FRAMEWORK PARTNERSHIP AGREEMENT ON COPERNICUS USER UPTAKE

Action 2019-3-27: Development of downstream applications supporting Sectoral Information system under Copernicus Climate Change Service

Pilot Activity Summary Report

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The project is supported by the European Union's Caroline Herschel Framework Partnership Agreement on Copernicus User Uptake under grant agreement No FPA 275/G/GRO/COPE/17/10042, project FPCUP (Framework Partnership Agreement on Copernicus User Uptake), Action No.: 2019-3-27 "Development of Downstream Applications Supporting Sectoral Information System under Copernicus Climate Change Service"
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1 Introduction

Land cover change, a fundamental component of global environmental dynamics, holds immense significance in understanding and managing the Earth's ecosystems. It encompasses the transformation of natural and semi-natural land surfaces due to natural processes and human activities. The accurate monitoring of land cover changes is crucial for numerous reasons, including the assessment of environmental impacts, the preservation of biodiversity, the management of natural resources, and the formulation of effective land use policies. Satellite-based monitoring, particularly through the Copernicus program and the utilization of Sentinel-1 and Sentinel-2 satellites, has emerged as a vital tool in comprehensively analyzing and monitoring land cover changes across various spatial scales and temporal resolutions. By harnessing the capabilities of satellite observations, scientists, policymakers, and land managers can gain valuable insights into the dynamics of land cover changes, allowing for informed decision-making and proactive environmental stewardship. Furthermore, initiatives like the Corine Land Cover program enhance the integration of satellite data, facilitating standardized land cover mapping and contributing to international efforts in preserving our planet's ecological integrity.

This approach aims to assess land use change using the Copernicus framework and satellite data. The Copernicus Climate Change Services and Copernicus Land Monitoring Service offer valuable land cover change products that enable the evaluation of land use changes over time. Additionally, the proposed application incorporates higher-resolution satellite inputs, such as Sentinel-1 SAR GR and Sentinel-2 MSI Level-1C and Level-2A, to provide enhanced spatial and temporal resolutions for the analysis. The period of interest spans from 2015 to 2021, with a yearly temporal resolution.

The Copernicus Climate Change Services offer a global land cover classification gridded map based on the United Nations Food and Agriculture Organization's Land Cover Classification System (LCCS). This dataset provides land cover information at a resolution of 300 m and covers the period from 1992 to 2020 on a yearly basis. The global coverage allows for a comprehensive understanding of land cover changes worldwide. The Copernicus Land Monitoring Service provides two distinct land cover change products:

- The Copernicus Global Land Service (CGLS) Dynamic Land Cover map offers a 100 m resolution dataset that depicts land cover changes globally. This product covers the period from 2015 to 2019, with yearly updates. The higher spatial resolution compared to the global land cover classification gridded map allows for a more detailed analysis of land cover changes.
- The CORINE Land Cover (CLC) vector inventory focuses on the pan-European region. Produced in 2000, 2006, 2012, and 2018, this dataset provides comprehensive land cover information for Europe. The spatial resolution of the CLC vector inventory is dependent on the region and offers valuable insights into land use changes in Europe.

To enhance the analysis of land use change, the proposed application incorporates the use of Sentinel-1 SAR GR and Sentinel-2 MSI Level-1C and Level-2A satellite data. These data sources provide a spatial resolution of 10 m, enabling a more detailed assessment of land cover changes.

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The temporal resolution remains yearly, covering the period from 2015 to 2021. By utilizing these higher-resolution satellite inputs, the application aims to provide a novel approach to evaluating land use change, capturing fine-scale details and enabling more accurate analysis. The Copernicus framework, along with the available land cover change products, offers valuable resources for assessing land use changes. The combination of global and pan-European datasets from the Copernicus Climate Change Services and Copernicus Land Monitoring Service, respectively, provides comprehensive coverage. Furthermore, the proposed application enhances the analysis by incorporating higher-resolution satellite data, allowing for a more detailed evaluation of land use change. This report sets the foundation for conducting a comprehensive land use change analysis, which can have significant implications for understanding and managing land resources effectively.

2 Consultation with Users

Monitoring land cover change is of significant importance in Poland for several reasons. Firstly, understanding land cover change helps in assessing the environmental health and ecological balance of the country. It provides insights into the impacts of human activities, such as urbanization, deforestation, and agricultural expansion, on natural ecosystems. By monitoring land cover change, policymakers and researchers can identify areas that require conservation efforts, restoration projects, or improved land management practices. Secondly, land cover change analysis plays a crucial role in evaluating the effectiveness of environmental policies and regulations. It allows policymakers to assess whether the implemented measures are achieving the desired outcomes in terms of land use sustainability, biodiversity conservation, and ecosystem protection. By identifying areas where land cover change is occurring rapidly or in an unsustainable manner, policymakers can take corrective actions and make informed decisions to promote sustainable land use practices. Moreover, monitoring land cover change helps in assessing the vulnerability and resilience of ecosystems to climate change. As climate patterns shift, land cover changes can influence local and regional climate conditions, including temperature, rainfall patterns, and wind patterns. By analyzing land cover change data, scientists can better understand the interactions between land cover, climate, and ecosystem dynamics, enabling more accurate climate modeling and prediction. In the context of our pilot efforts, it is crucial to investigate the requirements of end users in Poland. By engaging with stakeholders and soliciting their opinions, we can better understand their perspectives on existing methods and services related to land cover change monitoring. This information allows us to tailor our planning and service provision suggestions to address their specific needs effectively. To initiate this process, we gathered input from users through a comprehensive consultation. Table 1 presents the complete list of users who expressed their interest in participating and contributing to this consultation. This valuable feedback from a diverse range of stakeholders will guide us in developing a robust and user-centric approach to land cover change monitoring in Poland.

