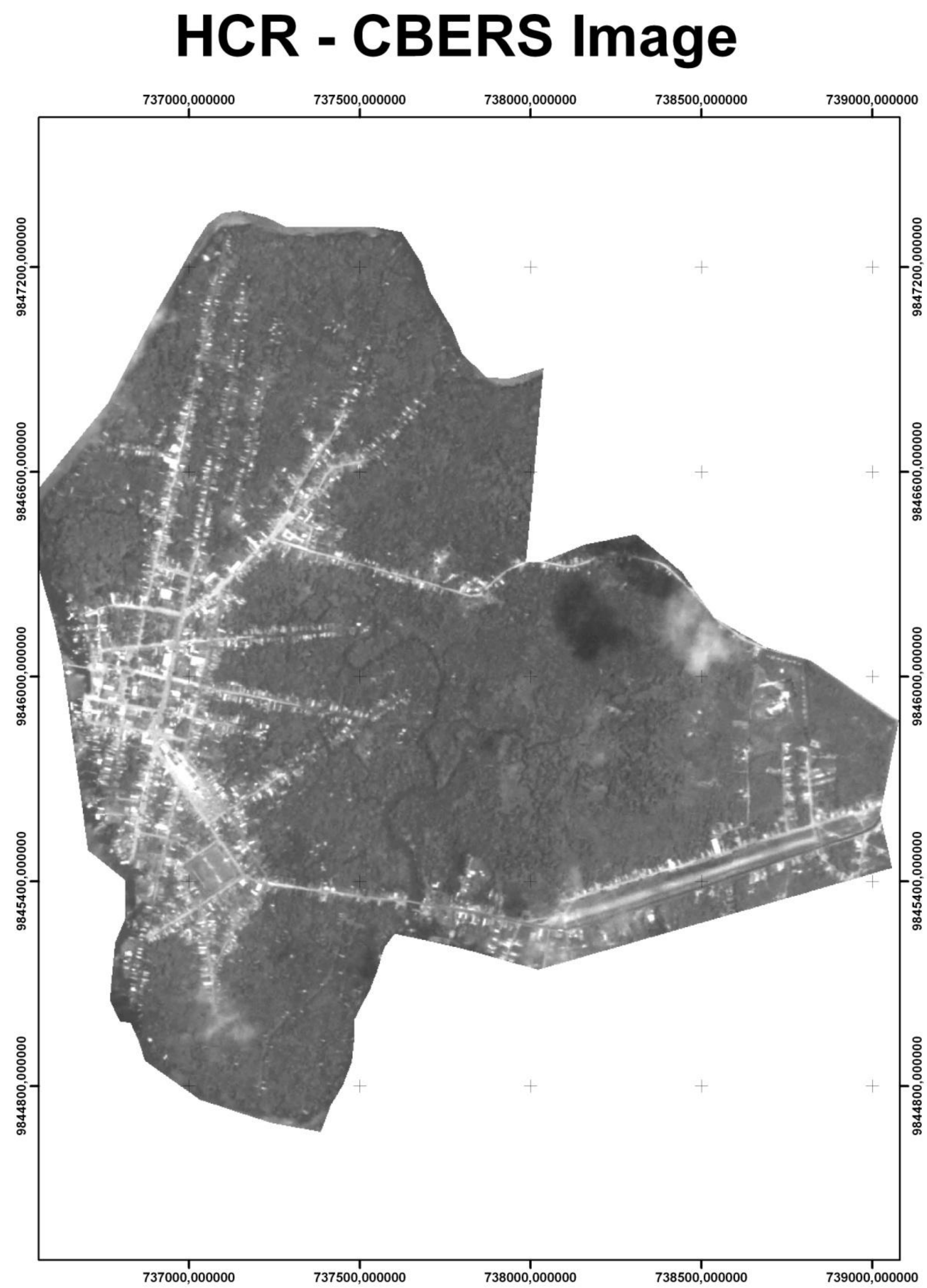

Figure 4. HCR subset image, in UTM coordinates, used to map limits of urban area of Ponta de Pedras and other land uses. Source: http://www.dgi.inpe.br/CDSR

