Journal of Life Sciences & Biomedicine, vol. 3(76), No 2, p. 54-69 (2021)

Mapping of LC/LU changes inside the Aghdam district of the Karabakh economics region applying object-based satellite image analysis

A.A. Rasouli[1], M.M. Asgarova[2]*, S.H. Safarov[3]

[1]*Department of Environmental Sciences, Macquarie University, 12 Wally's Walk, North Ryde, Sydney, Australia*
[2]*Faculty of History and Geography, Azerbaijan State Pedagogical University, 104 Hasan Aliyev Str., Baku AZ1072, Azerbaijan*
[3]*Institute of Geography, Azerbaijan National Academy of Sciences, 115 H. Javid Ave., Baku AZ1143, Azerbaijan*
***For correspondence:** matanat_askerova@mail.ru*
Received: September 29, 2021; Received in revised form: October 07, 2021; Accepted: October 09, 2021
Identification of the environmental consequences of the 30-year occupation of Karabakh and its adjacent territories by the Armenian armed formations is an important and urgent research task. Object-Based Image Analysis (OBIA) procedures were accordingly applied to examine the condition and changes in landcover and landuse (LC/LU) in the territories of Karabakh liberated from Armenian occupation within the Aghdam District. Firstly, Dynamic Thresholds Indexing (DTI) algorithms were operated to display the main LC by developing several spectral NDWI, NDVI, NBRI, and AVBI indices. At the next step, to recognize precise LU changes inside the study area, a rule-based Nearest Neighbour Classify (NNC) was considered by accompanying an advanced supervised classification technique within the Trimble eCognition setting (eCognition Developer, 2019). DTI results indicated that from 2016 to 2021 inside the Aghdam District, LC changes are quite meaningful. A significant decrease in vegetated cover (10.2 %), increases in the non-vegetated area (11.8 %), and the most noticeable changes are observed in vulnerable lands of about 45.1 km^2 (26.8 %). Subsequently, the rule-based NNC method approved various negative LU changes inside the study area that had occurred predominantly to the mixed forest-pasture classes (9.8 %). Besides, the areas of degraded lands have increased by 35 % and barren lands by 4.4 % according to the study. It should be noted that water and agricultural LU demonstrate the least changes overall of 3.4 % and 0.3 %, respectively. The overall accuracy of 0.95 and Kappa statistics of 0.93 confirmed the significant changes in the final LC/LU productions. Consequently, accurate image processing and mapping of the current situation of the liberated regions of Azerbaijan have to be the most urgent tasks of the geographers, ecosystem scientists, and remote sensing specialists prior to the start of reconstruction and rehabilitation projects by government officials and decision-makers.

***Keywords:** Aghdam district, Karabakh region, LC/LU changes, sentinel-2 imagery, OBIA-based dynamic and threshold indexing, NNC supervised classification*

INTRODUCTION

Occupying the territory of neighboring countries can have serious catastrophic social, economic, and, of course, geographical, and ecological consequences (General Assembly Security Council, 2009). One of the vital consequences of the occupation of the Karabakh districts by Armenia had had significant changes in LC/LU types; and other environmental features of the region (Scheffer, 2010). Although the terms land cover and land use are often used interchangeably, their actual meanings are quite distinct. LC refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil, or others.

http://dx.doi.org/10.29228/jlsb.22

Available online 30 December 2021

Identifying, delineating, and mapping LC is important for large-scale monitoring studies, resource management, and planning activities. Identification of LC establishes the baseline from which monitoring activities (change detection) can be performed and provides the ground cover information for baseline thematic maps. Nevertheless, LU refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. LU applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the LU changes from year to year (Rasouli et al., 2021a). This knowledge will help develop strategies to balance conservation, conflicting uses, and developmental pressures. Issues driving LU studies include the removal or disturbance of productive land, urban encroachment, and depletion of grasslands and forests. Accordingly, it is very important to distinguish this difference between LC and LU, and the timely updated information that can be ascertained from each. The properties measured with remote sensing imagery relate to LC, from which LU can be inferred, particularly with a priori knowledge obtained by advanced image processing techniques (Kato, 2020).

With high confidence, we believe that the fundamental driving force of LC/LU changes in the Karabakh Economics Region is related to temporal-spatial processes caused by war activities such as the compulsory seizure of agricultural and livestock activities, along with the destruction of rare forests (Hasanov et al., 2017). Moreover, we should consider the uncontrolled erosion of soil, pasture, and unique historical monument buildings destruction caused by unprincipled mining activities, multiple bombings, and land-mine landings within the occupied territories of Azerbaijan (Conflict and Environment Observatory, 2021). Remote sensing makes it possible to collect data by sensing and recording reflected or emitted energy and processing, analyzing, and production of a variety of practical information in various fields (Lillesand et al., 2004). Through this modern technology, large amounts of row data and information in the form of digital satellite images are prepared and made available to researchers (Khandelwal et al., 2014a; Copernicus, Sentinel-2, 2020). Up to now, many different methods have been developed in the processing data obtained from remote sensing technology, each with its advantages and limitations. To detect the LC/LU situations over time, advanced OBIA methods could be applied to analyze post-war changes, focusing on the interesting areas. To date, several methods have been proposed in the process of producing LC/LU maps through satellite image processing, as it could be regarded as the science and art of acquiring information about the Earth's surface without being in contact with it (Franklin and Wulder, 2002). Accordingly, in the last few decades, a wide range of image processing procedures, especially focusing on DTI and dissimilar NNC methods are provided, each with its own goals, strengths, and weaknesses (Nelson and Khorram, 2018).

Methods of extracting information through the indexing of satellite images have been common for many years, among these, may refer to NDVI and NDWI indicators with their advantages and limitations (Thenkabail et al., 2018). In recent years, intending to overcome the limitations of traditional methods in the processing of satellite images, new indexing methods have been introduced to high-light land surfaces such as vegetation cover, soil, and water bodies, by addressing a combination of fuzzy and thresholding methods (Rasouli et al., 2020). Traditionally, two indexes of NDVI and NDWI are well-known and widely used land-cover indicators (Rehman and Hussain, 2018). Nevertheless, there are other effective indexes such as NBRI and AVBI for better quantifying of vegetation and soil conditions and more importantly the rate of risk and vulnerability of LU types by war actions, fire events, and other destructive human activities (Pettorelli, 2013). Of course, the use of these indicators is associated with some limitations such as not recognizing and separating vegetation accurately, or mixing wetlands with water bodies. Nevertheless, it is possible that to justify and reduce such limitations by imposing rule-based thresholding methods and processing high-resolution satellites such as Sentinel-2 imagery (Sentinel-2 MSI User Guides, 2020).

In a more precise step of satellite image processing, the NNC method could be used based on fuzzy classification functions to classify image objects with more than one LU class (Khatami et al., 2016). NNC must be regarded as an advanced method in object-based classification that comes close to its capability to classify high spatial resolution Sentinel-2 images. The reason is that we have the advantage of using intelligent image objects with multiresolution segmentation in combination with a supervised classification outline. This allows researchers to select samples for each LU class, by defining some criteria (rule-based algorithms) for classification procedure inside the eCognition software that classifies all objects segmented in the image (eCognition Reference Book, 2019). Before this stage, a Multi-Resolution Segmentation (MRS) must be fined that aggregates spatial information into groups that finds logical objects in the satellite RGB combined imagery (Baatz and Schape, 2000). For example, MRS produces thin and long objects for water channels or roads, and it creates square objects of varying scales such as lakes or agricultural fields in the combined imagery bands of blue, green, red, infrared, and so on. To run any MRS procedure there is a need to define a few criteria parameters such as Scale Shape, and Compactness to get ideal image objects. As a rule of thumb, it is possible to produce image objects at the biggest possible scale, but furthermore, be able to discern between objects. By selecting training samples and a well-represented number of samples for assigned LU classes (such as forest, pasture, agricultural, and water surface) the classification process could be run based on the objects. The selected samples and the defined statistics expecting to reach the NN classification produce the final products, even though there are still a couple of options to improve the accuracy (Foody, 2002).