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Table 1 List of Users taking part in the consultation

No	Institution	Institution profile	Number of Users
1	DANKO Sp. z o.o.	Private company	15
2	Regionalna Dyrekcja Lasów Państwowych w Poznaniu	Government institution	5
3	Urząd Statystyczny w Poznaniu, Ośrodek Statystyki Małych Obszarów	Government institution	5
4	Białowieska Stacja Geobotaniczna (BSG) Wydziału Biologii Uniwersytetu Warszawskiego	Academic institution	3
5	Główny Urząd Statystyczny, Departament Badań Społecznych	Government institution	5
6	Urząd Marszałkowski woj. wielkopolskiego, Departament Korzystania i Informacji o Środowisku	Government institution	5
7	Zarząd Geodezji i Katastru Miejskiego GEOPOZ, Poznań	Government institution	2
8	Fundacja Instytut na rzecz Ekorozwoju	NGO	3
9	Stowarzyszenie Miasto jest Nasze	NGO	3
10	Instytut Geografii i Przestrzennego Zagospodarowania Polska Akademia Nauk	Academic institution	8
		Total:	54

In order to comprehensively understand the specific needs and preferences of our end users, we proceeded with the administration of questionnaires using the Google Forms platform. This approach aimed to gather a wide range of opinions and experiences, facilitating the development of a service that would be most beneficial to our target audience. The questionnaire round yielded insightful results. Among the respondents, a significant 70% indicated their preference for downloading and processing satellite data independently. This finding highlights the users' proficiency and self-sufficiency in handling such data. Furthermore, an impressive 90% of the respondents expressed a keen interest in utilizing land cover data and detecting changes in land cover. This strong desire to leverage these datasets underscores the value they hold for addressing the users' specific requirements. Regarding the tools employed for analysis, respondents indicated a preference for widely used programs such as QGIS, ArcGIS, and Google Earth Engine. These software platforms enable effective analysis and visualization of geospatial data, further emphasizing the respondents' proficiency in spatial analysis techniques. Building upon these findings, our pilot proposes a service that will offer an extensive spatial analysis of land cover changes. By harnessing the power of advanced geospatial techniques, this service aims to provide end users with comprehensive insights into the dynamic transformations occurring in land cover. Through our proposed service, users will gain a broader understanding of land cover changes, empowering them with the information necessary to make informed decisions and take appropriate actions. In summary, the questionnaire round has proven invaluable in informing the development of our pilot service. The high level of user involvement and interest in land cover data and change detection reaffirms the importance and relevance of our efforts. By delivering a comprehensive spatial analysis of land cover changes, we aspire to meet the needs and expectations of our end users effectively.

3 Proposed Services

In this report, an innovative land cover change monitoring application is introduced, focusing on the comprehensive analysis of land cover transformations within diverse geographical regions. The application has been developed with the aim of passively defining and monitoring five distinct classes of land cover changes (Figure 1). These classes include "no change," which represents areas where land cover remains stable over time. "Retained/reclassified" denotes regions where land cover experiences minor adjustments, such as reclassifications of land use categories without significant alterations. "Deurbanisation" highlights areas where urban developments undergo a reversal, returning to natural or rural landscapes. "Afforestation" pertains to regions where the process of tree planting and the establishment of new forests occur. "Urbanization" signifies the expansion and intensification of urban areas, leading to the transformation of natural or agricultural landscapes into built environments. Lastly, "natural to agricultural areas" denotes the conversion of natural habitats or non-agricultural land to agricultural land use. The passive categorization of these classes in the application facilitates the comprehensive monitoring and analysis of land cover changes, empowering researchers, policymakers, and environmental practitioners with valuable insights to make informed decisions and develop effective strategies for sustainable land management and conservation efforts.