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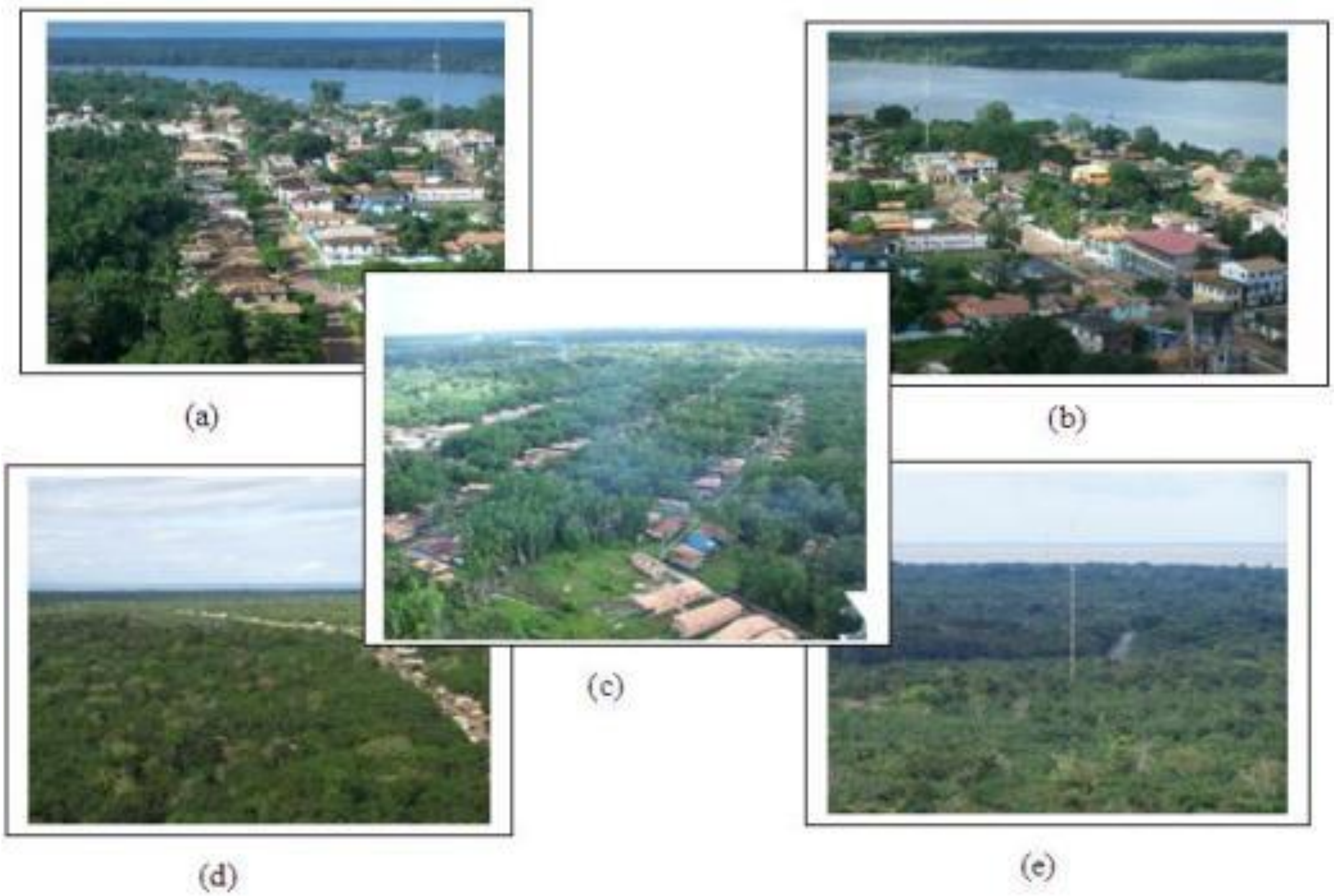

Figure 5. Field samples of classes used in visual interpretation: (a) and (b) are pictures of urban area; (c) example of some streets with home gardens of açaí palm tree and other rain forest trees; (d) and (e) represent the boundary of the city with rain forest, and also illustrates the flat landscape.