The authors believe that, after the liberation of the occupied territories, LC and LU changes would be perhaps the most important concern in many districts of the Karabakh Region (Rasouli et al., 2018b). It is recognized such contentious negative changes can significantly impact regional climate, ecosystem stability, water balance, stream silt up, biodiversity, and socioeconomic practices, thereby impinging on the regional economic progressing and overall quality of life in the coming years. Intending to extract accurate information from the resulting changes in the research topic, the basic objectives of the current study are: (a) applying DTI methods to understand the initial status of LC during the last period of the occupation stage inside the Aghdam District; (b) creating more accurate methods of rule-based NNC maps to access more details of LU status and resulting changes within the central district of Karabakh, which have been most affected during the occupation period. These aims could be accompanied by accurate information that facilitates future rehabilitations planning (Rasouli et al., 2021a).

THE STUDY AREA

The study area is specified to the Aghdam District that located in the Karabakh Economics Region, with its most recognized city of Aghdam. The geographical location of the study area is presented in Fig. 1. Aghdam is one of the 66 districts of Azerbaijan and is located in the west of the country and belongs to the Karabakh Economic Region. Most of these districts were under the occupation of Armenian forces following the First Karabakh war in the early 1990s (Sayilan, 2007). However, as part of the 2020 Karabakh war victory, Aghdam and the surrounding districts were returned to Azerbaijani control on 20 November 2020.

In the current study, two Sentinel-2 images (approximately sized to 110 * 108 Km dimension) were subsetted to cover the entire area of the Aghdam District. At the same size, they superimpose the Aghdam District and as well large parts of the administrative regions of Azerbaijan, including Ganja-Qazakh, Kalbajar-Lachin, Aran, and Karabakh that is one of the most important economic regions of Azerbaijan (Aliyev, I. The President of the Republic of Azerbaijan, 2021). The Aghdam District represents the geographical and strategic importance of all sounded districts in the region. Therefore, the entire range of two Sentinel-2 satellite images was taken on 12 August 2016 (during the occupation of the territory of Azerbaijan by Armenia forces) and on 21 August 2021, nearly about nine months after the recapturing of the occupied territories.

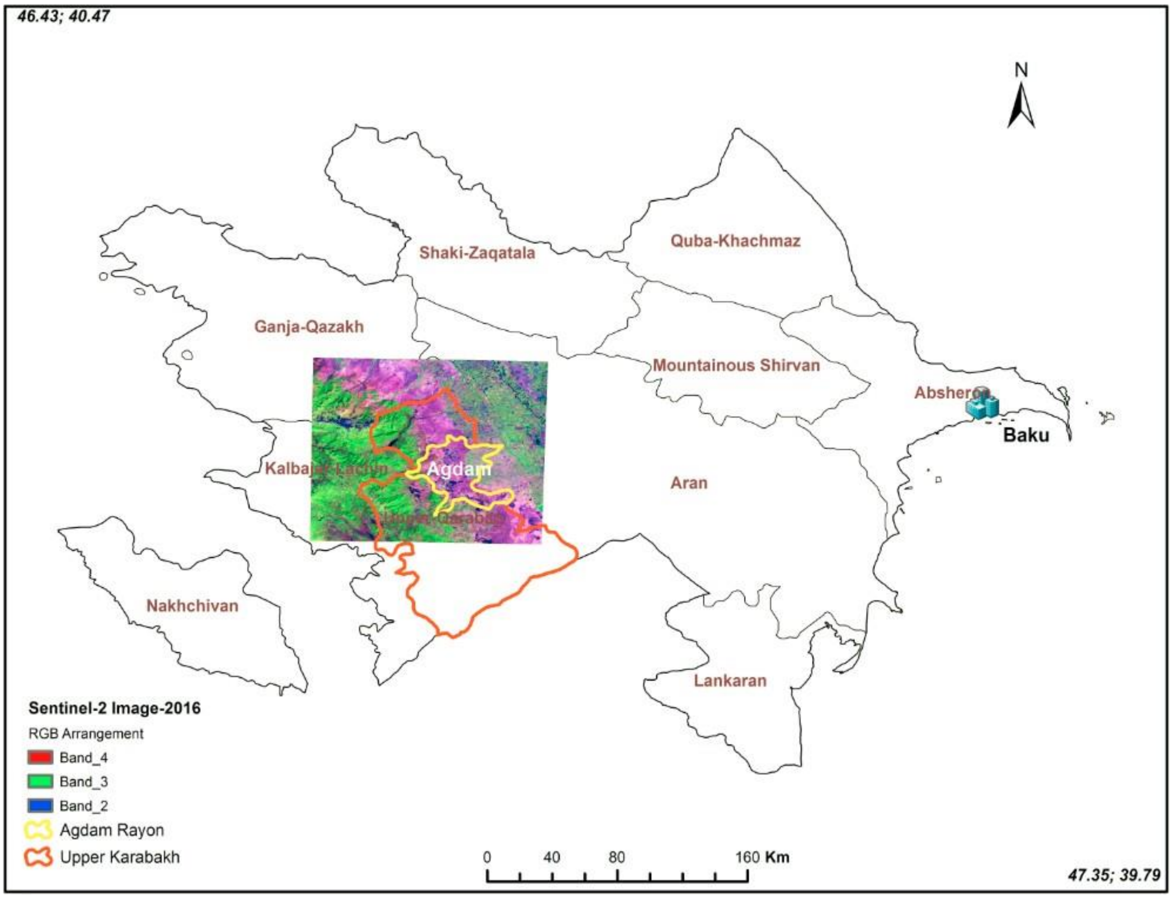

Fig. 1. The geographic location of Aghdam District in Azerbaijan and indicating of the Sentinel-2 image extension

Aghdam has a mainly warm semi-arid climate that could change to the wet conditions in the western parts would be affected by region complex relief and enduring water bodies. Most of the land in the study area includes agriculture, pastures, and unique forests (Rasouli et al., 2018c). Forests spread in the mountainous parts of the study area, gradually become lower and, create subalpine and alpine meadows. The occupation of the Azerbaijan territories by Armenia caused significant damage to the unique LC/LU types such as pasture, forests, especially those located in the frontal lines inside the Aghdam District, with a very rich flora species of higher plants (Valigholizadeh and Karimi, 2016). During the occupation period, agriculture became abounded and less economically important on the regional scale (FAOSTAT, 2014).

DATA PROCESSED AND TECHNIQUES APPLIED

a) Image Collection

To access the main aims of the current study, we analyzed two images from Sentinel-2 satellite acquired by ESA's Open Access (https://scihub.copernicus.eu), selected for specific dates, characterized in Table 1. Sentinel-2 is a European wide-swath, high-resolution, multi-spectral imaging mission. The full mission specification of the twin satellites flying in the same orbit but phased at 180°, is designed to give a high revisit frequency of 5 days at the Equator. Due to the balanced vegetation cover and the absence of cloud cover in the summer months, the satellite images are limited related to August months were processed (Sentinel Online, 2018).

