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HIGH SPATIAL RESOLUTION IMAGES FOR MONTHLY PIPELINE MONITORING

Monitoramento Mensal de Faixa de Dutos Utilizando Imagens de Alta Resolução Espacial

Mara Lúcia Marques[1]; Mateus Vidotti Ferreira[1]; Paulina Setti Riedel[1]; Marcelo Elias Delaneze[1] & Cristina Maria Bentz[2]

[1]Universidade Estadual Paulista – UNESP
Departamento de Geologia Aplicada – IGCE/UNESP/Rio Claro
Pós-Graduação em Geociências e Meio Ambiente
Poste 176 - 13506-900 – Rio Claro/SP, Brazil
maralucia.marques@hotmail.com; mateusvidotti@yahoo.com.br;
psriedel@rc.unesp.br; mdelaneze@yahoo.com.br

[2]Centro de Pesquisa da Petrobras - CENPES
Ilha do Fundão - 21941-598 – Rio de Janeiro - RJ, Brazil
cris@petrobras.com.br

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RESUMO

O objetivo do estudo foi propor um procedimento de detecção de mudanças, a partir do mapeamento da cobertura da terra, para o monitoramento mensal de faixa de dutos, com imagens de alta resolução espacial. Selecionou-se um trecho da faixa de dutos Rio de Janeiro-Belo Horizonte (largura de 400m e 30,7km de extensão), localizado em Duque de Caxias e Nova Iguaçu - RJ. Foram utilizadas seis imagens GeoEye (Janeiro a Junho/2010) e elaborado um mapa inicial de cobertura da terra a partir da interpretação visual da imagem de janeiro. As áreas de mudanças foram identificadas por álgebra multitemporal das bandas do vermelho para cada período (Jan/Fev, Fev/Mar, Mar/Abr, Abr/Mai e Mai/Jun). A cobertura da terra nas áreas de mudança foi classificada utilizando as funções de pertinência fuzzy. Os resultados mostram que, no período de seis meses, detectou-se 775.402m^{2}de área de mudança, em uma área total de 11.890.000m^2. As maiores mudanças ocorreram para Solo Exposto, Vegetação Rasteira e Cobertura/Solo Exposto. O acerto geral apresentou-se entre 71 e 80%, demonstrando que o procedimento empregado foi adequado para o monitoramento de faixa de dutos. No entanto, a implementação deste procedimento deve considerar a variação dos parâmetros de aquisição da imagem de alta resolução, bem como explorar sua aplicação em diferentes escalas e contextos geográficos.

Palavras chaves: GeoEye, Monitoramento de Faixa de Duto, Classificação de Imagem.

ABSTRACT

The objective of this study was to propose a change detection procedure to the monthly monitoring of a pipeline, by applying land cover mapping from high spatial resolution images. A section of the Rio de Janeiro-Belo Horizonte pipeline route (400m wide and 30.7km long) was selected in Duque de Caxias and Nova Iguaçu - RJ. The process was developed using six GeoEye images (January to June 2010), and an initial land cover mapping was obtained through visual interpretation of the January image. A multitemporal algebraic procedure using red bands from the images of each paired period (Jan/Feb, Feb/Mar, Mar/Apr, Apr/May e May/Jun) shows the changed areas. The identified land cover changes were classified, using fuzzy function. The results showed an area of 775,402 m^2 was detected as changed over six month, considering an overall area of 11,890,000 m^2. The largest changes occurred for Bare Soil, Grassland and Cover/Soil Ground. An accuracy range of 71 to 80% was obtained, showing that the procedure is appropriated to the monitoring of pipeline zones. However, to implement this monitoring it is necessary to consider the changes related to the acquisition parameters of high spatial resolution images, as well as to explore the performance reliability along a greater length of the pipeline in a different geographic environment.

Keywords: GeoEye, Change Detection, Image Classification.

1. INTRODUCTION

This research aims to develop a procedure for the monthly monitoring of pipelines using the detection of land cover changes using high resolution satellite images. This study considered changes in areas of vegetation, in buildings and in bare soil as indicators of activities of third parties which may interfere with the pipeline route. According to CETESB (2009), from installation, a pipeline undergoes from environmental influences and also impacts on the environment.

The installation and maintenance activities on pipelines are functions of the monitoring system. This monitoring consists of external and internal inspections.