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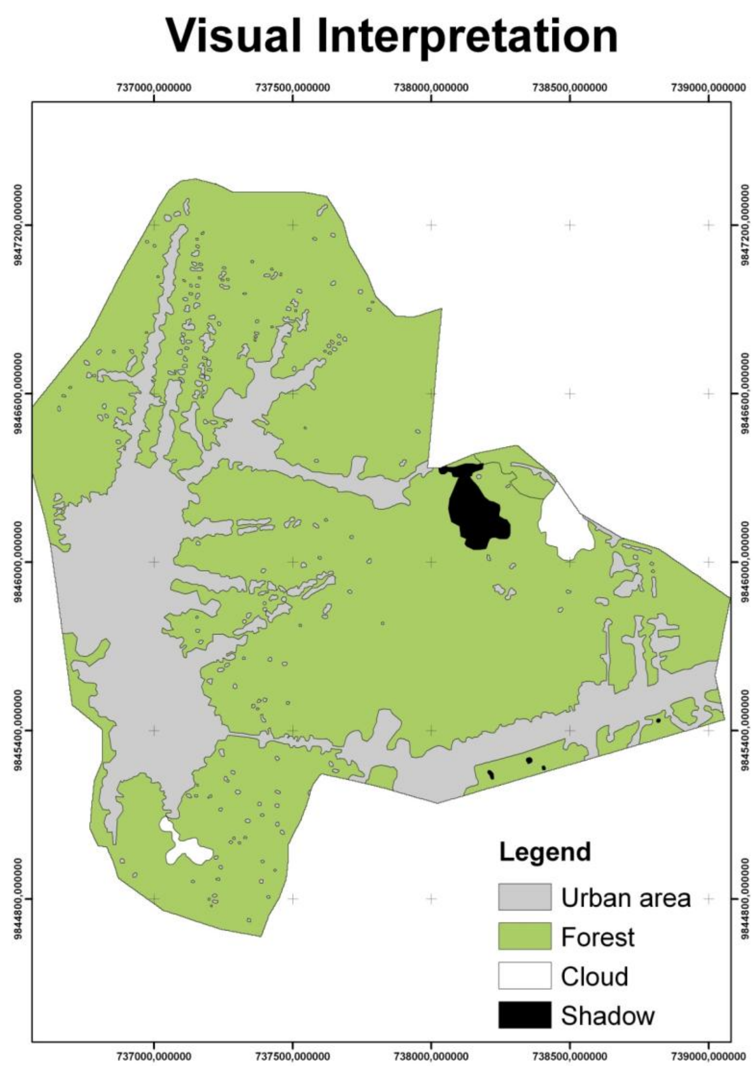

(a)

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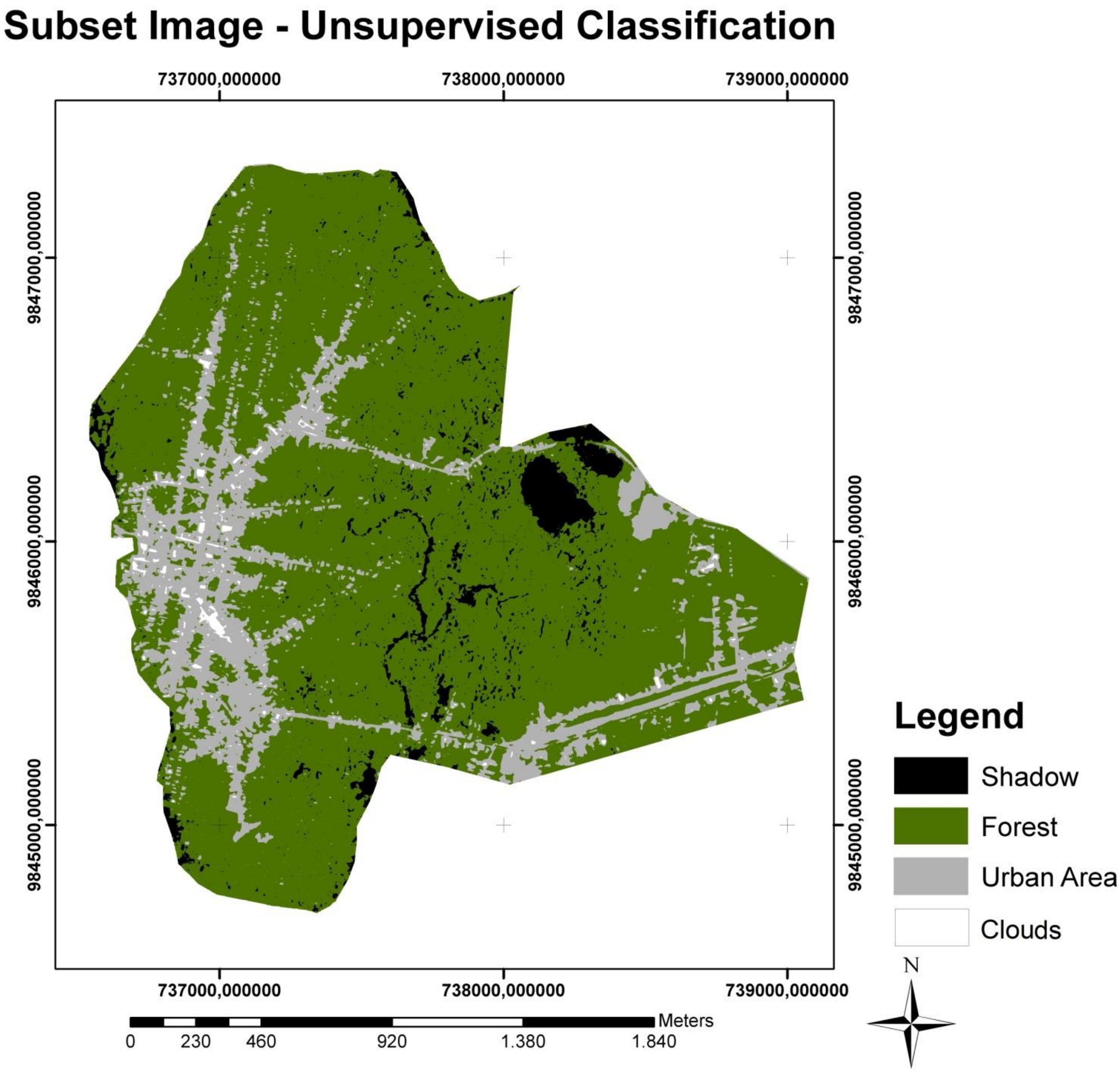