Table 1. Basic information of the Sentinel-2 satellites

Band Number	Basic Descriptions	Wavelength Range (μm)	Central Wavelength (μm)	Spatial Resolution (m)
1	Coastal Aerosol	0.433–0.453	0.443	60
2	Blue	0.4575–0.5225	0.490	10
3	Green	0.5425–0.5775	0.560	10
4	Red	0.65–0.68	0.665	10
5	Vegetation Red Edge 1 (VRE1)	0.6975–0.7125	0.705	20
6	Vegetation Red Edge 2 (VRE2)	0.7325–0.7475	0.740	20
7	Vegetation Red Edge 3 (VRE3)	0.773–0.793	0.783	20
8	Near-Infrared (NIR)	0.7845–0.8995	0.842	10
8A	Vegetation Red Edge 4	0.855–0.875	0.865	20
9	Water Vapor	0.935–0.955	0.945	60
10	Shortwave Infrared Cirrus	1.36–1.39	1.375	60
11	Shortwave Infrared $_a$	1.565–1.655	1.610	20
12	Shortwave Infrared $_b$	2.1–2.28	2.190	20

Sentinel-2 MSI covering 13 spectral bands (443–2190 nm), with a swath width of 290 km and a spatial resolution of 10 m (4 visible and NIR bands), 20 m (six red edge and shortwave infrared bands) and 60 m, three atmospheric correction bands (Sentinel-2 MSI User Guides, 2020). For both sample sites, the Sentinel-2 images were processed for investigating the changes of LC/LU for the years 2016 and 2021. The selection of study areas required the consideration that the experimental areas are representative and, thus, the vegetation and non-vegetation types in the study areas should be abundant and diverse. Water bodies include lakes, rivers and water reservoirs, and non-vegetation types include bare-land and other emerging classes such as degraded and burned lands. Fig. 2 shows two samples of Sentinel-2 images with 3 band combinations for years 2016 and 2021, with the highest spatial resolution (10*10 m). The reduction of vegetation is completely detectable, particularly the rapid decline of green cover is visible across the region. Even, the soil salinization process can visually be observed in the region marked with white, reddish, and orange colours in the satellite imagery (Sentinel-2 MSI, 2020).

b) Image Processing

To build the image dataset, the aforementioned Level 1C (TOA – Top of Atmosphere reflectance) images were chosen based on the low cloud cover percentage and pre-processed for atmospheric correction with the Sen2Cor plugin (SNAP software – Sentinel-2 Toolbox) provided by ESA (Szantoi and Strobl, 2019). Following the atmospheric correction, we obtained Level 2A (bottom of atmosphere reflectance) which is more useful than TOA reflectance when trying to detect a process on the surface such as vegetation and water, because of the atmospheric effects caused by the event itself are reduced. Then, each corrected multispectral satellite imagery was imported to the eCognition software setting, and accordingly, mixed RGB layers were created. To obtain functional information from the satellite images, we proposed a tool, called estimation of scale parameter (ESP), that builds on the idea of local variance (LV) of object heterogeneity within a scene (Ikokou and Smit, 2013). When segmentation settings were modified based on the ESP - depending on the image quality (bands available, and image spatial-resolution) pixels of any satellite image were grouped into image objects before object-based indexing and classification methods could be performed. In the segmentation stage of satellite images, for scale parameter is taken about 55 and the shape and compactness indexes (with trial and error) were suggested as 0.3 and 0.7 respectively. The other main features of Sentinel-2 image layer weighting and segmentation parameters are presented in Table 2.

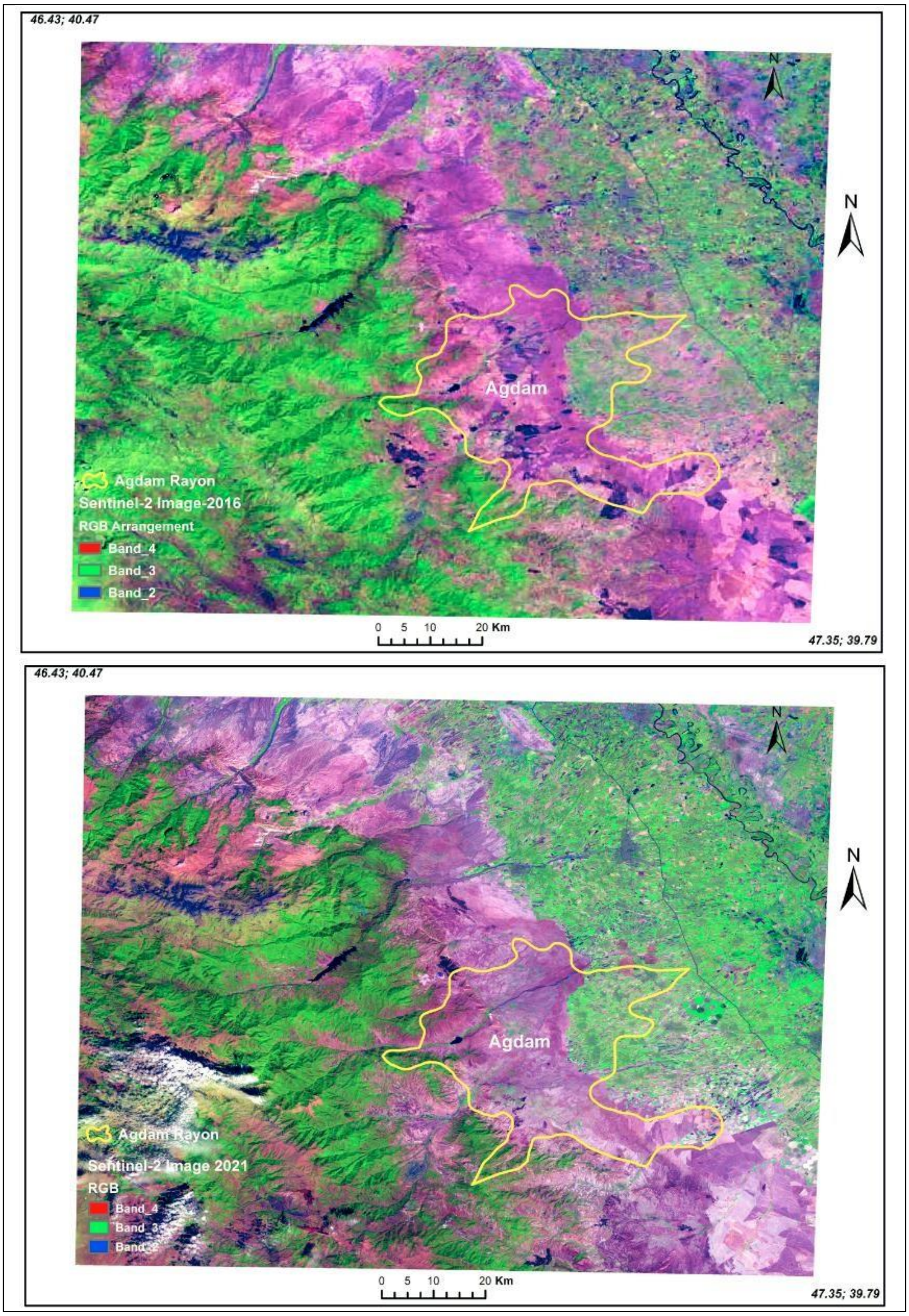

Fig. 2. Samples of Sentinel-2 imagery reflecting green cover destruction adjusted for the entire Aghdam District for years 2016 and 2021

Table 2: The main features of Sentinel-2 image layer weighting and segmentation features

Bands	b2	b3	b4	b7	b8	b8a	b11	b12
Image RGB Layer Mixing & Weighting	B1	B3	G1	G3	R1 & G1	R3	R1	--
Segmentation Setting	1	1	1	1	2	2	1	1

Along with implementing DTI procedures, equations 1-4 were step-wisely applied to create the basic NDWI, NDVI, NBRI, and AVBI indexes. In the dynamic thresholding stage, each index is regarded as an indicator of specified land surfaces, which typically refers to a spectral measure of the change in the satellite image band's reflections (Dozier, 1989).