The internal inspection sector is responsible for control variables such as pressure, flow, temperature, density and volume during the process of transferring products. The external inspection sector is composed of aerial and ground observations of a 20m wide strip that runs the length of the pipeline and adjacent areas. Geological and geotechnical inspections are carried out for verification of irregularities that may cause abnormal mechanical stress on the pipes or endanger the installation, such as erosion, mass movements, collapse, vehicle traffic and/or heavy equipment on the strip, vegetation growth and deficiencies in the track drainage, burned area, strip occupation by third parties, nearby construction work and strip border markings and warning signs, outcrops, streams, road, railway and power line crossings, and traffic conditions of the access roads (ZIRNIG *et al.*, 2002,HAUSAMANN *et al.*, 2005).

When monitoring the pipelines, the use of remote sensing and geographic information system (GIS) enhance the change detection. These allow a better frequency of systematic acquisition of information and this available information provides better tools to enable integration and analysis of spatial data (ROPER; DUTTA, 2005). The recent increase in the availability of high spatial resolution (less than or equal to 1m) satellite images acquired by systems such as Ikonos, QuikBird, GeoEye, OrbView and Eros among others, enable the use of these images as the main source of information for the monitoring.

The change detection can be described as a process of identification and quantification of changes in spatial objects or phenomena from multitemporal observations (SINGH, 1989, COPPIN; BAUER, 1994, SETO *et al.*, 2002, LU *et al.* 2004). Among the different techniques of change detection available, those using remote sensing products have been proven to be more appropriate to obtain better results, due to repetitive capacity of the acquisition of information and the integrated approach to using images from space. The process of change detection through these products requires the selection of images with the same spatial and spectral resolution, as well as the application of atmospheric and geometric corrections, which permit normalization and feature identification for comparisons between the images (LU et al, 2004).

Monitoring with the use of change detection techniques and remote sensing technologies can be applied in the identification of land-use and land-cover (LULC) change; forest or vegetation change; forest mortality, defoliation, damage assessment, deforestation, regeneration and selective logging; wetland change; forest fire; landscape change; urban change; environmental change; and other applications such as crop monitoring, shifting cultivation monitoring, road segments, and change in glacier mass balance and facies (LU et al, 2004).

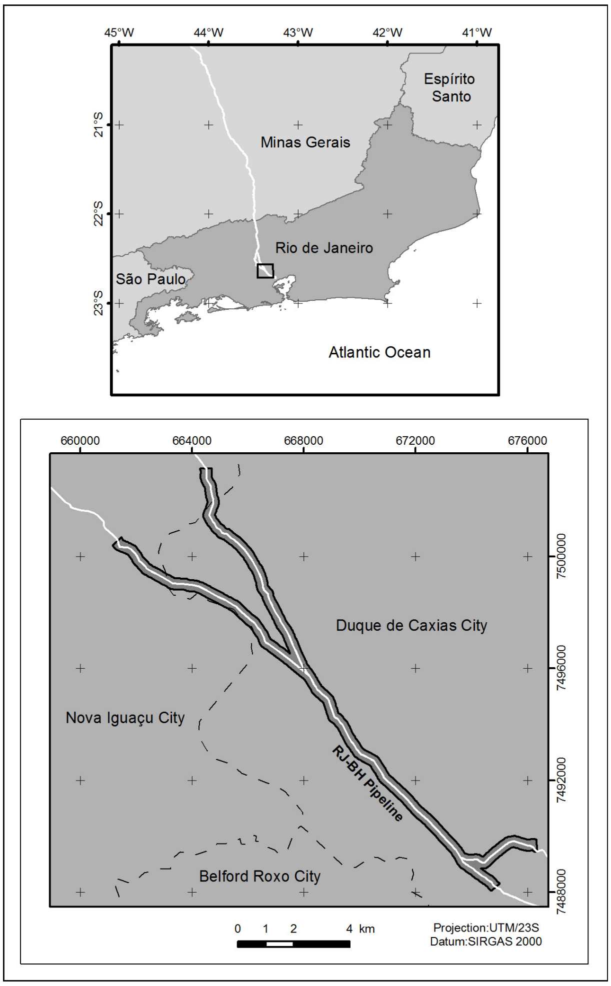


Fig. 1 - Location of the study area.

2. STUDY AREA

From the route of the Rio de Janeiro-Belo Horizonte pipeline that intersects the municipalities of Duque de Caxias and Nova Iguaçu (RJ), an area 30.7km long and 400m wide has been demarcated, covering an area of 11.89km^2 (Figure 1).

3. METHOD

To develop a monitoring procedure for land cover of the pipeline strip area change detection methods and techniques were used as well as object- based image classification approach.

3.1. Materials

GeoEye images were used, as described in Table 1. Due to the priority given to the temporal resolution, to guarantee the monthly pipeline monitoring using GeoEye images, it was not possible to control the "Collection Angle Elevation", which caused some additional difficulties in the procedures for change detection.

