EXTENSION OF COPERNICUS URBAN ATLAS TO NON-EUROPEAN COUNTRIES

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ABSTRACT

One of the parts of the Land Monitoring Service is Copernicus Urban Atlas, which provides reliable and comparable land use maps with high accuracy for large number European functional urban areas and their neighbors for every 6 years (2006, 2012, 2018). Unfortunately, there is no available such products for Ukrainian cities and there is no possibility to reproduce the technology by which they are obtained. This is due to the unavailability of sufficient high resolution satellite data information at the cities level, which is an integral part of the European methodology for obtaining the Urban Atlas. That is why we have proposed new approach on the base of open data which can be applicable to any other city. Kyiv (Ukraine) became the first city outside the Europe, for which the methodology by creating Urban Atlas was developed, which is compliant in structure and functionality to the European Copernicus Urban Atlas. The methodology was scaled for Lviv City, as well as applied and tested for other cities, in particular for Rivne, Irpin (Ukraine) and Lublin (Poland). In addition to the main management tasks that the Urban Atlas helps to solve, the obtained products can be used to unify and air quality monitoring in cities, and as a base for assessing the sustainable development goals indicator 11.6.2 "Annual mean levels of fine particulate matter in cities".

***Index Terms*—** Urban Atlas, neighboring countries, satellite monitoring, air quality monitoring

1. INTRODUCTION

The Copernicus Urban Atlas is part of the local component of the Land Monitoring Service, which provides reliable, highly comparable, highly spatial land use maps for more than 300 large urban areas and their environs as of 2006 in the Europe and for 800 functional urban areas and their neighborhoods as of 2012 and 2018 [1]. The Copernicus Urban Atlas was created by the French company Systèmes d'Information à Référence Spatiale (SIRS) [2]. The Urban Atlas is a tool for the land use comparing of the largest European cities. It uses satellite imagery to create reliable and comparable maps of urban areas with high spatial resolution (5 meters and above). High spatial resolution allows to solve a wide range of additional analysis problems, such as analyzing the density of greenery or buildings in the area of interest. Also, the Urban Atlas gives a much more accurate picture of urban growth on the outskirts of urban areas, provides data for analysis related to transport, land use and the environment. In particular, the building density analysis and forecasting, green areas of urban areas and temperature map is an indirect method of assessing air quality in different parts of the city.

It should be noted that Urban Atlas is not provided for the cities of Ukraine, so there is a need to develop technology for its production with taking into account the available free geospatial data, and especially satellite imagery, and scaling it to as many cities as possible. The Urban Atlas is an integral part of solving problems related to air quality monitoring in cities - to clearly visualize the air pollutants dissemination by quarter for the city and to be able to analyze the air quality for particular quarter of the city in time.

2. DATA

2.1. Satellite data

The time series of SAR Sentinel-1 acquired from 01-04-2020 to 15-09-2020 and clear of clouds images of optical Sentinel-2 satellite data were used for land cover classification map for Kyiv and Lviv cities in 2020. In particular, in 2020 were 12 images of Sentinel-2, and 14 images of Sentinel-1 for Kyiv city and 9 images of Sentinel-2 and 14 images of Sentinel-1, which are presented in the Table 1.

The following data pre-processing steps should be performed:

a. For SAR Sentinel-1 data - apply orbit file, border noise removal, thermal noise removal, radiometric calibration, orthorectification, filtration (Refined Lee method with 3x3 window), Range-Doppler Terrain Correction procedure using digital task terrain (SRTM 90 m), and save the results in GeoTIFF format.
b. For optical Sentinel-2 data - atmospheric correction, cloud masking, and saving results in GeoTIFF format. Processing and analysis of satellite data are performed in the Sentinel Application Platform (SNAP) [4].