$\boldsymbol{NDWI}_{S2} = "(\boldsymbol{b3} - \boldsymbol{b8}) / (\boldsymbol{b3} + \boldsymbol{b8})"$ *(Equation 1)*
If mean NDWI >= 0.1; classified as Water
$\boldsymbol{NDVI}_{S2} = "(\boldsymbol{b8} - \boldsymbol{b4}) / (\boldsymbol{b8} + \boldsymbol{b4})"$ *(Equation 2)*
if mean NDVI >= 0.25; classified as Vegetation
$\boldsymbol{NBRI}_{S2} = "(\boldsymbol{b8a} - \boldsymbol{b12}) / (\boldsymbol{b8a} + \boldsymbol{b12})"$ *(Equation 3)*
If mean NBRI >= 0.12; classified as Burned Lands
$\boldsymbol{AVBI}_{S2} = "(\boldsymbol{b2} + \boldsymbol{b3} + \boldsymbol{b4}) / \boldsymbol{3}"$ *(Equation 4)*
If mean AVBI >= 2000; classified as Degraded Lands

Inside the eCognition Developer version 9.5, based on the above-mentioned equations any index layer calculation algorithm inserts a new image layer by differentiating between dissimilar band combinations (Rasouli and Mammadov, 2020a). In usage, the NDWI index was first used NIR radiation and visible green light to enhance the presence of water bodies while in the study area by eliminating the presence of soil and terrestrial vegetation features. In turn, the NDVI standardized vegetation index allowed us to generate an indicator showing the relative biomass on the image. The chlorophyll absorption in the red band and relatively high reflectance of vegetation in the NIR band are used for calculating NDVI values. Furthermore, an NBRI was applied to the Sentinel-2 bands to capture likely burned lands in the local scales. It is a numerical indicator that combines Vegetation Red Edge (b8a) and Shortwave Infrared (b12) bands**.** Along with the other indicators, the standardized burning index NBRI has been used to highlight the burned areas, while muffing the difference in lighting and atmospheric conditions. It is ideal for detecting localized burned areas, especially in the detection of burned or burning places (farmlands and pastures) which intentionally were set on fires (Simone et al., 2020). Fire-affected areas have relatively low near-infrared reflectance (NIR) and high reflectance in the short-wave infrared band (SWIR). It should be noted that in the process of adjusting the above-mentioned indicators, the Average Visible Brightness Index (AVBI) was regulated by trial-and-error thresholds, with the goal of recognizing and producing existing degraded lands.

Lastly, for quantitative analysis of Sentinel-2 images, the NNC supervised classification procedure was used to create LU maps based on the OBIA structure (Kato, 2020). Supervised classification involves the use of training area data that are considered representative of each LU type to be classified, consists of a few major steps. First, after the creation of required projects inside the eCognition setting, multiresolution segmentation algorithms and parameters are set and executed in the creation of certain image objects. Then, inside the Class Hierarchy box different classes of water, forest & pasture, agriculture, barren-lands, degraded and burned lands (as vulnerable classes) were defined according to the objects structure in the image object domain and their nearest sample neighbors. The nearest neighbor classifies image objects in each feature space and with given samples for the classes of concern, inside the eCognition software, needed for each type of class. After a representative set of samples, objects have been declared, the algorithm searches for the closest sample object in the defined feature space for each image object. It selects the highest accurate features to be considered for the feature space closest sample object belongs to LU classes by applying certain membership functions allows defining the highest relationship between feature values and the degree of membership to a class using fuzzy logic operators. Then, if the image object differs from the sample, the feature space distance has a fuzzy dependency on the distance to the nearest sample classes during the NNC procedure (Kamusoko, 2019).

In a few cases, especially when classes were not clearly distinguished on the image sketch, the Sample Editor window, as a principal tool for checking samples, was applied to automatically generate membership functions. It was also used to compare the attributes or histograms of image objects and samples of different classes. It is helpful to get an overview of the feature distribution of image objects or samples of specific classes. The features of an image object can be compared to the total distribution of this feature over one or all image object levels. In addition, to assess the quality of samples the Sample Selection Information window was applied to decide if an image object contains new information for a class, or if it should belong to another LU class. To ensure that the output LU maps are reliable, and quantitative accuracy methods were employed to assess the producer's accuracy, user's accuracy, overall accuracy, and Kappa coefficient of NNC classification. In the end, applying different accuracy assessment tools, such as the Stability dialog box and The Error Matrix (based on TTA Mask) it was possible to produce statistical outputs to increase the quality of the classification results (eCognition Developer, 2021).

RESULTS

a) Indices LC Maps

To compare the changes of LC types all over the study area the water body, vegetation, non-vegetation, and vulnerable classes are shown in Fig. 3. The decrease in vegetation can be traced inside the Aghdam District by accurate examination of LC classes during the last years with significant negative changes inside the study area. Looking closely at the amounts of LC classes on the legend of maps in Fig. 4, it could be detected that the amount of vegetation cover over the last 6 years has reduced nearly to about 27.8 km^2 (10.2 %). At the same time, about 78.2 km^2 (11.8 %) has been added to the Non-Vegetated LC. Meanwhile, Vulnerable Lands were changed by about 45.1 km^2 (-26.8 %), even though this amount was at its maximum in 2016 with 168.4 km^2. This amount decrease could be related to the reduction of deliberate fires in the green-covers and ended the abolition of land occupation. To achieve more accuracy, it was necessary to create LU maps with more classes and accurate NNC techniques.

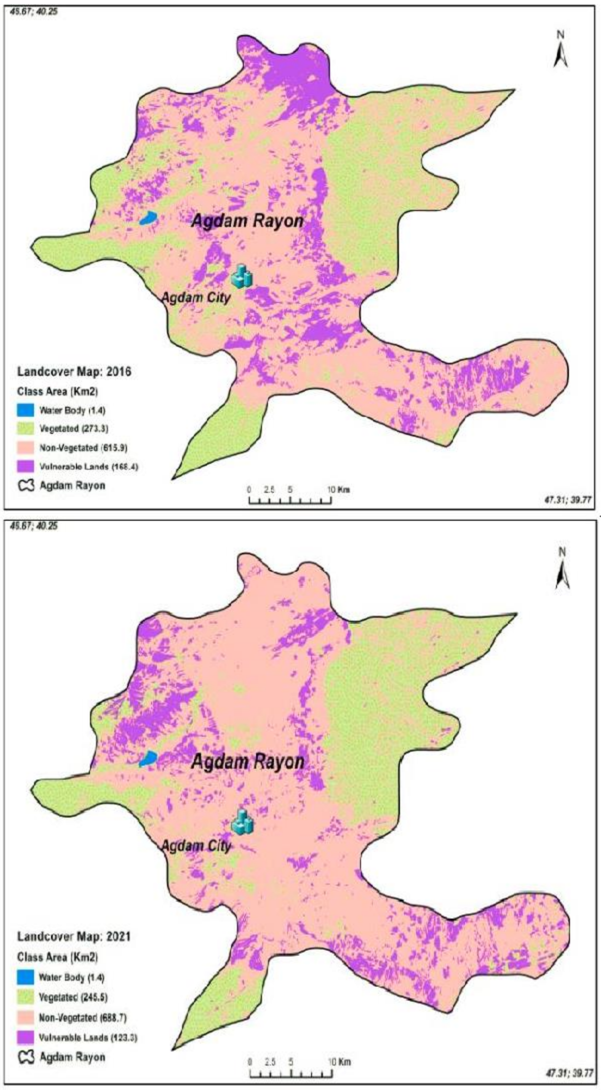

Fig. 3. LC maps produced by indexing techniques adjusted for the Sentinel-2 imagery 2016 and 2021

b) Classified LU Maps

By introducing MRS algorithms and NNC procedures, LU maps, with six classes, were produced and adjusted for the Aghdam District. To be certain about the result of NNC the performance of closing LU classes was cheeked in detail with different image mixed layer weights and multiresolution segmentation parameters (Fig. 4).