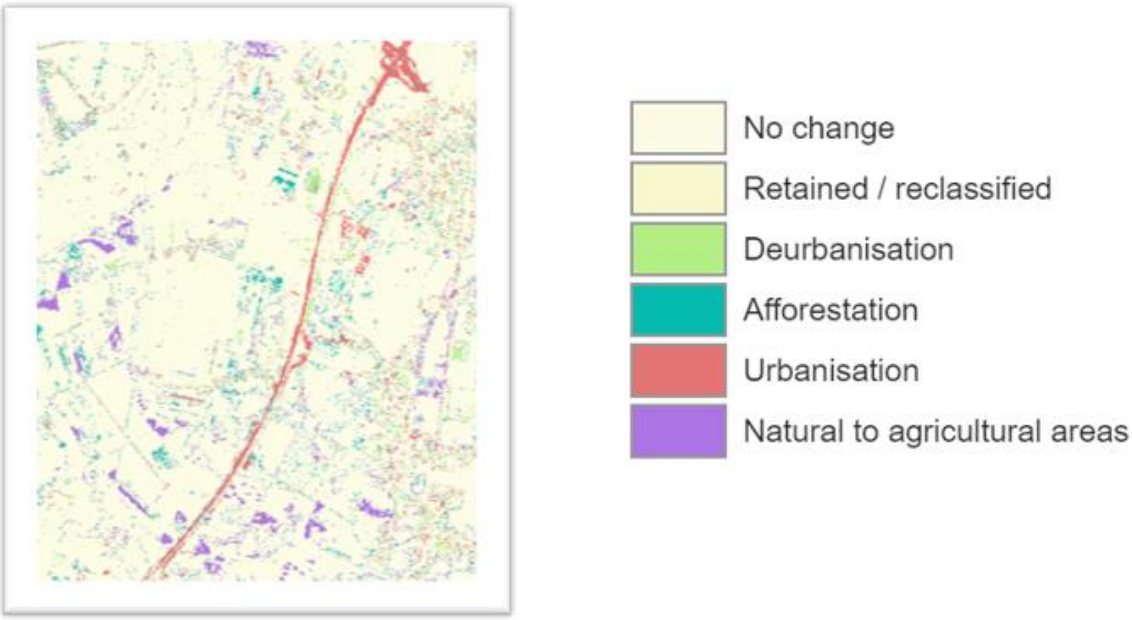

Figure 1. Defined land cover change classes.

The primary objective of this cutting-edge land cover monitoring application revolves around leveraging the power of machine learning algorithms to accurately classify land cover for two user-defined years. By harnessing the potential of advanced machine learning techniques, the application can effectively analyze satellite imagery and remotely sensed data to categorize the land cover into various classes based on the specified time frames. Subsequently, the application diligently compares the land cover classifications for these two chosen years, enabling the

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identification and quantification of the changes that have occurred within the study area. Through this comprehensive analysis, the application provides valuable insights into the spatial distribution and extent of land cover changes, allowing users to determine the exact areas and proportions of each class affected by alterations over time. This information empowers researchers, policymakers, and land managers to grasp the magnitude and significance of land cover transformations within their regions of interest accurately. By harnessing machine learning algorithms, the application significantly streamlines the laborious and time-consuming process of land cover analysis, enabling a more efficient and accurate assessment of changes. This powerful tool facilitates the identification of shifts in land use patterns, such as conversions from natural habitats to agricultural fields, urban sprawl, or afforestation efforts. Moreover, it enables the detection of areas that have remained unchanged or experienced minimal modifications, providing a holistic understanding of the overall land cover dynamics.

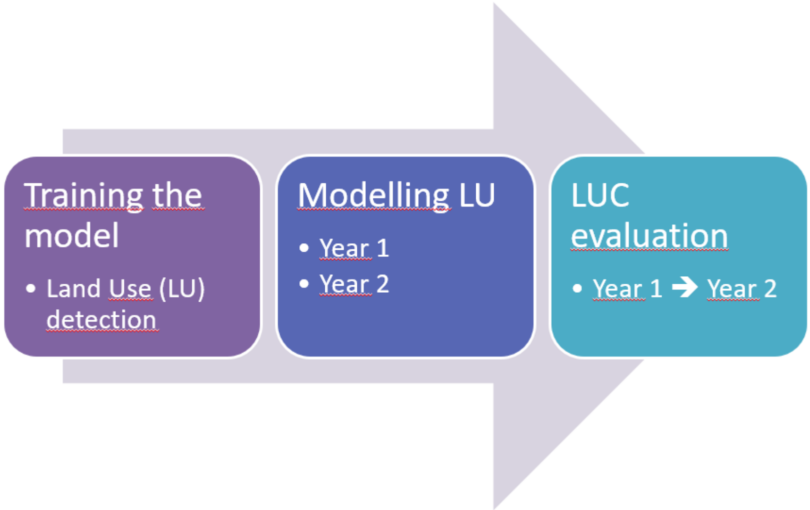

Figure 2. Application schema: main workflow.

The various steps involved in creating an automatic detection system for land cover changes will be discussed. These steps encompass the utilization of Sentinel-1 radar data, Sentinel-2 optical data, and advanced machine learning algorithms, allowing for precise and efficient detection of alterations in land cover (Figure 3). Firstly, a user-defined area serves as the basis for generating randomly distributed points extracted from Corine Land Cover data. These points constitute the dataset used for subsequent land cover classification. To achieve accurate classification, a combination of satellite imagery is employed, including Sentinel-1 radar data and Sentinel-2 optical data (level-2A and level-1C). Next, for the specified user-defined years, satellite imagery of Sentinel-1 and Sentinel-2 is acquired and processed to create multi-temporal compositions. These compositions are derived from the median values of the corresponding satellite imagery, enabling a robust analysis of land cover changes over time. The point dataset is subsequently partitioned into training (80%) and validation (20%) subsets, preparing the data for the training of the Random Forest (RF) algorithm. The RF algorithm is trained using the training subset, and its accuracy is rigorously assessed using the overall accuracy metric. Once the RF algorithm is trained and validated, it is utilized to classify Sentinel-1, Sentinel-2, and fused Sentinel-1 and Sentinel-2 data, based on the availability of the datasets. This classification process is carried out for each of the user-defined years. Finally, an automatic algorithm is employed

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to compare the classified maps of land cover for the user-defined years. This algorithm facilitates the creation of detailed land cover change maps and enables the calculation of essential statistics and prediction accuracy measures.