Table 1 - Properties of GeoEye image

Date	Collection Angle Elevation	Collection Angle Azimuth	Sun Angle Elevation	Sun Angle Azimuth
03/01/2010	62.34	140.41	62.43	96.19
11/02/2010	61.90	320.27	62.32	76.50
10/03/2010	62.53	165.11	55.08	62.28
28/04/2010	62.09	133.67	45.40	42.85
04/05/2010	72.51	20.70	43.47	36.12
17/06/2010	84.21	251.23	37.21	31.05

3.2. Research development

The methodology procedure proposed for the pipeline strip area monitoring consists of detecting changes in land cover using GeoEye images for the period of January to June 2009. The research development steps are presented in the flow diagram in Figure 2.

3.2.1. Image preprocessing

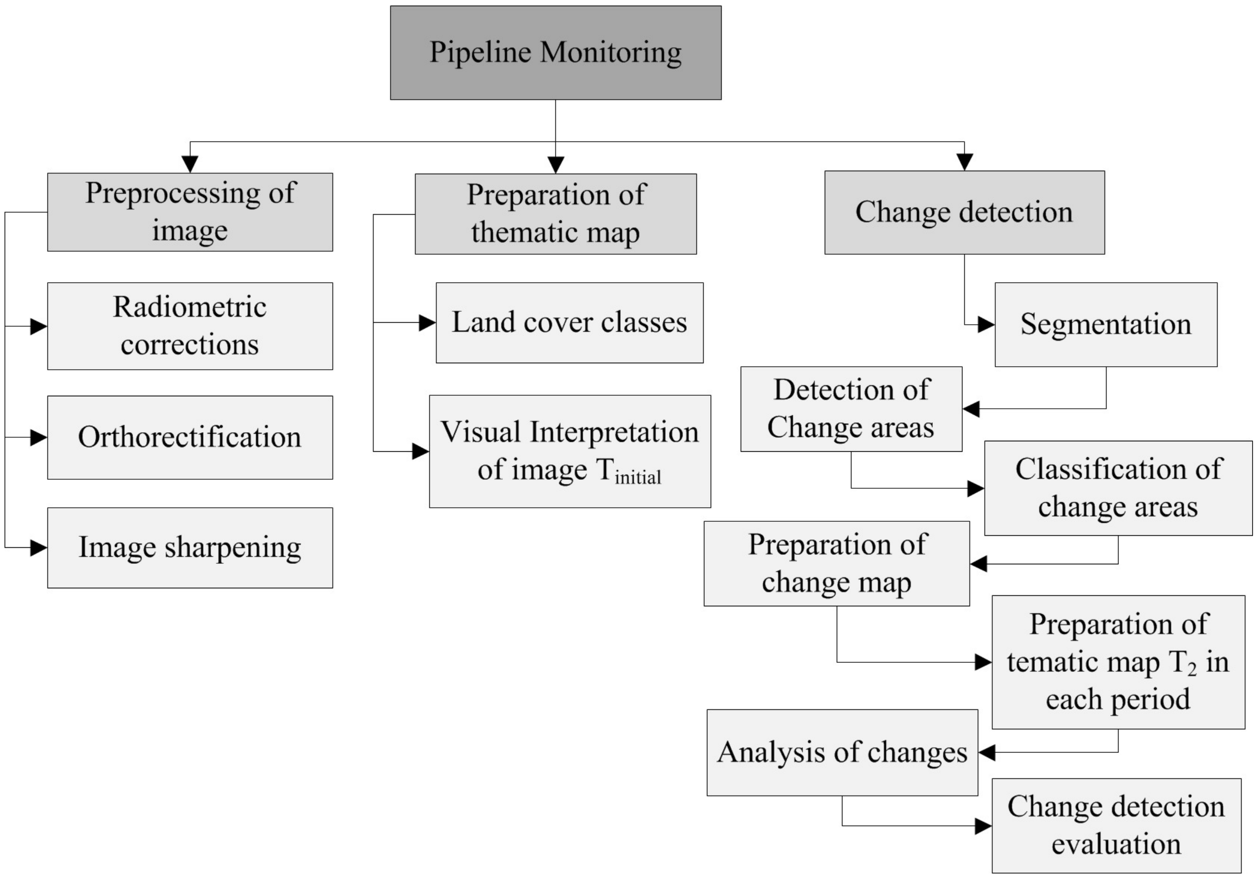
To begin the change detection process, atmospheric, radiometric and geometric corrections are recommended on the multi-temporal images:

(a) Radiometric Correction – in this research there were no radiometric corrections due to the unavailability of the calibration parameters of the sensor and the used change detection technique, since according to Lu et al. (2004), the technique of comparing multi-temporal images using an array of changes after classification, reduces atmospheric interference. In order to minimize the differences of the image lighting and atmospheric conditions, from January and June 2010, a linear contrast was applied, and 1% of maximum and minimum digital values were ignored. Thus, the 11 bit images were converted to 8 bits.