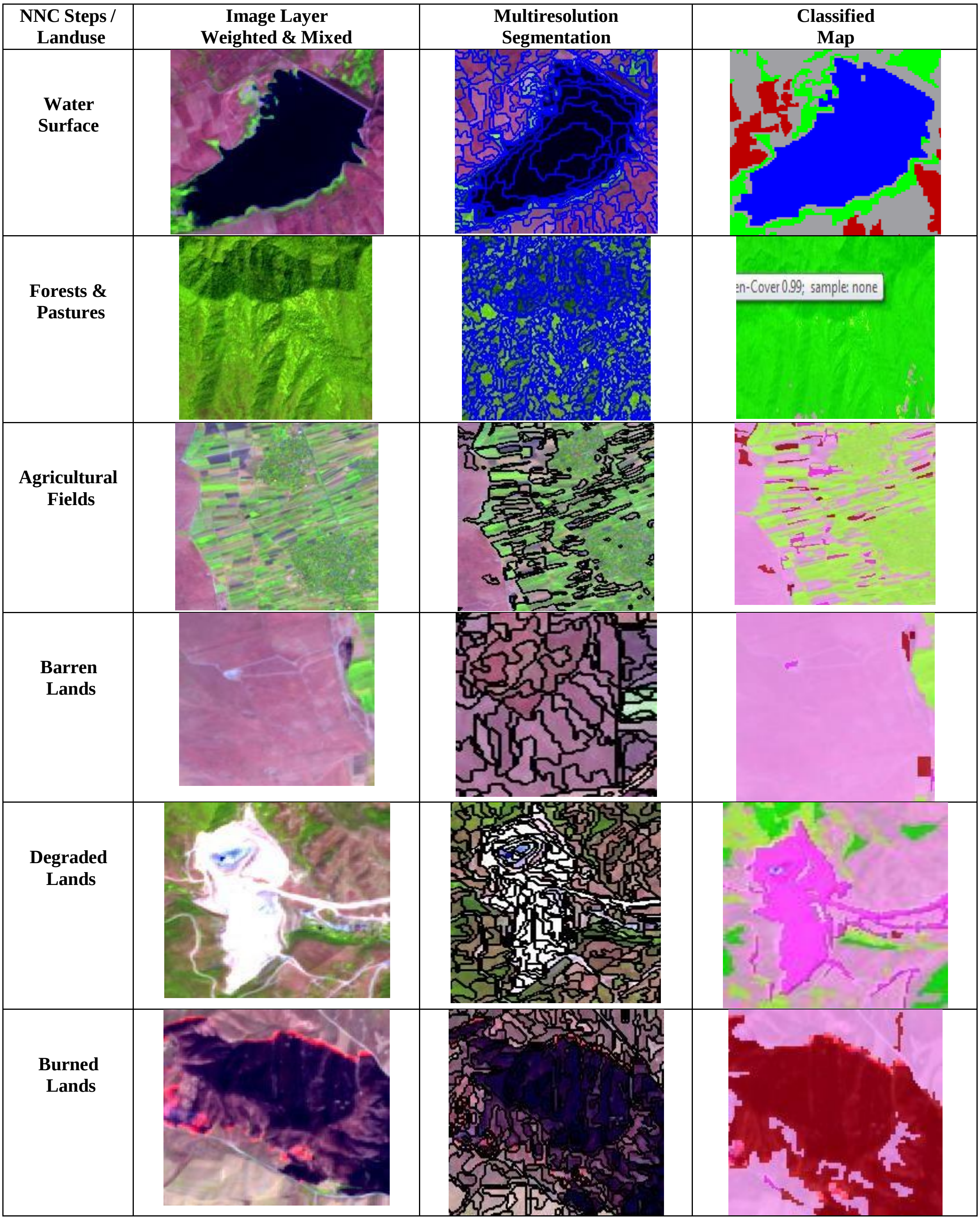

Fig 4. The performance of final NNC classified LU classes, examples with different image mixed layer weights, and multiresolution segmentation

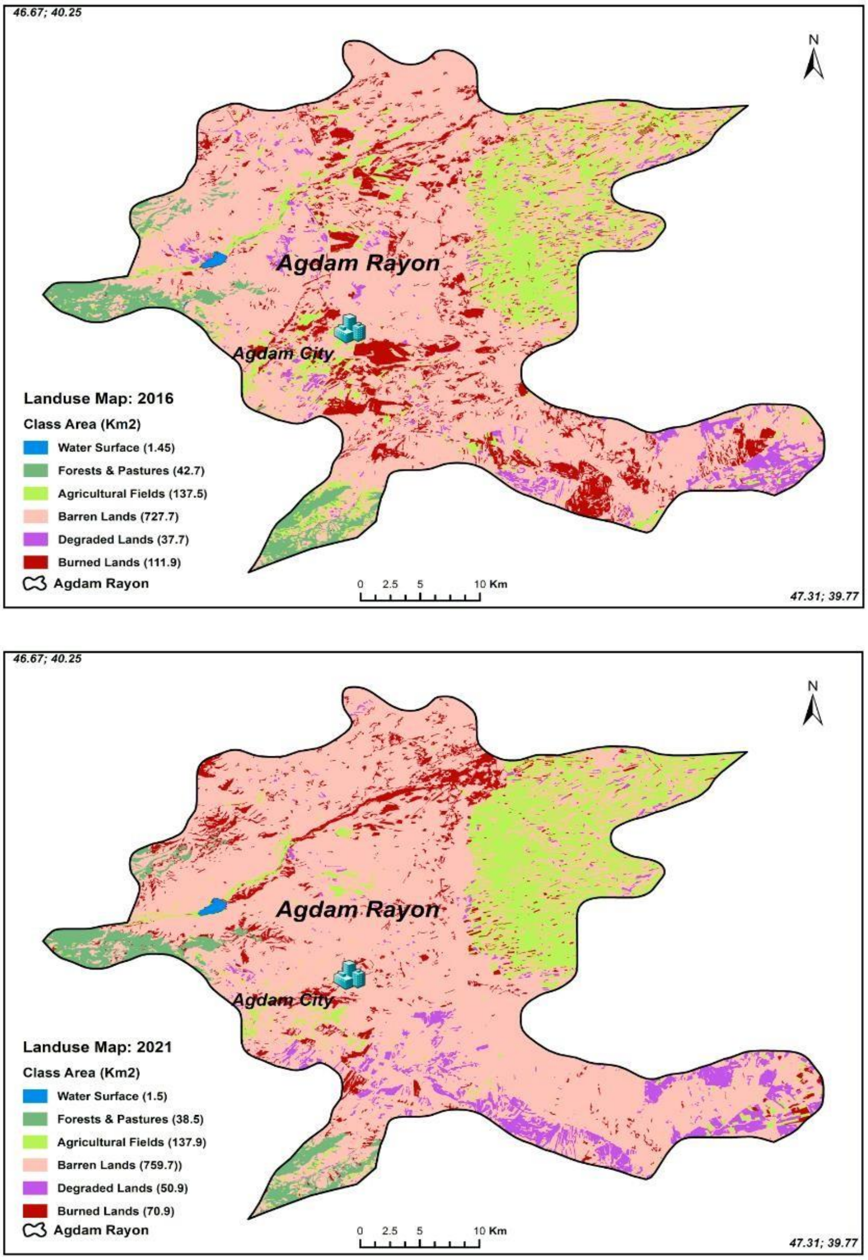

Fig. 5. Final LU maps of 2016 and 2021 classified by NNC techniques

Due to the careful visual interpretation and a quantitative accuracy index, the performance (for each class) was controlled, and promising accurate maps were produced. By carefully testing the preformed samples, produced layers were imported to the ArcGIS setting and final classified LU maps of 2016 and 2021 were mapped (Fig. 5).