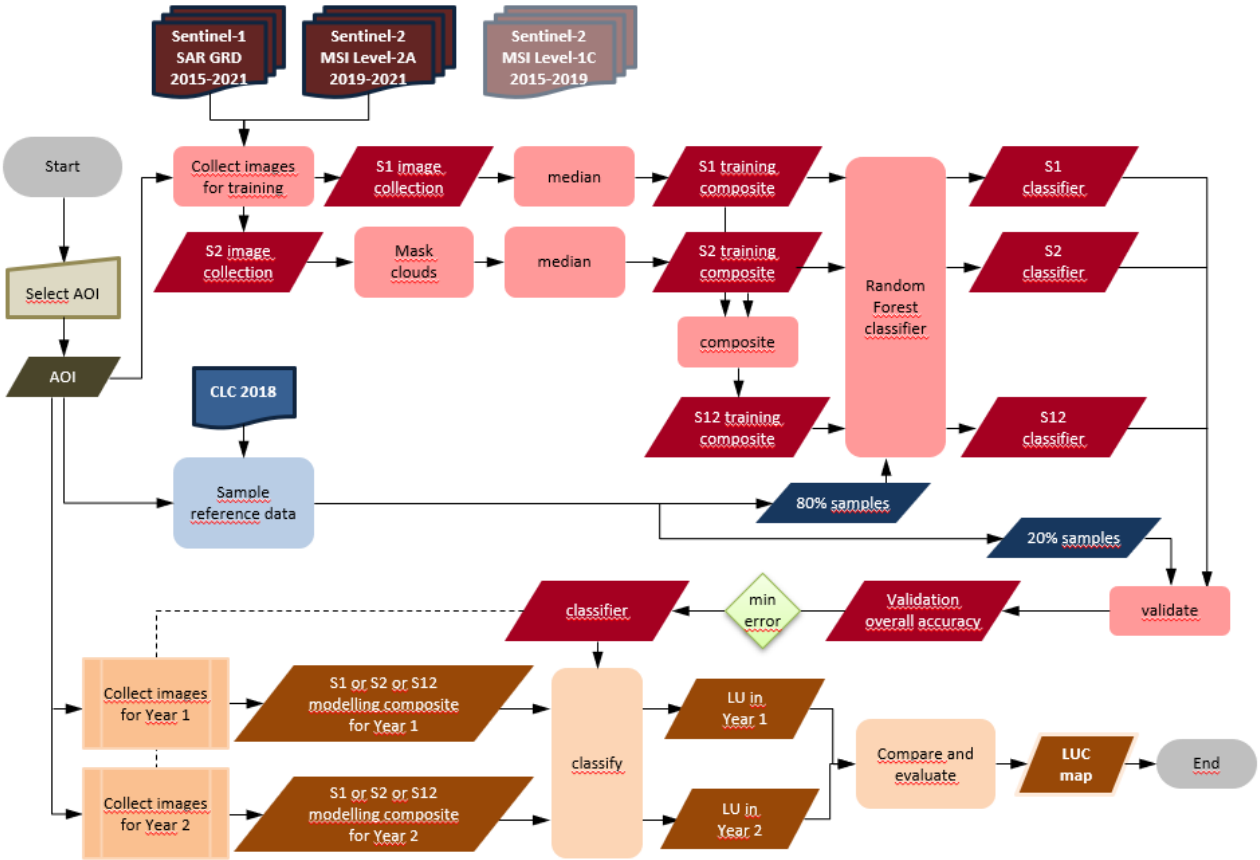

Figure 3. Methods scheme.

An application was developed to monitor land cover changes, utilizing Python Jupyter as the coding platform and subsequently implementing it in Voila. The integration with Voila allows the application to be used with various cloud application platforms, including open-source platforms like Heroku, as well as commercial alternatives. The user interface has been designed to provide extensive functionality, enabling users to define their research areas according to their specific requirements. Additionally, the application offers a selection of pilot areas in Poland, Greece, and Italy, catering to a broader range of geographical interests. Within the user interface, users have the convenience of using interactive bars to define the range of years they wish to analyze for land cover changes. This flexibility allows researchers and stakeholders to study long-term trends and patterns in land use transformations effectively. Furthermore, the application allows users to individually select layers of interest, thereby customizing their analysis to focus on specific aspects of land cover changes, such as vegetation, urbanization, or deforestation. One of the notable features of the application is its capability to display Sentinel-2 preview images for defined date ranges. These preview images offer valuable visual insights into the actual land cover conditions during specific time periods, facilitating a comprehensive understanding of the changes occurring in the selected regions. This image display functionality enhances the user experience, making the

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analysis more intuitive and accessible. Overall, the application provides a robust and user-friendly platform for monitoring land cover changes. Its implementation in Voila and compatibility with cloud application platforms enable users to access and utilize the application seamlessly, regardless of their preferred hosting environment. With the ability to define custom research areas, select pilot areas in multiple countries, and analyze land cover changes over specific time frames, this application empowers researchers, policymakers, and environmental professionals to make informed decisions and develop effective strategies for sustainable land management and conservation efforts.

Figure 4. Application user interface of monitoring land cover changes.

