HIGH RESOLUTION LAND COVER MAP FOR UKRAINE

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Land cover maps play an important role in studying and understanding the processes in ecosystems and solving many applied problems of satellite monitoring. In particular, these maps are invaluable source of information to determine and quantify trends in land use changes, improve the accuracy of classification and areas estimation, to analyze climate change and its impact on the biosphere [1—5].

Land cover data sets based on satellite images have been used since 1980s. They had low spatial resolution and not sufficiently accurate. Low-resolution maps usually underestimate or overestimate certain land cover types. Therefore, creation of global and regional land cover maps, based on high resolution satellite images, (such as Landsat series at 30 m) is an extremely important task.

In this study we produced land cover maps for the whole territory of Ukraine, based on the Landsat 4, 5, 7 images, for three decades, namely 1990s, 2000s and 2010s. These maps allow estimation of the general trends of land cover/land use in Ukraine. This paper discusses the methodological aspects to obtain retrospective maps of land cover, based on Landsat images at regional scale, including all preprocessing steps for satellite imagery, formation of training and test sets, classification method and analysis of obtained results.

Satellite data description

Visible (blue, green, red), near-infrared (NIR) and mid-infrared (MIR) bands of Landsat 4, 5, 7 at 30 m spatial resolution were used for classification. We used atmospherically corrected products for Landsat 4, 5, 7 provided by the US Geological Survey (USGS) Earth Explorer system. Each Landsat scene was re-projected to the Albers Equal Area (AEA) projection

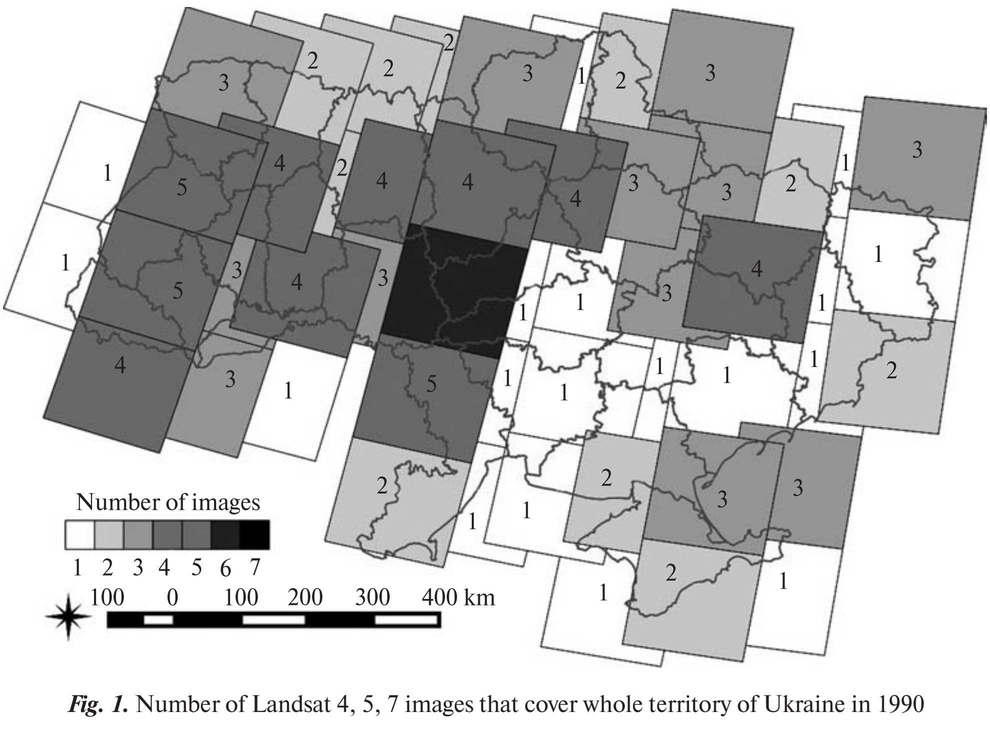

Fig. 1. Number of Landsat 4, 5, 7 images that cover whole territory of Ukraine in 1990