Examination of the resulting LU maps indicated that the reduction in forests & pastures (-9.8%) and barren lands (+4.4%) inside the Aghdam District are quite considerable (Fig.5). As it is noticeable in Fig 6, changes in other classes are also evident by emerging more degraded lands (+35%) and reducing burned lands (-36.9%). Amounts of raise in water surface class (+3.4%) and agricultural fields (+0.3%) are not quite meaningful from 2016 to 2021.

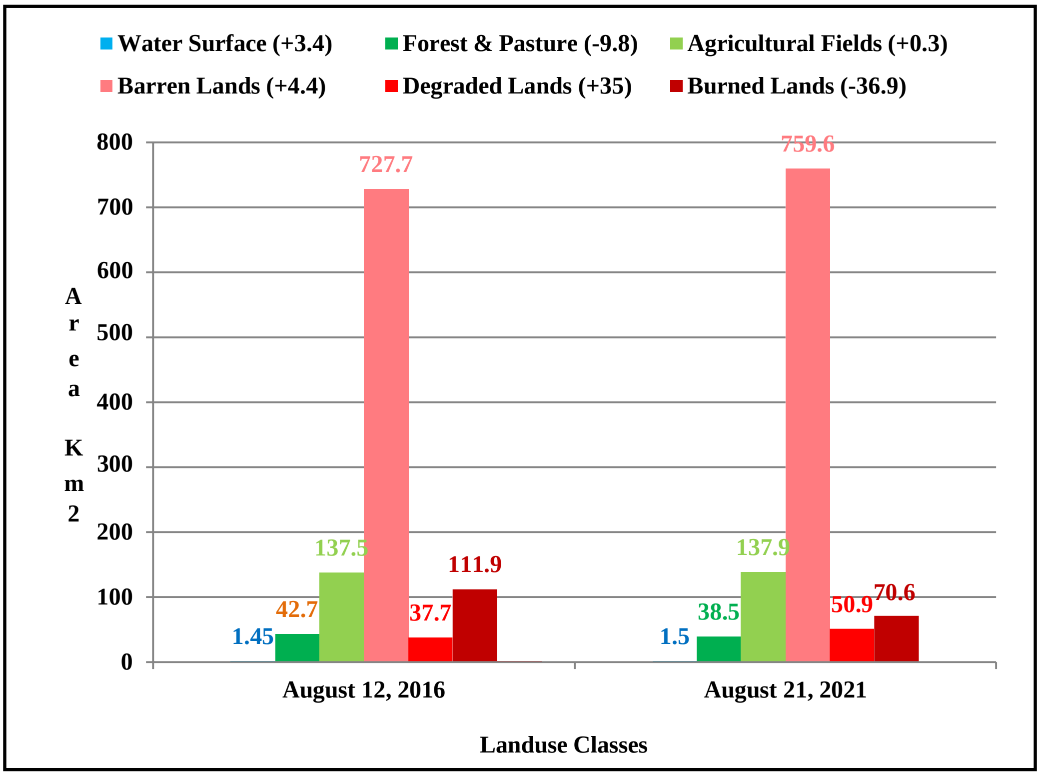

Fig. 6: Changes in the LU types in 2016 and 2021 adjusted to the Aghdam District. The values in parentheses (in %) indicate a decrease (-) or increase (+) concerning any of LU classes

DISCUSSION

During the long-term occupation stage, the fundamental driving force of LC/LU changes has been related to war activities such as the compulsory seizure of agricultural and livestock activities, along with the destruction of rare forests (IDMC, 2021). Moreover, we should consider the uncontrolled erosion of soil, pasture, and unique historical monument buildings destruction caused by unprincipled mining activities, multiple bomb- ings, and land-mine landings within the occupied territories (Hajiyeva, G. 2021). Eventually, the improper landuse and lack of proper care of human and natural re- sources led to widespread destruction and even extinction of many plants and wildlife species in the region (Baumann et al., 2013).

Thereafter, our main goal was to assess LC and LU changes inside the Aghdam District by applying OBIA DTI and rule based NNC methods respectively. Primary, to understand the extent of changes in basic LC types, we processed multi-temporal Sentinel-2 imagery (sampled for 2016 and 2021) and introduced a few rule-based indexes of NDWI, NDVI, NBRI and, AVBI consequences. It was found that alongside the study area, reduction of LC was accelerated during the recent years, and continuously green covers are being destroyed, particularly by degrading and burning procedures during the occupied periods (notice Fig. 3). With emphasis, vulnerable areas were defined in two states of burned and degraded lands that are areas that have lost a major degree of their natural productivity due to war-caused processes (Gibbs and Salmon, 2015). Other effective factors contributing to the rapid destruction of vegetation and soil loss include fires that are proposed by war behaviors and agricultural needs (Kust et al., 2017). Both destructive factors are influential in the process of LC/LU changes by properly using indicators, as were applied in the current study. Hence**,** DTI methods could be effective methods by enclosing the spectral, spatial, multitemporal, and multisensory information; and incorporation of ancillary data into indexing procedures (Mammadov and Rasouli, 2020).

Furthermore, the OBIA segmentation and NNC results (figures 5 and 6) indicated that the vegetation trend (particularly forests and pastures) is negative in the decreasing mode and the LU changes are signs all over the Karabakh Region (Hay and Castilla, 2006; Rasouli et al., 2021). As the result of the rule based NNC technique indicated the amount of burned lands in 2021 was much (36.9 %) lower than in 2016. This reduction can certainly be related to the recapturing of the occupied territories and the reduction of deliberate fires in the region. Nevertheless, accuracy assessment, with an overall accuracy of 0.95 and Kappa statistics with 93 %, was an integral part of the current study DTI and NNC procedure. Without doubts, uncertainty and error propagation in the modern image-processing chain is still an important factor influencing the final LU map's accuracy (Blaschke, 2010). Ultimately, identifying the weakest links in the chain and then reducing the uncertainties is critical to the improvement of digital image processing accuracy (Lobo and Chick, 1996). For future investigators, increasing the accuracy of the results of similar research field operations is a necessary profession.

CONCLUSION

The current introductory study's main goal was to map the LC/LU changes by the processing of satellite Sentinel-2 imagery inside the Aghdam District for the years 2016 and 2021. Considering so, the other objectives of this research were to evaluate the potential of the OBIA functions of DTI and rule based NNC methods inside the eCognition Developer setting. Based on these approaches, the following results were obtained:

- ✓ during the occupation period, LC and LC types have continuously been changed.
- ✓ LC and LU detection and mapping was a crucial task in previously occupied districts, by the processing of moderate resolution Sentinel-2A (10 m) images, in place of commercial satellite images, enable LU mapping with little to no cost.
- ✓ the OBIA methods could be regarded as a subdiscipline of geo-information science devoted to partitioning remote sensing imagery into meaningful image objects and assessing their characteristics through spatial, spectral, and temporal scales.
- ✓ although the OBIA is found to be a very advanced image processing procedure, nevertheless we think that it could be compared in future research along with quite professional programs as Support Vector Machine, and Machine-Learning / Deep-learning approaches to detect highly accurate LU changes with high confidence.
- ✓ by processing high-resolution imagery, we may carry out much more detailed information by expanding the study site to other liberated districts with an emphasis on the Karabakh Region to visualize the most likely reduction in green covers and associated damages that have been imposed on the country valuable ecological resources.
- ✓ a multi-platform and multi-purpose real-time monitoring system is almost immediately required if it is not yet too late. Such reclamation projects could be managed by Azeri-nation staff to do this critical nationwide advanced engagement.