(b)

Figure 6. Visual (a) and unsupervised (b) classifications.

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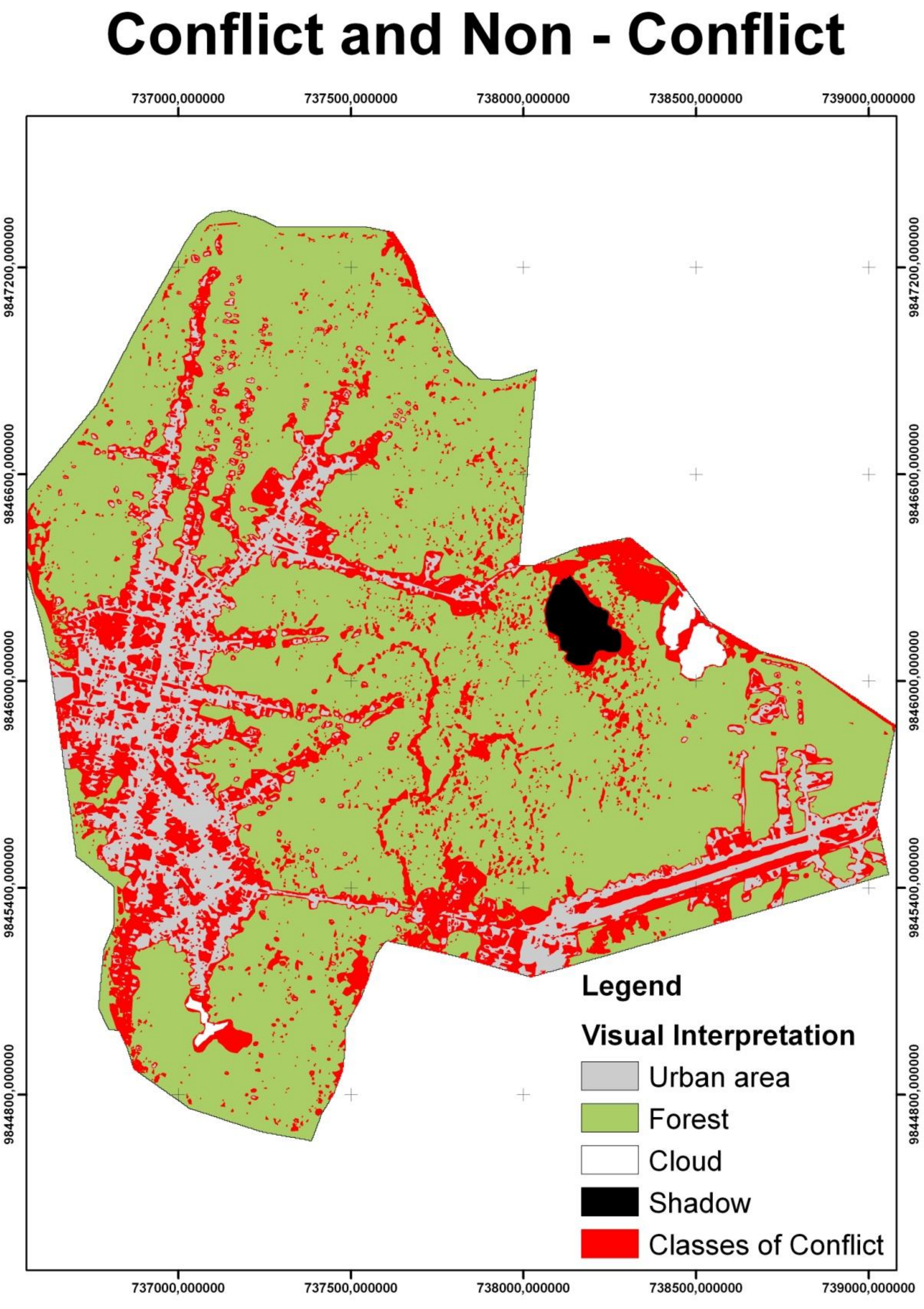