The developed application, aimed at monitoring land cover changes, adheres to the principles of open-source software and has been made easily accessible to the public via GitHub. Interested users, researchers, and developers can readily access the application's source code at the following GitHub repository: https://github.com/Remote-Sensing-Centre/FPCUP-Climate. By hosting the code on GitHub, the developers have demonstrated their commitment to transparency, collaboration, and community involvement in the ongoing enhancement of the application. The GitHub platform provides an ideal environment for fostering an active and engaged community around the project. Users and developers can easily contribute to the codebase by suggesting improvements, reporting issues, or submitting pull requests. This open collaboration approach fosters innovation and enables the application to continuously evolve, incorporating valuable contributions from a diverse range of perspectives.

4 Pilot activity

Throughout the course of project implementation, it is essential that our pilot activities and dedicated efforts culminate in delivering valuable consultation to the end users, including private companies, government institutions, academic institutions, and NGOs. As evidenced by the data presented in Table 3, a substantial number of users have expressed keen interest in accessing and

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utilizing the outcomes of this project. Remarkably, the level of interest exhibited by these users surpasses 1000 producers, underscoring their strong demand for land cover change products.

Table 2 List of Pilot Users participating in the pilot activities

No	Institution	Institution profile	Number of Users
1	DANKO Sp. z o.o.	Private company	15
2	Główny Urząd Statystyczny	Government institution	5
3	Instytut Geografii i Przestrzennego Zagospodarowania Polska Akademia Nauk	Academic institution	5
		Total:	25

A comprehensive series of case studies was conducted in Poland, focusing on three distinct regions that experienced varying types of land cover changes. These case studies aimed to provide in-depth insights into the environmental impact and implications associated with these transformations. The selected areas for examination were Kamieńsk, Białowieża, and Karczew, each representing a unique facet of land cover alteration in Poland (Figure 5). The first case study focused on Kamieńsk (Figure 6), a region where extensive motorway construction took place. This investigation delved into the effects of such infrastructure development on the surrounding land cover. By analyzing the changes in vegetation, soil composition, and ecosystem health, researchers aimed to understand the ecological consequences of motorway construction in this particular area. The second case study centered around Białowieża (Figure 7), an area notorious for changes in forest cover changes. Here, the research team aimed to examine the ecological repercussions of large-scale tree removal and its subsequent impact on biodiversity, soil fertility, and overall ecosystem stability. This investigation provided valuable insights into the consequences of deforestation on both local and regional levels. The third case study focused on Karczew (Figure 8), a region experiencing rapid urbanization and intensive land use changes. By studying the transformation of once-natural landscapes into urban environments, researchers sought to understand the ecological and social implications of such intense urbanization. This examination included analyzing changes in land cover, urban heat island effects, and socio-economic impacts on the local population. In addition to the Polish case studies, pilot areas were also identified in Italy and Greece to broaden the scope of the research. These pilot areas were carefully selected to represent diverse geographical and environmental conditions. By incorporating these regions into the study, researchers aimed to gain a more comprehensive understanding of land cover changes across different contexts and ecosystems. The case studies conducted in Poland, along with the pilot areas in Greece (Figure 9) and Italy (Figure 11), provided valuable insights into the complex relationship between land cover changes and their environmental consequences. The findings of these studies can serve as a foundation for informed decision-making in land management, urban planning, and environmental policy formulation. By understanding the impacts and challenges associated with land cover changes, stakeholders can work towards more sustainable and environmentally responsible practices to preserve ecosystems and ensure a balanced coexistence between human development and nature.

Figure 5. Poland pilot activities test areas.

In the case study conducted in Kamiensk, the overall accuracy of the analysis was determined to be an impressive 87%. This high level of accuracy indicates the reliability and precision of the findings. Moreover, the study revealed a notable change in artificial impervious surfaces, with an increase of approximately 3% observed in the region. This change in land cover highlights the impact of motorway construction on the landscape, emphasizing the transformation of natural areas into built environments.