Table 1. Satellite images for Kyiv and Lviv cities in 2020

	Dates of images (2020)	
	Sentinel-1	Sentinel-2
Kyiv	03.04, 15.04, 27.04, 09.05, 21.05, 02.06, 14.06, 26.06, 08.07, 20.07, 01.08, 13.08, 25.08, 06.09	02.04, 07.04, 12.04, 11.06, 26.06, 11.07, 29.07, 05.08, 30.08, 07.09, 12.09, 14.09
Lviv	12.04, 24.04, 06.05, 18.05, 30.05, 11.06, 23.06, 05.07, 17.07, 29.07, 10.08, 22.08, 03.09, 15.09	16.04, 18.04, 11.05, 12.06, 10.07, 06.08, 16.08, 10.09, 15.09

All satellite data were used for land cover classification in the cities based on technology developed and improved by the Space Research Institute NASU-SSAU [5].

2.2. Train and test data

To solve classification task, training and test data were generated from photointerpretation using optical Sentinel-2 data. The training samples were used to train the neural network model and create the land cover map. The test samples were used to determine the reliability of the obtained result. The collected training and test data are stored as polygons in the vector format. The test and training data contain five classes, which are presented in Table 2.

Table 2. Train and test data distribution for Kyiv and Lviv cities in 2020

	Kyiv		**Lviv**	
	Train	**Test**	**Train**	**Test**
Artificial	35	34	37	36
Low greenery	75	74	86	85
High greenery	32	33	34	35
Water bodies	13	14	8	9
Other lands	23	22	19	20
Total	178	177	184	185

2.3. Auxiliary data

As additional data sets, we used the Humanitarian Data Exchange (HDX) [6] for city boundaries identification and Open Street map (OSM) [7] data for products creation.

3. METHODOLOGY

The following steps are essential for Urban Atlas creation compliant to Copernicus Urban Atlas. First of all, it is the collection and pre-processing of satellite and geospatial data, which are described in paragraphs 2.1 and 2.2. The next step is land cover map creation by classifying satellite data using the collected training data. The classifier's inputs are pre-processed satellite data and formed training samples. The classification approach was developed and validated within different international projects by scientists in Space Research Institute NASU-SSAU [8] The deep learning classification approach was applied to time series satellite data which has established itself well in research of land cover mapping [9]. The proposed methodology provides a large-scale classification of land cover: artificial objects, high and low greenery, water bodies and other lands. Also, algorithms for classification maps filtering, which increases the accuracy of the product were developed [10].

The quality of the classification map is checked on test data using confusion matrix creation. In this case, each of the classes has the following estimates: user accuracy, producer accuracy and F1-score accuracy, as well as the Kappa coefficient - a statistical measure of the consistency between the obtained classes on the land cover map and the classes that are real (test data) [11].

The open data from Open Street Map were used to create a vector layer with city quarters, which were improved, detailed and corrected by editing them in GIS systems and other open systems, such as Google Earth. Once you have made city quarters, you can use them for other years by rewriting the class for a particular quarter. This scheme will be useful if OSM data is no longer updated or no longer available. As of now, OSM data are available throughout Ukraine.

The next stage of data processing involves the determining procedure of building and landscaping percentage for each of the city's quarter. To do this, the land use map and vector layer with city's quarters were used which were obtained in previous stages.

The next formula was used to determine the filling percentage of each quarter with a certain class of land cover:

$$\forall k = \overline{1,QN}, n = \overline{1,CN}: \; P_n^k = \frac{\sum_{i,j}\{\overline{p_{ij}} | \overline{p_{ij}} = n \wedge p_{ij} \in Q_k\}}{n \cdot \sum_{i,j}\{p_{ij} | p_{ij} \in Q_k\}} \cdot 100,$$

where QN – number of quarters; CN – the number of classes of land cover map obtained as a result of deep learning approach (in our case, 5 classes - artificial objects, water bodies, high and low greenery and other lands), P_n^k – the percentage of occupancy class n quarter k; p_{ij} – a pixel at the intersection of the i-th row and the j-th column; $\overline{p_{ij}}$ – the class value in the pixel at the intersection of the i-th row and the j-th column; Q_k – the set of all pixels in the k-th quarter.