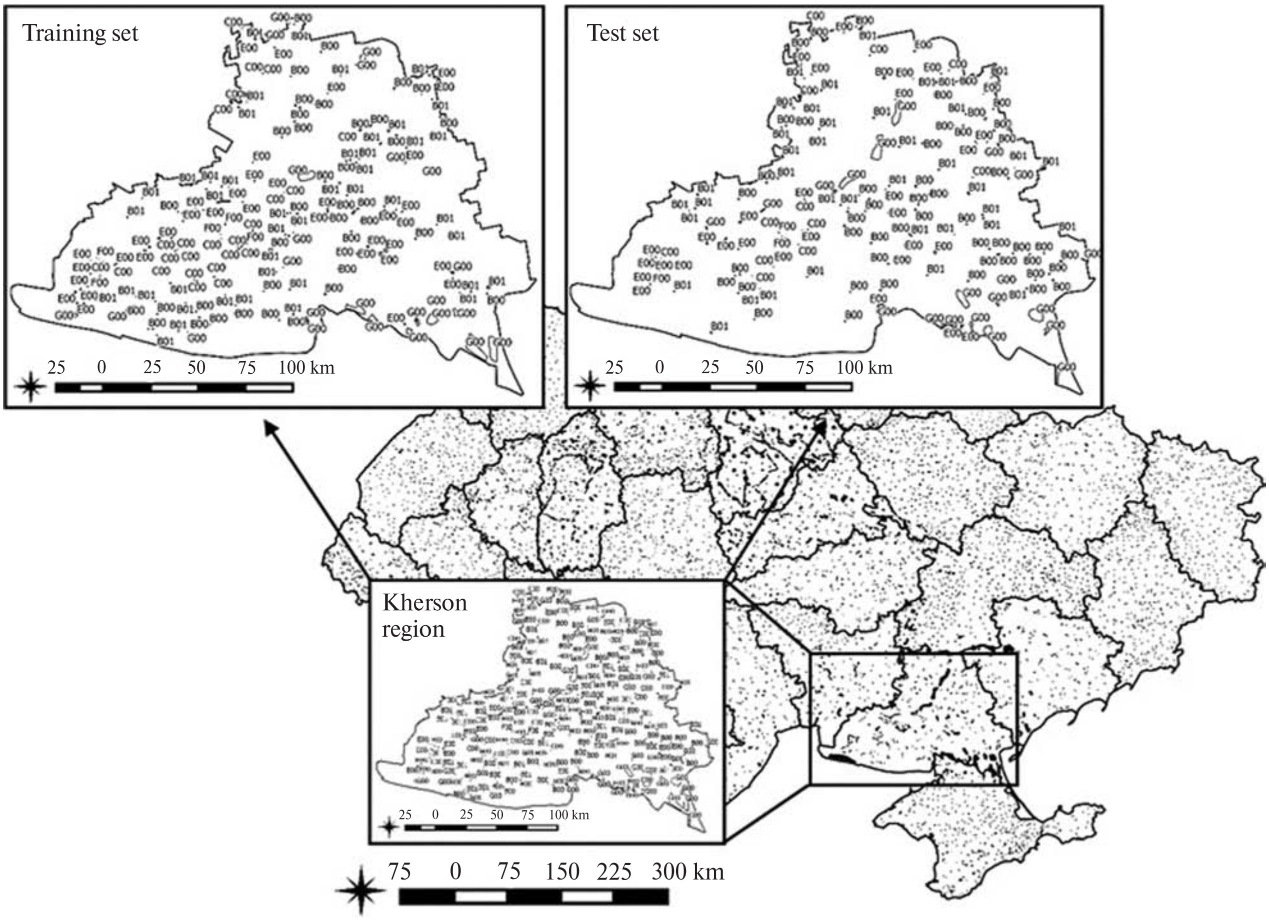

Fig. 2. Samples uniformly distributed over the whole territory of Ukraine. Example of random division of samples into training (50 %) and test (50 %) sets in Kherson region

to enable equal areas at different latitudes. In order to handle areas in the images that were contaminated with clouds, we restored clouded and shadowed pixels using the approach proposed in [6—7].

In total, we used 117, 161 and 185 Landsat 4, 5, 7 scenes for producing maps for 1990, 2000 and 2010, respectively. For the 1990s time period parts of Ukraine were covered by a single image only (Fig. 1). Therefore, we used Landsat images acquired in 1989 and 1991 to fill the gaps from 1990-year images due to clouds contamination.

