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Automated detection of deforestation based on multi-spectrum satellite data

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Abstract. A brief description and the results of experimental testing of a technique for automated processing and analyzing multispectral satellite images of medium and high spatial resolution with the aim of detecting and assessing the dynamics of large logging areas in the territory of the Republic of Kazakhstan are presented. More than 50 large logging areas of about 100 hectares were detected in the selected monitoring site (district of Kokshetau, Akmola territory).

1. Introduction

Regular monitoring of deforestation is currently an urgent task for many countries [1], [2], [3], [4]. The availability of relevant and reliable information ensures effective monitoring of compliance with the legislative acts providing protection and sustainable use of forests, wildlife and the existing forest regulations, e.g.:

- detect massive deforestation of wild and protected forests;
- determine the boundaries and dynamics of changes in commercial logging;
- identify violations of the existing land allocation regulations for commercial or sanitary logging;
- control economic activity in the areas being logged;
- analyze the consequences of deforestation, monitor the dynamics and nature of changes (soil erosion, restoration of vegetation, change in the species composition of the forest, waterlogging, desertification, etc.).

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Problem statement. In the Republic of Kazakhstan, the main forests are located in the vast and sparsely populated areas. Moreover, the most part of the largest forest areas is distinguished by a considerably remote location from the settlements. This causes high complexity of ground-based observation methods (car and horse patrols) due to the insufficient road density. Helicopters and other types of aircrafts are too expensive to be utilized for observing violations even in small areas, and UAVs do not provide the required coverage area.

Possible solutions. The above tasks can be effectively solved using modern Earth remote sensing satellites, which in recent years have been widely utilized to solve a range of environmental monitoring and emergency control tasks [5].

This is possible due to the numerous advantages of remote sensing, such as:

- objectivity and high reliability (satellite images can completely eliminate human errors, as well as intentional distortion or concealment of important information);
- high visibility and information content (any, even inaccessible territory on the Earth can be observed with a coverage of thousands of kilometers);
- maximum relevance and high efficiency (data are delivered to the user without delay directly to receiving stations or with a minimum delay through relay satellites);
- simultaneous and high frequency surveying of vast and extended territories (up to several images a day);
- comprehensiveness and multidisciplinarity (using the same images to solve a wide range of scientific and applied problems in the interests of various government agencies and private companies);
- the multispectral nature of observations (imagery in several spectral channels in the visible and infrared ranges, as well as in the radio frequency ranges);
- complete safety (no risks to human health and life);
- high economic efficiency (significantly lower costs compared to ground-based techniques and airborne imagery);
- maximum availability and confidentiality (easiness of obtaining data and minimizing the risks of information leakage).

Due to these advantages, satellite images allow managers of any level to receive the most timely and reliable information about the state of forests and related economic activities in any of the most remote and inaccessible areas, which is unattainable with ground surveys.

Therefore, the most effective method to ensure regular monitoring of the vast forest territories of the Republic of Kazakhstan, which are distinguished by their inaccessibility and remoteness from settlements, is satellite imagery.

Aims and objectives of the study. The main aim of the study is to develop and test a technique for the automated processing and analyzing multispectral satellite images of medium and high spatial resolution in order to identify and evaluate the dynamics of large logging areas.

To pursue the aim the following objectives should be solved:

- evaluate the possibility of using free multispectral satellite images of medium, high and ultra-high spatial resolution available on the Internet for regular automated satellite monitoring of forests;
- develop a technique for the automated detection of large logging areas using multispectral images of medium spatial resolution available on the Internet;
- test the developed technique in the forest areas 40 km south of the village Zerenda (district of Kokshetau, Akmola territory) using free multispectral satellite images of medium spatial resolution;

- conduct experimental testing of the developed methodology in the areas of mass deforestation in other test areas in the Akmola, Kostanai and North Kazakhstan regions;
- determine the preliminary qualitative characteristics of the developed technique for the automated detection of deforestation in various test areas of the selected monitoring location, including its reproducibility and stability;
- determine preliminary quantitative characteristics of the results obtained in the process of automated detection of deforestation for various test sites (the minimum detectable area of a new group logging and the error in determining the geographical coordinates of the logging area boundaries).

