LAND USE DYNAMICS OF AREAS THREATENED WITH FLOODS USING OBJECT-ORIENTED CLASSIFICATION OF VERY HIGH RESOLUTION IMAGERY

Eugenia Roumenina[1], Vassil Vassilev[1], Vanya Naydenova[1], Georgi Jelev[1], Petar Dimitrov[1], Kalin Ruskov[2]

[1]*Space Research Institute – Bulgarian Academy of Sciences*
e-mail: roumenina@space.bas.bg, vassilev_vas@yahoo.com, vnaydenova@gmail.com, g_jelev@abv.bg, petarkirilov@mail.bg
[2]*Eurosense EOOD*
e-mail: kalin.ruskov@eurosense.bg

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Abstract: *This paper presents the results from a conducted research on assessment of land use dynamics of areas threatened by floods, using geoinformational technologies. The studied area is the Town of Novi Iskur, Municipality of Sofia, Bulgaria, where in June 2005, the Iskur river suffered severe flooding as a result of intensive rainfall. Land use maps before and after the flooding were composed for the purpose. Object-oriented classification based on very high resolution satellite images from IKONOS and QuickBird was used. The overall accuracy assessment of the classifications is above 80%. Map and change detection matrix for 2008 compared to 2002 was composed. The effect of the flooding was greatest for the crop field class, which has decreased from 47% in 2002 to 1% in 2008. After the flooding the prevailing part of it was changed to meadows and pastures.*

ДИНАМИКА НА ЗЕМЕПОЛЗВАНЕТО В РАЙОНИ, ЗАСТРАШЕНИ ОТ НАВОДНЕНИЯ ЧРЕЗ ОБЕКТНО-ОРИЕНТИРАНА КЛАСИФИКАЦИЯ НА ИЗОБРАЖЕНИЯ СЪС СВРЪХВИСОКА ПРОСТРАНСТВЕНА РАЗДЕЛИТЕЛНА СПОСОБНОСТ

Евгения Руменина[1], Васил Василев[1], Ваня Найденова[1], Георги Желев[1], Петър Димитров[1], Калин Русков[2]

[1]*Институт за космически изследвания – Българска академия на науките*
e-mail: roumenina@space.bas.bg, vassilev_vas@yahoo.com, vnaydenova@gmail.com, g_jelev@abv.bg, petarkirilov@mail.bg
[2]*Евросенс ЕООД*
e-mail: kalin.ruskov@eurosense.bg

Ключови думи: *обектно-ориентирана класификация, земеползване, наводнения, IKONOS, QuickBird*

Резюме: *В настоящия доклад са представени резултатите от проведено изследване свързано с оценка на динамиката на земеозването за райони застрашени от наводнения с използване на геоинформационни технологии. Изследването е извършено в района на град Нови Искър, Столична община, където през юни 2005 г. след обилни валежи, р. Искър наводни значителни територии. За целта са съставени карти на земеползването преди и след наводнението като е използвана обектно-ориентирана класификация на изображения с много висока пространсвена разделителна способност от IKONOS и QuickBird. Точността на класификациите е над 80%. Съставена е карта и матрица на измененията на площите на земното покритие за 2008 г. спрямо 2002 г. Наводнението се е отразило най-силно върху класа ниви, който е намалял от 47% през 2002 г. на 1% през 2008 г. По-голямата част от тях са преминали в ливади и пасища след наводнението.*

Introduction

An increasing attention on hazard of floods has been paid in the past few decades. Remote sensing techniques for monitoring rivers are introduced for solving that issue (Smith, 1997; Sanyal and Lu, 2004). One of the primary causes of flooding is land use/land cover change. In the same time investigating of this hazard helps to provide useful solutions on minimizing the damages regarding territories threatened by floods. Part of these efforts is pointed out to conversion of land usage after flood events. Using temporal series of satellite images provide opportunity for composing land use thematic maps for change detection.