(b) Orthorectification – the process of orthorectification was performed using the Rational Polynomial Coefficient (RPC) and Digital Elevation Model, elaborated from the Topographic Maps of FUNDREN, 1975, on a scale of 1:10.000.

(c) Image sharpening – the GeoEye images from January, April and June went through the fusion process and the images from February, March and May were acquired with the fusion of multispectral bands (2m) and the panchromatic band (0.5m), resulting in 0.5m spatial resolution for all the bands.

Fig. 2 - Research development flow diagram.



3.2.2. Thematic map $T_{initial}$ preparation

(a) Land cover classes, presented in Table 2, were defined due to the identification of activities that may cause risk to the integrity of the pipeline. Classes were determined based on spectral characteristics of the objects. To define the Cover/ Soil class, the difficulty in separating objects belonging to buildings with ceramic tile roofs from objects with the characteristics of open land in a medium tone, was taken into consideration. According to Pinho et al. (2011) these two classes have very similar make-ups which can cause classification confusion.

(b) For the analysis of pipeline changes an initial land cover map was prepared by using the visual interpretation of the January 2010 image.

3.2.3. Change detection procedures

The process for change detection was applied in each study period in the eCognition software 8.0 (DEFINIENS, 2009), according to the procedures described below:

(a) Segmentation – segments were generated by a Multiresolution Segmentation algorithm that enables the generation of image contents at different levels of detail. This segmentation approach uses the growth of regions in which adjacent regions are grouped according to the similarity criterion which considers the internal heterogeneity of the regions. In the definition of similarity it is necessary to provide parameters of scale, form, tone, compactness, smoothness and spectral bands which also allow the use of a Thematic Layer (BAATZ; SCHAPER, 2000). In this process the most appropriate level of segmentation to delineate the objects was Level II, with the following parameters: 40 scale, shape and compactness 0.2, 0.5;

(b) Identifying areas of change – to delimit the change areas an analysis of the resulting image of the multitemporal algebra of red bands ([Red T_2] - [Red T_1]) was performed, taking into consideration three possibilities of occurrence: No Change (NC), areas that remain unchanged; Change Red (C_R), which occur when the objects have low spectral response (dark shades) in the T_1 image and high response (light shade) in T_2; Change Blue (C_B), when the objects have high spectral response in the T_1 image and low response in T_2 (Figure 3). Table 3 shows the thresholds used to determine change areas. It is observed that the non-radiometric

Table 2 - Description of land cover classes.

Land cover class	Description
Shadow	Natural and man-made shadow
Asphalt	Highways and streets paved with asphalt
Light BareSoil	Unbuilt areas and no vegetation cover, with a light color tone
DarkBareSoil	Unbuilt areas and no vegetation cover, with a dark color tone
ArborealVegetation	Medium to tall trees found in forest and urban areas
Grassland	Areas composed of grasses and small shrubs
Cover/Soil	Bright ceramic roofs and areas of bare soil with medium color tone
Concrete Cover	Dark ceramic concrete roofs, asbestos and dark concrete paved areas
White Cover	Light tone concrete or aluminium roofs and paved areas
Swimming pool	Swimming pools
Wetlands	Areas temporarily covered by water
Rivers/Reservoirs	Water courses, lakes and reservoirs

Table 3 - Description of the thresholds applied in determining change and no change.

Class	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun
No Change	$-90 \leq NC \leq 60$	$-90 \leq NC \leq 60$	$-70 \leq NC \leq 80$	$-100 \leq NC \leq 50$	$-80 \leq NC \leq 90$
Change Red	$C_R > 60$	$C_R > 60$	$C_R > 80$	$C_R > 50$	$C_R > 90$
Change Blue	$C_B < -90$	$C_B < -90$	$C_B < -70$	$C_B < -100$	$C_B < -80$

normalization of images caused a variation of value ranges for each period;