Figure 7. Overlaying process: visual and unsupervised classification.

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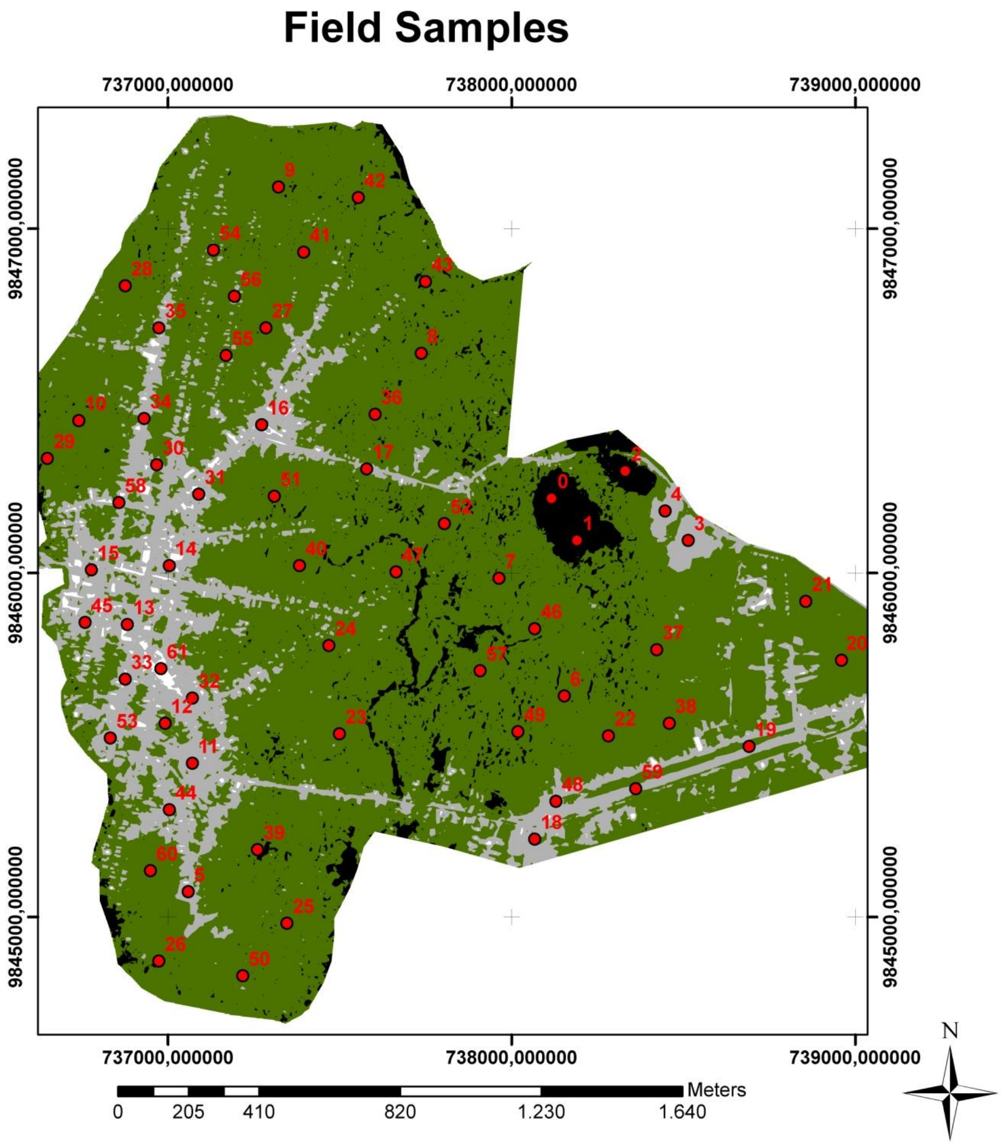

Figure 8. Field samples spread over unsupervised classification.