Change detection has had various applications within land use and land cover analysis. However, there are different approaches in applying this type of analysis. The change detection algorithms are divided into two categories: image-to-image comparison or map to map comparison. The map to map comparison is preferred as it can detect a full matrix of land-use/land-cover changes, while the first one is generally accurate, but it lacks detailed information on how various land-use/land-cover categories change (Yang and Lo, 2002).

The most commonly used automatic classification approach is to classify each image pixel as an independent observation regardless of its spatial context. Unfortunately, this is fraught with the limitations imposed by pixel-based image analysis. The general approach to symbolic identification is to compare two classifications pixel by pixel, although it generally results in low change detection accuracy (Singh, 1989).

Much attention has recently been shifted to the development of more advanced classification algorithms, including neural network, contextual, object-oriented, and knowledge-based classification approaches (Stuckens et al., 2000; Thomas et al., 2003; Zhang and Foody, 2001; Zhang and Wang, 2003). The shift towards object-orientation is driven by the limitations of the pixel in addressing the issues of location, scale, neighbourhood and distance (Strobl and Blaschke, 2001). Moreover image texture has been recognized as an important source of information for both the manual and automatic processing of remotely sensed images (Jensen, 2005).

In many parts of Bulgaria the environmental conditions in combination with the poor condition of the hydro-technical installations may cause flooding. The flooding in June 2005 in the Town of Novi Iskur, Metropolitan municipality, proved this. Using this event as a case study the main objective in the present work is to develop a spatial model for assessment of the land use/land cover changes resulting from the flooding created by intensive rainfalls. The following issues should be resolved for this purpose:

- Identifying areas threatened with floods using satellite images;
- Conducting digital image processing on the images acquired before, at the time of and after the flood;
- Assessing the condition of the land use/land cover before, at the time of and after the flooding and calculating the affected area.

Study area

The study area is located in the lowest, northern part of Sofia hollow and covers the floodplain of the Iskur River and adjacent slopes on which the Town of Novi Iskur is located. The territory is characterized by marshes, due to high underground waters.

The climate of the region regarding the precipitation rate is analyzed based on the data gathered at the NIMH-BAS rain-gauge station at Kourilo, Town of Novi Iskur, for the period of 1949-2005. The precipitation rate is characterized by spring-summer maximum with highest values in June (Figure 1a). The lowest rainfalls are recorded in August. The distribution of the maximum 24-hour precipitation for 2005 is characterized with two peaks – June and August (Figure 1b). On 07.VI.2005 in the NIMH-BAS rain-gauge station at Kourilo, Town of Novi Iskur, a maximum 24-hour precipitation for the month is recorded (Figure 1b), when rainfall of 62 mm (l/m²) poured out.

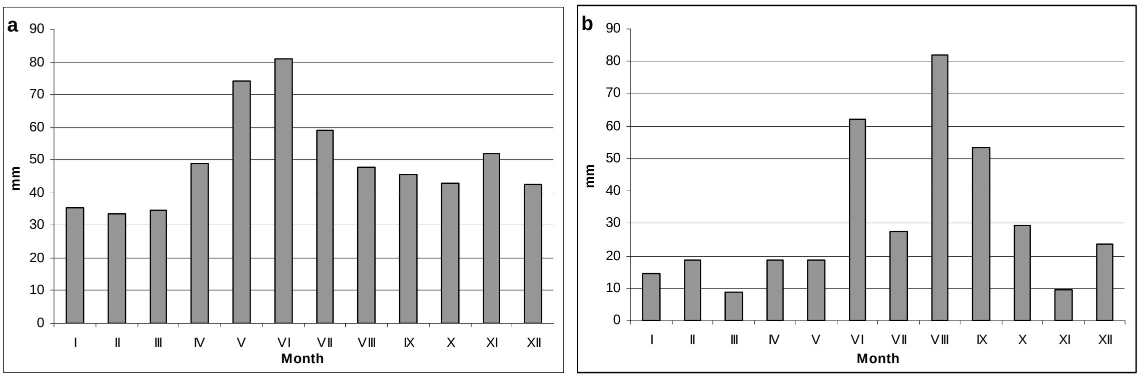


Fig. 1. Precipitation data for Kourilo rain-gauge station: (a) Average monthly amounts of precipitation for 1949-2005; (b) Monthly distribution of the maximal 24 hour precipitation for 2005.