(c) Classification of change areas - for all periods the object-based classification object-based method was employed using the segments generated by Level II. Therefore in areas defined as change Red and Blue, training samples of each class were acquired with the exception of classes of asphalt, rivers/reservoirs and swimming pools, considered constant for this monitoring. These samples are needed for class description and the context in which they occur. The attributes choice was done through the histogram analysis of attributes generated by the Sample Editor to enable classification. To discriminate the vegetation classes from the other classes, the value of NDVI was used through the Assign Class algorithm. The Classification algorithm was used considering the relevance value which permits the discrimination of the objects which must belong to a certain class, with a degree of relevance in the range from 0 to 1 (SHACKELFORD; DAVIS, 2003). This algorithm was used to separate Arboreal Vegetation from Grassland by using the attribute of homogeneous texture of the red band (R) and near infrared (NIR). For other land cover classes, relevance curves were generated for the attributes of spectral response of visible bands, with the exception of classes of Concrete Cover and Bare Soil, which also used the attribute H (Hue) of IHS;

(d) Change analysis– with the purpose of analysing the activities that may interfere with the integrity of the pipeline, the land cover classes determined by spectral behaviour were grouped according to land use characteristics, so the following classes were generated: Bare Soil which is the combination of Dark Bare Soil and Light Bare Soil, White Cover/Concrete which is the combination of White Cover and Concrete Cover, also the areas classified as shadow in T_2 were reclassified according to the classes in T_1. From the results of the land cover classification in each analysis period, comparison matrices were generated among the land cover classes inside change areas, allowing the change identification and quantification;

(e) Change detection evaluation - to determine the accuracy of land use changes resulting for each period, we used the error matrix and Kappa concordance coefficient. The error matrix represents the mapping accuracy through the concordance analysis between reference samples and classification product. Thus, in each change analysis period, 30 reference samples were acquired for each land cover class from the visual interpretation of the GeoEye image through a random stratified sampling method, according to Congleton and Green (2009).

4. RESULTS

The monitoring method employed allowed the extraction of the change information along the pipeline and the results from the change detection evaluation are presented in Table 4. It is observed that the overall accuracy values are between 71.33 and 82% and the Kappa concordance coefficient is between 0.64 and 0.77. These indices, according to the categorization proposed by Landis and Koch (1977), indicate a substantial concordance. It is worth noting that this index evaluates the accuracy