2. Methods

Free multispectral images of medium spatial resolution from Landsat-7 (ETM+), Landsat-8 (OLI)) and Terra (ASTER), as well as remote sensing data obtained from Sentinel-2A / B (MSI) can be used to conduct regular satellite monitoring of deforestation.

In this case, the basic requirements for satellite images made at different times and used to detect and monitor deforestation are as follows:

- processed images must be taken in the same location;
- images must be taken in the same season;
- the survey should be carried out with the same type of surveying instruments (channel-by-channel comparison of images taken at different times is possible only if the spectral ranges of surveying instruments are consistent);
- images must be of the same or close resolution, otherwise the images will contain different spatial information about the objects.

For research, we used multispectral images of a given area from Sentinel-2A / B for 2015 ... 2019 in the Akmola, Kostanai and North Kazakhstan territories. Fragments of the original images of the test site No. 1 from the Sentinel-2A for 2015 and 2019 are shown in figure 1.

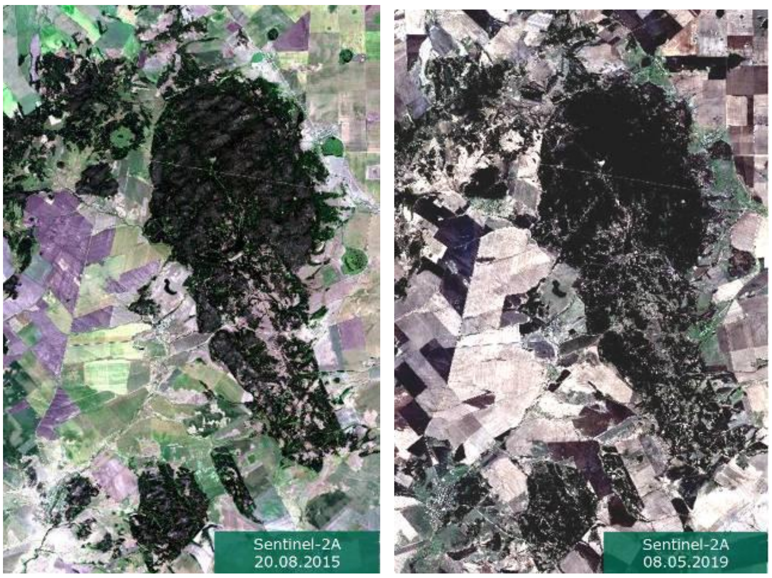

Figure 1. Fragments of the original images of the test site No. 1 from the Sentinel-2A for 2015 and 2019.

The images of the test site No. 1 for 2015 and 2019 were taken in condition of cloudlessness, and the overall percentage of cloud cover in the images for 2014 ... 2016 was acceptably low. Therefore, for the correct comparison of different-time images and accurate determination of the logging area, it was necessary to mask cloud pixels before the analysis using the created cloud masks.

To assess the logging area visually in each image, spectral synthesis of RGB composites was performed using visible and IR channels. In the synthesized images, logging areas are clearly distinguished against the background of vegetation due to the use of infrared channels. In order to detect new logging areas from the source satellite images of the visible and IR ranges, some standard normalized vegetation indices NDVI, EVI, ARVI, SAVI, etc. were calculated for each observation date, and their RGB composites were synthesized.

Using a normalized difference between pixel values of the selected pair of spectral channels instead of the simple ratio significantly increases the stability of the obtained measurement results. In addition, this allows one to reduce the influence of such incidental factors as differences in the illumination of images taken at different times, the presence of scattered clouds, aerosol haze, the absorption of radiation by the atmosphere, etc.

For visual evaluation of the temporary changes in the observation area for the selected pairs of different-time images we performed spectral synthesis of different-time RGB composites using visible and IR channels, as well as previously calculated images of NDVI, EVI, ARVI, SAVI, etc.