Training and validation sets creation

Classification was performed for six main land cover classes of the European Land Use and Cover Area frame Survey (LUCAS) nomenclature: artificial surface, cropland, grassland, forest, bare land and water. We formed training and test sets using a photointerpretation method with uniform spatial sampling over the territory of interest and proportional representation of all classes. As a result, we gathered 14261, 13492 and 13575 polygons for 1990, 2000 and 2010, respectively, which cover whole territory of Ukraine evenly (Fig. 2). These polygons were randomly divided into training (50 %) and test (50 %) sets. We used a vector mask of inhabited localities for the whole territory of Ukraine in order to exclude from the consideration the territory of cities and villages.

Data preprocessing and classification method

During preliminary processing stage Landsat 4, 5, 7 scenes were merged to multi-channel images for each path, row and date. The basic images contained six spectral bands and three bands with shadow, cloud and cloud contours masks. Images with less than 50 % of cloud cover were selected for classification. First, we restored cloudy pixels from time-series of images using self-organising Kohonen maps (SOM) [6, 7, 9—11]. After that, we provided classification, based on the time-series of restored images available for the certain year [10—16]. Classification was done using an ensemble of neural networks, namely multilayer perceptrons (MLPs) [17, 18].

Two different experiments with Landsat time-series images fusion were conducted. Within the first approach, time-series of satellite imagery were fused in a single feature vector that was used for classifica-

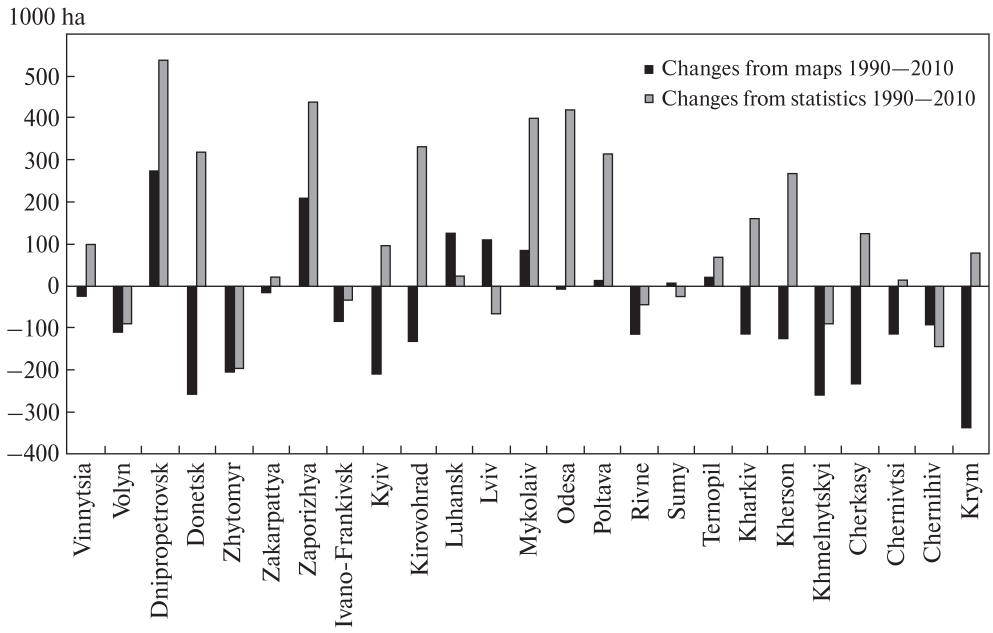

Fig. 5. Land cover changes from 1990 to 2010 according to the statistics and by classification maps

tion and generation of classification map. The second approach was to classify each image separately and then fuse multiple classification maps into a single map. Fusion of classification maps was done by maximizing average a posteriori probability of classes taking into account the number of cloud-free pixels. This was to ensure that only pixels of high quality are used for final decision on a land cover class.

As a result, first approach with fusion of all images during classification phase using neural networks ensemble provided the most accurate final classification maps on an independent test sample.