REFERENCES

Aliyev I. (2021) President of Republic of Azerbaijan, 2021. İnzibati-ərazi vahidləri, Azərbaycan Respublikası Prezidentinin İşlər İdarəsi Prezident Kitabxanasi.

Baatz M., Schape A. (2000) Multi-resolution segmentation – an optimization approach for high quality multi-scale segmentation. In: J.Strobl et al. (eds.), *Angewandte Geographische Informations verarbeitung XII, Beiträgezum AGIT Symposium.* Salsburg, Karlruhe, Herbert Wichmann Verlag, p.12-23.

Baumann M., Volker C., Radeloff V., Avedian T. (2013) Land-use change in the Caucasus during and after the Nagorno-Karabakh conflict. *Reg. Environ Change*, **15:**170.

Blaschke T. (2010) Object-based image analysis for remote sensing. *ISPRS International Journal of Photogrammetry and Remote Sensing*, **65(1):** 2-16.

Conflict and Environment Observatory (2021) Report: Investigating the environmental dimensions of the 2020 Nagorno-Karabakh conflict Published: February 2021; Categories: Publications, Law and Policy.

Copernicus Sentinel-2 (2020) Satellite Missions – eoPortal Directory. Directory.eoportal.org. Retrieved 5 March.

Dozier J. (1989) Spectral signature of Alpine snow cover from LANDSAT Thematic Mapper. *Remote Sensing of Environment*, **45:** 9-22.

eCognition Reference Book (2019) eCognition Developer for Windows operating system, Version 9.5.1, Trimble. Munich, Germany.

eCognition Developer Software 10.1 (2021) Trimble Germany GmbH, Munich, Germany.

FAOSTAT (2014) Statistical database of the Food and Agricultural Organization. Available at: http://faostat.fao.org/.

Foody G.M. (2002) Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, **80(1):** 185-201.

Franklin S.E., Wulder M.A. (2002) Remote sensing methods in medium spatial resolution satellite data land cover classification of large areas. Progress in Physical Geography, 26, 173−205.

General Assembly Security Council (2009) Letter dated 30 September 2009 from the Permanent Representative of Azerbaijan to the United Nations addressed to the Secretary-General, Protracted conflicts in the GUAM area and their implications for international peace, security, and development. The situation in the occupied territories of Azerbaijan Security Council Sixty-fourth year.

Gibbs H.K., Salmon J.M. (2015) Mapping the world's degraded lands. *Applied Geography*, **57:** 12-21.

Hajiyeva, G. (2021). Teaching biology teaching methodology in higher pedagogical schools. Science, Education and Innovations in the Context of Modern Problems, Baku, Azerbaijan. **4 (2):** 273-279

Hay G.J., Castilla G. (2006) Object-based Image Analysis, Strengths, weaknesses, opportunities, and threats (SWOTs). From OBIA 2006. *International Archives of Photogrammetry, Remote sensing, and Spatial Information Sciences*.

Ikokou G., Smit J. (2013) A technique for optimal selection of segmentation scale parameters for object-oriented classification of urban scenes. *South Afr. J. Geomatica*, **2 (4)**:

International Displacement Monitoring Centre (IDMC) (2021) Nagorno-Karabakh conflict: finding common ground in respect of the dead, News and Press Release ICRC.

Kamusoko C. (2019) Remote Sensing Image Classification (Springer Geography) 1st ed., Publisher: Springer.

Kato L. (2020) Integrating Open-street map Data: in Object-Based Land-Cover and Land-Use Classification for Disaster Recovery, Publisher: LAP LAMBERT Academic Publishing, 76 p.

Khandelwal P., Singh K., Mehrotra A. (2014a) Unsupervised Change Detection from Satellite Images Using KCN, LAP LAMBERT Academic Publishing.

Khatami R., Mountrakis G., Stehman S.V. (2016) A meta-analysis of remote sensing research on supervised pixel-based land cover image classification processes: general guidelines for practitioners and future research. *Remote Sens. Environ.*, **177:** 89–100.

Kust G., Andreeva O., Cowie A. (2017) Land Degradation Neutrality: Concept development, practical applications and assessment. *Journal of Environmental Management*, **195:** 16-24.

Lillesand T., Kiefer R., Chipman J. (2004) Remote Sensing and Image Interpretation. 5th ed. John Wiley and Sons Inc, New Jersey.

Lobo A., Chick O.A., Casterad A. (1996) Classification of Mediterranean crops with multisensory data: Per-pixel versus per-object statistics and image segmentation, *Int. Journal of Remote Sensing*, **17 (12):** 2385-2400.

Nelson S., Khorram S. (2018) Image Processing and Data Analysis with ERDAS IMAGINE. 1st ed., Kindle Edition, CRC Press.

Pettorelli, N. (2013) The Normalized Difference Vegetation Index, 1st Edition, Kindle Edition, OUP Oxford.

Rasouli A.A., Mammadov R., Pishnamaz M., Hushmand A., Safarov E. (2018b) Assessment of Forest Cover Changes by Applying Object-Oriented Procedures inside the Karabakh Occupied Region. Eurasian GIS 2019 Congress 04-07 September 2018. Baku, Azerbaijan.

Rasouli A.A., Mammadov R., Safarov E., Mohammadzadeh K. (2018c) Fuzzy Object-Based Landcover/Use Mapping of The Karabagh Region by Processing of Sentinel Satellite Imageries. Eurasian GIS 2019 Congress 04-07 September 2018. Baku, Azerbaijan.

Rasouli A.A., Mammadov R. (2020a) Preliminary Satellite Image Analysis Inside the ArcGIS Setting, Lambert Academy Publishing, Germany.

Rasouli A.A., Mammadov G.SH., Asgarova M.M. (2021a) Mastering Spatial Data Analysis Inside the GIS Setting, Azerbaijan State Pedagogical University. Faculty of History and Geography, Baku.

Rasouli A.A., Mammadov R., Asgarova M.M. (2021b) Application of Satellite Image Processing Methods in Mapping of Landcover/Landuse Changes inside the Karabakh Liberated Territories. Azərbaycan Milli Elmlər Akademiyasi, AMEA-nın Biologiya və Tibb Elmləri Bölməsinin Konfransı.

Rehman S., Hussain M. (2018) Fuzzy C-means algorithm-based satellite image segmentation. *Indonesian Journal of Electrical Engineering and Computer Science*, **9(2):** 332–334.

Sayilan M.O. (2007) 1988–95 Arası dağlık Karabağ Sorunu, Karabakh conflict between 1988–1995. Master Project, Ankara University.

Scheffer M. (2010) Foreseeing tipping points. *Nature*, **467:** 411–412.

Sentinel Online (2018) Multispectral Instrument (MSI) Overview, European Space Agency. Retrieved 3 December 2018.

Sentinel-2 MSI User Guides (2020) Radiometric Resolutions Sentinel-2 MSI (2020) Sentinel Online. Sentinel.esa.int. Retrieved 5 March 2020.

Simone W.D., Musciano M.D., Cecco W.D., Ferella G., Frattaroli A.R. (2020) The potentiality of Sentinel-2 to assess the effect of fire events on Mediterranean mountain vegetation. *Plant Sociology*, **57:** 11-22.