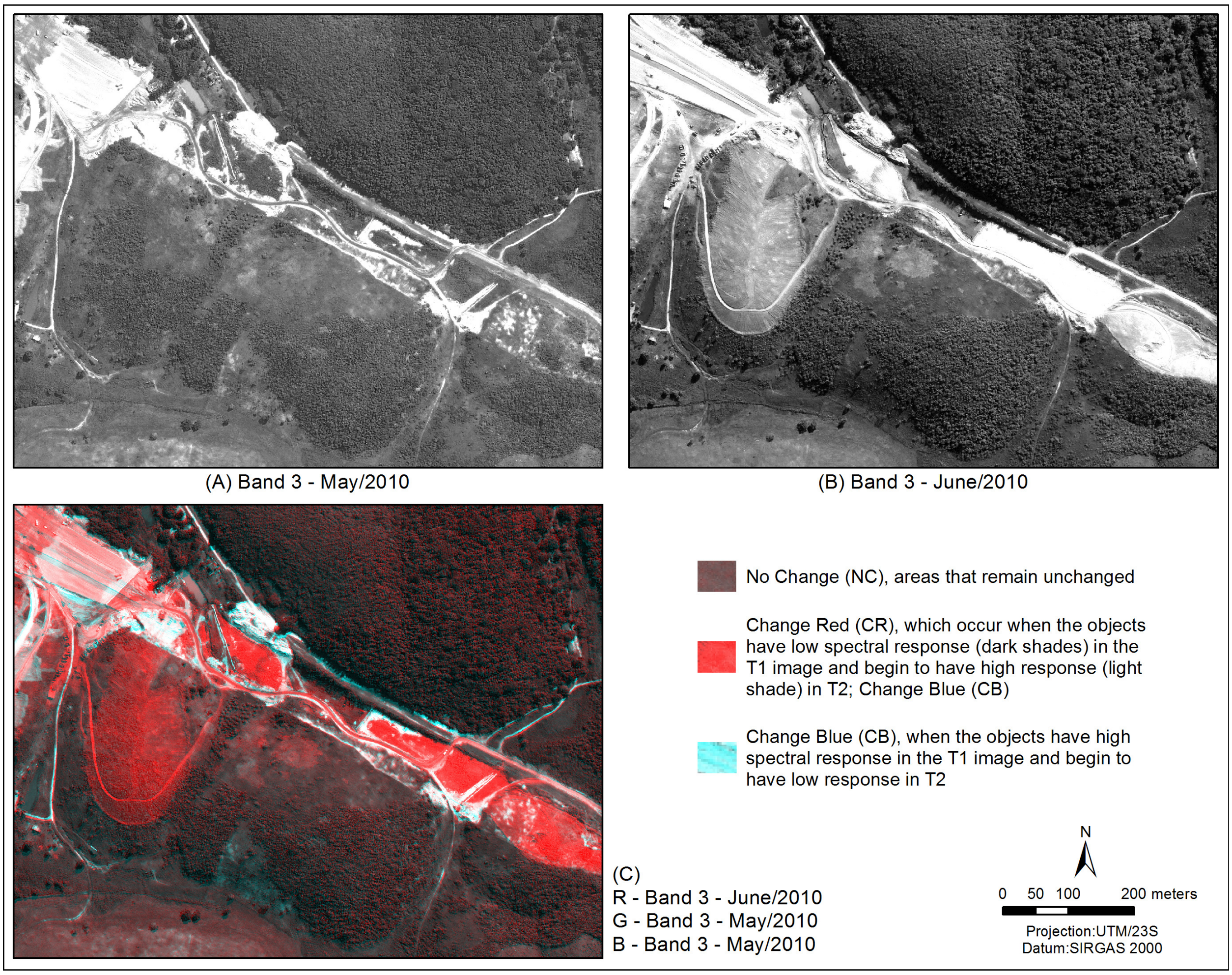


Fig. 3 - Definition of change areas.

of classification of T_2 images, but does not consider the accuracy of the identified change areas.

The obtained results in the cover types identification process in change areas have been expressive and confirm Almeida's et al. (2009) statement that using orbital sensors, with a high space resolution, associated with object based approach makes detailed surface object discrimination possible, differentiating between pavement materials and buildings with vegetation types.

The results enabled us to identify and quantify the changes of land cover classes in each period, according to Table 5 and Figure 4. It is observed that in the study area, which is about 11,890,000m^2, the largest changes occurred from January to February due to the decrease of moisture that caused changes from Wetland class to Grassland (53003m^2) and Bare Soil (74906m^2) classes.

From the analysis of all change areas, the Bare Soil class is highlighted as presenting high change values (between 31,305 and 75,427m^2) in all periods, which is associated with areas of material extraction, planting stages and construction activities of the Metropolitan Highway. In reference to the highway construction, the change increase to the Cover/Soil class in the periods from March to April (34,042m^2) and May-June (33,161m^2) can also be verified due to the intensification of land levelling and slope removal.

In this change detection process, despite obtaining a high rate of concordance for land cover classification, the variation of the acquisition parameters of high resolution images causes changes in the position of high objects, such as tree canopies, tops of buildings and street lights. These changes lead to the mistaken identification of change areas, which can be seen in change areas classified as Arboreal Vegetation and especially White Cover/ Concrete. This should be taken into account to guarantee that mistaken interpretation related to vegetation growth and constructed areas expansion should not be considered as changed areas. The increase in changes of the White Cover/Concrete class also occurs due to spectral confusion of objects

Table 4 - Change detection evaluation.

Accuracy	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun
Overall	80.0%	78.67%	82.0%	77.33%	71.33%
Kappa	0.75	0.73	0.77	0.71	0.64

Table 5 – Land cover classes in the change areas for each period.

Class	Jan-Feb (m^2)	Feb-Mar (m^2)	Mar-Apr (m^2)	Apr-May (m^2)	May-Jun (m^2)
White Cover/Concrete	24915	33536	11690	22908	6337
Bare Soil	74906	42594	75427	31305	44375
Cover/Soil	19936	7079	34042	17994	33161
Arboreal Vegetation	80679	16988	12225	19264	16188
Grassland	53003	27382	12917	24343	32208
Total	**253439**	**127579**	**146301**	**115814**	**132269**

corresponding to Light Bare Soil and Dark Bare Soil with concrete.

Variations in the geometry and size of land surface features were verified even in the images which had undergone the orthorectification procedure. Thus, this process was not effective for the correction of all distortions produced by the variation of "Collection Angle Elevation".

According to tests made by Araujo et al. (2008) the polynomial rational model (RPC), when it uses control points and refined MDE is efficient, however, for low collection angle images rigorous orthorectification procedures should be used, so the sensor's physical geometry can be reconstructed. Even though rigorous methods are recommended, in this study it was not possible to execute them, since metadata was not furnished by the company that supplies the images. These distortions caused displacement of surface features, such as the route of pipelines and roads, as well as land slope shape variation, which resulted in false changes. Other false changes can be observed as a result of the variation in the "Solar Angle Elevation", which caused the rise and/or enlargement of the shadow areas. These false changes can be observed in Figure 5.