The practical implementation of the classification method and analysis of the results

The developed methodology was used to generate land cover maps for the whole territory of Ukraine (Fig. 3, see color plate). These maps make possible to estimate general trends of different land cover/land use in Ukraine in these time periods. For example, comparison of cropland areas for 1990, 2000 and 2010 revealed the increase of grassland instead of cropland, in particular, in the northern part of Ukraine.

It was discovered, that during quite long time intervals a large amount of cultivated lands (with agricultural usage) became abandoned. This issue especially is presented in north-western part of Kyiv region (Fig. 3) in 1990s.

To assess the accuracy of classification we used two approaches: accuracy assessment on independent test set and comparison of the class areas in land cover with official statistics.

Accuracies for each individual class were more than 70 %. The lowest accuracy was for artificial since this class had small representation in the sets and small area polygons, and for grassland since it is difficult to separate grassland from cropland. Another validation approach is the comparison of the areas of each class with official statistics. This comparison of the obtained areas and official statistics was provided for each region and for the whole territory of Ukraine for each time period (1990, 2000, and 2010). Though statistical data are not quite consistent and reliable, it is the only way to evaluate the classification accuracy not only in a limited area, but for the whole territory of Ukraine.

During the analysis of land cover changes indicators were obtained on three different levels (at pixel level, districts and regions). The results are shown in Fig. 4 (see color plate). The left map shows the result on the pixel level (purple color presents the transition from arable to uncultivated lands, green — uncultivated lands to arable ones). The generalization results are presented on the middle and right maps for county and district levels (Fig. 4). Administrative units with increased area of cultivated lands are shown by red color, whereas decreased cultivated area — by green color.

There are differences between the obtained results for administrative units and official statistics for the period from 1990 to 2010 (Fig. 5).

For the most regions in Ukraine the ratio between difference in official statistics and classification results and region area was in the range of 5 % to 15 % for grassland and cropland and was within 5 % for the forest class. We also compared the accuracy of our classification for Ukraine with global land cover map GlobeLand30-2010 at 30 m resolution. The overall accuracy of our classification for Ukraine was approximately 8 % higher than GlobeLand30-2010. Also accuracy of grassland from our maps was +25 % (producer's accuracy) and +55 % (user's accuracy) better than GlobeLand30-2010. The main problem of the GlobeLand30-2010 map is that it does not take into account regional specifics.

Conclusions

In this work a retrospective land cover mapping methodology for the territory of Ukraine, based on Landsat data at 30 m resolution was developed. The proposed methodology consists of restoration of no-data pixels due to presence of clouds and shadows in Landsat optical images and classification of multi-temporal satellite images based on the fusion of all images in classification phase using neural networks ensemble. The maps were produced for the whole territory of Ukraine at 30 m spatial resolution [19].

Usage of the intelligent methods for temporal Landsat data processing allowed to receive the overall classification accuracy not lower than 70 % (on an independent dataset — regular grid of points) for separate classes, and considerable improved the quality of the maps (comparing to GlobeLand30-2010 by approximately 8 %). The proposed methodology allows obtain land cover maps for the territory of Ukraine on a regular basis that is extremely important for many applications.