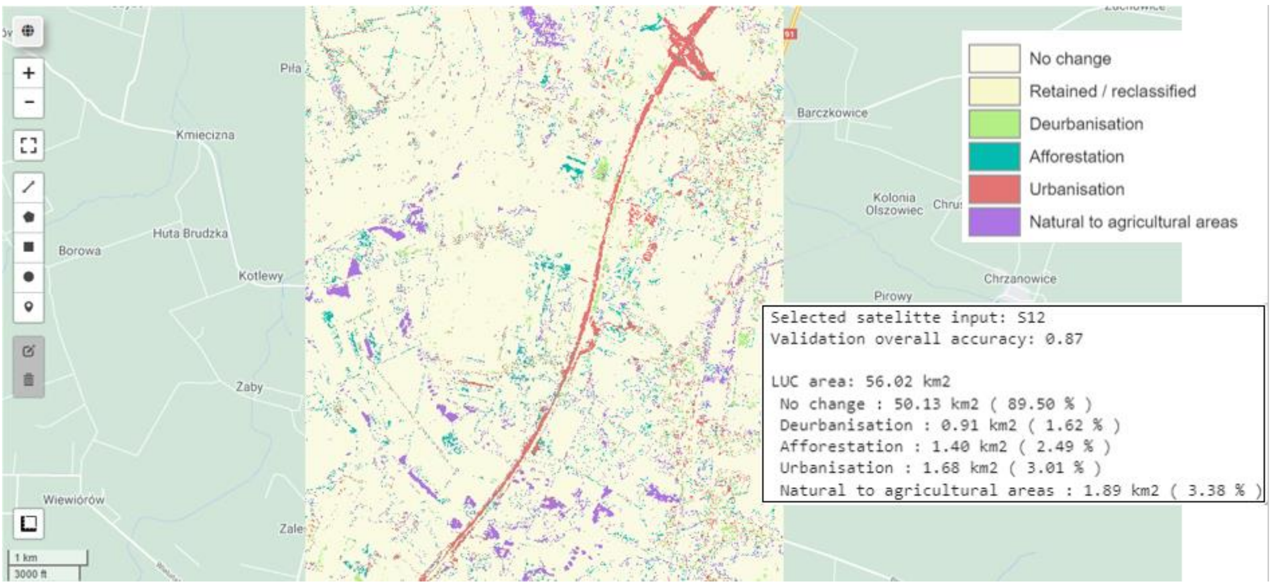

Figure 6. Polish case studies: Kamieńsk area, land cover changes between 2017-2020.

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Moving on to the case study in Bialowieza, the findings showcased a significant afforestation rate of approximately 1.5%. This indicates a positive trend in terms of reforestation efforts within the region, potentially contributing to the restoration of natural habitats and the preservation of biodiversity. The overall accuracy of the analysis conducted in Bialowieza was an impressive 95%, further reinforcing the credibility and validity of the research outcomes. Such a high accuracy rate underscores the robustness of the methodologies employed and strengthens the confidence in the reported results.

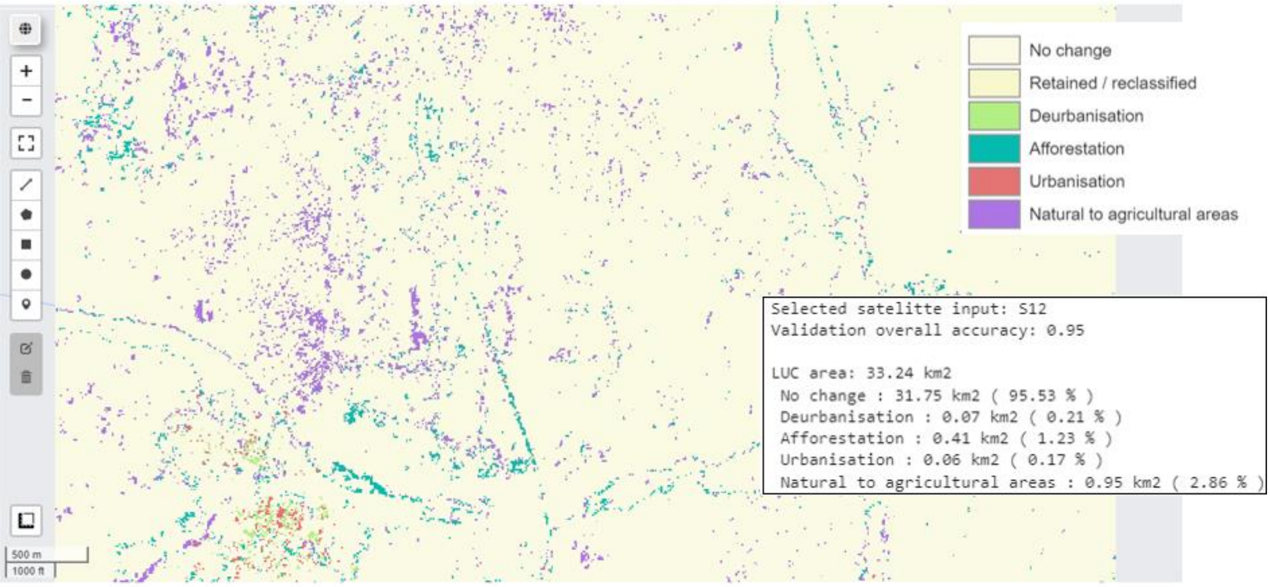

Figure 7. Polish case studies: Białowieża area, land cover changes between 2017-2020.

In contrast, the case study carried out in the Karczew area revealed a lower overall accuracy of approximately 68%. While this accuracy rate is comparatively lower than in the other two regions, it still provides valuable insights into the land cover changes occurring in Karczew. Notably, the study highlighted substantial changes in urbanization, with urban areas expanding to cover approximately 11% of the total area. This significant shift from natural landscapes to urban environments underlines the rapid and intensive urbanization processes taking place in the Karczew region.