To quantify the area of deforestation, we processed multispectral images from Sentinel-2A / B s for 2015 ... 2019 in the Akmola, Kostanay and North Kazakhstan territories, which included the following steps:

- selection and downloading of images for a given observation season, taking into account cloudiness;
- automatic cropping of images along the borders of a given monitoring site;
- automated creation of a cloud mask for a given territory using spectral channels of atmospheric correction (if necessary);
- calculation of NDVI index images for selected images in order to detect new logging areas (in automated mode);
- threshold binarization of NDVI index images (in semi-automatic mode);
- morphological filtering of the binary image and sifting;
- vectorization of a binary image, determination of boundaries and area of vegetation;
- creation of differential images for the selected pairs of images, binarization, vectorization and determination of boundaries and areas of deforestation (an example of detected logging areas is shown in figure 2);
- visualization of changes on a digital map, recording the objects attributes (logging areas) in a DBF file and exporting a vector layer to a KML file.

Figure 2. An example of automated detection of deforestation images on test site No. 1.

The binarization threshold of NDVI index images is within 0.2 ... 0.4 and depends on the season. Using NDVI instead of supervised classification ensures complete automation of image processing. In addition, compared to clustering (e.g., ISODATA), NDVI requires much less time for computation and provides a more stable result.

When processing satellite images, the following metrics are used to quantify the accuracy of automatic recognition and classification of objects [6]:

- a matrix of classification errors for one class, which allows to determine the number of unrecognized pixels of the class, the number of falsely recognized pixels of the class, as well as the overall accuracy of the classification result;
- the compliance matrix for several classes (it is calculated in almost all software packages for processing remote sensing data).
- statistical indicators (e.g., the well-known and often used Kappa coefficient calculated with the compliance matrix).

In this very case, the classification errors matrix and Kappa coefficient were chosen as the main quantitative indicators of the classification accuracy. We did not have the results of the ground based measurements, which are usually used as reference ones. Therefore, the results of deforestation detection, taken manually by an experienced operator (direct vectorization of the multi-temporal images in the visible range) were used as a reference. The expert estimate of the error for such standards was 3 ... 5%, which was acceptable in this case.

It should be noted that multispectral image files from Sentinel-2A / B tend to have large sizes (one image taken in the visible and infrared ranges can take several gigabytes of storage). This circumstance demands higher system requirements. It is advisable to use modern computers with multi-core processors of class Intel I-7 or higher and a RAM of at least 64 GB to process such images in real time. The software can be both paid (ERDAS, ENVI, MapInfo, ArcGIS, etc.), and free (SNAP, SAGA, GRAAS, QGIS, ILWIS, etc.), working both in MS Windows, and in a Linux environment.

To provide a greater degree of automation for processing procedures, it is possible to use appropriate tools (for example, Imagine Model Maker in the ERDAS package, Graph Builder in the SNAP package) or programming languages (e.g., IDL in the ENVI package, Python + GDAL in the QGIS system).

Since the authors did not have the opportunity to conduct ground verification with visits to the affected areas due to their significant remoteness and dispersal over a large territory, the reliability of the results was evaluated using indirect methods:

- for the largest logging areas of temporary changes detected by data from Sentinel-2A / B, a comparative analysis of temporary changes was performed using free images taken from the other existing medium resolution satellites Landsat-7 during the same period (ETM +) , Landsat-8 (OLI) and Terra (ASTER), available on the Internet;
- for the mid-sized logging areas detected by Sentinel-2A / B, a visual analysis of high spatial resolution satellite imagery available on the PlanetLabs web service was performed;
- for small logging areas detected by data from Sentinel-2A / B, a visual analysis of satellite sub-meter resolution imagery available on various geographic information web services (Google, Bing, Here, Yandex, etc.) was performed;
- for large logging areas detected by data from Sentinel-2A / B, a visual analysis of satellite sub-meter resolution imagery available on various geographic information web services (Google, Bing, Here, Yandex, etc.) was performed;
- the boundaries for the logging areas, identified with sub-meter resolution, were determined and their areas were measured using free geo-information applications Google Earth and SAS Planet.