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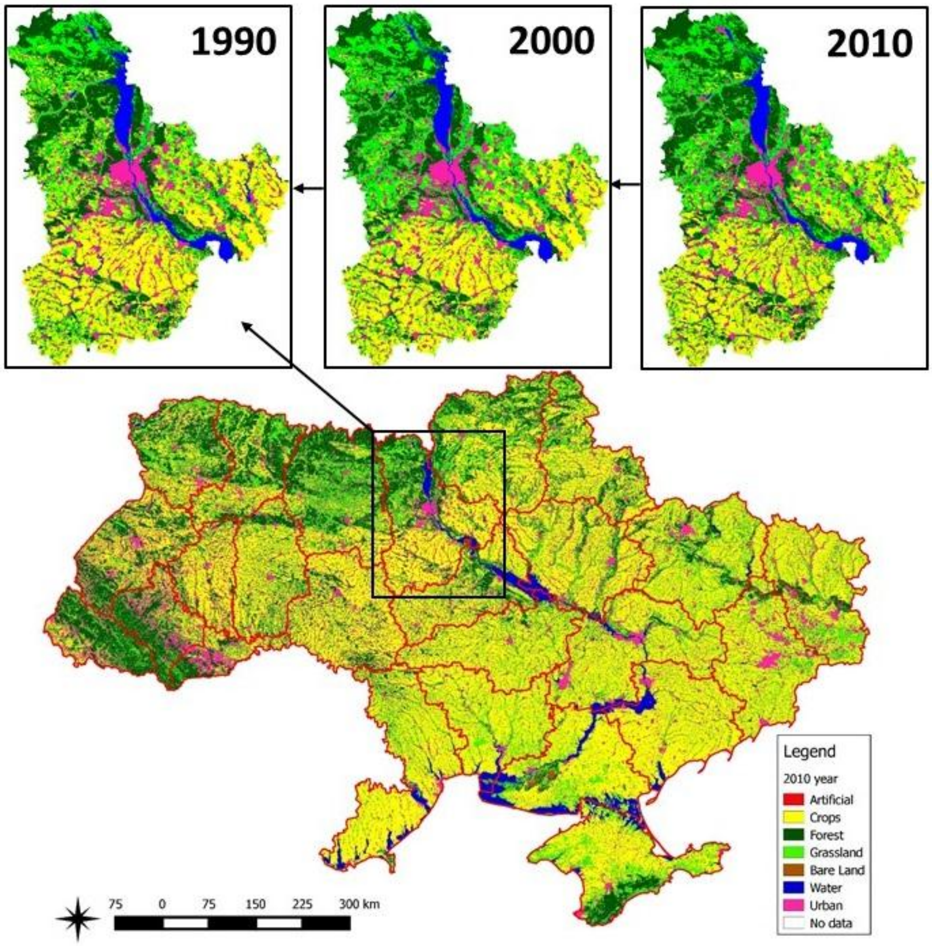
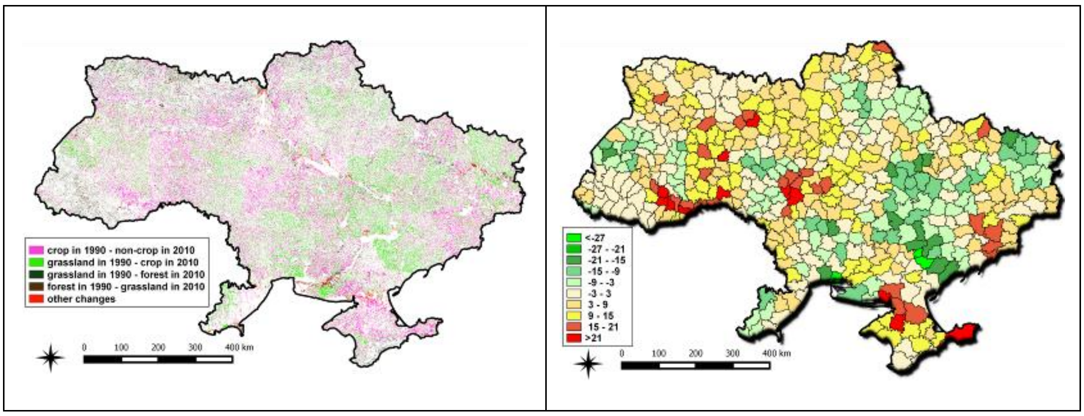


Fig. 3. Final crop classification map for the whole Ukraine using Landsat 5, 7 satellite imagery in 2010



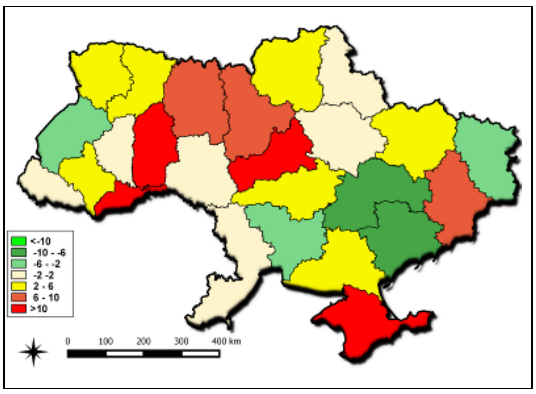


Fig. 4. Land cover changes from 1990 to 2010