Methods and results

The proposed approach for land use dynamics assessment in regions threatened by floods includes five major stages (Figure 2). Their accomplishment is conducted using geo-informational technologies, including remote sensing data processing and geographical informational systems (GIS) (Lillesand, 2000), and (Burrough, 1996).

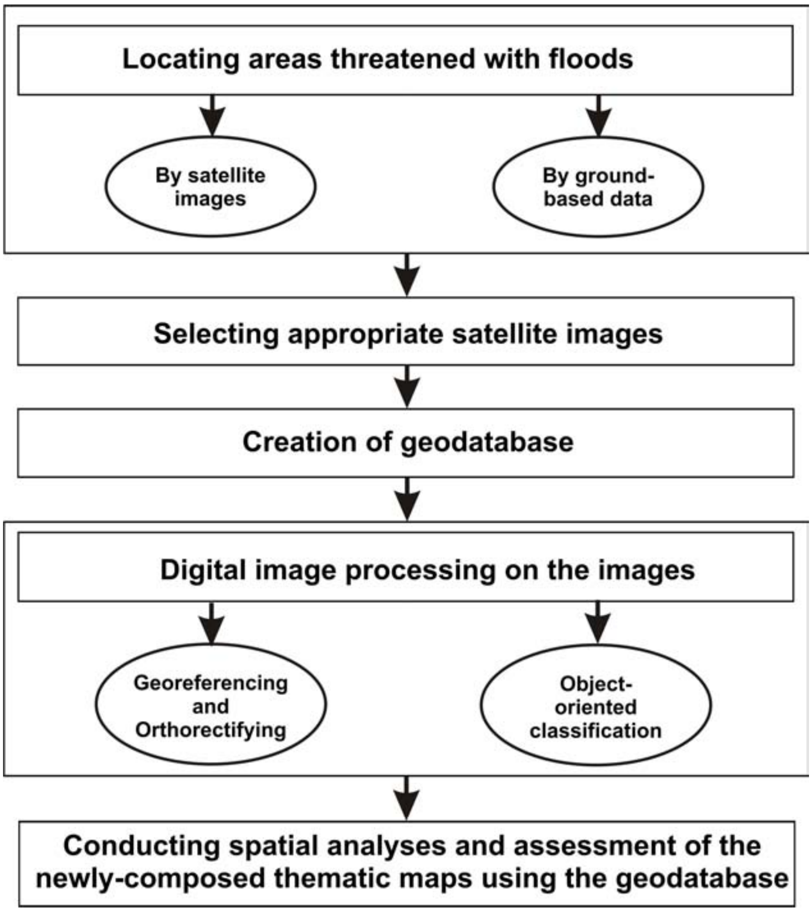


Fig. 2. Flow chart of the study

1. *Identification of the areas threatened with floods*

The location of the areas threatened with floods is determined using satellite images and ground-based data. Depending on the scale and characteristics of the flood, satellite images with different spatial resolution are used. The necessity of having information with high spatial and temporal resolution requires the use of various satellite sensors. The territory threatened by flooding in the first level is detected using low resolution satellite images from the spectroradiometer MODIS on the satellites Terra and Aqua (Figure 3), downloaded free of charge from MODIS Rapid Response System. On the images acquired in the period 09.06 - 26.06.2005 was identified the location of the flooded area – the floodplain of the Iskur river, Town of Novi Iskur, Metropolitan Municipality. In the first few days the flooded area is not identified on the satellite images due to dense cloud cover.