According to this formula for the land cover class "artificial objects", the percentage of buildings in each of the city's quarters was calculated. According to the accepted classes in the European compliant Urban Atlas, and according to a certain percentage of buildings, we refer the quarter to one of 5 classes 11100 Continuous Urban fabric (S.L. > 80%); 11210 Discontinuous Dense Urban Fabric (S.L. 50 - 80%); 11220 Discontinuous Medium Density Urban Fabric (S.L. 30 - 50%); 11230 Discontinuous Low Density Urban Fabric (S.L. 10 - 30%); or 11240 Discontinuous very low-density urban fabric (S.L. < 10%). Similar operations occur for other types of land cover with a threshold of 60%. Combining the class of high and low greenery in one class and using the same formula we get the percentage of landscaping for each of the selected quarter of the city.

4. RESULTS

According to the developed methodology, land cover maps were created that are compatible with the Copernicus Urban Atlas product, which contains information only for 2006 and 2012. The advantage of the proposed Urban Atlas creation technology is the free satellite data use with high frequency of shooting. This allows to create new products annually and monitor major changes in the city, taking into account environmental aspects.

Fig. 1 shows the land cover classification maps for 2020 for Kyiv and Lviv cities based on the deep learning technology developed and improved by the authors.

The maximum spatial resolution that can be used for Ukrainian cities is 10 meters since only free satellite data is used in the research. Some European products have a higher spatial resolution, but a 10-meter resolution is enough to monitor cities, as well as to form high-quality geospatial products based on them, including the urban atlas and air quality analysis based on it. The overall accuracy of the obtained land cover maps for both cities exceeds 95%.

Within the project H2020 ERA-PLANET SMURBS (SMart URBan Solutions for air quality, disasters and city growth) the authors began to develop a methodology for Urban Atlas creation for the Kyiv city, which is compliant in structure, functionality and nomenclature to the European Copernicus Urban Atlas [12]. The Lviv city is another city in Ukraine, which is fully scalable developed methodology. Within the project «Geospatial models and information technologies of satellite monitoring of smart city problems», with the grant support of National Research Foundation of Ukraine from the state budget the developed methodology of Urban Atlas creation has been improved and scaled to other cities in Ukraine. Based on the land cover maps and open geospatial data for Kyiv and Lviv cities, a segmentation of these cities was created and Urban Atlases for them were obtained according to the proposed methodology. The result is presented on the Fig. 2.

5. CONCLUSIONS

The proposed technology of creating products for neighboring countries, which is compliant and consistent with the European Urban Atlas, has significant advantages over existing ones. Also, the Urban Atlas opportunities includes air quality monitoring within the city quarters [13]. The analysis of existing technologies shows that such a service is still inapplicable for the cities of Ukraine, as the necessary data are also missing. The European compliant Urban Atlas can be used as a base for assessing the sustainable development goals indicator 11.6.2 "Annual mean levels of fine particulate matter (e.g., PM2.5 and PM10) in cities (population weighted)" for the territory of Ukraine and other cities. Also, classification maps make it possible to monitor not only air quality, but also other ecosystems, in particular water bodies [14], as well as the consequences of certain natural disasters, including floods [15].

The pilot version of Urban Atlas for Kyiv based on the open geospatial data from other open sources was created within the SMURBS project, and also implemented in the public organization Kyiv Smart City for the Kyiv and Lviv City State Administration and Professional Association of Ecologists of Ukraine. The methodology is fully scalable and validated for the pilot city of Lviv, as well as for the cities of Rivne, Irpin and Lublin. The results for all cities show high accuracy - more than 95%.