3. Results and discussion

The results of our studies have confirmed the possibility and rather high efficiency of using free multispectral images from Sentinel-2A / B satellites to estimate deforestation and forest cover. In the selected monitoring site (Kokshetau, Akmola territory), more than 50 large logging areas of more than 100 hectares were detected.

Preliminary quantitative characteristics of the developed technique for automated detection of deforestation are as follows:

- the minimum area of the new group logging areas is 0.3 ha;
- the error in determining the coordinates of the area boundaries is ± 10 m.

The proposed technique showed fairly high quality characteristics in the process of experimental testing:

- good reproducibility (repeatability of results on various test samples);
- high stability (slight deviations in the input data or in the settings of the processing procedures should not cause significant deviations in the processing results).

The analysis of image processing results showed a rather high accuracy in determination of the detected logging areas in different test sites with the same binarization threshold settings. At the same time, the accuracy of automated classification (without taking into account the standard errors) for various test sites was within 82..93%, and the Kappa coefficient values were in the range from 0.67 to 0.82.

Existing problems. The main problem of real-time and regular satellite monitoring to assess deforestation is that almost 50% of the available images have high percentage of dense cloud cover (from 20% to 80%). This requires to develop the methods for creating high-precision cloud and shadow masks using appropriate spectral channels. To increase the efficiency of data collection on the monitoring site, taking into account the actual cloudiness, it is advisable to use, along with Sentinel-A / B satellite images, images taken from Terra (ASTER), Landsat-7 (ETM +), Landsat-8 (OLI). It is inefficient to use all-weather radar data from Sentinel-1A / B for these purposes due to the worse resolution of the original images as well as granularity and speckle noise.

Advantages of the proposed technique. The high degree of automation of the technique developed, as well as the orientation toward the use of free satellite images available on the Internet, makes possible its implementation in the form of a geographic information web service, which can significantly improve the efficiency of processing, storage and use of remote sensing data. In particular, the use of such web services provides significant organizational, technical and economic advantages, such as the follows:

- free access to multispectral satellite images of low and medium spatial resolution from various existing Earth remote sensing satellites, as well as to archival data;
- high economic efficiency due to a significant reduction in financial costs (there is no need in buying powerful computers and expensive software);
- software and hardware independence, which allows one to use this web service on mobile devices;
- all procedures for processing satellite images are performed directly in the browser, which does not require installation of additional software;
- the results of processing satellite images are stored on a remote server, which allows all customers to use the web service regardless of their location, and also eliminates the risks of physical data loss associated with natural disasters and emergencies;
- minimum requirements for the level of user training (there is no need to spend time studying large and complex software packages).

Areas of implementation. Due to its simplicity, low cost and relatively high features, the developed technique can be operated by a wide range of users, including:

- public supervisory or regulatory authorities (supervision of agricultural, construction and production activities in forests, wild and protected forests);
- forest service (violations of the existing land allocation regulations for commercial or sanitary logging, updating forestry maps);
- police, special forces and patrol services (detection of illegal logging areas and fight against poachers);
- environmental service (monitoring of forest restoration activities);
- TV and radio companies and other mass media (propaganda against poachers and measures against illegal logging);
- people living near forests (obtaining objective and reliable information regarding the pace and extent of deforestation and forest degradation).

4. Conclusion and further research

The studies developed and subsequently tested a technique for automated processing and analysis of medium and high spatial resolution multi-spectrum satellite images to identify and assess the dynamics of large logging areas. The developed technique was validated at various test sites, as well as its main quantitative and qualitative indicators were evaluated.

To obtain more accurate quantitative indicators for automated deforestation detection, it is necessary to use satellite images of high (1... 10m) and ultra-high (0.3... 1m) spatial resolution. In order to assess the reliability of automated detection of new group logging areas and confirm the preliminary quantitative characteristics of the technique developed, it is necessary to carry out ground based validation at the selected test sites or perform UAV-based survey of the detected area. It is advisable to test the developed technique on a greater number of satellite images taken at forest areas located in different climatic zones to estimate stability and repeatability of the results.

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