2. *Selecting appropriate satellite images*

For selecting appropriate satellite images and conducting assessment for change detection of land use/land cover in the most damaged part of the flooded area, the following criteria were used:

- Spatial resolution not less than 5 m;
- Minimal number of the spectral bands in the following wavelength diapason: 0.6-0.7 μm and 0.8-0.9 (0.8-1.1) μm; it is also recommended to have one band in the 0.5-0.6 μm spectral diapason;
- The images to be georeferenced and orthorectified;
- The temporal resolution to be from 1 to 3 years before and after the flood;
- To be acquired in the same season.

The chosen satellite images are presented in Table 1.

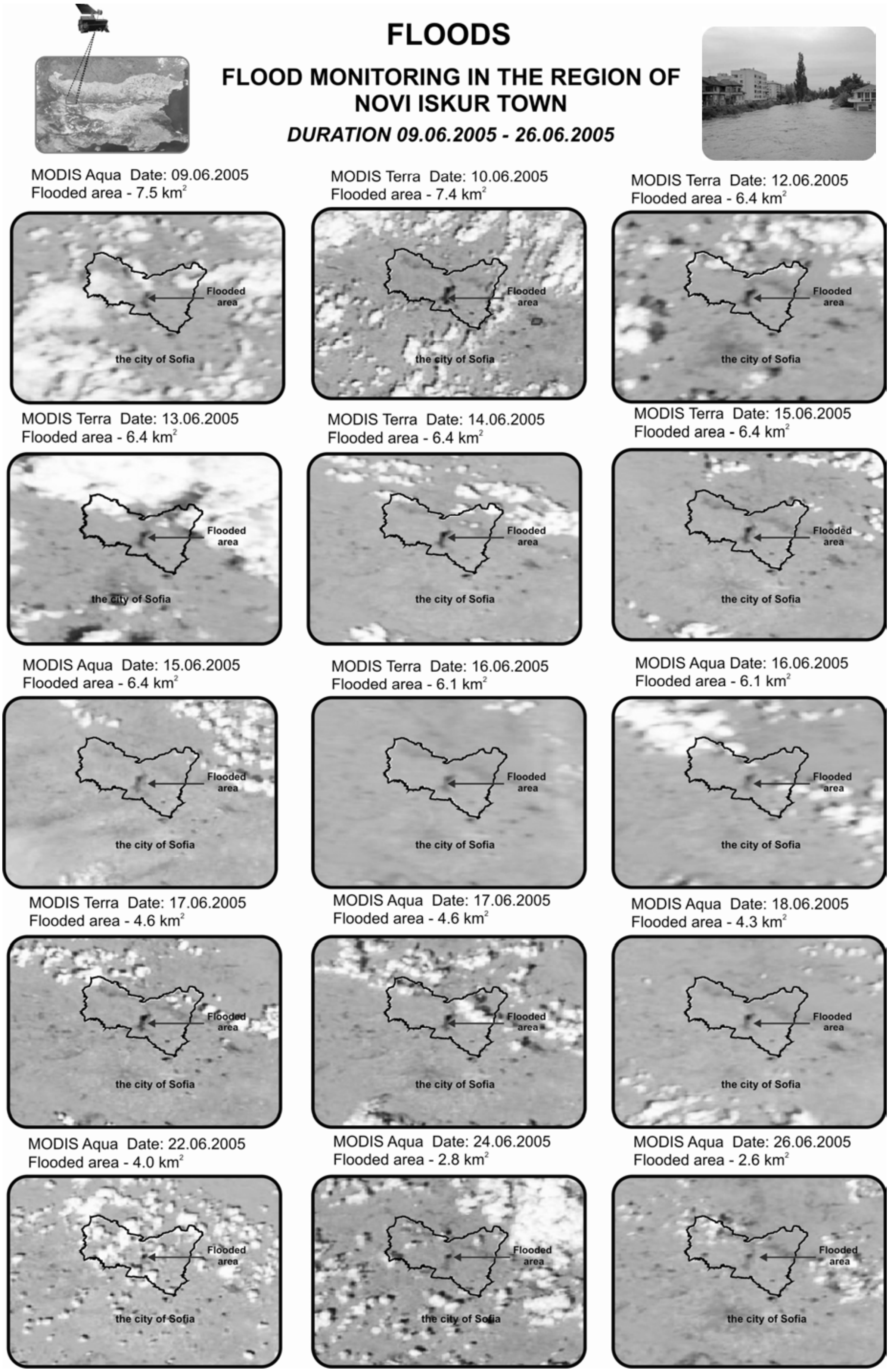


Fig. 3. Locating floods using spectroradiometer MODIS on the satellites Terra and Aqua

Table 1. Used images

Sensor	Acquisition Date	Spatial Resolution (m)	Spectral Resolution (nm)
QuickBird Panchromatic	07.03.2007 31.05.2008	0.60 m	450–900 nm
QuickBird Spectral	07.03.2007 31.05.2008	2.44 m	450–520 nm (blue), 520–600 nm (green), 630–690 nm (red), 760–900 nm (near IR)
IKONOS Panchromatic	03.07.2002 16.06.2005	1 m	526–929 nm
IKONOS Spectral	03.07.2002 16.06.2005	4 m	445–516 nm (blue), 506–595 nm (green), 632–698 nm (red), 757–853 nm (near IR)
Coloured aerial photos	20.06.2006	0.50 m	-

3. Creation of geodatabase

The thematic geodatabase created for the present study in the Town of Novi Iskur is distributed in two major datasets – raster and feature. The Geographical Informational System (GIS) created for the Novi Iskur aerospace test site, with integrated geodatabase composed of large-scale aerospace and ground-based data for landscape-ecological planning of land use was used. It also contains: climate, relief, geology, soil, vegetation and land use/land cover data. The geodatabase includes also archive aerial and satellite images for the period 1940–2009. The composed file geodatabase for the Novi Iskur GIS contains 6 feature datasets with 27 feature classes, 1 raster catalogue with 385 images, 51 raster datasets, 14 tables, 6 stand-alone feature classes and the relevant topological and relationship classes.

4. Digital image processing