5. CONCLUSIONS

The proposed change detection procedures through high-resolution images proved to be feasible as a monitoring technique.

It should be considered that automatic classification, through the object-based method, has achieved accuracy values close to the limit for the application of this technique for multitemporal data, in areas with great complexity and diversity of space occupation. Thus, to achieve a better overall classification manual editing of some misclassified segments must be done.

This limitation was also verified by Conchedda et al. (2008) in a study to analyze changes in mangrove areas. The authors considered that the stablishment of specific rules integrated to user knowledge increases change detection accuracy, however, more precise results can be reached through manual editing.

The change detection can be improved by the application and comparison of results generated by different acquisition parameters and techniques, as well as the use of statistical analysis to measure the accuracy of the identified change areas.

In order to better evaluate the applicability of this monitoring procedure it is necessary to perform the method in areas with different spatial contexts and in different cartographic scales, as well as assessment another sensors with different spatial and spectral resolutions.

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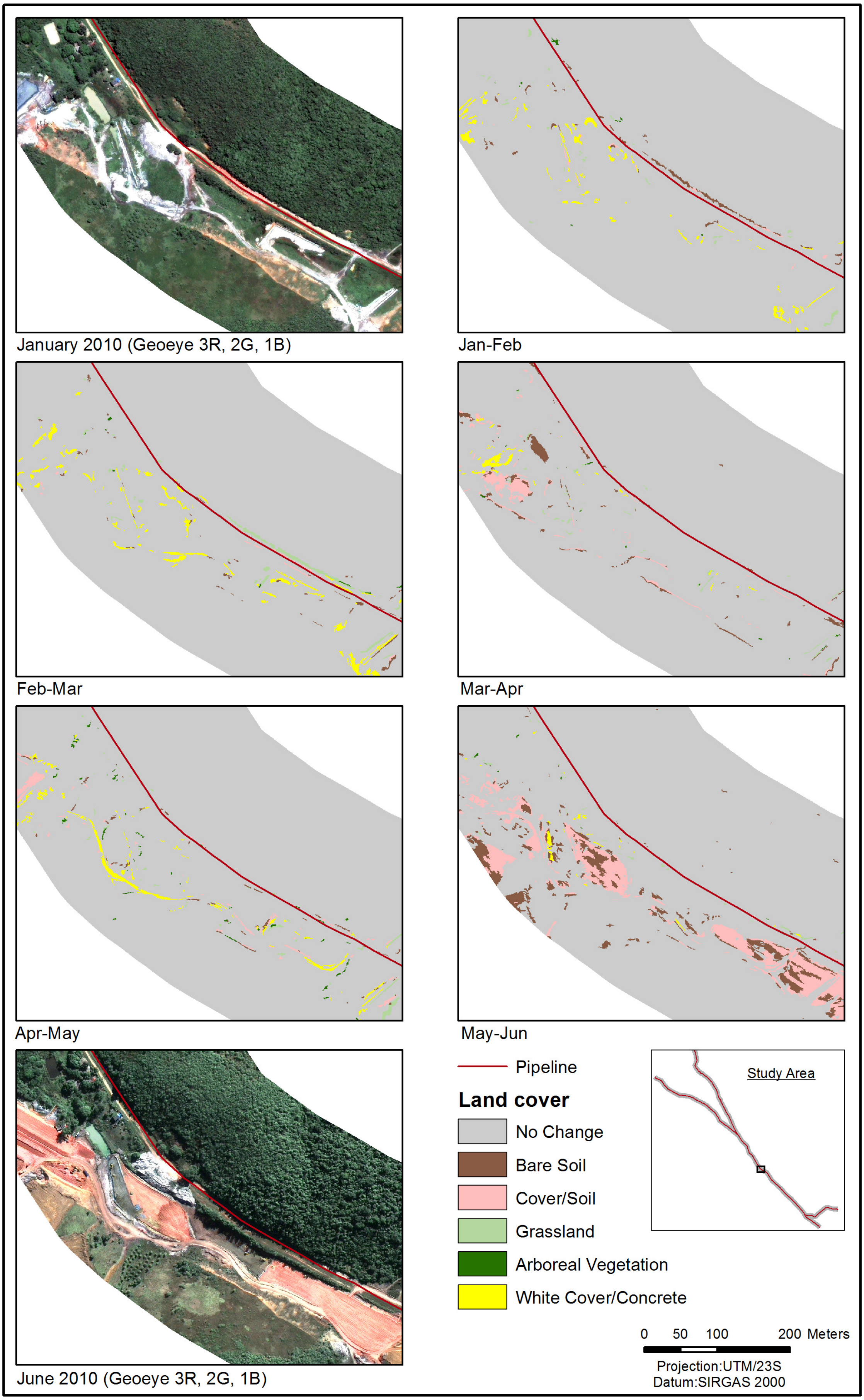

Fig. 4 - Land cover changes in each period, on a under construction section of the Metropolitan Highway.