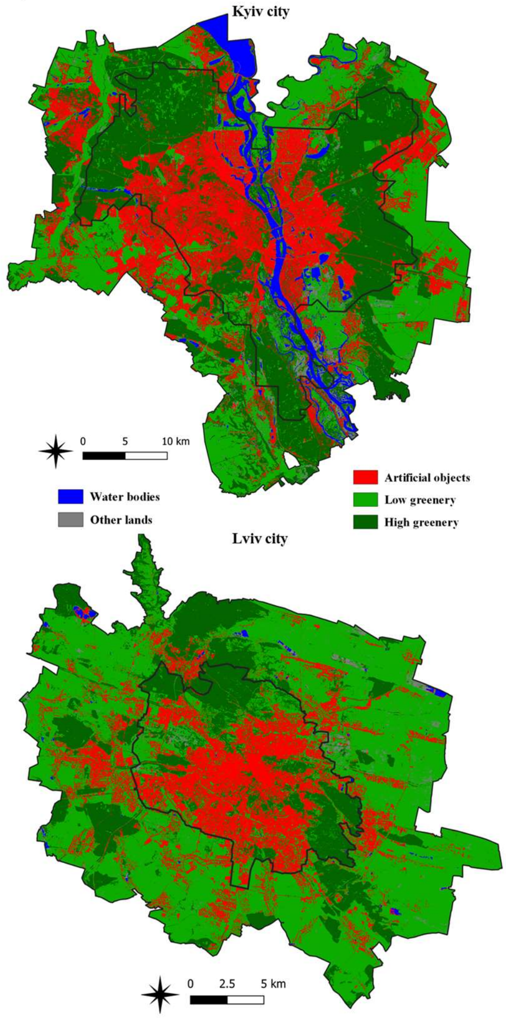

Fig. 1. Land cover maps for Kyiv and Lviv cities for Urban Atlas creation in 2020.

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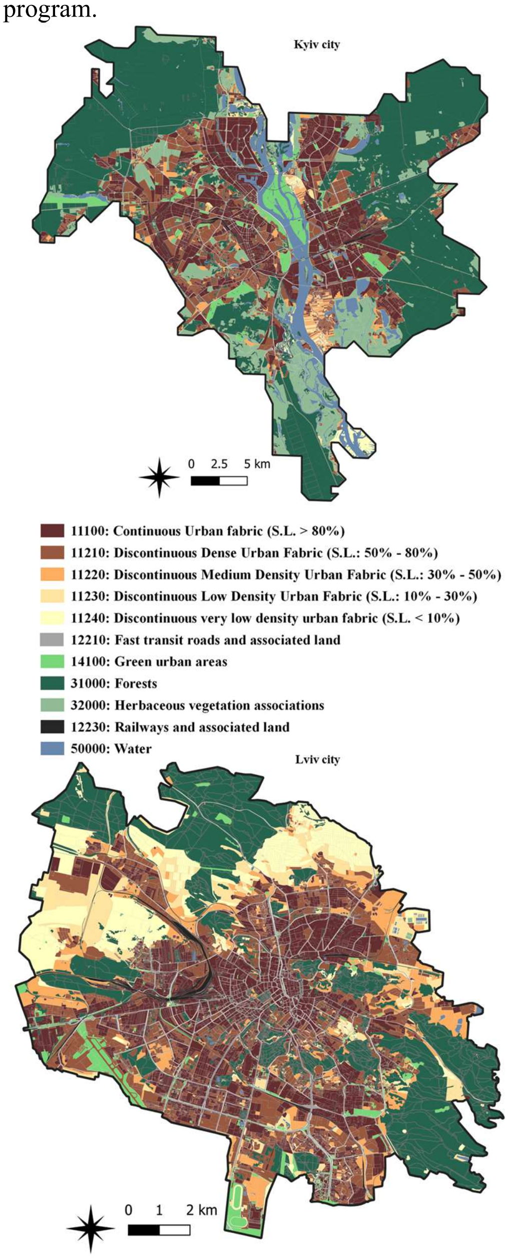

Fig. 2. Copernicus compliant Urban Atlases for Kyiv and Lviv cities in 2020 (based on the open-source satellite and geospatial data)

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