The preliminary processing and interpretation on the satellite images is conducted in GIS with the purpose of deriving land cover thematic layers for the studied territory. These layers are used for composing a map and change detection matrix for the land use/land cover classes after the flood in 2005. Since very high resolution satellite images acquired in various years are used it is necessary to be georeferenced and orthorectified preliminary. Digital Elevation Model (DEM) with 40-meter cell size and Rational Polynomial Coefficients (RPC) geometric correction model in ERDAS IMAGINE were used for orthorectifying the images. Ground control points selected from orthophoto images with resolution of 0.5 m were used to adjust the RPC values. The RPC model uses cubic polynomials for transformation from ground surface coordinates to image coordinates (Figure 4).

Fig. 4. Orthorectifying and georeferencing of the images

The identification of the different land cover classes on the satellite images was conducted using object-oriented classification software product Feature Analyst 4.2 for ArcGIS. For classifying the chosen satellite images (Table 1) from QuickBird and IKONOS the following options available in the software were chosen: Input Representation field Manhattan, Pattern width 5, Aggregate area 25 pixels, Approach 1, wall to wall selected. The panchromatic image was used as texture and reflectance and the multispectral one only as reflectance. For better accuracy in identifying the training samples, Normalized Difference Vegetation Index (NDVI) image was used. Depending on the land cover condition and their appearance the following classes are identified: three classes of crop fields, three classes of natural meadows, pastures, forest and scrub vegetation, water bodies and roads. The accuracy assessment of the classification of the satellite image, acquired in 2008 is conducted based on field check with preliminary selected routes.

Accuracy Assessment tool in ERDAS Imagine software was used for the accuracy assessment of the three object-oriented classifications. Over 100 randomly distributed reference points were generated for that purpose.