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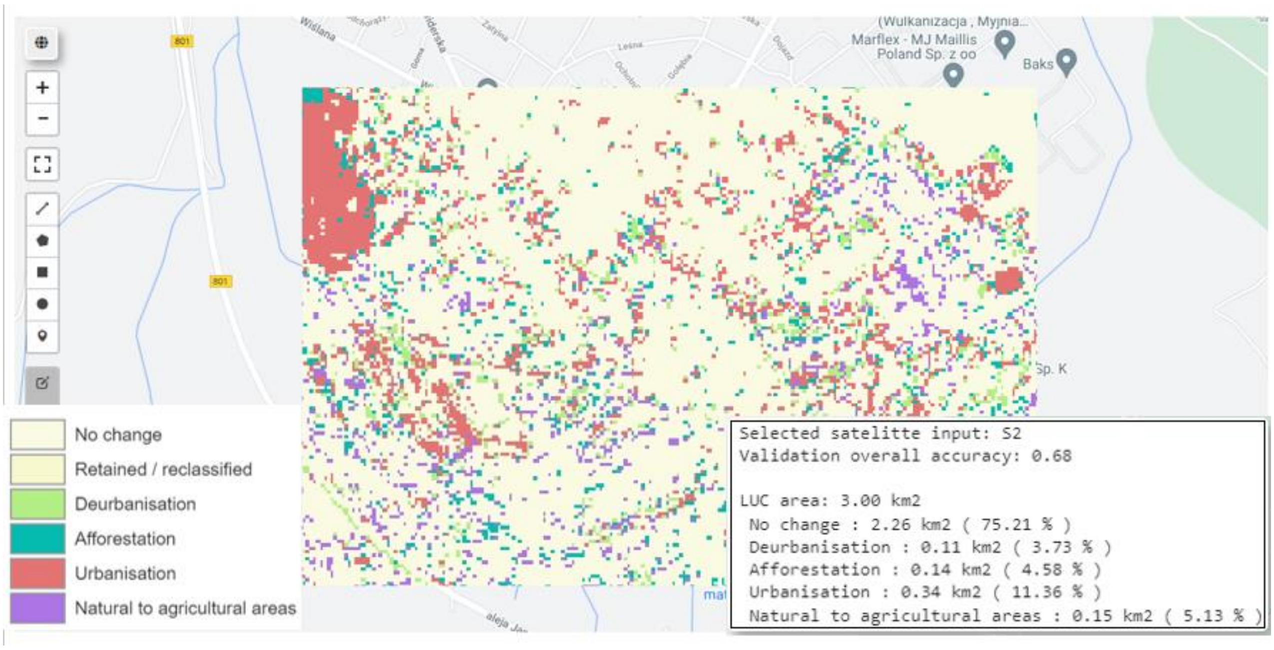

Figure 8. Polish case studies: Karczew area, land cover changes between 2017-2020.

Collectively, these statistics and validation results from the case studies in Kamiensk, Bialowieza, and Karczew provide a comprehensive overview of the land cover changes and their associated accuracies. They offer valuable data for policymakers, researchers, and stakeholders to understand and address the environmental consequences of these transformations. By recognizing the extent and impacts of changes such as the expansion of artificial impervious surfaces, afforestation efforts, and urbanization, informed decisions can be made to promote sustainable land management practices, preserve natural habitats, and mitigate potential ecological challenges.

The pilot study conducted in Greece (Figure 10), focusing on an area near Thessaloniki, aimed to analyze land cover changes between the years 2017 and 2018. The comprehensive analysis employed advanced machine learning algorithms in conjunction with Sentinel-1 radar data and Sentinel-2 optical data to achieve accurate and automated detection of land cover transformations. The overall accuracy of the classification process was determined to be 74%, indicating a reliable assessment of the land cover changes within the study area. This accuracy metric reinforces the robustness of the methodology and instills confidence in the reported results. Of particular interest were the significant changes observed in two specific land cover classes. Afforestation exhibited substantial growth, accounting for approximately 6% of the total study area. This noteworthy increase highlights the region's positive efforts in reforestation and the establishment of new forested areas, which can have positive implications for biodiversity and ecosystem health.

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Figure 9. Greece pilot study: area near Thessaloniki, Sentinel-2 image for 2017.