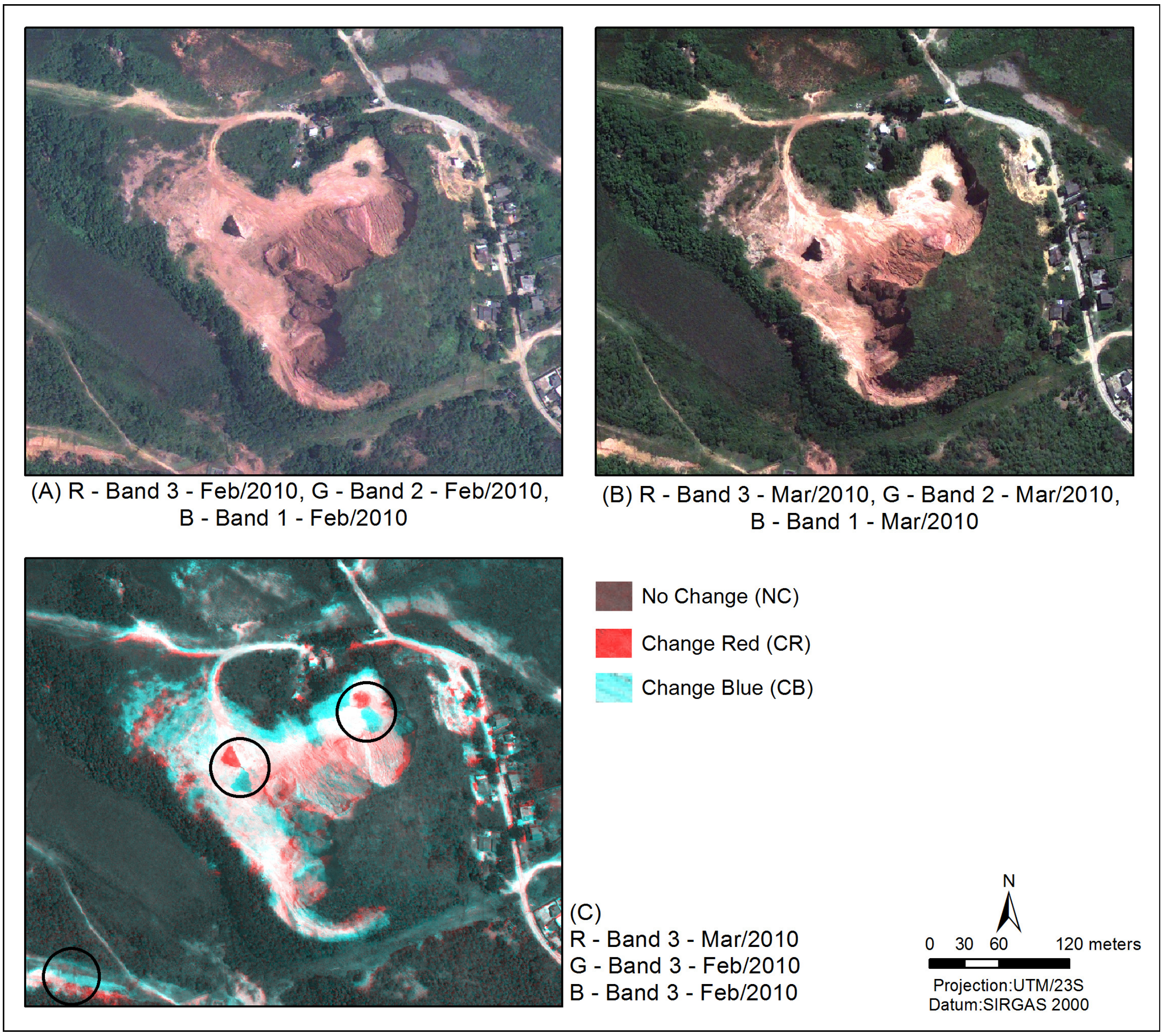

Fig. 5 – Area of false changes.

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