The accuracy assessment report for the object-oriented classification on the IKONOS image acquired in 03.07.2002 shows overall classification accuracy of 80.26% and overall Kappa statistics of 0.7669. From 76 randomly distributed reference points throughout the image, 61 points are correct. According to the reference data table from the error matrix, it can be concluded that there are some problems regarding the accurate extraction of the classes “Meadow 3”, “Crop 2” and “Meadow 2”. The particular problems are as follows: 1) Class “Meadow 3” is mixed with the “Crop 3” class and this is reflected on the accuracy totals table where 50% producer accuracy is observed; 2) Class “Crop 2” is mixed with the “Crop 3” class which can be explained with the difficulties in the discrimination between the three agricultural classes. The producers’ accuracy of the “Crop 2” class is 66.67%. The “Meadow 2” class is considered as the most difficult class for extraction from the IKONOS image because it has some mixtures with both other classes: “Crop 3” and “Meadow 1”. This conclusion can easily be seen in the accuracy totals table, where the class “Meadow 2” has producer’s accuracy of just 35.61%. There are two other classes that experience some accuracy assessment problems for that classification. These classes are “Trees” and “Crop 3” which have users’ accuracy of less that 70%. The classes “Pastures” and “Water” have both producers’ and users’ accuracy of 100%.

The accuracy assessment report for the classification on the QuickBird image, acquired on 07.03.2007 shows overall classification accuracy of 80.60% and overall Kappa statistics of 0.7543. According to the error matrix table of the accuracy report, it can be concluded that the classification process has some difficulties regarding the “Meadow 2” class, which is mixed with the “Meadow 1” and “Crop 2” classes. This conclusion is evident from the accuracy totals table, where this class has producers’ accuracy of just 33.33%. The “Water” class has 100% accuracy and this can be explained with the excellent extraction of this class from the Feature Analyst software and also with the fact that the water bodies have only 4 reference points in total for that classification.

The accuracy assessment report for the classification on the QuickBird image, acquired on 31.05.2008 shows overall classification accuracy of 91.75% and overall Kappa statistics of 0.8693. From 97 reference points in the image, 89 are correct and represent the real distribution of the classes throughout the studied territory. According to the error matrix table of the accuracy report, it can be concluded that this classification has some inaccuracies’ regarding the “Meadow 1” class, which is mixed with the “Meadow 2” class and this is reflected on the error matrix table. This classification is the most accurate from the three classifications made. The reason for that could be the acquisition date of the image, in particular the growth stage and the condition of the meadows and crops, which makes interpretation of the image more easy compared to the other two images.

Despite using Normalized Difference Vegetation Index (NDVI) and ground-based data to separate between different growths stages of the classes “Meadows” and “Crops”, it is still very difficult to receive a 100% accuracy assessment report. Having in mind that we analyze three images, each from different time of the year and growth stage, we consider that this study will be useful for future research in this field.

5. *Conducting spatial analyses and assessment of the newly-composed thematic maps using the geodatabase.*

The border of the flooded areas and the level of dryness are evaluated using visual computer-aided interpretation on very high resolution IKONOS image, acquired on 16.06.2005. A notable part from the territory of Novi Iskur was affected by the flooding - 10.6% of the territory was flooded, and the prevailing part of it has already partially dried (Figure 5).