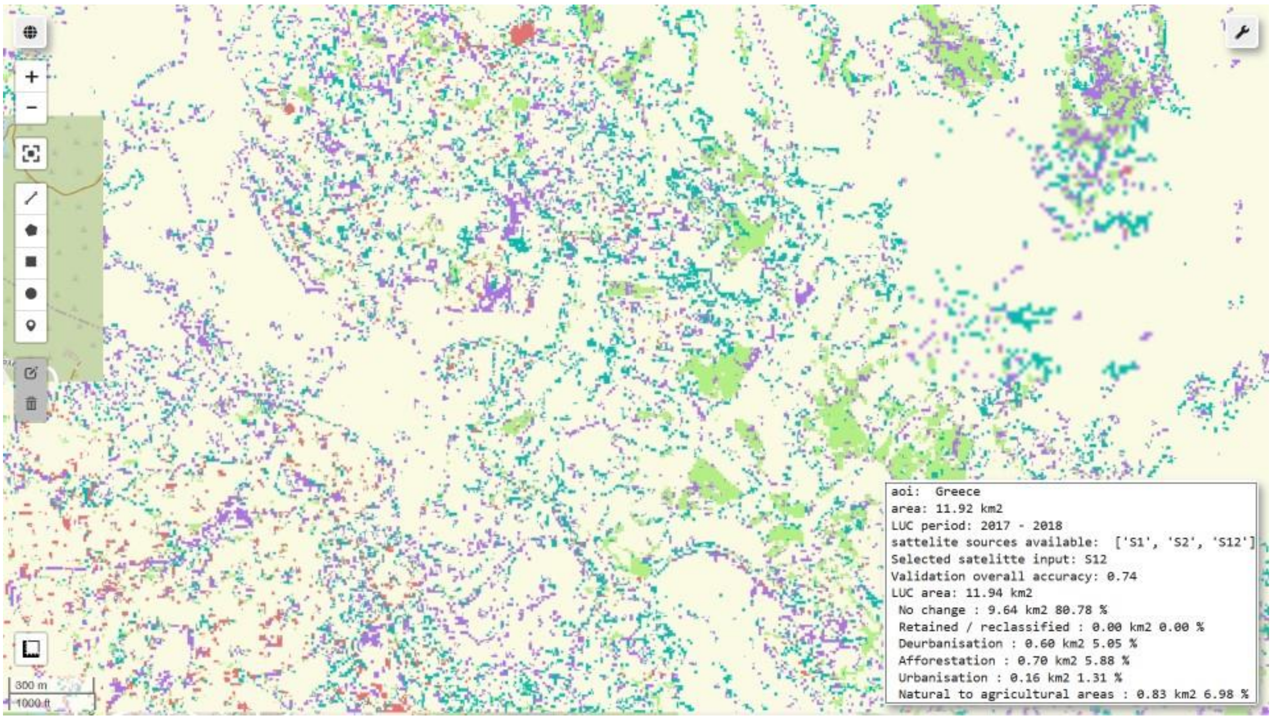

Figure 10. Greece pilot study: area near Thessaloniki, land cover changes between 2017-2018.

The pilot study conducted in Italy focused on an area near Rome (Figure 12), with the objective of analyzing land cover changes between the years 2017 and 2018. To achieve this, state-of-the-art machine learning algorithms were employed, in conjunction with the integration of Sentinel-1 radar data and Sentinel-2 optical data, facilitating the accurate and automated detection of land cover transformations. The overall accuracy of the classification process in this Italian pilot study was

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determined to be 81%, demonstrating the reliability and precision of the methodology utilized. This high overall accuracy metric further underscores the robustness of the approach and instills confidence in the accuracy of the findings. Of significant interest were the observed changes in urbanization, with approximately 6% of the total study area experiencing urban expansion and intensification between 2017 and 2018. This notable increase in urban areas signifies the region's continued urban development and highlights the potential challenges of managing urban sprawl and its impact on natural ecosystems.

Figure 11. Italy pilot study: area near Rome, Sentinel-2 image for 2017.

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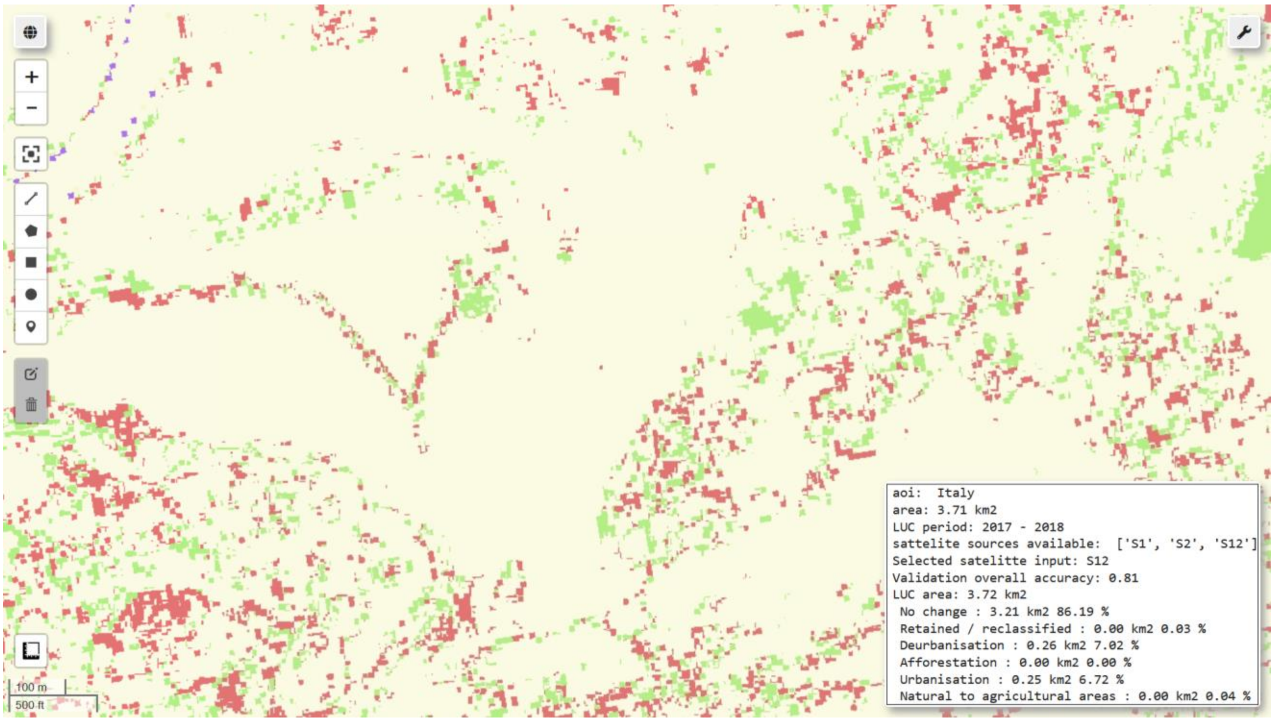

Figure 12. Italy pilot study: area near Rome, land cover changes between 2017-2018.

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