Szantoi Z., Strobl P. (2019) Copernicus Sentinel-2 Calibration and Validation, European Journal of Remote Sensing, 52, Issue 1.

Thenkabail P.S., Lyon J.G., Huete A. (2018) Fundamentals, Sensor Systems, Spectral Libraries, and Data Mining for Vegetation (Hyperspectral Remote Sensing of Vegetation). 2nd ed., CRC Press.

Valigholizadeh A., Karimi M. (2016) Geographical explanation of the factors disputed in the Karabakh geopolitical crisis, *Journal of Eurasian Studies*, **7:** 172–180.

Qarabağ iqtisadi rayonu torpaq örtüyü və torpaqdan istifadədəki dəyişikliklərin Ağdam rayonu daxilində peyk şəkillərinin obyekt yönümlü təhlili əsasında xəritələşdirilməsi

A.A. Rəsuli[1], M.M. Əsgərova[2], S.H. Səfərov[3]

[1]*Makkuari Universitetinin Ətraf Mühit Elmləri Departamenti, Sidney, Avstraliya*
[2]*Azərbaycan Dövlət Pedaqoji Universitetinin Tarix-coğrafiya fakültəsi, Bakı, Azərbaycan*
[3]*AMEA-nın Coğrafiya İnstitutu, Bakı, Azərbaycan*

Erməni silahlı birləşmələri tərəfindən Qarabağın və ona bitişik ərazilərin 30 illik işğalının ekoloji nəticələrinin araşdırılması və müəyyən edilməsi vacib və təxirəsalınmaz vəzifələrdən biridir. Ağdam rayonu daxilində erməni işğalından azad edilmiş ərazilərdə torpaq örtüyünün və torpaqdan istifadənin (LC/LU) vəziyyətini və ehtimal edilən dəyişiklikləri öyrənmək üçün obyekt yönümlü görüntü analizi (OBIA) prosedurları tətbiq edilmişdir. Əvvəlcə, bir neçə spektral indekslərdən istifadə etməklə - NDWI, NDVI, NBRI və AVBI, torpaq örtüyünü (LC) əks etdirmək üçün dinamik fərq indeksinin (DTI) alqoritmləri tətbiq edilmişdır. Sonra, tədqiqat sahəsi daxilində dəqiq torpaqdan istifadə dəyişikliklərini müəyyən etmək üçün Trimble eCognition platformasında təkmilləşdirilmiş nəzarət siniflәndirmə metodu olan ən yaxın qonşu təsnifatı (NNC) metodundan istifadə edilmişdir (eCognition Developer, 2019).

Dinamik həddlərin indeksləşdirilməsi (DTI) alqoritmlərinin istifadəsi göstərdi ki, 2016-2021-ci illərdə Ağdam rayonu daxilində torpaq örtüyündə (LC) olduqca əhəmiyyətli dəyişikliklər baş vermişdir, bitki örtüyünün əhəmiyyətli dərəcədə azalmış (10,2%), bir hissəsi tamamilə məhv olmuş (11,8%), həssas torpaqlarda olduqca nəzərə çarpan dəyişikliklər (26,8%) meydana çıxmışdır. Ən yaxın qonşu klassifikasiya metodu (NNC) əsasında bir neçə torpaq istifadəsi dəyişiklikləri aşkar edilib: meşə və otlaq sahələrinin 9,8% azalmış, deqradasiya olunmuş torpaq sahələri 35%-ə qədər, qeyri-münbit torpaq sahələri 4,4%-ə qədər artmışdır və bu proses davam etməkdədir. Qeyd edək ki, su səthinin və kənd təsərrüfatı torpaqlarından istifadədə (LU) dəyişikliklər daha az müşahidə olunmuş və müvafiq olaraq 3,4% və 0,3% təşkil etmişdir. Ümumi dəqiqliyin 0,95 və Kappa əmsalının 93% olması torpaq örtüyü və torpaqdan istifadənin (LC/LU) vəziyyətində baş vermiş dəyişikliklərin statistik əhəmiyyətli olduğunu təsdiq edir. Beləliklə, səlahiyyətli hökümət nümayəndələrinin bərpa və layihə işlərinə başlamaq haqqında qərar verməsindən əvvəl, Azərbaycanın azad edilmiş rayonlarının hazırkı vəziyyətinin hərtərəfli analizi və xəritələşdirilməsi coğrafiyaçıların, ekoloqların və uzaqdan alqılama mütəxəssislərinin ən təxirəsalınmaz vəzifələrinə çevrilməlidir.

Açar sözlər: *Ağdam rayonu, Qarabağ, torpaq örtüyü və torpaqdan istifadənin dəyişməsi (LC/LU), Sentinel-2 şəkilləri, OBIA əsasında dinamik və həddi indeksləşdirmə, ən yaxın qonşu təsnifatı (NNC)*

Картирование изменений земельного покрова и землепользования в Карабахском экономическом районе на основе объектно-ориентированного анализа спутниковых снимков в пределах Агдамского района

А.А. Расули[1], М.М. Асгарова[2], С.Г. Сафаров[3]

[1]*Департамент наук об окружающей среде Университета Маккуори, Сидней, Австралия*
[2]*Факультет истории и географии Азербайджанского государственного педагогического университета, Баку, Азербайджан*
[3]*Институт географии НАН Азербайджана, Баку, Азербайджан*

Исследование и выявление экологических последствий 30-летней оккупации Карабаха и прилегающих к нему территорий армянскими вооруженными формированиями, является одним из важных и актуальных задач. Для изучения состояния и вероятных изменений земельного покрова и землепользования (LC/LU) на освобождённых от армянской оккупации территориях Карабаха в пределах Агдамского района были использованы процедуры объектно-ориентированного анализа изображений (OBIA). Сначала были применены алгоритмы динамической индексации пороговых значений (DTI) для отображения земельного покрова (LC) путём разработки нескольких спектральных индексов NDWI, NDVI, NBRI и AVBI. Затем, с целью выявления точных изменений землепользования внутри исследуемой области, был использован усовершенствованный контролируемый метод классификации в рамках настройки Trimble eCognition - метод классификации ближайшего соседа (NNC) (eCognition Developer, 2019). Результаты динамической индексации пороговых значений (DTI) показали, что с 2016 по 2021 годы внутри Агдамского района произошли существенные изменения земельного покрова (LC), значительное уменьшение растительного покрова (10,2%), увеличение невегетативной зоны (11,8%) и появление довольно заметных изменений на ранее оккупированных землях (26,8%). Впоследствии, методом классификации ближайшего соседа (NNC) были обнаружены различные отрицательные изменения землепользования внутри исследуемой области - сокращение лесов и пастбищ на 9,8%, увеличение площади деградированных земель до 35% и бесплодных земель до 4,4%. Следует отметить, что минимальные изменения наблюдались для водной поверхности и сельскохозяйственного землепользования (LU) до 3,4% и 0,3%, соответственно. Значения общей точности 0,95 и коэффициента Каппа 0,93 подтвердили статистическую значимость изменений состояния земельного покрова и землепользования (LC/LU). Следовательно, точная обработка изображений и картирование текущего положения освобожденных районов Азербайджана должны стать наиболее актуальными задачами ученых географов, экологов и специалистов по дистанционному зондированию до того, как лица, принимающие решения в правительстве, приступят к проектам реконструкции и реабилитации.

Ключевые слова: *Агдамский район, Карабах, изменения земельного покрова и землепользования (LC/LU), снимки Sentinel-2, динамическая и пороговая индексация на основе OBIA, контролируемая классификация* ближайшего соседа *(NNC)*