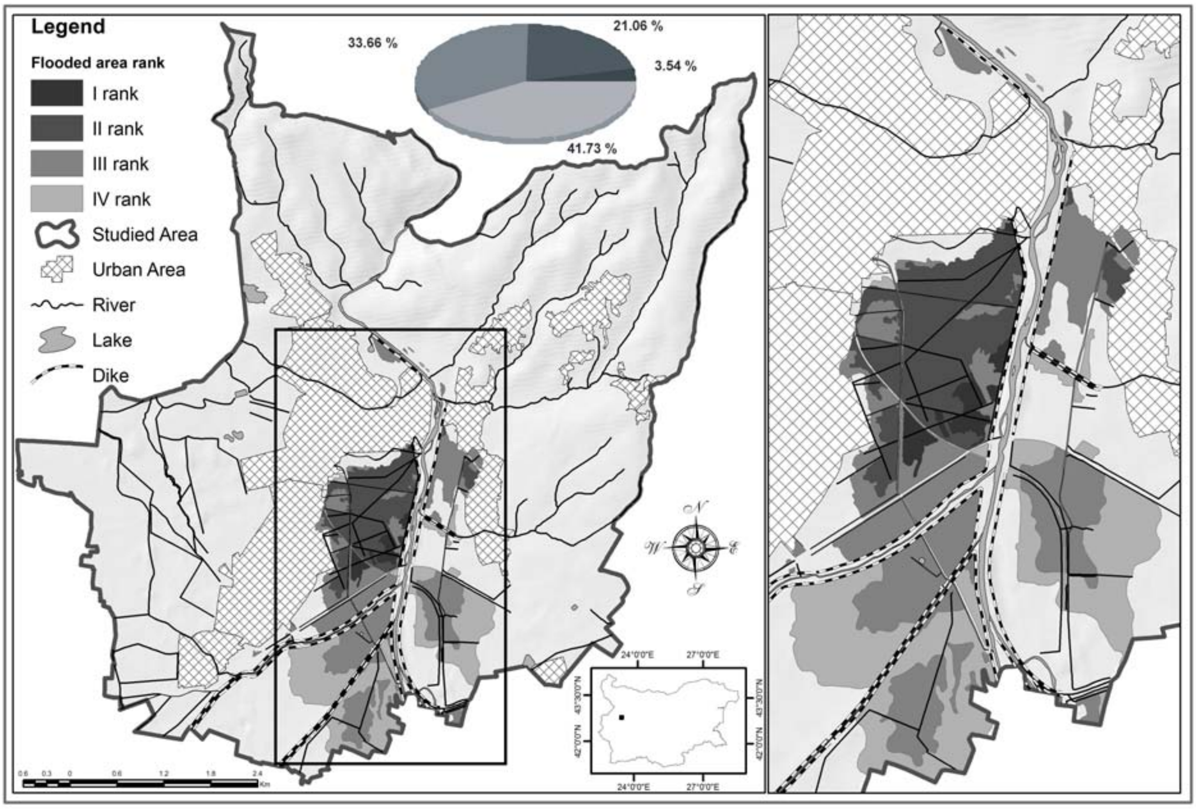


Fig. 5. Map and diagram of the flooded areas and the level of dryness

For assessing land cover change caused by the flooding, difference map were created using the vector layers from the object-oriented classification of 2002 and 2008 images. A simplified difference map showing changed and unchanged territories between 2002 and 2008 is shown in Figure 6. Change detection matrix for the same years is also presented (Table 2), showing the change occurred from one class to another.

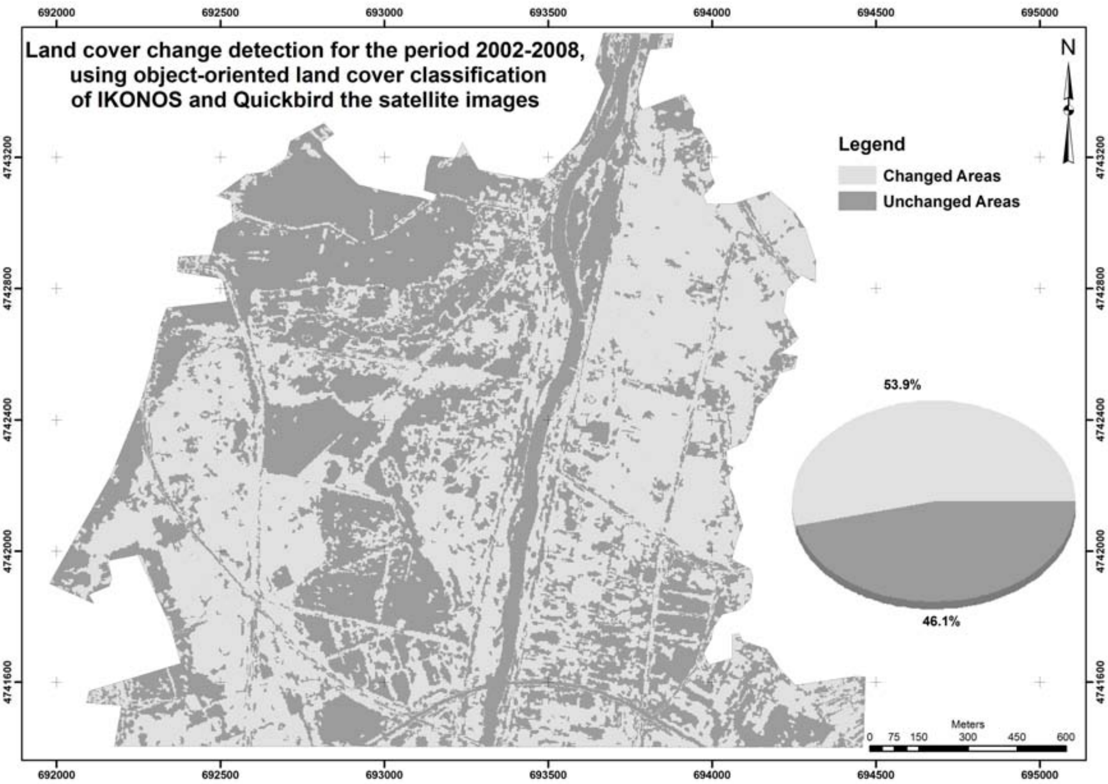


Fig. 6. Map of changed and unchanged areas for the period 2002-2008

Table 2. Change matrix of the land cover areas (%) for 2008 compared to 2002

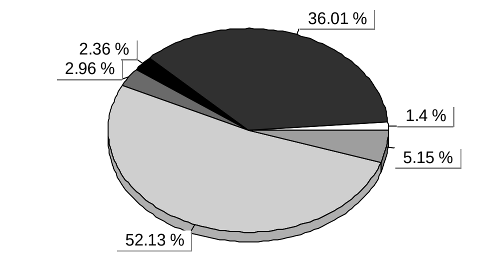
Land cover classes		2008			Total
		Crop	Meadow/ Pastures	Other	
2002	**Crop**	**0.47%**	40.76%	5.44%	46.67%
	Meadows/Pastures	0.49%	**38.69%**	3.85%	43.03%
	Other	0.12%	3.28%	**6.90%**	10.30%
Total		1.08%	82.73%	16.18%	100.00%

The studied territory appears labile as far as land use is concerned. In 2008 53.9% of the study area is changed (Figure 6) with biggest shares for the class agricultural land. The arable land affected by the flood is abandoned and it is occupied mostly by meadows and pastures. The meadows/pastures land for 2002 is 43.03%, while in 2008 it occupies 82.73% from the territory (Table 2). This conclusion was confirmed from the conducted field check.

Land use categories, affected by the flood are defined for registering the damages and their percent shares are calculated using the created geodatabase (Table 3). The most affected classes are crop fields and natural meadows, respectively 52% and 36% from the flooded areas. The least affected class is forest and shrub vegetation of the territory. As a result from the flood, parts of the irrigation equipment was damaged and flooded - mainly dikes and two channels.

Table 3. Land use categories for the Town of Novi Iskur affected by the flood in 2005.

Land use categories	Area (%)
Crop fields	52.13%
Meadows	36.01%
Transport and infrastructure	5.15%
Pastures	2.96%
Urban area	2.36%
Water bodies	1.40%



Conclusion

The effect from the flooding has biggest reflection on the crop class. In the recent years the usage of the territory for agricultural purposes has decreased.

The use of very high resolution (VHR) satellite images integrated in GIS allows for regular monitoring of the land use/land cover change to be conducted.

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